PONTIFICIA UNIVERSIDAD CATÓLICA DEL PERÚ

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FACULTAD DE CIENCIAS E INGENIERIA

Sistema de medición y registro ambulatorio de presión arterial usando el método no invasivo oscilosmétrico

TESIS PARA OPTAR EL TITULO DE:

INGENIERO ELECTRÓNICO

PRESENTADO POR:

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Resumen

Actualmente, en el Perú como en el resto de mundo las enfermedades cardiovasculares y cerebrovasculares presentan un alto índice de morbilidad y mortalidad, esto a pesar del desarrollo de la ciencia y la tecnología. Diferentes estrategias médicas y tecnológicas se han planteado para controlarlas, pese a ello no se ha logrado encontrar solución a estos problemas.

En este sentido, se requiere de un adecuado soporte tecnológico además de recursos económicos y humanos especializados que faciliten estas tareas. Entre los equipos que pueden cumplir esta misión se destaca el MAPA, que permite a los especialistas detectar con gran exactitud posibles enfermedades cardiovasculares y definir terapias acertadas.

Es así, que luego de largos estudios del comportamiento fisiológico de los seres humanos, se demuestra que la medicina preventiva es la mejor forma de controlar a las enfermedades cardio y cerebro vasculares. La medición de la presión arterial es esencial para establecer la condición fisiológica cardiovascular, pues indica cambios en el volumen sanguíneo, eficiencia cardiaca y resistencia del sistema vascular periférico. Estos parámetros permiten determinar casos de hipertensión, monitorear pacientes con transplantes, pacientes con el síntoma de la “bata blanca”, controlar la evolución de pacientes con tratamientos antihipertensivos, entre otros.

El sistema de medición y registro de presión arterial brinda al especialista información detallada sobre las fluctuaciones de la presión arterial durante la actividad cotidiana del paciente, permitiendo tener un panorama claro del perfil cardiovascular, facilitando la indicación del diagnóstico adecuado, la elección del tratamiento y el seguimiento de la enfermedad. El monitoreo ambulatorio de la presión arterial, permite medir la presión arterial durante periodos de 12 a 72 horas con el fin de entregar una idea de la condición cardiovascular del paciente. Esta es una técnica, que por su seguridad, estabilidad, carencia de riesgo alguno y ausencia de complicación, resulta una alternativa más eficiente que el control aislado de la presión arterial.

Por lo tanto, el objetivo de este trabajo es diseñar un sistema de monitoreo, medición y registro de presión sanguínea ambulatorio. Este sistema estará conformado por una parte mecánica que generará la presión sobre la arteria braquial en el brazo; una parte electrónica que permitirá adquirir las presiones diastólica, sistólica y principal para mostrarlas en una pantalla y/o transferirlas a una computadora donde un programa de control permitirá configurar el equipo, transferir, procesar y presentar la información.

Finalmente, se establecerá una estructura funcional del sistema, de tal forma que posteriormente se pueda estudiar, mejorar y desarrollar sus diferentes etapas en forma independiente e integrarlas nuevamente al sistema para optimizarlo.

TEMA DE TESIS PARA OPTAR EL TITULO DE INGENIERO ELECTRÓNICO

TITULO	:	**SISTEMA DE MEDICIÓN Y REGISTRO AMBULATORIO DE PRESIÓN ARTERIAL USANDO EL MÉTODO NO INVASIVO OSCILOSMÉTRICO**
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DESCRIPCIÓN Y OBJETIVOS

La medición de la presión arterial es esencial para establecer la condición fisiológica cardiovascular, pues indica cambios en el volumen sanguíneo, eficiencia cardiaca y resistencia del sistema vascular periférico. Estos parámetros permiten determinar casos de hipertensión, monitorear pacientes con trasplantes, pacientes con el síntoma de la “bata blanca”, controlar la evolución de pacientes con tratamientos antihipertensivos, entre otros.

El sistema de medición y registro de presión arterial brinda al especialista información detallada sobre las fluctuaciones de la presión arterial durante la actividad cotidiana del paciente, permitiendo tener un panorama claro del perfil cardiovascular para luego indicar el diagnostico adecuado, la elección del tratamiento y el seguimiento de la enfermedad.

El objetivo del presente trabajo es desarrollar un sistema que permita monitorear y medir, en forma ambulatoria, la presión arterial (presión sistólica, presión diastólica, presión media) y las pulsaciones por periodos largos de hasta dos días tomando hasta cuatro muestras por hora.

Este sistema estará conformado por una parte mecánica que generará la presión sobre la arteria braquial; una parte electrónica que permitirá adquirir las presiones diastólica, sistólica y principal para mostrarlas en un display o transferirlas a una computadora y un software de control que permitirá programar el equipo, transferir, procesar y presentar la información.

Finalmente, se establecerá una estructura funcional del sistema, de tal forma que posteriormente se pueda estudiar, mejorar y desarrollar sus diferentes etapas en forma independiente e integrarlas nuevamente al sistema para optimizarlo.

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Dedicatoria:

"A todos los que a pesar del tiempo estuvieron a mi lado."

Agradecimientos:

"A mis padres, hermanos, familiares y amigos."

"A mi corazón, que a pesar de todo esta allí."

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INTRODUCCIÓN

La medición de la presión arterial es un indicador esencial de la condición fisiológica cardiovascular. Entre otros parámetros, nos muestra los cambios en el volumen sanguíneo, eficiencia cardiaca y resistencia del sistema vascular periférico, permitiendo la determinación de casos como hipertensión limítrofe, identificación de hipertensión nocturna, diagnóstico de hipotensión, descarte del "síntoma de la bata blanca", monitoreo de pacientes con trasplantes, control de la evolución de pacientes con tratamientos antihipertensivos, identificación de sujetos con resistencia a terapia medicamentosa antihipertensiva, determinación de la efectividad del tratamiento, definición del tratamiento en caso de presión alta en ancianos o en embarazadas, entre otros.

Pese a los indudables avances en el control de los factores de riesgo y a la progresiva mentalización de médicos, pacientes y sociedad conjuntan; las enfermedades cardiovasculares y cerebrovasculares siguen ocupando los primeros puestos en cuanto a su frecuencia en el mundo occidental (ver anexo Nº 1a).

Diversas investigaciones fueron realizadas por el hombre para conocer el funcionamiento del cuerpo y la fisiología cardiovascular. Desde las primeras pruebas realizadas por Hales en 1713, donde se midió por primera vez la presión sanguínea de un ser vivo; hasta los estudios iniciados en 1948 por el Instituto Nacional del Corazón de los Estados Unidos de Norteamérica a los pobladores de la localidad de Framingham, Massachussets. En este ultimo caso se monitoreó durante 30 años a 5209 habitantes cuyas edades oscilaron entre 30 a 62 años, donde se llegó a obtener información que hoy en día permite conocer los "factores de riesgo" que contribuyen a la generación y desarrollo de enfermedades cardiovasculares (ver anexo Nº 1b) y por consiguiente prevenir y/o determinar su cura. (Framingham, 2004), (AHA, 2005)

En el anexo N° 1c se muestran eventos y fechas importantes que demuestran la relación permanente entre la ingeniería y la medicina en su búsqueda por investigar y conocer el funcionamiento del cuerpo humano y alcanzar una mejor calidad de vida. (Geddes, 1991), (Hoel, 1997), (AHA ,2005) Entre las más importantes tenemos:

- La primera medición de la presión arterial realizada por Hales en 1713,
- El invento del estetoscopio en 1816 por el físico Lanaennec,
- El descubrimiento de los sonidos cardiacos por el Dr. Korotkoff en 1905,
- El inicio de los estudios de la American Heart Association en la localidad de Framingham en 1949,
- El diseño del primer equipo de medición de presión arterial electrónico en 1962 por los científicos Inman y Sokolow,
- Las primeras aplicaciones del método oscilosmétrico por la empresa Del Mar en 1979. Entre otros no menos importantes.

Asimismo, se han realizado diferentes investigaciones referentes a sistemas de medición, monitoreo y registro ambulatorio de presión sanguínea, a cargo de organismos e instituciones como la “American Heart Association” (AHA), “American College Clinical Engineering” (ACCE), “Emergency Care Research Institute” (ECRI), “Institute Electrical Electronic Engineering” (IEEE), entre las que se destacan:

- “The Framingham Heart Study” del National Heart, Lung and Blood Institute; “Heart Disease and Stoke Statistics – 2005 Update” de la American Heart Association;
- “Blood Pressure Measurement” de S. Rithalia; y
- “Common Problems in Blood Pressure Measurement”,de H. Woo; entre otras, las mismas que se referencian en posteriores capítulos.

En este sentido, este trabajo de tesis plantea diseñar un sistema de medición, monitoreo y registro ambulatorio de presión sanguínea que brinde al especialista información que le permita tener un panorama claro del perfil cardiovascular del paciente.

Justificación

Las conclusiones preliminares establecen que la prevención es la mejor forma de combatir el desarrollo de las enfermedades cardiovasculares, cerebrovasculares y sus "factores de riesgo", siendo uno de los principales la hipertensión arterial. Asimismo se concluye que una forma de poder controlar la hipertensión es medirla y evaluarla continuamente, con la finalidad de determinar su peligrosidad y evitar futuras consecuencias generalmente irreversibles. (Framigham, 2004)

Esto implica que para prevenir y/o determinar un problema hipertensivo se debe tener una perspectiva detallada de la presión arterial. Normalmente, los estudios clínicos se realizan luego de una manifestación de la enfermedad cardiovascular y cerebrovascular, es decir, se busca una solución paliativa a un problema existente, siendo lo ideal prevenirla. Ante esta necesidad, surge el monitoreo continuo de la presión arterial, y en particular el monitoreo ambulatorio de la presión arterial, en el que se mide la presión arterial durante periodos de 12 a 72 horas, permitiendo tener una idea de la condición cardiovascular del paciente. Esta técnica, por su seguridad, estabilidad, carencia de riesgo y ausencia de complicación, es una alternativa más eficiente que el control aislado de la presión arterial. Actualmente se tienen en el mercado equipos de monitoreo cardiaco de cabecera, portátiles y ambulatorios.

Objetivos generales

Diseñar un sistema que entregue información detallada de los cambios que sufre la presión arterial de un ser humano durante un periodo aproximado de doce horas, bajo condiciones de vida normales. Los datos generados darán al especialista una visión clara de la patología y condición cardiovascular del individuo monitoreado. Esto le permitirá realizar un mejor diagnóstico, definir mejor el tratamiento y tener un seguimiento de la evolución de la enfermedad.

Objetivos específicos

- Diseñar un sistema de adquisición de presiones utilizando el método de medición indirecta (ó no invasiva) oscilosmétrico.
- Diseñar un sistema de control realimentado, basado en un microcontrolador de propósito específico optimizando recursos y reduciendo costos.
- Diseñar un sistema totalmente modular, de tal forma que permita el posterior estudio y desarrollo de cada una de las etapas, para lo que se detallarán las características de cada una y sus requerimientos básicos. Así como también, se presentarán las normas internacionales que regulan aspectos de funcionalidad y seguridad.
- Diseñar un sistema de seguridad y monitoreo que verifique el correcto funcionamiento de la fuente de energía, sistemas de adquisición de presiones, digitalización de señales, temporización, control, alarmas y transferencia de datos.
- Diseñar un sistema de administración de energía, basado en el microcontrolador, que permita la portabilidad del sistema de control base con una autonomía operativa de doce horas continuas.
- Analizar y evaluar las características más adecuadas de un programa de aplicación, basado en la experiencia de especialistas y sistemas comerciales en el mercado actual que les permitan tener la información adquirida clara y detallada así como gráficas y datos estadísticos que ayuden a su diagnóstico.

Contenido

El capítulo uno “Conceptos Básicos de la Presión Arterial” presenta información referente a la fisiología cardiovascular necesaria relacionada específicamente a las presiones arteriales que permitan un mejor entendimiento y sustento teórico del sistema propuesto. Para este capitulo se tiene como referencia básica a “Fisiología Humana” de Guyton (1999) y “Hablando de alta presión sanguínea” de H. P. Wolff (1989).

La clasificación de los métodos de medición de presión arterial existentes así como sus características son detalladas en el capitulo dos “Métodos de Medición de la Presión Arterial”. Como referencias se tienen: “The direct and indirect measurement of blood pressure” de L. A. Geddes (1991), y “Biomedical transducers and instruments” de T. Togawa (1997).

En el capítulo tres “Análisis del Problema y Alternativas de Solución” se definen las razones por las cuales se plantea el sistema, además los antecedentes históricos que fundamentan su evolución tecnológica. Asimismo, se presenta el actual estado del arte, y se comparan características técnicas. También se detallan los problemas presentados en el proceso de estudio y se plantean algunas tareas pendientes por desarrollar en otras áreas como mecánica e informática. Las referencias de este capitulo son “Heart Disease and Stoke Statistics – 2005 Update” de la American Heart Association – AHA (2005), “Hablando de alta presión sanguínea” de H. P. Wolf (1989), y “Healthcare Product Comparison System” de Emergency Care Research Institute –ECRI (2002).

En el capítulo cuatro “Descripción y Desarrollo del Sistema” se muestra la metodología aplicada, características, especificaciones técnicas y detalles del diseño del sistema propuesto así como sus ventajas respecto a productos comercializados actualmente en el mercado internacional y nacional. Para este capitulo se tomó como referencias a “Healthcare Product Comparison System” de Emergency Care Research Institute – ECRI (2002), “Maintanance manual MAPA 33, SAVE 33 electronique medicale” de SAVE (2004) y “Service Manual 90207 ABP Monitor” de Space Labs (2005), además de información técnica de los webs de empresas fabricantes de dispositivos electrónicos como Microchip, Intel, Atmel, Motorola, Toshiba, Silicon Labs, Phillips y Nacional Semiconductors. Asimismo, los resultados y pruebas ejecutadas por cada etapa serán mostradas en el capitulo cinco “Ensayos y Resultados” donde se sustenta lo propuesto en los capítulos anteriores.

Finalmente se plantean las “Observaciones y Conclusiones” producto de las pruebas realizadas.

CAPITULO 1

Conceptos Básicos de la Presión Sanguínea

1.1 Introducción.

Las enfermedades cardiovasculares y cerebrovasculares son unas de las causas más importantes de invalidez y muerte en el mundo. Es por este motivo que la información y difusión de las medidas de prevención de estas enfermedades, asociadas a los progresos que se han dado en su tratamiento, han logrado un efecto positivo en la reducción de la mortalidad de los países que decidieron implementarlas.

En la actualidad, el infarto del miocardio ocasiona el 30% de las muertes en las personas que padecen de alta presión y casi el mismo porcentaje en las que padecen ataques cerebrales. Cuando se eleva la presión sanguínea, también lo hace la amenaza a la salud. Y si están presentes otros factores de riesgo, el peligro para el sistema cardiovascular aumenta proporcionalmente. Un diabético hipertenso tiene una probabilidad diez veces mayor de sufrir un ataque cardiaco que un diabético con presión normal; y la incidencia de ataques cardiacos fue diez veces mayor entre los fumadores hipertensos que entre aquellos cuya presión era normal (AHA, 2005).

El presente capítulo tiene como propósito dar a conocer los principios fisiológicos fundamentales del sistema cardiovascular, permitiendo identificar sus partes y funciones. Asimismo, dar a conocer los mecanismos que regulan la presión sanguínea y los factores de riesgos que contribuyen a la formación de las enfermedades cardiovasculares y cerebrovasculares, en especial la hipertensión arterial.

1.2 Estructura y función del sistema cardiovascular.

El sistema cardiovascular está compuesto por el corazón, arterias, arteriolas, venas y capilares. En la figura N° 1 se observa detalladamente la estructura del sistema cardiovascular.

1.2.1 El corazón.

El corazón es un músculo del tamaño aproximado al del puño de un hombre; se encuentra dentro del pecho, hacia la izquierda y entre los dos pulmones. Está dividido en dos cavidades iguales separadas por una pared muscular: el corazón "izquierdo" y el corazón "derecho". Cada mitad está, a su vez, dividida en dos cámaras: la superior es el atrio ó aurícula y la inferior es el ventrículo. Un sistema de válvulas separa los atrios de los ventrículos y regula el flujo de la sangre que ingresa y sale del corazón.

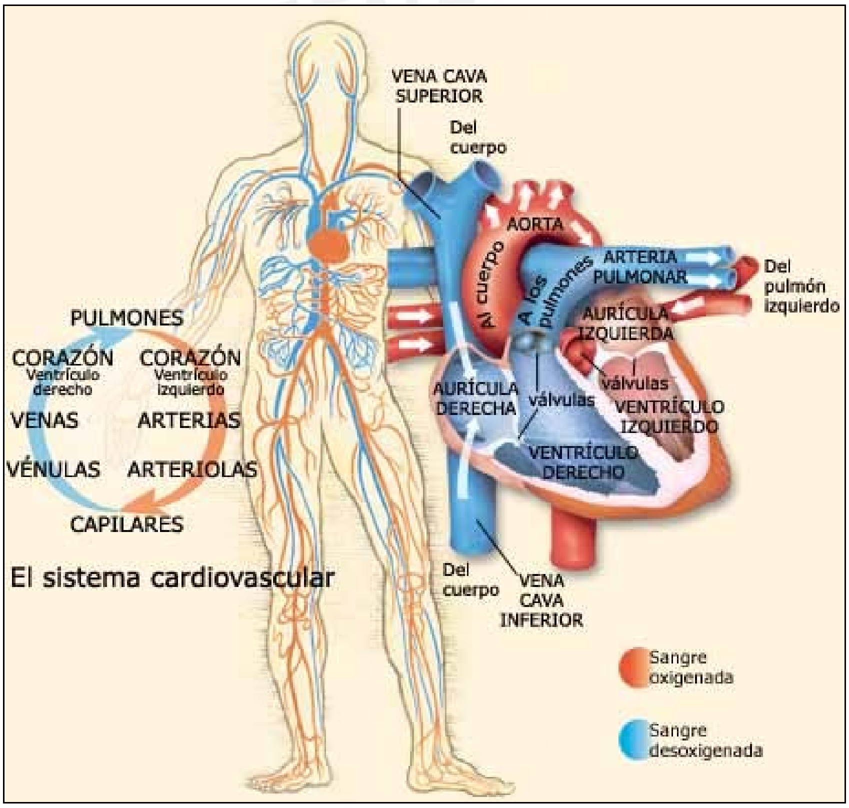

Figura N° 1 El Sistema cardiovascular (Wolff, 1989)

La estructura del corazón puede compararse a la de dos bombas independientes, pero que trabajan sincronizadas. Tal como el corazón, el sistema circulatorio también está formado por dos partes separadas: la circulación pulmonar que sirve a los pulmones, y la circulación sistémica que alimenta al resto del cuerpo. El corazón derecho bombea sangre a la circulación pulmonar y el corazón izquierdo satisface las demandas de la circulación sistémica. En la figura N° 2 se muestra la circulación sanguínea con detalle.

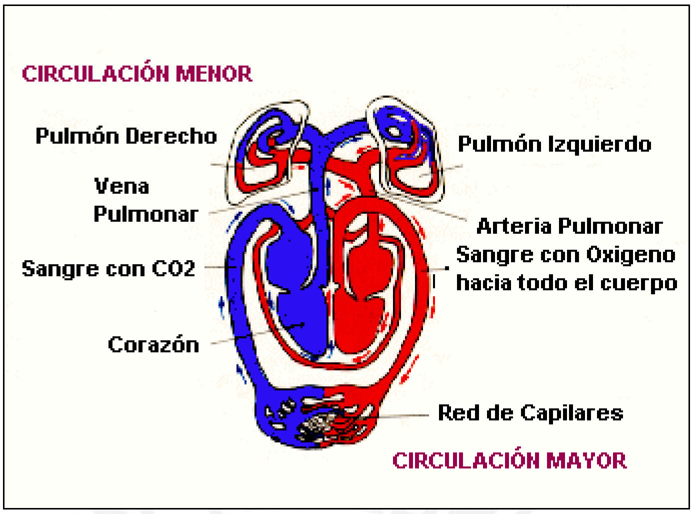

Figura N° 2 La Circulación sanguínea (Wolff, 1989)

La provisión y excreción de oxigeno y dióxido de carbono respectivamente, se lleva a cabo de la siguiente forma: el ventrículo derecho recibe a la sangre desoxigenada de la vena cava y la bombea a la circulación pulmonar. La extensa red capilar permite el intercambio gaseoso en las células de los alvéolos pulmonares. La sangre desoxigenada es bombeada por el corazón a los pulmones; los glóbulos rojos eliminan el dióxido de carbono y se cargan de oxígeno. La sangre oxigenada es conducida al corazón por la vena pulmonar que la envía al ventrículo izquierdo donde luego se dirige a la corriente sanguínea por la arteria Aorta. En la figura N° 3 se presenta el ciclo de trabajo del corazón (Guyton, 1999), (Birkenhager, 2004).

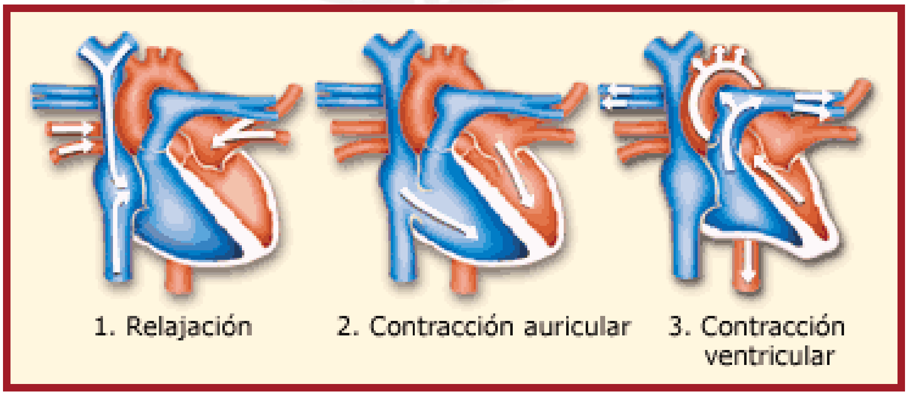

Figura N° 3 Ciclo de trabajo del corazón (Wolff, 1989)

Para que el intercambio gaseoso se produzca sin sobresaltos, los dos atrios y los dos ventrículos deben trabajar en armonía. Esto se logra por la acción coordinada de los atrios y los ventrículos. Los dos atrios dejan pasar la sangre, en forma simultánea, a los ventrículos adyacentes y éstos, a su vez, de manera simultánea, bombean la sangre a las arterias pulmonar y sistémica (Aorta). El sistema que controla esta acción coordinada funciona como un "generador eléctrico" y su "distribuidor". El "generador" situado en la zona de los atrios, envía impulsos eléctricos rítmicos que producen la contracción de los atrios, y la salida de la sangre hacia los ventrículos. Entonces, con un mínimo retraso, el "distribuidor" envía estos impulsos a los ventrículos llenos de sangre y estos la descargan al sistema circulatorio. Este "sistema de conducción" eléctrico constituye la parte más sensible del corazón. Es por ello que los latidos irregulares (arritmia) a menudo constituyen la primera indicación de una perturbación circulatoria ó cardiaca.

A continuación se muestran algunos indicadores que nos darán una idea del gran esfuerzo realizado por el corazón:

- La frecuencia de los latidos o número de latidos por minuto se encuentra, normalmente entre 60 y 80. En condiciones de stress ó ejercicio físico, puede llegarse a doblar estas cifras.
- Una medida del trabajo que realiza el corazón, es el volumen por minuto. Mientras que en reposo, ese volumen está entre 3 y 5 litros, puede aumentar de 3 a 5 veces con el ejercicio físico, según el estado del individuo.
- El corazón es una bomba de 0.1 caballo de fuerza. No sólo realiza un trabajo extenuante, sino que, a diferencia de otros músculos, debe hacerlo durante toda la vida. Para esto depende, totalmente de un flujo, constante y adecuado, de oxigeno y de combustibles necesarios, cuya distribución recae en las arterias coronarias, que son ramificaciones de la aorta que se encuentran al lado de la salida del corazón izquierdo. El sistema de vasos coronarios es una zona de peligro para las personas con factores de riesgo, en particular aquellas con hipertensión (Wolff, 1989).

1.2.2 La sangre

Es un fluido compuesto por un líquido rico en proteínas, llamado plasma sanguíneo (60%), células rojas ó eritrocitos (35%), entre otros componentes. El plasma conduce todas las sustancias (nutrientes y estructurales) que necesitan las células: azúcar, grasas, minerales, vitaminas y hormonas. Las células rojas pueden compararse con diminutos reservorios de un pigmento rojo, llamado hemoglobina, los mismos que transportan tanto oxígeno como dióxido de carbono. Los glóbulos rojos llevan el oxígeno inhalado por los pulmones a las células de los órganos y músculos. Sin oxígeno, las células no pueden vivir ni realizar su trabajo, a su vez el sistema metabólico necesita oxígeno para convertir los alimentos (azúcar, carbohidratos, grasas) en energía. Al mismo tiempo, las células deben librarse del dióxido de carbono o desecho metabólico. En su recorrido, la sangre atraviesa órganos que la desintoxican, como el hígado y que se encargan de la excreción de los residuos, como los riñones (Guyton, 1999), (Birkenhager, 2004).

1.2.3 Las arterias.

Las arterias cumplen un papel crucial en el origen de la hipertensión, ésto debido a que no solo tienen que transportar la sangre del corazón a todos los tejidos del cuerpo, sino que también tienen la vital tarea de la distribución y regulación de la presión y del flujo sanguíneo. Se tienen dos tipos de arterias: elásticas y musculares.

Las arterias de tipo elásticas están conformadas por un gran número de fibras elásticas, lo que les permite distribuir pareja y continuamente la sangre que reciben del corazón de forma rítmica y pulsátil. Esto garantiza un volumen constante de sangre a los órganos claves y los músculos, siendo la mayor la arteria Aorta.

En la periferia del sistema circulatorio arterial, las arterias elásticas son reemplazadas por las musculares, las que se ocupan de la distribución de la sangre. Los poderosos músculos de sus paredes las capacitan para expandirse (dilatarse) ó contraerse, de forma que aumentan ó disminuyen el flujo de sangre según las necesidades de los tejidos del cuerpo. Las arterias musculares más pequeñas se denominan arteriolas. Estas se ramifican en una red de vasos todavía más pequeños llamados capilares, los que se encargan de acarrear nutrientes a las células y se llevan sus productos de desecho.

La dilatación ó contracción de la arteria altera la resistencia de sus paredes. La resistencia combinada de todas las arterias periféricas musculares se llama resistencia arterial periférica lo que constituye un factor significativo en el nivel de presión sanguínea del sistema arterial. Esta resistencia es regulada por las arteriolas bajo un control local, neural y endocrino (Guyton, 1999), (Birkenhager, 2004).

1.2.4 Las venas.

Luego de alimentar los tejidos, la sangre transporta los desechos de estos a los capilares venosos que se unen con grandes vasos de paredes delgadas que se conocen como venas. El flujo de sangre en la red capilar es muy lento, la sangre venosa que vuelve al corazón se desplaza a muy baja velocidad, casi sin ninguna presión. Las venas convergen a dos vasos grandes denominadas venas cavas. La vena cava superior es la que transporta la sangre que retorna de la cabeza, cuello y brazos, al corazón; la vena cava inferior es la que transporta la sangre que retorna del tronco y las piernas. Ambas venas desembocan en el atrio derecho del corazón (Wolff, 1989), (Guyton, 1999), (Birkenhager, 2004).

En la figura N° 4 se muestran los tipos y estructura de los vasos que se encargan de transportar la sangre del corazón a todos los tejidos del cuerpo así como de retornarla para luego llevarla a los pulmones para su purificación y reingreso al corazón, cerrando la circulación sanguínea.

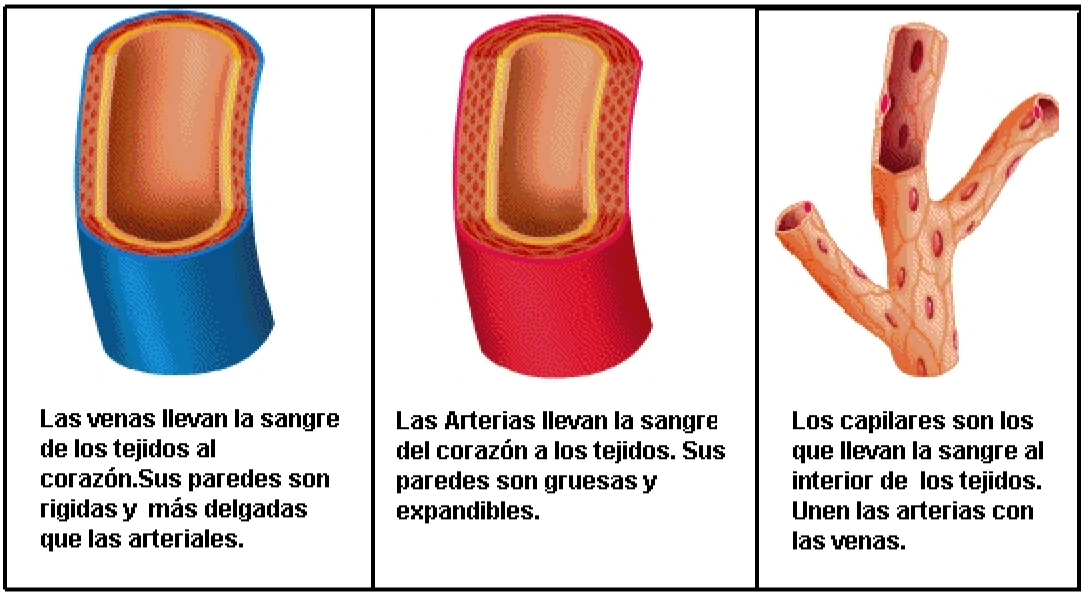

Figura N° 4 Estructura de los vasos sanguíneos (Wolff, 1989)

1.3 Presión Arterial.

El sistema cardiovascular posee dos mecanismos simples que le permiten adaptarse a las demandas fluctuantes de sangre del organismo: uno consiste en aumentar ó disminuir la cantidad de sangre que se bombea a la circulación (volumen por minuto); y el otro es el aumento ó disminución de la resistencia de las arterias musculares debido a la contracción ó dilatación. Este mecanismo regulador, aparentemente simple, es coordinado por un complejo sistema de control. Ya que la cantidad de sangre es constante, entre 4 a 5 litros en adultos, la presión deberá adaptarse a los cambiantes requerimientos del organismo (Guyton, 1972).

Los valores más bajos de la presión sanguínea se producen mientras se duerme. Durante el día, con las tensiones y demandas físicas y psicológicas por lo general se generan cambios en la presión, ajustándose a los variables requerimientos y actividades musculares. Cada vez que se mide la presión, se registran dos cifras: la superior o presión sistólica y la inferior o diastólica. El corazón con sus contracciones rítmicas, envía una corriente de sangre (onda del pulso) a las arterias periféricas donde puede percibirse como una pulsación. Según el corazón se contraiga ó dilate, la presión en las arterias, puede ser más alta ó más baja. La onda del pulso, como todas las ondas, tiene un pico y valles. El valor más alto, producido por la contracción (sístole) de las cámaras del corazón, es lo que se llama presión sistólica. La presión menor, correspondiente a la dilatación (diástole) se conoce como presión diastólica. Como los niveles de las dos presiones así como su relación, proveen claves valiosas al médico, siempre se toman ambas presiones. La presión sanguínea (como la barométrica) se expresa en milímetros de mercurio (mm de Hg.). Por ejemplo: 13/8 significa una presión sistólica de 130 mm de Hg. y una diastólica de 80 mm de Hg.

Se debe tener en cuenta que los niveles de presión sanguínea pueden establecerse sólo después de medir y repetir el proceso varias veces, pues los niveles de presión de personas sanas varían mucho, lo que dificulta establecer una línea divisoria rígida entre la presión normal (normotensión) y la presión alta (hipertensión). Por otra parte, es vital establecer, con exactitud, los límites superiores normales pues sin ellos no podemos detectar la presión alta ni evaluar la eficacia del tratamiento (Wolf, 1989). Después de mucho debate se ha llegado a una regla empírica:

- Determinación del límite superior normal sistólico: más 100 (máximo 160mm.de Hg.) a cualquier edad.
- Determinación del límite superior normal diastólico. 90mm de Hg. a cualquier edad.

La tabla N° 1 presenta una clasificación de la presión arterial según niveles estándares establecidos por la Organización Mundial para la Salud.

Tabla N° 1 Clasificación de la presión arterial (OMS, 2005)

	Presión sistólica	**Presión diastólica**
Hipertensión	160 ó más	95 ó más
Ligera hipertensión	140-159	90-94
Presión normal	101-139	61-90
Hipotensión	100 ó menos	60 ó menos

1.4 Hipertensión y factores de riesgo.

La alta incidencia de enfermedades cerebrovasculares y cardiovasculares ha estimulado la investigación de sus causas y de las condiciones que las desencadenan.

La hipertensión arterial es el factor más importante en la producción de ataques cerebrales y cardiacos, y uno de los principales de la enfermedad cardiaca congestiva; razón por la cual se destaca la importancia de la detección y tratamiento precoz debido a su papel fundamental en la producción de la arteriosclerosis. Se considera como un factor de riesgo al estado dañino en potencia, que puede desencadenar una enfermedad ó incapacidad específica.

En la siguiente tabla N° 2 se muestran los factores de riesgo que pueden desencadenar una enfermedad cerebro-cardiovascular:

Tabla N° 2 Factores de riesgo de las enfermedades cerebro-cardiovasculares. (AHA, 2005)

Factores de Riesgo
1) Alta presión sanguínea (hipertensión arterial).
2) Metabolismo anormal de lípidos: a) Alto colesterol en suero sanguíneo (hipercolesterolemia). b) Alto nivel de triglicéridos en suero sanguíneo (hipertrigliceridemia).
3) Fumar cigarrillos.
4) Diabetes.
5) Alto nivel de ácido úrico en suero sanguíneo (hiperuricemia).
6) Obesidad.
7) Stress.

En el estudio realizado en la ciudad de Framingham, Massachussets, iniciado en 1949, se investigaron los efectos de los distintos factores sobre el sistema cardiovascular en más de 5 000 personas. Se encontró que, en el mismo grupo de edad, el riesgo de problemas cardiovasculares era seis veces mayor en los hipertensos que en las personas con presión normal (Framingham, 2004).

En el pasado, casi el 50% de los hipertensos, moría por infarto ó congestión cardiaca. En la figura N° 5 se muestra como se alteran los tejidos de las arterias baja la condición antes mencionada.

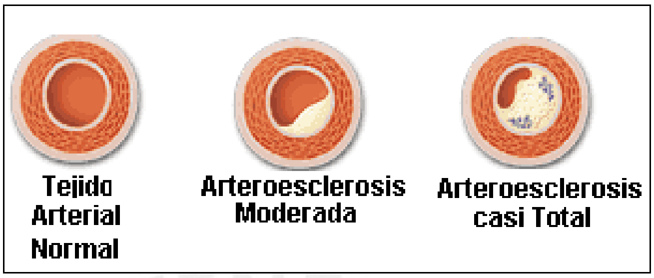

Figura N° 5 Degeneración del tejido arterial por la arterosclerosis. (Wolff, 1989)

En el anexo N° 1b se detallan las características de los otros factores de riesgo que pueden desencadenar enfermedades cardiovasculares y que a su vez están íntimamente relacionados con la forma en que vivimos, como por ejemplo: obesidad, stress, hiperuricemia, diabetes, hipercolesterolemia, hipertrigliceridemia, entre otros (Barreda, 2001).

CAPITULO 2

Métodos de medición de la presión sanguínea

2.1 Introducción

Existen diversos métodos de medición de presión, los directos o invasivos, y los indirectos o no invasivos. En los métodos directos se ingresa un sensor de presión en el sistema vascular, mientras que los métodos indirectos utilizan sensores de flujo, presión o ultrasonido para detectar la presión pero a través de un brazalete o bolsa elástica que ocluye una arteria para luego calcular la presión en ella. Asimismo, se debe tener en cuenta que para medir la presión de la sangre en alguna parte del cuerpo, debemos conocer antes las unidades de presión con las que trabajaremos, el punto de medición y sus rangos, así como el punto de referencia que debemos tomar.

2.2 Unidades de presión

El fenómeno físico denominado presión, esta definido como la fuerza que ejerce un cuerpo sobre una unidad de superficie. En el Sistema Internacional de medidas (SI) la unidad de presión es el Pascal (Pa). Las presiones fisiológicas se expresan en la mayoría de los casos en milímetros de mercurio (mm. Hg.) o en centímetros de agua (cm. H_2O) debido a que son relativamente pequeñas (Togawa, 1997). En la tabla N° 3 se muestran la conversión de unidades de presión:

Tabla Nº 3 Conversión de unidades de presión. (Motorola, 2003)

(Ejemplo: 0.5 In H_2O x .2491 = 0.1245 KPa)

	PSI	In H2O	In Hg	KPa	mBar	cm. H2O	mm H2O	mm Hg.	Kg / cm2	Atm
PSI	1.0000	27.6806	2.0360	6.8948	68.9475	70.3088	703.0700	51.7149	0.0703	0.0681
In H2O	0.0361	1.0000	0.0736	0.2491	2.4908	2.54000	25.4000	1.8683	0.0025	0.0025
In Hg	0.4912	13.5945	1.0000	3.3864	33.8638	34.5324	345.3240	25.4000	0.0345	0.3342
KPa	0.1450	4.0147	0.2953	1.0000	10.0000	10.1974	101.9716	7.5006	0.0102	0.0099
mBar	0.0145	0.4015	0.0295	0.1000	1.0000	1.0197	10.1972	0.7501	0.0010	0.0010
cm H20	0.0142	0.3937	0.0290	0.0981	0.9806	1.0000	10.0000	0.7355	0.0010	0.0010
mm H20	0.0014	0.0394	0.0029	0.0098	0.0981	0.1000	1.0000	0.0736	0.0001	0.0001
mm Hg	0.0193	0.5353	0.0394	0.1333	1.3332	1.3595	13.5954	1.0000	0.0014	0.0013
Kg/cm2	14.2233	393.711	28.9589	98.0665	980.6650	1000.020	10000.20	735.561	1.0000	0.9678
Atm	14.6959	406.793	29.9213	101.325	1013.250	1033.250	10332.50	760.002	1.0332	1.0000

2.3 Requerimientos para la medición de la presión sanguínea

Para realizar una correcta medición de la presión, debemos considerar la siguiente información como necesaria: la ubicación de la presión que se desea medir, el punto de referencia respectivo, así como el rango de presión. Con esta información podremos obtener una medida confiable y útil de la presión de interés. Posteriormente se detallará las características de estos requerimientos para una buena medición (Togawa, 1997).

2.3.1 Puntos de medición y rango de presión sanguínea

La medición de la presión en el cuerpo humano es parte de los exámenes clínicos y estudios fisiológicos. En la tabla Nº 4 se presentan las presiones (en mmHg) generadas en diferentes puntos, tanto bajo condiciones fisiológicas como en condiciones no fisiológicas. Cotidianamente la presión sanguínea de la sangre es medida en la mayoría de los seres humanos y es aceptada como indicador de la condición circulatoria.

Asimismo se tienen otros puntos del cuerpo donde la presión sanguínea nos da valiosa información, la que permitirá a los especialistas identificar algunas enfermedades y sus posibles tratamientos (Geddes, 1991), (Togawa. 1997).

Tabla Nº 4 Puntos y rangos de presión. (Togawa, 1997)

Presiones medidas en mmHg	Condiciones Fisiológicas	Condiciones No Fisiológicas
Presión Aórtica	75 a 135	25 a 300
Presión Ventricular Izquierda	0 a 125	(-) 15 a 300
Presión Arterial Pulmonar	10 a 25	0 a 150
Presión Ventricular Derecha	0 a 25	(-) 10 a 150
Presión Venosa Central	0 a 5	0 a 30
Presión Intracraneal	0 a 100	0 a 50
Presión Intraocular	10 a 20	0 a 50
Presión Intrauterina	0 a 75	0 a 200
Presión Intraureteral y Presión Intravesical	0 a 100	0 a 150
Presión Intraintestinal y Intragástrica	0 a 40	0 a 100
Presión Intratraqueal y Intraalveolar	0 a 15	(-) 75 a 100

2.3.2 Puntos de referencia para la medición de la presión sanguínea

La presión atmosférica se aplica uniformemente en el cuerpo humano, por lo que sus efectos son prácticamente los mismos en cualquier punto. Para poder realizar una correcta medición se debe considerar la ubicación de un punto de referencia adecuado. Es así que para esta medición existen de dos tipos de transductores, los de presión relativa, que no son afectados por los cambios de la presión atmosférica, y los de presión absoluta, que son afectados por las variaciones de la presión. Estos son introducidos en el sistema circulatorio por medio de catéteres, sondas o vías estériles. En este caso es necesario calibrar frecuentemente la presión atmosférica y realizar las correcciones en la medición de la misma. Por otro lado, el efecto de la fuerza gravitacional entre dos puntos es igual al producto de la densidad del fluido, la diferencia de altitud entre ambos y la aceleración de la gravedad.

Además se debe tener en cuenta la falta de precisión en la medición debido a la variación en la densidad del fluido al interior del catéter (para una solución salina es de 1.009 g/cm., en el conducto entre el punto de medición y el punto de referencia es de 1.055 g/cm.), por lo que la contribución de la presión gravitacional no es la misma.

En la Figura Nº 6, se observa el efecto que tiene la presión gravitacional en la medición de la presión sanguínea, así como la importancia de seleccionar correctamente el punto de referencia para obtener la mayor exactitud. (Geddes, 1991), (Togawa, 1997)

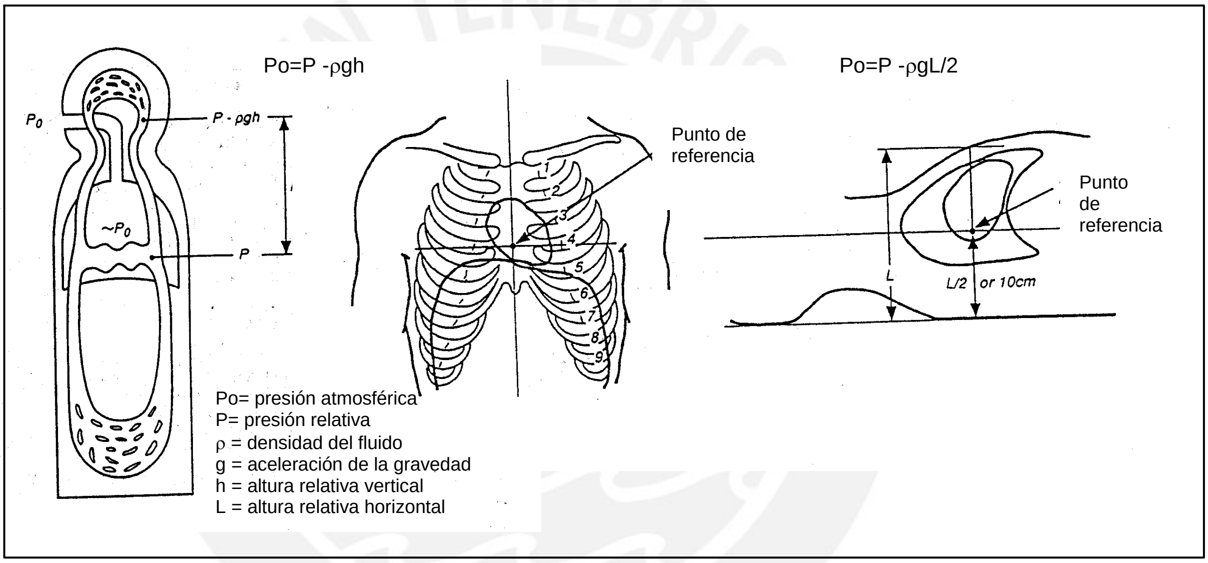

Figura N° 6 Selección del punto de referencia para la medición de la presión (Togawa, 1997)

2.4 Métodos de medición de la presión sanguínea

Son muchos los métodos o técnicas existentes para la medición de la presión arterial, sin embargo se ha logrado clasificarla en dos grandes grupos; el primero lo constituyen los métodos invasivos o directos, el segundo lo forman los métodos no invasivos o indirectos. A lo largo del desarrollo del capitulo se detallará su clasificación (Rithalia, 2000).

2.4.1 Métodos de medición de presión sanguínea Invasivos o Directos

Esta técnica requiere el ingreso o invasión del sistema circulatorio, ya sea en una arteria, o vena, insertando un dispositivo que permita la medición directa de la presión sanguínea. Para cumplir con este objetivo se requiere de catéteres, agujas y transductores de presión, sistema que en conjunto recibe la denominación de línea o equipo de presión invasiva.

2.4.1.1 Transductores de presión sanguínea

Los transductores de presión están constituidos por una pequeña membrana elástica conectada a un elemento sensor como una galga extensiométrica, sensor capacitivo o inductivo u óptico variable, elemento que recibirá de la membrana un desplazamiento proporcional a la presión externa que se desea medir. La deformación que recibe el elemento sensor permite determinar la presión según su principio transducible. Según su configuración puede ser frontal o lateral, dependiendo del tipo de catéter. Para evitar daños posteriores, el elemento sensor debe ser separado con una columna de solución salina, gas inerte o de gel.

2.4.1.2 Catéteres

Son tubuladuras, vías o conductos flexibles de material derivado del plástico, totalmente inerte al tejido interno de las venas y arterias; de diámetro inferior al de una arteria o vena. La escala de medición de las dimensiones del diámetro para este tipo de dispositivos se denomina French, donde un french equivale a 0.33 mm.

Los catéteres tienen diferentes diseños según la aplicación que se quiera dar con ellos, tales como catéteres con elemento sensor frontal o lateral, de un canal o duales, con balón, para monitoreo, para radiología y de material anticoagulante (Togawa, 1997).

2.4.1.3 Medición de presión sanguínea diferencial

La medición de la presión diferencial requiere de la evaluación de las presiones picos extremas, ya sea en las vías respiratorias o en el sistema cardiovascular, según sea el caso. En principio, la diferencia de presión se puede medir utilizando dos transductores de presión independientes. Si las presiones diferenciales son pequeñas comparadas con la variación de presión de cada persona, pequeños cambios en la sensibilidad y el nivel de referencia cero de los transductores pueden causar grandes errores de medición. En situaciones de este tipo, la medición de la presión diferencial es la más recomendada. Los rangos característicos de presión diferencial son de +- 0.05 KPa a +-0.l2 KPa para una frecuencia portadora de 3.3 KHz a 5 KHz y una respuesta de 1000 Hz. Además presenta una no-linealidad nominal menor que 0.5% a escala total y error de histéresis menor de 0.1% (Geddes, 1991), (Togawa, 1997), (Rithalia, 2000).

2.4.2 Métodos de medición de presión sanguínea No invasivos o Indirectos

La medición de la presión arterial por medio de la técnica de oclusión de un brazalete es la más usada, simple y difundida debido a que solo se requiere de un tensiómetro o esfigmomanómetro y un estetoscopio. Esta técnica se denomina auscultatoria. Se tienen a su vez otros métodos, los que serán explicados a continuación. En la figura N° 7 se observan diversos dispositivos utilizados para la medida de la presión sanguínea no invasiva a lo largo de su evolución tecnológica.

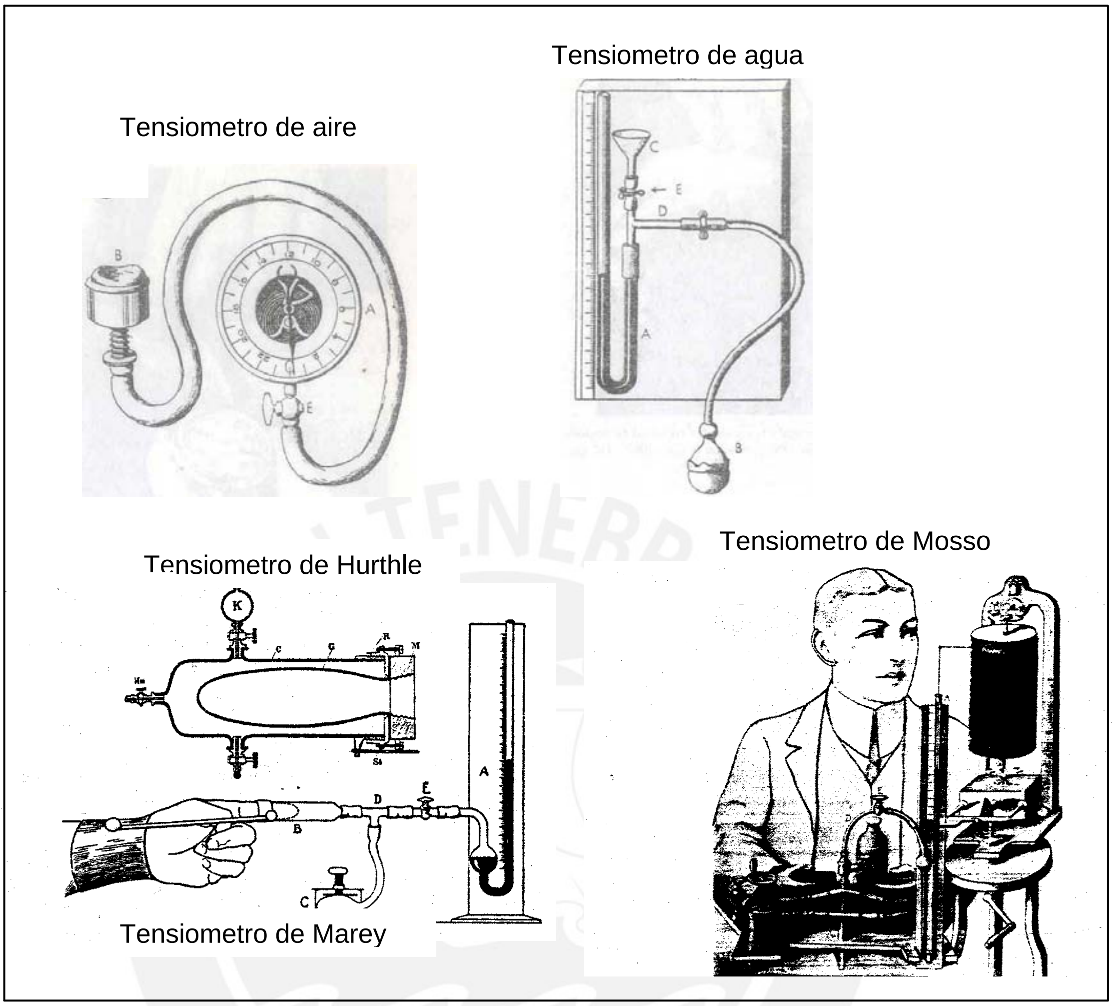

Figura Nº 7 Primeros dispositivos para la medición de presión (Geddes, 1991)

2.4.2.1 Método Palpatorio

El Método palpitatorio es el rutinariamente usado por los médicos y enfermeras para la medida de la presión sistólica, donde usualmente otros métodos de medición indirecta fallan.

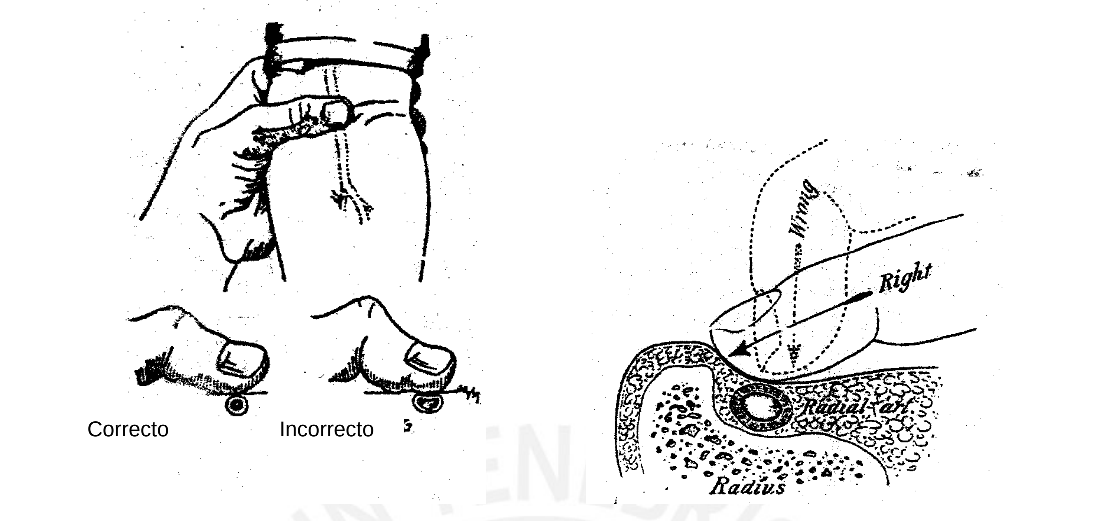

Figura Nº 8   Modo de aplicación del método palpatorio (Geddes, 1991)

Este método consiste en identificar el pulso distal durante la deflación de un brazalete que ocluye la arteria braquial del brazo. Este pulso se determina palpando con la yema del dedo anular la superficie de la piel sobre la arteria, la palpación permite identificar el paso gradual de la sangre desde la oclusión total hasta apertura completa de la arteria. En las siguientes figuras se observa gráficamente lo antes explicado, así como los dispositivos utilizados en este procedimiento. Asimismo en la tabla posterior se muestra la evolución tecnológica de este método, el mismo que por su naturaleza, no requiere de dispositivos muy sofisticados.

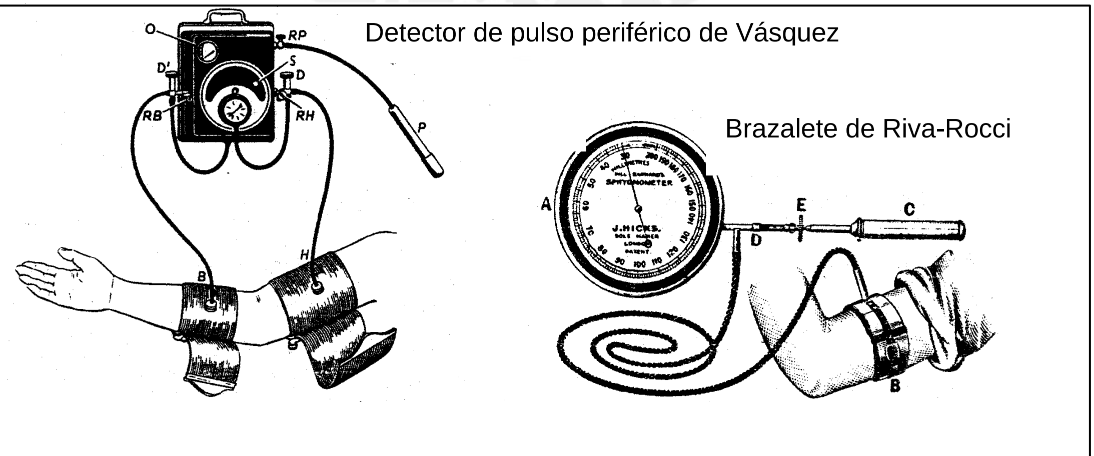

Figura Nº 9 Dispositivos para la aplicación del método palpatorio (Geddes, 1991)

Tabla Nº 5 Desarrollo tecnológico del método palpatorio. (Geddes, 1991)

Investigador	Año	Descripción
Norris	1916	Detección de aparición del pulso distal durante la deflación del brazalete.
Asociación Americana Corazón.	1951	Estandariza la técnica recomendada al uso de un brazalete de 1.2 veces el diámetro del miembro o 0.4 veces su circunferencia.
Von Barger	1954	Investigó la relación entre la presión sistólica obtenida directamente y por el método palpatorio.
Segall	1940	Detectó la presión diastólica y sistólica sin el uso de estetoscopio, solo sintiendo las vibraciones con el dedo pulgar sobre la arteria braquial.
Einselberg	1961	Grabó los cambios en el pulso braquial detectándolos por el método palpatorio.
Rogge / Meyer	1967	Comparó el método palpatorio y el ausculta torio.

2.4.2.2 Método Flush

En este caso, la aplicación consiste en presionar la yema de un dedo sobre una membrana flexible, al ejercer presión la sangre queda expelida del dedo, dejando vacíos los pequeños vasos terminales. Se nota que el color del dedo cambia de rojo a blanco. Luego se coloca un pequeño brazalete alrededor del dedo y se insufla hasta mantener la coloración blanca de la yema. Finalmente se desinsufla hasta notar el retorno de la coloración del dedo de blanco a rojo. El punto donde se inicia la coloración es el de la presión sistólica. Este método no es muy aplicado en la actualidad en los dispositivos de medición, sin embargo se estudian sus ventajas y aplicación.

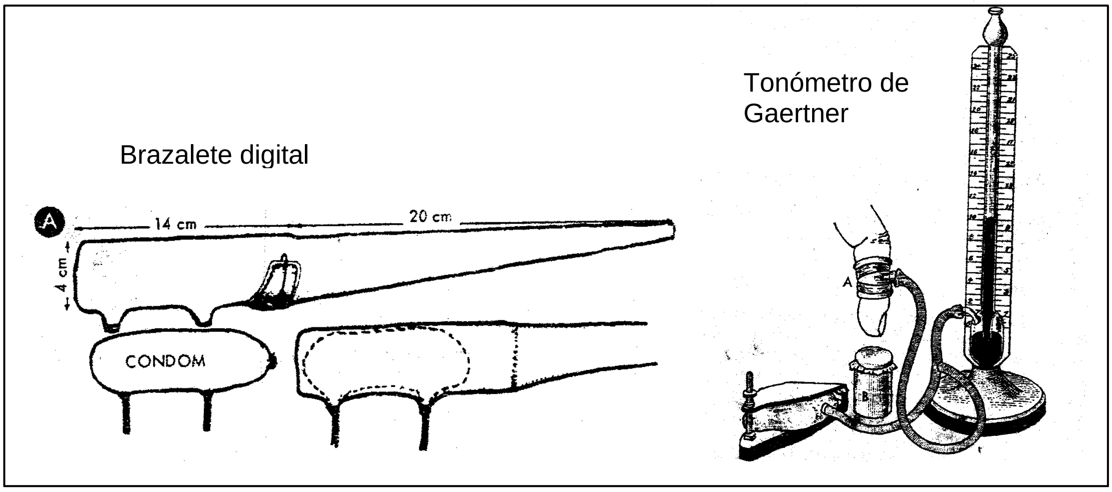

Figura Nº 10 Brazalete y dispositivos de medición con el método del flush. (Geddes, 1991)

Tabla Nº 6 Desarrollo tecnológico del método del flush. (Geddes, 1991)

Investigador	Año	Descripción
Marey	1879	Aplicación de una contra presión superior a la presión sistólica en el brazo.
Gaerther	1899	Aplicación del método flush en un dedo (para esto diseño un dispositivo para hallar la presión sistólica digital).
Wolf / Martín	1902/ 1903	Generación de controversia sobre las dimensiones del brazalete de oclusión.
Weaver / Boro	1950	Determino la presión sistólica en la arteria digital obteniendo valores comparables con los de la presión braquial del método auscultatorio.
Holding / Wohtmann	1952	Aplicación pediátrica del método. Investiga la relación entre el método flush y auscultatorio en niños.

2.4.2.3 Método Auscultatorio (Brazaletes, Sonidos de Korotkoff)

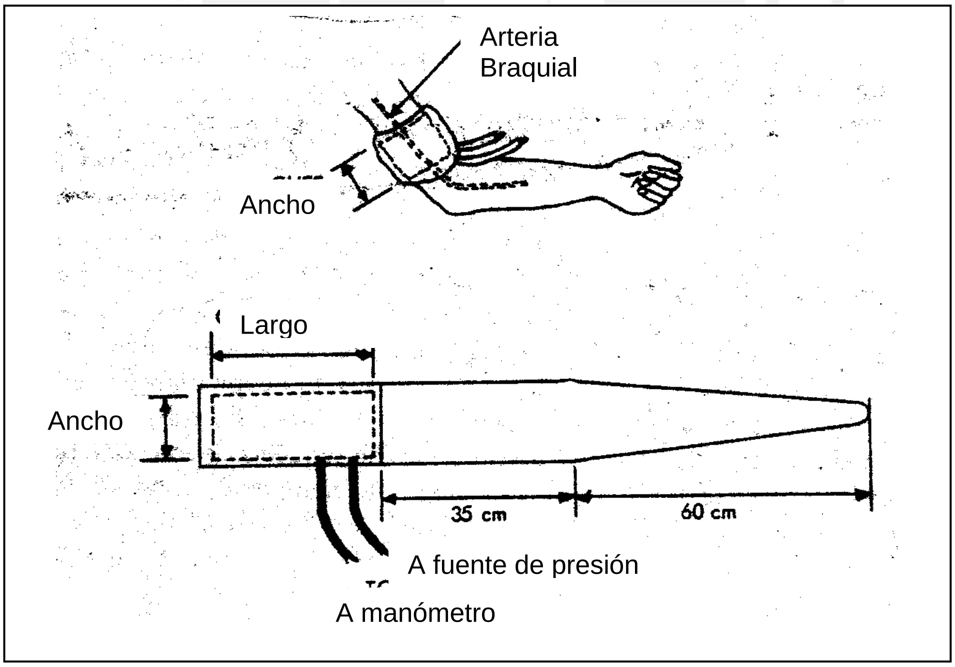

Figura Nº 11 Aplicación del método auscultatorio. (Geddes, 1991)

El método auscultatorio requiere de la aplicación de un brazalete de oclusión en el brazo que se conecta a un estetoscopio y un esfigmomanómetro o tensiómetro. Este tensiómetro es el encargado de transmitir la programación del insuflado del brazalete y la de almacenar toda la información. En la actualidad estos equipos son pequeños, de poco peso, silenciosos y precisos. En algunos casos este método incorpora un pequeño micrófono situado en el interior del brazalete, que se ha de colocar sobre la arteria braquial. El micrófono detecta los sonidos de Korotkoff de la misma forma que lo hace el oído humano con la ayuda del estetoscopio. Asimismo, algunos equipos incorporan un registro electrocardiográfico simultáneo destinado a hacer coincidir los sonidos percibidos con la onda R del electrocardiograma, de manera que puedan excluirse sonidos externos que generen artefactos (Rithalia, 2000), (Beevers, 2005).

Como se observa en casi todos los métodos de medición de presión no invasivos, es indispensable utilizar el brazalete de oclusión. Por ello es muy importante su correcta selección es decir el tamaño adecuado, la posición correcta en el método indicado. En la tabla Nº 7 se muestran las diferentes características de los brazaletes de oclusión.

Tabla Nº 7 Características de los brazaletes de oclusión. (OMS, 2005)

Brazalete	Ancho (cm.)	Largo (cm.)
Neonatal	3 x 6	Menor o igual a 6
Infante	5 x 10	6 – 10
Pediátrico	8 x 16	10 – 16
Adulto pequeño	10 x 20	16 – 25
Adulto	13 x 26	26 – 32.5
Adulto grande	16 x 32	32 – 40
Obeso	20 x 40	Mayor o igual que 40

Asimismo en la tabla Nº 8 se muestran los detalles del desarrollo tecnológico sufrido por los brazaletes de oclusión.

Tabla Nº 8 Desarrollo tecnológico de los brazaletes de oclusión. (Geddes, 1991)

Investigador	Año	Descripción
Von Reckinghauser	1901	Estableció que el ancho del brazal debe ser de 10 a 12 cm para una buena transferencia de presiones.
Rogan y Bordley	1941	Realizaron estudio para determinar la relación del brazalete y su ancho para el método auscultatorio
Rogan y Bordley	1955	Resumen tabla con factores de corrección
Kotte	1941	Estudio de la relación del brazalete y el tamaño del miembro al que se aplica.
Geddes	1966	Presenta gráficamente la información investigada por Rogan y Bordley
Wobung, Roobinow	1938	Estudios con método auscultatorio en niños.
Roobinow	1939	Investiga relación entre extensión y ancho del brazaletes 62 niños con diferentes brazaletes

Finalmente se muestran algunos de los dispositivos utilizados en este método de medición así como se detalla el desarrollo y evolución del método.

Tabla Nº 9 Desarrollo tecnológico del método auscultatorio. (Geddes, 1991)

Investigador	Año	Descripción
Korotkoff	1905	Propone el método auscultatorio.
Gittings	1910	Primer reporte de uso satisfactorio del método en USA.
Warfield	1912	Primera verificación del método comparando con el método directo en un perro.
MacWilliam / Melvin	1914	Primer reporte de la existencia y uso del método en Inglaterra.
Von Bonsdorff	1931	Primeras pruebas comparativas del método en humanos.
Hamilton	1936	Uso de un manómetro óptico y brazalete de 13 cm.
Ragan / Bordley	1941	Verificación y uso del método de Hamilton.
Steele	1941	Investigo la relación entre el método auscultatorio y el directo en humanos.
Kotte	1944	Verifico la presión diastólica comparándola con método auscultatorio y el directo.
Robert	1953	Inicio estudios para determinar el mejor valor de la PD.
Van Bergen	1954	Relación entre método Auscultorio y directo en sujetos normo y hipotensos.
Román	1965	Prueba la eficiencia del método auscultatorio.

2.4.2.4 Método Oscilosmétrico

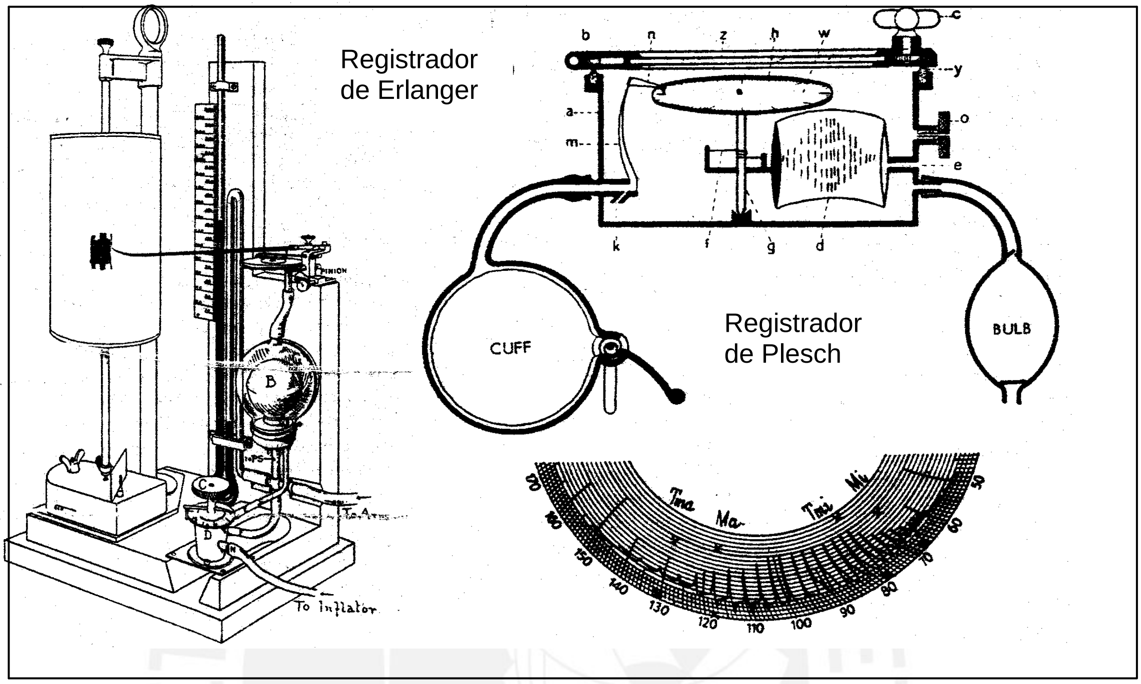

Figura Nº 12 Dispositivos para la aplicación del método oscilosmétrico (Geddes, 1991)

En la figura se observa un dispositivo básico para la medición de la presión utilizando el método oscilosmétrico. Este método se basa en la aparición de pequeñas oscilaciones o vibraciones en el brazalete al ocluirse una arteria principal de un miembro. Primero debe ocluirse el paso sanguíneo, es decir debe superarse la presión sistólica. Luego, se desinsufla levemente y la sangre comienza a circular con dificultad sobre el brazalete generando unas vibraciones proporcionales a la presión interna. Estas oscilaciones o vibraciones son capturadas para determinar la presión sistólica, la presión principal y con alguna dificultad la diastólica. En la tabla N° 10 se detalla el desarrollo tecnológico del método y los diferentes avances alcanzados (Geddes, 1991), (Rithalia, 2000).

Tabla Nº 10 Desarrollo tecnológico del método oscilosmétrico. (Geddes, 1991)

Investigador	Año	Descripción
Roy / Adami	1890	Adaptaron el principio desarrollado por Marey en su instrumento de oclusión del brazo.
Gumprecht	1900	Observo la existencia de presiones oscilatorias en el brazalete de Riva Rocci.
Hill / Brush	1897	Encontró que cuando se tiene la presión principal la presión del brazalete alcanza su máxima excursión.
Von Reckilnghausen	1901	Demostró que cuando decrece la contra presión, aumenta la amplitud de la oscilación después de la presión sistólica.
Martín	1903	Demostró que el punto de máxima oscilación no coincide con la presión diastólica o la presión principal.
Erlanger	1903	Investigaciones en la arteria femoral de perros mostraron que el punto mas bajo de la máxima oscilación indica la presión diastólica.
Howell / Brush	1901	Realizaron investigaciones entre la presión arterial y las oscilaciones producto de la contrapresión en la arteria carótida de un perro.
Janeway / Uskoff / Pachon	1904 / 1905 / 1909	Diseño instrumento para la medición de la presión con el método oscilosmétrico.
Plesch	1931	Diseño dispositivos para la visualización de la presión arterial por medio de las oscilaciones.
Dehon	1912	Comparo el método de las oscilaciones con personas con miembros amputados.
Macwillian / Melvin	1913	Determino que la máxima oscilación difiere de la presión diastólica solo en unos varios mmHg.
Brooks / Lockhardt	1916	Determino que la máxima oscilación de contrapresión difiere de la presión diastólica.
Erlanger	1921	Investigo en la determinación de la relación entre la presión diastólica y la máxima oscilación de contrapresión en la arteria femoral.
Pachon / Fabre	1921	Realizaron un modelo circulatorio para determinar la relación entre la presión diastólica y la máxima oscilación de contrapresión.
Kimura / Kaslow	1962	Sentaron las bases para la aplicación del método oscilosmétrico en la arteria ocular.
Kunze	1963	Reporto la aplicación del método oscilosmétrico para determinar la presión ocular.
Uzmann / Wood	1950	Adapto al método un sistema fotoeléctrico que permite determinar el pulso arterial.

2.4.2.5 Método Doppler o Ultrasónico

Este método puede ser usado en vez de los sonidos de Korotkoff. Dos diferentes métodos cumplen el mismo propósito. El primer método implica detección del movimiento de las paredes arteriales, y el segundo implica detectar la velocidad de la sangre arterial debajo del punto de oclusión. Para este objetivo un par de cristales transmisor y detector son incorporados dentro del brazalete de oclusión, y la señal de reflexión de las paredes arteriales puede ser recibida.

Los estudios comparativos han demostrado que las presiones sistólicas y diastólicas, obtenidas por las medidas de doppler del movimiento arterial de la pared, están siempre bastante cercanas a las de medidas directas. También han precisado que el método de doppler puede ser utilizado incluso cuando los pacientes están en shock, mientras que los sonidos del Korotkoff son inaudibles. Un problema con el método doppler es que la onda de ultrasonido es relativamente estrecha, y un movimiento leve de la punta de prueba causa una falla de la detección de la señal de doppler. Este problema es serio cuando el doppler se utiliza para la supervisión de la presión arterial continua. Esto ha sido solucionado usando diversos cristales para los emisores y los receptores (Geddes, 1991), (Togawa, 1997). En las figuras N° 13 y 14 se observa la aplicación del método. Mientras que en la tabla N° 11 se aprecia el desarrollo tecnológico del método.

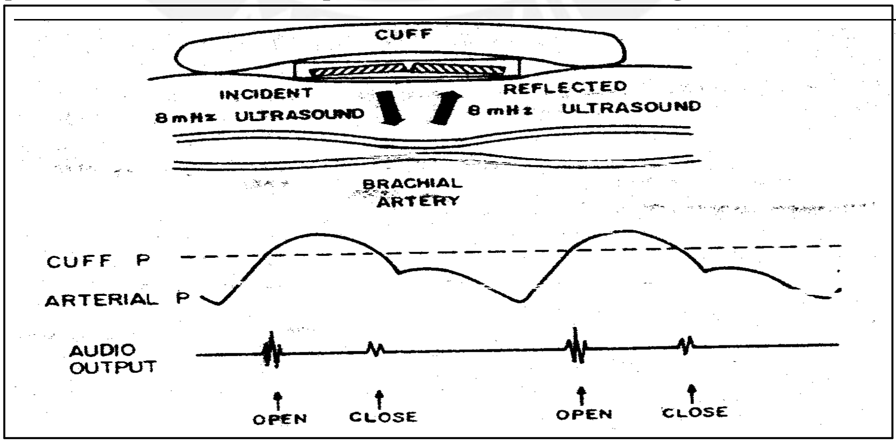

Figura Nº 13 Dispositivos para la aplicación del método ultrasonido (Geddes, 1991)

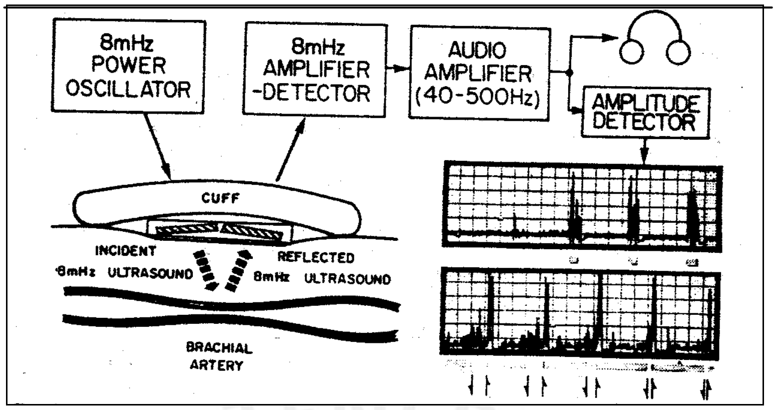

Figura Nº 14 Diagrama de bloque referente a la aplicación del método ultrasónico (Geddes, 1991)

Tabla Nº 11 Desarrollo tecnológico del método ultrasónico. (Geddes, 1991)

Investigador	Año	Descripción
Ware / Launger / Mc Cutcheon / Rusmer	1965 / 1966 / 1967	Describieron un método usando ultrasonido donde pudieron identificar el movimiento pulsátil en las paredes de la arteria braquial al ocluirla con un brazalete neumático.
Kemmerer / Kardon / Ware / Segall	1967 / 1968	Realizaron estudios para validar el método ultrasónico kinetoarteriográfico. Compararon las presiones detectadas con la de otros métodos

Finalmente, se muestra una tabla comparativa de los métodos de medición de presión arterial, indicando sus ventajas y desventajas:

Tabla N° 12 Comparación entre métodos de medición de presión arterial.

Métodos de medición de presión arterial		Ventajas	Desventajas
Invasivo o Directo		• Los valores obtenidos son los bastante exactos y directos. • Se pueden obtener datos instantáneos.	• Se requiere ingresar en una arteria. • Existe contacto directo con la sangre, por lo que podría haber infecciones, entre otros problemas.
No invasivo o Indirecto	Palpatorio	• Se obtienen la presión sistólica con relativa exactitud. • Solo se requiere de un manómetro y de la experiencia analítica y comparativa del especialista.	• Es un método muy antiguo, basado en información fisiológica del paciente • Se basa en la experiencia y conocimientos del especialista. • Se basa en la precisión del instrumental con que se cuenta. • Sus fuentes de error pueden afectar considerablemente la medición.
	Flush	• No requiere de mucho instrumental solo un manómetro.	• Se basa en la experiencia y conocimientos del especialista. • Se basa en la precisión del instrumental con que se cuenta. • Sus fuentes de error pueden afectar considerablemente la medición.
	Auscultatorio	• Los valores de la presión sistólica, diastólica y las pulsaciones dependen directamente de la exactitud del sistema de detección de latidos o sonidos de korotkoff. En la mayoría de los casos el error es aceptable. • La presión principal se calcula externamente.	• Depende de la correcta posición del brazalete, así como del sistema de detección de latidos. • Su principal fuente de error es la capacidad auditiva y visual humana al usar el estetoscopio y el tensiometro. • Se basa en la precisión del instrumental con que se cuenta.
	Oscilosmétrico	• Menor número de fuentes externas de error. • Los valores de la presión principal y presión sistólica son bastante exactos. • Fácil diseño e implementación lo hace seguro, portable y confiable.	• Depende básicamente de la correcta posición del brazalete. • Los valores referenciales y constantes en algoritmo son sus fuentes de error. • Los valores de la presión diastólica y de las pulsaciones se obtienen por medio de un algoritmo. • Se basa en la precisión del instrumental con que se cuenta.
	Ultrasonido	• La medida de las presiones sistólica y diastólica son bastante exactas a pesar de basarse en un cálculo matemático sobre el flujo sanguíneo.	• Método aun en prueba. • Su principal fuente de error es la correcta ubicación del brazalete. • Cualquier daño en los cristales altera la medición. • Señales de ultrasonido externas pueden alterar la medida. • Se basa en la precisión del instrumental con que se cuenta.

CAPITULO 3

Análisis del problema y alternativas de solución

3.1 Introducción

A lo largo de su existencia la humanidad ha combatido con innumerables y devastadoras epidemias y enfermedades. Valiéndose de su ingenio, inventiva, y de su capacidad de descubrir los fundamentos más importantes de la naturaleza, ha logrado desarrollar diferentes tecnologías con el objetivo de alcanzar una mejor calidad de vida. Esta necesidad de enfrentar y solucionar la problemática natural, lleva a la interacción de las ciencias exactas y biológicas, permitiendo esta forma el nacimiento de la bioingeniería. Así como se logro controlar epidemias como el cólera, la peste bubónica y la tuberculosis, en la actualidad se lucha tenazmente contra otras no menos temibles y quizás silenciosamente más devastadoras como lo son las enfermedades cardiovasculares y cerebrovasculares.

Hoy en día, las enfermedades cardiovasculares y cerebrovasculares ocupan los primeros puestos en cuanto a su frecuencia en el mundo occidental; y para los próximos 30 años se estima que serán las principales causas de mortalidad en el ámbito mundial, esto pese a los indudables avances en el seguimiento o "control" de los factores de riesgo y la progresiva mentalización de médicos, pacientes y la sociedad conjunta. Estas enfermedades, antes exclusivas de los países desarrollados ó del primer mundo, son ahora comunes en todo el planeta, incrementando su incidencia a medida que las naciones tercermundistas ingresan a la carrera del progreso, industrialización y mercantilismo (Wolff, 1989).

3.2 Definición y Análisis del problema.

En los últimos años, los índices de morbilidad y mortalidad debido a las enfermedades cardio y cerebro vasculares se han incrementado notoriamente en países como el Perú, mientras que disminuyen lentamente en las grandes potencias. Los siguientes indicadores estadísticos nos muestran los grados de incidencia de estas enfermedades:

- Cerca del 20% de la población mundial menor de 40 años padece de hipertensión.
- En los países desarrollados cerca del 40% de las muertes, antes de los 65 años, se deben a las consecuencias de la presión alta.
- El 40% de las personas que se retiran de la actividad laboral, padecen enfermedades cardiovasculares, entre las cuales la hipertensión es una causa frecuente.
- Se estima además, que alrededor del 30% de la población norteamericana es hipertensa sin saberlo.
- Según información del Ministerio de Salud del Perú, anualmente fallecen 12,000 personas debido a enfermedades cardiovasculares. El índice de morbilidad cardiovascular fue de 9.9%, mientras que el cerebrovascular fue de 4.7%. La población con mayor incidencia corresponde a los mayores de 45 años de edad. Ver las tablas Nº 13 y N° 14 (MINSA, 2005)

Tabla Nº 13 Índice de morbilidad cardiovascular en el Perú. (MINSA, 2005)

Enfermedades Cardiovasculares						
Edad	Total		Hombres		Mujeres	
	Nro.	%	Nro.	%	Nro.	%
15 a 19	38	2.45	20	1.29	18	1.16
20 a 24	63	2.89	31	1.42	32	1.47
25 a 49	314	3.17	181	1.83	133	1.34
50 a 64	1,104	8.80	687	5.50	417	3.30
65 a más	7,511	18.00	3,574	8.00	3,937	9.00

Tabla Nº 14 Índice de morbilidad cerebrovascular en el Perú. (MINSA, 2005)

Enfermedades Cerebrovasculares						
Edad	Total		Hombres		Mujeres	
	Nro.	%	Nro.	%	Nro.	%
15 a 19	39	2.5	23	1.5	16	1.0
20 a 24	48	2.2	29	1.3	19	0.9
25 a 49	282	2.8	144	1.5	138	1.4
50 a 64	694	5.6	348	2.8	346	2.8
65 a más	2,682	6.3	1,243	2.9	1,439	3.4

Es común observar en estas enfermedades, el incremento de la presión arterial debido a una gradual degeneración del sistema cardiovascular, pues cuando la presión arterial es alta se obliga al corazón a bombear sangre venciendo una mayor resistencia. Como consecuencia de esto, el corazón se fatiga, produciéndose debilidad e incrementando las posibilidades de ocurrencia de un ataque cardiaco. Además la presión alta de la sangre, ocasiona una carga enorme en las arterias desgastándolas, en particular en zonas muy irrigadas como el cerebro, las coronarias y los vasos sanguíneos renales. Debido a lo antes mencionado los ataques cerebrales y los infartos al miocardio son consecuencias frecuentes y muy peligrosas de la hipertensión no tratada. En el anexo N° 1a se muestran algunos datos respecto a la incidencia de las enfermedades cardiovasculares y cerebro vasculares en el mundo (Rocella, 2003), (AHA, 2005).

Cabe resaltar que la hipertensión no presenta síntomas típicos que resulten signos precoces, por el contrario, muchas personas se sienten bien a pesar de la presión alta, siendo la medición la única forma de saber si la presión es “peligrosa” ó no. Si es detectada a tiempo, un tratamiento inmediato puede ayudar a evitar consecuencias fatales. El tratamiento consiste básicamente en el “control” ó medición regular de la presión, tomar todos los días los medicamentos recetados, así como algunos cambios en los hábitos alimentarios y en el estilo de vida (Wolff, 1989).

3. 3 Tecnología Actual.

En Perú, así como en Latinoamérica y demás países tercermundistas el desarrollo económico, tecnológico y la transculturización han traído consigo cambios en los hábitos y forma de vida de sus poblaciones. Esta ha determinado que se comiencen a desarrollar enfermedades propias de sociedades altamente industrializadas, por lo que es muy común observar problemas de obesidad, estrés, hipertensión, entre otros.

El desarrollo de la ciencia médica nos permite tener conocimiento de las causas que generan las enfermedades cardiovasculares y cerebrovasculares, así como su evolución y métodos de control. En las últimas décadas, todos estos esfuerzos se enfocan en prevenir el padecimiento de la enfermedad en lugar de esperar para tratarla. Con este fin se busca reducir las condiciones que contribuyen al desarrollo de las mismas, es decir, controlar los factores de riesgo. En este sentido, la hipertensión es uno de los principales factores de riesgo, quizá el más peligroso, debido a sus características asintomáticas.

Una forma de poder controlarlo es medirlo y evaluarlo continuamente, con la finalidad de determinar su peligrosidad y evitar futuras consecuencias, generalmente irreversibles. Por ello se recurre a diferentes métodos que permiten la medición de la presión arterial, entre los que destacan el auscultatorio y el oscilosmétrico, ambos métodos de medición de presión no invasivos o indirectos, que nos permiten determinar la presión máxima ó sistólica, la presión mínima ó diastólica, además de la presión principal y la frecuencia cardiaca (Guyton, 1999), (Rithalia, 2000), (AHA, 2005).

3.3.1 Desarrollo Tecnológico.

La tendencia hoy en día en lo que respecta a métodos de medición de la presión arterial no invasiva es buscar alcanzar una mayor exactitud, disminuyendo el error, y ocasionando la menor molestia e incomodidad. Los métodos más utilizados son el auscultatorio y el oscilosmétrico, los mismos que son aplicados en equipos de medición ambulatoria y de monitoreo continuo. A continuación se describen brevemente las técnicas o métodos mencionados:

- El método auscultatorio esta basado en la detección de los sonidos de Korotkoff. Estos sonidos son detectados con un estetoscopio o micrófono colocado sobre la arteria que ha de ocluirse, debajo del brazalete de compresión u oclusión (Togawa, 1997).
- El método oscilosmétrico se basa en la generación de pequeñas oscilaciones debajo de la zona comprimida del brazalete, donde las presiones sistólica y diastólica guardan correspondencia con las mencionadas oscilaciones en la banda elástica del brazal (Togawa, 1997).
- Otra aplicación del método oscilosmétrico es la basada en la detección del volumen de las pulsaciones debajo del brazalete de oclusión, usualmente sobre un dedo. La presión sistólica y la presión media se estiman de la primera y de la máxima oscilación del brazalete respectivamente. Estas oscilaciones corresponden a las presiones y cambios de volumen en el dedo. La presión de diastólica es determinada por medio de un algoritmo matemático en donde se relacionan entre otros parámetros la presión sistólica y media (Rithalia, 2000).
- Asimismo, se están desarrollando equipos de medición instantánea de la presión arterial, basados en métodos que utilizan transductores de ultrasonido, permitiendo determinar el flujo sanguíneo instantáneo, para luego derivar de esta la presión sanguínea instantánea (Togawa, 1997).

Estas técnicas se basan en los fenómenos físicos ocurridos durante la compresión de una arteria. El método auscultatorio depende de los fenómenos ocurridos en el flujo sanguíneo durante la oclusión, este flujo cambia de laminar a turbulento y luego nuevamente a laminar, así como de los sonidos de Korotkoff que corresponden a las aperturas y cierres de las válvulas del corazón. Mientras tanto, en el método de oscilosmétrico se toma como referencia las oscilaciones generadas en el brazalete durante la insuflación del mismo sobre el brazo, muñeca o dedo.

En los anexos N° 2a, N° 2b y N° 2c, respectivamente, se presenta información que permitirá alcanzar un claro entendimiento de las técnicas para la detección de la presión arterial utilizando métodos no invasivos, la clasificación de equipos de medición de presión arterial, así como las normas técnicas y estándares internacionales para los equipos de medición de presión arterial utilizando el método no invasivo.

3.4 Equipo de Monitoreo Ambulatorio de Presión Arterial (MAPA)

En este punto se desarrolla con mayor detalle las ventajas, desventajas, características técnicas, aplicación y uso correcto del MAPA, que es finalmente el punto central de este trabajo de tesis.

3.4.1 MAPA

El MAPA es un sistema que permite la medición ambulatoria de la presión arterial durante 24 a 72 horas. Los resultados del control ambulatorio nos entregan un perfil integral de la presión arterial y permiten tener una idea de la condición cardiovascular del paciente. Es útil para la detección de la hipertensión difícil de diagnósticar, así como el control de la terapia antihipertensiva. Esta técnica es por su seguridad, estabilidad, predictividad, carencia de riesgo alguno y ausencia de complicación, una alternativa superior al control aislado de la presión arterial. Asimismo permite evitar y detectar el "síntoma de bata blanca" y casos de hipertensión emotiva, se aplica también en pacientes hipertensos confirmados que no responden positivamente al tratamiento y en el monitoreo de pacientes con trasplante de corazón. Otra ventaja muy importante de esta técnica, es la de concientizar al paciente respecto a la gravedad de su enfermedad, pues al revisar los datos dados por el MAPA, conocerá la magnitud y características de su enfermedad, comprendiendo la necesidad de tratamiento contribuyendo a su ejecución (Togawa, 1997), (Rithalia, 2000), (AMPA, 2001) y (ECRI, 2002).

3.4.2 Características Técnicas del MAPA

En la actualidad existen diferentes fabricantes de equipos de monitoreo de presión arterial ambulatoria, sin embargo las características básicas son comunes en casi todos ellos. En el anexo Nº 2d se muestran unas tablas comparativas de diferentes productos comercializados actualmente en el mercado mundial, así como las características técnicas de los mismos (AMPA, 2001), (ECRI, 2002).

A continuación, en la tabla N° 15 se muestran las características más importantes, las mismas que se deben tener en cuenta para una evaluación (AMPA, 2001), (ECRI, 2002):

Tabla N° 15 Especificaciones técnicas del MAPA. (ECRI, 1998)

ESPECIFICACIONES TÉCNICAS	DESCRIPCIÓN
Método de medición utilizado	Auscultatorio Oscilosmétrico Doppler
Rango de la presión sanguínea	Sistólica: 50-290 mmHg, Diastólica: 30-200 mmHg
Exactitud	2 – 5 %
Tasa de pulsaciones	40 – 180 bpm
Frecuencia de la medición	3 – 120 minutos
Periodo de duración de la medición programada	1 – 3 días
Dispositivo de insuflación del brazalete	Bomba Pulsátil, Micro bomba peristáltica, Micro bomba de Diafragma
Presión de insuflación	160 – 250 mmHg Pre-seleccionada o Automática
Dispositivo de deflación del brazalete	Válvula solenoide, Electroválvula micro controlada
Tipos de alarmas	Auditiva, Visual
Límites de alarmas	Bajo: 1 –1 20 mmHg, Alto: 10 – 200 mmHg
Dimensiones del brazalete	Obeso, Adulto, Pediátrico, Neonatal
Marcador de sucesos o eventos	Permite al usuario registrar el momento en que ocurre algún suceso que pueda alterar la medición.
Sistema de auto calibración o autocero	Manual, Automático (inicio de cada lectura)
Modo de almacenamiento y capacidad de memoria	Memoria dinámica no volátil provista de RTC
Recuperación y transferencia de datos	Puerto Serial (RS232) Puerto Paralelo o Puerto USB
Requerimientos del programa de visualización	DOS, Windows
Características ergonómicas del equipo	Dimensiones físicas y peso
Tipo de baterías y Tiempo de operación	Alcalina, Ni-Cd, recargable / 24 – 72 horas

3.4.3 Aplicación y uso del MAPA

Se sugiere utilizar en:

- Pacientes con posibilidades de tener hipertensión, es decir con presiones diastólicas igual o superior a 100 mmHg y que no tienen evidencia de daño del corazón y/o problemas renales.
- Pacientes con presión arterial fronteriza o cercana a los valores considerados para la hipertensión.
- Control de la terapia antihipertensiva medicamentosa con el fin de encontrar la más adecuada al paciente.
- Pacientes que presentan un deterioro de su condición cardiovascular o daño en el músculo cardiaco a pesar del control de la presión arterial.
- Pacientes que no aceptan ni reconocen su enfermedad hipertensiva. El MAPA permite demostrar el inadecuado control de su presión arterial, logrando el entendimiento de su problema, así como convicción y complacencia del tratamiento.
- Pacientes con historia sugestiva de síncope, es decir la perdida súbita y momentánea del conocimiento acompañada de la no percepción de los latidos cardiacos y de la respiración En tales pacientes el MAPA puede usarse el mejor junto a un holter.
- Síntomas o señales sugestivas de hipertensión episódica.
- Investigación clínica, puesto que los datos del MAPA contienen muchas más muestras de lecturas de presión arterial, estos datos son una fuente estadística más robusta que las medidas aisladas. Esto permite a los especialistas definir nuevas terapias y tratamientos, siendo esto es muy importante para la evaluación eficaz de nuevos agentes terapéuticos.

Estos equipos no deben ser utilizados en pacientes con las lecturas de presión arterial claramente elevadas, donde el daño del sistema cardiovascular es evidente y no es requerido para propósito de diagnóstico; ni con paciente con un régimen antihipertensivo satisfactorio y con la evidencia de buena evolución.

El entrenamiento del personal en la calibración y mantenimiento básico del MAPA, así como sus accesorios son de vital importancia. De igual manera, el análisis e interpretación de los datos requieren de un cuidado considerable y de la experiencia del médico especialista (Rithalia, 2000), (Mc Grath, 2001).

3.4.4 Análisis de la información

Los actuales equipos se programan para tomar lecturas adicionales en caso de producirse un aparente error en alguna de ellas. En promedio se obtienen 60 lecturas cada 24 horas si se programan grabaciones de lecturas cada media hora durante el día y a cada hora por la noche, incluyendo los procedimientos de calibración, grabación de lecturas de prueba y reintentos. Es recomendable que el paciente lleve siempre consigo una agenda de sucesos, donde anote todos los eventos relacionados con su estado cardiovascular e inclusive medicación y horarios de su rutina diaria.

El análisis de la información se realiza primeramente transfiriendo los datos grabados a una computadora, además de los sucesos importantes anotados en la agenda. Asimismo se recomienda considerar los códigos de alerta y error generados durante el periodo de medición.

Los datos necesarios para la historia clínica y programación del equipo son: Tiempo de ciclo diurno, tiempo de ciclo nocturno, hora de acostarse, hora de levantarse, fecha y hora de inicio de prueba. También son importantes los datos del paciente como nombre, edad, sexo, otras enfermedades, tratamientos médicos y medicamentos ingeridos, otras características resaltantes que el especialista considere importantes del perfil clínico del paciente. Para el análisis de la información cardiovascular adquirida por el equipo son importantes: El porcentaje de lecturas mientras está despierto, porcentaje de lecturas cuando duerme, área debajo de la curva de presiones para obtener la “carga de presión arterial”, inclusión de los eventos externos o alteraciones (Mc Grath, 2001), (Woo, 2004).

Toda la información obtenida permite a los especialistas realizar estudios epidemiológicos de todo nivel, obteniendo el perfil cardiovascular de pacientes en forma individual, pero también el perfil cardiovascular y epimediológico de toda una población, tanto a nivel local como regional. Esta información, junto con la calidad de vida de la población, características culturales y sociales permiten definir diferentes tratamientos y sobre todo políticas sociales para el control y erradicación de estas enfermedades, en beneficio de la salud y desarrollo de los seres humanos.

3.5 Evaluación Tecnológica de adquisición de un MAPA

3.5.1 Análisis comparativo.

A continuación enumeramos las características que son evaluadas comúnmente para seleccionar un equipo de monitoreo ambulatorio de presión arterial:

- Perfomance y autonomía del equipo.
- Exactitud y precisión de las medidas adquiridas.
- Método de medición
- Modo de operación y programación.
- Programa de transferencia, programación y visualización de datos.
- Costos del equipo, así como de sus insumos accesorios y repuestos.
- Soporte técnico.

Estas características permiten al evaluador de tecnologías definir el concepto de calidad del producto, ventajas y desventajas de la tecnología, y el análisis de costo beneficio; para su posterior selección según las necesidades epidemiológicas, sociales y económicas del sector que pretende adquirir esta tecnología (ECRI, 2002).

CAPITULO 4

Descripción y desarrollo del problema

4.1 Introducción.

En este capitulo se plantea el desarrollo de un sistema de adquisición de presiones con características que en primer lugar permitan medir, almacenar y registrar las presiones arteriales cumpliendo con los requisitos de portabilidad, exactitud, eficiencia y seguridad. Se elige la técnica de medición de presión oscilosmétrica, pues prácticamente no requiere de la intervención del ser humano por lo que se eliminan muchas posibles fuentes de error en la detección de las presiones, como el error humano auditivo y visual.

4.2 Funcionamiento del sistema de adquisición de presiones arteriales.

El siguiente diagrama de bloques dará una idea del funcionamiento del sistema de adquisición de presiones arteriales no invasivo, así como su concepción.

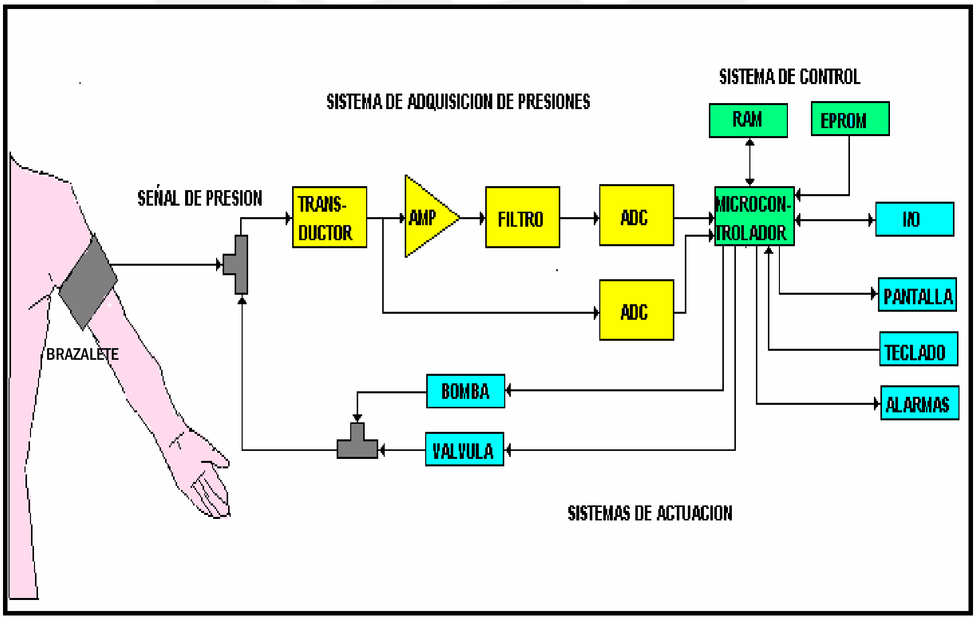

Figura N° 15 Diagrama de bloques del monitor ambulatorio de presión arterial

4.3 Análisis del Sistema de adquisición de presiones

Podemos observar en el diagrama de bloques anterior que el MAPA esta constituido por tres sistemas:

- Sistema de adquisición,
- sistema de control y
- sistema de actuación.

El análisis siguiente pretende mostrar y verificar las características del sistema de adquisición de presión asegurando la estabilidad del sistema diseñado. El sistema de adquisición de presiones está compuesto a su vez por el transductor de presión y el circuito de acondicionamiento de señal. Como se verá con más detalle luego la curva característica del transductor, según el fabricante, responde a:

$V_O = V_S\,(P \text{ x } 0.018 + 0.04)$ +/- (ErrorPresión x FactorTemperatura x $0.018\text{x } V_S$)

Donde $V_S = V_{DD}$+/-$0.25V_{DD}$,

$V_{DD}=5V$,

P= presión de entrada.

De esta ecuación se concluye que el sistema de transducción es básicamente lineal, teniéndose mínima dependencia de error, siendo considerables por las variaciones de la fuente de alimentación (20%), y en menor grado el error de presión (2.5%), y las variaciones de temperatura en condiciones normales (1.25%).

A continuación, en la figura N° 16 se muestra el circuito de acondicionamiento de señal:

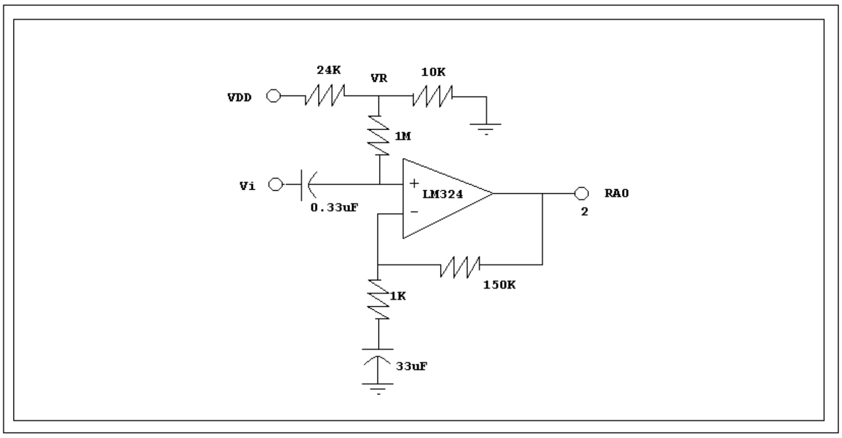

Figura N° 16 Circuito de acondicionamiento de señal

Análisis del circuito de acondicionamiento de señal

De la malla superior se obtiene la siguiente ecuación:

$(V_i - V) / X_2 = (V_i - V_R) / R_2 \quad => \quad V = ((V_i \times R_2) + (V_R \times X_2)) / (X_2 + R_2)$ .... (i)

De la malla inferior se obtiene:

$(V_0 - V) / R_3 = V / X_1 \quad => \quad V = V_0 \times X_1 / (R_3 + X_1)$............................... (ii)

De (ii) y (iii) se tiene:

$((V_i \times R_2) + (V_R \times X_2)) / (X_2 + R_2) = V_0 \times X_1 / (R_3 + X_1)$....................................... (iii)

$V_0 = [V_i \times (R_2 / (X_2 + R_2)) \times ((R_3 + X_1) / X_1)] +$

$[V_R \times (X_2 / (X_2 + R_2)) \times ((R_3 + X_1) / X_1)]$...(iv)

Reemplazando $X = 1 / jwC$ en (iv):

$V_0 = V_i \times [(jwR_2C_2/(jwR_2 C_2 + 1)) \times ((jw(R_1+R_3)C_1 + 1) / (jwR_1 C_1 + 1))] +$

$V_R \times [((jw(R_1+R_3)C_1 + 1) / ((jwR_2 C_2+1) \times (jwR_1C_1+1))]$ ....(v)

Reemplazando $s = jw$ en (v) y se tiene:

$V_0 = V_i [(sR_2C_2/(sR_2 C_2 + 1))((s(R_1+R_3)C_1 + 1) / (sR_1 C_1 + 1))] +$

$V_R [((s(R_1+R_3)C_1 + 1) / ((sR_2 C_2 + 1)(sR_1 C_1 + 1))]$ ....(vi)

Luego, se reemplaza R_1= 1KΩ, R_2=1MΩ, R_3=150KΩ, C_1= 33uF, C_2= 0.33uF, y

$V_R = V_{DD} \times R_5 / (R_4 + R_5)$, donde V_{DD}=5V, R_4=24KΩ y R_5=10KΩ => V_R = 1.47V en (vi) tenemos:

$V_0 = V_i$ [(0.33s/(0.33s + 1))(4.98s/(4.95s + 1))] +
V_R [(4.98s + 1)/((0.33s + 1)(4.95s + 1))] , ...(vii)

finalmente

$V_0 = V_i$ [164.34s^2/(1.634s^2 + 5.28s +5.28)] +
V_R [(4.98s + 1)/(1.634s^2 + 5.28s + 5.28)]…..(viii)

La ecuación (viii) corresponde a la respuesta del circuito de acondicionamiento, se evidencia que la tensión de salida depende de dos componentes, una correspondiente a la transducción de la presión y la otra a la fuente de alimentación. Podemos definir a esta última como una perturbación del sistema.

Utilizando el programa de procesamiento matemático MATLAB se analiza las respuestas de las dos componentes:

Analizando la componente dependiente de la señal de transducción de presión se tiene:
a=[164.34 0 0]
b=[1.634 5.28 5.28]
Bode (a,b)

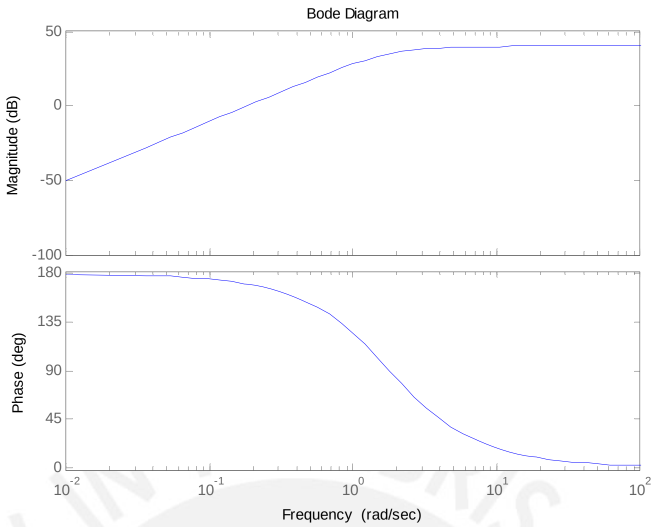

Figura N° 17 Diagrama de Bode del Circuito de acondicionamiento

Nyquist (a,b)

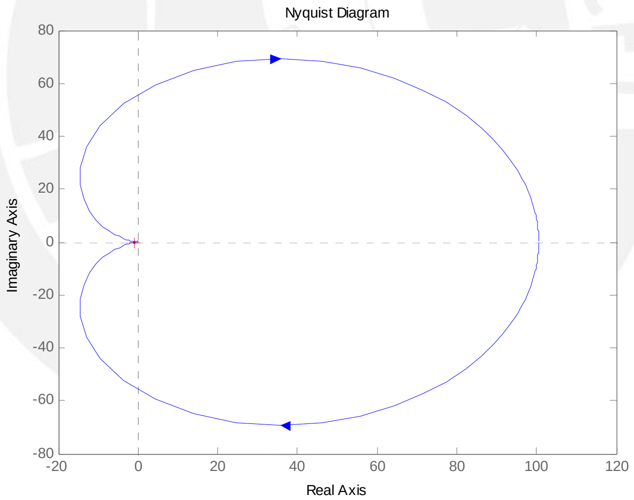

Figura N° 18 Diagrama de Nyquist del Circuito de acondicionamiento

De las respuestas obtenidas tanto por los diagramas Bode y el análisis del criterio de estabilidad de Nyquist, se determina que esta etapa es estable.

Mientras que de análisis de la componente dependiente de la fuente de alimentación o perturbación se obtiene: c = [7.32 1.47]

Bode (c,b)

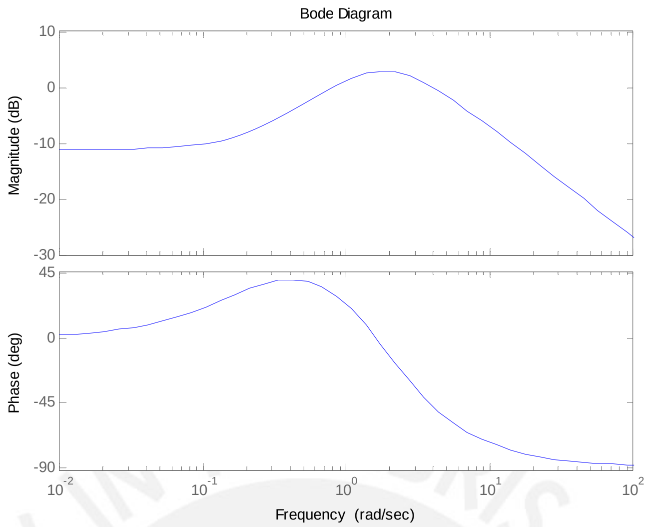

Figura N° 19 Diagrama de Bode del Circuito de perturbación

Nyquist (c,b)

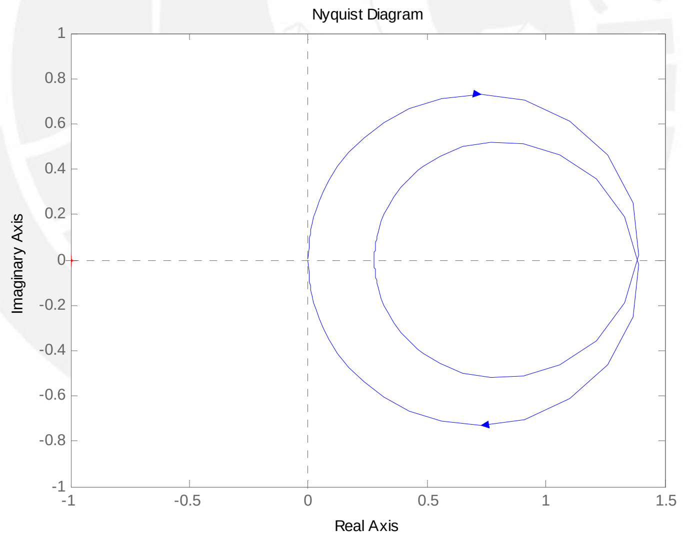

Figura N° 20 Diagrama de Nyquist del Circuito de perturbación

Los diagramas muestran las características de inestabilidad que genera el efecto de las variaciones en la tensión de la fuente de alimentación.

En resumen, se observa que tanto en la ecuación de respuesta del transductor, como del circuito de acondicionamiento presentan una gran dependencia a las variaciones de la tensión entregada por la fuente de alimentación, estas variaciones pueden afectar hasta en un 20% de error en el proceso de adquisición, contribuyendo además a la inestabilidad del sistema. Es por este motivo, que se incluye en el diseño del MAPA, un sistema de monitoreo de las variaciones que genera la fuente de alimentación. Entre las opciones de monitoreo se eligió la función de monitoreo por microcontrolador, esta toma permanentemente una tensión referencial y la compara, invalidando la operatividad del sistema en caso de variaciones fuera de rango. De esta forma se asegura que las mediciones realizadas sean confiables.

4.4 Especificaciones Técnicas.

Las especificaciones o características técnicas tienen por objetivo dar información del funcionamiento, rendimiento, eficiencia y calidad de un equipo médico o dispositivo mecánico, eléctrico o electrónico. Por este motivo, estas se rigen por los estándares internacionales que aseguran entre otras cosas la calidad del producto. En la tabla N° 15 presentada en el capitulo N° 2 se muestran las especificaciones técnicas establecidas por entidades internacionales reguladoras y normativas como la Asociación para el avance de la instrumentación médica (AAMI), la Sociedad británica contra la hipertensión (HBS) y la Comunidad europea (CE), con el fin de mantener un estándar común en el desarrollo de equipos médicos.

4.5 Características del sistema mecánico.

4.5.1 Brazalete de oclusión.

Como se observó en los capítulos anteriores, depende de la correcta selección del brazalete, tanto en dimensiones como ubicación, el obtener una buena medida de la presión. En este sentido, se sabe que para cada tipo de paciente, según su edad y peso, se tienen que utilizar el brazalete correspondiente, de manera que no se dañe al paciente ni se obtengan medidas erradas. En la tabla N° 10 del capitulo N° 2 se mostró el detalle de las dimensiones de los mismos, así como también en el ítem 3.1 del capitulo N° 3 se indica la manera de ubicarlo correctamente y reducir errores. En la siguiente figura (figura N° 21) se observa el brazalete para pacientes adultos utilizado en las pruebas.

Figura N° 21 Brazalete de oclusión para medición de presión arterial no invasiva o indirecta

4.5.2 Bomba.

Debido a las características de portabilidad del diseño se requiere utilizar bomba del tipo de desplazamiento positivo. Según el American Petroleum Institute (API) la clasificación de las bombas de desplazamiento positivo: Reciprocantes (estándar 674), Controladas por Volumen (estándar 675) y Rotatorias (estándar 676). Según el Hydraulic Institute Standards, para el diseño de una bomba de desplazamiento positivo reciprocante se deben tener en cuenta las especificaciones que muestran en la siguiente tabla N° 16. Asimismo, las bombas reciprocantes se clasifican en: Fuerza y Acción Directa. Estas últimas se sub clasifican en: Horizontal, Vertical, Acción simple, Doble acción, Pistón, Embolo y Diafragma. Es recomendable el uso de bombas de diafragma para situaciones donde se requiere controlar volumen, exactitud, linealidad, contar con aislamiento y tener bajo flujo (Matley, 1989), (Miller, 1995), (HIS, 2005).

Tabla N° 16 Especificaciones técnicas de bombas.
(Hydraulic Institute Standards, 2005)

ESPECIFICACIONES
Aceleración de cabezal
Tasa de cambio de capacidad
Tasa de cambio de presión diferencial
Succión positiva disponible (NPSHA)
Succión positiva requerida (NPSHR)
Eficiencia volumétrica
Movimiento perdido
Relación de capacidad
Linealidad
Flujo repetitivo
Exactitud en estado estacionario
Desplazamiento
Tasa de cambio velocidad
Cantidad de fluido por segundo (slip)

En este sentido, para nuestro diseño se requiere de una mini bomba de diafragma, con una tensión de alimentación de máxima de 7.5 Vdc, corriente de carga máxima de 100 mA, flujo de carga máxima de 6 PSI y tiempo de respuesta de 100mseg. En la siguiente figura N° 22 se muestran las mini bombas usadas para el diseño del MAPA.

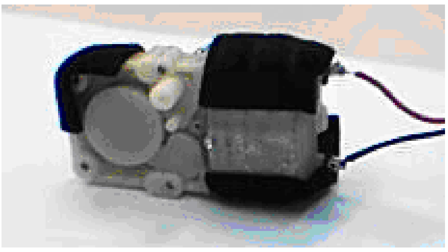

Figura N° 22 Mini bombas para insuflado de presiones automático

4.5.3 Electroválvula

La micro o mini electro válvula cumple una función muy importante en el diseño debido a que se encarga de regular la presión del brazal sincronizando permanentemente la deflación y permitiendo la aplicación del método oscilosmétrico. En la tabla N° 17 se muestran las especificaciones técnicas de la electroválvula.

Tabla N° 17 Especificaciones técnicas de electroválvulas. (Asco Scientifics, 2005)

ESPECIFICACIONES	RANGOS
Material del Cuerpo	Latón, bronce o acero inoxidable
Material de los sellos	Elastómero: de Nitrilobutileno (NBR), de Fluorocarbono(FPM), de Etilenopropileno (EPDM), de Perfluorate (PFPM)
Material de las Bobinas	Estándares de la EC, 73/23CEE directivo y la modificación relativa 93/68EEC.
Voltajes (VAC)	24V/50Hz
Voltajes (VCC)	12-24V.
Tolerancias del voltaje	+10% -15% para AC; +10% -5% para CC
Rango de Temperatura	0 a 50°C
Tiempo de reacción	Generalmente más bajo de 10 mseg.
Potencia consumida	1.9 a 2.5 Watts a 23°C
Vida útil	Depende de la presión, la temperatura, el tipo de medio y el voltaje.

En el proceso de evaluación para la selección de una electroválvula se recurrió a información de fabricantes como Asco Scientifics y Clippard Instrument Laboratory (ver anexo N° 3a). Luego de la evaluación, la electroválvula seleccionada es de una vía, tensión de alimentación de máxima de 5 Vdc, corriente de carga máxima de 75 mA, flujo de carga máxima de 8 PSI y tiempo de respuesta de 100mseg. En la siguiente figura N° 23 se tienen las electroválvulas probadas en esta evaluación.

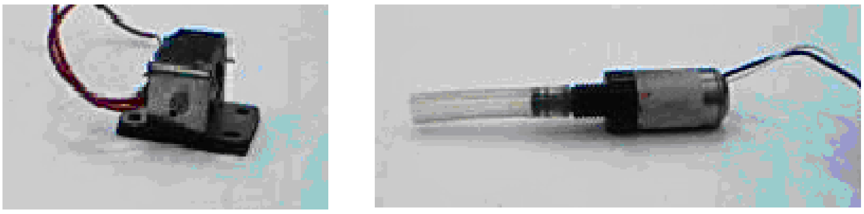

Figura N° 23 Electroválvulas para control de presiones

4.6 Características del sistema de adquisición de presiones.

4.6.1 Transductor de presión.

Para el caso de la selección de un transductor de presión para sensar la presión sanguínea se debe tener en cuenta las siguientes especificaciones:

Tabla N° 18 Especificaciones técnicas de transductores de presión. (Freescale, 2005)

ESPECIFICACIONES	RANGOS
Rango de Presión (Pop)	0 a 50 Kpa
Tensión Alimentación (Vs)	3 Vdc
Corriente Alimentación (Io)	6 mA
Voltaje Full Escala (Vfss)	45 a 90 mV
Offset (Voff)	0 a 35 mV
Sensibilidad (AV/AP)	1.2 mV/kPa
Linealidad	-1.6 a 1.4 %Vfss
Histéresis Presión	+- 0.1%Vfss
Histéresis Temperatura	+- 0.5%Vfss
Coeficiente de temperatura de full escala (Tcvfss)	-0.22 a -0.16%Vfss/°C
Coeficiente de temperatura de offset (Tcvoff)	+- 15uV/°C
Coeficiente de temperatura de resistencia (TCR)	0.31 a 0.37 %Zin/°C
Impedancia de entrada (Zin)	355 a 505 ohm
Impedancia de salida (Zo)	750 a 1875 ohm
Tiempo de respuesta (tr)	1mseg
Tiempo de calentamiento	2mseg
Offset Estabilidad	+-0.55%Vfss

Los transductores de presión más adecuados para sensar la presión de insuflado de un brazalete son los de Freescale Semiconductors, entre ellos MPX5050 (ver figura N° 24), MPX100, MPX2050 y MPX10, en los cuales las variaciones básicas se encuentran en los rangos de presión, valores de sobre presión, ancho de banda, y tiempos de respuesta (ver anexo N° 3b).

Figura N° 24 Transductor de presiones MPX 5050GP

4.6.2 Circuitos de acondicionamiento de señal.

La etapa de acondicionamiento de señal debe constar de un amplificador, filtros, muestreadores y convertidores análogo digital. Evaluando las características del sistema requerido se diseñaron sistemas independientes de amplificación y filtrado, así como diseños integrados, a cada uno se le comparo según características de complejidad, respuestas características y consumo, optándose por el diseño que se muestra en la figura N° 25. El diseño requiere de solo dos amplificadores operacionales para el circuito amplificador y de filtrado. Mientras que las etapas de muestreo y conversión se integran a las correspondientes entradas ADC del PIC, como se detalla más adelante.

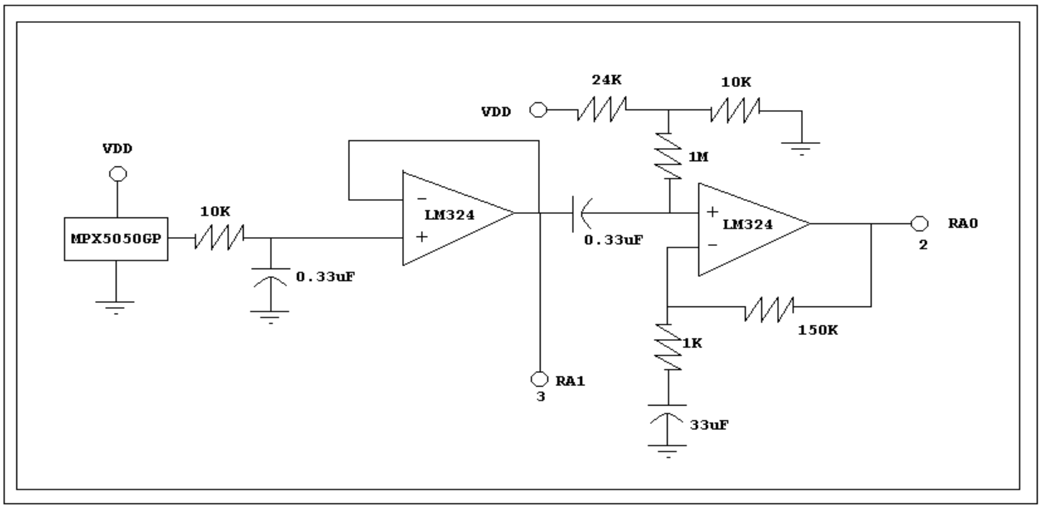

Figura N° 25 Etapa de acondicionamiento de señal

4.6.2.1 Amplificador

Para este caso se requiere un amplificador que tenga una sola fuente de alimentación debido a que la señal a sensar es positiva y con el objeto de reducir el número de fuentes de alimentación en el sistema. Asimismo, no se requiere una alta ganancia pues el transductor entrega una señal de casi 5 voltios. Por otro lado, tanto para el amplificador y el filtro se requiere se cumpla con las siguientes características mínimas.

Tabla N° 19 Especificaciones técnicas amplificador operacional (Natsemi, 2005)

ESPECIFICACIONES	RANGOS
Entrada de voltaje offset (Vos)	1.5 a 5 mV
Promediación Drift Entrada de voltaje offset (TCVos)	2 a 6 uV/°C
Entrada Corriente de polarización (Ib)	10 a 11 nA
Entrada Corriente de offset (Ios)	5 a 10 nA
Relación Rechazo Modo Común (CMRR)	50 a 70dB
Relación Rechazo Fuente de poder (PSRR)	50 a 60 dB
Fuente Corriente (Vcc)	0, +5V
Ganancia por Ancho de banda (GBW)	1 a 2 MHz
Slew Rate (SR)	1 a 1.5V/useg
Potencia Disipada (Pd)	40 a 100 mW
Voltaje entrada de ruido (Vin)	3 a 5 nV/√Hz
Ruido (N)	50 a 90 nVpp

Para el análisis y selección del amplificador operacional se compararon los integrados de los fabricantes: Analog Devices, Nacional Semiconductors y Texas Instruments.

Entre estos se tiene a los LM324 y OPA087. Luego de la evaluación de características se determino es uso del LM324, (ver anexo N° 3c) por contar con 4 circuitos en un solo encapsulado y cumplir con los requerimientos eléctricos mínimos (Natsemi, 2005), (Texas, 2005), (Analog, 2005).

4.6.2.2 Filtros.

Para el diseño planteado se requiere de un filtro pasa banda de 0.04 Hz a 1 Hz. Se debe tener en cuenta que se pretende eliminar la señal DC, así como considerar que un periodo cardiaco tiene un tiempo de duración de aproximadamente 1 segundo por lo que la frecuencia correspondiente es de 1 Hz. Con el fin de integrar etapas se diseña el filtro en el mismo operacional amplificador. La función de la red es $f = 1/(2\pi RC)$

Para 0.04Hz se diseña una red cuyo R1 es de 1Kohm y C1 de 33 micro faradios, en el caso de la frecuencia de corte alta de 1 Hz diseña una red cuyo R3 es de 1 megaohm y C2 de 0.33 microfaradios (Ver figura N° 26).

El amplificador operacional seleccionado es el LM324, diseñando un circuito de amplificador no inversor de ganancia 151, filtro pasaalto de segundo orden con frecuencias corte, f1= 0.04Hz para señal del brazal, f2= 1Hz para señal de oscilación. La función de transferencia del sistema amplificador-filtro es:

$$Vo = ((S^2(1.633) + S(0.33))Vi + (S(4.95) + 1)Vr) / (S(0.33) + 1)$$

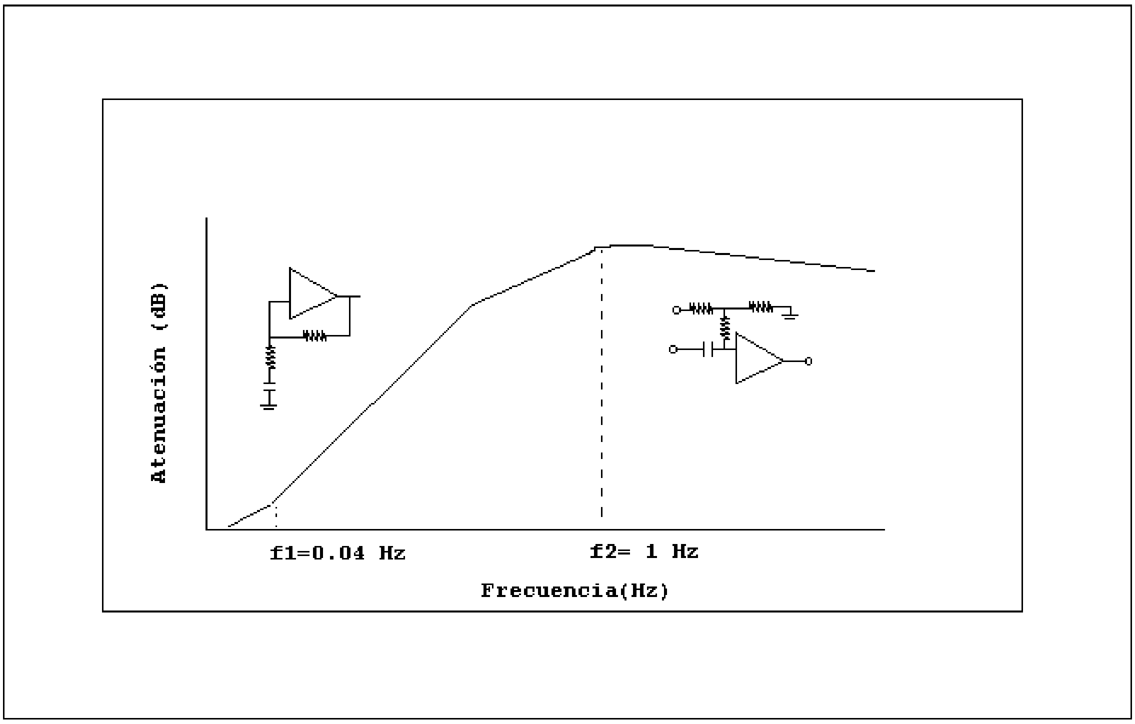

Figura N° 26 Características de la respuesta del filtro

4.6.2.3 Convertidor análogo digital

Con el objetivo de tener una mejor resolución al digitalizar el sistema diseñado requiere mínimo una capacidad de conversión que debe ser mínimo de 10 bit digitalización para una adecuada conversión de datos al momento de la adquisición y aplicación del procedimiento oscilosmétrico. En el capitulo siguiente se muestran las tablas que detallan las perdidas obtenidas al aplicar el método oscilosmétrico en conversiones de 8 bits. Como se observará después, la mayoría de microcontroladores posee conversores de más de 10 bits integrados a ellos, lo que facilita el diseño del sistema. Asimismo, permite un diseño más sencillo, menor espacio, una mayor resolución y menor tiempo de conversión que si se utiliza en el caso de por ejemplo ADC1210 ó ADC0804. Por otro lado, en la tabla N° 19 vista en el ítem 4.6.2.1, se detallan las características mínimas requeridas para el conversor análogo digital. En este sentido, se evaluaron diferentes conversores análogos digitales, tanto externos como internos, comparando sus principales características, y concluyéndose en primera instancia, utilizar un ADC interno a un microcontrolador y finalmente elegir entre el PIC y el Atmel, por ser económicos, de bajo consumo y muy simple de programar (Microchip, 2005), (Atmel, 2005), (Silabs, 2005), (Texas, 2005).

Tabla N° 20 Especificaciones técnicas de conversor análogo digital. (Microchip, 2005)

ESPECIFICACIONES	RANGOS
Resolución	10 bits.
No linealidad integral	0.5 LSB.
Exactitud absoluta	+-2 LSB.
Tiempo de conversión	15 a 250 useg.
Resolución mínima	15 kSPS.
Error Offset	+- 2 LSB.
Error ganancia	+- 0.4%.
Error voltaje absoluto	+-3 LSB.
Cruces entre entradas analógicas	< -60 dB @ 100KHz.
Rango de voltaje de entrada	0 a 5 Vcc.
Voltaje referencia ADC	2.56V.
Modos de conversión	Simple o carrera libre.
Aproximación	Lineal sucesiva con monoticidad.
Clock ADC	Seleccionable
Registro de datos.	Interrupción o bandera de conversión completa

4.6.3 Microcontrolador.

En la actualidad, se cuenta en el mercado con innumerables micro controladores (MCU), como por ejemplo, el C8051 de Silicon Labs, el TI MSP430 de Texas Instrument, el 68HC908GP32 de Motorola, el P89CE558 de Philips, la familia Atmel AVR, la familia Microchip PIC 18XX, el COP8CxR9 de Nacional Semiconductors entre otros de similar característica. Se muestra luego una tabla comparativa donde podemos observar las principales características de alguno de los MCU antes mencionados.

Para poder realizar una correcta selección primeramente requerimos conocer las características para el MCU de nuestro sistema: bajo consumo, Conversor A/D de 10 o 12 bits, 3 puertos I/O, comunicación serial, I2C, soporte RS232, salida PWM, 1 a 10 MIPS, mínimo 4KB RAM, de 32 a 64 KB FLASH, programación sencilla y tamaño pequeño. De la tabla se puede concluir que los 68HC908, COP8CXR9, P89CE558, TI MSP430 tienen características que superan largamente el requerimiento del sistema. En este sentido, en la búsqueda de un MCU a medida de la necesidad planteada nos conviene trabajar con el PIC o con el Atmel. Se debe resaltar que los fabricantes de la mayoría de los MCU mostrados indican que no se responsabilizan por cualquier aplicación médica que se les de a sus productos. Finalmente, a pesar de las obvias ventajas de los Atmel tanto por sus direccionamiento directo, ahorro de memoria y mayor reprogramabilidad; se decide seleccionar el PIC, principalmente debido a cumplir con lo requerido, tener menor tamaño, contar con un pin de control de tensión y contar con las entradas requeridas para el diseño (ver figura N° 27) . Asimismo por contar con los accesorios y herramientas para su manejo es que se decide utilizar el PIC 18F877 (ver anexo N° 3d), (Microchip, 2005).

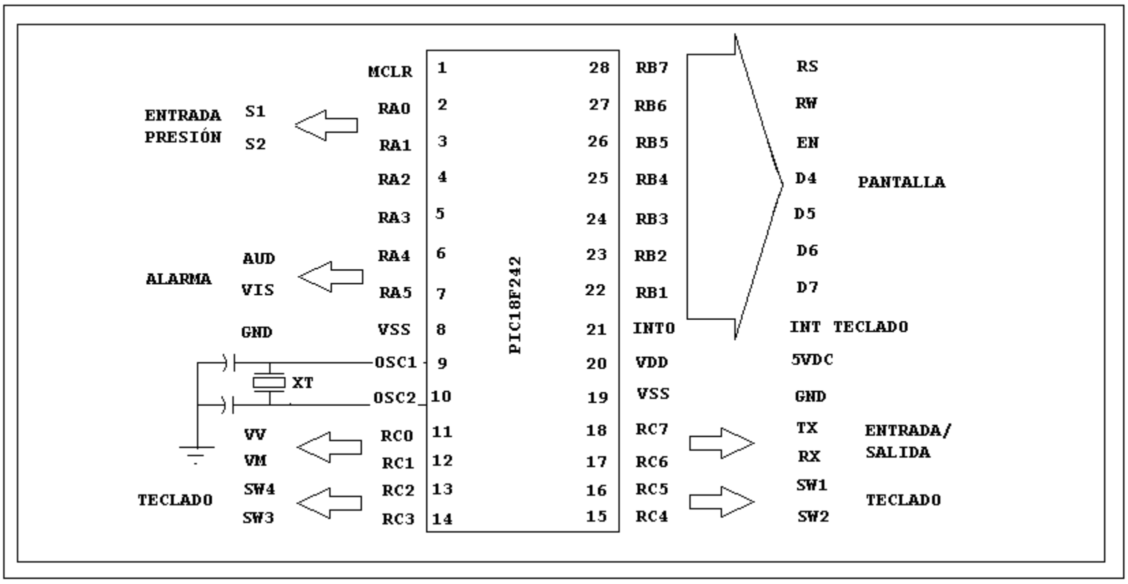

Figura N° 27 Circuito de control

Tabla N° 21 Comparación de características técnicas de microcontroladores

Fabricante	Silicon Labs	Microchip	Texas Ins	Atmel	Motorola	Philips	National
MCU	Si Labs C8051	PIC18xx	TI MSP430	AVR	68HC908	P89CE558	COP8CxR9
MIPS	25 -> 100	5 -> 10	8	1 - > 16	2 -> 8	20 -> 100	20 -> 100
Conversor A/D (bits)	8, 10, 12, 14, 16	8, 10, 12	10, 12	10	8, 10	10, 12, 16	10
Rendimiento A/D	excelente	Regular	excelente	regular	buena	excelente	excelente
Conversor D/A (bits)	10, 12	No	12	no	no	12	12
Conectividad Serial	UART, SPI, I2C, USB, CAN	UART, SPI, I2C, CAN	UART, I2C	UART, SPI, I2C	UART, SPI, I2C, USB	UART, SPI, I2C, USB, CAN	UART, SPI, I2C, USB, CAN
Baja potencia	bueno	Regular	excelente	regular	regular	bueno	bueno
Empaque pequeño (pin, mm2)	11, 9	8, 27	20, 95	8, 45	20, 138	11, 9	10
FLASH (KB)	128	64	60	128	62	128	32
RAM (KB)	8	3.8	10	4	4	8	1
# Flash MCU	52	90	29	42	43	52	52
Timer 16 bit (canales)	3	1, 2	3	1	3	3	3
Watch Dog	si	Si	si	no	no	si	si
A/D 10 bit (canales)	8	8	8	8	8	8	16
Voltaje Detector de salida	bajo	Bajo	bajo	bajo	bajo	bajo	bajo
Sistema de programación real	si	No	si	si	si	si	si
Precisión emulación analógica	no	No	no	no	no	no	si

4.6.4 Circuitos de actuación.

En la mayoría de los casos es mucho mejor contar con un sistema integrado al microcontrolador, pues permite controlar directamente los procesos y manejo de alarmas, interrupciones, dispositivos, entre otros. Actualmente los microcontroladores vienen prepararados para este tipo de tareas, es decir, tienen puertos de entrada / salida para manejar digitalmente motores, bobinas, pantallas, etc. En este sentido, los microcontroladores evaluados cuentan con estas opciones siendo estas más eficientes que la utilización de controladores independientes o diseñar circuitos para estas tareas.

4.6.4.1 Controlador de bomba.

Para esta etapa se requiere manejar las señales de control del puerto C1 del microcontrolador. Esta ofrece las características eléctricas mínimas necesarias, sin embargo se debe colocar un transistor en configuración emisor común con el objetivo de estabilizar y conformar la corriente de salida y generar una señal alta que permita desactivar la mini bomba y otra señal baja para activarla. Asimismo se requiere se cumpla con las siguientes características:

Tabla N° 22 Especificaciones técnicas del controlador de bomba

ESPECIFICACIONES	RANGOS
Constante de tiempo de respuesta eléctrica.	0.5 mseg.
Constante de tiempo de respuesta mecánica.	20 mseg.
Corriente de salida.	25 mA
Tensión de entrada	-0.3Vdd
Tensión de salida	0.7 Vdd

4.6.4.2 Controlador de electroválvula.

En esta etapa se requiere un circuito similar al anterior, solo que ahora se utilizara el puerto C0 del microcontrolador. En este caso se requiere de una señal baja para activar la electroválvula y mantenerla cerrada.

Tabla N° 23 Especificaciones técnicas del controlador de electroválvula

ESPECIFICACIONES	RANGOS
Constante de tiempo de respuesta eléctrica.	0.5 mseg.
Constante de tiempo de respuesta mecánica.	20 mseg.
Corriente de salida.	25 mA
Tensión de entrada	-0.3Vdd
Tensión de salida	0.7 Vdd

Finalmente en la siguiente figura N° 28 se muestran el diseño final para controlar la bomba así como el de control de la electroválvula, basado en transistores en configuración emisor común (Microchip, 2005).

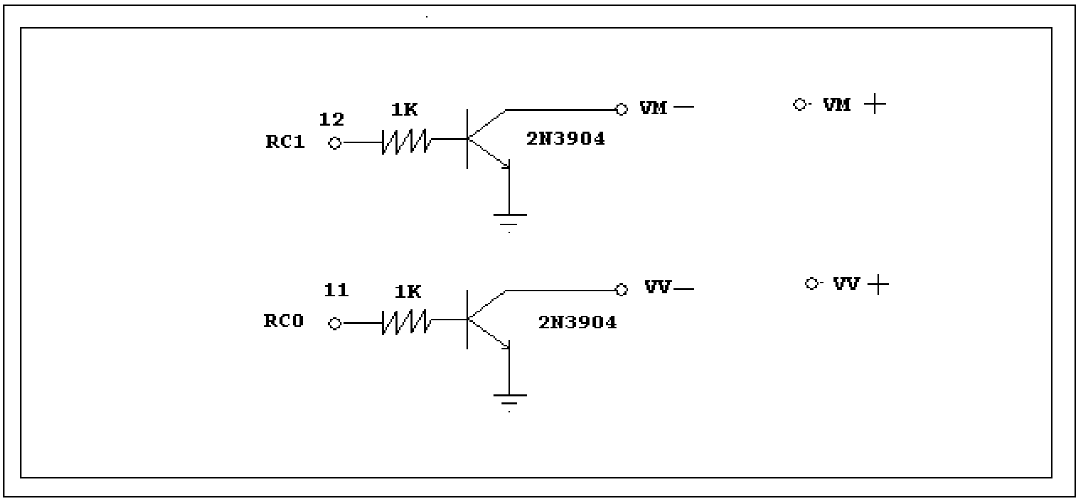

Figura N° 28 Diagrama esquemático de circuito controlador de bomba y electroválvula

4.6.4.3 Controlador de alarma, teclado y pantalla de cristal liquido.

El sistema cuenta con alarmas auditivas como visuales, en la figura siguiente se muestra el circuito encargado de esto. En este sentido, un parlante se encarga de emitir con tonos de alarma enviados por el microcontrolador (pin 6, correspondiente al RA4) al detectarse algún error ya sea por mala operación, defecto de algún componente del sistema o alguna interferencia externa. Esta alarma auditiva esta acompañada por una alarma o intermitencia luminosa de color rojo, la misma que en el caso de no ser atendida se mantendrá permanentemente y que es controlada por el RA5 (pin 7).

Por otro lado, por medio de un circuito lógico simple compuesto por un 74LS32N (tres compuertas OR, para sumar las 4 entradas del teclado, SW1, SW2, SW3 y SW4) se logra acoplar y controlar el teclado desde el puerto RC (RC2, RC3, RC4 y RC5) pines 13, 14, 15 y 16 respectivamente; y el INT0 (pin 21) del microcontrolador. En el caso de la pantalla de cristal líquido o LCD este cuenta con su propio controlador incorporado el mismo que será gobernado por el microcontrolador desde el puerto RB (RB1, RB2, RB3, RB4, RB5, RB6 y RB7) pines 22 al 28.

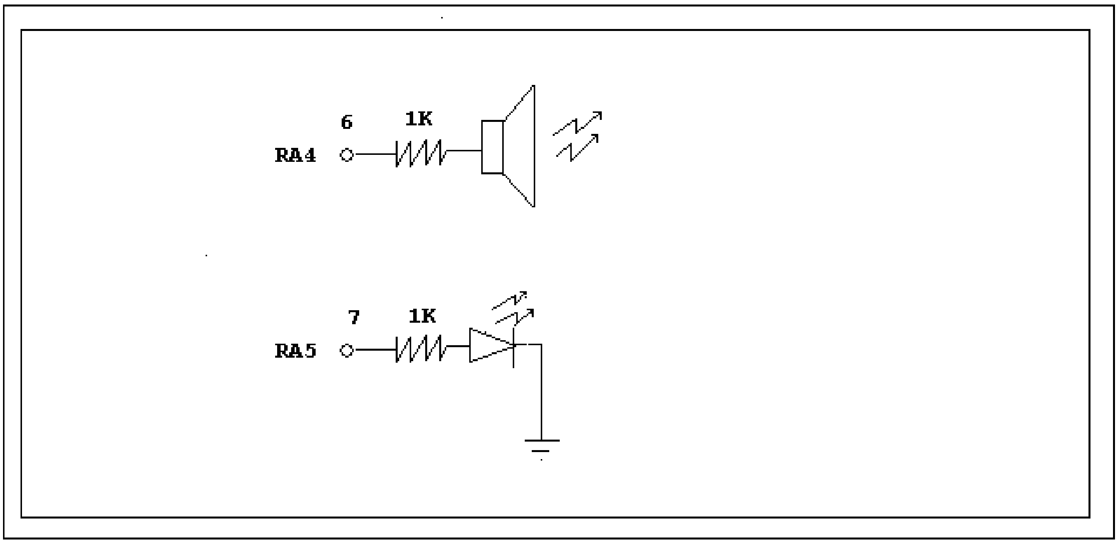

Figura N° 29 Diagrama esquemático de circuito de alarma

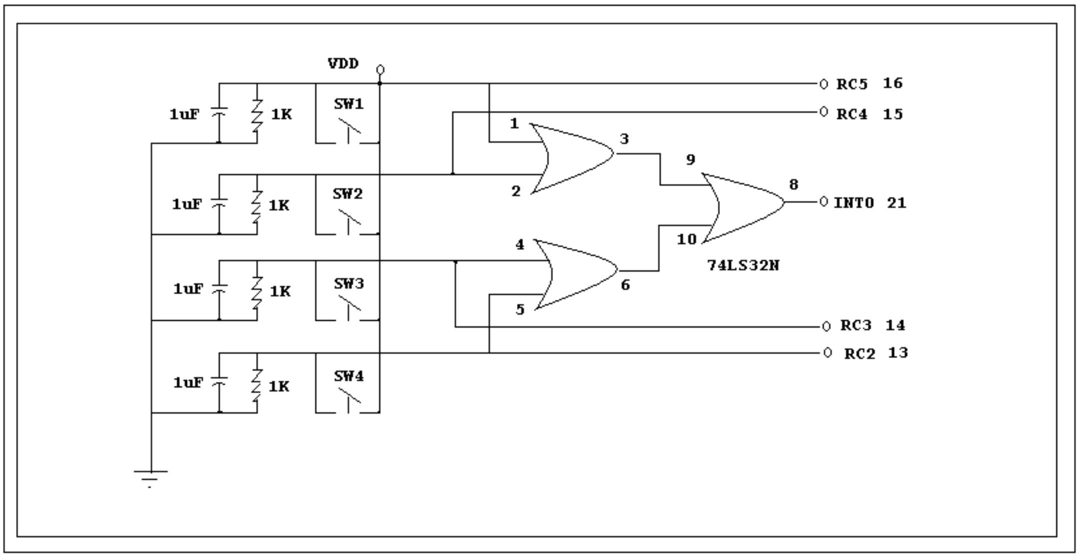

Figura N° 30 Diagrama esquemático de circuito de teclado

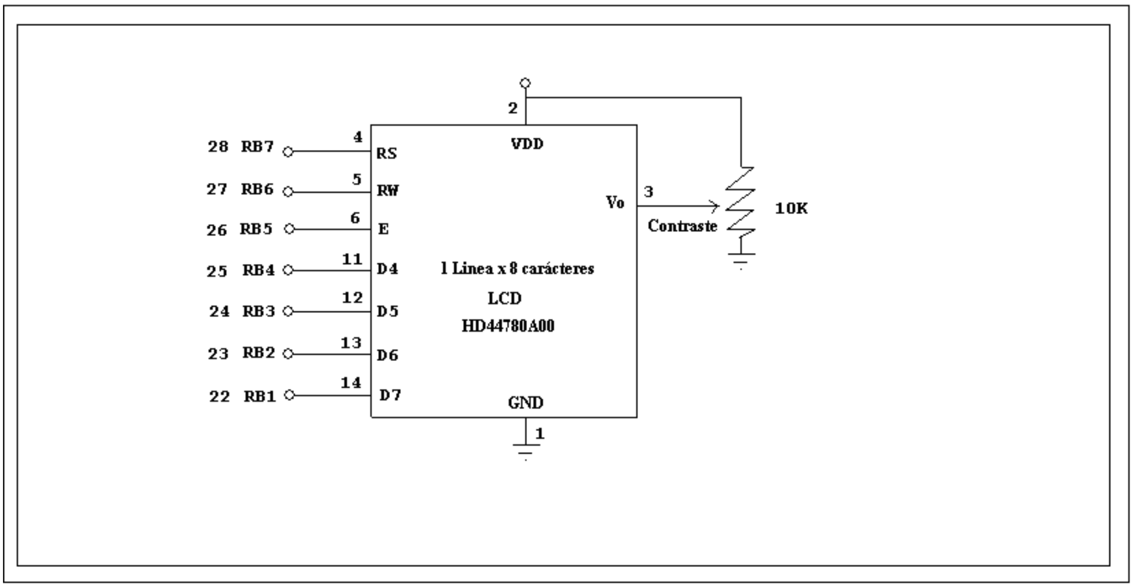

Figura N° 31 Diagrama esquemático de circuito controlador de pantalla

4.6.4.4 Circuito de entrada / salida de datos.

El sistema cuenta con un circuito de manejo de datos o de entrada / salida, este se conforma básicamente por el MAX 232 y el puerto de salida del microcontrolador (pines 17 y 18, correspondientes al RC7 y RC6 respectivamente). En la figura posterior se muestra el circuito en mención.

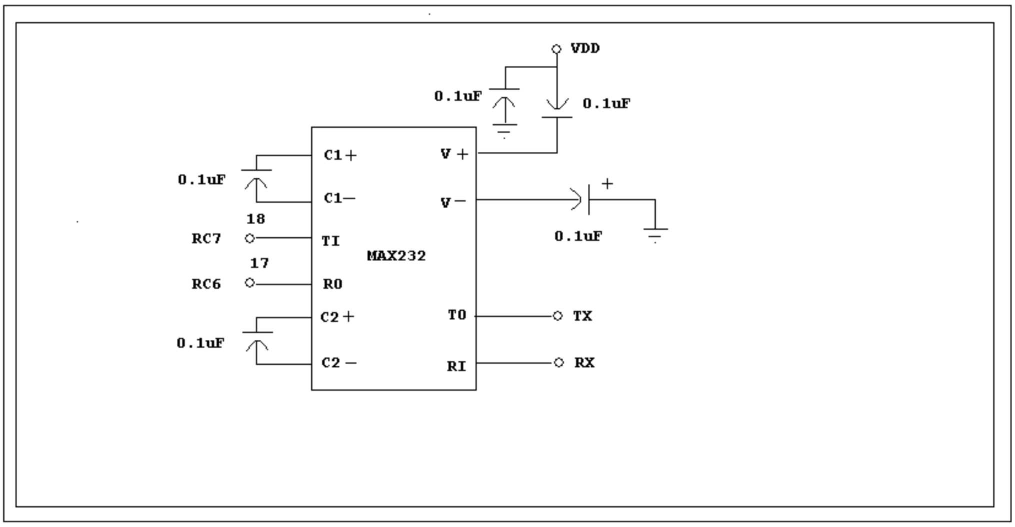

Figura N° 32 Diagrama esquemático de circuito de entrada / salida de datos

4.6.5 Fuente de alimentación.

Para este diseño se requiere una fuente de alimentación con las siguientes características: Entrada de alimentación de 9 a 12 Vdc, salida de 5Vdc con intensidad de corriente de 1000mA, basada en un conversor DC-DC o similar, estabilidad de salida, nivel de rizado minimo y salida para monitoreo de microcontrolador. Así también, se colocar en paralelo a la salida de la fuente una batería de Litio Cadmio de 3.6 Vdc para alimentar al microcontrolador en caso de una caída de tensión por debajo de los 3.6 Vdc, esto asegura la integridad de la información adquirida. Cabe resaltar, que el microcontrolador seleccionado tiene la facultad de evaluar permanentemente el valor de salida de la fuente de alimentación, estas variaciones le permiten estabilizar los proceso de digitalización y con alterar los resultados finales (Microchip, 2005).

Una fuente tradicional no cumpliría con las exigencias planteadas debido a las dimensiones de la misma, consumo de corriente, eficiencia y regulación de la salida. En este sentido se evaluaron las características de diversos dispositivos, seleccionándose finalmente el regulador conmutado integrado PT5041, que cumple con los requerimientos mínimos, asegura estabilidad y duración de la fuente de entrada. Las características de este se observan en la tabla N° 24. Asimismo, se consideró las dimensiones del componente y de todo el circuito de la fuente. Se realizaron pruebas con diferentes baterías y pilas entre 6 a 12 Vdc, obteniéndose mejores resultados con una batería de Litio-Ion recargable de 7.2Vdc, la misma que ofrece una corriente de carga estable de 950mA durante aproximadamente por 12 horas. (Texas, 2005).

Tabla N° 24 Especificaciones técnicas de fuente de alimentación

ESPECIFICACIONES	LM2662	UC3844	PT5041
Corriente de salida (mA)	100	1 - 1000	10 -1 000
Voltaje de entrada (Vdc)	3.5 – 5.5	18 - 30	4.5 – 11
Tolerancia de voltaje de entrada (Vdc)	+- 2	+- 2	+- 1.5
Tensión rizado (Vdc)	+- 2	+- 2	+-2
Eficiencia	60%	75%	85%
Tiempo de respuesta (uSeg)	600	---	500
Regulación de línea	+- 0.3	+- 0.3	+- 0.5
Regulación de carga	+- 0.3	+- 0.3	+- 0.5
Encapsulado (pines)	DIP 8pin	DIP 8pin	3 pin
Temperatura almacenada (°C)	150	150	125
Componentes adicionales	SI	SI	NO

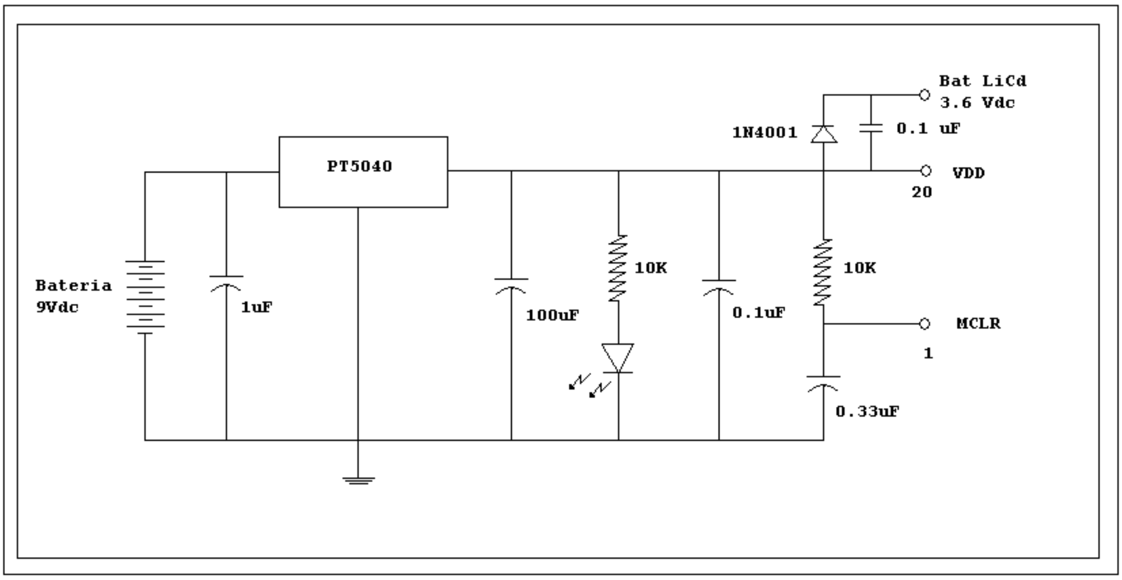

Figura N° 33 Diagrama esquemático de fuente de alimentación

En el anexo N° 4a se presenta el circuito esquemático general, así como en el anexo N° 4b se muestra la tarjeta de circuito impreso. A continuación, en la figura N° 34 vemos el diseño de la tarjeta prototipo del MAPA desde diferentes ángulos.

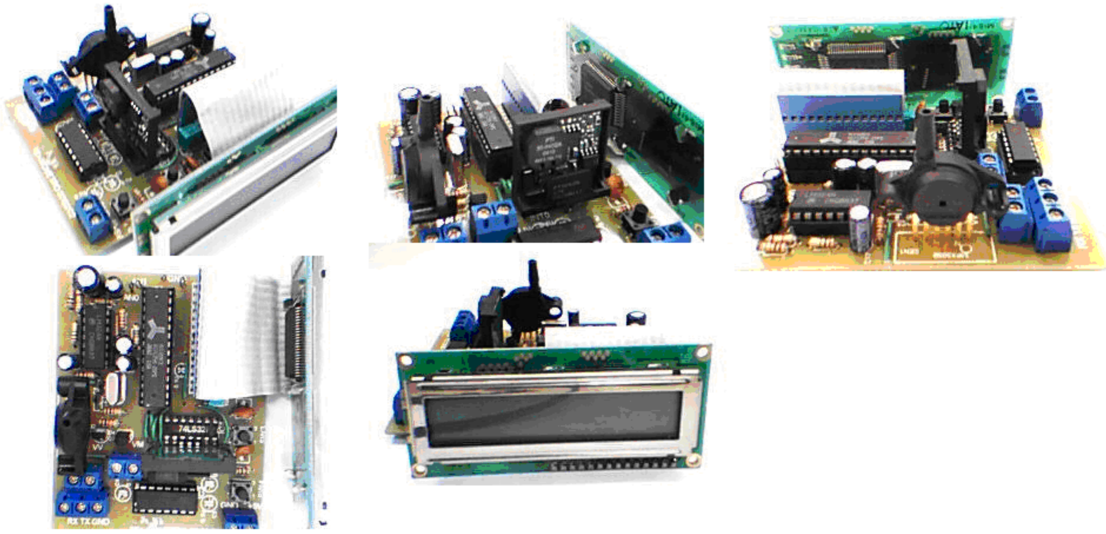

Figura N° 34 Prototipo de la tarjeta de control del MAPA

En la siguiente figura (Figura N° 35) se muestra el diagrama esquemático del MAPA para facilitar su compresión así como también una tabla (Tabla N° 25) con el listo de componentes utilizados.

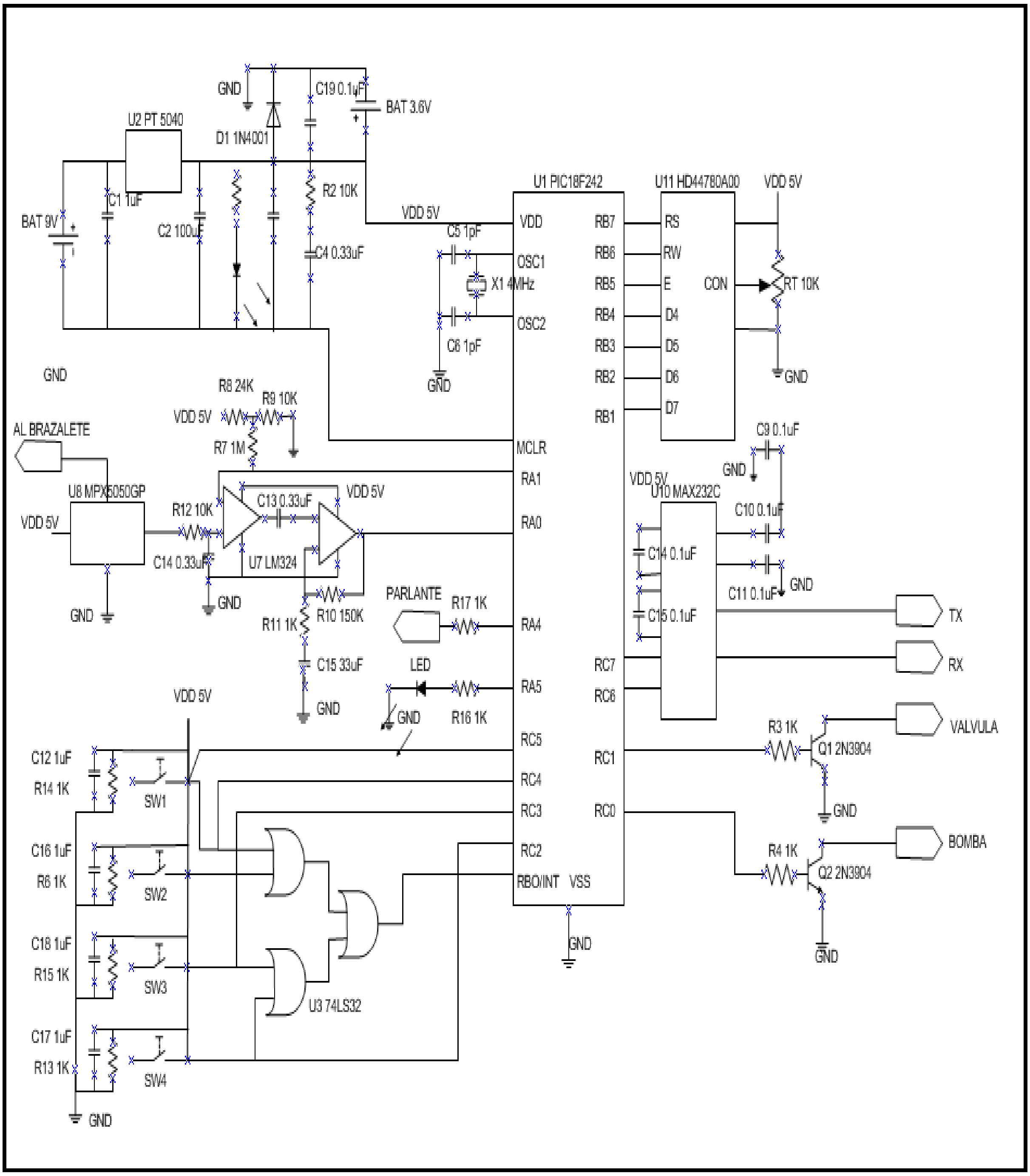

Figura N° 35 Diagrama esquemático del MAPA

Tabla N° 25 Listado de componentes del MAPA

Componente	Descripción	Característica
R1	Resistencia	10 K ohm, Carbón, ¼ W
R2	Resistencia	10 K ohm, Carbón, ¼ W
R3	Resistencia	1 K ohm, Carbón, ¼ W
R4	Resistencia	1 K ohm, Carbón, ¼ W
R6	Resistencia	1 K ohm, Carbón, ¼ W
R7	Resistencia	1 M ohm, Carbón, ¼ W
R8	Resistencia	24 K ohm, Carbón, ¼ W
R9	Resistencia	10 K ohm, Carbón, ¼ W
R10	Resistencia	150 K ohm, Carbón, ¼ W
R11	Resistencia	1 K ohm, Carbón, ¼ W
R12	Resistencia	10 K ohm, Carbón, ¼ W
R13	Resistencia	1 K ohm, Carbón, ¼ W
R14	Resistencia	1 K ohm, Carbón, ¼ W
R15	Resistencia	1 K ohm, Carbón, ¼ W
R16	Resistencia	1 K ohm, Carbón, ¼ W
R17	Resistencia	1 K ohm, Carbón, ¼ W
RP	Potenciómetro	10 K ohm, Carbón, logarítmico
C1	Condensador	1 uF, Electrolítico, 16 V
C2	Condensador	100 uF, Electrolítico, 16 V
C3	Condensador	0.1 uF, Cerámico
C4	Condensador	0.33 uF, Cerámico
C5	Condensador	0.1 pF, Cerámico
C6	Condensador	0.1 pF, Cerámico
C7	Condensador	0.1 uF, Tantalio
C8	Condensador	0.1 uF, Tantalio
C9	Condensador	0.1 uF, Tantalio
C10	Condensador	0.1 uF, Tantalio
C11	Condensador	0.1 uF, Tantalio
C12	Condensador	1 uF, Cerámico
C13	Condensador	0.33uF, Cerámico
C14	Condensador	1 uF, Cerámico
C15	Condensador	1 uF, Cerámico
C16	Condensador	1 uF, Cerámico
C17	Condensador	1 uF, Cerámico
C18	Condensador	1 uF, Cerámico
C19	Condensador	33 uF, Electrolítico, 16 V
X1	Cristal	4 MHz
Q1	Transistor 2N3904	2N3904, TO92
Q2	Transistor 2N3904	2N3904, TO92
D1	Diodo LED	LED ROJO
D2	Diodo rectificador 1N1001	1N 1001
D3	Diodo LED	LED AMARILLO
U1	Microcontrolador PIC 18F242	PIC 18F242, 28 PINES
U2	Regulador conmutado integrado PT50401	PT50401
U3	Compuerta lógica TTL74HC34	Compuertas OR, 12 PINES
U7	Amplificador operacional LM324	LM324, 14 PINES
U8	Transductor de presión MPX5050GP	MPX5050GP, 5 PINES
U10	Manejador de trasmisión recepción MAX232C	MAX232C, 16 PINES
U11	Controlador de pantalla HD400A00	HD400A00, 10 PINES

4.7 Características del programa de comunicación, control, visualización y medición.

En los siguientes puntos se presentan las tres etapas de las que se compone el programa de interfase.

4.7.1 Etapa de control y comunicación.

Para el desarrollo de esta etapa se diseñaron los programas tanto en el microcontrolador, como en interfase de computadora, es decir, en ensamblador de Microchip y en Visual Studio de Microsoft. En el caso de los programas en el microcontrolador las siguientes son las rutinas de control y comunicación realizadas: Iniciar, Guardar/Borrar, Programar y Adquirir/Medir.

Tabla N° 26 Funciones de las rutinas de control y comunicación

Rutina	Función
Iniciar	Permite el control del sistema de encendido y ejecución de la rutina de auto chequeo según el listado de errores en memoria. En caso de todo estar correcto permite continuar con el proceso de verificación de memoria.
Guardar / Borrar	Verifica si se tiene algún dato en memoria, para luego borrarlo o guardarlo ya sea vía el sistema o por medio de una computadora.
Programar	Permite la carga de datos y configuración del sistema, tanto por medio del sistema o por computadora.
Adquirir / Medir	Ejecuta el proceso de adquisición de presiones, las digitaliza, almacena en memoria y presenta en la pantalla del sistema.

Se detallan las rutinas Iniciar, Guardar/Borrar, Programar y Adquirir/Medir, en el anexo N° 5ª, 5b, 5c y 5d.

Asimismo, se muestra en el anexo N° 5e el diagrama de flujo general, el mismo que permitirá entender el sistema de control y comunicación ejecutado por el microcontrolador así como la modalidad de trabajo del sistema general.

4.7.2 Etapa de visualización y medición.

Esta etapa se desarrolla en entorno Windows, utilizando MS Visual Basic. El programa de visualización y medición permite en primera instancia verificar la correcta conexión entre el sistema y la computadora, luego permite la programación o configuración del sistema, verificar el estado de la memoria, transferir la información y almacenarla en la computadora, y finalmente realizar mediciones, generar informes, gráficas estadísticas entre otras herramientas. En el anexo N° 5f se detallan las características, herramientas y funciones del programa comercializado por Save, empresa francesa fabricante de monitores ambulatorios de presión arterial.

El programa cuenta con una herramienta que permite enlazar información de cualquier hoja de cálculo y/o procesador de texto compatible al MS Excel y MS Word. Asimismo se resaltan las ventajas y facilidades que brinda MS Visual Basic, sobretodo por contar con librerías para el manejo de los puertos de la computadora.

Finalmente, se muestra a continuación una tabla indicando algunos requerimientos realizados por un grupo de médicos especialistas que utilizan equipos similares al sistema planteado en la tesis:

Tabla N° 27 Recomendaciones de médicos especialistas

1. Opción de imprimir directamente conectando el equipo a una impresora.
2. Contar con herramientas gráficas y estadísticas de aplicación científica.
3. Contar con herramientas de desarrollo de funciones gráficas y estadísticas.
4. Permitir enlaces con procesadores de texto y hojas de cálculo compatibles.
5. Interfase sencilla, sin muchas opciones.
6. Mínimos requerimientos de sistema de cómputo y sistema operativo.
7. Opción de editar datos adquiridos e insertar comentarios.

CAPITULO 5:
Ensayos y Resultados

5.1 Elección de brazaletes y cálculo del error en la medición.

En esta prueba se plantea y verifica la importancia de la correcta selección del brazalete para obtener una correcta medición. Para esta prueba se utilizo un simulador de presiones y no el prototipo.

a) Objetivo

- Demostrar que las dimensiones (largo y ancho) del brazalete así como su correcta instalación y ubicación en el brazo.
- Determinar los factores que generan error en la medición de la presión arterial.
- Calcular el error generado por una mala selección del brazalete.

b) Materiales

- Brazaletes de dos lúmenes: Neonatal (2.5cmx5cm), Infante (8.9cmx11.9cm), Pediátrico (9.4cmx21.3cm), Adulto (11.9cmx21.9cm), Adulto Obeso (17.5cmx35cm).
- Pera o bombilla.
- Transductor de presión.
- Cinta métrica.
- Simulador y verificador de presiones. (Monitor BioTek BPPUMP)
- Manómetro de –10 a 50 Kpa
- Tres pacientes por cada tipo (peso promedio): Neonato (400 gramos), Infante (4 .8 Kilos), Pediátrico (26 Kilos), Adulto (60 Kilos), Adulto Obeso (98 Kilos), Estetoscopio.

c) Metodología

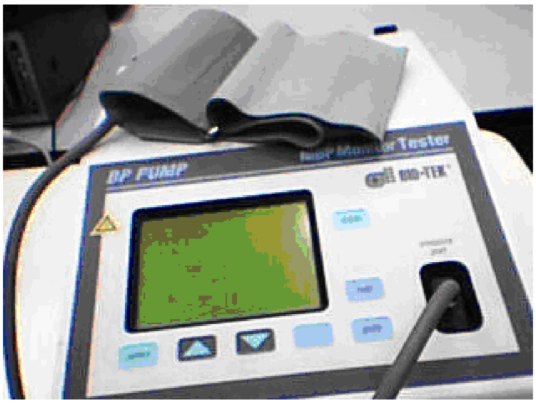

Figura N° 36 Simulador y verificador de presiones. (Monitor BioTek BPPUMP)

- Realizar veinte (20) pruebas de medición con un tensiometro (brazalete, manómetro y pera) con cada tipo de paciente, anotar mediciones y calcular la media, y el error obtenido. Esta cantidad de pruebas es la mínima apropiada para asegurar la calidad de la medición.
- Colocar correctamente el brazalete y el sistema de medición de presión. (ver anexo N° 20 y figura N° 36).

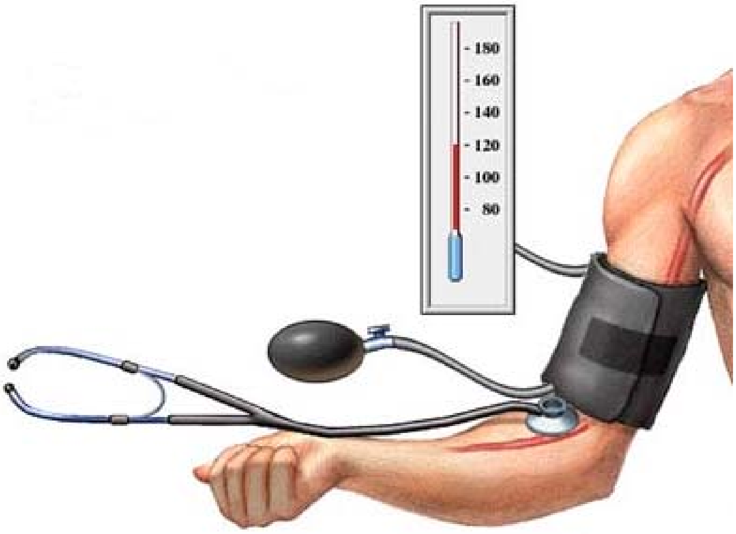

Figura N° 37 Ubicación correcta del brazalete de presión (ADAM, 2005)

- Anotar la posición del brazalete.
- Anotar la medición obtenida en cada caso y preparar unas tablas resumen tanto para el promedio de medición como para el error obtenido.

- Calcular y anotar el porcentaje de error obtenido en las mediciones; para este propósito usamos la ecuación $e = \sum (P_i - P_{i-1}) \times 100/n$
- Observar y determinar todas las posibles causas que generen alteración de las mediciones realizadas.

d) Resultados

Tabla Nº 28 Análisis de promedios de medición con diferentes brazales y pacientes.

		Paciente				
Brazal		Neonatal	Infante	Pediátrico	Adulto	Obeso
	Neonatal	60/40		N	N	N
	Infante	61/41	70/49	108/68	N	N
	Pediátrico	N	70/50	107/64	131/80	N
	Adulto	N	N	109/67	129/79	N
	Obeso	N	N	N	130/80	130/90

Asimismo, se observa que se generan variaciones en la medición si se obstruye o dificulta el proceso de adquisición, ya sea por golpe, presión externa y movimientos durante de la medición.

Tabla Nº 29 Análisis de errores de medición con diferentes brazales y pacientes.

		Paciente				
Brazal		Neonatal	Infante	Pediátrico	Adulto	Obeso
	Neonatal	0.0025/0.56	-	-	-	-
	Infante	-	0.06/0.9	-	-	-
	Pediátrico	-	-	0.49/2.2	-	-
	Adulto	-	-	-	0.39/0.095	-
	Obeso	-	-	-	-	0/0

e) Conclusiones

- Se demuestra la importancia de la adecuada selección de los brazaletes según las características dimensionales del brazo. El error promedio de la medición de la presión sistólica fue de 0.24 y de la presión diastólica fue 0.94 %.
- Asimismo, se determina el porcentaje de error que se puede generar por factores como la incorrecta selección del brazalete, la inadecuada ubicación del brazalete y el movimiento o artefactos físicos externos (presión, golpes, fugas), influyendo en el valor obtenido en la medición de la presión arterial.

f) Referencias

(Towaga, 1999), (Geddes, 1991), (GE, 2005), (AHA, 2005), (OMS, 2005)

5.2 Prueba y elección de transductores de presión.

En la siguiente prueba se evaluaron las características y rendimientos de diferentes transductores de presión, verificando las características mostradas en la información del fabricante y realizando pruebas operativas tanto con el prototipo y el simulador.

a) Objetivo

- Determinar las características de los transductores de presión analizando la linealidad, rango de presiones, rango de alimentación electrónica.
- Seleccionar el transductor más adecuado para las condiciones requeridas por el MAPA.

b) Materiales

- Transductores de presión: MPX10DP, MPX100, MPX2010GP y MPX5050GP.
- Multimetro digital.
- Osciloscopio digital de 20MHz.
- Fuente de alimentación de 5 Voltios y 12 Voltios.
- Simulador y verificador de presiones. (Monitor BioTek BPPUMP)
- Tarjeta de pruebas, dispositivos electrónicos varios y cables de conexión.

c) Metodología

- Preparar el circuito eléctrico y control del sensor de presión según sus características de alimentación y de conexiones. (Ver figura N° 25)
- Probar cada sensor y preparar los circuitos de medición.
- Generar presiones (desde 10, 20, 30, 40, 50, 60, 80, 100, 120, 140, 160, 180, 200, 220, 240, 260, 280) con el Monitor BPPUMP.
- Registrar los datos obtenidos.

d) Resultados

De los resultados obtenidos en la tabla podemos analizar la linealidad de los transductores así como estimar el nivel de error

Tabla Nº 30 Análisis de promedios de medición con diferentes brazales y pacientes.

		P(mmHg)															
		10	**20**	**40**	**60**	**80**	**100**	**120**	**140**	**160**	**180**	**200**	**220**	**240**	**260**	**280**	**300**
	V1	9.80	18.80	40.01	61.40	79.05	100.90	120.91	140.99	160.34	180.90	200.40	220.20	240.80	261.20	281.60	300.70
	V2	9.88	18.99	38.98	60.90	80.25	102.00	122.04	141.01	161.56	181.02	199.80	222.50	240.77	260.40	282.70	300.50
	V3	9.90	19.30	39.01	59.60	80.90	101.78	120.90	141.90	160.56	180.40	200.20	220.90	245.10	261.90	282.00	306.03
	V4	9.99	19.35	40.00	59.06	80.45	98.20	119.03	141.90	161.05	178.90	201.40	220.80	239.01	259.50	278.90	298.90
TX1	**V5**	9.90	19.66	38.97	60.90	78.90	100.98	120.40	140.30	160.90	179.04	200.40	221.00	240.40	259.70	280.30	300.10
	V1	9.99	21.05	40.30	60.60	80.50	100.50	120.40	141.50	160.30	180.90	199.99	219.90	240.70	260.90	280.50	300.10
	V2	10.10	21.07	40.10	60.37	80.60	99.98	121.90	141.04	160.50	180.50	200.40	219.78	240.50	261.20	280.60	300.50
	V3	9.98	20.56	40.40	60.45	80.16	100.60	121.30	140.40	161.10	180.94	199.90	220.80	240.40	260.70	280.50	300.60
	V4	9.97	20.99	40.20	60.45	80.45	99.99	120.40	140.10	160.40	180.88	200.20	220.40	240.10	261.10	280.10	300.70
TX2	**V5**	9.98	20.06	39.25	60.60	80.50	100.30	120.80	141.10	159.90	180.60	198.00	220.80	240.90	260.90	280.70	300.90
	V1	10.10	20.10	39.99	60.20	79.97	100.05	121.10	140.04	160.05	180.01	199.98	220.00	240.10	260.01	280.05	300.00
	V2	10.00	20.06	40.01	60.14	79.99	100.10	120.60	140.01	159.99	179.98	199.99	220.50	239.69	259.90	279.98	300.30
	V3	10.10	19.99	40.04	59.98	80.10	99.98	120.30	140.10	159.95	179.80	200.01	220.40	240.00	260.10	280.20	303.00
	V4	9.99	19.96	39.98	60.10	80.13	99.99	120.50	139.99	159.79	179.99	200.11	220.30	240.10	259.80	280.10	301.50
TX3	**V5**	9.98	19.95	40.10	59.99	79.98	100.04	120.40	139.79	160.10	179.98	200.10	220.60	239.90	260.20	280.01	300.40
	V1	9.99	19.99	40.20	60.30	80.50	100.70	120.40	140.40	160.80	180.50	200.10	220.80	240.40	260.80	280.40	300.70
	V2	10.20	20.10	40.30	60.70	80.40	100.69	120.90	140.50	161.40	181.10	200.50	220.30	241.80	260.40	281.07	300.90
	V3	10.00	20.14	40.50	60.00	81.20	100.50	120.60	140.30	161.90	180.50	200.60	220.40	241.90	260.30	280.30	300.50
	V4	9.99	19.98	40.20	60.60	80.01	100.80	120.70	140.70	160.90	180.40	200.15	220.70	241.60	260.40	280.70	300.70
TX4	**V5**	10.10	20.99	40.70	60.30	80.40	100.70	120.78	140.50	160.50	180.90	200.70	220.50	240.50	260.50	280.50	300.80

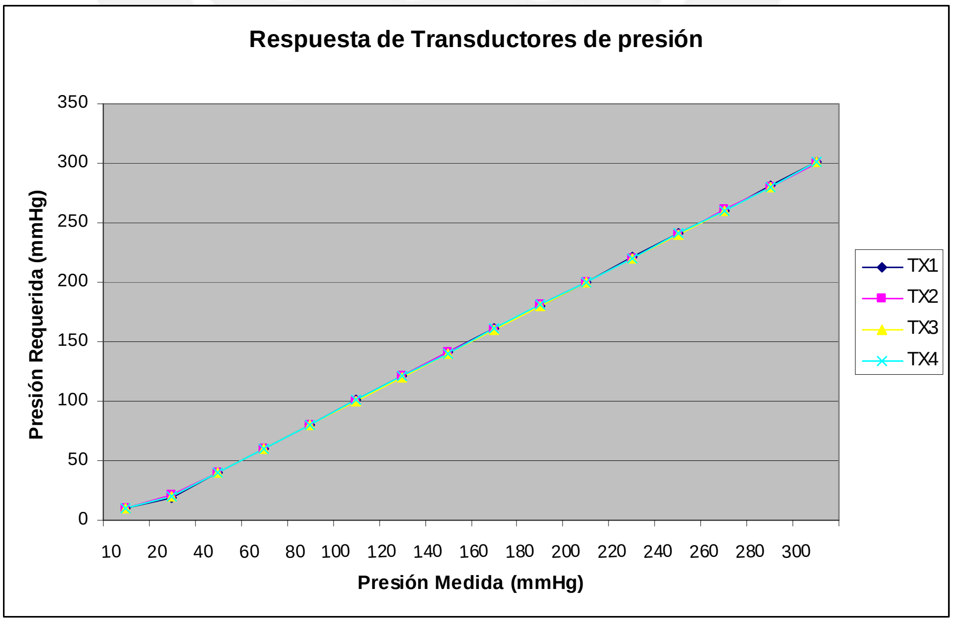

Figura N° 38 Curvas de Respuesta de los transductores de presión (pruebas de laboratorio)

e) Conclusiones

- Las curvas de respuesta de los transductores demuestran que la mayoría tienen un comportamiento lineal dentro del rango de trabajo.
- Las características de transductores están dentro del rango requerido por el MAPA, rango de presión, suministro eléctrico, tiempo de respuesta.
- El transductor MPX5050GP es el más práctico para el MAPA debido a que se requiere en primer lugar solo de una fuente de alimentación a diferencia de los otros transductores que requieren de dos fuentes de tensión.

f) Referencias

(Save, 2005), (Space Labs, 2005), (Freescale, 2005)

5.3 Calculo de error en el transductor de presión

En el siguiente informe se calcula experimentalmente el error generado por el transductor durante la medición, asimismo se realiza la simulación del mismo utilizando un programa matemático.

a) Objetivo

- Determinar el error propiamente generado por el transductor de presión.
- Buscar el método que permita reducirlo.

b) Materiales

- Información técnica del transductor de presión.
- Programa de cómputo, análisis, visualización y desarrollo de algoritmos matemáticos MATLAB.

c) Metodología

- Determinar la curva característica del transductor, según el fabricante,

$V_O = V_S (P \times 0.018 + 0.04)$ +/- (ErrorPresión x FactorTemperatura x $0.018 \times V_S$)

donde $V_S = V_{DD} +/- 0.25V_{DD}$, $V_{DD}=5V$, P= Presión de entrada.

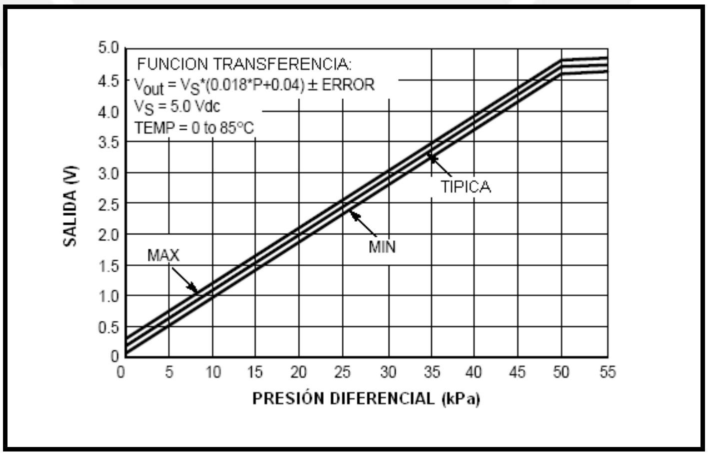

Figura N° 39 Curva característica de transductor de presión MPX 5050GP (Freescale, 2005)

- Realizar el análisis matemático de la curva utilizando MATLAB.

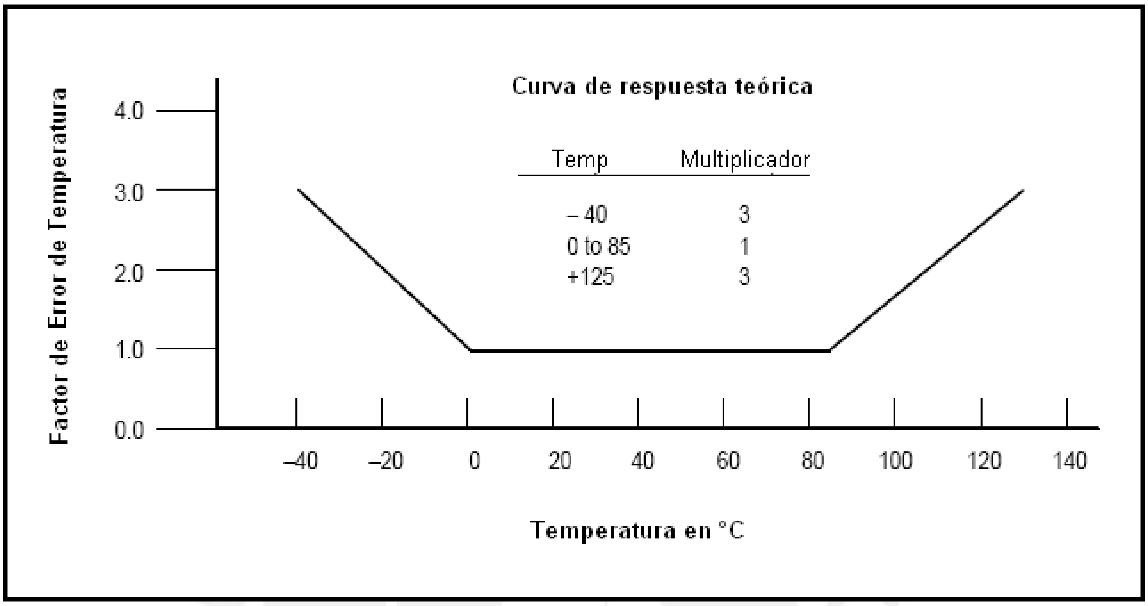

Figura N° 40 Curva de factor de error por temperatura MPX 5050GP (Freescale, 2005)

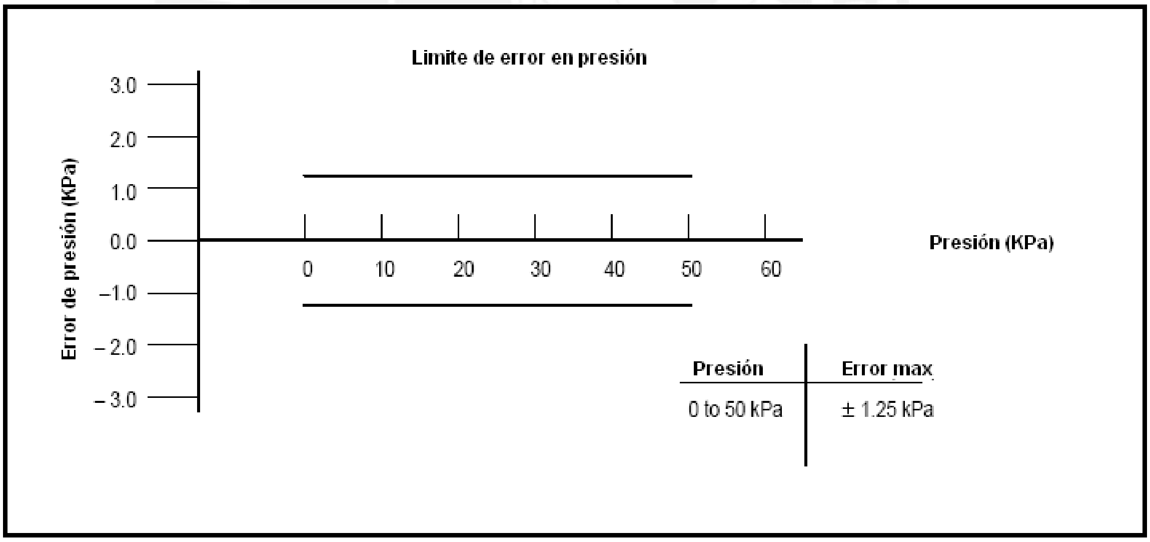

Figura N° 41 Curva de error de presión MPX 5050GP (Freescale, 2005)

d) Resultados

- De la hoja de datos técnicos y la ecuación del transductor se puede deducir que la temperatura es estable entre los 0° C a 85° C, así como linealmente variable entre -40° C a 0° C y 85° C a 125° C. En lo que respecta a la presión, el transductor mantiene una respuesta continua entre los 0KPa a 40KPa con un error de +/-1.25 KPa.

- Reemplazando los datos en curva tenemos que:

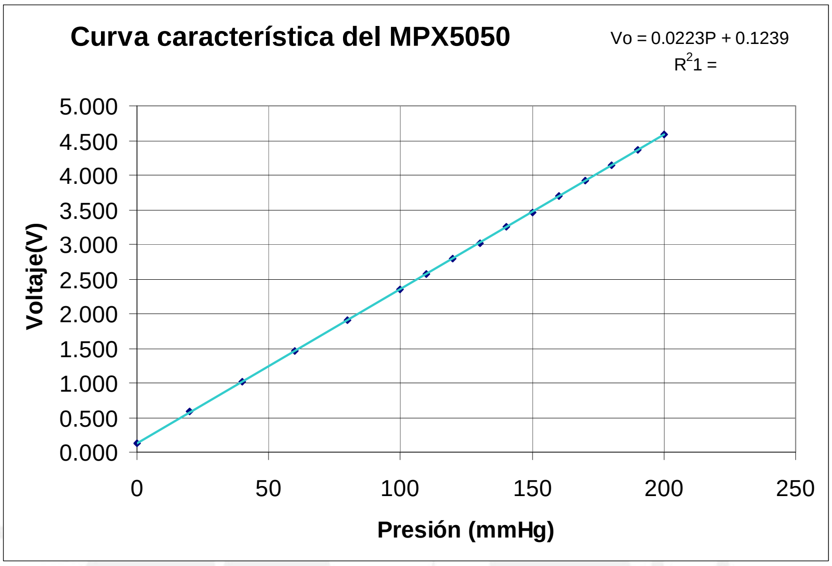

Figura N° 42 Curva característica obtenida en laboratorio del transductor de presión MPX 5050GP

e) Conclusiones

El sistema de transducción es básicamente lineal, teniéndose mínima dependencia de error, siendo considerables por las variaciones de la fuente de alimentación (20%), y el menor grado el error de presión (2.5%), y las variaciones de temperatura en condiciones normales (1.25%). Según las referencias se pueden obtener errores de 12 a 20 mmHg en la medida de la presión diastólica y errores de 5 a 20 mmHg en la medida de la presión sistólica en el método auscultatorio y errores de 9% en presión sistólica y 6% en diastólica con el método derivativo oscilosmétrico.

f) Referencias

(Freescale, 2005), (Matlab, 2005), (David, 2003)

5.4 Prueba y elección del circuito de acondicionamiento.

Esta prueba permite evaluar la respuesta de los componentes del filtro amplificador para de esta forma seleccionar el circuito amplificador operacional más adecuado.

a) Objetivo

- Evaluar las características de tres amplificadores operacionales para la aplicación requerida.
- Diseñar, probar y seleccionar un circuito amplificador y filtro según los requerimientos del MAPA.

b) Materiales

- Amplificadores operacionales: LM324, INA116, OPA027.
- Resistencias, tarjeta de pruebas, dispositivos electrónicos varios y cables de conexión.
- Multimetro digital.
- Osciloscopio digital de 20MHz.
- Fuente de alimentación de 5 Voltios y 12 Voltios.
- Generador de señales analógicas.

c) Metodología

- Comparar las especificaciones de los opamps, verificar las características de alimentación, slew rate, ganancia., drift y tiempo de respuesta.
- Preparar circuitos amplificadores y filtros con estos opamps (ver figura N° 25).
- Probar circuitos y verificar respuestas de ganancia, frecuencia, consumo, introduciendo una señal sinusoidal de 10Hz y 1 Vdc de amplitud.
- Calcular errores de las respuestas de los circuitos para realizar una evaluación adecuada de circuito a utilizar.

d) Resultados

- Comparando las tablas de los parámetros de las hojas de datos técnicos tenemos:

Tabla Nº 31 Análisis de promedios de medición con diferentes brazales y pacientes.

	Vcc	Slew Rate	Ganancia BW	Drift
Circuito LM324	+ 5.0 .0Vdc	1.0 V/us	1.0 MHz	5uV/°C
Circuito INA116	+/- 15.0 Vdc	0.8 V/us	0.8 MHz	2uV/°C
Circuito OPA027	+/- 15.0 Vdc	0.8 V/us	1.0 MHz	10uV/°C

- En lo referente al diseño del circuito de acondicionamiento el LM324 presenta mayores facilidades por requerir solo de una fuente de +5.0 Vdc. El resto de opamps requiere de dos fuentes y una referencia.

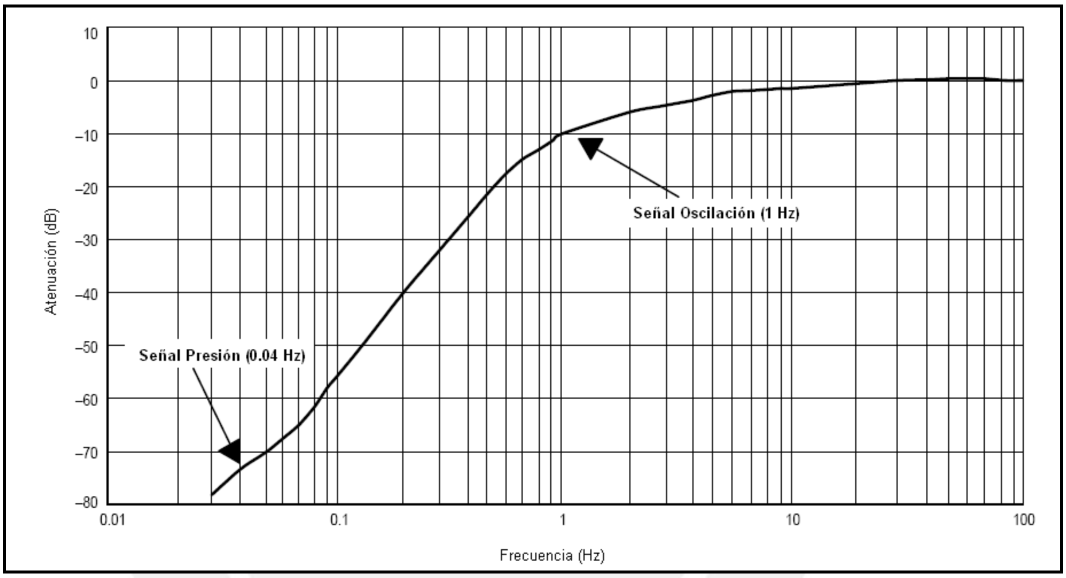

Figura N° 43 Curva de respuesta del amplificador y filtro (Freescale, 2005)

e) Conclusiones

- De la evaluación se selecciona al circuito LM324 debido a sus características de salida, integral filtro y amplificador, así como por el bajo consumo.
- El circuito INA116 resulta sobredimensionado para lo requerido así como requiere de doble fuente de alimentación.
- El circuito OPA027 requiere de 4 CI para construir el amplificador y filtro.

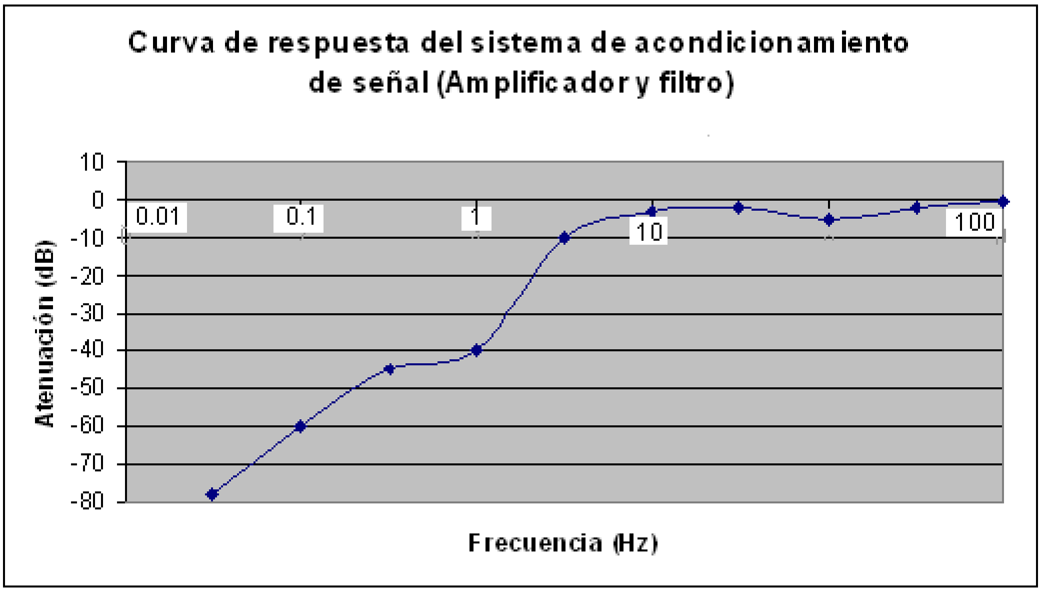

Figura N° 44 Curva de respuesta del sistema de acondicionamiento de señal

f) Referencias

(Savant, 2000), (Cougling, 1999)

5.5 Pruebas y cálculo de error en medición del sistema de adquisición de datos.

En la siguiente experiencia se determina el error generado por el sistema de adquisición integrando tanto los errores propios del método oscilosmétrico, con el error del transductor y circuito de acondicionamiento de señal.

a) Objetivo

- Determinación de los factores que afectan la medición de la presión en el sistema de adquisición.
- Calculo de error en la medición de las presiones.

b) Materiales

- Etapa de adquisición de presiones del MAPA.
- Computadora.
- Hojas técnicas de los componentes de la etapa de adquisición de presiones.

c) Metodología

- Determinar los factores que afectan la medición de la presión tanto en el transductor de presión, circuito amplificador y filtros.
- Para esta tarea se debe modelar matemáticamente estos componentes teniendo como referencia la información del fabricante de los mismos.
- Calcular el error generado por cada uno de estos factores en la medición de las presiones.

d) Resultados

- Como se vera con más detalle luego la curva característica del transductor, según el fabricante, responde a:

  $V_O = V_S$ (P x 0.018 + 0.04) +/- (ErrorPresión x FactorTemperatura x 0.018x V_S)

  Donde $V_S=V_{DD}$+/-0.25V_{DD}, V_{DD}=5V, P= presión de entrada.

- En lo que respecta al circuito de amplificación y filtrado el modelo resultante es el siguiente (en el capitulo 4 se desarrollo el modelamiento):

  $V_0 = V_i\,[164.34s^2/(1.634s^2 + 5.28s + 5.28)] + V_R\,[(4.98s + 1)/(1.634s^2 + 5.28s + 5.28)]$

e) Conclusiones

- De esta ecuación se concluye que el sistema de transducción es básicamente lineal, teniéndose mínima dependencia de error, siendo considerables por las variaciones de la fuente de alimentación (20%), y el menor grado el error de presión (2.5%), y las variaciones de temperatura en condiciones normales (1.25%). Tal como se menciona en la referencia (David, 2003), los errores generados por el sistema pueden llegar a superar el 20 % dependiendo del método utilizado. Es por ese motivo que el método oscilosmétrico tiene una mejor característica contra los artefactos externos.
- Mientras tanto, en referencia al circuito de amplificación y filtrado tenemos las variaciones de tensión son las que más afectan la adquisición de las presiones por lo que se debe asegurar la estabilidad de la fuente de alimentación durante el proceso de medición, en caso contrario, se alterarán los resultados esperados en la medición.
- Se recomienda que para cada medición se utilicen nuevas baterías con el fin de asegurar la linealidad y estabilidad del sistema de adquisición de presiones.

f) Referencias

(Freescale, 2005), (Natsemi, 2005), (Couling, 1999), (Savant, 2000), (David,2003)

5.6 Prueba y elección del microcontrolador.

Esta metodología tiene por objetivo el realizar una prueba de rendimiento teórica en base a las especificaciones técnicas ofrecidas por los fabricantes de microcontroladores. Finalmente nos permite seleccionar el componente más adecuado para la aplicación del sistema.

a) Objetivo

Comparar las características y rendimiento de microcontroladores según el cumplimiento de las actividades requeridas por el sistema. Evaluar y seleccionar el adecuado.

b) Materiales

- Hojas de datos técnicos de microcontroladores
- Computadora

c) Metodología

- Comparar las características técnicas de cada microcontrolador.
- Definir las condiciones técnicas mínimas requeridas por el sistema.
- Preparar una tabla, determinar las ventajas y desventajas.

d) Resultados

Condiciones mínimas: Bajo consumo, Conversor A/D de 10 o 12 bits, 3 puertos I/O, comunicación serial, I2C, soporte RS232, salida PWM, 1 a 10 MIPS, mínimo 4KB RAM, de 32 a 64 KB FLASH, programación sencilla y tamaño pequeño.

Tabla N° 32 Comparación de características técnicas de microcontroladores

Fabricante	Silicon Labs	Microchip	Texas Ins	Atmel	Motorola	Philips	National
MCU	Si Labs C8051	PIC18xx	TI MSP430	AVR	68HC908	P89CE558	COP8CxR9
MIPS	25 -> 100	5 -> 10	8	1 - > 16	2 -> 8	20 -> 100	20 -> 100
Conversor A/D (bits)	8, 10, 12, 14, 16	8, 10, 12	10, 12	10	8, 10	10, 12, 16	10
Rendimiento A/D	excelente	Regular	excelente	regular	buena	excelente	excelente
Conversor D/A (bits)	10, 12	No	12	no	no	12	12
Conectividad Serial	UART, SPI, I2C, USB, CAN	UART, SPI, I2C, CAN	UART, I2C	UART, SPI, I2C	UART, SPI, I2C, USB	UART, SPI, I2C, USB, CAN	UART, SPI, I2C, USB, CAN
Baja potencia	bueno	Regular	excelente	regular	regular	bueno	bueno
Empaque pequeño (pin, mm2)	11, 9	8, 27	20, 95	8, 45	20, 138	11, 9	10
FLASH (KB)	128	64	60	128	62	128	32
RAM (KB)	8	3.8	10	4	4	8	1
# Flash MCU	52	90	29	42	43	52	52
Timer 16 bit (canales)	3	1, 2	3	1	3	3	3
Watch Dog	si	Si	si	no	no	si	si
A/D 10 bit (canales)	8	8	8	8	8	8	16
Voltaje Detector de salida	bajo	Bajo	bajo	bajo	bajo	bajo	bajo
Sistema de programación real	si	No	si	si	si	si	si
Precisión emulación analógica	no	No	no	no	no	no	si

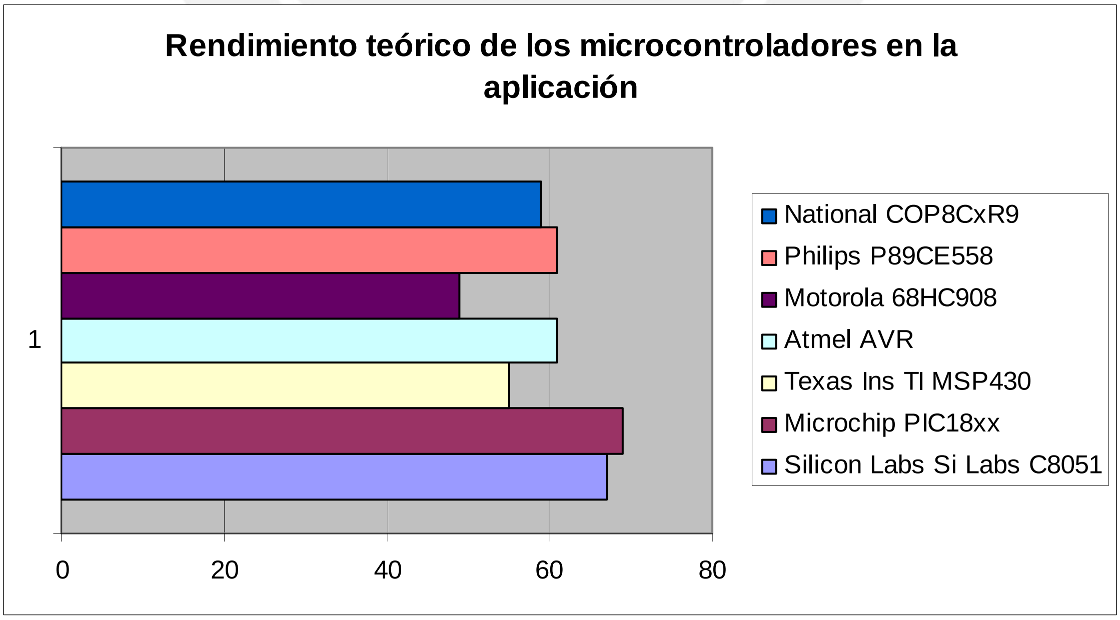

Figura N° 45 Rendimiento teórico de los microcontroladores para la aplicación del MAPA

e) Conclusiones

- De la tabla se puede concluir que los 68HC908, COP8CXR9, P89CE558, TI MSP430 tienen características que superan largamente el requerimiento del sistema.
- En este sentido, en la búsqueda de un MCU a medida de la necesidad planteada nos conviene trabajar con el PIC o con el Atmel.
- Se debe resaltar que los fabricantes de la mayoría de los MCU mostrados indican que no se responsabilizan por cualquier aplicación medica que se les de a sus productos. Finalmente, a pesar de las obvias ventajas de los Atmel tanto por sus direccionamiento directo, ahorro de memoria y mayor reprogramabilidad; se decide seleccionar el PIC, principalmente debido a cumplir con lo requerido, tener menor tamaño, contar con un pin de control de tensión y contar con las entradas requeridas para el diseño.
- Dentro de los PICS, el 18F877 se ajusta a los requerimientos planteados, permitiendo el desarrollo y mejora futura del sistema.

f) Referencias

(Natsemi, 2005), (Texas, 2005), (Analog, 2005), (Microchip, 2005), (Atmel, 2005), (Silabs, 2005)

5.7 Pruebas y cálculo de error en medición del sistema de control.

En esta prueba se determina los errores generados a medida que el sistema esta en funcionamiento y cuando los parámetros internos varian básicamente por la reducción de la energía de alimentación.

a) Objetivo

- Obtener la ecuación de error del sistema de control completo y determinar los factores que pueden afectar la medición.
- Determinar el porcentaje de error del sistema.

b) Materiales

- Multimetro digital.
- Osciloscopio digital de 20MHz.
- Fuente de alimentación de 5 Voltios y 12 Voltios.
- Simulador y verificador de presiones. (Monitor BioTek BPPUMP)
- Sistema de adquisición de presiones diseñado. (Transductor de presión, circuito de acondicionamiento de señal, microcontrolador).
- Información técnica del sistema de adquisición de presiones.

c) Metodología

- Determinar los factores que afectan la medición de la presión tanto en la etapa de adquisición de presiones como en la etapa de actuadores, como lo son la electroválvula, bomba y brazalete.
- Modelar matemáticamente estos componentes teniendo como referencia la información del fabricante de los mismos.
- Calcular el error generado por cada uno de estos factores en la medición de las presiones.
    - Realizar prueba de batería:
    - Colocar batería nueva.
    - Programar el MAPA (3 mediciones por hora de 7 a.m. a 7 p.m. y 2 mediciones por hora de 7 p.m. a 7 a.m.)

- Conectar el MAPA a un brazo de pruebas (botella de plástico de gaseosa de 1.5 litros llena de agua)
- Medir variaciones de la tensión de alimentación del MAPA en las 60 medidas a realizar.
- Registrar las medidas realizadas y calcular el porcentaje de error en la medición.

d) Resultados

Del estudio realizado en el capitulo anterior se determinaron los factores de influencia en la medición de la presión:

- Variaciones de la alimentación eléctrica,
- Cambios temperatura en los componentes electrónicos,
- Fluctuaciones de la presión de entrada,

Ruido eléctrico producido tanto por la electroválvula y la mini bomba.

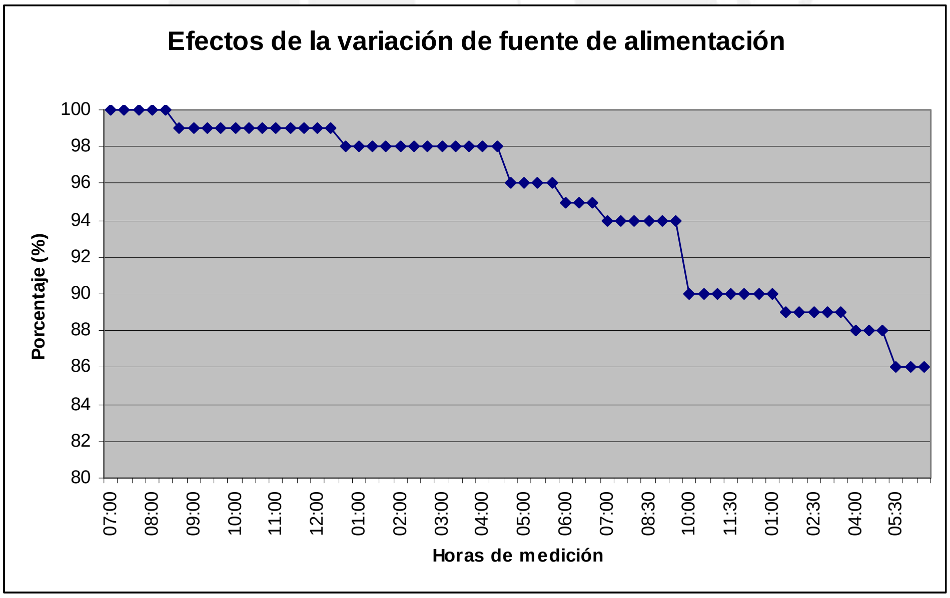

Figura N° 46 Efectos de la variación de la fuente de alimentación (baterías) del MAPA

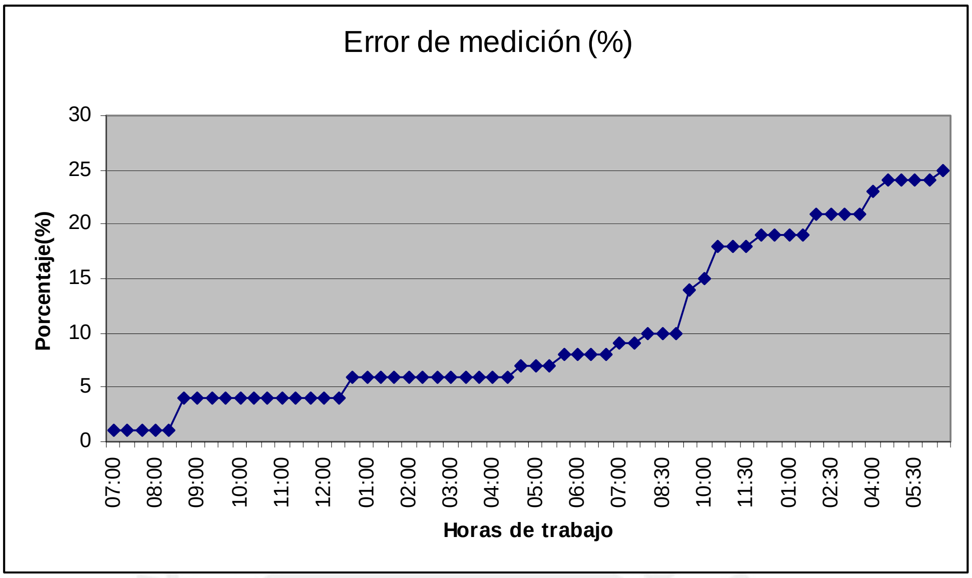

Figura N° 47 Error de medición en la adquisición de las presiones del MAPA

e) Conclusiones

- Se realizaron 60 mediciones detectándose variaciones propias del sistema que suman hasta el 25% de error, básicamente generada por la caída de la tensión de alimentación.
- Por lo anterior, se destaca la importancia del control de la tensión entregado por el microcontrolador, pues permite conocer las variaciones de las baterías y asegurar la estabilidad de la conversión de los datos durante la adquisición de los mismos. A lo largo del periodo de adquisición (que puede durar hasta 24 horas) el sistema debe encontrarse encendido.
- En este estudio no se incluyen factores externos como la selección del brazalete, la colocación del mismo, fugas y presiones externas durante la medición, movimientos del paciente, entre otros.

f) Referencias

(David, 2003), (Natsemi, 2005), (Texas, 2005), (Freescale, 2005), (Microchip, 2005) y (Savant, 2000)

5.8 Pruebas de etapas de comunicación y manejo de puertos.

La presente experiencia permite verificar el correcto envío y recepción de la información entre el prototipo y una computadora, obteniendo rangos aceptables de error y asegurando una correcta trasmisión y recepción de datos.

a) Objetivo

Verificar la correcta transmisión y recepción de información entre la computadora y el sistema diseñado a través del puerto serial.

b) Materiales

- Sistema de adquisición y control de presiones diseñado.
- Computadora.
- Cable de transmisión serial.

c) Metodología

- Conectar el sistema y la computadora
- Inicializar el programa de control
- Configurar el sistema a través de la computadora
- Cargar datos de configuración al sistema.
- Verificar funcionamiento del sistema.
- Verificar señal de control de transmisión y su confirmación. (TXSTA, RCSTA)
- Enviar información adquirida por el sistema a la computadora.
- Repetir la experiencia para determinar el porcentaje de paquetes errados

d) Resultados

Se verifico el estado del bit 0 de las direcciones 98h (TXSTA) y 18h (RCSTA) del PIC corroborando la correcta transmisión y recepción de la información remitida al PIC por la computadora vía el puerto serial obteniéndose la siguiente tabla. Se realizó un muestreo de la misma y se obtuvo un error de comunicación del 3.95%. En las hojas de datos del PIC se observa el detalle de cómo se realiza la comunicación con una computadora.

Tabla N° 33 Cálculo del error en la transmisión y recepción de datos en el MAPA (Muestra de 76 datos)

Prueba	Bit de envío	Bit de recepción	Error
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0
11	0	0	0
12	0	0	0
13	0	0	0
14	0	0	0
15	0	0	0
16	0	0	0
17	0	0	0
18	0	0	0
19	0	0	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
24	0	0	0
25	0	0	0
26	0	0	0
27	0	0	0
28	0	0	0
29	0	0	0
30	0	0	0
31	0	0	0
32	0	0	0
33	0	0	0
34	0	0	0
35	0	0	0
36	0	0	0
37	0	0	0
38	0	0	0
39	0	0	0
40	0	0	0
41	0	0	0
42	0	0	0
43	0	0	0
44	0	0	0
45	0	0	0
46	0	0	0
47	0	0	0
48	0	0	0
49	0	0	0
50	0	0	0
51	0	0	0
52	0	0	0
53	0	0	0
54	0	0	0
55	0	0	0
56	0	1	1
57	0	1	1
58	0	0	0
59	0	0	0
60	0	0	0
61	0	0	0
62	0	0	0
63	0	1	1
64	0	0	0
65	0	0	0
66	0	0	0
67	0	0	0
68	0	0	0
69	0	0	0
70	0	0	0
71	0	0	0
72	0	0	0
73	0	0	0
74	0	0	0
75	0	0	0
76	0	0	0

% Error 3.947

e) Conclusiones

- Se determina que el protocolo de transmisión y recepción de información es correcto.
- Se observó que el incremento del porcentaje de error es directamente proporcional a las variaciones de tensión de alimentación.

f) Referencias

(Microchip, 2005), (Save, 2005), (Space Labs, 2004)

5.9 Pruebas de verificación de funcionamiento del sistema.

Esta prueba consolida las experiencias realizadas en los puntos 5.3, 5.5 y 5.7. De esta forma se calcula el error final generado por el sistema durante su operación, comparándolo con el rendimiento del simulador y de un equipo de medición de presiones.

a) Objetivo

- Verificar la correcta medición del sistema.
- Calcular el porcentaje de error de medición.

b) Materiales

- Sistema de adquisición de presiones.
- Computadora.
- Brazalete
- Botella plástica de 1.5 litros llena de agua o cilindro sólido de aproximadamente 10 cm. de diámetro.
- Mangueras y conexiones de 2 y 3 vías.
- Simulador y verificador de presiones. (Monitor BioTek BPPUMP)
- Tensiometro de mercurio.

c) Metodología

- Preparar el sistema de simulación realizando las siguientes conexiones:
- Conectar el sistema de adquisición de presiones MAPA, con la computadora.
- Colocar el brazalete correctamente alrededor de la botella o cilindro.
- Conectar la botella en paralelo al MAPA, al simulador de presiones y al tensiometro.
- Iniciar las pruebas de medición de presiones.
- Registrar los valores obtenidos por el MAPA, el simulador y el tensiometro

d) Resultados

- De los resultados obtenidos se tiene un error de medida de 2.5% entre los resultados obtenidos con el MAPA, el simulador y el tensiometro.
- La corrección de este error de 2.5% requiere que modificar la ganancia del circuito amplificador en la máxima medida de error (220 mmHg), hasta reducirla a cero y realizar nuevamente la prueba de verificación. Este procedimiento se debe repetir hasta reducir el error al minimo posible por el sistema.

Tabla N° 34 Prueba de verificación de funcionamiento del MAPA

Presión (mmHg)	MAPA (mmHg)	Simulador (mmHg)	Tensiometro (mmHg)	Error de medida
10	10	10.3	9	-0.35
20	20	20.1	21	0.55
30	30	32.5	30	1.25
40	40	43.2	39	1.1
50	50	52.4	52	2.2
60	60	62.6	61	1.8
70	70	72.4	72	2.2
80	80	83.4	83	3.2
90	90	92.6	92	2.3
100	100	102.8	103	2.9
110	110	113.6	112	2.8
120	120	123.5	121	2.25
130	130	132.5	134	3.25
140	140	144.6	143	3.8
150	150	153.5	152	2.75
160	160	160.9	164	2.45
170	170	172.4	173	2.7
180	180	183.3	182	2.65
190	190	193.2	195	4.1
200	200	200.4	206	3.2
210	210	213.8	214	3.9
220	220	222.4	226	4.2

e) Conclusiones

- El MAPA se encuentra prácticamente calibrado según lo corroborado en la prueba realizada estando su valor dentro de los parámetros permisibles.
- El MAPA cuenta con un sistema de calibración según lo planteado en los estándares regulatorios para estos equipos de medición de presiones.

f) Referencias

(Microchip, 2005), (Save, 2005), (Space Labs, 2004), (David, 2003)

5.10 Pruebas de verificación del estado de la fuente de alimentación.

Se realiza esta prueba con el objetivo de evaluar las características eléctricas del sistema y asegurar un minimo periodo de autonomía del mismo. De esta manera se puede modelar en forma más cercana las características de la batería externa.

a) Objetivo

- Determinar las características eléctricas del sistema de adquisición de presiones.
- Determinar las características de la batería externa y verificar su autonomía.

b) Materiales

- Sistema de adquisición de presiones.
- Computadora.
- Brazalete.
- Botella plástica de 1.5 litros llena de agua o cilindro sólido de aproximadamente 10 cm. de diámetro.
- Mangueras y conexiones de 2 y 3 vías.
- Simulador y verificador de presiones. (Monitor BioTek BPPUMP)
- Multimetro digital.
- Osciloscopio digital de 20MHz.

c) Metodología

- Preparar el circuito de adquisición de presiones, accesorios y colocar la botella de simulación.
- Utilizando un multimetro digital tomar medidas en los puntos indicados en la figura N° 47.
- Durante el proceso de medición del consumo de corriente se deben considerar cuatro etapas o zonas de trabajo, tal como se menciona en la tabla N° 34:
    - Activación de la bomba.
    - Activación de la electroválvula.
    - Adquisición de las presiones y procesa la información.
    - Ajustes para la determinación de la presión.

- Para validar la medición se realizaron 10 mediciones por punto de prueba, luego se determinó la media correspondiente.

d) Resultados

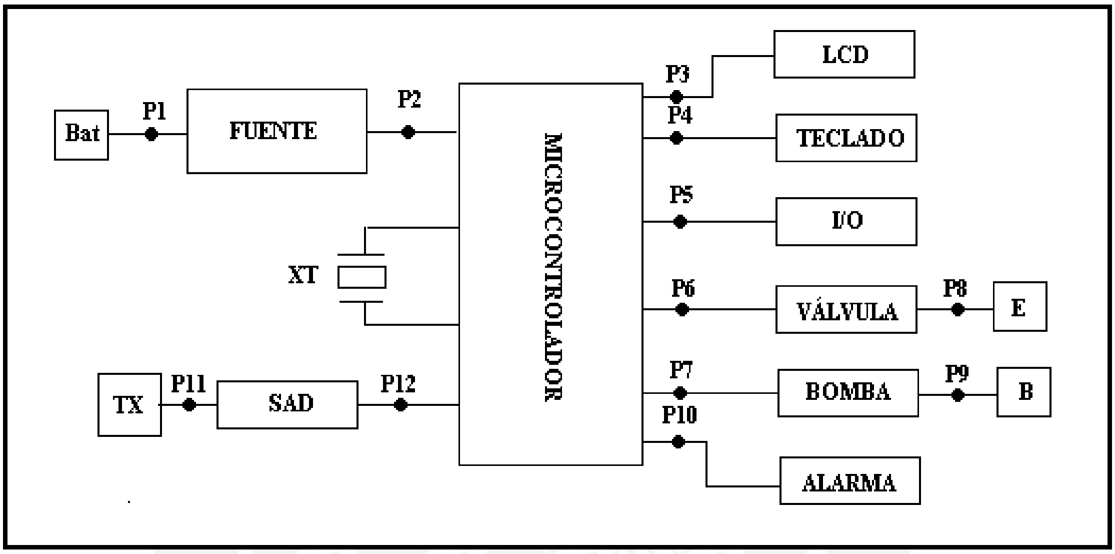

Figura N° 48 Diagrama de ubicación de puntos de prueba para la medición del consumo de corriente del MAPA

Tabla N° 35 Prueba de verificación de consumo eléctrico del MAPA (promedios)

	Etapa I Bomba Activa	Etapa II Electroválvula Activa	Etapa III SAD Activa	Etapa IV Ajuste de Medición
P1	1261	1223	980	987
P2	1077	1129	905	1039
P3	19.5	21	24	22
P4	21	21	24	23
P5	21	22	24	25
P6	23	24	24	23
P7	22	23	24	28
P8	101	39	0	74
P9	46	71	0	45
P10	37	0	72	0
P11	8	8	9	10
P12	92	91	94	92

e) Conclusiones

- Según lo medido se tiene que el consumo de corriente medio es de 1.113 amperios, sin embargo debemos tener en cuenta que las etapas de trabajo no tienen periodos de tiempo constantes. Estos periodos varian según la capacidad de determinar el valor de las presiones del MAPA.
- A pesar que en teoría la batería entrega 1.2 amperios/hora, el rendimiento de la misma decae en periodos de tiempo mayores a las 12 horas de forma considerable, (aproximadamente en un 6% con tendencia a caída abrupta).
- En este sentido, se determina que el consumo de corriente eléctrica depende tanto del diseño de la fuente de alimentación, como de la eficiencia del sistema en determinar las presiones, es decir, en la capacidad de reducir el número de aproximaciones en la medición, en la capacidad de reducir las interferencias y los errores de la medición. .

f) Referencias

(Save, 2005), (Space Labs, 2004), (Texas, 2005)

Observaciones y Conclusiones

A continuación, se listan las observaciones más importantes de este trabajo de tesis. Asimismo, se resaltan las conclusiones que permitirán comprender y aclarar lo evaluado:

Observaciones.

- En la selección y uso correcto del brazalete es de gran importancia considerar las dimensiones adecuadas del brazalete según el paciente que se pretende auscultar, así como el efecto de la correcta ubicación y posición del brazalete para obtener una buena medida de la presión arterial.

- En el caso de electroválvulas, las más adecuadas son las que presentan una alta sensibilidad, tiempo de reacción y establecimiento adecuado para permitir un control de la presión de desinsuflado menor a 5 mmHg.

- Respecto al programa de interfase, adquisición, medición y presentación, en esta tesis no se diseño ni desarrollo el programa, solamente se realizó el estudio comparativo de los programas utilizados por los equipos más comercializados como Space Labs, General Electric y Save. Asimismo, se consultó con cardiólogos y usuarios del MAPA al respecto, concluyéndose en la propuesta de algunas mejoras para permitir el mejor aprovechamiento del programa en sus etapas de medición y presentación de la información adquirida. Estas propuestas u opciones a mejorar son:
    - Contar con un marcador de eventos automático.
    - Formato de reporte con opción múltiple para llenado rápido.
    - Sistema de inteligencia artificial que permita realimentar la información almacenada para optimizar algunos diagnósticos.

Por otro lado, a continuación se enumera una lista de posibles trabajos de investigación relacionados con la ejecución del prototipo en esta tesis de grado y que requieren de un estudio y desarrollo más detallado por parte de bachilleres de informática, mecánica y física, ya que guardan relación directa con estas ramas de la ciencia:

- Diseñar un programa que adicione las siguientes características:
    - Interfase visual amigable para el manejo del prototipo, así como se sugiere tener en cuenta las siguientes características solicitadas por algunos médicos especialistas.
    - Ingreso de fórmulas estadísticas de interés del médico especialista y contar con una interfase gráfica personalizada.
    - Inserción de comentarios y observaciones en cada estudio y facilidad para realizar reportes.
    - Manejo de una base de datos que facilite el análisis del especialista.
- Se sugiere además realizar una encuesta entre médicos especialistas que utilizan este tipo de equipos con el fin de recabar otros requerimientos que permitan mejorar el programa de aplicación.
- Realizar un estudio para el rediseño del sistema neumático del MAPA con el fin de alcanzar los siguientes objetivos:
    - Reducción del tamaño del prototipo.
    - Reducción del peso del prototipo.
    - Menor consumo de energía eléctrica.
    - Menor ruido y vibración.
- Investigar sobre nuevos métodos no invasivos que permitan reducir el porcentaje de error en la adquisición de las presiones, así como otros tipos de transductores de presión con mayor sensibilidad que permitan una mejor adquisición de datos.
- Rediseñar la fuente de alimentación mejorando la autonomía de 12 horas a 24 horas como minimo.

Conclusiones.

Luego de realizadas las pruebas a través de un prototipo del sistema de adquisición de presiones arteriales no invasivo ambulatorio:

- Queda demostrado que el método oscilosmétrico es el que menores errores e inexactitudes presenta en la adquisición automática de presiones alcanzando un error de 15%, mientras que el método auscultatorio y otros superan el 40 % de error en la medición; así como también presenta más facilidades en el control digital y diseño de algoritmos para la obtención de la presión diastólica, media y sistólica. (David, 2003)

- La bomba pulsátil se ajusta mejor a lo requerido al presentar mejores características en lo referente a menor consumo, mayor flujo y potencia de insuflación alcanzando insuflar el brazalete superando presiones de 240 mmHg con un error máximo del 10% como consta en las pruebas realizadas y cuyos resultados se anexan. (Save, 2005)

- Se prefirió trabajar con los transductores de presión marca Motorola, debido a que son especialmente diseñados para trabajar en equipos médicos, brindando condiciones de precisión, estabilidad y confiabilidad. Asimismo, se considero en primera instancia a los transductores de presión cuyos requerimientos de alimentación permiten un menor consumo y facilidades de diseño, seleccionándose el MPX5050GP que requiere de solo una fuente de suministro de cinco voltios (5 Vdc). (Freescale, 2005)

- El Circuito de Acondicionamiento de Señal, constituido por circuito amplificador y el circuito de filtrado pasa banda. se encontró que el LM324 presenta las características solicitadas, además de usar solo una fuente de suministro, lo que facilita el diseño de la fuente de alimentación del MAPA. Asimismo, este amplificador permite diseñar una estructura de amplificación y filtro integrando los dos requerimientos en un solo circuito. (Freescale,2005)

- En lo que respecta a la etapa de control de actuadores (para el control de la bomba, electroválvula, pantalla, alarmas, realimentación de control de la fuente de alimentación, teclado y puerto de comunicaciones) se podría tener un controlador independiente para cada caso, sin embargo con el objeto de optimizar los eventos se busco un controlador que pudiera integrar la mayoría de los requerimientos necesarios. Por este motivo se encontró que quienes mejor se ajustan a este requerimiento son los PIC`s y los Atmel. En este caso, fue seleccionado un PIC.

- En lo que refiere al diseño de la fuente de alimentación, esta fue diseñada en base al regulador conmutado integrado, utilizando como generador autónomo un set de baterías de 9 Vdc y 1200 mA. El regulador permite aislar para disminuir errores de adquisición debido a la interferencia de artefactos en el transductor. La salida del regulador es aproximadamente de 12 Vdc y 1000mA. Asimismo, el microcontrolador que permite monitorear las variaciones de voltaje de salida por el pin MCLR modificando el valor de referencia manteniéndolo prácticamente constante los factores de adquisición de un evento evitando la distorsión de la adquisición misma.

- Sin embargo en las pruebas y mediciones realizadas solo se tuvo una autonomía de aproximadamente 12 horas. Se determinó que se alcanza un máximo consumo en los instantes de carga de la bomba e intercambio con la electroválvula para ajustar la medición de la presión, llegando a registrar en promedio 1245mA. En condiciones de adquisición se reduce el consumo a 700 mA y en periodos de insuflación a 1260 mA. En este sentido, a pesar de tener un mejor rendimiento, las baterías no mantienen la carga, sobre todo en los periodos de ajuste de medición. Dentro de las mejoras a realizar en el sistema, con el objetivo de mejor el rendimiento de la fuente y alcanzar una autonomía de 24 horas es necesario mejorar las condiciones eléctricas del sistema mecánico reduciendo el consumo eléctrico de la bomba y de la electroválvula, así como también mejorar la eficiencia del sistema de adquisición de presiones y reduciendo los tiempos de adquisición.

- A pesar que en teoría la batería entrega 1.2 amperios/hora, el rendimiento de la misma decae en periodos de tiempo mayores a las 12 horas de forma considerable, (aproximadamente en un 6% con tendencia a caída abrupta). En este sentido, se determina que el consumo de corriente eléctrica depende tanto del diseño de la fuente de alimentación, como de la eficiencia del sistema en determinar las presiones, es decir, en la capacidad de reducir el número de aproximaciones en la medición, en la capacidad de reducir las interferencias y los errores de la medición. .

Finalmente, los resultados obtenidos en este trabajo han permitido llegar a la conclusión que para el diseño, desarrollo e implementación de un sistema automático, portátil y eficiente se requiere contar con un dispositivo que cumpla con las siguientes características mínimas:

- Bajo consumo,
- Tamaño pequeño,
- Atender los requerimientos de adquisición, comunicación y control, subdimensionado su capacidad de manejo de información,
- Integrar la mayor cantidad de funciones posibles con el fin de optimizar tareas.

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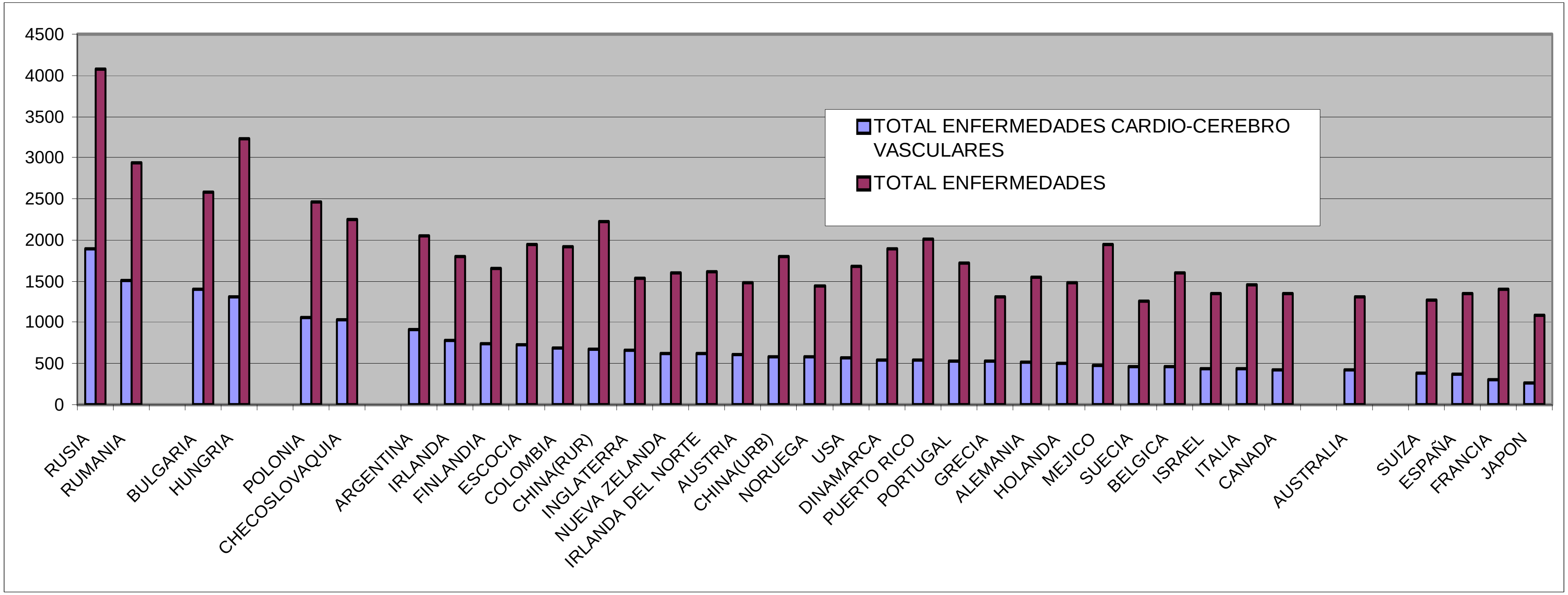
Anexo N° 1a Incidencia de las enfermedades cardiovasculares y cerebrovasculares en el mundo.

Referencia: American Heart Association (AHA), Heart Disease and Stoke Statistics – 2005 Update http://www.aha.org, (AHA, 2005)



Anexo N° 1b

Factores de Riesgo de las enfermedades cardiovasculares

Obesidad.

Promueve el desarrollo de otros factores de riesgo y es, por si mismo, una grave amenaza a la salud. Tienen exceso de peso el 85% de los diabéticos, el 80% de las personas que tienen niveles altos de colesterol en sangre y/o o triglicéridos, el 70% de los casos de hiperuricemia (exceso de ácido úrico en la sangre) y el 60% de los hipertensos. Las causas principales de la obesidad son el exceso de alimentación y la carencia de ejercicio.

Metabolismo anormal de lípidos.

La arteriosclerosis es el proceso en el cual la alta concentración crónica de grasas en la sangre (hiperlipidemia) que puede desencadenar y acelerar el proceso degenerativo de la pared arterial. Hay dos clases de lípidos sanguíneos (el colesterol y los triglicéridos). El colesterol es producido por el organismo mismo, en gran parte, pero el nivel de colesterol en la sangre está ligado a la dieta, al tipo de grasas que ingerimos y al colesterol contenido en los alimentos.

Fumar.

Los cigarrillos constituyen un valor de riesgo significativo en la producción de enfermedades cardiovasculares, según los resultados de los estudio de Framingham y la Organización Mundial de la Salud. Las personas que fuman un paquete por día tienen una probabilidad tres veces mayor de sufrir ataques cardiacos que los no fumadores.

Diabetes.

Estudios realizados en Framingham demuestran, con claridad, que uno de cada dos diabéticos, tarde ó temprano, tendrá dañados los vasos sanguíneos y correrá el riesgo de tener un ataque cardiaco. La incidencia de la hipertensión entre los diabéticos es mayor que entre los no diabéticos del mismo grupo de edad y es el doble entre los hombres que entre las mujeres que padecen la enfermedad. La relación entre estos dos factores de riesgo, diabetes e hipertensión, explica la relativa frecuencia de enfermedad de las coronarias entre las personas que tienen ambos factores. Existe una relación más importante todavía, entre la diabetes no tratada ó tratada en forma inadecuada, y la enfermedad de los vasos sanguíneos (arteriosclerosis) de las piernas, es la que conduce en casos extremos a la gangrena diabética.

Hiperuricemia.

O acumulación de ácido úrico en la sangre, es un trastorno metabólico que puede traer consecuencias muy dolorosas. El organismo convierte al exceso de ácido úrico en diminutos cristales que pueden alojarse en los tejidos de las articulaciones generando la enfermedad denominada gota. Un aspecto importante es que un hipertenso con hiperuricemia tiene tres veces más probabilidad de experimentar la enfermedad coronaria que los hipertensos con nivel normal de ácido úrico en la sangre.

Stress.

Condición bajo la cual el sistema cardiovascular se descontrola y desencadena la producción de grandes cantidades de hormonas que aumentan las defensas y la resistencia del cuerpo. Estas reacciones se inician con la combinación de muy variados factores: frío y calor, infecciones y heridas, tensión psicológica y emocional. El stress, a diferencia de otros factores de riesgo (como la presión sanguínea), no puede medirse con números ni se presta a estudios comparativos. Los diferentes tipos de stress afectan a personas diferentes, en forma diferente y les producen diferentes reacciones orgánicas.

La relación entre los factores de riesgo y el sistema cardiovascular ha sido estudiada cuidadosamente. Se sabe que contribuyen al desarrollo de la arteriosclerosis y ésta a la mayor parte de las enfermedades cardiovasculares. La arteriosclerosis ó endurecimiento de las arterias, es el resultado de las tensiones y daños que experimentan las paredes de las arterias en el curso de la vida. Esto es lo que determina nuestra edad "biológica" contra nuestra edad "cronológica". Los factores de riesgo pueden acelerar e intensificar el progreso de la arteriosclerosis. La elasticidad y la estructura muscular de las paredes internas arteriales, se deterioran y aparece el tejido de cicatriz; se forman depósitos de lípidos y sales de calcio (que provienen de la sangre) en la pared arterial. Luego se forman coágulos de sangre en el interior de las paredes y las arterias se transforman en tubos rígidos con paredes engrosadas que interfieren con la afluencia normal de oxígeno y nutrientes a los órganos clave. Luego, las células del tejido mal nutrido, degeneran y mueren. Los tres órganos más expuestos al peligro son: el corazón, el cerebro y los riñones. (Wolff, 1989), (OMS, 2005).

La existencia e importancia de los factores de riesgo son descubrimientos bastante recientes. Durante el desarrollo de la Investigación Conjunta Norteamericana que reunió datos de Framingham, Albany, Tecumsah, Los Ángeles y Minneapolis, así como los de la Compañía de Gas, y la Western Electric, ambas de Chicago, se examinaron 7,342 hombres entre 30 y 59 años, sin problemas aparentes de salud. De éstos, sólo 1,249 (el 17%) carecían de dos de los mayores factores de riesgo de alta presión sanguínea: el cigarrillo y la hipercolesterolemia. El 45% de los hombres tenía, por lo menos un factor de riesgo: el 30% tenía dos y el 8%, tres. (Framingham, 2004).

En la tabla Nº 5 se presentan los factores de riesgo y sus niveles normales permitidos en una evaluación médica.

Los Factores de riesgo: Niveles normales y altos. (Wolff, 1989)

Presión sistólica de la sangre (mm de Hg.) Presión diastólica de la sangre (mm de Hg.)	Normal Marginal Alta	100-139 mm de Hg., sistólica y 60 a 89, diastólica 140-159 mm de Hg. sistólico y 90 -94 mm de Hg. Diastólica 160 y mayor, sistólica o 95 y mayor, diastólica.
Azúcar en sangre (en mgrs)	Hasta los 49 años Normal Desde los 50 años en adelante Normal	 Hasta 100 mgrs% (en ayunas) y 100 mgrs (sin ayuno) Hasta 110 mgrs% en ayunas y 129 mgrs % sin ayuno.
Nivel de Lípidos Colesterol (mgrs%) Triglicéridos (mgrs%) en ayunas	Normal Marginal Normal Marginal	Hasta 220 mgrs% 221 – 259 mgrs % necesita tratamiento desde 260 mgrs% en adelante. Hasta 150 mgrs% 150-180 mgrs% necesita tratamiento desde 181 mgrs% en adelante.
Ácido úrico (mgrs%) Hombres Mujeres	Normal Marginal Normal Marginal	Hasta 6 mgrs% 6,1 – 7,0 mgrs% necesita tratamiento desde 7,1 en adelante. Hasta 5,5 mgrs% 5,6 – 6,0 mgrs% necesita tratamiento desde 6,1 en adelante

Anexo N° 1c Eventos Importantes relacionados a la medición de la presión sanguínea del 400 al 1950. (Geddes, 1991)

Fecha	Nombre	Profesión y nacionalidad	Evento
400	Hipócrates	Médico griego	Reconoció las arterias y venas, pero pensaba que conducían aire.
460	Galeno	Médico romano	Mostró que las arterias y venas conducían sangre.
1628	William Harvey	Físico ingles	Describió por primera vez la circulación sanguínea.
1646	Marcelo Malpighi	Científico italiano	Visualizo en un microscopio los capilares sanguíneos.
1706	Raymond de Vieussens	Profesor de anatomía francés	Realizó la primera descripción de las cámaras del corazón y las venas.
1713	Stephen Hales	Sacerdote y científico ingles	Realizó la primera medición de la presión sanguínea.
1816	Rene T. H.Lanaennec	Físico francés	Inventó el estetoscopio.
1876	Ritter von Basch	Científico alemán	Fue el primero en demostrar aplicaciones de contrapresión ocluyendo una arteria usando una pelota llena de agua
1876	E. J. Marey	Fisiólogo francés	Realizó aplicaciones de contrapresión hidráulica sobre el antebrazo
1896	Hurthle	Científico	Uso de brazal ó bolsa llena de agua para generar contrapresión
1896	Riva-Rocci	Físico italiano	Uso de brazal lleno de aire para ocluir arteria
1900	Gaertner	Médico alemán	Aplicación del método del flush sobre un dedo.
1901	Von Recklinghausen	Médico alemán	Investigó sobre el tamaño del brazalete y su influencia en la medición.
1903	Eindhoven	Fisiólogo ingles	Desarrolló el electrocardiógrafo.
1905	NS Korotkoff	Médico ruso	Determino los diferentes sonidos generados por las contracciones del corazón y su coincidencia con la variación de la presión.
1909	Launder Brunton	Médico británico	Emitió reporte en la Asociación Británica Médica explicando el método palpatorio
1912	James Herrick	Físico americano	Describió resultados de las enfermedades del corazón debidas al endurecimiento de las arterias.
1916	Norris	Fisiólogo americano	Uso del método palpatorio para medición de presión arterial sistólica
1938	Robert E. Gross	Cirujano americano	Realizó la primera cirugía al corazón.
1940	Segall	Médico canadiense	Medición de la presión arterial diastólica usando el método palpatorio
1940	RW Gifford	Médico americano	Inicio tratamientos farmacológicos para reducir la hipertensión
1944	Walter Kempner	Físico americano	Crea el centro para el tratamiento de la hipertensión por medio de dietas.
1947	Taylor y Page	Médicos americanos	Presentan investigaciones sobre sintomatología y tratamiento para la hipertensión; así como clasificación de pacientes con problemas hipertensivos y sus características
1949	American Heart Association	Organismo americano	Se inicia el Estudio de Framingham.
1950	Weaver y Bohr	Científicos ingleses	Investigación sobre método de flush y el auscultatorio.

Fecha	Nombre	Profesión y nacionalidad	Evento
1951	Asociación Americana del Corazón	Organización Americana	Recomienda y estandariza el método palpatorio
1952	Goldring y Wohltmann	Médicos americanos	Aplicación del método de flush en pediatría (defectos de método auscultatorio en infantes neonatos)
1952	F. John Lewis	Cirujano americano	Realizó la primera operación a corazón abierto.
1953	John H. Gibbon	Cirujano americano	Utilizó el primer corazón mecánico y purificador de sangre.
1954	Van Bergen	Médico americano	Relación entre las mediciones de la presión arterial directamente y con el método palpatorio
1960	Veterans Administration Hospital	Organización Americana	Mostró tratamientos antihipertensivos para reducir los riesgos de infarto y problemas cardiovasculares en pacientes con elevada presión diastólica.
1961	Enselberg	Medico americano	Grabación de cambios en la forma del pulso braquial ocluyendo un dedo.
1962	Inman- Sokolow	Científicos americano y ruso	El primer equipo electrónico de medición de presión arterial, usando un registrador y brazalete de oclusión para grabar las presiones, el ECG y los sonidos de Korotkoff.
1965	DeBakey y Kantrowitz	Cirujanos americanos	Implantaron el primer mecanismo para ayudar a un corazón enfermo.
1967	Christian Barnard	Cirujano sudafricano	Realizó el primer trasplante completo de corazón, de una persona a otra.
1968	Schneider	Científico americano	El primer equipo totalmente automatizado, utilizó un tanque de dióxido de carbono comprimido para insuflar el brazalete.
1979	DelMar Avionics	Empresa americana	Utilizó por primera vez una bomba eléctrica para la función de insuflación. Se inicia la evolución tecnológica y comercial acelerada entre empresas.
1982	William DeVries	Cirujano americano	Implantó el primer corazón artificial, diseñado por Robert Jarvik, físico americano, en un paciente.
2002	National High Blood Pressure Education Programs	Organización Internacional	Crea el primer Centro de prevención y control de la hipertensión y otros factores de riesgo cardiovascular.
La evolución tecnológica ha permitido la generación y el desarrollo de Centros de investigación, Industrias farmacéuticas y de equipamiento médico en campos de la electrónica y medicina, iniciando una gran competencia a nivel científico como comercial.			

Anexo N° 2a

Técnicas para la detección de la presión arterial utilizando métodos no invasivos

El método auscultatorio depende de los fenómenos ocurridos en el flujo sanguíneo durante la oclusión, este flujo cambia de laminar a turbulento y luego nuevamente a laminar, así como de los sonidos de Korotkoff que corresponden a las aperturas y cierres de las válvulas del corazón, por lo que se tiende a subestimar la presión sistólica, sin embargo la presión diastólica es muy fácil de determinar debido a su relación con estos fenómenos. Asimismo se debe tener en cuenta en los equipos manuales esta detección se ve afectada por los sentidos del especialista o persona que realiza esta medición.

El método oscilosmétrico puede sobrestimar la presión sistólica pues las oscilaciones generadas en el brazalete corresponden a la verdadera presión sistólica, además existe una relación entre las medidas de la presión arterial sistólica en el brazo, en la muñeca o en el dedo, mientras que se presentan problemas en la detección de la presión arterial diastólica. Los valores determinados en este método no sufren de las distorsiones mencionadas para el caso anterior, y son resultado de un sistema digital de adquisición de presiones así como de algoritmos matemáticos producto de múltiples estudios e investigaciones. (Geddes, 1991), (Togawa, 1997), (Rithalia, 2000), (AHA, 2005), (MDA, 2003).

Anexo N° 2b

Clasificación de equipos de medición de presión arterial

La clasificación de los equipos de medición de presión arterial no invasiva dependen principalmente del método o técnica de medición utilizado.

a) Equipos que utilizan el método auscultatorio:

Estos equipos de clasifican a su vez según su modo de trabajo, por lo que se tienen esfigmomanómetros o tensiometros manuales o mecánicos, semiautomáticos y automáticos o digitales. En los equipos manuales, tanto los dispositivos de insuflación, deflación y de medición son neumáticos y requieren de un operador o especialista. Mientras que en los equipos digitales o automáticos todos los dispositivos son controlados electrónicamente. En el caso de los equipos semiautomáticos, estos presentan un dispositivo de insuflación manual, el dispositivo de deflación puede ser manual o controlado electrónicamente, mientras que la medición es totalmente electrónica. Asimismo, los equipos automáticos estos a su vez se clasifican en equipos de medición instantánea y equipos de monitoreo.

b) Equipos que utilizan el método oscilosmétrico:

Estos se clasifican según su modo de trabajo en semiautomáticos y automáticos, teniendo en el primer caso un dispositivo de insuflación manual. En el caso de los equipos automáticos estos a su vez se clasifican en equipos de medición instantánea y equipos de monitoreo. Estos últimos pueden tener capacidad de almacenamiento de datos así como posibilidad de conexión a un sistema de cómputo externo que permita la transferencia de información del paciente como para reprogramar el equipo.

A continuación se muestra una tabla donde se presenta la clasificación de los equipos para medición de la presión arterial no invasiva o indirecta y sus diversas características:

Clasificación de Equipos de medición de presión arterial no invasivos portátiles.

Descripción	Dispositivo insuflación	Dispositivo deflación	Indicador presiones	Dispositivo detección	Tipo de control	Método o técnica	Capacidad Almacenar
Tensiometro de Mercurio	Pera	Válvula	Manómetro de columna	Especialista/ Estetoscopio	Manual	Auscultatorio	NO
Tensiometro Aneroide	Pera	Válvula	Manómetro	Especialista/ Estetoscopio	Manual	Auscultatorio	NO
Tensiometro Semiautomático	Pera	Válvula	Pantalla Digital	Especialista/ Estetoscopio	Manual	Auscultatorio	NO
Tensiometro Semiautomático	Pera	Electro válvula	Pantalla Digital	Micrófono	Electrónico	Auscultatorio	NO
Tensiometro Digital	Electro bomba	Electro válvula	Pantalla Digital	Micrófono	Electrónico	Auscultatorio	NO
Tensiometro Digital	Electro bomba	Electro válvula	Pantalla Digital	Micrófono Electrodos	Electrónico	Auscultatorio	NO
MAPA	Electro bomba	Electro válvula	Pantalla Digital	Micrófono Electrodos	Electrónico	Auscultatorio	SI
Tensiometro Digital Manual	Pera	Válvula	Pantalla Digital	Transductor de presión	Electrónico	Oscilosmétrico	NO
Tensiometro Digital	Electro bomba	Electro válvula	Pantalla Digital	Transductor de presión	Electrónico	Oscilosmétrico	NO
MAPA	Electro bomba	Electro válvula	Pantalla Digital	Transductor de presión	Electrónico	Oscilosmétrico	SI

Se debe indicar que todos estos equipos son portátiles, pero también existen equipos fijos o de cabecera, que normalmente presentan adicionalmente otras funciones y miden otros parámetros como frecuencia cardiaca, pulsaciones, saturación de oxigeno, temperatura, presión invasiva, entre otros Asimismo, algunos equipos que utilizan el método oscilosmétrico a su vez utilizan dispositivos que les permiten detectar o “sensar” los sonidos de Korotkoff, los que utilizan como indicadores de referencia o para corroborar lo determinado por los dispositivos oscilosmétricos.

Por otro lado, se muestran a continuación las características básicas y las desventajas de tres equipos de medición de presión arterial no invasiva, el esfigmomanómetro o tensiometro de mercurio, el tensiometro aneroide y el tensiometro digital.

a) Esfigmomanómetro o Tensiometro de mercurio

Características básicas

- Es el equipo estándar y más difundido para la medida de la presión arterial.
- De fácil lectura y solo requiere de calibración si se tiene perdida de mercurio.
- Mecanismo simple, su principio de trabajo se basa en la ley de gravedad y el comportamiento del Mercurio permitiendo obtener lecturas constantes y exactas.
- No se recomienda para el uso casero debido a lo peligroso del mercurio; sin embargo, son relativamente seguros por diseño.
- Larga duración con mantenimiento mínimo

Desventajas

- Puede ser complicado de transportar
- Un derrame de mercurio podría ser peligroso
- Debe estar sobre una superficie plana durante la medida, el tubo debe estar perpendicular al piso.

b) Esfigmomanómetro aneroide

Características básicas

- Es simple, liviano, portátil y más barato que el de mercurio.
- El manómetro funciona en cualquier posición si el lector puede visualizar la aguja directamente.
- De fácil lectura.

Desventajas

- El manómetro es delicado.

- La única manera de decir si la medida es exacta es comprobarla contra uno de mercurio.
- Puede ser dañada fácilmente sin el conocimiento del usuario, requiriendo de la reparación y reajuste o calibración de fábrica.
- Si el brazalete se coloca mal se obtendrá errores en la lectura de las presiones

c) Tensiometro digital

Características básicas

- Requiere de menos destreza manual que para los sistemas con el manómetro y estetoscopio separados.
- Es fácil utilizar, reduce al mínimo error humano y es bueno para la gente con pérdida de la audición o de la visión.
- La mayoría de las unidades son portátiles.
- Modelos más costosos tienen sistemas automáticos de insuflación y de deflación.
- Fácil lectura, indicador digital muestra lectura de presión e incluso incorporan medida del pulso (ritmo cardíaco).

Desventajas

- El mecanismo es complejo, frágil y sensible.
- La exactitud debe ser comprobada primero comparando a un dispositivo del mercurio.
- Los dispositivos más exactos no dan lecturas exactas en ciertos individuos.
- Los movimientos del cuerpo pueden influenciar en la exactitud de la medida.
- Puede ser costosa; requiere las baterías y un adaptador de tensión eléctrica.

- Puede requerir la reparación y el reajuste o calibración la fábrica cuando falla.
- Requiere la colocación cuidadosa del brazalete para la medida correcta y exacta, especialmente el modelo de muñeca.
- Algunos modelos están para el uso exclusivo en el brazo derecho o izquierdo.
- Los brazaletes grandes pueden ser relativamente costosos o difíciles obtener.

Se debe resaltar que en el caso de los Tensiometros digitales se pueden tener equipos semiautomáticos, los mismos que poseen una pequeña pera o bomba externa, manual o eléctrica para insuflar el brazalete y cuyo sistema de adquisición de presiones es electrónico, ya sea utilizando el método auscultatorio o el oscilosmétrico. También los equipos totalmente automáticos, que poseen una pequeña bomba eléctrica interna que insufla el brazalete. Asimismo, entre los totalmente automáticos se tienen los equipos de brazalete para brazo, para la muñeca y para el dedo.

En los últimos 30 años se han desarrollado diversos equipos totalmente automatizados, con microcontroladores o microprocesadores que han permitido un mejor control, disminuyendo progresivamente el peso y permitiendo la conexión a computadoras. Actualmente existen equipos capaces de almacenar gran cantidad de información así como de compensar problemas en la adquisición, tales como interferencias o artefactos, repitiendo la medición, así como también casos como por ejemplo pacientes con el pulso débil o irregular, o en movimiento. (Rithalia, 2000), (Woo, 2004), (AHA, 2005)

Anexo N° 2c

Normas técnicas y estándares internacionales para los equipos de medición de presión arterial utilizando el método no invasivo

En lo que respecta a las normas técnicas que definen la estandarización de estos equipos. A continuación se presenta una lista de las instituciones que desarrollan estas normas, las mismas que permiten el desarrollo continuo y aplicación de nuevas tecnologías:

- American College of Cardiology. Ambulatory blood pressure monitoring [position statement]. *J AmColl Cardiol* 1994 May; 23(6):1511-3.
- American College of Physicians. Automated ambulatory blood pressure and self-measured blood pres-sure monitoring devices: their role in the diagnosis and management of hypertension [guideline]. *Ann Intern Med* 1993 Jun; 118(11):889-92.
- American Heart Association. Human blood pressure determination by sphygmomanometry [recommendation]. *Circulation* 1993 Nov; 88(5):2460-70.
- Association for the Advancement of Medical Instrumentation. AAMI standards and recommended practices: biomedical equipment — volume 2. 4th ed. BEBK4-152-EC. 1993.
- Association for the Advancement of Medical Instrumentation/ American National Standards Institute. Electronic or automated sphygmomanometers [standard]. 2nd ed. SP10-152-EC. 1992.
- Blue Cross and Blue Shield Association. Automated ambulatory blood pressure monitoring [technology assessment report]. 1988. Automated and semi-

automated ambulatory blood pressure monitoring [technology assessment report]. 1986.

- British Hypertension Society. Management guidelines in essential hypertension. *BMJ* 1993 Apr; 306(4):983-7.
- European Committee for Standardization.

  Non-invasive sphygmomanometers

  - Part 1: general requirements [standard]. EN 1060-1:1995. 1995. Noninvasive sphygmomanometers
  - Part 2: supplementary requirements for mechanical sphygmomanometers [draft standard]. Pr EN 1060-2:1995. 1995.
  - Part 3: supplementary requirements for electro-Mechanical blood pressure measuring systems [draft standard]. Pr EN 1060-3:1995. 1995.
- International Electrotechnical Commission.

  Medical electrical equipment

  - Part 1: General requirements for safety [standard]. 2nd ed. 60601-1. 1988.
  - Part 1: General requirements for safety. Amendment 1 [standard]. 2nd ed. 60601-1- am1. 1991.
  - Part 1: General requirements for safety. Amendment 2 [standard].2nd ed. 60601-1- am2. 1995.
  - Part 1: General requirements for safety. Section 2. Collateral standard: electromagnetic compatibility — requirements and tests. 2nd ed. 60601-1-2. 1993.

- Standards Association of Australia. Sphygmomanometers [standard]. AS 3655-1989. 1989.
- Standards Institution of Israel. Sphygmomanometers [standard]. 1460. 1990.
- World Health Organization. Detecting preclampsia: a practical guide: using and maintaining blood pressure equipment. 1930037. 1992.

Esta información es tomada de: “Recorders, Electronic Storage, Data, Blood Pressure”; Healthcare Product Comparison System– HPCS; Emergency Care Research Institute (ECRI, 2002)

HEALTHCARE PRODUCT
hpcs
COMPARISON SYSTEM

February 2002

Recorders, Electronic Storage, Data, Blood Pressure

Scope of this Product Comparison

This Product Comparison covers portable long-term blood pressure recorders that noninvasively measure blood pressure, typically over a 24- to 48-hour period; are battery operated; and can download or print stored recordings. These portable devices are worn continuously during daily routines and use automatic cuff inflation and measurement cycles to record a series of blood pressure measurements for analysis. Excluded are stand-alone, noninvasive, nonambulatory blood pressure monitors; devices that measure other physiologic conditions in addition to blood pressure, with or without automatic measurement cycles; and portable electrocardiogram (ECG) monitors. For more information on these devices, see the following Product Comparisons:

- Physiologic Monitoring Systems, Acute Care; Neonatal; ECG Monitors
- Recorders, Electrocardiography; Scanners, ECG
- Sphygmomanometers, Electronic, Automatic

These devices are also called: Ambulatory blood pressure monitors (ABPMs).

UMDNS information

This Product Comparison covers the following device terms and product codes as listed in ECRI's Universal Medical Device Nomenclature System™ (UMDNS™):

- Recorders, Electronic Storage, Data, Blood Pressure [18-364]
- Recorders, Tape, Data, Blood Pressure [12-386]

Purpose

Arterial blood pressure measurement is an essential indicator of physiologic condition. Blood pressure measurements can provide information on changes in blood volume, the pumping efficiency of the heart, and the resistance of the peripheral vasculature. Patient anxiety can cause elevated blood pressure readings (referred to as "white coat" hypertension) when taken in medical settings such as a physician office.

Using an ABPM, blood pressure readings can be taken away from the medical setting, while the patient is at home, at work, or asleep, and can monitor the effect on blood pressure of daily activities or heightened emotional or physical states.

In diagnostic use, ABPMs evaluate patients with episodic hypertension, monitor patients with transplants, assess responses to drug therapy, distinguish between

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borderline and true hypertension, monitor blood pressure with end-organ changes, and prevent the misclassification of “white coat” hypertension. These recorders can, within a few hours, confirm increased blood pressure measurements or prevent misclassification and can reduce or eliminate costs associated with unnecessary or inappropriate treatments.

Principles of operation

ABPMs consist of a blood pressure cuff and a microprocessing unit that fits into a pouch. The unit can be strapped over the shoulder or attached to a belt around the waist (see Fig. 1). Although some ABPMs can operate for up to 72 hours, most provide 24-hour intermittent monitoring of blood pressure during work, physical activity (e.g., exercise), and rest. The pressure cuff is placed around the upper right or left arm (external site of the brachial artery). Measurements are typically taken four to eight times per hour during the day and two to four times per hour during sleep.

The pumping action of the heart causes blood to flow to the tissues of the body. During the systolic stage, the heart’s left ventricle contracts, and blood is ejected into the aorta. The blood pressure then rises to a peak called the systolic pressure (SP). As the left ventricle relaxes during diastole, the pressure in the aorta and peripheral arteries falls to the diastolic pressure (DP). These pressures are recorded in millimeters of mercury (mm Hg)

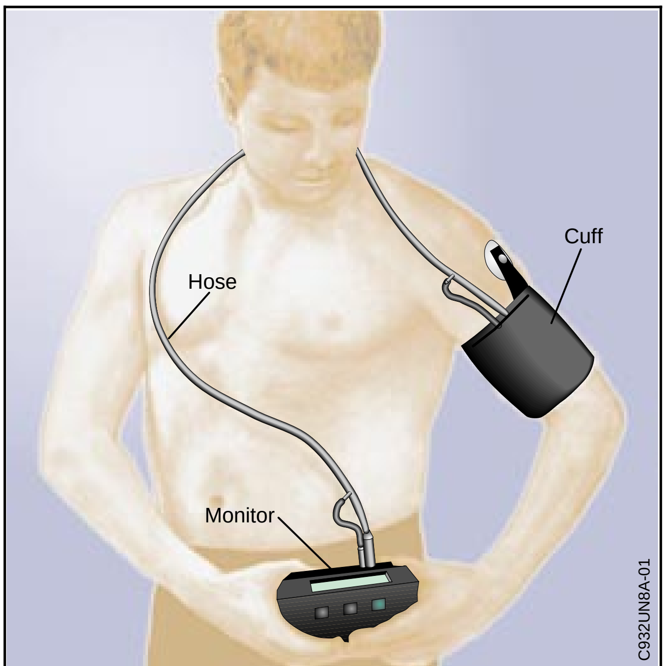

Figure 1. Typical ABPM configuraton demonstrating ABPM in use

and written as SP/DP. The typical pressure difference between the SP and DP is approximately 50 mm Hg; a typical reading is between 110/60 and 140/90 mm Hg.

There are two main methods of determining blood pressures: auscultatory and oscillometric. The auscultatory method, also called the Riva-Rocci/Korotkoff method, relies on detecting Korotkoff sounds, which represent the audible portion of arterial vibrations.

When an inflated air cuff exerts pressure on an artery that is greater than the SP, the artery closes and stops the flow of blood through it. Cuff pressure is gradually lowered, eventually falling below that of the SP, and some blood does force its way through the artery during the brief period that the arterial blood pressure is higher than the cuff pressure; the resulting turbulence produces Korotkoff sounds. These sounds persist until the cuff pressure falls below the DP and the blood flow returns to normal. Thus, the pressure at which Korotkoff sounds first begin marks the SP, while the pressure at which they disappear reflects the DP (see Fig. 2). In an ABPM, a microphone positioned against the compressed artery detects Korotkoff sounds, enabling the recorder to directly determine both systolic and diastolic values. Mean arterial pressure (MAP), the mean value exerted by flowing blood throughout the cardiac cycle, is calculated from these values.

The vibrations are measured in five phases:

- Phase I: The pressure when faint, clear, tapping sounds are heard. As the cuff deflates, the sounds increase in intensity (point at which SP is noted).
- Phase II: Murmurs or swishing sounds are heard during cuff deflation.
- Phase III: Sounds increase in intensity.
- Phase IV: Distinct muffling, like a soft blowing sound, is heard (point at which DP is noted in children and pregnant women).
- Phase V: Pressure at which the last sound is heard and all sound dissipates (point at which DP is noted).

Conversely, in the oscillometric technique of determining blood pressure, when the pressure in the cuff falls, a pressure transducer located in the monitor detects air pressure fluctuations in the cuff (pressure oscillations) instead of Korotkoff sounds. These pressure fluctuations are due to arterial volume changes that occur because of the pulsatile flow of blood. The pressure at which the amplitude of the oscillations peaks corresponds to the MAP. The ABPM uses algorithms to calculate the systolic and diastolic pressures

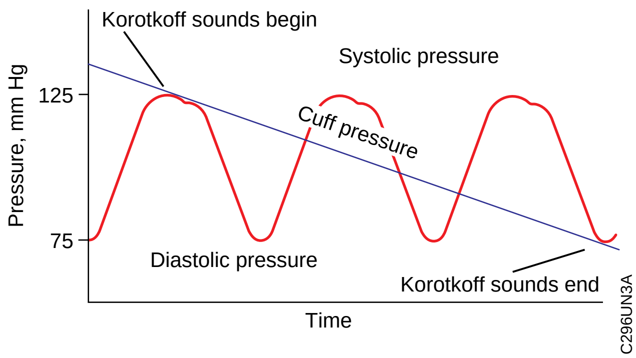

Figure 2. Korotkoff sounds begin when cuff pressure falls below systolic pressure and end when cuff pressure falls below diastolic pressure

from the increasing and decreasing magnitudes of these oscillations.

Full disclosure

Full disclosure (FD) systems continuously store blood pressure measurements for an extended period of time, usually 24 hours. The patient's blood pressure measurements can later be recalled for any segment of this period and can be viewed, analyzed, and printed as necessary. FD allows clinicians to view any previous measurements, rather than only those printed during alarms. Some models highlight inconsistencies so that they can be reviewed. This storage capability may eliminate the need to automatically print every alarm strip; when a hard-copy strip is necessary, it can be obtained from the recorder.

Event markers are used by the patient to identify periods of dizziness or chest pain. The patient presses a button to mark readings on demand in addition to the programmed readings.

Data management

Data management is an important asset when evaluating responses from an ABPM. ABPMs can typically store up to 300 readings that can later be reviewed by a physician or healthcare provider and have either an LCD (liquid crystal display) or an LED (light-emitting diode) for viewing results. Data can be retrieved via an interface (e.g., RS232 port) to a desktop or personal computer in increments or as a whole; selections of readings can also be made available. Measurement results, as well as the mean and standard deviation of the systolic and diastolic pressures, can be displayed graphically on a computer. An ABPM can be connected to a printer so that displayed readings can be directly printed as a hard copy for a patient's files.

Alarm parameters are set by the clinician before each ABPM use. Some suppliers' models offer visual and/or audible alarms and create an event marker if readings exceed set limits; other suppliers' models create an event marker with no visual or audible indicator.

Different-size cuffs are necessary to allow the monitoring of many types of patients, including neonates and the very obese. Cuffs usually come in adult, large adult, neonatal, and pediatric sizes; finger cuffs can also be used for special medical conditions (e.g., emaciation, vasoconstriction).

Reported problems

Some patients initially experience anxiety when using an ABPM, resulting in elevated blood pressure measurements. "Turn-on stress" should therefore be considered when reviewing results; some medical professionals recommend disregarding readings taken in the first hour of use. They also recommend that when reviewing hypertension cases, the monitoring cycle be greater than 24 hours and upgraded ABPM software be used. Mechanical and user errors can contribute to the variable nature of systolic, diastolic, and mean blood pressure values taken from ABPM devices, so considering the average of a few successive readings rather than just a single reading is important. For accurate results, tubing, hoses, cuffs, and batteries should be inspected before and after each use. Erroneous results can be produced if batteries become depleted; some suppliers offer devices that can use rechargeable batteries.

Before use by patients for clinical monitoring, ABPMs should be tested and calibrated — including verifying that the cuff deflates completely, that tubing is not faulty, that inflation systems function properly, that the exhaust valve is opened, and that the displayed pressure returns to zero when the cuff is deflated completely.

A distinct drawback to the ABPM is its inability to effectively monitor patients with certain conditions (e.g., tremors, convulsions, abnormal heart rhythms). Readings from patients with extremely low blood pressure, such as those in shock, are difficult to obtain with auscultatory monitors. Conditions that might preclude use of a device employing a finger cuff include emaciation, hypovolemia, low central venous pressure, low cardiac output, low peripheral temperature, and vasoconstriction.

Only a few instances of problems specific to automatic ABPMs have been reported. In one case, partial obstruction of a cuff vent caused an erroneous zero setting for the pressure transducer and, consequently, lower-than-normal pressure readings were obtained. In another case, a unit's audible alarm volume was set too low to be heard; when the unit was unable to detect a signal, it continued to display the last good reading.

Other problems associated with ABPMs, such as ulnar nerve palsy and venous hemostasis, depend on factors such as cuff placement and fit, pressure, and duration of inflation. (It has been suggested that to minimize venous occlusion and keep pressure from damaging the ulnar nerve, users place the cuff as high as possible on the arm.) If possible, the cuff should be placed on a limb that is at heart level to avoid the need to correct for differences in hydrostatic pressure. Excessive patient movement, external vibrations, extreme noise, improper cuff size, or improper placement (e.g., placing the cuff over clothing) can produce artifacts that result in inaccurate readings. The cuff can also deflate too quickly, causing erroneous results (e.g., low systolic, high diastolic), or inflate to high pressures, causing pain; in addition, sleep disturbances caused by cuff discomfort can occur.

Thrombophlebitis — inflammation of a vein associated with thrombus formation — can result when the cuff inflates more frequently than programmed. The use of ABPMs is not recommended for diabetic patients because of the risk of swelling and arrhythmias.

Both invasive and noninvasive methods have certain limitations that should be considered when measuring blood pressure. Studies have shown that automatic electronic blood pressure monitors may give readings that are substantially different from those taken by a direct arterial catheter. However, direct arterial measurements do not necessarily represent the true arterial pressure, although many clinicians use them as a standard reference.

Purchase considerations

ABPMs range in price from $2,400 to $4,500. More expensive models usually have additional software capabilities (e.g., spreadsheets) or come equipped with a printer. The degree of sophistication chosen often depends on a hospital's utilization requirements and the type of monitor it currently uses.

Suppliers frequently offer accessories such as pressure cuffs of assorted sizes, tubes, hoses, pumps, and batteries. The value of this equipment, along with that of the warranty and the possible discount, should be assessed before making a purchase. When purchasing an ABPM, hospitals should review the capacity for data storage, retrieval, and computer interfacing. The ability of the recorder to store and retrieve readings is important for gathering large quantities of information. Users should also consider the cost of disposable/reusable batteries, the charging time, and the operating time. At an additional cost, software can be provided that takes stored readings and correlates them into a graph (e.g., bar, pie).

There are two recognized standards for testing ambulatory blood pressure equipment: the Association for the Advancement of Medical Instrumentation (AAMI) protocol and the British Hypertension Society protocol. The validation procedure for approval of ambulatory blood pressure monitoring devices by the U.S. Food and Drug Administration requires that the units be tested according to the current 1992 voluntary recommendations of AAMI. When purchasing an ABPM, users need to consider which AAMI protocol (1987 or 1992) was used, which version or model of the device was tested, whether the validation procedure tested all components of the AAMI recommendations, and whether there have been any hardware or software changes since the validation. The revised 1992 AAMI validation standard provides the procedures to test ambulatory blood pressure equipment for conformance with certain safety requirements and performance standards related to temperature, humidity, vibration or shock, and altitude.

Cost containment

When purchasing an ABPM, a hospital should consider the cost of a service contract, equipment upgrades, or a rental/leasing agreement. Discounts may be available if the hospital purchases more than one ABPM. The hospital should evaluate the supplier's service (which should include 24-hour hotline access), inquire about the terms of the warranty (e.g., some may not include preventive maintenance visits), and find out what service contracts are available, what they include, and what discounts are available if the contracts are purchased at the same time as the device. The hospital should also retain the option to accept or reject a service contract at the end of the warranty period.

A hospital should request an unedited list of device users from the manufacturer to help assess the reliability of the device and the company's service record. Suppliers may also allow a hospital to use a device for a trial period before an actual purchase is made.

Insurance reimbursement status should also be considered at the time of ABPM purchase. The U.S. insurance industry currently requires further instrumentation and technology studies and more evidence on the usefulness of data obtained from ABPMs before reimbursement is allocated.

Treatment of hypertension costs from $500 to $1,000 per case for a patient taking medications. To reduce this cost, physicians are using ABPMs to verify a primary diagnosis. The cost-effectiveness of an ABPM depends on the pattern of use and the charges associated for each use based on the capital purchasing cost. Tests using ABPMs range in cost from $100 to $450 per test. A test's resource cost, which includes the capital and operating costs, is approximately $120, based on the following assumptions:

- Purchase of two $5,000 monitors
- Purchase of one $500 printer
- Purchase of $500 annual maintenance contract/ monitor
- Cost of $15,000 for a half-time technician
- Throughput of 300 tests/year
- Physician interpretation fee of $30/test
- Institutional overhead of 40%

The resource cost is sensitive to the number of procedures, the technician's salary, and the institutional overhead rate.

ABPMs can save time, space, and labor costs. They are relatively easy to use and allow for longer testing times than conventional noninvasive blood pressure monitors do. Although they have a high initial purchase cost, they reduce the necessity for inpatient testing.

Stage of development

Although clinicians have been listening for peripheral blood flow since Nicolai Korotkoff correlated the sound to systolic and diastolic pressures in 1905, ambulatory electronic blood pressure monitors were not highly developed until microprocessor-based equipment became available. ABPMs are becoming more accepted, in part because they eliminate some of the risks associated with invasive methods and require no hospital stay and minimal user training.

In addition to changes in equipment, changes in the site of cuff placement are being investigated. Using the oscillometric method, blood pressure monitoring can now be done at the wrist using the radial artery. This site was chosen for its ease of access and convenience. However, studies are still being conducted to review the accuracy and precision of this method.

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Standards and guidelines

Note: *Although every effort is made to ensure that the following list is comprehensive, please note that other applicable standards may exist.*

American College of Cardiology. Ambulatory blood pressure monitoring [position statement]. *J Am Coll Cardiol* 1994 May;23(6):1511-3.

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World Health Organization. Detecting pre-eclampsia: a practical guide: using and maintaining blood pressure equipment. 1930037. 1992.

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About the chart specifications

The following terms are used in the chart:

Measurement method: ABPMs use two main methods to determine the systolic, diastolic, and MAP pressures: auscultatory and oscillometric. The auscultatory method is based on Korotkoff sounds; the oscillometric method is based on pressure oscillations.

Full disclosure: FD allows clinicians to view any previous measurements made during an extended period, rather than only those printed during alarms. Blood pressure measurements can be recalled later for any segment of this period and can be viewed, analyzed, and printed as necessary.

Event marker: Event markers are used by the patient to identify periods of dizziness or chest pain; a button is pressed to mark readings on demand in addition to the programmed readings.

List price: Some of the pricing information in this chart has been derived from list prices reported to ECRI's in-house information services by healthcare institutions and by suppliers. A footnote identifies these prices. In these instances, suppliers have declined to provide *HPCS* directly with prices and may not have confirmed the information. These prices are estimates and may or may not reflect discounts, options, special packages, and multiple-unit sales. They are provided for the convenience of our readers.

Abbreviations:

AAMI — Association for the Advancement of Medical Instrumentation

A/D — Analog to digital (converter)

ARO — After receipt of order

BHS — British Hypertension Society

BP — Blood pressure

bpm — Beats per minute

CE mark — Conformite Europeene mark

FDA — U.S. Food and Drug Administration

HD — Hard drive

LCD — Liquid crystal display

MAP — Mean arterial pressure

MB — Megabyte

MDD — Medical Devices Directive

mm Hg — Millimeters of mercury

Ni-Cd — Nickel-cadmium

Ni-MH — Nickel-metal hydride

PC — Personal computer

RS232 — Recommended Standard 232; transmission standard recommended by the Electronic Industries Association

SW — Software

UL — Underwriters Laboratories

Note: The data in the charts derive from suppliers' specifications and have not been verified through independent testing by ECRI or any other agency. Because test methods vary, different products' specifications are not always comparable. Moreover, products and specifications are subject to frequent changes. ECRI is not responsible for the quality or validity of the information presented or for any adverse consequences of acting on such information.

When reading the charts, keep in mind that, unless otherwise noted, the list price does not reflect supplier discounts. And although we try to indicate which features and characteristics are standard and which are not, some may be optional, at additional cost.

For those models whose prices were supplied to us in currencies other than U.S. dollars, we have also listed the conversion to U.S. dollars *to facilitate comparison among models.* However, keep in mind that exchange rates change often.

Need to know more?

For further information about the contents of this Product Comparison, contact the *HPCS* Hotline at +1 (610) 825-6000, ext. 5265; +1 (610) 834-1275 (fax); or hpcs@ecri.org (e-mail).

Product Comparison Chart

MODEL	BMS GH 9232	BMS GH 9241	CUSTO MED FAILED TO RESPOND * Custo Screen	DEL MAR MEDICAL Pressurometer Model P6
WHERE MARKETED	Worldwide	Worldwide	Worldwide	Worldwide
FDA CLEARANCE	Yes	Yes	Not specified	Yes
CE MARK (MDD)	Yes	Yes	Yes	Yes
MEASUREMENT METHOD	Oscillometric	Oscillometric	Yes	Oscillometric
BLOOD PRESSURE				
Systolic range, mm Hg	50-280	50-280	70-290	60-250
Diastolic range, mm Hg	30-180	30-180	40-150	30-195
Accuracy, %	3 mm Hg	3 mm Hg	2, ±1 mm Hg	2
PULSE RATE RANGE, bpm	40-150, ±1	40-150, ±5	40-180	20-240
MEASUREMENT				
Frequency	1 min to 72 hr	5 min to 4 hr	5-90 min	2 min to 24 hr
Duration	Up to 72 hr	Up to 72 hr	Up to 72 hr	Any
INFLATION				
Method	Internal quiet pump	Internal quiet pump	Internal quiet pump	Internal battery-operated rolling pump
Pressure, mm Hg	Selectable	Selectable	300 (maximum)	6 above last valid systolic pressure
DEFLATION	Auto exhaust system	Auto exhaust system	Not specified	Step down, double pulse
ALARM TYPE	Audible	Audible	Audible, visual	Internal buzzer, LCD
ALARM LIMITS				
Heart rate, bpm				
High	None	None	100-220 (increments of 5)	Not specified **
Low	None	None	35-70 (increments of 5)	Not specified **
Pressure, mm Hg				
High	None	None	70-270 (increments of 5)	Not specified **
Low	None	None	40-155 (increments of 5)	Not specified **
CUFF SIZE	Large, medium, small	Large, medium, small	Adult, large adult, neonatal, pediatric	Adult, large adult, pediatric
FULL DISCLOSURE	No	No	Yes	Yes
AUTOZERO	No	No	Yes	Yes
EVENT MARKER	Yes	Yes	Yes	Yes
DISPLAY	LCD	LCD	LCD	LCD

Colons separate data on similar models of a device.
* Specifications current as of October 1998.
** No alarms during recording.

This is the first of two pages covering the above model(s). These specifications continue onto the next page.

Product Comparison Chart

MODEL	BMS GH 9232	BMS GH 9241	CUSTO MED FAILED TO RESPOND * Custo Screen	DEL MAR MEDICAL Pressurometer Model P6
DATA MANAGEMENT				
Storage	255 readings	255 readings	Not specified	300 readings
Retrieval	Computer interface	A/D interface	Not specified	Transfer all readings to patient's files
Computer interface	RS232	A/D interface	Intranet (IrDa 1.0)	RS232 serial interface with cable
PC REQUIREMENTS	IBM compatible	IBM compatible	80486 or larger	IBM PC
Software	Included	Included	DOS 6.0 or larger	Not specified
Type	Windows software	Windows software	Not specified	DOS, Windows 95/98
Memory, MB	Not specified	Not specified	4 main memory, HD	8
H x W x D, cm (in)	3.9 x 11 x 13.5 (1.5 x 4.3 x 5.3)	3.9 x 11 x 13.5 (1.5 x 4.3 x 5.3)	9.6 x 6.2 x 2.4 (3.8 x 2.4 x 0.9)	12.8 x 7.8 x 2.7 (5 x 3.1 x 1.1)
WEIGHT, g (oz)	423 (14.9)	457 (16.1)	190 (6.7)	252 (8.9)
BATTERY				
Type	4 AA x 1.5 V	4 AA x 1.5 V	3 AAA, 3 Ni-Cd	2 AA
Operating time, hr	72	72	72	24 (minimum)
Rechargeable	Yes	Yes	Yes (only Ni-Cd)	Yes
Recharging time, hr	6	6	Not specified	See footnote **
PURCHASE INFORMATION				
List price	$2,995	$2,995	$1,577	$2,950 ***
Warranty	1 year	1 year	1 year	1 year
Delivery time, ARO	2 weeks	2 weeks	2-3 weeks	30 days
Service contract	Not specified	Not specified	Not specified	Yes
Year first sold	1993	1991	1992	1997
Number sold				
USA	Not specified	Not specified	Not specified	Not specified
Worldwide	Not specified	Not specified	6,700	Not specified
Fiscal year	January to December	January to December	July to June	January to December
OTHER SPECIFICATIONS	7 intervals of measurements available.	Statistics program.	Automatic calibration before each measurement.	DOS and Windows 95 designed to allow data entry, recorder setup, data transfer, data review and analysis/printing, and export file generation.

Colons separate data on similar models of a device.
* Specifications current as of October 1998.
** Depends on rechargeable batteries and charger used.
*** Price derived from ECRI in-house resources; not verified by supplier. See “About the Chart Specifications” for details.

Product Comparison Chart

MODEL	H & C MEDICAL Cardiette bp one	IEM FAILED TO RESPOND * Mobile-O-Graph	KOVEN TECHNOLOGY NISSEI DS-250 ABPM	MEDITECH ABPM 04
WHERE MARKETED	Worldwide	Worldwide	Worldwide	Worldwide
FDA CLEARANCE	Not specified	Yes	Yes	Submitted
CE MARK (MDD)	Yes	Yes	Yes	Yes
MEASUREMENT METHOD	Oscillometric	Oscillometric	Auscultatory, oscillometric, or both	Oscillometric
BLOOD PRESSURE				
Systolic range, mm Hg	70-280	60-290	50-260	30-260
Diastolic range, mm Hg	30-150	30-195	30-200	Not specified
Accuracy, %	Not specified	2	3 mm Hg	2, ±3 mm Hg
PULSE RATE RANGE, bpm	30-220	20-240	30-199	40-200
MEASUREMENT				
Frequency	5, 10, 15, 20, 30, 45, 60 min	2 min to 24 hr	See footnote **	1-90 min
Duration	300 measurements	Any	48 hr maximum	1 min to 51 hr
INFLATION				
Method	Not specified	Internal membrane pump with noise control	Internal quiet pump	Automatically controlled pump
Pressure, mm Hg	160	Automatic (auto feedback logic)	Selectable; preset at 80, 240, or 260	Max 220, 240, 260, 280, 300
DEFLATION	Not specified	Step-down, double-pulse system	3 mm Hg/sec	Automatic pressure-release valve, safety release for power failure
ALARM TYPE	Acoustic	Audible, visual	None	None
ALARM LIMITS				
Heart rate, bpm				
High	Not specified	Not specified	NA	NA
Low	Not specified	Not specified	NA	NA
Pressure, mm Hg				
High	Not specified	Not specified	NA	NA
Low	Not specified	Not specified	NA	NA
CUFF SIZE	3 available	Adult, large adult, small adult/child	Adult, large adult, small adult	Adult, large, pediatric
FULL DISCLOSURE	Yes	Yes	Yes	No
AUTOZERO	Yes	Yes	Yes	Yes
EVENT MARKER	Yes	Yes	Yes	Yes
DISPLAY	LCD	LCD	LCD	LCD

Colons separate data on similar models of a device.
* Specifications current as of May 2000.
** 12 hr mode: 3, 5, 10, 15, 20, 30, 60 min intervals with 3 divisions; 24 hr mode: 15, 20, 30, 60 min intervals with 6 divisions; 48 hr mode: 15, 20, 30, 60 min intervals with 6 divisions.

This is the first of two pages covering the above model(s). These specifications continue onto the next page.

Product Comparison Chart

MODEL	H & C MEDICAL Cardiette bp one	IEM FAILED TO RESPOND * Mobile-O-Graph	KOVEN TECHNOLOGY NISSEI DS-250 ABPM	MEDITECH ABPM 04
DATA MANAGEMENT				
Storage	300 readings	300 readings	User configured	600 readings
Retrieval	Computer interface, printer	Computer interface, recall of stored readings, error codes and events	Not specified	Optoelectronic cable
Computer interface	RS232	RS232	RS232/IR	9-pin Canon, RS232
PC REQUIREMENTS	Not specified	IBM compatible	IBM compatible	IBM compatible
Software	Included	Optional	Included	Included
Type	Proprietary	Windows or DOS	Windows 95 or 98, need minimum capability of Windows 95	Diagram, spreadsheet, statistic
Memory, MB	Not specified	8	≥16	8; 16 recommended
H x W x D, cm (in)	12.4 x 9 x 2.6 (4.9 x 3.5 x 1)	2.7 x 7.8 x 12.8 (1.1 x 3.1 x 5)	11.5 x 7.3 x 3.1 (4.5 x 2.9 x 1.2)	12.4 x 8.2 x 3.4 (4.9 x 3.2 x 1.3)
WEIGHT, g (oz)	275 (9.7)	250 (8.8) with batteries	183 (6.5) without batteries	350 (12.3)
BATTERY				
Type	Disposable/recharge	2 AA	4 AA alkaline **	4 AA
Operating time, hr	48	Up to 48	48	24
Rechargeable	Yes	Yes	No	Yes
Recharging time, hr	14	5	NA	19
PURCHASE INFORMATION				
List price	Not specified	Not specified	$1,850 ***	$2,100
Warranty	1 year	2 years, Germany; 1 year, other	1 year	2 years, unit; 1 year, accessories
Delivery time, ARO	20 days	Stock to 6 weeks	2 weeks	~2 weeks
Service contract	Not specified	No	Not specified	None
Year first sold	1998	1994	Not specified	1990 (w/ABPM 01)
Number sold				
USA	Not specified	Not specified	Not specified	Not specified
Worldwide	Not specified	20,000	Not specified	3,500
Fiscal year	Not specified	October to September	September to August	January to December
OTHER SPECIFICATIONS	None specified.	Day/night button; auto feedback logic; event button; cables; floppy.	None specified.	None specified.

Colons separate data on similar models of a device.
* Specifications current as of May 2000.
** Includes internal vanadium lithium backup.
*** Price derived from ECRI in-house resources; not verified by supplier. See “About the Chart Specifications” for details.

Product Comparison Chart

MODEL	MEDSET SCANLIGHT II ABPM	PROGETTI PG MAP ABPM	PROGETTI PX MAP ABPM	PULSE METRIC DYNAPULSE 5000A ABPM
WHERE MARKETED	Worldwide	Worldwide	Worldwide	Worldwide
FDA CLEARANCE	Submitted	No	No	Yes
CE MARK (MDD)	Yes	Yes	Yes	Yes
MEASUREMENT METHOD	Oscillometric	Oscillometric	Oscillometric	Oscillometric
BLOOD PRESSURE				
Systolic range, mm Hg	60-290	50-250	50-250	60-240
Diastolic range, mm Hg	30-195	40-150	40-150	30-200
Accuracy, %	3 mm Hg	3	2	5 mm Hg
PULSE RATE RANGE, bpm	20-240	40-150	40-150, ±5	20-200
MEASUREMENT				
Frequency	0, 1, 2, 4, 6, or 30 per hr	5 min to 2 hr	5 min to 2 hr	5 min to 2 hr
Duration	15 sec	Up to 250 readings	Up to 250 readings	24 hr
INFLATION				
Method	Internal quiet pump	Internal quiet pump	Internal quiet pump	Micro rolling pump
Pressure, mm Hg	Individual adaptation to BP (300 max)	Automatic	Automatic	Selectable 120-240
DEFLATION	Exhaust system, solenoid valve	Exhaust system controlled	Exhaust system, solenoid valve	Automatic
ALARM TYPE	Audible, visual	Not specified	Not specified	None
ALARM LIMITS				
Heart rate, bpm				
High	None	Selectable	Selectable	NA
Low	None	Selectable	Selectable	NA
Pressure, mm Hg				
High	315	Selectable	Selectable	NA
Low	305	Selectable	Selectable	NA
CUFF SIZE	Small, medium, large	Adult, pediatric, large adult (XXL)	Adult, large adult, neonatal, pediatric	Large, medium, small
FULL DISCLOSURE	Yes	Yes	Yes	Yes
AUTOZERO	Yes	Yes	Yes	Yes
EVENT MARKER	Yes	Yes	Yes	No
DISPLAY	LCD	LCD	LCD	LCD

Colons separate data on similar models of a device.

This is the first of two pages covering the above model(s). These specifications continue onto the next page.

Product Comparison Chart

MODEL	MEDSET SCANLIGHT II ABPM	PROGETTI PG MAP ABPM	PROGETTI PX MAP ABPM	PULSE METRIC DYNAPULSE 5000A ABPM
DATA MANAGEMENT				
Storage	300 readings	>250 readings	250 readings	100 readings or 24 hr
Retrieval	Printer or software	Yes	Yes	All readings
Computer interface	Printer or serial interface, RS232	RS232	RS232	RS232
PC REQUIREMENTS	IBM compatible	Pentium	Pentium	IBM
Software	Optional	Windows 98	Windows 98	Included
Type	SCANLIGHT PADSY	Windows applications	Windows applications	Proprietary
Memory, MB	64	64	64	2
H x W x D, cm (in)	13 x 8 x 2.8 (5.1 x 3.1 x 1.1)	12 x 7 x 3 (4.7 x 2.8 x 1.2)	15 x 8 x 4.5 (5.9 x 3.1 x 1.8)	13 x 8 x 4 (5.1 x 3.1 x 1.6)
WEIGHT, g (oz)	220 (7.8) without batteries	280 (9.9)	350 (12.3)	369 (13) with batteries
BATTERY				
Type	2 AA Ni-Cd/Ni-MH/alk	2 AA	4 AA	4 AA
Operating time, hr	24	52	48	24
Rechargeable	Yes	Optional	No	No
Recharging time, hr	2	3	NA	NA
PURCHASE INFORMATION				
List price	E1,531 (US$1,368)	Not specified	Not specified	$1,800
Warranty	1 year	1 year	1 year	1 year
Delivery time, ARO	2 weeks	1 week	1 week	1 week
Service contract	Available	None	None	$250
Year first sold	1996	2001	1997	Not specified
Number sold				
USA	Not specified	Not specified	Not specified	Not specified
Worldwide	990	120	450	Not specified
Fiscal year	January to December	January to December	January to December	Not specified
OTHER SPECIFICATIONS	Day/night key; printer or network-compatible software solution SCANLIGHT PADSY for evaluation of recorded values.	PG Win Pro PC interface enables monitoring plan creation with up to 3 time periods; full disclosure of BP readings, heart rate, MAP, BP load, and trend of BP versus time.	Windows SW operating package; compares last and actual exam.	Can transmit AP waveforms recorded w/each BP measurement to DynaPulse Analysis Center Web site; within 1 min of data upload waveform analysis algorithms calculate 17 hemodynamic values. UL listed. *

Colons separate data on similar models of a device.

* Values calculated include cardiac output, arterial compliance, and systemic vascular resistance.

Product Comparison Chart

MODEL	ROZINN ELECTRONICS	SAVE 33	SCHILLER	SPACELABS
	RZ250 Ambulatory BP Recorder *	MAPA 33	BR-102	90207 : 90217
WHERE MARKETED	Worldwide	Worldwide	Worldwide, except USA	Worldwide
FDA CLEARANCE	Yes	No	No	Yes
CE MARK (MDD)	Yes	Yes	Yes	Yes
MEASUREMENT METHOD	Oscillometric	Oscillometric	Auscultatory (Korotkoff), oscillometric	Oscillometric
BLOOD PRESSURE				
Systolic range, mm Hg	60-290	40-280	15-300	60-260
Diastolic range, mm Hg	30-195	30-160	15-300	30-200
Accuracy, %	3 mm Hg	1.5	2 mm Hg	5 mm Hg
PULSE RATE RANGE, bpm	20-240	40-150, ±5	20-240, ±2	40-180
MEASUREMENT				
Frequency	0-6, 12, 15, 20, 30 per hr and on demand	6 programmable intervals	10 min to 4 hr	Programmable from 6 to 120 min
Duration	Typically 24 hr	Up to 48 hr	5 days	240 readings
INFLATION				
Method	Quiet internal pump	Micro pump	Internal pump	Internal pump
Pressure, mm Hg	300	Automatic	Measured with inflation + 50 max	285, max : 300, max
DEFLATION	Automatic valve	Solenoid valve	Rotary-angle valve, 2-9 mm Hg/sec	Exhaust system
ALARM TYPE	None	None	Audible, visual	None
ALARM LIMITS				
Heart rate, bpm				
High	NA	NA	30-240	Not specified
Low	NA	NA	30-240	Not specified
Pressure, mm Hg				
High	NA	NA	15-300	Not specified
Low	NA	NA	15-300	Not specified
CUFF SIZE	Pediatric, adult, large adult	Adult, large adult, child	Large, medium, small	Different sizes available from pediatric to adult
FULL DISCLOSURE	Yes	Yes	Numeric/graphical	Yes
AUTOZERO	Yes	Yes	Yes	Yes
EVENT MARKER	Yes	Yes	Yes	Yes
DISPLAY	LCD	LCD	LCD	LCD

Colons separate data on similar models of a device.
* RZ2020 (processor/printer) is required for a complete system; one processor/printer can service multiple recorders.

This is the first of two pages covering the above model(s). These specifications continue onto the next page.

Product Comparison Chart

MODEL	ROZINN ELECTRONICS	SAVE 33	SCHILLER	SPACELABS
	RZ250 Ambulatory BP Recorder *	MAPA 33	BR-102	90207 : 90217
DATA MANAGEMENT				
Storage	300 readings per test	225 readings	200 readings	240 readings
Retrieval	Computer interface, recall of last 300 readings	Computer interface, Epson printer interface	Computer interface	Computer interface, printer
Computer interface	RS232	RS232	RS232	Not specified
PC REQUIREMENTS	IBM compatible	IBM	Pentium	IBM compatible
Software	ABP for Windows	Optional	Optional	Optional
Type	Windows	Windows 3.1, Windows 95/98/2000/ ME	Windows 95/98/NT 4.0 data management	Report generation, base station
Memory, MB	16 (minimum)	Not specified	10	20
H x W x D, cm (in)	12.8 x 7.8 x 2.7 (5 x 3.1 x 1.1)	12 x 8.5 x 3 (4.7 x 3.3 x 1.2)	12 x 7.1 x 2.1 (4.7 x 2.8 x 0.8)	2.8 x 11.4 x 8.6 (1.1 x 4.5 x 3.4) : 2.5 x 10 x 7 (1 x 3.9 x 2.8)
WEIGHT, g (oz)	250 (8.8) with batteries	290 (10.2)	310 (10.9)	347 (12.2) : 190 (6.7)
BATTERY				
Type	2 AA alkaline dispos	4 AA Ni-MH/alkaline	Ni-Cd	AA Ni-Cd/alkaline
Operating time, hr	24	48	~250 readings	192
Rechargeable	2 AA Ni-MH	Yes	Yes	No
Recharging time, hr	14-16	6	2	NA
PURCHASE INFORMATION				
List price	$2,495	$2,400	Not specified	$2,625 **
Warranty	1 year	1 year	1 year	1 year
Delivery time, ARO	1 week	1 week	2 weeks	60 days
Service contract	$250 per year	Exchange warranty	Not specified	Yes
Year first sold	1999	1995	1993	1989
Number sold				
USA	Not specified	Not specified	NA	Not specified
Worldwide	150	1,800	5,000	Not specified
Fiscal year	October to September	January to December	January to December	January to December
OTHER SPECIFICATIONS	Day and night pre-programmed groups of measurement intervals.	Measurement of patient activity and detection of sitting down, standing up, and lying down; programmable with integrated keyboard.	Includes interface cable.	Meets requirements of AAMI and EN.

Colons separate data on similar models of a device.
* RZ2020 (processor/printer) is required for a complete system; one processor/printer can service multiple recorders.
** Price derived from ECRI in-house resources; not verified by supplier. See "About the Chart Specifications" for details.

Product Comparison Chart

MODEL	SUNTECH Accutracker II	SUNTECH Accutracker Dx	SUNTECH Oscar 2	WELCH ALLYN Quiet Trak ABPM
WHERE MARKETED	Worldwide	Worldwide	Worldwide	Worldwide
FDA CLEARANCE	Yes	Yes	Yes	Yes
CE MARK (MDD)	Yes	Yes	Yes	Yes
MEASUREMENT METHOD	Auscultatory	Auscultatory	Oscillometric with step deflation	Auscultatory (diastolic based on 5th Korotkoff sound)
BLOOD PRESSURE				
Systolic range, mm Hg	10-250	10-250	25-260	60-250
Diastolic range, mm Hg	10-250	10-250	25-260	30-160
Accuracy, %	Not specified	Not specified	Not specified	See Other Specifications
PULSE RATE RANGE, bpm	10-200	10-200	40-200	40-160
MEASUREMENT				
Frequency	Programmable from 5 to 120 min	Programmable from 5 to 120 min	Programmable from 5 to 120 min	Selectable from 5 to 120 min with up to 4 time periods
Duration	Up to 250 readings	Up to 250 readings	Up to 250 readings	Not specified
INFLATION				
Method	Internal quiet pump	Internal quiet pump	Internal quiet pump	Internal quiet pump
Pressure, mm Hg	30 over previous systolic	30 over previous systolic	30 over previous systolic	Selectable 160-270 (increments of 10)
DEFLATION	User selectable, 2, 3, 4, 5, 6 mm Hg/sec	User selectable, 2, 3, 4, 5, 6 mm Hg/sec	User selectable, 2, 3, 4, 5, 6 mm Hg/sec	Continuous silent linear deflation
ALARM TYPE	Visual	Visual	Visual	None
ALARM LIMITS				
Heart rate, bpm				
High	None	None	None	NA
Low	None	None	None	NA
Pressure, mm Hg				
High	None	None	None	NA
Low	None	None	None	NA
CUFF SIZE	Large adult, medium, small	Large adult, medium, small	Large adult, medium, small	Large adult, adult, pediatric
FULL DISCLOSURE	Yes	Yes	Yes	No
AUTOZERO	Yes	Yes	Yes	Yes
EVENT MARKER	Yes	Yes	Yes	Yes
DISPLAY	LCD	LCD	LCD	LCD

Colons separate data on similar models of a device.

This is the first of two pages covering the above model(s). These specifications continue onto the next page.

Product Comparison Chart

MODEL	SUNTECH Accutracker II	SUNTECH Accutracker Dx	SUNTECH Oscar 2	WELCH ALLYN Quiet Trak ABPM
DATA MANAGEMENT				
Storage	254 readings	254 readings	254 readings	300 readings
Retrieval	Computer interface	Computer interface	Computer interface	Computer interface or printer interface
Computer interface	RS232	RS232	RS232	Serial interface
PC REQUIREMENTS	Any PC	Any PC	Any PC	IBM compatible
Software	AccuWin Pro	AccuWin Pro	AccuWin Pro	Optional
Type	Windows 95 or higher	Windows 95 or higher	Windows 95 or higher	Not specified
Memory, MB	56	56	56	4
H x W x D, cm (in)	12.7 x 8.4 x 3.3 (5 x 3.3 x 1.3)	12.7 x 8.4 x 3.3 (5 x 3.3 x 1.3)	11.9 x 7.9 x 3.3 (4.7 x 3.1 x 1.3)	11.4 x 8.6 x 4.1 (4.5 x 3.4 x 1.6)
WEIGHT, g (oz)	357 (12.6)	357 (12.6)	350 (12.3)	355 (12.5) with batteries
BATTERY				
Type	4 AA	4 AA	2 AA	4 AAA
Operating time, hr	Not specified	Not specified	Not specified	24
Rechargeable	No	No	Yes	Optional Ni-Cd
Recharging time, hr	NA	NA	NA	Not specified
PURCHASE INFORMATION				
List price	$3,500	$2,500	$1,995	$2,035
Warranty	1 year	1 year	1 year	2 years
Delivery time, ARO	2 weeks	2 weeks	2 weeks	2 weeks
Service contract	Yes	Yes	Yes	Not specified
Year first sold	1989	1993	2000	1993
Number sold				
USA	Not specified	Not specified	Not specified	Not specified
Worldwide	Not specified	Not specified	Not specified	Not specified
Fiscal year	Not specified	Not specified	Not specified	January to December
OTHER SPECIFICATIONS	None specified.	None specified.	None specified.	Meets requirements of 1987 AAMI standards and BHS rating for “A” systolic and “A” diastolic.

Colons separate data on similar models of a device.

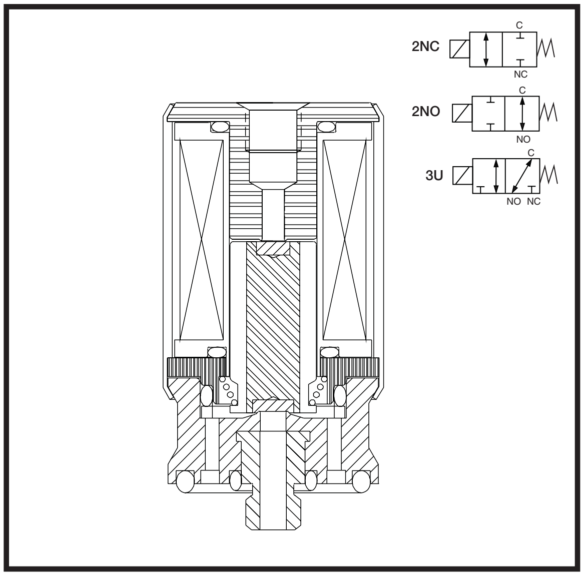
ASCO SCIENTIFIC®

The Series AM Valves are suitable for a wide range of OEM applications where small size , low power and long life are a must.

- Cycle life in the hundreds of millions.
- Corrosion resistant materials of construction.
- Manifold mount construction allows for easy assembly.
- Magnetic latching construction available to maintain valve position with loss of power, eliminate coil heat rise and extend battery life.

Construction

Valve Parts in Contact with Fluids	
Body	POM/300 Series Stainless Steel or all 300 Series Stainless Steel
Disc	FKM
Gaskets	FKM
Bobbin/CoreTube	PBT
Core and Plugnut	400 Series Stainless Steel
Springs	300 Series Stainless Steel



Electrical

Standard Voltages	6, 12, 24 VDC+ 10%, -5% 115 VAC (with rectifier in lead wires)
Power Consumption	0.65-2.0 Watts (10 watts for latching version)
Duty Cycle Rating	Continuous (Intermittent for latching version)
Coil Insulation	266˚F (130˚C)
Electrical Connection	26 gage lead wire

Valve

Response time	~5 ms at rated voltage (2 watt coil) ~12 ms at rated voltage (0.65 watt coil)
Internal Volume	2-Way NC = 360 µL, 2-Way NO = 400 µL, 3-Way = 400 µL
Options	• Oxygen service construction available • Lubricant free construction available
Vacuum Rating	29" Hg

Alternative Constructions

Many alternative constructions are available and include a variety of voltages, electrical connectors and materials of construction. ASCO Scientific can also custom design a valve for your specific application.

Contact your local ASCO sales office for more information.

Temperature Range:

Ambient & Media:

32˚F to 77˚F (0˚C to 25˚C) continuous duty
up to 104˚F (40˚C) intermittent duty

Approvals:

Meets applicable CE directives.

ASCO SCIENTIFIC®

Specificatons

Mounting Stud	Orifice Size (ins.)	Cv Flow Factor	Maximum Pressure (psi)	Catalog Number	Watt Rating @ 20˚C	Weight (oz.)
2-WAY NORMALLY CLOSED (Closed when de-energized)						
#10-32 UNF	0.025	0.015	110	AM11xx	0.65	1.3
#10-32 UNF	0.055	0.038	50	AM21xx	0.65	1.3
#10-32 UNF	0.055	0.038	100	AM31xx	2.0	1.3
#10-32 UNF	0.090	0.07	30	AM41xx	2.0	1.3
2-WAY NORMALLY OPEN (Open when de-energized)						
#10-32 UNF	0.025	0.013	110	AM12xx	0.65	1.3
#10-32 UNF	0.048	0.033	50	AM22xx	0.65	1.3
#10-32 UNF	0.048	0.033	100	AM32xx	2.0	1.3
#10-32 UNF	0.078	0.06	30	AM42xx	2.0	1.3
3-WAY UNIVERSAL OPERATION (Pressure at any port)						
#10-32 UNF	0.025/0.025	0.015/0.013	110	AM13xx	0.65	1.3
#10-32 UNF	0.055/0.048	0.038/0.033	50	AM23xx	0.65	1.3
#10-32 UNF	0.055/0.048	0.038/0.033	100	AM33xx	2.0	1.3
#10-32 UNF	0.090/0.078	0.07/0.06	30	AM43xx	2.0	1.3
2-WAY LATCHING						
#10-32 UNF	0.025	0.015	110	AM11xxL	10*	1.8
#10-32 UNF	0.055	0.038	100	AM31xxL	10*	1.8
#10-32 UNF	0.090	0.07	30	AM41xxL	10*	1.8
3-WAY LATCHING						
#10-32 UNF	0.025/0.025	0.015/0.013	110	AM13xxL	10*	1.8
#10-32 UNF	0.055/0.048	0.038/0.033	100	AM33xxL	10*	1.8
#10-32 UNF	0.090/0.078	0.07/0.06	30	AM43xxL	10*	1.8

Notes
"xx" Denotes place in catalog number for voltage, three characters may be used when required.
* Latching valves are designed for intermittent duty only. Wattage rating applies to 20 – 30 ms duration required to actuate valve. Once switched no additional power is required to hold the valve in its position.

Catalog Number Description and Options

AM33	xx	L	O	S
Base Catalog Number	Voltage - 06 (DC) - 12 (DC) - 24 (DC) - 115 (AC)	Latching Suffix	Options Suffix A = AC service (rectifier in lead wire) O = No Lubricant K = Oxygen Service Construction PBT Valve Body, FKM Seals, PFPE lubricant	Optional Body Material S= 300 Series Stainless Steel

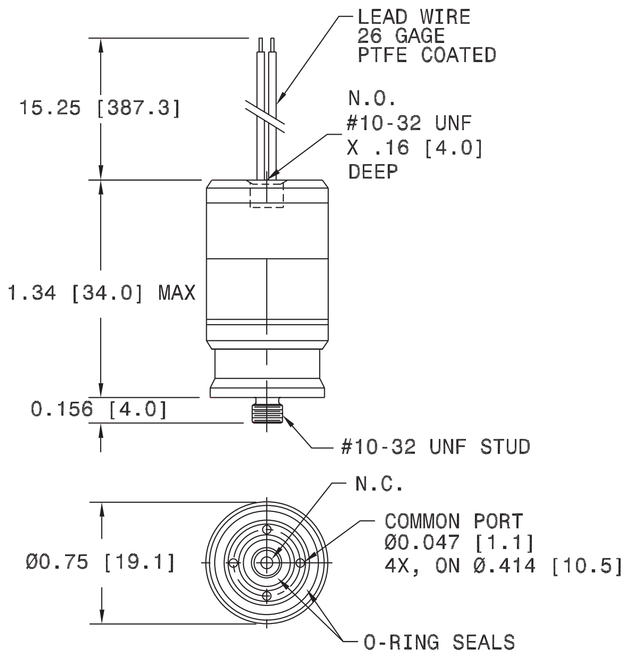
To Construct Catalog Number

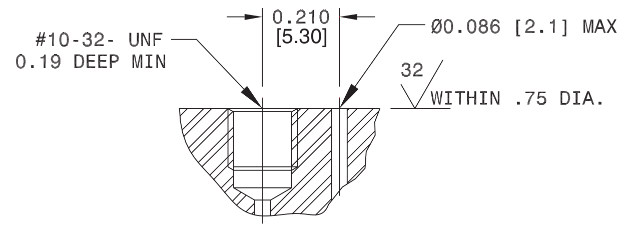
- Select base catalog number
- Insert voltage into the 5th, 6th, (and 7th when required), digits denoted by "xx"
- Add suffix for optional features to end of base catalog number

Examples

AM1124 = 2-Way Normally Closed valve with 0.025" orifice, 110 psig max pressure rating, and 24 VDC coil rated at 0.65 watts.
AM32115A = 2-Way Normally Open valve with 0.048" orifice, 100 psig max pressure rating, and 115 VAC coil with rectifier.
AM4306LK = 3-Way Latching valve with 0.090" and 0.078" orifices, 30 psig max pressure rating, 6 VDC coil and suitable for oxygen service.

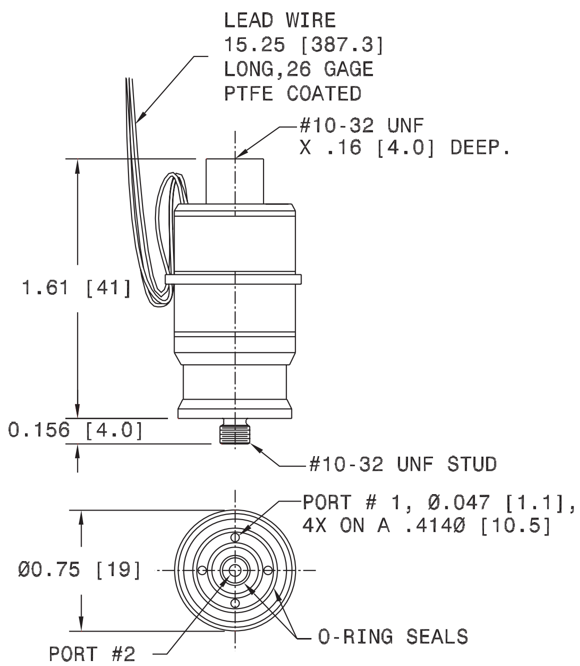
Dimensions 2 and 3-Way Standard Solenoid: Inches [mm]



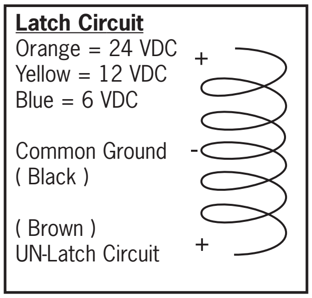


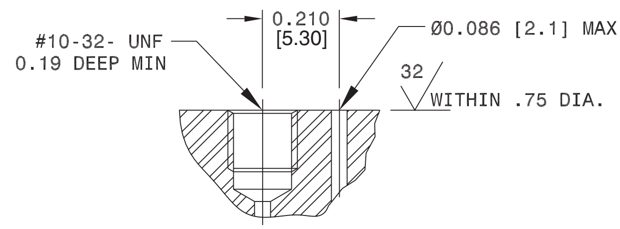
MANIFOLD DIMENSIONS

Dimensions 2 and 3-Way Latching Solenoid: Inches [mm]



Latching Wiring Diagram





MANIFOLD DIMENSIONS

Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPX5050
MPXV5050G
SERIES

Motorola Preferred Device

INTEGRATED PRESSURE SENSOR
0 to 50 kPa (0 to 7.25 psi)
0.2 to 4.7 Volts Output

The MPX5050/MPXV5050G series piezoresistive transducer is a state–of–the–art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This patented, single element transducer combines advanced micromachining techniques, thin–film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

Features

- 2.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller–Based Systems
- Temperature Compensated Over – 40° to +125°C
- Patented Silicon Shear Stress Strain Gauge
- Durable Epoxy Unibody Element
- Easy–to–Use Chip Carrier Option

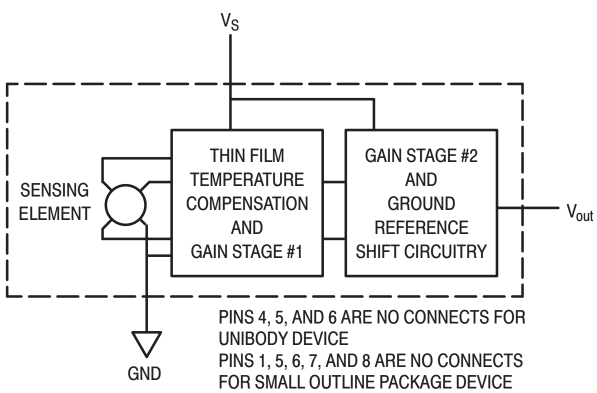
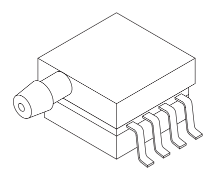
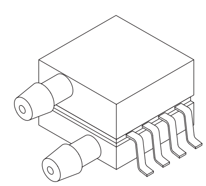


Figure 1. Fully Integrated Pressure Sensor Schematic

SMALL OUTLINE PACKAGE SURFACE MOUNT



MPXV5050GP
CASE 1369

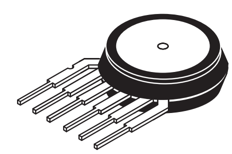


MPXV5050DP
CASE 1351

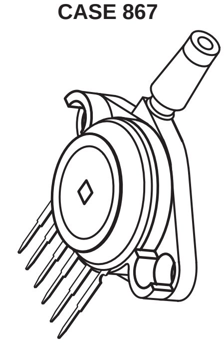
PIN NUMBER			
1	N/C	5	N/C
2	V_S	6	N/C
3	Gnd	7	N/C
4	V_{out}	8	N/C

NOTE: Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

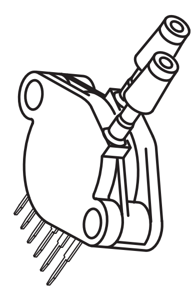
UNIBODY PACKAGE



MPX5050D
CASE 867



MPX5050GP
CASE 867B



MPX5050DP
CASE 867C

PIN NUMBER			
1	V_{out}	4	N/C
2	Gnd	5	N/C
3	V_S	6	N/C

NOTE: Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

REV 6

MAXIMUM RATINGS(NOTE)

Parametrics	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{max}	200	kPa
Storage Temperature	T_{stg}	–40° to +125°	°C
Operating Temperature	T_A	–40° to +125°	°C

NOTE: Exposure beyond the specified limits may cause permanent damage or degradation to the device.

OPERATING CHARACTERISTICS (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 4 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	0	—	50	kPa
Supply Voltage(2)		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	—	7.0	10.0	mAdc
Minimum Pressure Offset(3) @ V_S = 5.0 Volts	(0 to 85°C)	V_{off}	0.088	0.20	0.313	Vdc
Full Scale Output(4) @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSO}	4.587	4.70	4.813	Vdc
Full Scale Span(5) @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSS}	—	4.50	—	Vdc
Accuracy(6)		—	—	—	± 2.5	$\%V_{FSS}$
Sensitivity		V/P	—	90	—	mV/kPa
Response Time(7)		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_o+	—	0.1	—	mAdc
Warm–Up Time(8)		—	—	20	—	ms
Offset Stability(9)		—	—	± 0.5	—	$\%V_{FSS}$

NOTES:

1. 1.0kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS} at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm–up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

MECHANICAL CHARACTERISTICS

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	grams
Weight, Basic Element (Case 1369)	1.5	grams

Figure 3 illustrates the Differential/Gauge Sensing Chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm.

The MPX5050/MPXV5050G series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long–term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 2 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit shown in Figure 4. The output will saturate outside of the specified pressure range.

Figure 4 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

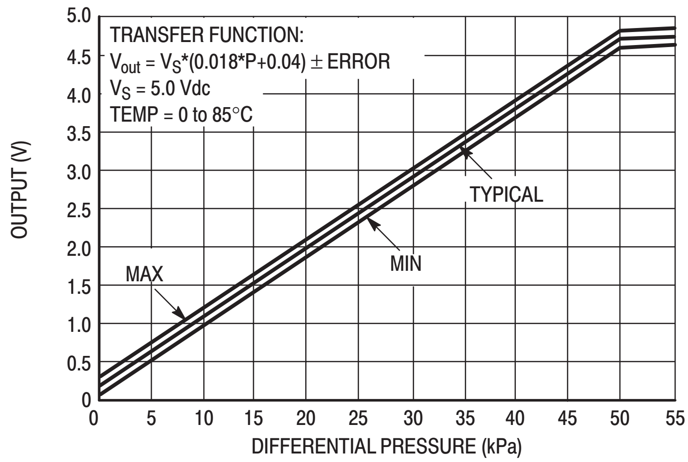


Figure 2. Output versus Pressure Differential

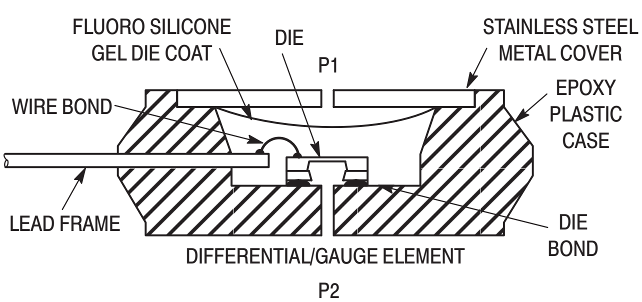


Figure 3. Cross–Sectional Diagram (Not to Scale)

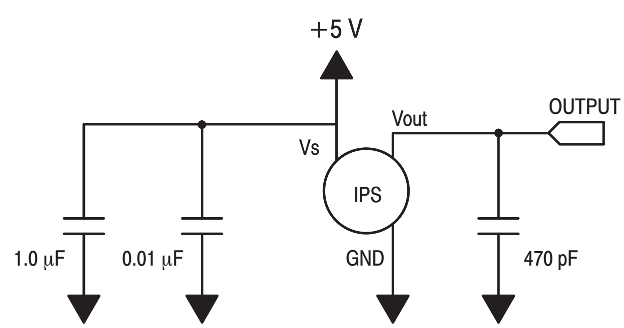


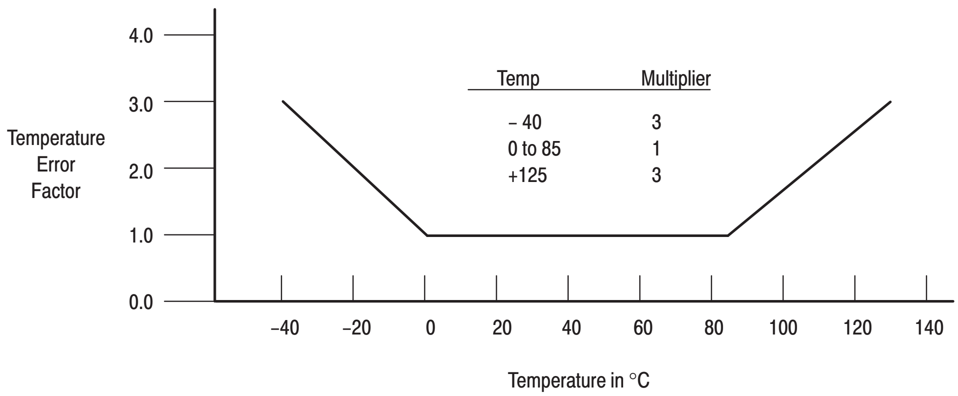
Figure 4. Recommended power supply decoupling and output filtering. For additional output filtering, please refer to Application Note AN1646.

Transfer Function

Nominal Transfer Value: $V_{out} = V_S$ (P x 0.018 + 0.04)
+/– (Pressure Error x Temp. Factor x 0.018 x V_S)
V_S = 5.0 V ± 0.25 Vdc

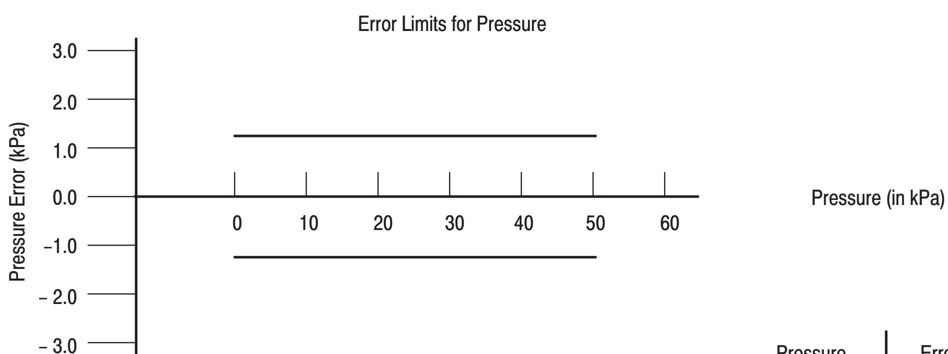
Temperature Error Band

MPX5050/MPXV5050G Series



NOTE: The Temperature Multiplier is a linear response from 0° to –40°C and from 85° to 125°C.

Pressure Error Band



Pressure	Error (Max)
0 to 50 kPa	± 1.25 kPa

PRESSURE (P1) / VACUUM (P2) SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluorosilicone gel which protects the die from harsh media. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX5050D	867	Stainless Steel Cap
MPX5050DP	867C	Side with Part Marking
MPX5050GP	867B	Side with Port Attached
MPXV5050GP	1369	Side with Port Attached
MPXV5050DP	1351	Side with Part Marking

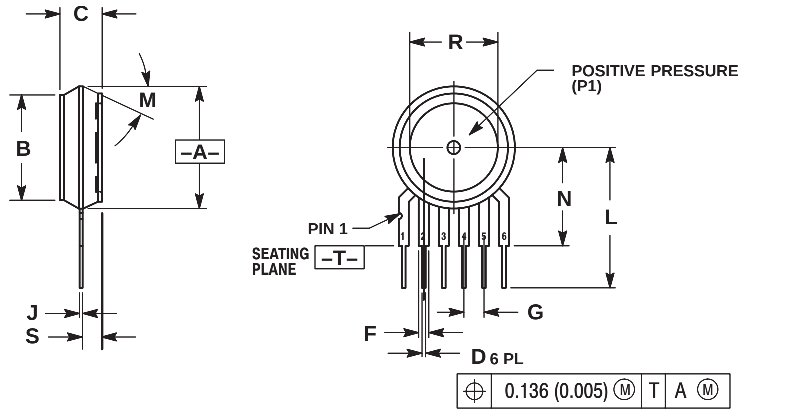
ORDERING INFORMATION — UNIBODY PACKAGE (MPX5050 SERIES)

Device Type	Options	Case Type	MPX Series	
			Order Number	Device Marking
Basic Element	Differential	867	MPX5050D	MPX5050D
Ported Elements	Differential Dual Ports	867C	MPX5050DP	MPX5050DP
	Gauge	867B	MPX5050GP	MPX5050GP

ORDERING INFORMATION — SMALL OUTLINE PACKAGE (MPXV5050G SERIES)

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Marking
Ported Elements	Side Port	1369	MPXV5050GP	Trays	MPXV5050G
	Dual Port	1351	MPXV5050DP	Trays	MPXV5050G

PACKAGE DIMENSIONS
UNIBODY PACKAGE



NOTES:
10. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
11. CONTROLLING DIMENSION: INCH.
12. DIMENSION –A– IS INCLUSIVE OF THE MOLD STOP RING. MOLD STOP RING NOT TO EXCEED 16.00 (0.630).

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.595	0.630	15.11	16.00
B	0.514	0.534	13.06	13.56
C	0.200	0.220	5.08	5.59
D	0.027	0.033	0.68	0.84
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.40
L	0.695	0.725	17.65	18.42
M	30° NOM		30° NOM	
N	0.475	0.495	12.07	12.57
R	0.430	0.450	10.92	11.43
S	0.090	0.105	2.29	2.66

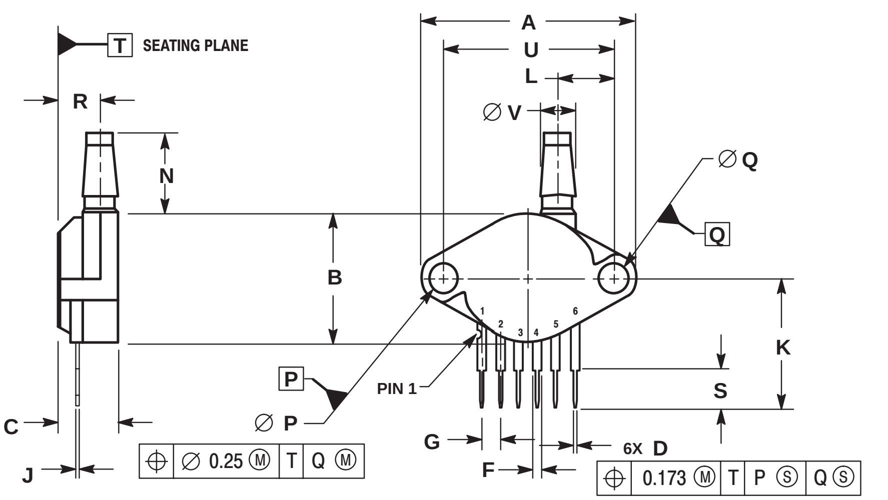
STYLE 1:
PIN 1. VOUT
2. GROUND
3. VCC
4. V1
5. V2
6. VEX

STYLE 2:
PIN 1. OPEN
2. GROUND
3. –VOUT
4. VSUPPLY
5. +VOUT
6. OPEN

STYLE 3:
PIN 1. OPEN
2. GROUND
3. +VOUT
4. +VSUPPLY
5. –VOUT
6. OPEN

CASE 867–08
ISSUE N

BASIC ELEMENT



NOTES:
1. DIMENSIONS ARE IN MILLIMETERS.
2. DIMENSIONS AND TOLERANCES PER ASME Y14.5M, 1994.

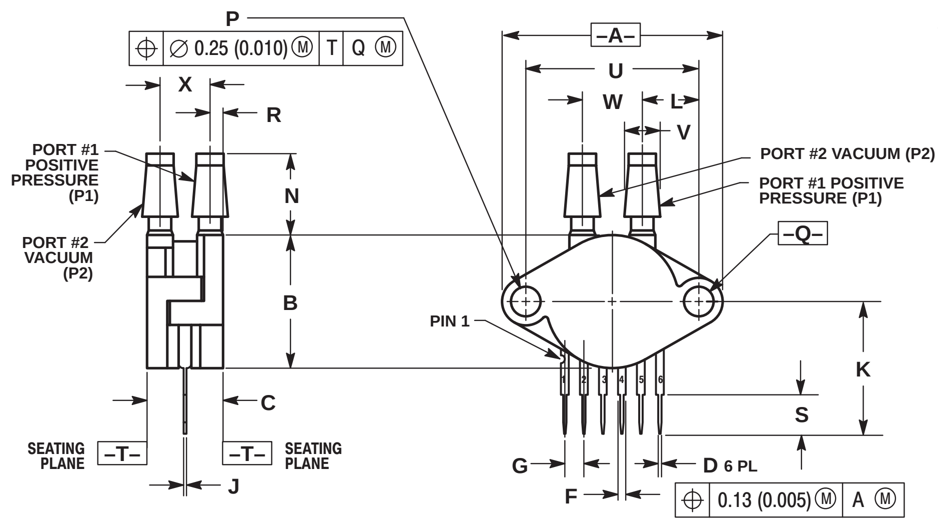
	MILLIMETERS	
DIM	MIN	MAX
A	29.08	29.85
B	17.4	18.16
C	7.75	8.26
D	0.68	0.84
F	1.22	1.63
G	2.54 BSC	
J	0.36	0.41
K	17.65	18.42
L	7.37	7.62
N	10.67	11.18
P	3.89	4.04
Q	3.89	4.04
R	5.84	6.35
S	5.59	6.1
U	23.11 BSC	
V	4.62	4.93

STYLE 1:
PIN 1. V_{OUT}
2. GROUND
3. V_{CC}
4. V1
5. V2
6. V_{EX}

CASE 867B–04
ISSUE F

PRESSURE SIDE PORTED (AP, GP)

PACKAGE DIMENSIONS–CONTINUED
UNIBODY PACKAGE



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

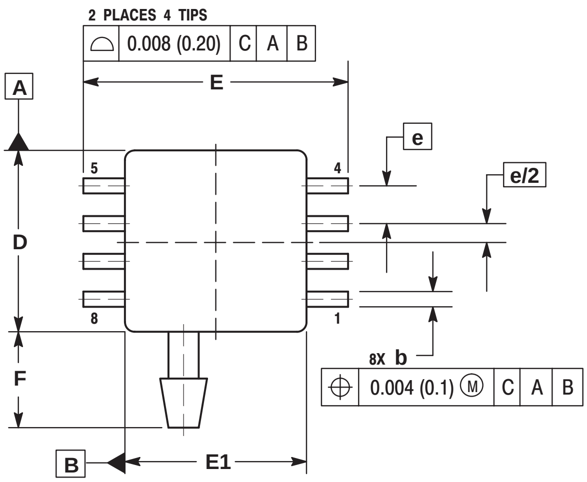
DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX
A	1.145	1.175	29.08	29.85
B	0.685	0.715	17.40	18.16
C	0.405	0.435	10.29	11.05
D	0.027	0.033	0.68	0.84
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.41
K	0.695	0.725	17.65	18.42
L	0.290	0.300	7.37	7.62
N	0.420	0.440	10.67	11.18
P	0.153	0.159	3.89	4.04
Q	0.153	0.159	3.89	4.04
R	0.063	0.083	1.60	2.11
S	0.220	0.240	5.59	6.10
U	0.910 BSC		23.11 BSC	
V	0.182	0.194	4.62	4.93
W	0.310	0.330	7.87	8.38
X	0.248	0.278	6.30	7.06

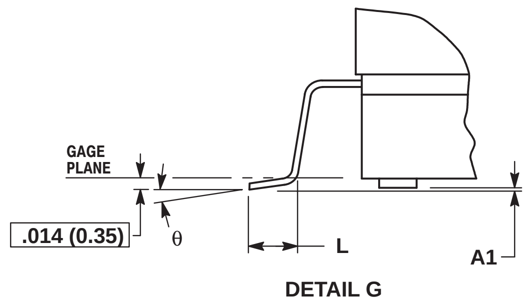
STYLE 1:
PIN 1. V_{OUT}
2. GROUND
3. V_{CC}
4. V1
5. V2
6. V_{EX}

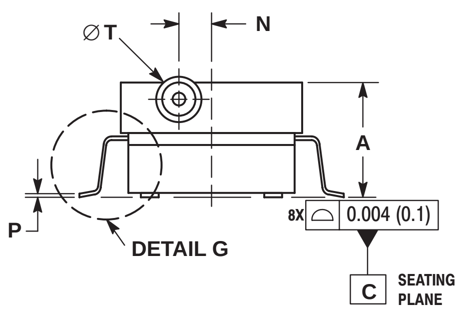
CASE 867C–05
ISSUE F

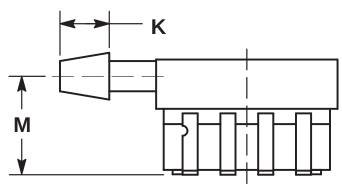
PRESSURE AND VACUUM SIDES PORTED (DP)

SMALL OUTLINE PACKAGE DIMENSIONS
SURFACE MOUNT







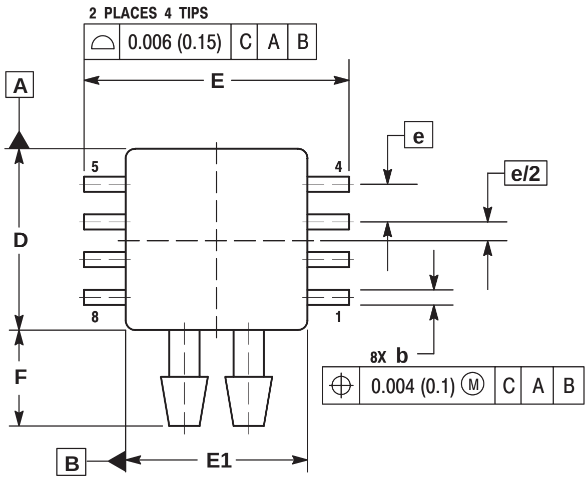


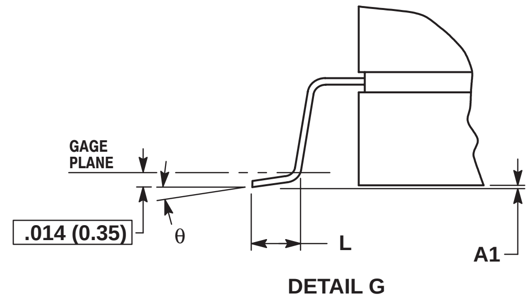
NOTES:
1. CONTROLLING DIMENSION: INCH.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M–1994.
3. DIMENSIONS "D" AND "E1" DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS. MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.006 (0.152) PER SIDE.
4. DIMENSION "b" DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.008 (0.203) MAXIMUM.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.300	0.330	7.11	7.62
A1	0.002	0.010	0.05	0.25
b	0.038	0.042	0.96	1.07
D	0.465	0.485	11.81	12.32
E	0.717 BSC		18.21 BSC	
E1	0.465	0.485	11.81	12.32
e	0.100 BSC		2.54 BSC	
F	0.245	0.255	6.22	6.47
K	0.120	0.130	3.05	3.30
L	0.061	0.071	1.55	1.80
M	0.270	0.290	6.86	7.36
N	0.080	0.090	2.03	2.28
P	0.009	0.011	0.23	0.28
T	0.115	0.125	2.92	3.17
θ	0°	7°	0°	7°

CASE 1369–01
ISSUE O

SMALL OUTLINE PACKAGE DIMENSIONS – CONTINUED
SURFACE MOUNT



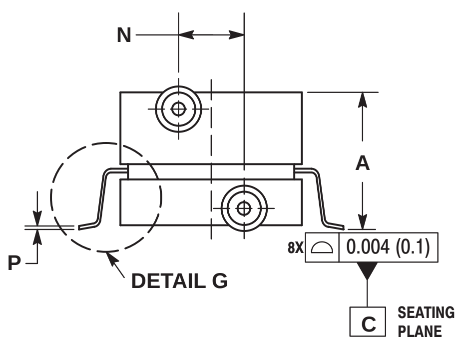


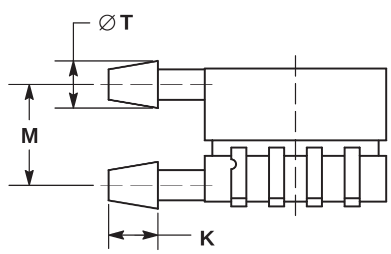
STYLE 1:
PIN 1. GND
2. +Vout
3. Vs
4. −Vout
5. N/C
6. N/C
7. N/C
8. N/C

STYLE 2:
PIN 1. N/C
2. Vs
3. GND
4. Vout
5. N/C
6. N/C
7. N/C
8. N/C

NOTES:
1. CONTROLLING DIMENSION: INCH.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M–1994.
3. DIMENSIONS "D" AND "E1" DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS. MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.006 (0.152) PER SIDE.
4. DIMENSION "b" DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.008 (0.203) MAXIMUM.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.370	0.390	9.39	9.91
A1	0.002	0.010	0.05	0.25
b	0.038	0.042	0.96	1.07
D	0.465	0.485	11.81	12.32
E	0.680	0.700	17.27	17.78
E1	0.465	0.485	11.81	12.32
e	0.100 BSC		2.54 BSC	
F	0.240	0.260	6.10	6.60
K	0.115	0.135	2.92	3.43
L	0.040	0.060	1.02	1.52
M	0.270	0.290	6.86	7.37
N	0.160	0.180	4.06	4.57
P	0.009	0.011	0.23	0.28
T	0.110	0.130	2.79	3.30
θ	0°	7°	0°	7°





CASE 1351–01
ISSUE O

NOTES

NOTES

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USA/EUROPE/Locations Not Listed: Motorola Literature Distribution; P.O. Box 5405, Denver, Colorado 80217. 1–303–675–2140 or 1–800–441–2447

JAPAN: Motorola Japan Ltd.; SPS, Technical Information Center, 3–20–1, Minami–Azabu. Minato–ku, Tokyo 106–8573 Japan. 81–3–3440–3569

ASIA/PACIFIC: Motorola Semiconductors H.K. Ltd.; Silicon Harbour Centre, 2 Dai King Street, Tai Po Industrial Estate, Tai Po, N.T., Hong Kong. 852–26668334

Technical Information Center: 1–800–521–6274

HOME PAGE: http://www.motorola.com/semiconductors/

National Semiconductor

June 2003

LMV321/LMV358/LMV324 Single/Dual/Quad General Purpose, Low Voltage, Rail-to-Rail Output Operational Amplifiers

General Description

The LMV358/324 are low voltage (2.7–5.5V) versions of the dual and quad commodity op amps, LM358/324, which currently operate at 5–30V. The LMV321 is the single version.

The LMV321/358/324 are the most cost effective solutions for the applications where low voltage operation, space saving and low price are needed. They offer specifications that meet or exceed the familiar LM358/324. The LMV321/358/324 have rail-to-rail output swing capability and the input common-mode voltage range includes ground. They all exhibit excellent speed-power ratio, achieving 1MHz of bandwidth and 1V/µs of slew rate with low supply current.

The LMV321 is available in space saving SC70-5, which is approximately half the size of SOT23-5. The small package saves space on pc boards, and enables the design of small portable electronic devices. It also allows the designer to place the device closer to the signal source to reduce noise pickup and increase signal integrity.

The chips are built with National's advanced submicron silicon-gate BiCMOS process. The LMV321/358/324 have bipolar input and output stages for improved noise performance and higher output current drive.

Features

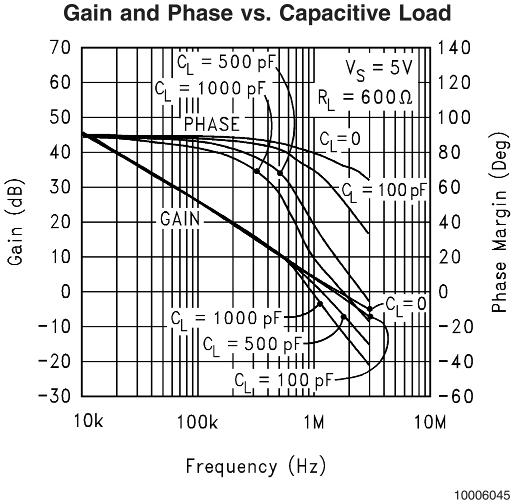
(For V^+ = 5V and V^- = 0V, Typical Unless Otherwise Noted)

- Guaranteed 2.7V and 5V Performance
- No Crossover Distortion
- Space Saving Package — SC70-5 2.0x2.1x1.0mm
- Industrial Temp. Range — −40˚C to +85˚C
- Gain-Bandwidth Product — 1MHz
- Low Supply Current
  - — LMV321 — 130µA
  - — LMV358 — 210µA
  - — LMV324 — 410µA
- Rail-to-Rail Output Swing @ 10kΩ — V^+ −10mV, V^- +65mV
- V_{CM} — −0.2V to V^+−0.8V

Applications

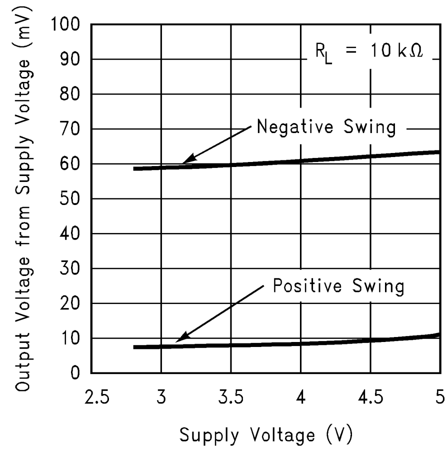
- Active Filters
- General Purpose Low Voltage Applications
- General Purpose Portable Devices

Gain and Phase vs. Capacitive Load



10006045

Output Voltage Swing vs. Supply Voltage



10006067

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

ESD Tolerance (Note 2)	
Machine Model	100V
Human Body Model	
LMV358/324	2000V
LMV321	900V
Differential Input Voltage	± Supply Voltage
Supply Voltage ($V^+ – V^-$)	5.5V
Output Short Circuit to V^+	(Note 3)
Output Short Circuit to V^-	(Note 4)
Soldering Information	
Infrared or Convection (20 sec)	235˚C
Storage Temp. Range	−65˚C to 150˚C
Junction Temperature(Note 5)	150˚C

Operating Ratings (Note 1)

Supply Voltage	2.7V to 5.5V
Temperature Range	
LMV321, LMV358, LMV324	−40˚C to +85˚C
Thermal Resistance (θ_{JA})(Note 10)	
5-pin SC70-5	478˚C/W
5-pin SOT23-5	265˚C/W
8-Pin SOIC	190˚C/W
8-Pin MSOP	235˚C/W
14-Pin SOIC	145˚C/W
14-Pin TSSOP	155˚C/W

2.7V DC Electrical Characteristics

Unless otherwise specified, all limits guaranteed for T_J = 25˚C, V^+ = 2.7V, V^- = 0V, V_{CM} = 1.0V, V_O = $V^+/2$ and R_L > 1MΩ.

Symbol	Parameter	Conditions	Typ (Note 6)	Limit (Note 7)	Units
V_{OS}	Input Offset Voltage		1.7	7	mV max
TCV_{OS}	Input Offset Voltage Average Drift		5		μV/˚C
I_B	Input Bias Current		11	250	nA max
I_{OS}	Input Offset Current		5	50	nA max
CMRR	Common Mode Rejection Ratio	0V ≤ V_{CM} ≤ 1.7V	63	50	dB min
PSRR	Power Supply Rejection Ratio	2.7V ≤ V^+ ≤ 5V V_O = 1V	60	50	dB min
V_{CM}	Input Common-Mode Voltage Range	For CMRR≥50dB	−0.2	0	V min
			1.9	1.7	V max
V_O	Output Swing	R_L = 10kΩ to 1.35V	V^+ -10	V^+ -100	mV min
			60	180	mV max
I_S	Supply Current	LMV321	80	170	μA max
		LMV358 Both amplifiers	140	340	μA max
		LMV324 All four amplifiers	260	680	μA max

2.7V AC Electrical Characteristics

Unless otherwise specified, all limits guaranteed for T_J = 25˚C, V^+ = 2.7V, V^- = 0V, V_{CM} = 1.0V, V_O = V^+/2 and R_L > 1MΩ.

Symbol	Parameter	Conditions	Typ (Note 6)	Limit (Note 7)	Units
GBWP	Gain-Bandwidth Product	C_L = 200pF	1		MHz
Φ_m	Phase Margin		60		Deg
G_m	Gain Margin		10		dB
e_n	Input-Referred Voltage Noise	f = 1kHz	46		$\frac{nV}{\sqrt{Hz}}$
i_n	Input-Referred Current Noise	f = 1kHz	0.17		$\frac{pA}{\sqrt{Hz}}$

5V DC Electrical Characteristics

Unless otherwise specified, all limits guaranteed for T_J = 25˚C, V^+ = 5V, V^- = 0V, V_{CM} = 2.0V, V_O = V^+/2 and R_L > 1MΩ. **Boldface** limits apply at the temperature extremes.

Symbol	Parameter	Conditions	Typ (Note 6)	Limit (Note 7)	Units
V_{OS}	Input Offset Voltage		1.7	7 **9**	mV max
TCV_{OS}	Input Offset Voltage Average Drift		5		μV/˚C
I_B	Input Bias Current		15	250 **500**	nA max
I_{OS}	Input Offset Current		5	50 **150**	nA max
CMRR	Common Mode Rejection Ratio	0V ≤ V_{CM} ≤ 4V	65	50	dB min
PSRR	Power Supply Rejection Ratio	2.7V ≤ V^+ ≤ 5V V_O = 1V V_{CM} = 1V	60	50	dB min
V_{CM}	Input Common-Mode Voltage Range	For CMRR≥50dB	–0.2	0	V min
			4.2	4	V max
A_V	Large Signal Voltage Gain (Note 8)	R_L = 2kΩ	100	15 **10**	V/mV min
V_O	Output Swing	R_L = 2kΩ to 2.5V	V^+ -40	V^+ -300 **V^+ -400**	mV min
			120	300 **400**	mV max
		R_L = 10kΩ to 2.5V	V^+ -10	V^+ -100 **V^+ -200**	mV min
			65	180 **280**	mV max
I_O	Output Short Circuit Current	Sourcing, V_O = 0V	60	5	m min
		Sinking, V_O = 5V	160	10	mA min
I_S	Supply Current	LMV321	130	250 **350**	μA max
		LMV358 Both amplifiers	210	440 **615**	μA max
		LMV324 All four amplifiers	410	830 **1160**	μA max

5V AC Electrical Characteristics

Unless otherwise specified, all limits guaranteed for $T_J = 25^\circ C$, $V^+ = 5V$, $V^- = 0V$, $V_{CM} = 2.0V$, $V_O = V^+/2$ and $R_L > 1M\Omega$. **Boldface** limits apply at the temperature extremes.

Symbol	Parameter	Conditions	Typ (Note 6)	Limit (Note 7)	Units
SR	Slew Rate	(Note 9)	1		V/µs
GBWP	Gain-Bandwidth Product	$C_L = 200pF$	1		MHz
Φ_m	Phase Margin		60		Deg
G_m	Gain Margin		10		dB
e_n	Input-Referred Voltage Noise	f = 1kHz	39		$\frac{nV}{\sqrt{Hz}}$
i_n	Input-Referred Current Noise	f = 1kHz	0.21		$\frac{pA}{\sqrt{Hz}}$

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but specific performance is not guaranteed. For guaranteed specifications and the test conditions, see the Electrical Characteristics.

Note 2: Human body model, 1.5kΩ in series with 100pF. Machine model, 0Ω in series with 200pF.

Note 3: Shorting output to V^+ will adversely affect reliability.

Note 4: Shorting output to V^- will adversely affect reliability.

Note 5: The maximum power dissipation is a function of $T_{J(MAX)}$, θ_{JA}, and T_A. The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{J(MAX)}–T_A)/\theta_{JA}$. All numbers apply for packages soldered directly into a PC board.

Note 6: Typical values represent the most likely parametric norm.

Note 7: All limits are guaranteed by testing or statistical analysis.

Note 8: R_L is connected to V^-. The output voltage is $0.5V \leq V_O \leq 4.5V$.

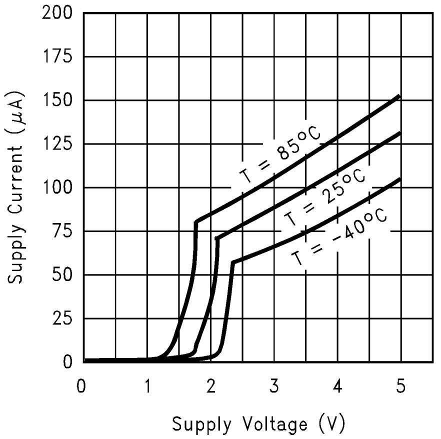
Note 9: Connected as voltage follower with 3V step input. Number specified is the slower of the positive and negative slew rates.

Note 10: All numbers are typical, and apply for packages soldered directly onto a PC board in still air.

Typical Performance Characteristics

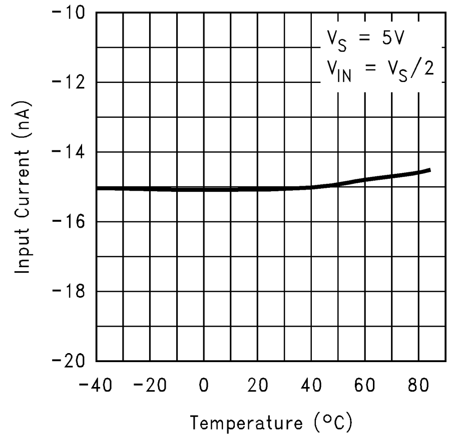
Unless otherwise specified, V_S = +5V, single supply, T_A = 25˚C.

Supply Current vs. Supply Voltage (LMV321)



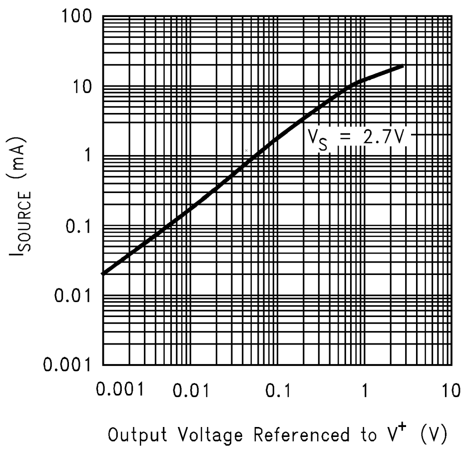
10006073

Input Current vs. Temperature



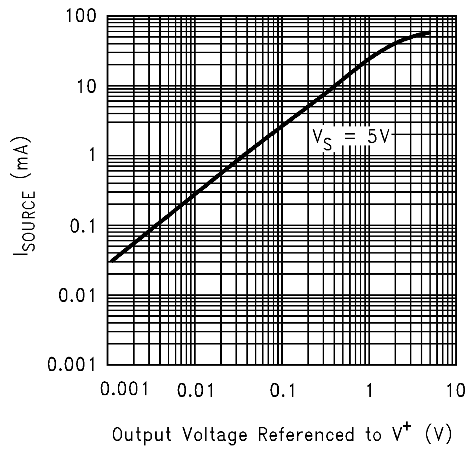
100060A9

Sourcing Current vs. Output Voltage



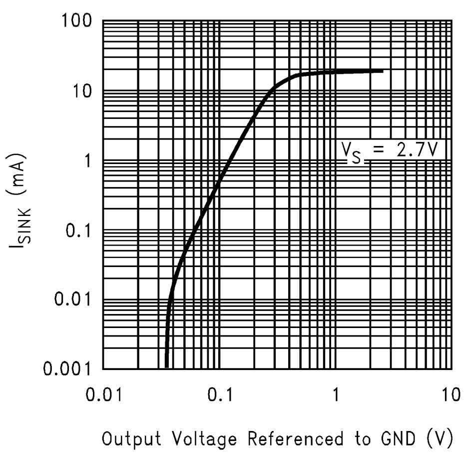
10006069

Sourcing Current vs. Output Voltage



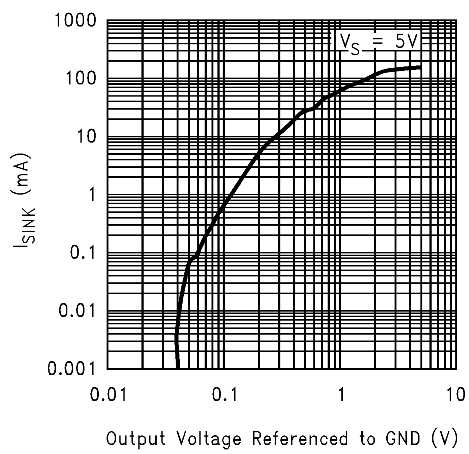
10006068

Sinking Current vs. Output Voltage



10006070

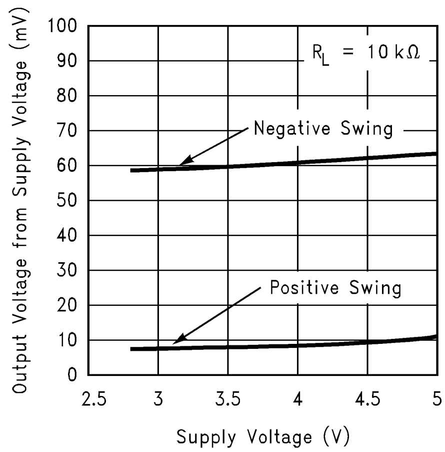
Sinking Current vs. Output Voltage



10006071

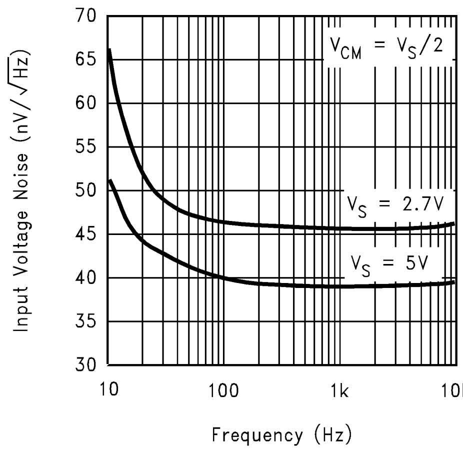
Typical Performance Characteristics Unless otherwise specified, V_S = +5V, single supply, T_A = 25˚C. (Continued)

Output Voltage Swing vs. Supply Voltage



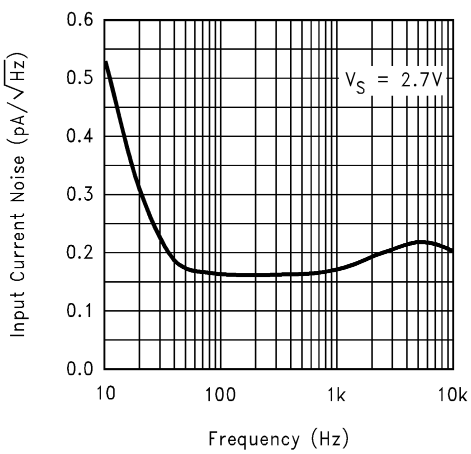
10006067

Input Voltage Noise vs. Frequency



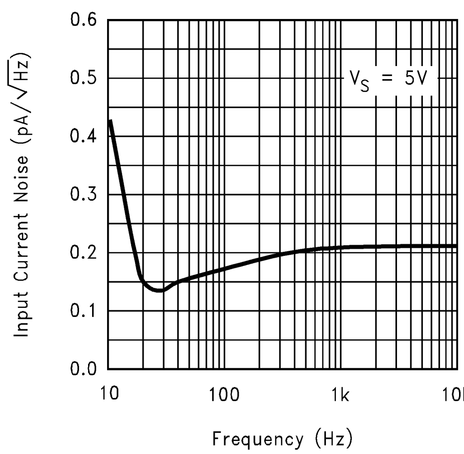
10006056

Input Current Noise vs. Frequency



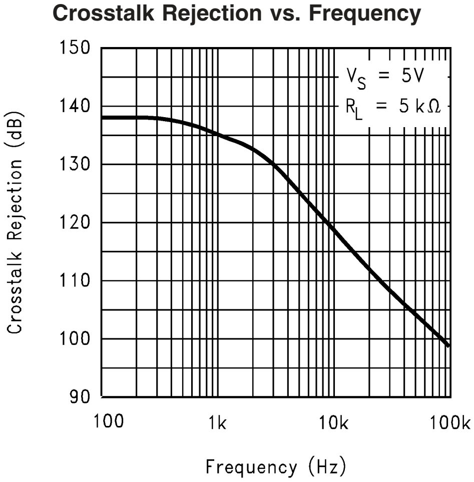
10006060

Input Current Noise vs. Frequency



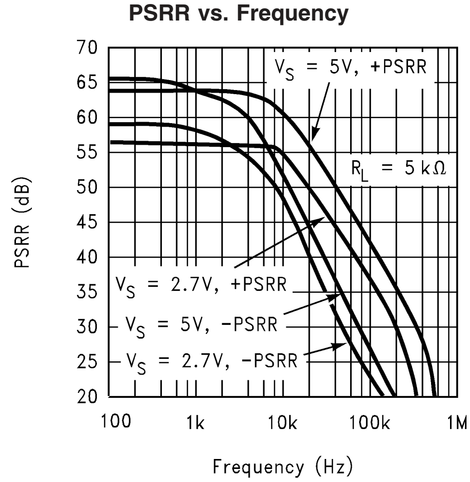
10006058

Crosstalk Rejection vs. Frequency



10006061

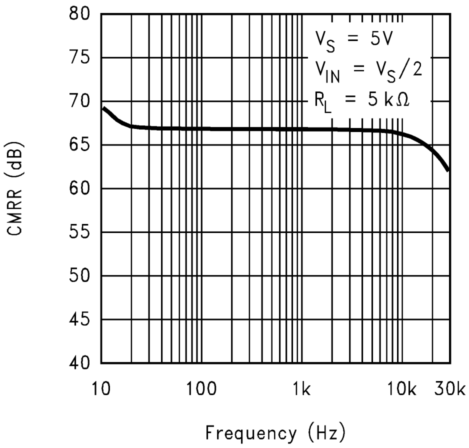
PSRR vs. Frequency



10006051

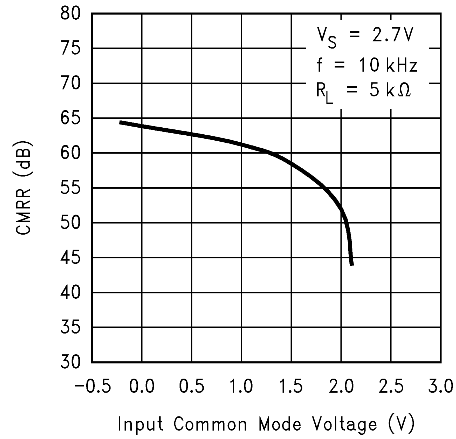
Typical Performance Characteristics Unless otherwise specified, V_S = +5V, single supply, T_A = 25˚C. (Continued)

CMRR vs. Frequency



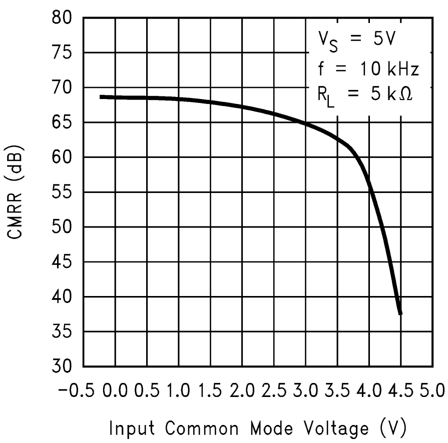
10006062

CMRR vs. Input Common Mode Voltage



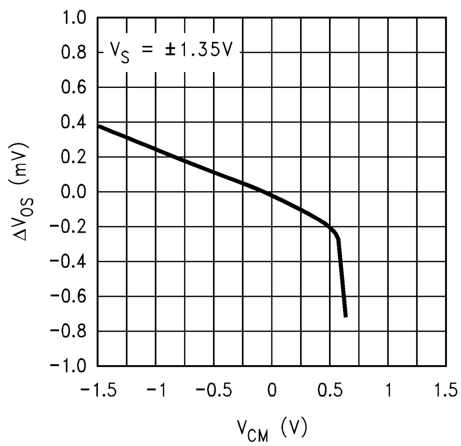
10006064

CMRR vs. Input Common Mode Voltage



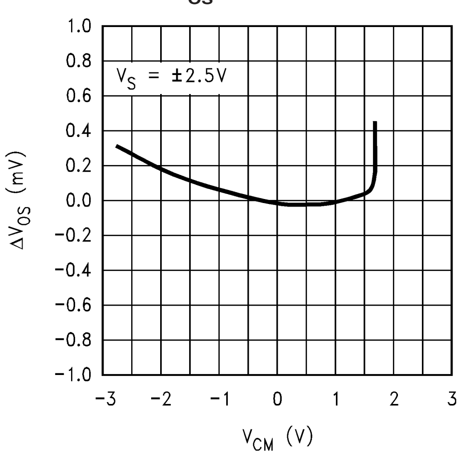
10006063

ΔV_{OS} vs. CMR



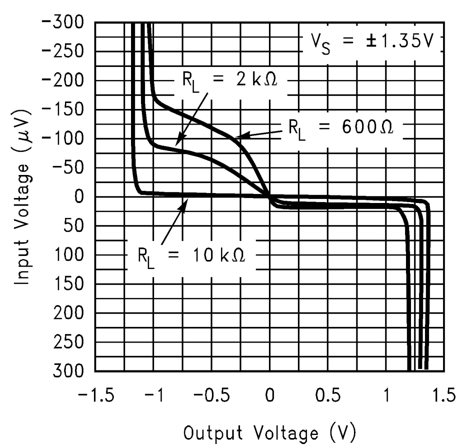
10006053

ΔV_{OS} vs. CMR



10006050

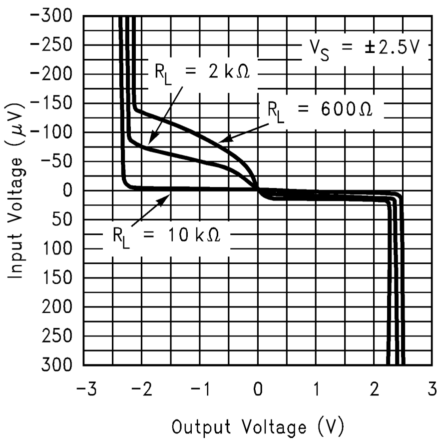
Input Voltage vs. Output Voltage



10006054

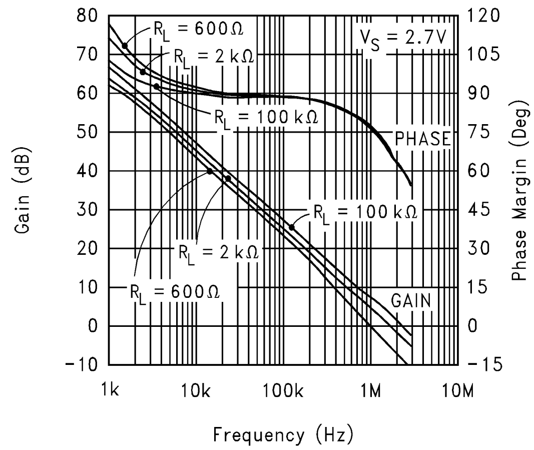
Typical Performance Characteristics Unless otherwise specified, V_S = +5V, single supply, T_A = 25˚C. (Continued)

Input Voltage vs. Output Voltage



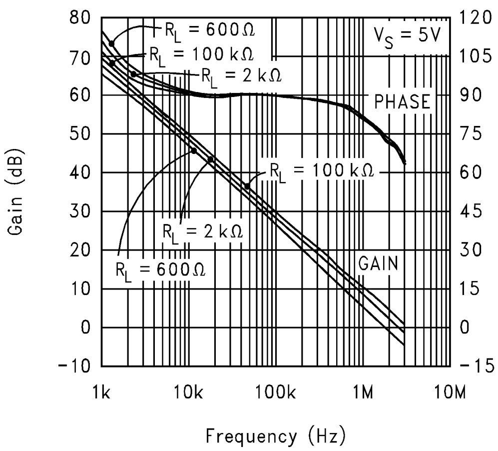
10006052

Open Loop Frequency Response



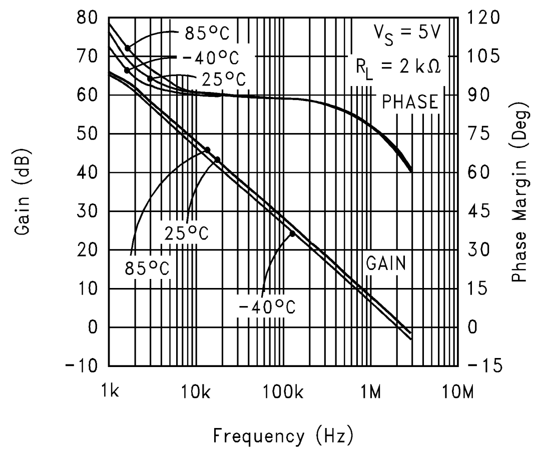
10006042

Open Loop Frequency Response



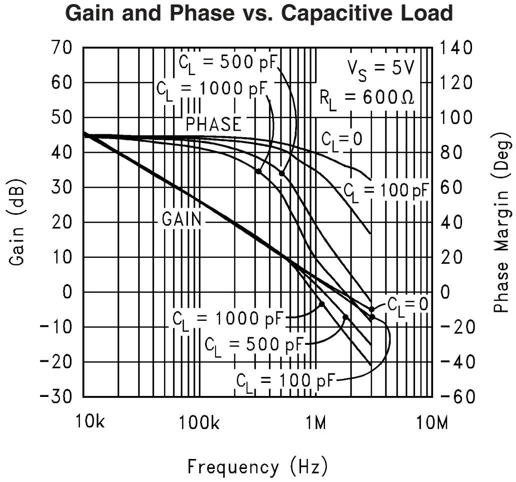
10006041

Open Loop Frequency Response vs. Temperature



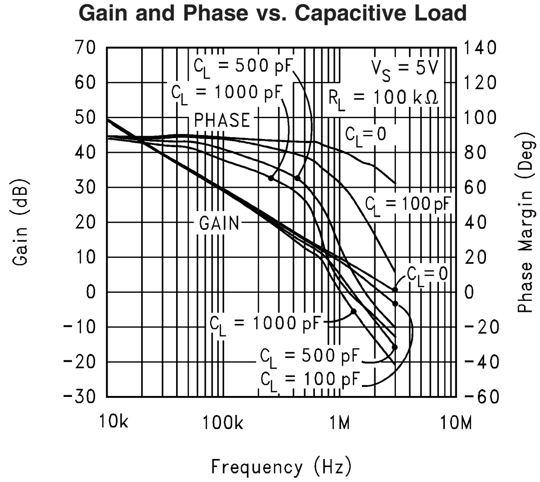
10006043

Gain and Phase vs. Capacitive Load



10006045

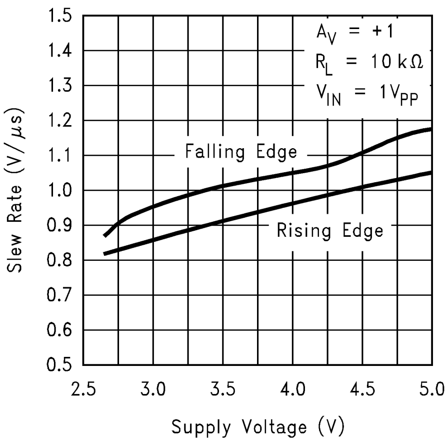
Gain and Phase vs. Capacitive Load



10006044

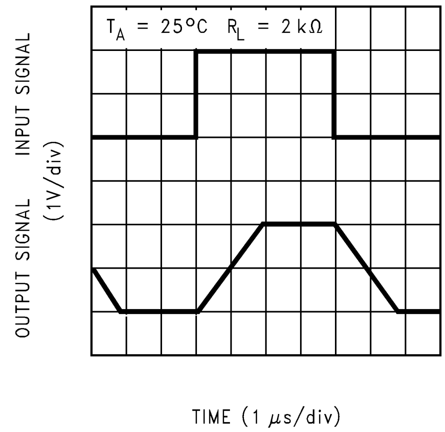
Typical Performance Characteristics Unless otherwise specified, V_S = +5V, single supply, T_A = 25˚C. (Continued)

Slew Rate vs. Supply Voltage



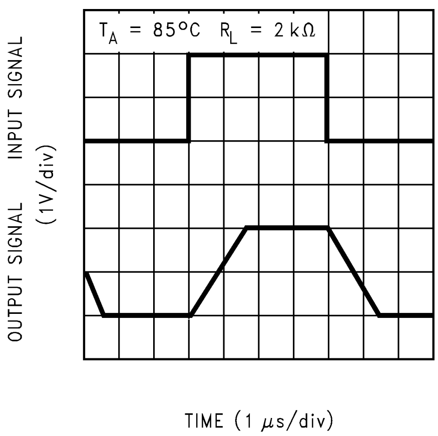
10006057

Non-Inverting Large Signal Pulse Response



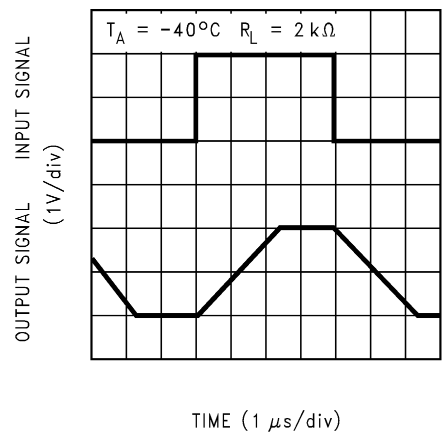
10006088

Non-Inverting Large Signal Pulse Response



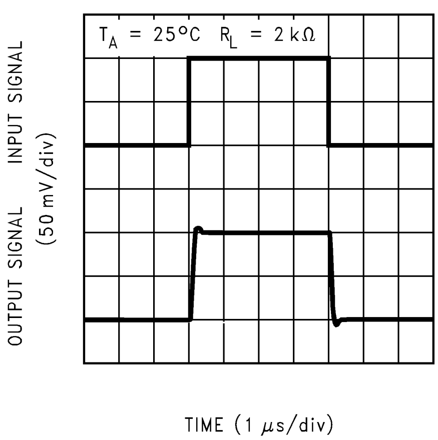
100060A1

Non-Inverting Large Signal Pulse Response



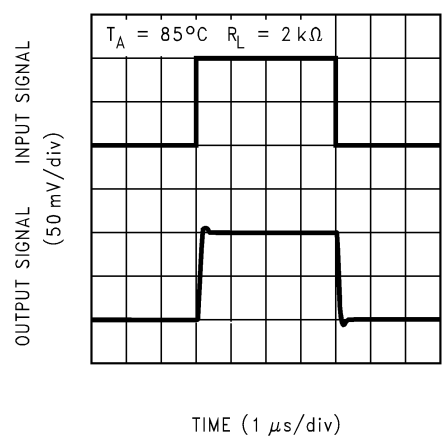
100060A0

Non-Inverting Small Signal Pulse Response



10006089

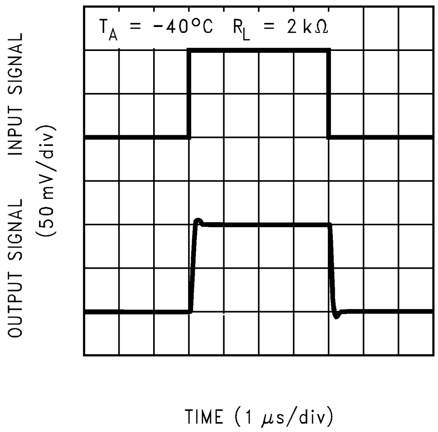
Non-Inverting Small Signal Pulse Response



100060A2

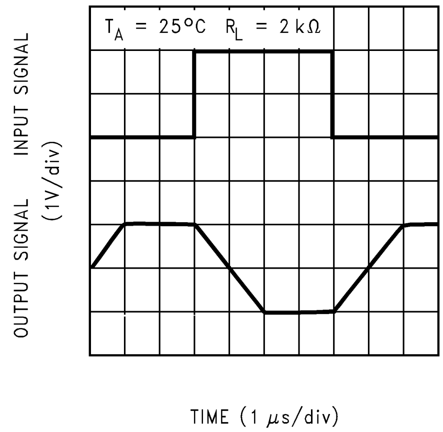
Typical Performance Characteristics Unless otherwise specified, V_S = +5V, single supply, T_A = 25˚C. (Continued)

Non-Inverting Small Signal Pulse Response



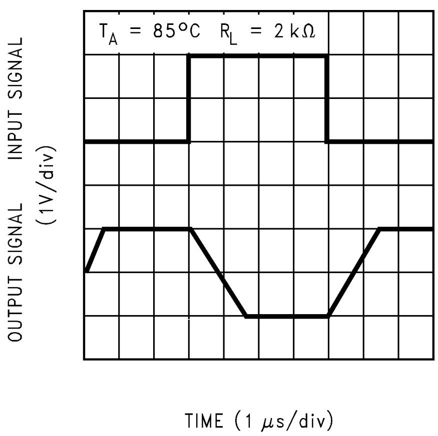
100060A3

Inverting Large Signal Pulse Response



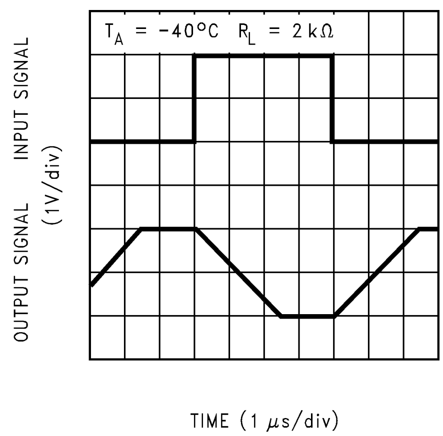
10006090

Inverting Large Signal Pulse Response



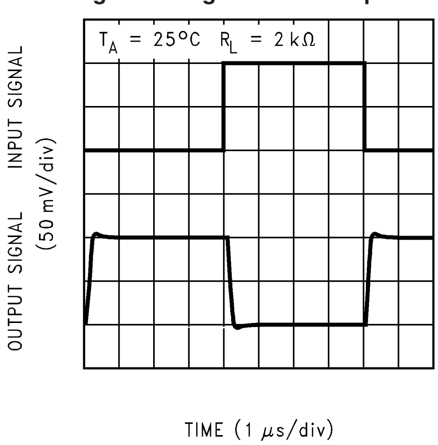
100060A4

Inverting Large Signal Pulse Response



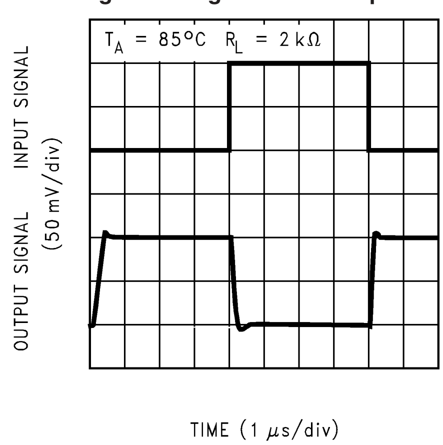
100060A5

Inverting Small Signal Pulse Response



10006091

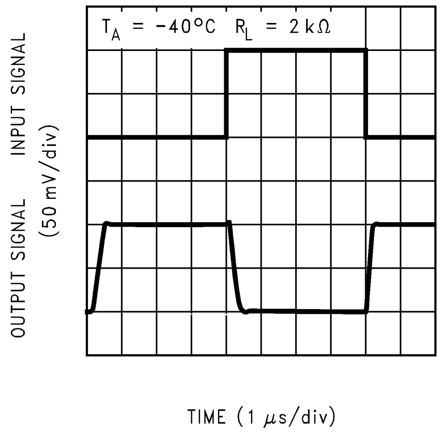
Inverting Small Signal Pulse Response



100060A6

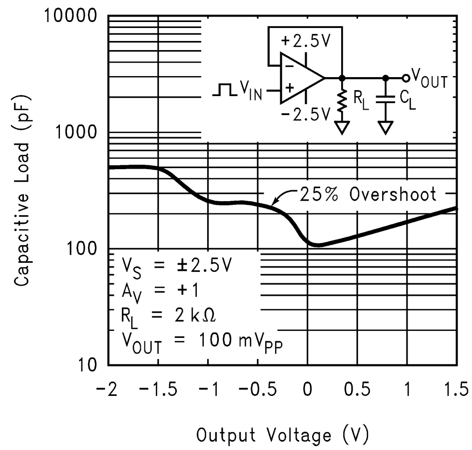
Typical Performance Characteristics Unless otherwise specified, V_S = +5V, single supply, T_A = 25˚C. (Continued)

Inverting Small Signal Pulse Response



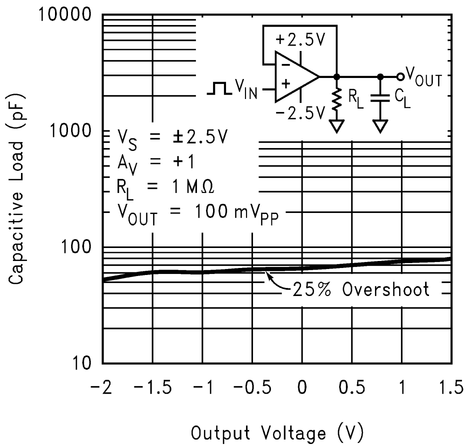
100060A7

Stability vs. Capacitive Load



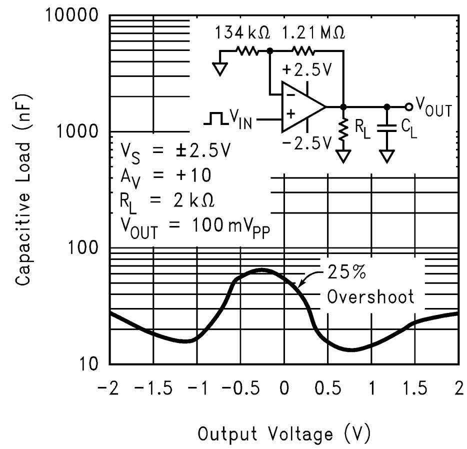
10006046

Stability vs. Capacitive Load



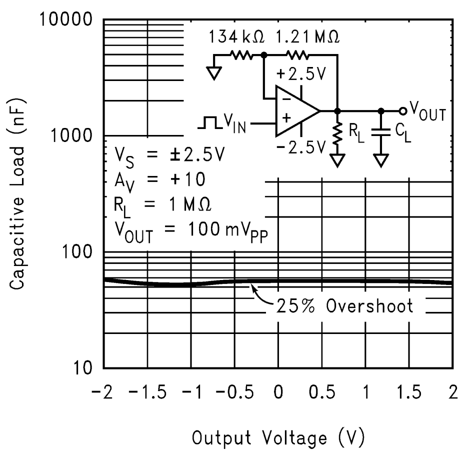
10006047

Stability vs. Capacitive Load



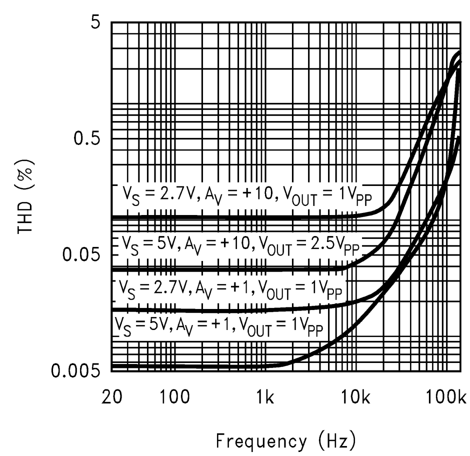
10006049

Stability vs. Capacitive Load



10006048

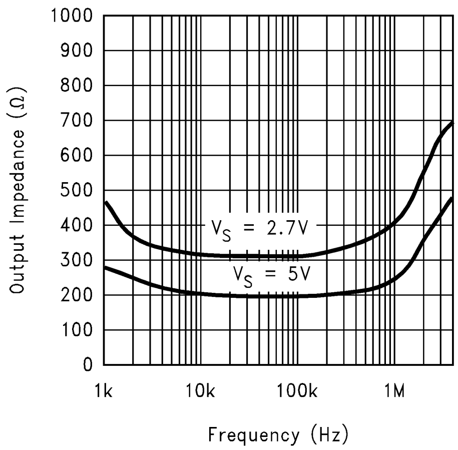
THD vs. Frequency



10006059

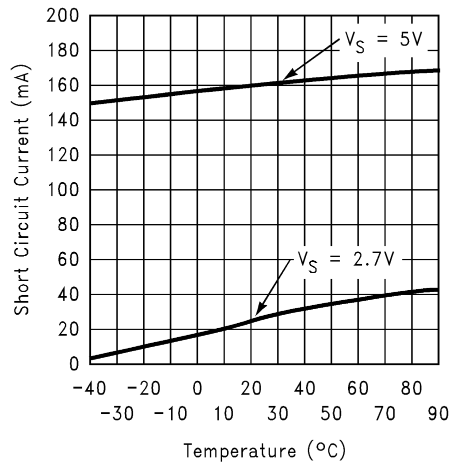
Typical Performance Characteristics
Unless otherwise specified, V_S = +5V, single supply, T_A = 25˚C. (Continued)

Open Loop Output Impedance vs. Frequency



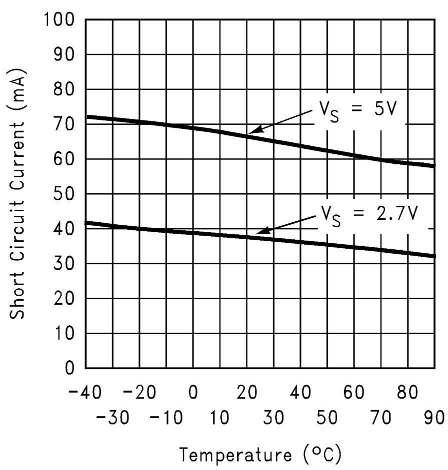
10006055

Short Circuit Current vs. Temperature (Sinking)



10006065

Short Circuit Current vs. Temperature (Sourcing)



10006066

Application Notes

1.0 BENEFITS OF THE LMV321/358/324

Size: The small footprints of the LMV321/358/324 packages save space on printed circuit boards, and enable the design of smaller electronic products, such as cellular phones, pagers, or other portable systems. The low profile of the LMV321/358/324 make them possible to use in PCMCIA type III cards.

Signal Integrity

Signals can pick up noise between the signal source and the amplifier. By using a physically smaller amplifier package, the LMV321/358/324 can be placed closer to the signal source, reducing noise pickup and increasing signal integrity.

Simplified Board Layout

These products help you to avoid using long pc traces in your pc board layout. This means that no additional components, such as capacitors and resistors, are needed to filter out the unwanted signals due to the interference between the long pc traces.

Low Supply Current

These devices will help you to maximize battery life. They are ideal for battery powered systems.

Low Supply Voltage

National provides guaranteed performance at 2.7V and 5V. These guarantees ensure operation throughout the battery lifetime.

Rail-to-Rail Output

Rail-to-rail output swing provides maximum possible dynamic range at the output. This is particularly important when operating on low supply voltages.

Input Includes Ground

Allows direct sensing near GND in single supply operation.

The differential input voltage may be larger than V^+ without damaging the device. Protection should be provided to prevent the input voltages from going negative more than −0.3V (at 25˚C). An input clamp diode with a resistor to the IC input terminal can be used.

Ease Of Use & Crossover Distortion

The LMV321/358/324 offer specifications similar to the familiar LM324. In addition, the new LMV321/358/324 effectively eliminate the output crossover distortion. The scope photos in *Figure 1* and *Figure 2* compare the output swing of the LMV324 and the LM324 in a voltage follower configuration, with $V_S = \pm 2.5V$ and R_L (= 2kΩ) connected to GND. It is apparent that the crossover distortion has been eliminated in the new LMV324.

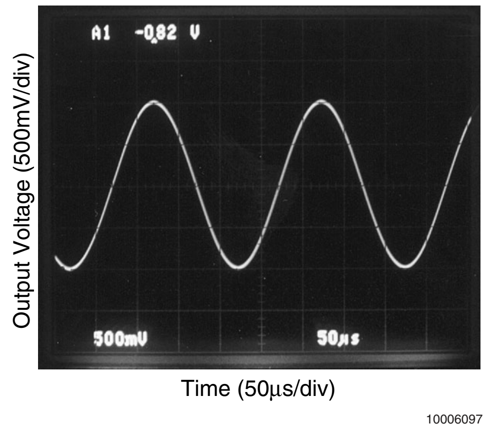


FIGURE 1. Output Swing of LMV324

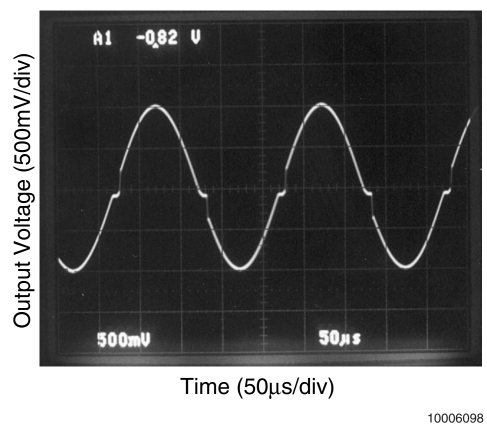


FIGURE 2. Output Swing of LM324

2.0 CAPACITIVE LOAD TOLERANCE

The LMV321/358/324 can directly drive 200pF in unity-gain without oscillation. The unity-gain follower is the most sensitive configuration to capacitive loading. Direct capacitive loading reduces the phase margin of amplifiers. The combination of the amplifier's output impedance and the capacitive load induces phase lag. This results in either an underdamped pulse response or oscillation. To drive a heavier capacitive load, circuit in *Figure 3* can be used.

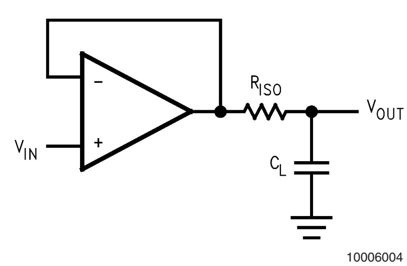


FIGURE 3. Indirectly Driving A Capacitive Load Using Resistive Isolation

Application Notes (Continued)

In *Figure 3* , the isolation resistor R_{ISO} and the load capacitor C_L form a pole to increase stability by adding more phase margin to the overall system. The desired performance depends on the value of R_{ISO}. The bigger the R_{ISO} resistor value, the more stable V_{OUT} will be. *Figure 4* is an output waveform of *Figure 3* using 620Ω for R_{ISO} and 510pF for C_L.

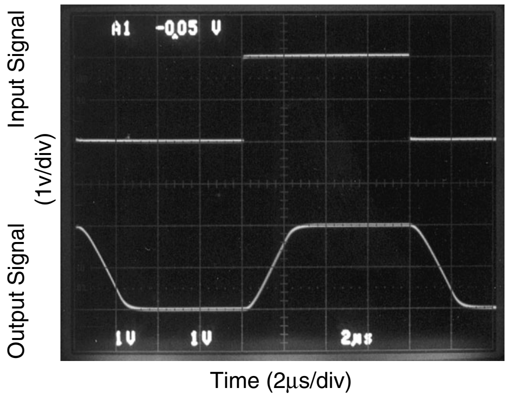


FIGURE 4. Pulse Response of the LMV324 Circuit in Figure 3

The circuit in *Figure 5* is an improvement to the one in *Figure 3* because it provides DC accuracy as well as AC stability. If there were a load resistor in *Figure 3*, the output would be voltage divided by R_{ISO} and the load resistor. Instead, in *Figure 5*, R_F provides the DC accuracy by using feed-forward techniques to connect V_{IN} to R_L. Caution is needed in choosing the value of R_F due to the input bias current of the LMV321/358/324. C_F and R_{ISO} serve to counteract the loss of phase margin by feeding the high frequency component of the output signal back to the amplifier's inverting input, thereby preserving phase margin in the overall feedback loop. Increased capacitive drive is possible by increasing the value of C_F . This in turn will slow down the pulse response.

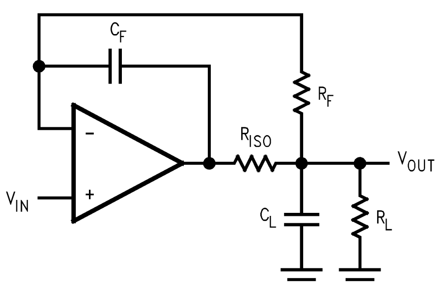


FIGURE 5. Indirectly Driving A Capacitive Load with DC Accuracy

3.0 INPUT BIAS CURRENT CANCELLATION

The LMV321/358/324 family has a bipolar input stage. The typical input bias current of LMV321/358/324 is 15nA with 5V supply. Thus a 100kΩ input resistor will cause 1.5mV of error voltage. By balancing the resistor values at both inverting and non-inverting inputs, the error caused by the amplifier's input bias current will be reduced. The circuit in *Figure 6* shows how to cancel the error caused by input bias current.

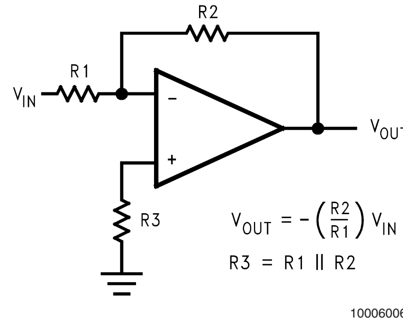
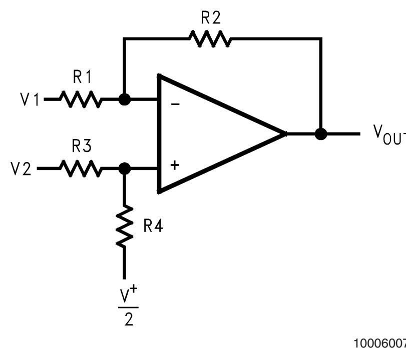


FIGURE 6. Cancelling the Error Caused by Input Bias Current

4.0 TYPICAL SINGLE-SUPPLY APPLICATION CIRCUITS

4.1 Difference Amplifier

The difference amplifier allows the subtraction of two voltages or, as a special case, the cancellation of a signal common to two inputs. It is useful as a computational amplifier, in making a differential to single-ended conversion or in rejecting a common mode signal.



$$V_{OUT} = \left(\frac{R1 + R2}{R3 + R4}\right)\frac{R4}{R1} V_2 - \frac{R2}{R1} V_1 + \left(\frac{R1 + R2}{R3 + R4}\right)\frac{R3}{R1} \bullet \frac{V^+}{2}$$

for R1 = R3 and R2 = R4

$$V_{OUT} = \frac{R2}{R1}\left(V_2 - V_1\right) + \frac{V^+}{2}$$

10006019

FIGURE 7. Difference Amplifier

4.2 Instrumentation Circuits

The input impedance of the previous difference amplifier is set by the resistors R_1, R_2, R_3, and R_4. To eliminate the problems of low input impedance, one way is to use a voltage follower ahead of each input as shown in the following two instrumentation amplifiers.

Application Notes (Continued)

4.2.1 Three-Op-Amp Instrumentation Amplifier

The quad LMV324 can be used to build a three-op-amp instrumentation amplifier as shown in *Figure 8*.

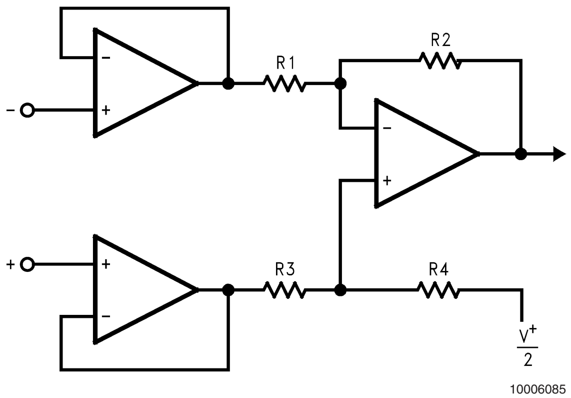
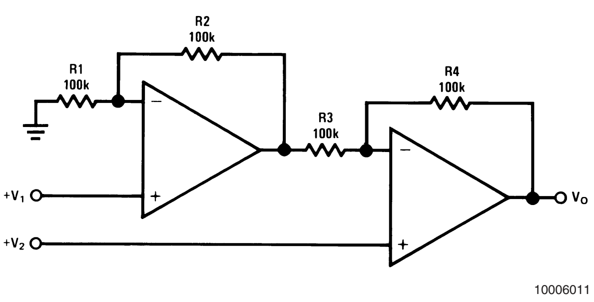


FIGURE 8. Three-op-amp Instrumentation Amplifier

The first stage of this instrumentation amplifier is a differential-input, differential-output amplifier, with two voltage followers. These two voltage followers assure that the input impedance is over 100 MΩ. The gain of this instrumentation amplifier is set by the ratio of R2/R1. R_3 should equal R_1, and R_4 equal R_2. Matching of R_3 to R_1 and R_4 to R_2 affects the CMRR. For good CMRR over temperature, low drift resistors should be used. Making R_4 slightly smaller than R_2 and adding a trim pot equal to twice the difference between R_2 and R_4 will allow the CMRR to be adjusted for optimum.

4.2.2 Two-op-amp Instrumentation Amplifier

A two-op-amp instrumentation amplifier can also be used to make a high-input-impedance dc differential amplifier (*Figure 9*) . As in the three-op-amp circuit, this instrumentation amplifier requires precise resistor matching for good CMRR. R_4 should equal to R_1 and R3 should equal R_2.



$$V_O = \left(1 + \frac{R4}{R3}\right)(V_2 - V_1), \text{ where } R1 = R4 \text{ and } R2 = R3$$

$$\text{As shown: } V_O = 2(V_2 - V_1)$$

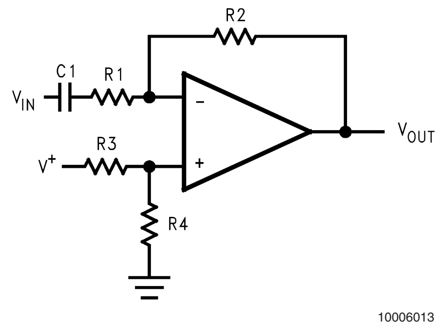
10006035

FIGURE 9. Two-Op-amp Instrumentation Amplifier

4.3 Single-Supply Inverting Amplifier

There may be cases where the input signal going into the amplifier is negative. Because the amplifier is operating in single supply voltage, a voltage divider using R_3 and R_4 is implemented to bias the amplifier so the input signal is within the input common-mode voltage range of the amplifier. The capacitor C_1 is placed between the inverting input and resistor R_1 to block the DC signal going into the AC signal source, V_{IN}. The values of R_1 and C_1 affect the cutoff frequency, fc = $1/2\pi R_1 C_1$.

As a result, the output signal is centered around mid-supply (if the voltage divider provides $V^+/2$ at the non-inverting input). The output can swing to both rails, maximizing the signal-to-noise ratio in a low voltage system.



$$V_{OUT} = -\frac{R2}{R1} V_{IN}$$

10006020

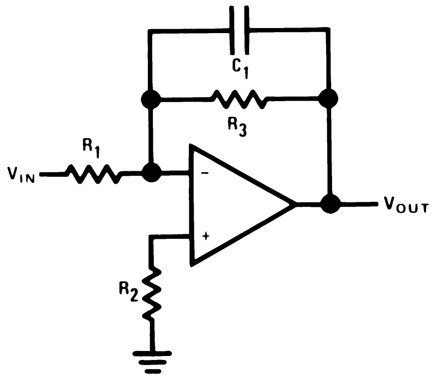
FIGURE 10. Single-Supply Inverting Amplifier

4.4 ACTIVE FILTER

4.4.1 Simple Low-Pass Active Filter

The simple low-pass filter is shown in *Figure 11*. Its low-frequency gain ($\omega \rightarrow 0$) is defined by $-R_3/R_1$. This allows low-frequency gains other than unity to be obtained. The filter has a -20dB/decade roll-off after its corner frequency fc. R_2 should be chosen equal to the parallel combination of R_1 and R_3 to minimize errors due to bias current. The frequency response of the filter is shown in *Figure 12*.

Application Notes (Continued)



$$A_L = -\frac{R_3}{R_1}$$

$$f_c = \frac{1}{2\pi R_3 C_1}$$

$$R_2 = R_1 \,||\, R_3$$

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FIGURE 11. Simple Low-Pass Active Filter

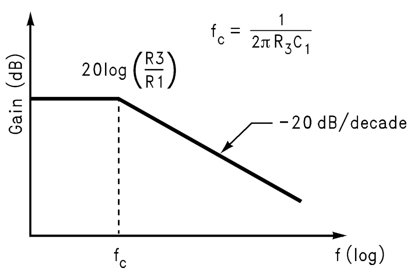


FIGURE 12. Frequency Response of Simple Low-Pass Active Filter in Figure 11

Note that the single-op-amp active filters are used in to the applications that require low quality factor, Q(≤ 10), low frequency (≤ 5 kHz), and low gain (≤ 10), or a small value for the product of gain times Q (≤ 100). The op amp should have an open loop voltage gain at the highest frequency of interest at least 50 times larger than the gain of the filter at this frequency. In addition, the selected op amp should have a slew rate that meets the following requirement:

Slew Rate ≥ 0.5 x ($\omega_H V_{OPP}$) x 10^{-6} V/µsec

where ω_H is the highest frequency of interest, and V_{opp} is the output peak-to-peak voltage.

4.4.2 Sallen-Key 2nd-Order Active Low-Pass Filter

The Sallen-Key 2nd-order active low-pass filter is illustrated in *Figure 13*. The dc gain of the filter is expressed as

$$A_{LP} = \frac{R_3}{R_4} + 1 \quad (1)$$

Its transfer function is

$$\frac{V_{OUT}}{V_{IN}}(S) = \frac{\frac{1}{C_1 C_2 R_1 R_2} A_{LP}}{S^2 + S\left(\frac{1}{C_1 R_1} + \frac{1}{C_1 R_2} + \frac{1}{C_2 R_2} - \frac{A_{LP}}{C_2 R_2}\right) + \frac{1}{C_1 C_2 R_1 R_2}} \quad (2)$$

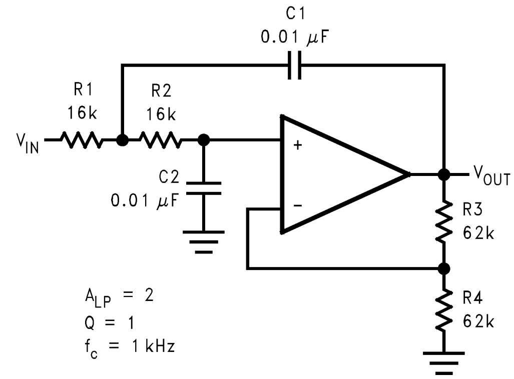


FIGURE 13. Sallen-Key 2nd-Order Active Low-Pass Filter

The following paragraphs explain how to select values for R_1, R_2, R_3, R_4, C_1, and C_2 for given filter requirements, such as A_{LP}, Q, and f_c.

The standard form for a 2nd-order low pass filter is

$$\frac{V_{OUT}}{V_{IN}}(S) = \frac{A_{LP}\,\omega_c^2}{S^2 + \left(\frac{\omega_c}{Q}\right)S + \omega_c^2} \quad (3)$$

where

Q: Pole Quality Factor

ω_C: Corner Frequency

Comparison between the *Equation (2)* and *Equation (3)* yields

$$\omega_c^2 = \frac{1}{C_1 C_2 R_1 R_2} \quad (4)$$

$$\frac{\omega_c}{Q} = \frac{1}{C_1 R_1} + \frac{1}{C_1 R_2} + \frac{1}{C_2 R_2} - \frac{A_{LP}}{C_2 R_2} \quad (5)$$

To reduce the required calculations in filter design, it is convenient to introduce normalization into the components and design parameters. To normalize, let $\omega_C = \omega_n$ = 1rad/s, and $C_1 = C_2 = C_n$ = 1F, and substitute these values into *Equation (4)* and *Equation (5)*. From *Equation (4)*, we obtain

$$R_1 = \frac{1}{R_2} \quad (6)$$

From *Equation (5)*, we obtain

$$R_2 = \frac{1 \pm \sqrt{1 - 4Q^2(2 - A_{LP})}}{2Q} \quad (7)$$

Application Notes (Continued)

For minimum dc offset, $V^+ = V^-$, the resistor values at both inverting and non-inverting inputs should be equal, which means

$$R_1 + R_2 = \frac{R_3 R_4}{R_3 + R_4} \tag{8}$$

From *Equation (1)* and *Equation (8)*, we obtain

$$R_3 = (R_1 + R_2)A_{LP} \tag{9}$$

$$R_4 = \left(\frac{A_{LP}}{A_{LP} - 1}\right)(R_1 + R_2) \tag{10}$$

The values of C_1 and C_2 are normally close to or equal to

$$C = \frac{10}{f_c}\,\mu F$$

As a design example:

Require: $A_{LP} = 2$, Q = 1, fc = 1KHz

Start by selecting C_1 and C_2. Choose a standard value that is close to

$$C = \frac{10}{f_c}\,\mu F$$

$$C_1 = C_2 = \frac{10}{1 \times 10^3}\,\mu F = 0.01\,\mu F$$

From *Equations (6), (7), (9), (10)*,

$R_1 = 1\Omega$

$R_2 = 1\Omega$

$R_3 = 4\Omega$

$R_4 = 4\Omega$

The above resistor values are normalized values with ω_n = 1rad/s and $C_1 = C_2 = C_n$ = 1F. To scale the normalized cut-off frequency and resistances to the real values, two scaling factors are introduced, frequency scaling factor (k_f) and impedance scaling factor (k_m).

$$k_f = \frac{\omega_c}{\omega_n} = \frac{2\pi \times 1 \times 10^3}{1} = 2\pi \times 10^3$$

$$k_m k_f = \frac{Cn}{C1}$$

$$k_m = 1.59 \times 10^4$$

Scaled values:

$R_2 = R_1 = 15.9\ k\Omega$

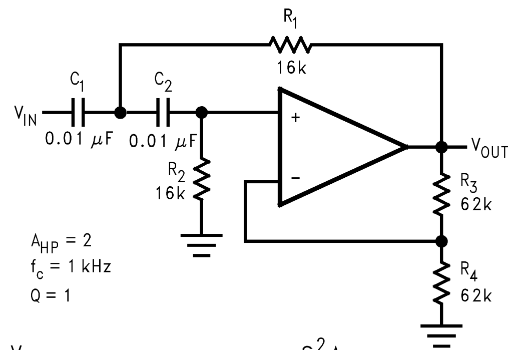
$R_3 = R_4 = 63.6\ k\Omega$

$C_1 = C_2 = 0.01\ \mu F$

An adjustment to the scaling may be made in order to have realistic values for resistors and capacitors. The actual value used for each component is shown in the circuit.

4.4.3 2nd-order High Pass Filter

A 2nd-order high pass filter can be built by simply interchanging those frequency selective components (R_1, R_2, C_1, C_2) in the Sallen-Key 2nd-order active low pass filter. As shown in *Figure 14*, resistors become capacitors, and capacitors become resistors. The resulted high pass filter has the same corner frequency and the same maximum gain as the previous 2nd-order low pass filter if the same components are chosen.



$$\frac{V_{OUT}}{V_{IN}}(S) = \frac{S^2 A_{HP}}{S^2 + S\left(\frac{1}{C_1 R_2} + \frac{1}{C_2 R_2} + \frac{(1 - A_{HP})}{C_1 R_1}\right) + \frac{1}{C_1 C_2 R_1 R_2}}$$

Where $A_{HP} = 1 + \frac{R_3}{R_4}$

10006083

FIGURE 14. Sallen-Key 2nd-Order Active High-Pass Filter

4.4.4 State Variable Filter

A state variable filter requires three op amps. One convenient way to build state variable filters is with a quad op amp, such as the LMV324 (*Figure 15*).

This circuit can simultaneously represent a low-pass filter, high-pass filter, and bandpass filter at three different outputs. The equations for these functions are listed below. It is also called "Bi-Quad" active filter as it can produce a transfer function which is quadratic in both numerator and denominator.

Application Notes (Continued)

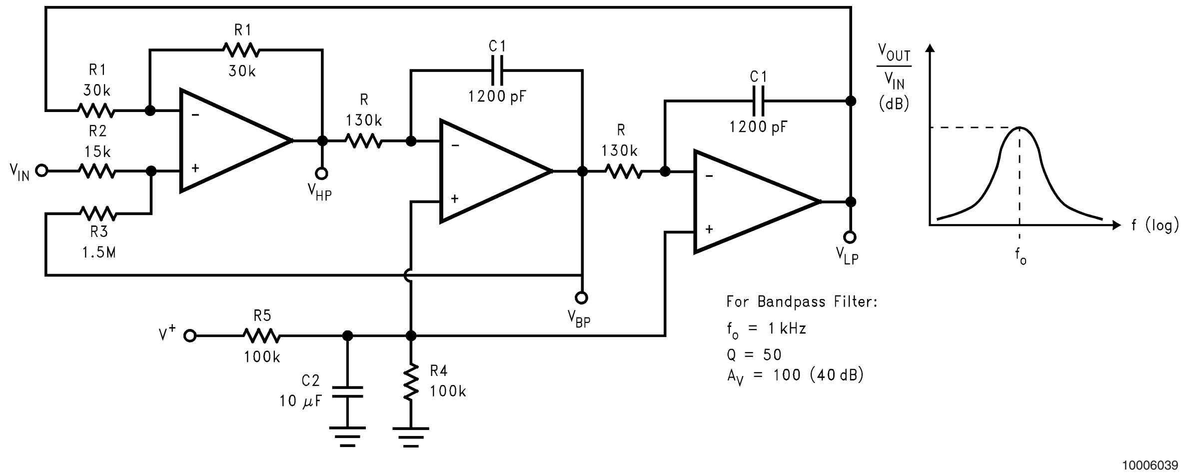


FIGURE 15. State Variable Active Filter

$$V_{LP} = \left(\frac{2R_3}{R_2+R_3}\right)\frac{\frac{1}{R^2C^2}}{S^2 + \frac{1}{\left(\frac{R_2+R_3}{2R_2}\right)RC}S + \frac{1}{R^2C^2}}V_{IN}$$

$$V_{HP} = \left(\frac{2R_3}{R_2+R_3}\right)\frac{S^2}{S^2 + \frac{1}{\left(\frac{R_2+R_3}{2R_2}\right)RC}S + \frac{1}{R^2C^2}}V_{IN}$$

$$V_{BP} = \left(\frac{2R_3}{R_2+R_3}\right)\frac{\left(\frac{1}{RC}\right)S}{S^2 + \frac{1}{\left(\frac{R_2+R_3}{2R_2}\right)RC}S + \frac{1}{R^2C^2}}V_{IN}$$

where for all three filters,

$$Q = \frac{R_2+R_3}{2R_2} \quad (11)$$

$$\omega_0 = \frac{1}{RC} \quad \text{(resonant frequency)} \quad (12)$$

A design example for a bandpass filter is shown below:

Assume the system design requires a bandpass filter with f_O = 1kHz and Q = 50. What needs to be calculated are capacitor and resistor values.

First choose convenient values for C_1, R_1 and R_2:

$$C_1 = 1200\text{pF}$$

$$2R_2 = R_1 = 30\text{k}\Omega$$

Then from *Equation (11)*,

$$R_3 = R_2(2Q-1)$$

$$R_3 = 15\,\text{k}\Omega \times (2 \times 50-1)$$

$$= 1.5\,\text{M}\Omega$$

From *Equation (12)*,

$$R = \frac{1}{\omega_0 C_1}$$

$$R = \frac{1}{(2\pi \times 10^3)(1.2 \times 10^{-9})}$$

$$= 132.7\,\text{k}\Omega$$

From the above calculated values, the midband gain is $H_O = R_3/R_2$ = 100 (40dB). The nearest 5% standard values have been added to *Figure 15*.

4.5 PULSE GENERATORS AND OSCILLATORS

A pulse generator is shown in *Figure 16*. Two diodes have been used to separate the charge and discharge paths to capacitor C.

Application Notes (Continued)

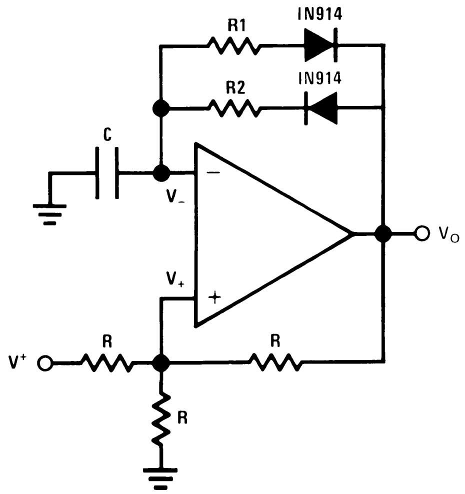
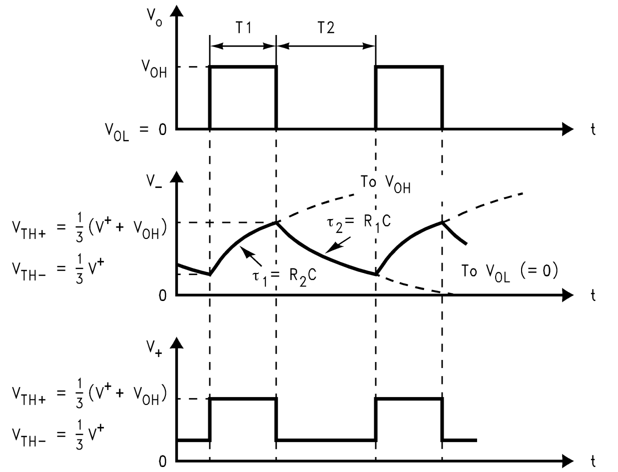


FIGURE 16. Pulse Generator

When the output voltage V_O is first at its high, V_{OH}, the capacitor C is charged toward V_{OH} through R_2. The voltage across C rises exponentially with a time constant $\tau = R_2C$, and this voltage is applied to the inverting input of the op amp. Meanwhile, the voltage at the non-inverting input is set at the positive threshold voltage (V_{TH+}) of the generator. The capacitor voltage continually increases until it reaches V_{TH+}, at which point the output of the generator will switch to its low, V_{OL} (= 0V in this case). The voltage at the non-inverting input is switched to the negative threshold voltage (V_{TH-}) of the generator. The capacitor then starts to discharge toward V_{OL} exponentially through R_1, with a time constant $\tau = R_1C$. When the capacitor voltage reaches V_{TH-}, the output of the pulse generator switches to V_{OH}. The capacitor starts to charge, and the cycle repeats itself.



$$T_1 = R_2C \ln \frac{3V_{OH} - V_{OL} - V^+}{2V_{OH} - V^+} \quad \text{and} \quad T_2 = R_1C \ln \frac{3V_{OL} - V_{OH} - V^+}{2V_{OL} - V^+}$$

When $V_{OL} = 0V$

$$T_1 = R_2C \ln \frac{3V_{OH} - V^+}{2V_{OH} - V^+} \quad \text{and} \quad T_2 = R_1C \ln \left(1 + \frac{V_{OH}}{V^+}\right)$$

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FIGURE 17. Waveforms of the Circuit in Figure 16

As shown in the waveforms in *Figure 17*, the pulse width (T_1) is set by R_2, C and V_{OH}, and the time between pulses (T_2) is set by R_1, C and V_{OL}. This pulse generator can be made to have different frequencies and pulse width by selecting different capacitor value and resistor values.

Figure 18 shows another pulse generator, with separate charge and discharge paths. The capacitor is charged through R_1 and is discharged through R_2.

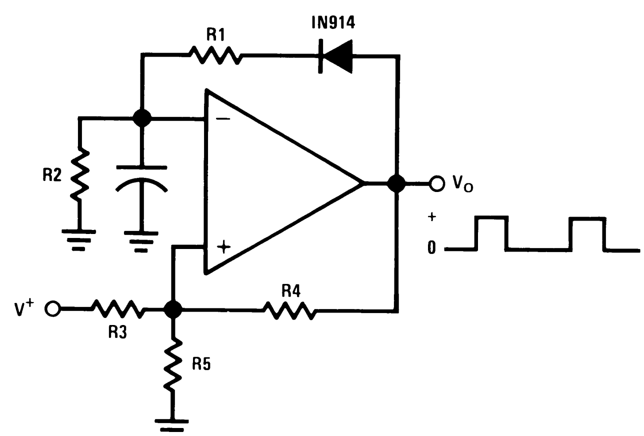


FIGURE 18. Pulse Generator

Figure 19 is a squarewave generator with the same path for charging and discharging the capacitor.

Application Notes (Continued)

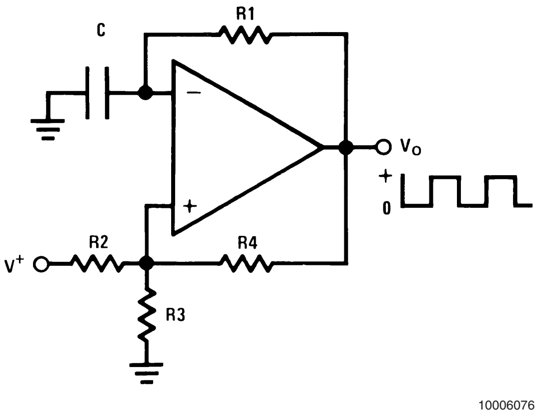


FIGURE 19. Squarewave Generator

4.6 CURRENT SOURCE AND SINK

The LMV321/358/324 can be used in feedback loops which regulate the current in external PNP transistors to provide current sources or in external NPN transistors to provide current sinks.

4.6.1 Fixed Current Source

A multiple fixed current source is show in *Figure 20*. A voltage (V_{REF} = 2V) is established across resistor R_3 by the voltage divider (R_3 and R_4). Negative feedback is used to cause the voltage drop across R_1 to be equal to V_{REF}. This controls the emitter current of transistor Q_1 and if we neglect the base current of Q_1 and Q_2, essentially this same current is available out of the collector of Q_1.

Large input resistors can be used to reduce current loss and a Darlington connection can be used to reduce errors due to the β of Q_1.

The resistor, R_2, can be used to scale the collector current of Q_2 either above or below the 1mA reference value.

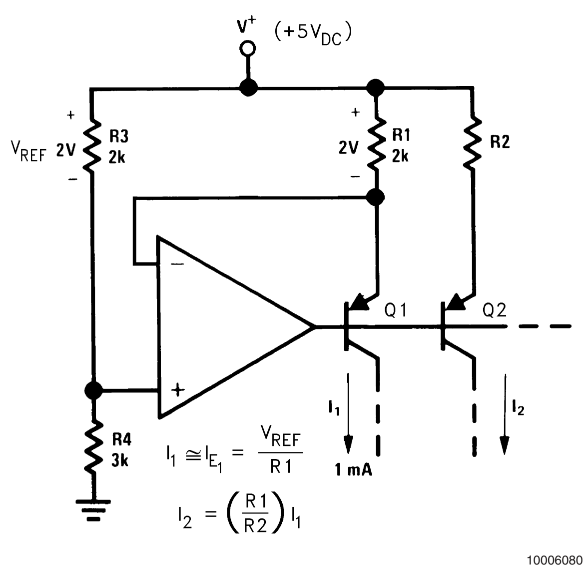


FIGURE 20. Fixed Current Source

4.6.2 High Compliance Current Sink

A current sink circuit is shown in *Figure 21*. The circuit requires only one resistor (R_E) and supplies an output current which is directly proportional to this resistor value.

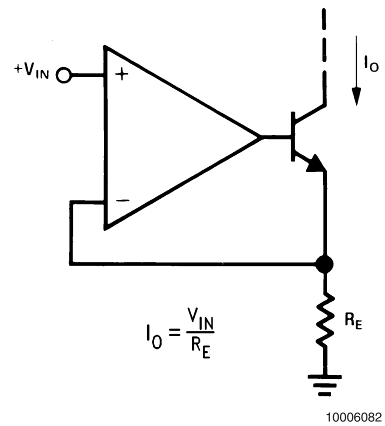


FIGURE 21. High Compliance Current Sink

4.7 POWER AMPLIFIER

A power amplifier is illustrated in *Figure 22*. This circuit can provide a higher output current because a transistor follower is added to the output of the op amp.

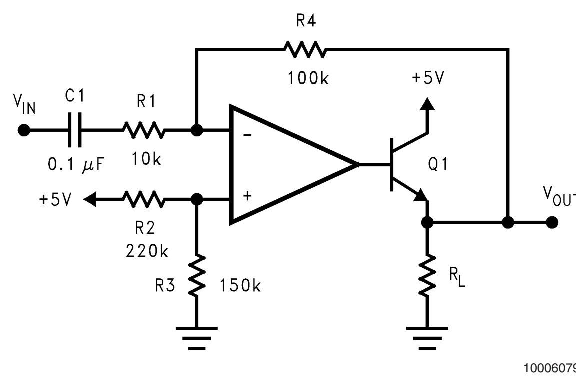


FIGURE 22. Power Amplifier

4.8 LED DRIVER

The LMV321/358/324 can be used to drive an LED as shown in *Figure 23*.

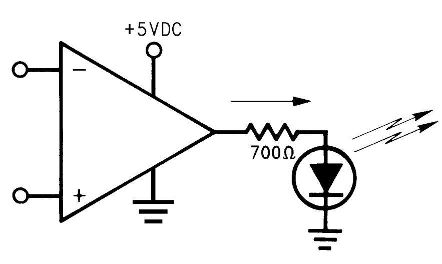


FIGURE 23. LED Driver

Application Notes (Continued)

4.9 COMPARATOR WITH HYSTERESIS

The LMV321/358/324 can be used as a low power comparator. *Figure 24* shows a comparator with hysteresis. The hysteresis is determined by the ratio of the two resistors.

$$V_{TH+} = V_{REF}/(1+R_1/R_2)+V_{OH}/(1+R_2/R_1)$$

$$V_{TH-} = V_{REF}/(1+R_1/R_2)+V_{OL}/(1+R_2/R_1)$$

$$V_H = (V_{OH}-V_{OL})/(1+R_2/R_1)$$

where

V_{TH+}: Positive Threshold Voltage

V_{TH-}: Negative Threshold Voltage

V_{OH}: Output Voltage at High

V_{OL}: Output Voltage at Low

V_H: Hysteresis Voltage

Since LMV321/358/324 have rail-to-rail output, the $(V_{OH}-V_{OL})$ equals to V_S, which is the supply voltage.

$$V_H = V_S/(1+R_2/R_1)$$

The differential voltage at the input of the op amp should not exceed the specified absolute maximum ratings. For real comparators that are much faster, we recommend you to use National's LMV331/393/339, which are single, dual and quad general purpose comparators for low voltage operation.

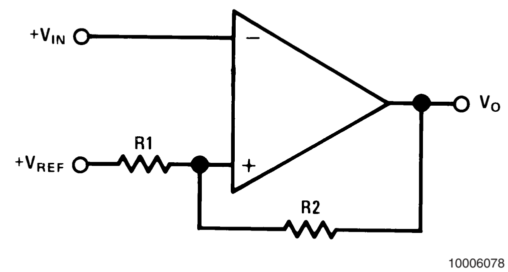
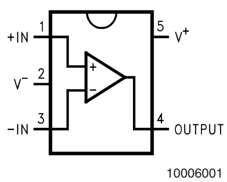


FIGURE 24. Comparator with Hysteresis

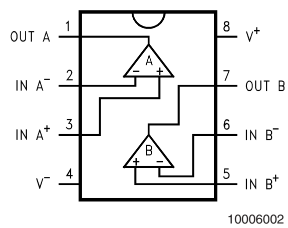
Connection Diagrams

5-Pin SC70-5/SOT23-5



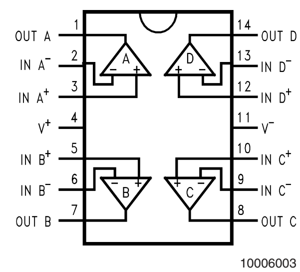
Top View

8-Pin SO/MSOP



Top View

14-Pin SO/TSSOP

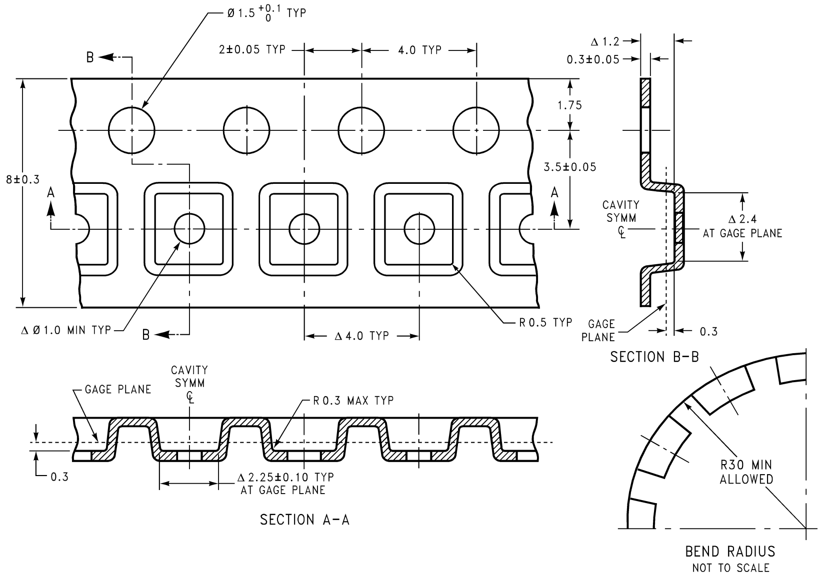


Top View

Ordering Information

Package	Temperature Range Industrial −40˚C to +85˚C	Packaging Marking	Transport Media	NSC Drawing
5-Pin SC70-5	LMV321M7	A12	1k Units Tape and Reel	MAA05
	LMV321M7X	A12	3k Units Tape and Reel	
5-Pin SOT23-5	LMV321M5	A13	1k Units Tape and Reel	MA05B
	LMV321M5X	A13	3k Units Tape and Reel	
8-Pin Small Outline	LMV358M	LMV358M	Rails	M08A
	LMV358MX	LMV358M	2.5k Units Tape and Reel	
8-Pin MSOP	LMV358MM	LMV358	1k Units Tape and Reel	MUA08A
	LMV358MMX	LMV358	3.5k Units Tape and Reel	
14-Pin Small Outline	LMV324M	LMV324M	Rails	M14A
	LMV324MX	LMV324M	2.5k Units Tape and Reel	
14-Pin TSSOP	LMV324MT	LMV324MT	Rails	MTC14
	LMV324MTX	LMV324MT	2.5k Units Tape and Reel	

SC70-5 Tape and Reel Specification



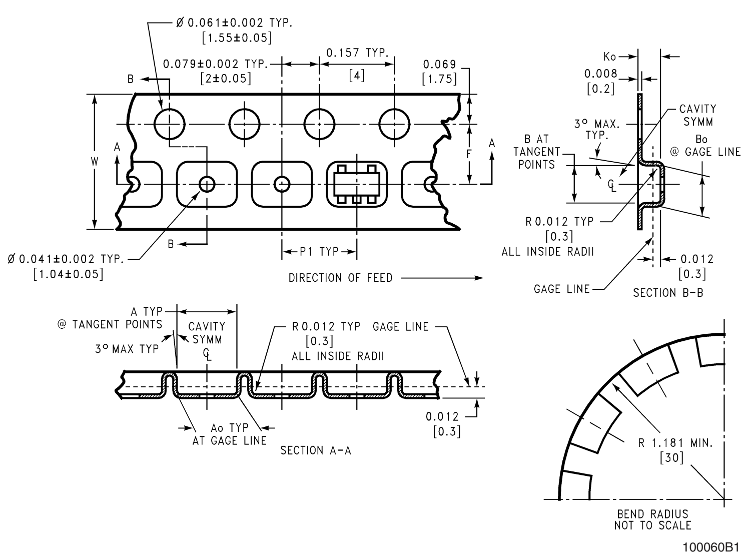
100060B3

SOT-23-5 Tape and Reel Specification

TAPE FORMAT

Tape Section	# Cavities	Cavity Status	Cover Tape Status
Leader	0 (min)	Empty	Sealed
(Start End)	75 (min)	Empty	Sealed
Carrier	3000	Filled	Sealed
	250	Filled	Sealed
Trailer	125 (min)	Empty	Sealed
(Hub End)	0 (min)	Empty	Sealed

TAPE DIMENSIONS

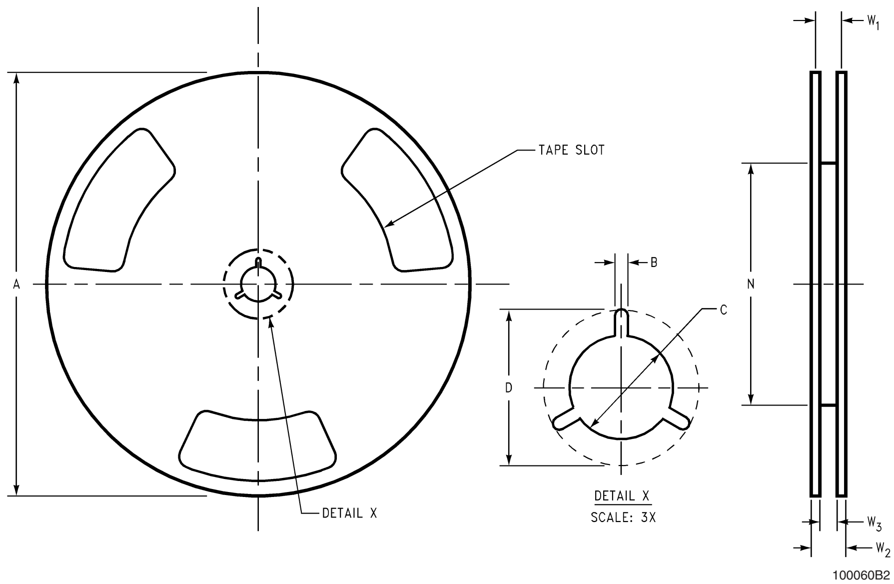


100060B1

SOT-23-5 Tape and Reel Specification (Continued)

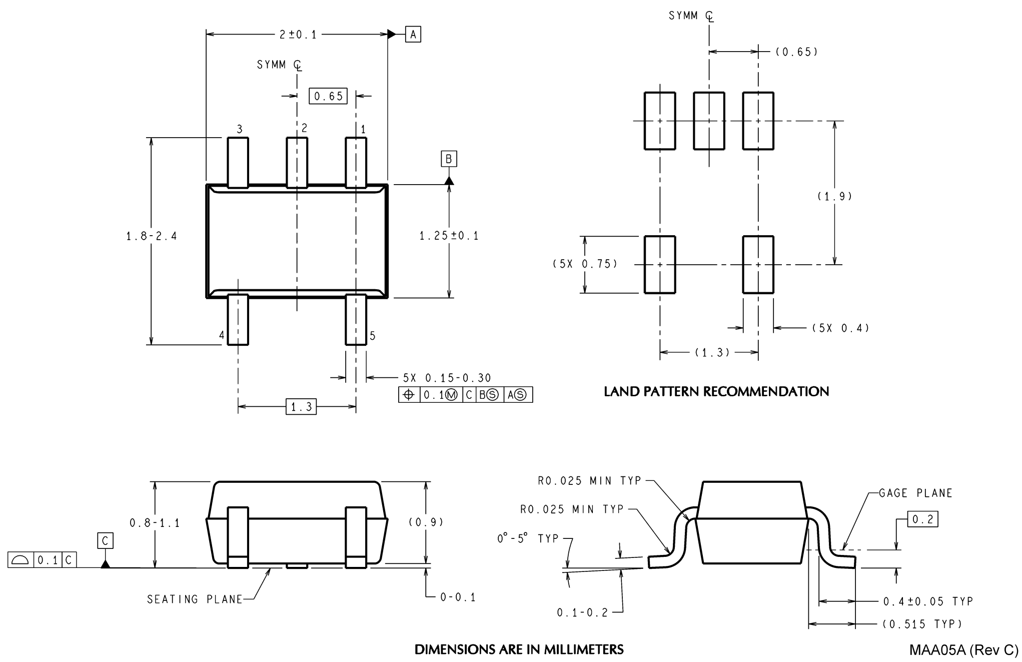
8 mm	0.130 (3.3)	0.124 (3.15)	0.130 (3.3)	0.126 (3.2)	0.138 ±0.002 (3.5 ±0.05)	0.055 ±0.004 (1.4 ±0.11)	0.157 (4)	0.315 ±0.012 (8 ±0.3)
Tape Size	DIM A	DIM Ao	DIM B	DIM Bo	DIM F	DIM Ko	DIM P1	DIM W

REEL DIMENSIONS

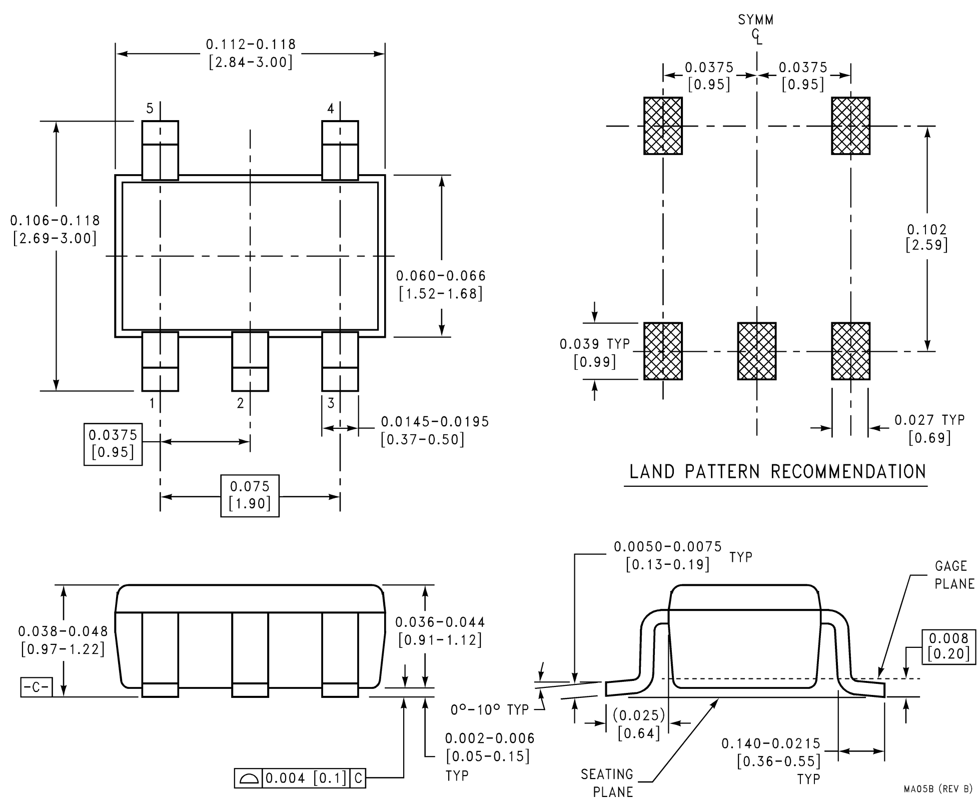


8 mm	7.00 330.00	0.059 1.50	0.512 13.00	0.795 20.20	2.165 55.00	0.331 + 0.059/−0.000 8.40 + 1.50/−0.00	0.567 14.40	W1+ 0.078/−0.039 W1 + 2.00/−1.00
Tape Size	A	B	C	D	N	W1	W2	W3

Physical Dimensions inches (millimeters) unless otherwise noted

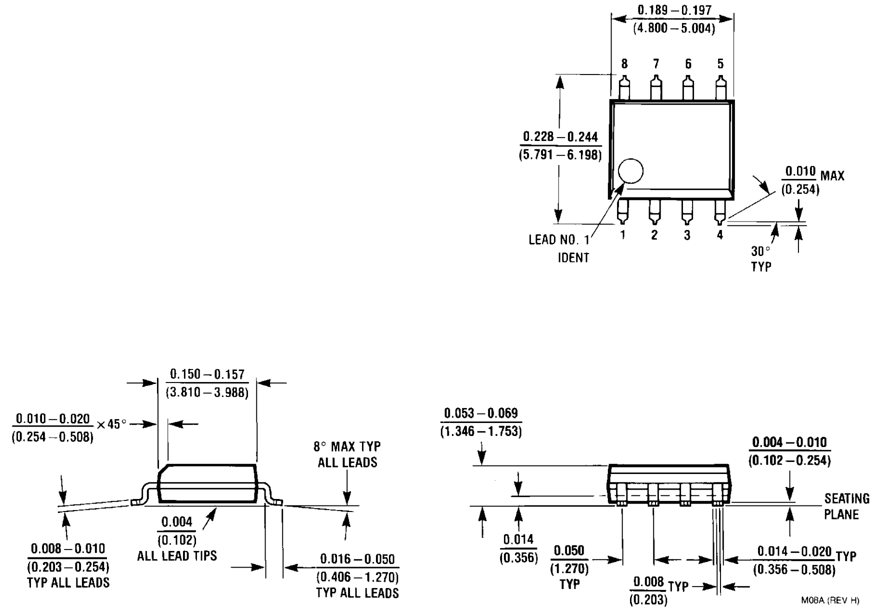


5-Pin SC70-5
NS Package Number MAA05A

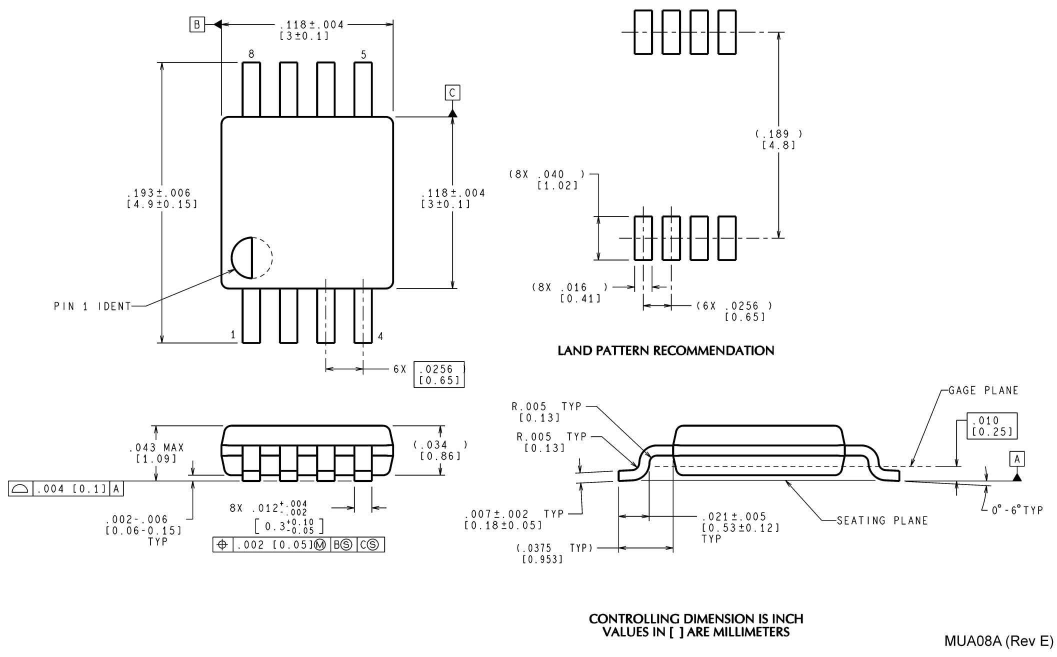


5-Pin SOT23-5
NS Package Number MA05B

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)

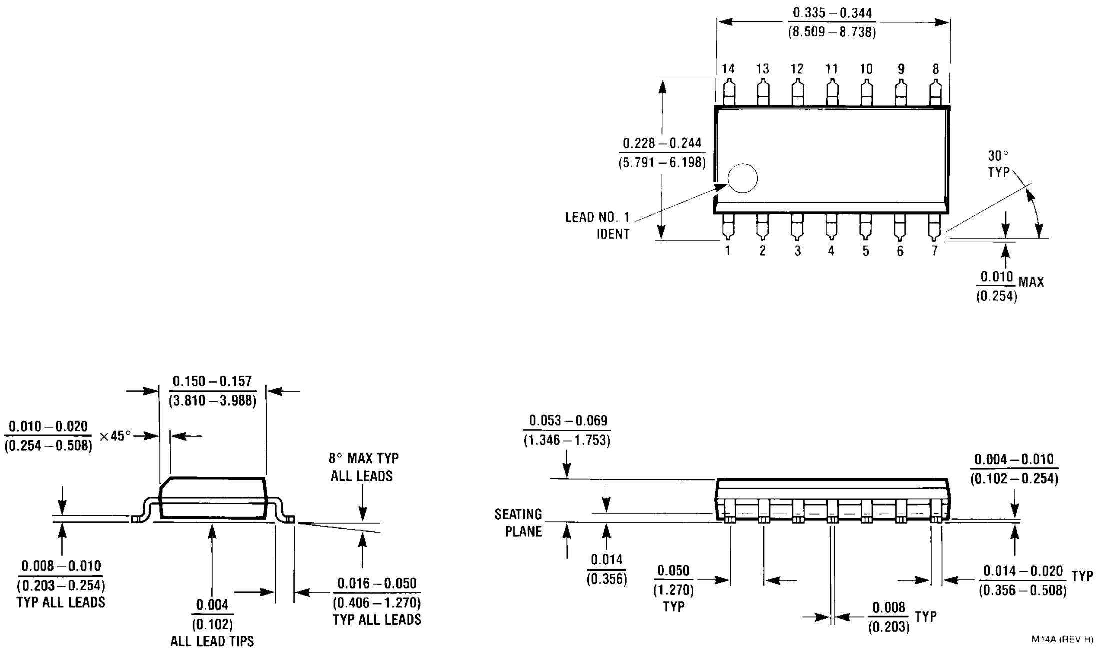


8-Pin SOIC
NS Package Number M08A

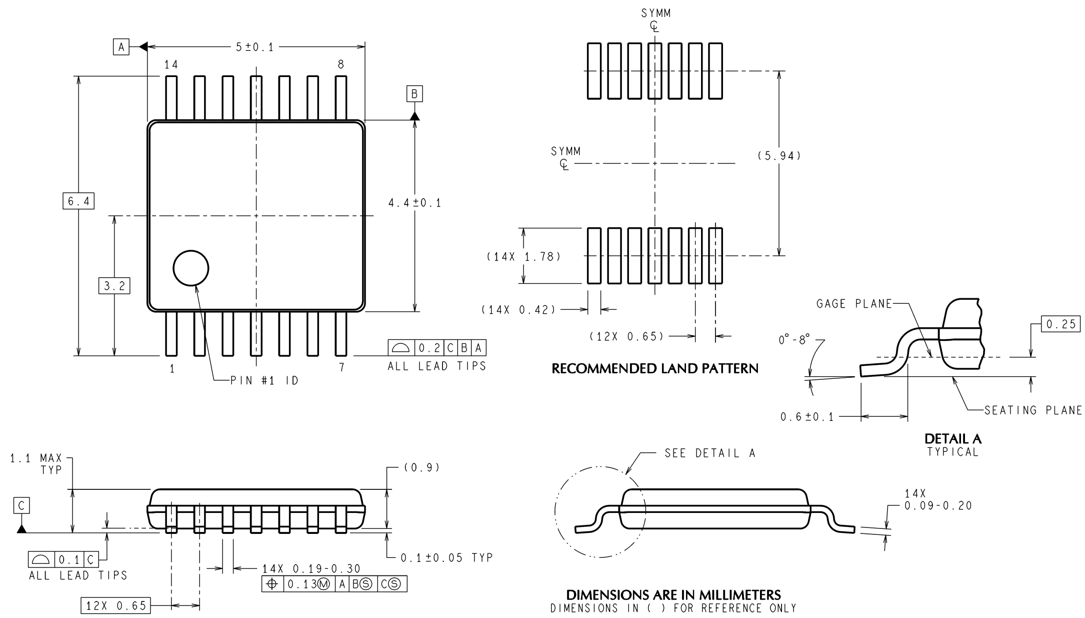


8-Pin MSOPNS Package Number MUA08A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



14-Pin SOIC
NS Package Number M14A



MTC14 (Rev D)

14-Pin TSSOPNS Package Number MTC14

Notes

LIFE SUPPORT POLICY

National Semiconductor
Americas Customer
Support Center
Email: new.feedback@nsc.com
Tel: 1-800-272-9959

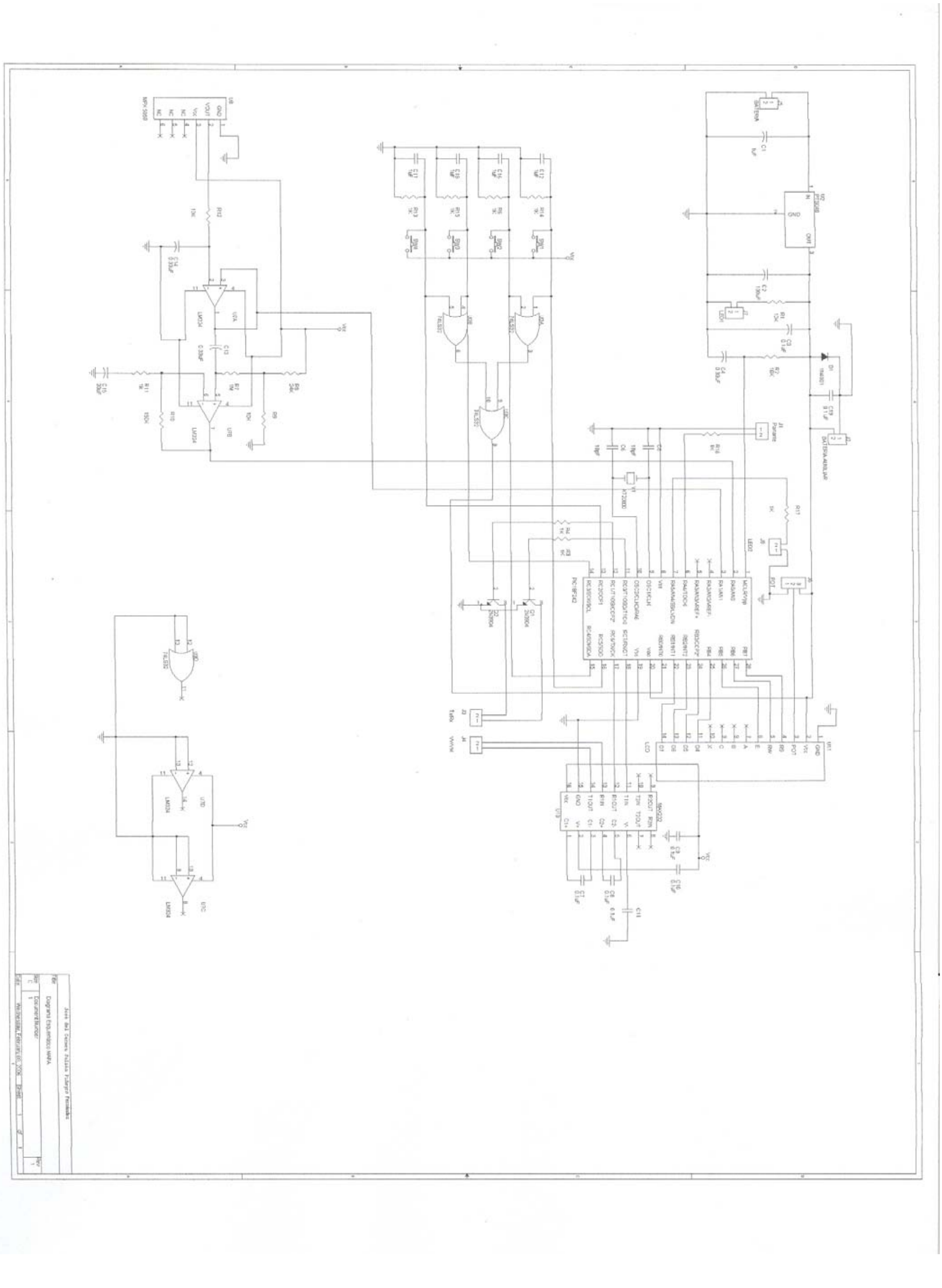
www.national.com

National Semiconductor
Europe Customer Support Center
Fax: +49 (0) 180-530 85 86
Email: europe.support@nsc.com
Deutsch Tel: +49 (0) 69 9508 6208
English Tel: +44 (0) 870 24 0 2171
Français Tel: +33 (0) 1 41 91 8790

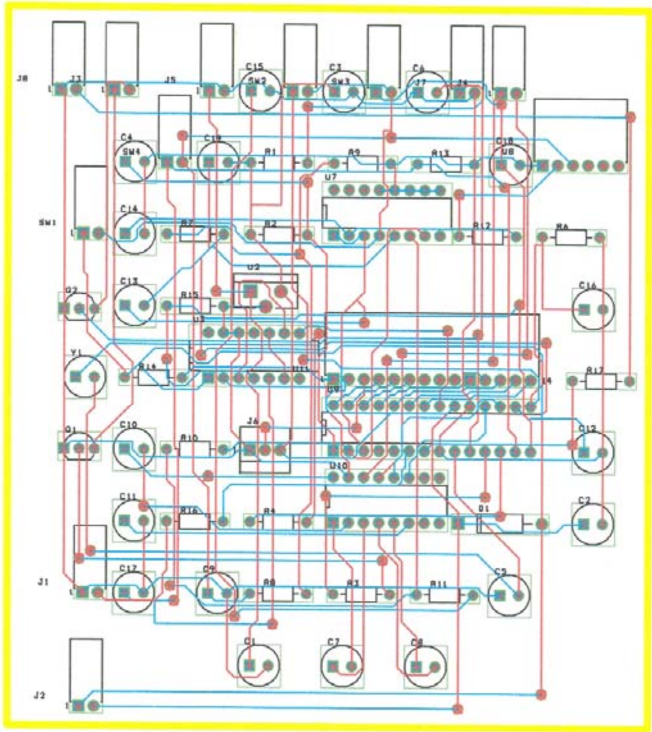
National Semiconductor
Asia Pacific Customer
Support Center
Email: ap.support@nsc.com

National Semiconductor
Japan Customer Support Center
Fax: 81-3-5639-7507
Email: jpn.feedback@nsc.com
Tel: 81-3-5639-7560

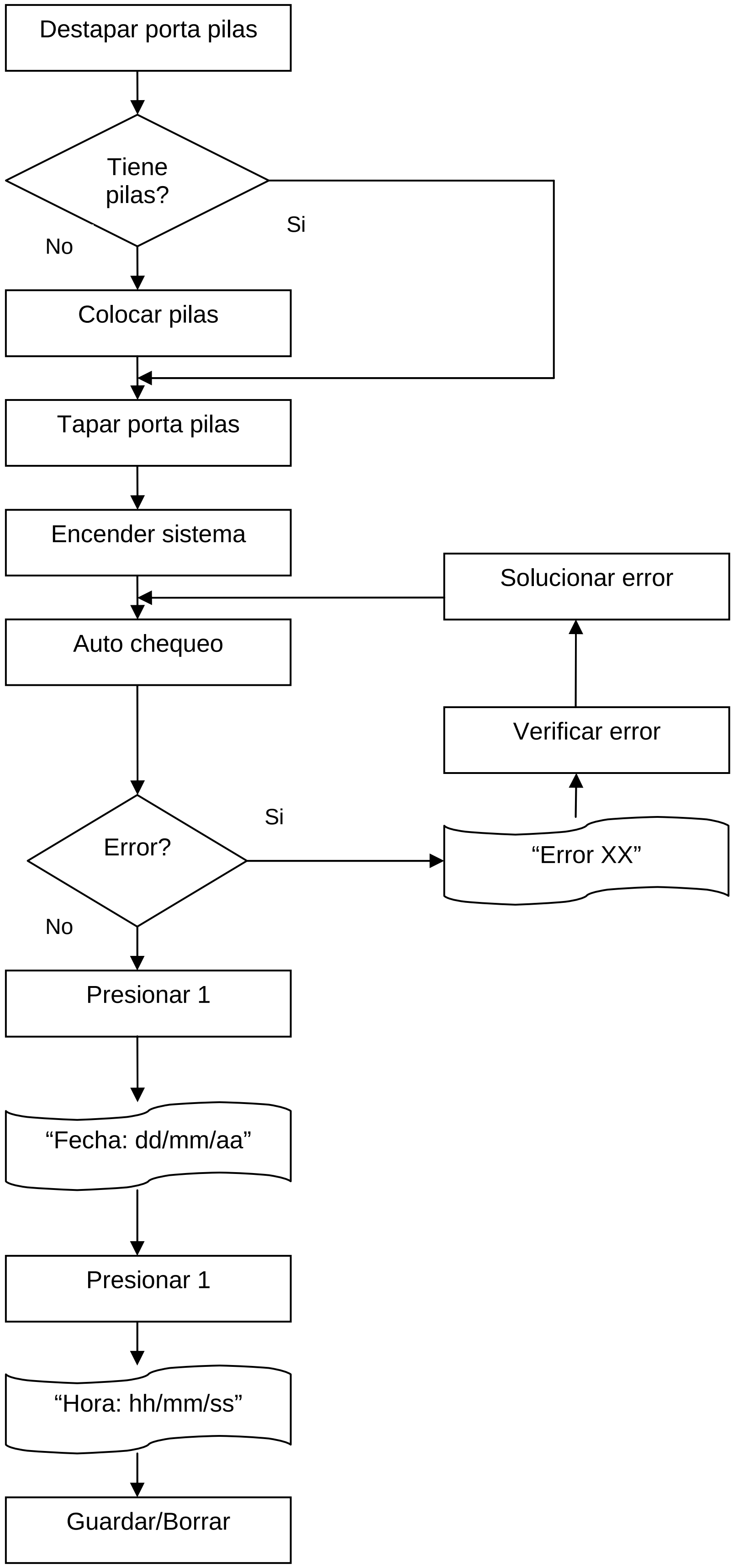
Anexo N° 4a Diagrama eléctrico esquemático del MAPA



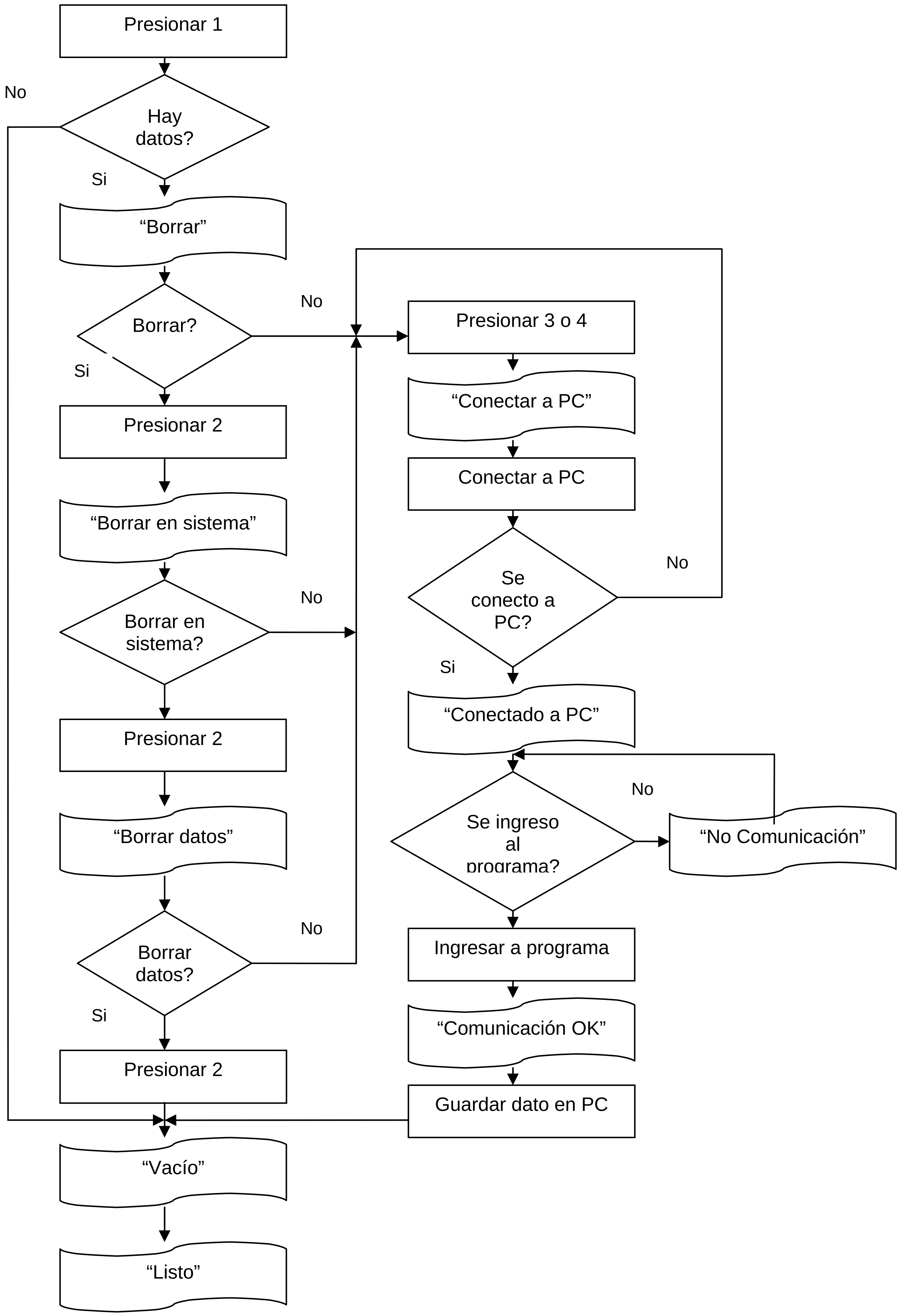
Anexo N° 4b Diagrama de la tarjeta de circuito impreso del MAPA



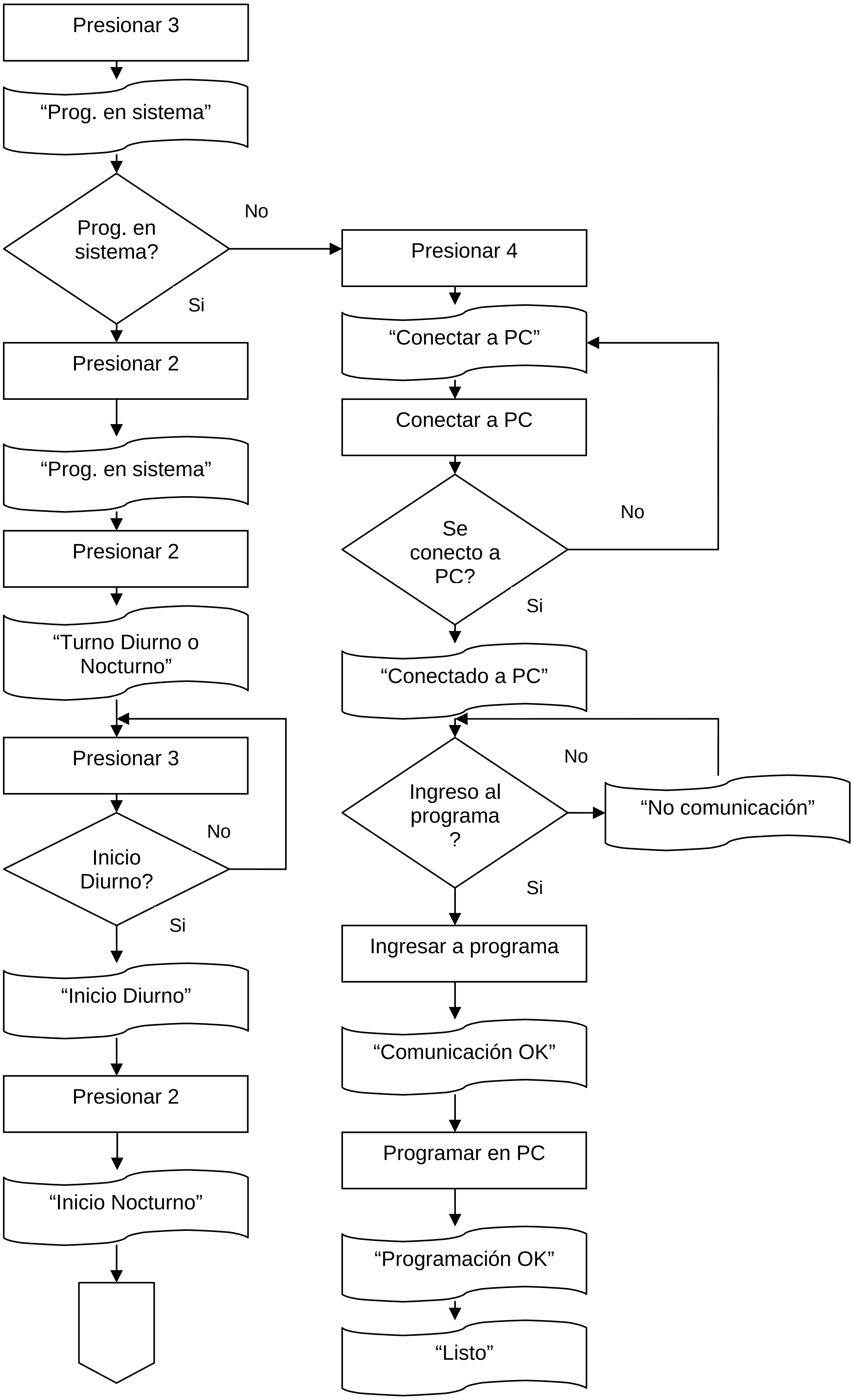
Anexo N° 5a   Rutina Iniciar

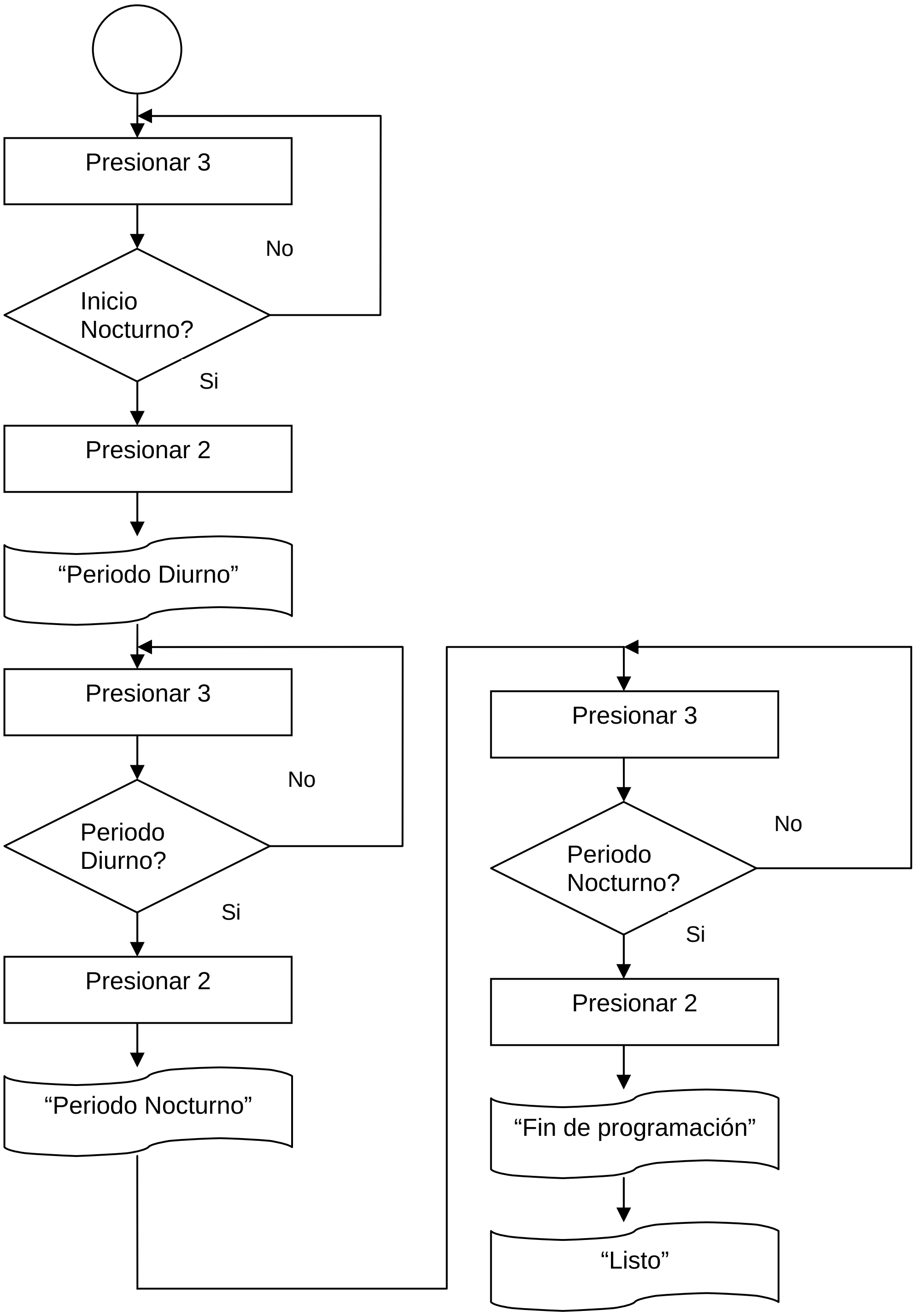


Anexo N° 5b   Rutina Guardar / Borrar

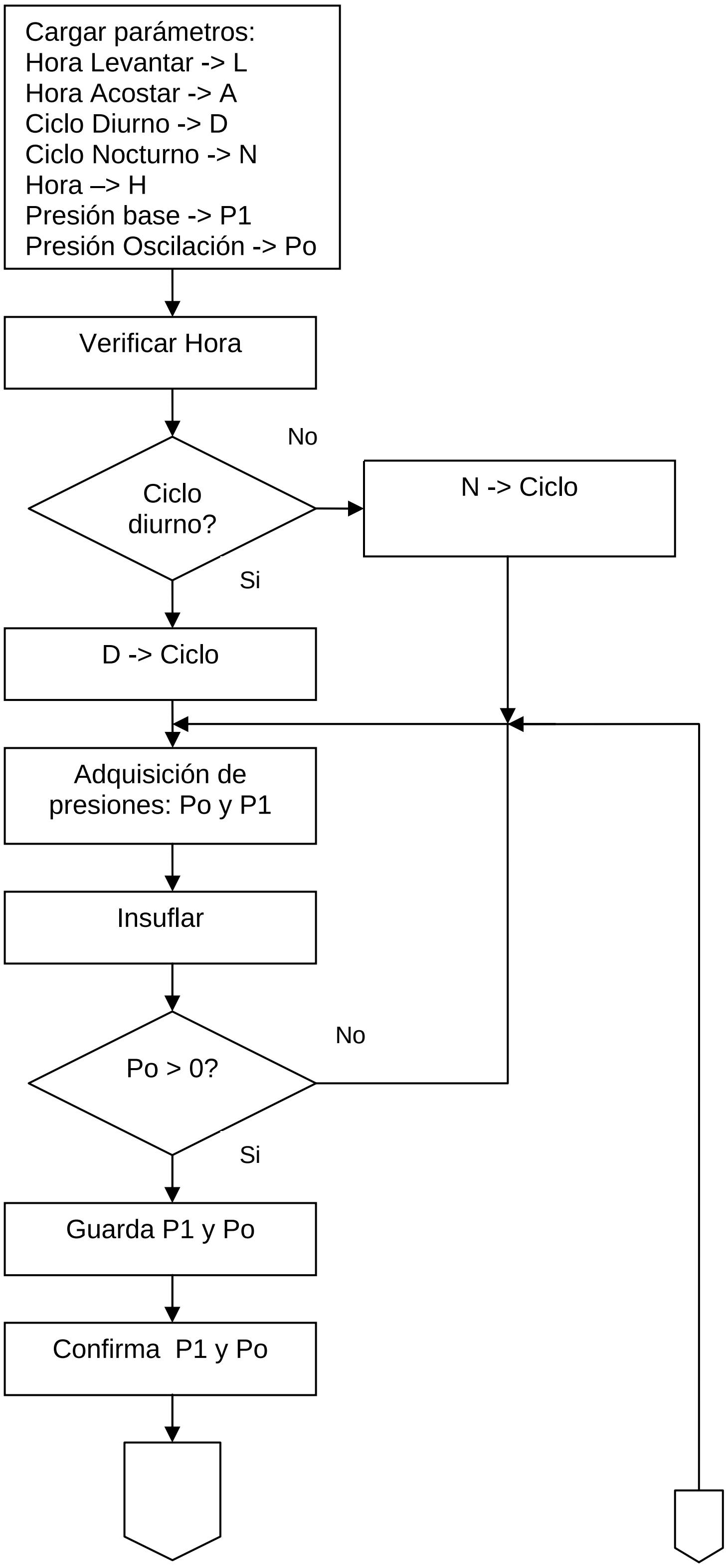


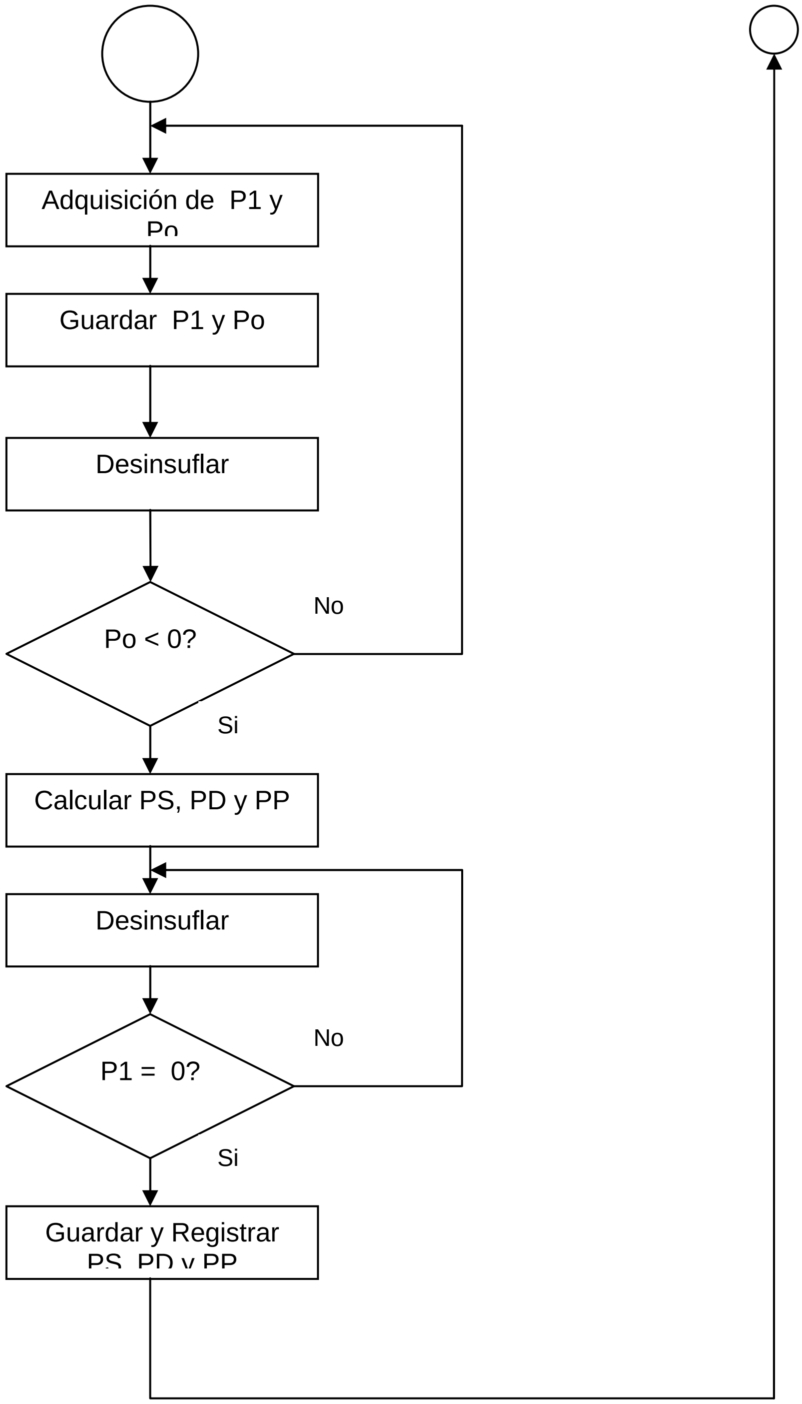
Anexo N°5c Rutina Programar



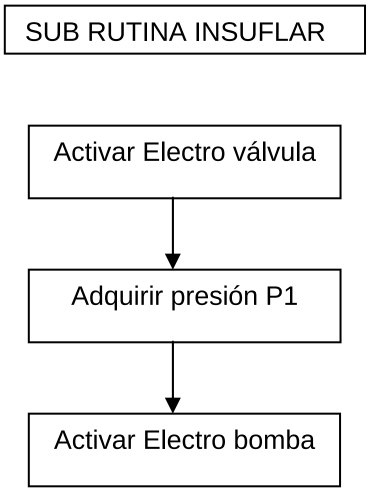

Presionar 3
No
Inicio
Nocturno?
Si
Presionar 2
"Periodo Diurno"
Presionar 3
No
Periodo
Diurno?
Si
Presionar 2
"Periodo Nocturno"
Presionar 3
No
Periodo
Nocturno?
Si
Presionar 2
"Fin de programación"
"Listo"

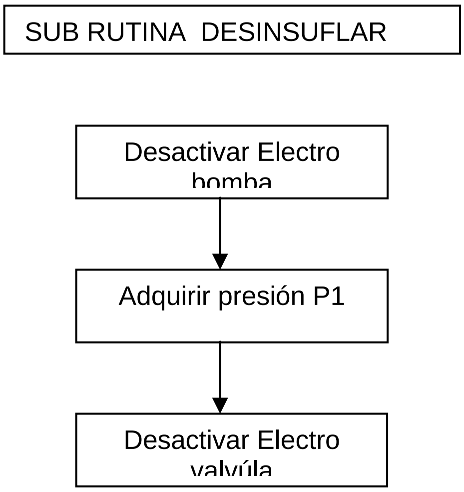
Anexo N° 5d Rutina Adquirir Medir

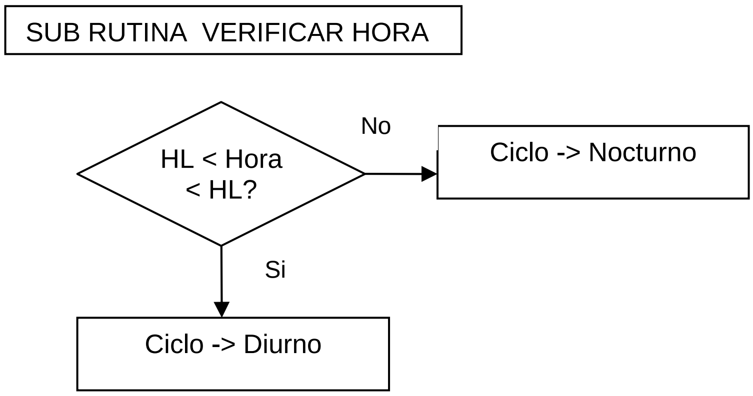




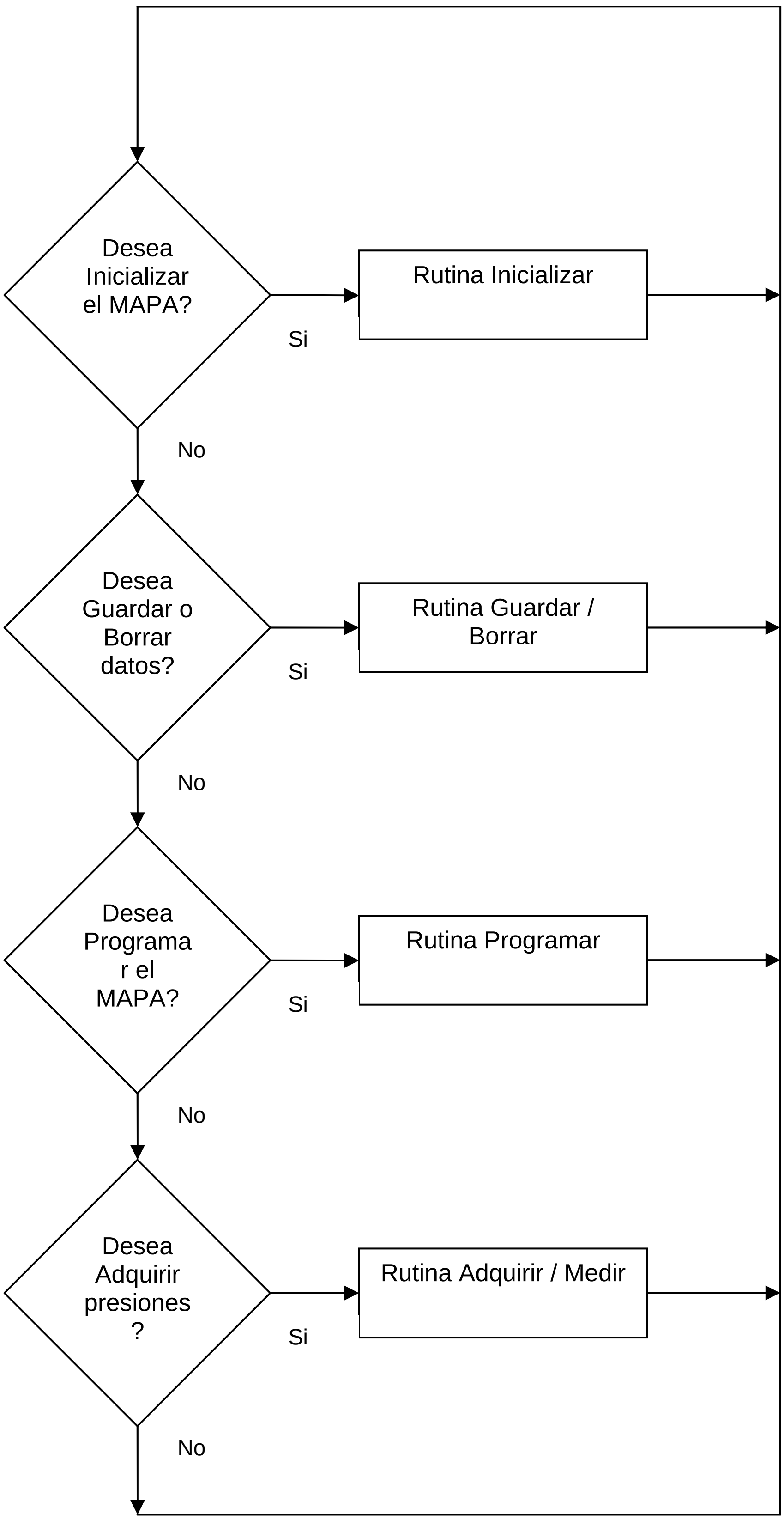
Adquisición de P1 y Po
Guardar P1 y Po
Desinsuflar
Po < 0?
No
Si
Calcular PS, PD y PP
Desinsuflar
P1 = 0?
No
Si
Guardar y Registrar PS, PD y PP


SUB RUTINA INSUFLAR
Activar Electro válvula
Adquirir presión P1
Activar Electro bomba


SUB RUTINA DESINSUFLAR
Desactivar Electro bomba
Adquirir presión P1
Desactivar Electro valvúla


SUB RUTINA VERIFICAR HORA
HL < Hora
< HL?
No
Ciclo -> Nocturno
Si
Ciclo -> Diurno

Anexo N°5e Diagrama de flujo general del MAPA



MANUAL DE UTULIZACION DEL SOFTWARE MAPASAV PLUS 1.0

Rev: 00	Fecha: 26.02.2001	P/N: MAPASAVPLUS.DOC

CONDICIONES DE GARANTIA

La garantía de 12 meses de SAVE 33 cubre el coste de las piezas y mano de obra de todos los productos originales SAVE 33 a partir de la fecha de la compra, la factura atestiguando.

Componentes defectuosos que no están fabricados por SAVE 33 como ordenadores, tarjeta opcionales y periféricos diferentes de los originales quedan excluidos.

Los daños producidos por un trato y utilización incorrectos, deterioro o equivocaciones producidos por inexpertos o reparaciones no permitidas, así como consumibles y gastos de transportes quedan también excluídos.

Exclusiones de la Garantía:

La garantía de 12 meses de SAVE 33 se aplicará para los aparatos si :

- Las instrucciones se respetan y especialmente las indicadas en la utilización de las pilas y baterías.

- El aparato junto con los accesorios se devolverán devueltos en su caja original.

SUMARIO

PREAMBULO

Estas líneas precisan los términos empleados en este manual y corrientemente utilizados en la especialidad de la hipertensión arterial.

MAPA : 1. Medida ambulatoria de la presión arterial.
2. Designa también el aparato de medida ambulatorio de la presión arterial.

MAPA33 : Aparato de MAPA comercializado por la sociedad SAVE 33. Dos versiones son disponibles:

- el MAPA33 simple que efectua el registro de la presión arterial siguiente dos tiempos de ciclo, el tiempo de ciclo día y el tiempo de ciclo noche principiante respectivamente la hora de levantar y la hora de acostar.
- el MAPA33 multiciclos puede tener hasta 12 diferentes tiempos de ciclos hace falta determinar la hora de principio para cada uno. La hora de levantar y de acostar ya no intervienen para designar un aparato de medida ambulatoria.

HOLTER : Término corriente utilizado para designar un aparato de medida ambulatoria.
Se encuentra así:

- Holter ECG registran la señal electrocardiógrafo.
- Holter tensionales registran la presión arterial de modo periódico siguiente ciclos pre-definidos.

ACTIVIDAD : Junto a los movimientos efectuados por un paciente quien informa el práctico sobre las condiciones de la presa de las medidas de presión arterial.

Para esta opción, contactar a su distribuidor.

I - INTRODUCCIÓN

I-1. Composición del kit PC

Su kit PC se compone de :

- un diskét de la última versión del software MAPASAV PLUS
- un cable RS 232 de interface entre el MAPA y su ordenador
- un cordón adaptador
- un manual de utilización del software MAPASAV PLUS

I-2. A cerca de este manual

Este manual está destinado a los usuarios ya acostumbrados al MAPA. Las nociones de base en cuanto a la utilización de Windows son también necesarias.
En caso contrario, refiérase a las documentaciones pertinentes.

Para los usuarios que no tengan un ratón, el símbolo ☞ aparece para explicar la utilización de los mandos en el teclado.

I-3. Algunas explicaciones breves

El software MAPASAV PLUS permite aprovechar en su totalidad el uso del MAPA. Permite establecer una base de datos de todas las grabaciones que habrá efectuado, presentarlas en la pantalla de su ordenador en forma de gráficos, efectuar cálculos estadísticos, publicar informes. Conjuga las ventajas de un sístema de lectura personalizada y las posibilidades de diagnóstico profesional de la presión arterial ambulatoria.

Presentación de los datos

Los datos pueden ser presentados en forma de lista, de gráficos linearios, de barras gráficas o sectoriales.

Cálculos en los datos

- lista mediana hora por hora de las medidas
- cálculo de mínimo, máximo, medias, diferencias típicas
- cálculo de porcentajes de medidas salvando umbrales personalizables

Edición

El informe puede ser personalizado :

- membrete de la consulta
- número de páginas con arreglo a las informaciones deseadas
- campos comentarios
- informaciones generales sobre el paciente

I-4.Conexión del MAPA33 al ordenador

Los datos del MAPA33 son transmitidos al ordenador por medio de un cable interface. Los datos son transferidos bajo el control del ordenador.
El cable interface no necesita una alimentación externa, no tiene botón.
El cable interface puede quedarse conectado al ordenador, lo que permite una lectura del MAPA33 en cualquier momento sin reconectarlo. La figura 1 describe la conexión.

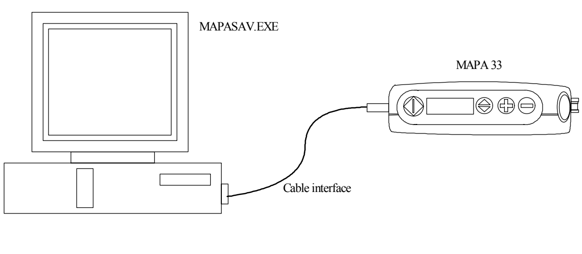


Figure 1

II - - MATERIAL REQUERIDO PARA UTILIZAR EL SOFTWARE

II-1. Sístema mínimo

- Un PC compatible (386 o superior), conforme con las normas CE en vigor, con la pantalla VGA
- 1 puerto serie libre (o USB, ver II-2)
- l lector de diskét 3.5''
- Microsoft Windows 95, Windows 98, Windows Millenium, Windows 2000, Windows XP
- 8 MB RAM y mínimo 2MB de espacio disponible en el disco duro

II-2. Accesorios (caja de conmutación)

El cable interface debe ser conectado con un puerto serie de su ordenador (COM1, COM2, COM3 o COM4). Podría ser necesario utilizar el adaptador proporcionado si su ordenador tiene un conectador de 9 puntos o 25 puntos (macho).
Si su ordenador no tiene un puerto libre, es posible procurarse un conmutador de puerto serie o añadir un interface interno que permite el acceso a los puertos COM3 o COM4.
(Consultar a su especialista).

Nota: el MAPA33 puede ser empalmado a un puerto USB via una caja convertidor de tipo UMC 100 disponible en el comercio.

II-3. Protección de los datos

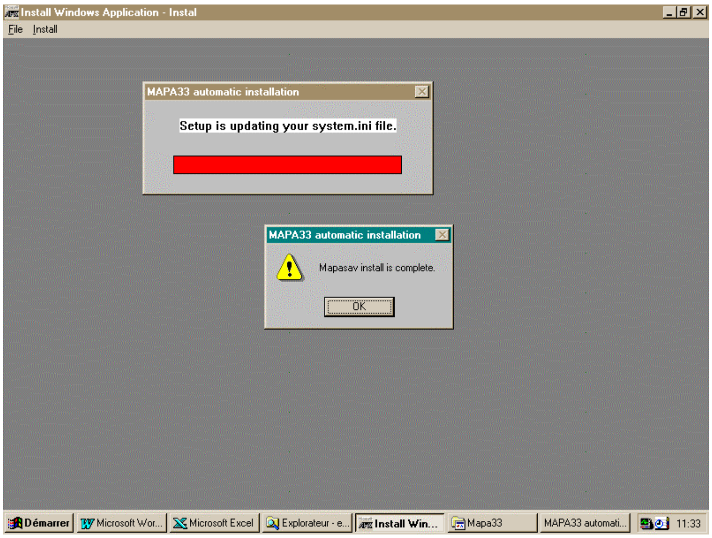
Para proteger los datos grabados en su ordenador, es necesario salvarlos regularmente (con un diskét por ejemplo). Esto permitirá prevenir una pérdida total de los datos si un problema surge en el ordenador

III -INSTALACIÓN

III-1. Instalación del software

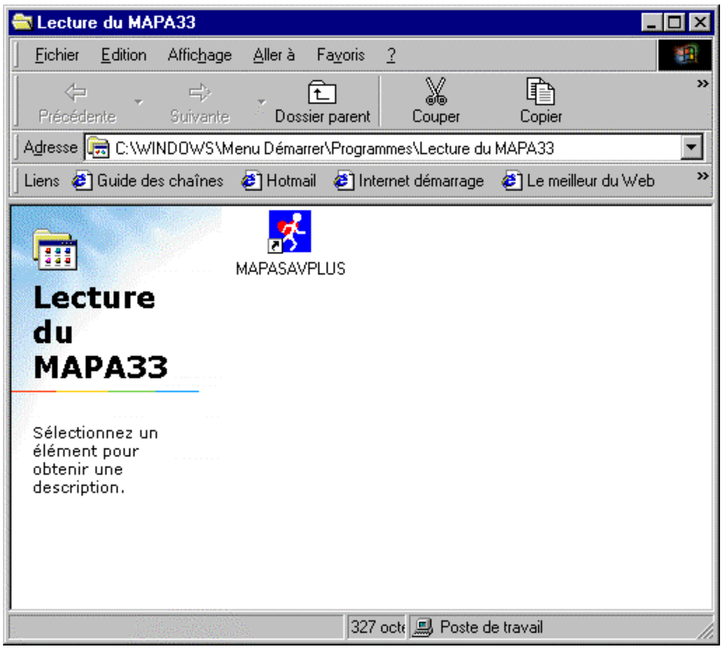
La instalación del software MAPASAV PLUS en el disco duro se hace por medio del diskét proporcionado en el kit. Cuando lo está instalando, le recomendamos que no abra otro programa.

1/ Lanzar Windows 95 o 98
2/ Poner el diskét en el lector
3/ Seleccionar con el botón 'Lanzar' y seleccionar 'Ejecutar'.
4/ Escribir a : instal.exe
Seleccionar con el botón OK.
5/ Cuando la instalación finaliza, seleccionar con el botón OK. La pantalla se fija como la ventana 1 más abajo.



Ventana 1

Seleccionar con el botón OK. El nuevo grupo MAPASAV PLUS que está creándose se fija en la pantalla con el ícono del programa (ventana 2).



Ventana 2

Seleccionar este ícono para lanzar el programa.

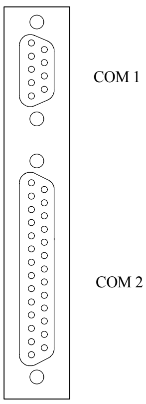
Nota:
En la versión Windows 95 o 98, los lanzamientos ulteriores se harán así:

- seleccionar Lanzar
- Seleccionar Programas
- Seleccionar el programa LECTURA del MAPA
- Seleccionar el ícono MAPASAV PLUS

III-2. Descripción de conexión del MAPA33

El cable de interface se conecta al ordenador en un conector de puerto serie. Según el tipo de ordenador, este conectador puede ser de 25 o de 9 contactos.
El kit Pc incluye un adaptador para evitar este problema.
El conectador del cable de interface es de tipo 25 contactos hembras. El ordenador debe poseer este tipo de conectador pero en contactos machos.
La figura 2 más abajo indica la manera como los conectadores de puerto serie están colocados detrás de los ordenadores.

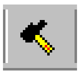
Figura 2



IV – TRABAJAR CON MAPASAV PLUS

IV-1. La configuración

La ventana de configuración abajo es accesible en el menú Fichero, mando configuración. Está compuesto de 3 ingletes: Informe, Valores límites, Comunicación.

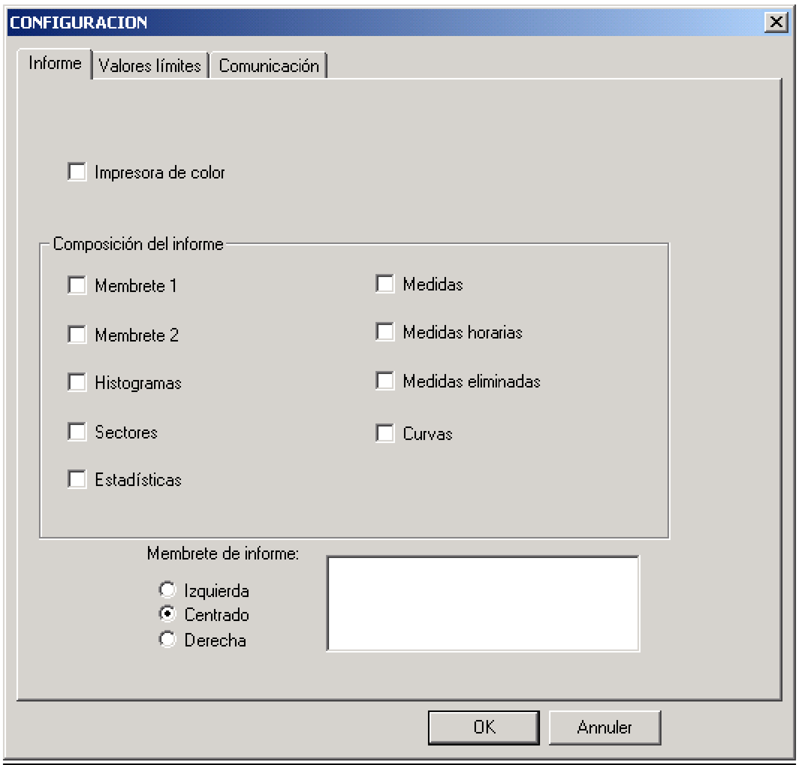


Si una modificación ulterior es necesaria, esta ventana es accesible por este ícono.

Nota: un quinto inglete 'ACTIVIDAD' es disponible si esta opción ha sido validada en el inglete 'COMUNICACION'. Si su MAPA no posee la opción actividad será automaticamente invalidada por el software cada comunicación con su MAPA.

IV-1.1. El informe

Para configurar el informe, seleccionar el inglete 'INFORME' de le ventana de configuración. La ventana abajo aparece así:



Ventana 3

Para validar una opción, ponga una cruz en la casilla correspondiente seleccionando esta última con el cursor del ratón (misma operación para invalidar una opción).

A/ *Opción 'Impresora de color'*

La opción 'Impresora de color' permite publicar las curvas y los gráficos a color en una impresora a color. Para velar por la calidad de los gráficos en una impresora blanco y negro, invalidar esta opción.

B/ *Encuadrado 'Composición del informe'*

El informe puede tener 8 páginas de informaciones (o más según el número de medidas).
Para seleccionar las páginas por imprimir, seleccione con el ratón las casillas delante de los números de páginas.

La página 1 incluye:

- el membrete de la consulta
- informaciones sobre el paciente
- datos técnicos del examen (hora de descanso, porcentaje de éxito, …)
- un campo comentario
- un campo tratamiento

La página 2 o membrete 2 vuleve a tomar las precedentes informaciones, y las medidas estadisticas (páginas 5) se sustituyen a los campos « comentario « y « tratamiento ».
La página 3 incluye histogramas en barra de los datos de la pantalla.
La página 4 incluye gráficos sectoriales de los datos del examen.
La página 5 incluye cuadros estadísticos (medias, diferencias típicas).
La página 6 incluye un cuadro reagrupando las medidas del examen.
La página 7 incluye un cuadro de las medidas eliminadas.
La página 8 incluye un cuadro de las medidas por hora.
La página 9 incluye curvas (gráficas horarias) de la presión arterial.

☞ Seleccionar la opción con la tecla TABULACIÓN o las teclas SHIFT y TABULACIÓN hundidas al mismo tiempo y validar o invalidar con la barra de espaciamiento o las teclas + - de la tecla numérica.
.

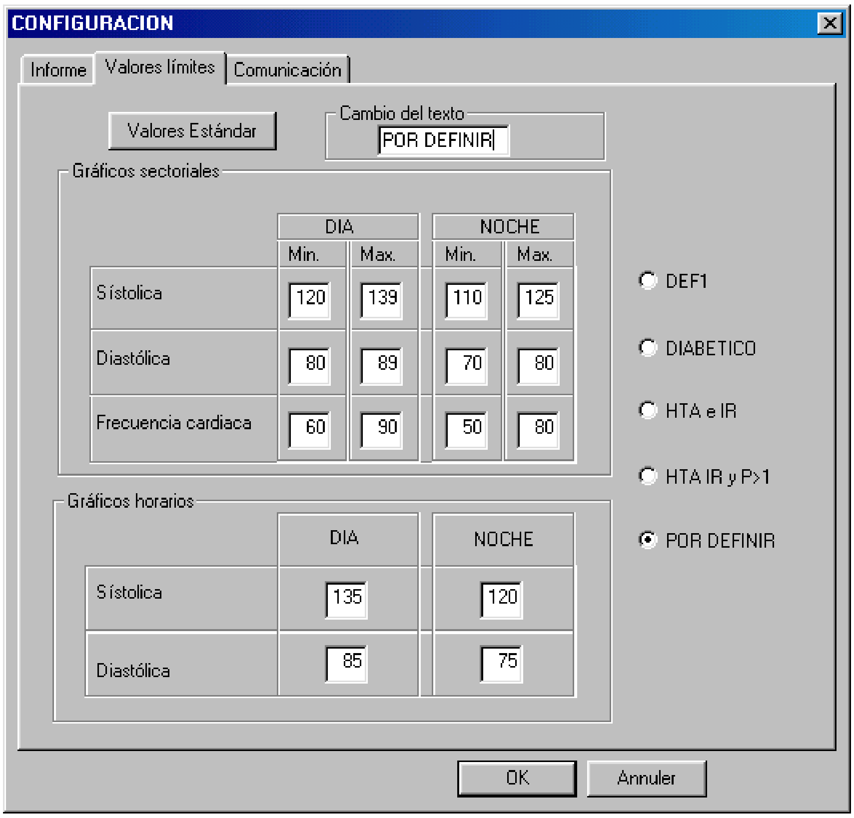
C/ *Encuadrado 'Membrete de informe'*

Esta zona de texto permite personalizar el informe al escribir el nombre y la dirección de la consulta.
El texto se centra a la derecha, a la izquierda o centrado. El membrete puede incluir un máximo de 4 líneas. Se pasa de una línea a otra con la tecla ENTRADA. Si la tecla ENTRADA es ineficaz (4 líneas entradas), utilizar las teclas ← ↑ ↓ → para los desplazamientos en esta ventana (o seleccionar con el ratón donde así lo quiera).

Para validar seleccionar la tecla OK.

IV-1.2. Los valores límites

Para fixar sus propios valores límites necesarios a los cálculos de los diferentes gráficos y estadísticas, seleccionar el inglete ' VALORES LIMITES '. La ventana abajo se presenta así:



Ventana 4

La ventana está compuesta de dos cuadrados de valores limites: uno para los gráficos sectoriales, otro para los gráficos horarios.

A/ Encuadrado ‘Gráficos sectoriales’

Este cuadrado permite fijar los valores límites minimales y maximales presiones sistólicos y diástolicos y de la frecuencia cardíaca para el periodo día y el periodo noche.

B/ Encuadrado ‘Gráficos horarios’

Este cuadrado permite fijar los valores límites presiones sistólicos y diástolicos para el periodo día y el periodo noche.

Tiene la posibilidad de recordar valores entrados en los campos de embargo como cuadro de valores por defecto validando unos de los botones redactados DEF1, DIABETICO, HTA e IR, HTA IR y P>1, POR DEFINIR. Así puede fijar y guardar sus propias cuadros de valores límites por defecto en el límite de 5 botones.
El encuadrado « Cambio del texto » permite nombrar de nuevo el cuadro de valores límites seleccionado.
El texto se modifica automáticamente al embargo a cerca del botón.
Después, puede seleccionar uno de estos cuadros límites en la ventana Personalización gracias a 5 botones llevando al mismo redactado (Ver párrafo IV.4).

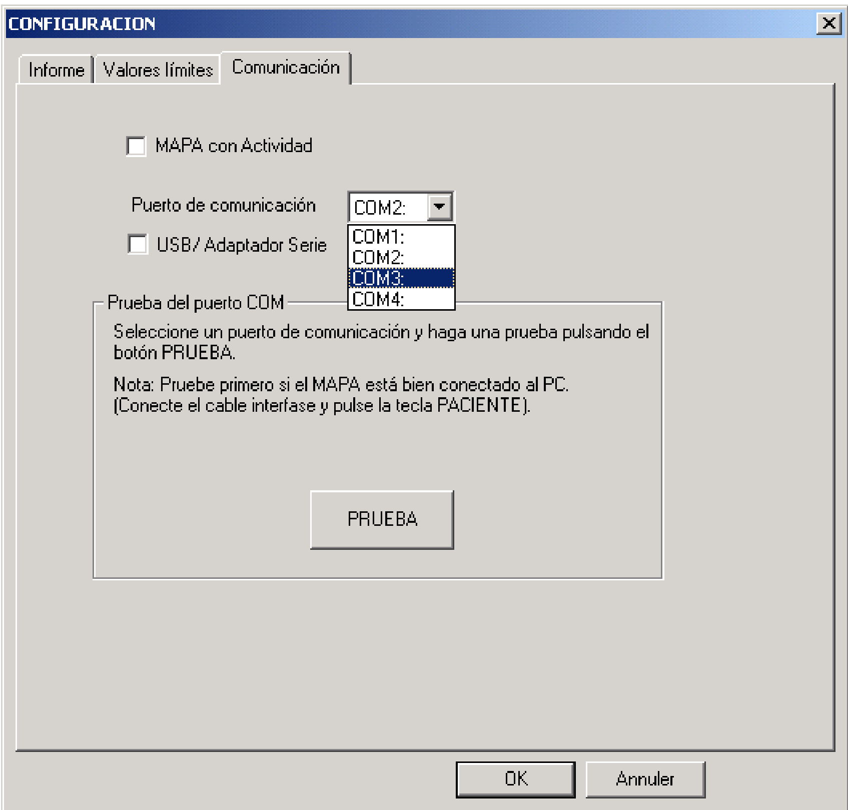
El botónValores Estándar permite iniciar los valores limítes por defecto según el JNC6 valores como el ejemplo arriba.

☞ Seleccionar los campos con la tecla TABULACION o las teclas SHIFT y TABULACION hundidas al mismo tiempo y los botones DEF con las teclas ↑ ↓.

Para validar cualquiera modificación efectuada en la ventana ‘Valores limítes’, seleccionar la tecla OK.

<u>IV-1.3 La Comunicación</u>

El inglete Comunicación permite a llamar la ventana de comunicación del ordenador en la cual el MAPA33 está conectado. Consultar a su especialista para esta opción



Ventana 5

☞ Seleccionar la opción con la tecla TABULACIÓN o las teclas SHIFT y TABULACIÓN hundidas al mismo tiempo y validar o invalidar con la barra de espaciamiento o las teclas + - de la tecla numérica.
Para seleccionar un puerto de comunicación:
- Seleccionar la tecla situada a la derecha de la caja incluido la designación del puerto

- coger un puerto entre las 4 posibilidades propuestas seleccionadas con la tecla del ratón.
  Seleccionar la tecla OK para validar su elección

☞ Seleccionar esta casilla con la tecla TABULACION y coger la puerta con las teclas ← ↑ ↓ →.

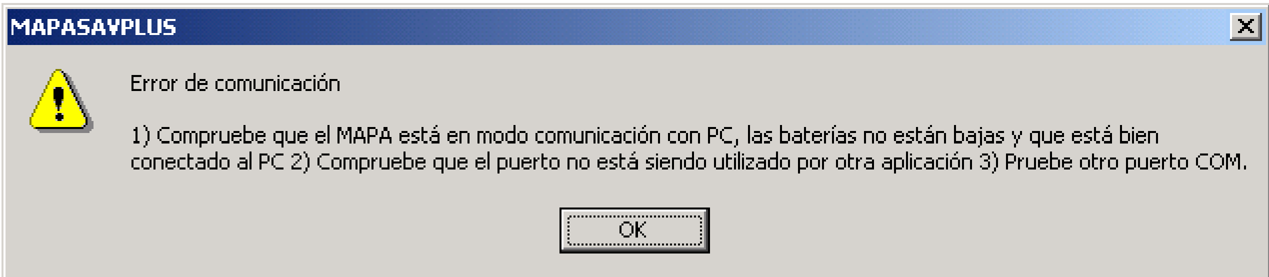
Si conecta su MAPA sobre un puerto USB via una caja convertisidor tipo UMC 100, activa la opción adaptador USB/Serie.

☞ Seleccionar la opción con la tecla TABULACION o las teclas SHIFT y TABULACION hundidas al mismo tiempo y validar o invalidar con la barra de espaciamiento o las teclas + - de la tecla numérica.

<u>Nota</u>:
Seleccionando el botón, TEST, es posible de probar el puerto seleccionado.
Si el test es concluyente, el mensaje abajo se presenta:

Ventana 7

En caso de errores, el mensaje siguiente aparece:



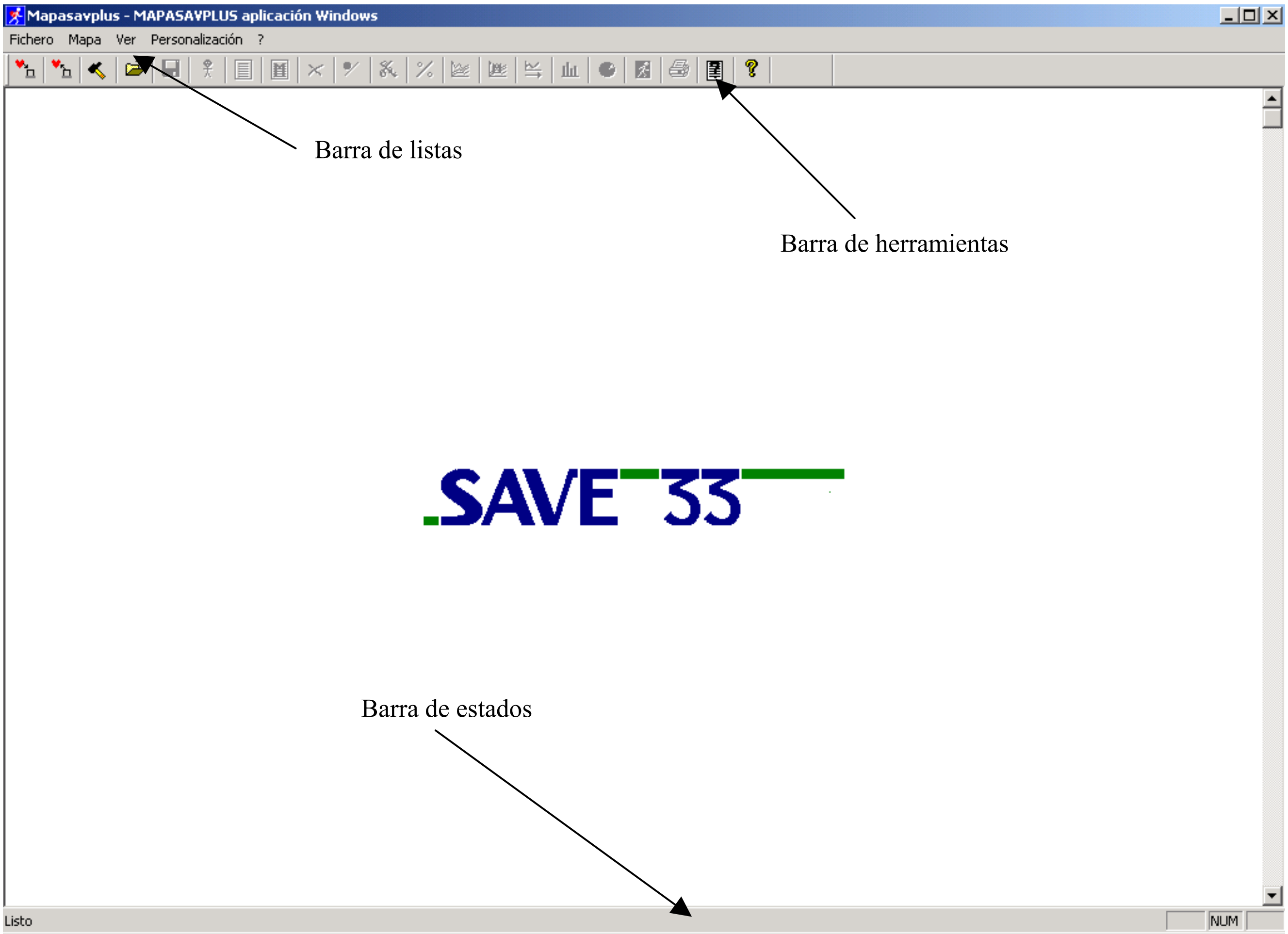
Ventana 7

Para salir de esta ventana de configuración y guardar las opciones efectuadas, seleccionar la tecla OK.

☞ Seleccionar la tecla OK con la tecla TABULACION y validar con la tecla ENTRADA.

IV-2 La barra de herramientas y la barra de estados

Al salir del tablero de configuración, la pantalla aparece así como se presenta a continuación:



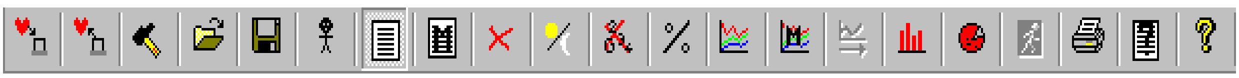
Ventana 8

Como todos los programas que funcionan bajo Windows, encuentra:

- una barra de listas
- una barra de herramientas
- una barra de estados

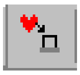
Las barras de herramientas y de estados no pueden ser seleccionadas en la lista 'Anuncio'. Entonces desaparecen de la pantalla.

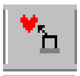
La barra de herramientas se compone de íconos (o botones) que no son sino reducciones de las elecciones propuestas en las listas. Su utilización se hace al seleccionarlos con el ratón.
Un ícono aparece en gris en la pantalla cuando su utilización no es posible en ese momento en el programa.

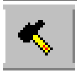


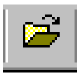
Los diferentes íconos de la barra de herramientas están descritos más abajo:

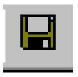
La barra de estados indica brevemente la utilidad de un mando seleccionado en una de las listas.

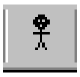
 Vaciar las medidas del MAPA en el ordenador.

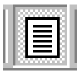
 Programación del MAPA.

 Configuración del informe,valores límites y del puerto de comunicación.

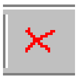
 Apertura de un fichero existente en el ordenado.

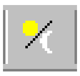
 Salvaguarda de las medidas en un fichero

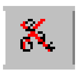
 Personalización del informe.

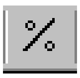
 Anuncia el cuadro de las medidas

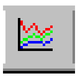
 Anuncia el cuadro de las medias hora por hora.

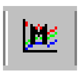
 Permite eliminar una medida

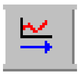
 Inversión del estado día/noche de una medida

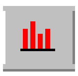
 Elimina automáticamente todas las medidas que han necesitado más de un inflato

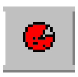
 Anuncia el cuadro de las estadísticas

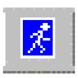
 Anuncia la gráfica horaria de las presiones y de la frecuencia de corazón.

 Anuncia la gráfica de las medias horarias de las presiones y de la frecuencia de corazón

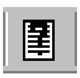
 Permite adaptar la escalera horaria con arreglo al número de medidas.

 Anuncia los histogramas de las presiones

 Anuncia las gráficas sectoriales de las presiones y de la frecuencia de corazón.

 Anuncia las curvas de la actividad.

 Salida del informe en la impresora.

 Anuncia el significado de las abreviaciones utilizadas en la columna ESTADOS del cuadro de las medidas.

 Anuncia la versión del software.

IV-3. Vaciar las medidas del MAPA33 en el ordenador

Conectar el MAPA como indicado anteriormente en el conectador (marca 2 figura 3).
- lanzar el MAPA (marca 1 figura 3).
- pulsar el botón paciente (marca 3 figura 3).

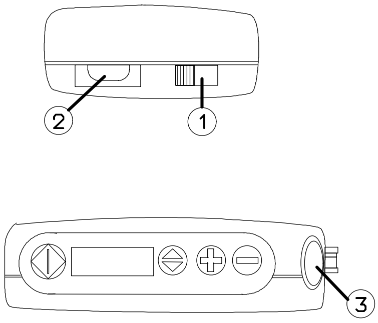
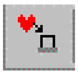


Figura 3

- el fijador del MAPA indica 'Comunicación PC'.



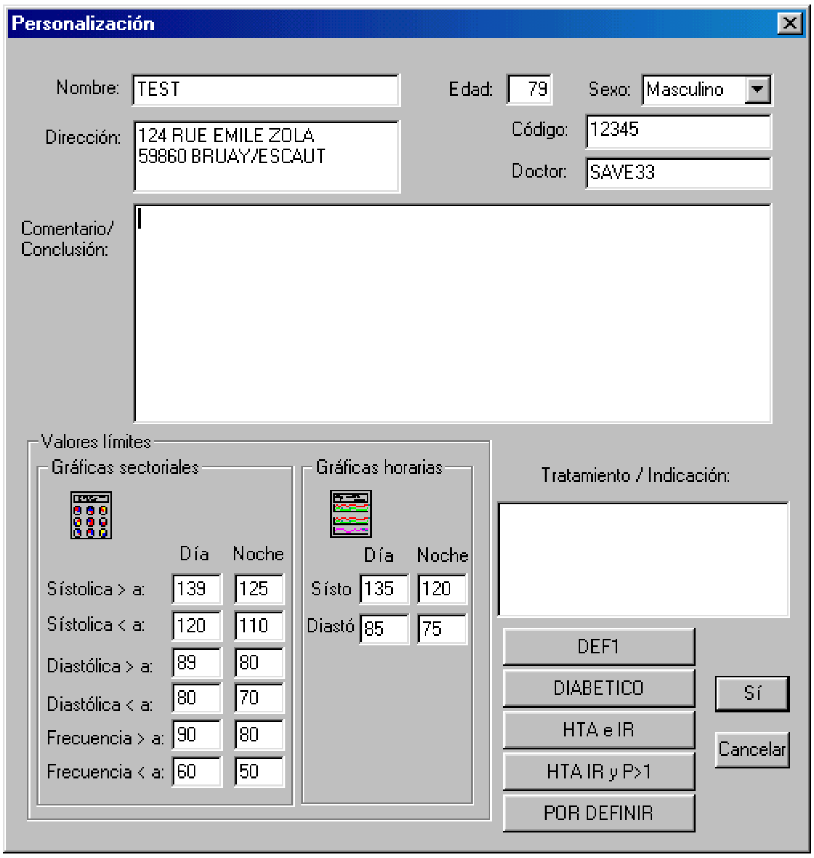
- seleccionar el ícono 'Vaciar las medidas del MAPA' para recoger los datos memorizados en el MAPA

☞ Pulsar las teclas ALT y M al mismo tiempo para llamar la lista Mapa y la tecla C para utilizar el mando Cargar.

La ventana de conexión del MAPA entonces se abre. La barra azul representa la progresión del cargamento
Si un mensaje de error interviene, compararse al anexo 1.

IV-4. Personalización del informe

Cuando la transferencia es efectuada, la ventana 'Personalización' abre automáticamente y aparece como abajo:



Ventana 9

Esta ventana permite entrar los datos específicos a esta grabación:
- Nombre del paciente, Dirección, Edad, Sexo, Código, Medico prescriptor, Comentario/Conclusión, Tratamiento/Indicación

Estos datos serán imprimidos en la página 1 y 2 del informe.

El Encuadrado 'Valores límites'

Permite fijar los umbrales necesarios a los cálculos de los diferentes gráficos y estadísticas.
Los botones DEF1, DIABETICO, HTA e IR, HTA IR y P>1 y POR DEFINIR permiten iniciar los valores limítes por defecto registrados en la ventana 'Valores limítes'de la ventana de configuración.

Durante la recogida de estos parámetros, ciertos controles de los valores entrados en el teclado son efectuados. Valores límites están fijados como más abajo :

40 < sístolica < 250
40 < diastólica < 250
30 < frecuencia cardiaca < 150

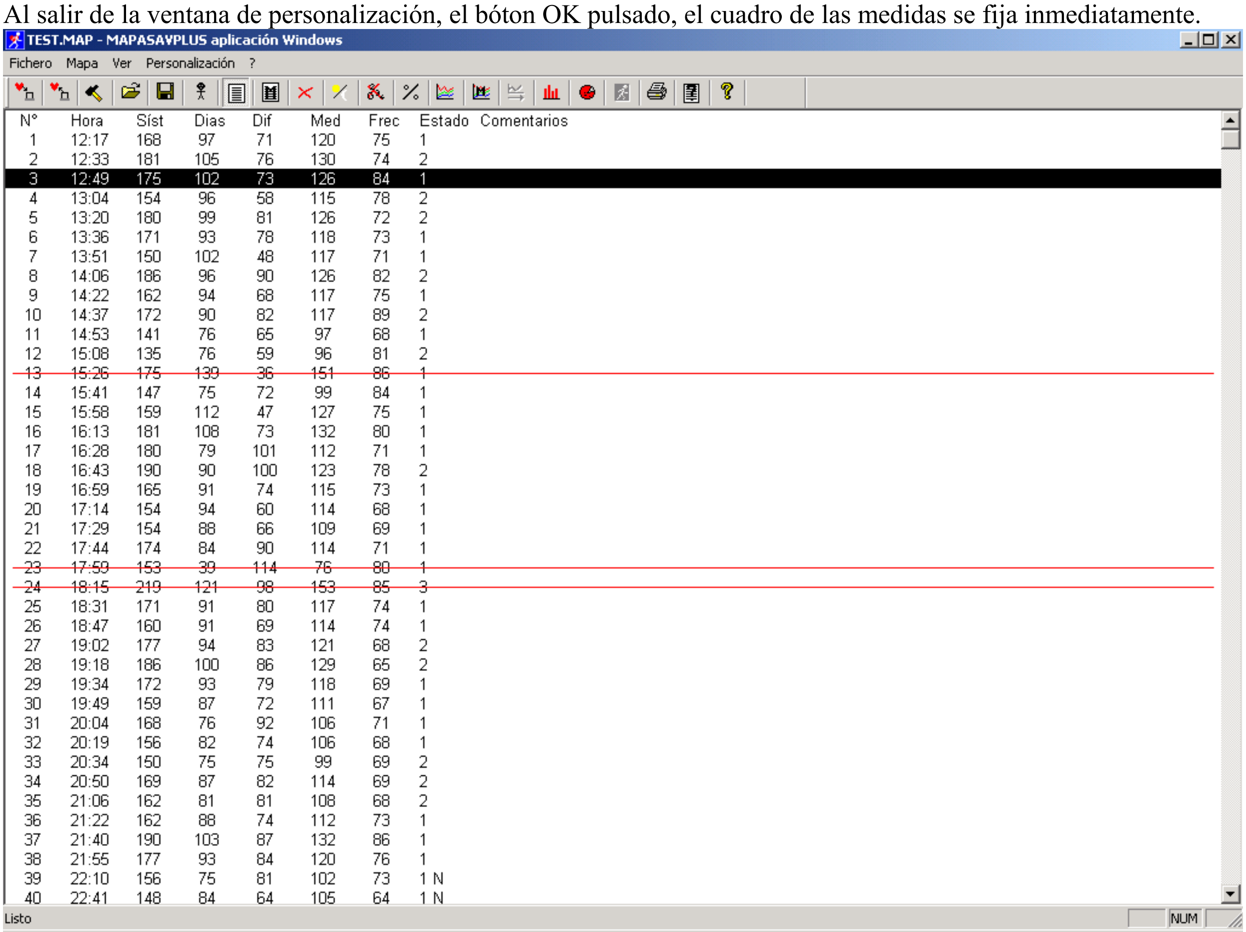
El campo NOMBRE es obligatorio. No se podrá validar esta ventana al seleccionar OK sin rellenar la zona 'NOMBRE'.
Un clic con el ratón permite seleccionar un campo y escribir las informaciones deseadas.
Si el nombre del paciente ha sido dado durante de la colocación del aparato, este campo informará automáticamente.

☞ Los desplazamientos en esta ventana se hacen con la tecla de Tabulación.
La elección del sexo se hace con las teclas ← ↑ ↓ → en cuanto el campo ha sido seleccionado.

V - EXPLOTACIÓN DE LAS MEDIDAS GRABADAS

V-1. El cuadro de las medidas

Al salir de la ventana de personalización, el bóton OK pulsado, el cuadro de las medidas se fija inmediatamente.



N°	Hora	Síst	Dias	Dif	Med	Frec	Estado	Comentarios
1	12:17	168	97	71	120	75	1	
2	12:33	181	105	76	130	74	2	
3	12:49	175	102	73	126	84	1	
4	13:04	154	96	58	115	78	2	
5	13:20	180	99	81	126	72	2	
6	13:36	171	93	78	118	73	1	
7	13:51	150	102	48	117	71	1	
8	14:06	186	96	90	126	82	2	
9	14:22	162	94	68	117	75	1	
10	14:37	172	90	82	117	89	2	
11	14:53	141	76	65	97	68	1	
12	15:08	135	76	59	96	81	2	
~~13~~	~~15:26~~	~~175~~	~~139~~	~~36~~	~~151~~	~~86~~	~~1~~	
14	15:41	147	75	72	99	84	1	
15	15:58	159	112	47	127	75	1	
16	16:13	181	108	73	132	80	1	
17	16:28	180	79	101	112	71	1	
18	16:43	190	90	100	123	78	2	
19	16:59	165	91	74	115	73	1	
20	17:14	154	94	60	114	68	1	
21	17:29	154	88	66	109	69	1	
22	17:44	174	84	90	114	71	1	
~~23~~	~~17:59~~	~~153~~	~~39~~	~~114~~	~~76~~	~~80~~	~~1~~	
~~24~~	~~18:15~~	~~219~~	~~121~~	~~98~~	~~153~~	~~85~~	~~3~~	
25	18:31	171	91	80	117	74	1	
26	18:47	160	91	69	114	74	1	
27	19:02	177	94	83	121	68	2	
28	19:18	186	100	86	129	65	2	
29	19:34	172	93	79	118	69	1	
30	19:49	159	87	72	111	67	1	
31	20:04	168	76	92	106	71	1	
32	20:19	156	82	74	106	68	1	
33	20:34	150	75	75	99	69	2	
34	20:50	169	87	82	114	69	2	
35	21:06	162	81	81	108	68	2	
36	21:22	162	88	74	112	73	1	
37	21:40	190	103	87	132	86	1	
38	21:55	177	93	84	120	76	1	
39	22:10	156	75	81	102	73	1 N	
40	22:41	148	84	64	105	64	1 N	

Ventana 10

☞ Pulsar las teclas ALT y V al mismo tiempo para llamar la lista Ver y la tecla M para utilizar el mando 'Medidas'.

El cuadro se compone de líneas que corresponden a las medidas efectuadas y de 9 columnas :

Columna 1: número de la medida
Columna 2: hora de la toma de la medida
Columna 3: valor de la presión sistólica
Columna 4: valor de la presión diastólica
Columna 5: valor de la presión diferencial igual a la desviación entre la presión sistólica y la presión diastólica.
Columna 6: presión media medida sobre la curva oscilométrica
Columna 7: frecuencia de corazón expresada en palpitaciones por minuto
Columna 8: estado representado por un símbolo que describe el contexto de la toma de la tensión
Columna 9: campo 'Comentarios' que permite la inserción de una cadena de 16 letras ASCII

Nota:
Los valores de las presiones en las columnas 3, 4, 5 y 6 están expresados en mmHg.

A/ *Desplazamientos en el cuadro de medidas*

A la derecha del cuadro, un cursor llamado elevador permite desplazar el cuadro para visualizar en la pantalla la totalidad de las medidas.

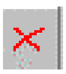
Un clic del ratón sobre la flecha por encima del elevador hace bajar el cuadro si la primera medida no aparece en la pantalla.
Un clic del ratón sobre la flecha al pie del elevador hace subir el cuadro de una medida (la medida de encima desaparece, una nueva medida aparece abajo).
☞ Pulsar las teclas ↓ ↑ para utilizar este mando.

Un clic bajo el cursor del elevador permite subir el cuadro de una página pantalla.
Un clic encima del cursor del elevador permite bajar el cuadro de una página pantalla.
☞ Pulsar las teclas PAGE UP y PAGE DOWN para utilizar este mando.
Al pulsar la tecla HOME ⇱ permite volver inmediatamente a la primera medida, la tecla FIN permite fijar la última medida.

B *Selección de una medida*

Un clic sobre la línea de medida permite seleccionarla (ver barra negra en la ventana 7).
☞ Pulsar la tecla ENTRADA para poner la selección sobre la primera medida de la página fijada. Pulsar las teclas ← → para desplazarlas.

C/ *Eliminación de una medida*



Seleccionar el ícono de la barra de herramientas para eliminar una medida seleccionada (o revalidada en el caso contrario).

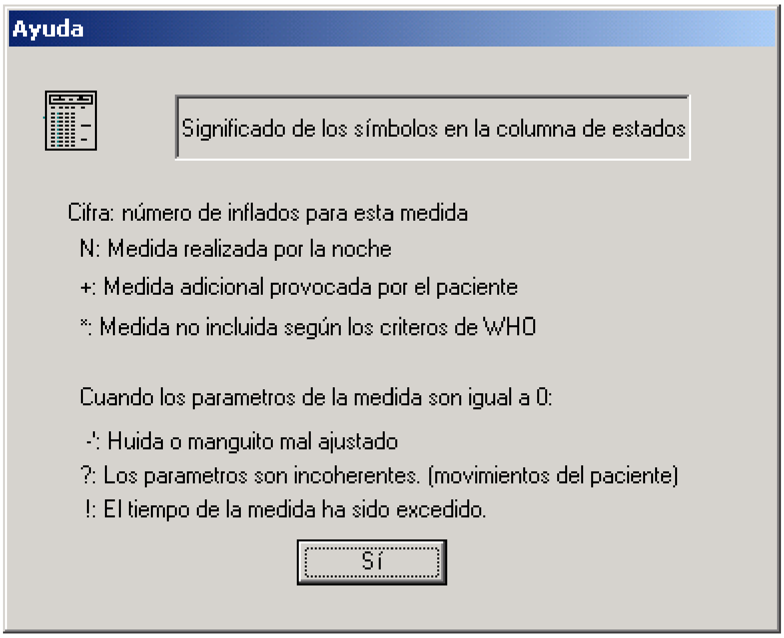
☞ Pulsar las teclas ALT y P al mismo tiempo para obtener la lista Personalización y la tecla V para utilizar el mando Inválido ⇔ Valido.

Una medida cruzada está excluida de los diferentes cálculos (media, estadísticas,…).

D/ *La columna 'Estados'*

Para un mejor análisis de las medidas, el aparato memoriza las condiciones de grabación de éstas (para conocer por ejemplo las causas de fracaso de una medida). Esta columna no es accesible al usario. Una llamada de los símbolos es disponible por intermedio del menú ? en la función 'Ayuda' o por este ícono.

☞ Pulsar las teclas ALT y SHIFT y ? al mismo tiempo para llamar el menú ? y la tecla A para seleccionar 'Ayuda'. Entonces une ventana aparece como abajo:



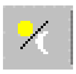
Ventana 11

Para cerrar esta ventana seleccionar OK o pulsar la tecla ENTRADA del teclado.

E/ *Eliminación de las medidas que han necesitado más de un inflato.*

Antes de utilizar este mando, es necesario efectuar una salvaguarda del fichero porque su acción es irreversible
La cifras que aparecen en la columna Estados indican el nombre de inflatos que el aparato debía efectuar para obtener una medida. Se revela que los inflatos suplementarios (al máximo 4) muchas veces se deben a los movimientos del paciente durante la toma de la tensión. Entonces las cifras son muchas veces no interpretables.
☞ Pulsar las teclas ALT y P al mismo tiempo para llamar la lista Personalización y la tecla I para utilizar el mando I1.

F) Modificación de la asignación del estado noche-día de la medida



Pulsar este ícono para modificar el estado noche-día de la medida.

☞ Pulsar las teclas ALT y P al mismo tiempo para llamar la lista Personalización y la tecla N para utilizar el mando Noche. ⇔ Día.

Nota:
Gracias al ratón, es posible seleccionar todo un grupo de medidas. Seleccionar una medida y al pulsar el botón de la izquierda del ratón desplazar ésta hacia el pie. Aflojar el botón sobre la última medida.
Entonces las acciones anteriores se aplicarán a todo el grupo.

☞ Esta función no está disponible en el teclado.

G/ *Acceso a la columna comentario de una medida*

Con el cursor del ratón, seleccionar la medida en cuestión y pulsar el botón de la derecha del ratón. La ventana se abre así:

Ventana 12

Entonces es posible entrar el comentario por medio del teclado (no superar 16 letras) por ejemplo aquí medicina.
Es también posible cambiar el estado de noche o de día en esta ventana. Por eso debe puntear o no la casilla correspondiente. En caso de un MAPA con la opción Actividad si una mala detección de la posición del paciente descubrió, es posible de la corregirla por eso debe puntear o no la casilla acostado. (casilla punteado = posición acostado, casilla no punteado = posición de pie). Luego validar con el botón OK o Cancelar para no grabar las modificaciones

☞ Debe poner la barra de selección sobre la medida concernida (ver párrafo V1B) y pulsar la tecla INSER. La misma ventana se abre.
Los desplazamientos en esta ventana se hacen con la tecla de TABULACIÓN.
Para validar la casilla noche, seleccionar Noche con la tecla de TABULACIÓN y poner o quitar la cruz en la casilla correspondiente con las teclas + y -.

E/ Rechazo WHO medidas

En el menú Personalización, el mando Rechazo WHO permite rechazar la o las medidas que entran en los criterios de la exclusión siguiente el WHO. Para que las medidas no rechacen, hace falta que satisfagan las condiciones siguientes:

1/ 40 mmHg < presión sistolica < 250 mmHg
2/ 30 mmHg < presión diastolica < 150 mmHg
3/ en el caso en que la presión es > 100 mmHg, el valordiferencial (sistólico-diastólico) debe ser > a 10 mmHg.

☞ Pulsar las teclas ALT y P al mismo tiempo para llamar el menú Personalización y pulsar la tecla R para utilizar el mando Rechazo WHO.

V-2. Tabla de las medidas por horario

Clic este ícono para anunciar la tabla y las medidas por horario.

☞ Pulsar las teclas ALT y V al mismo tiempo para llamar la lista Ver y la tecla D para utilizar el mando Medidas por hora.

Entonces el cuadro aparece así:

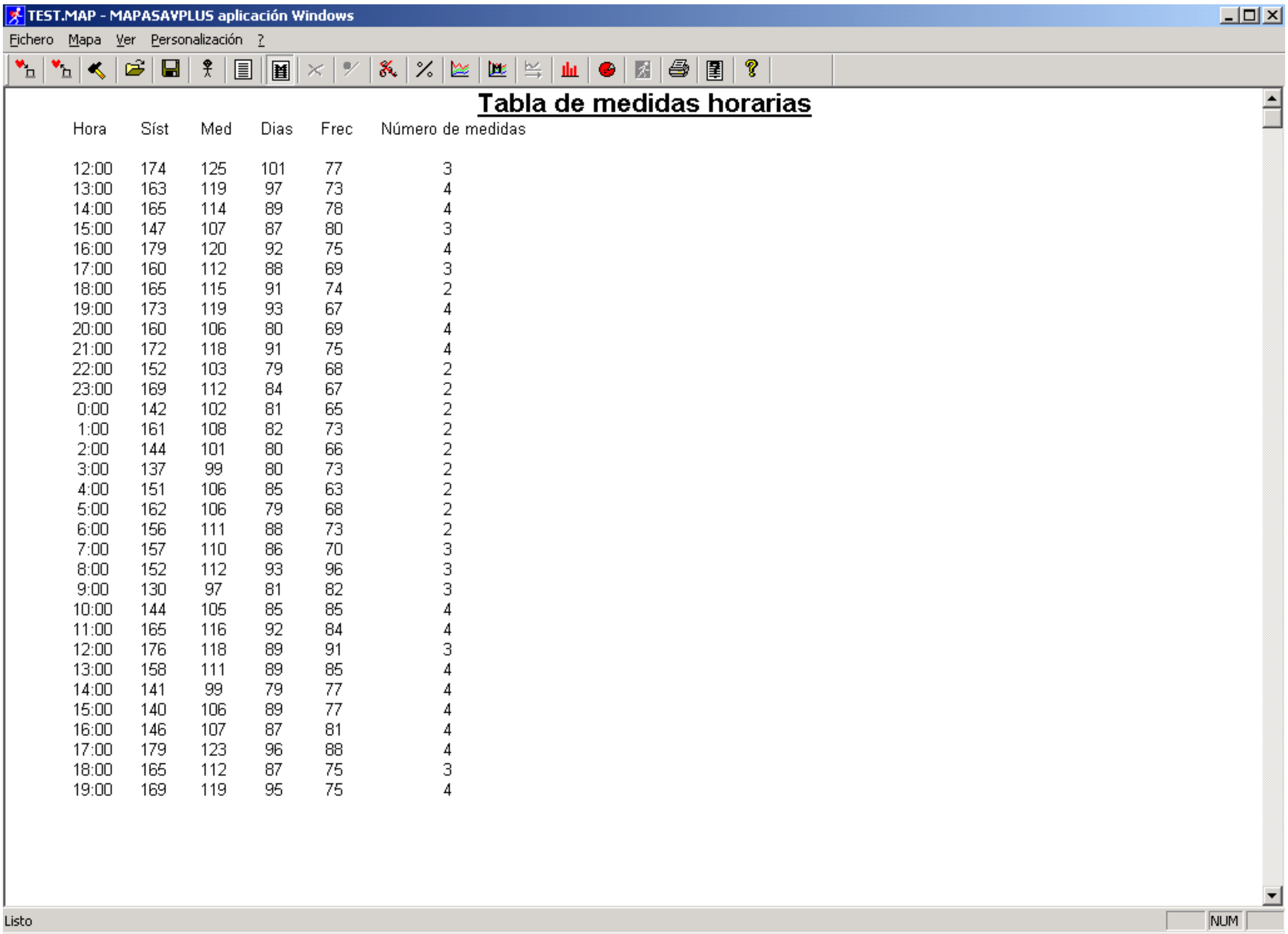


Tabla de medidas horarias

Hora	Síst	Med	Dias	Frec	Número de medidas
12:00	174	125	101	77	3
13:00	163	119	97	73	4
14:00	165	114	89	78	4
15:00	147	107	87	80	3
16:00	179	120	92	75	4
17:00	160	112	88	69	3
18:00	165	115	91	74	2
19:00	173	119	93	67	4
20:00	160	106	80	69	4
21:00	172	118	91	75	4
22:00	152	103	79	68	2
23:00	169	112	84	67	2
0:00	142	102	81	65	2
1:00	161	108	82	73	2
2:00	144	101	80	66	2
3:00	137	99	80	73	2
4:00	151	106	85	63	2
5:00	162	106	79	68	2
6:00	156	111	88	73	2
7:00	157	110	86	70	3
8:00	152	112	93	96	3
9:00	130	97	81	82	3
10:00	144	105	85	85	4
11:00	165	116	92	84	4
12:00	176	118	89	91	3
13:00	158	111	89	85	4
14:00	141	99	79	77	4
15:00	140	106	89	77	4
16:00	146	107	87	81	4
17:00	179	123	96	88	4
18:00	165	112	87	75	3
19:00	169	119	95	75	4

Ventana 13

Los desplazamientos en este cuadro de medias se hacen a través del elevador.

☞ Pulsar las teclas ↑ y ↓ del teclado como para el cuadro anterior.

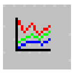
La última columna indica el número de medidas utilizadas para efectuar la media de la hora concernida. Las otras columnas son las medias sobre las presiones sistólicas, medias y diastólicas expresadas en mmHg.

V-3. Los gráficos

Los datos pueden ser presentados en forma de gráficos:

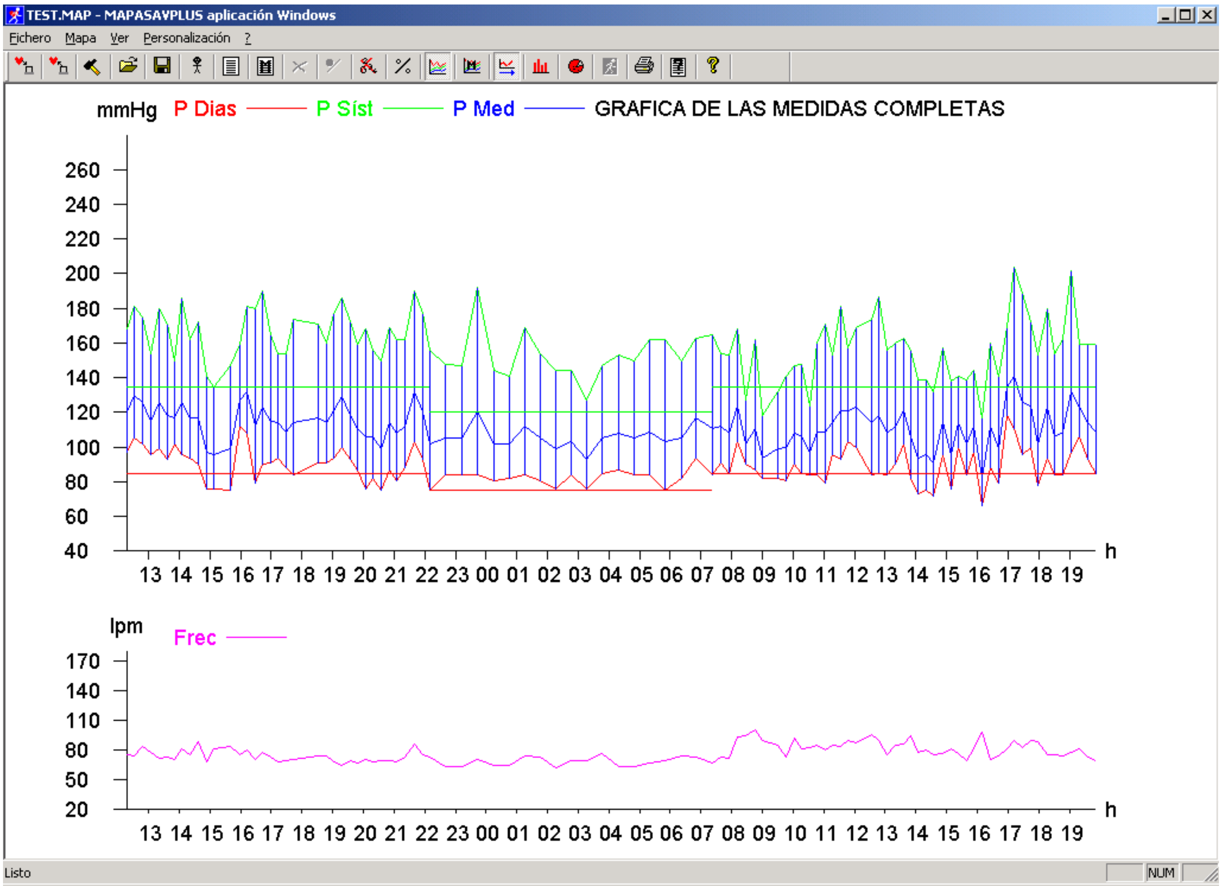
- gráfico de la evolución de los paramétros con arreglo al tiempo
- histogramas en barra
- gráficas sectoriales

A/ El gráfico horario



Clic este ícono para anunciar el gráfico horario.

☞ Pulsar las teclas ALT y V al mismo tiempo para llamar la lista Ver y la tecla G para fijar las Gráficas horarias en la pantalla



Ventana 14

El gráfico de la parte superior de la pantalla representa la evolución de las presiones, el de abajo representa la evolución de la frecuencia del corazón.

Las escaleras horizontales representan las horas de las tomas de medida.
Verticalmente las escaleras de presiones están expresadas o en mmHg.
En el gráfico de las presiones, las presiones están representadas por curvas de color:

- en verde : la presión sistólica
- en rojo : la presión diastólica
- en azul : la presión media

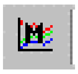
La presion diferencial está representada por una raya azul que enlaza las presiones sistólicas y diastólicas a la hora de la toma de la medida.

Los límites superiores día y noche de las presiones sistólicas y diastólicas, fijados en el encuadrado 'Gráficas horarias' de la ventana de Personalización (lista Personalización, función Personalización) están representados por rectas horizontales del color de su presión respectiva:

- en verde para la sístolica
- en rojo para la diastólica

Si el período del examen es inferior a 24 horas, la representación gráfica estandard puede difícilmente ser interpretable.
En efecto todas las medidas estarán agrupadas a la izquierda de los gráficas.
☞ Pulsar las teclas ALT y V al mismo tiempo para llamar la lista Ver y la tecla Z para utilizar el mando 'Zoom'

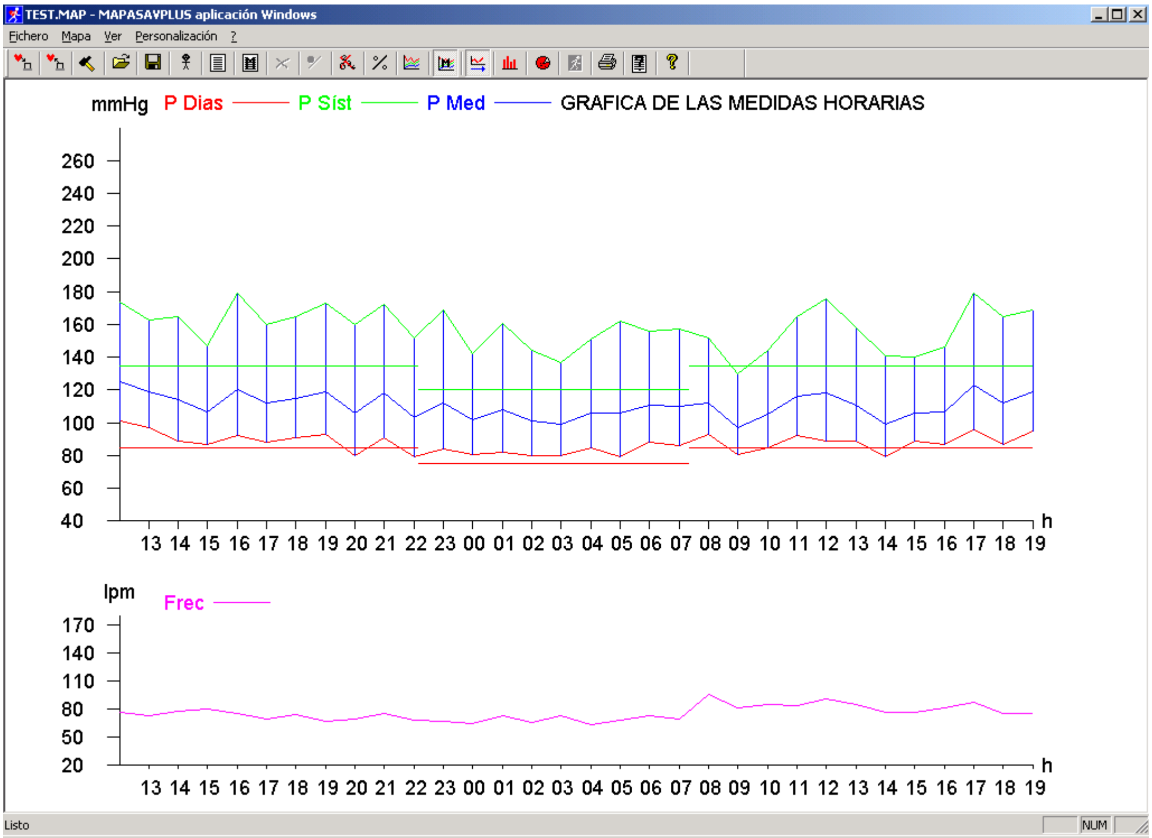
B/ *El gráfico de las medias horarias*



Clic este ícono para anunciar el gráfico de las medidas horarias.

☞ Pulsar las teclas ALT y V al mismo tiempo para llamar la lista Ver y la tecla R para fijar las Gráficas horarias.

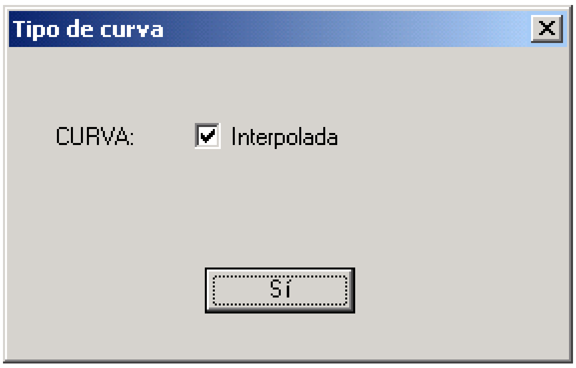
Entonces la pantalla se presenta de la siguiente manera:

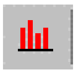


Ventana 15

La función Zoom anteriormente dicha es siempre práctica en esta representación

Doble-clic con el botón izquierda del ratón en las gráficas y las gráficas horarias, tiene la posibilidad de interpolar o no las curvas.

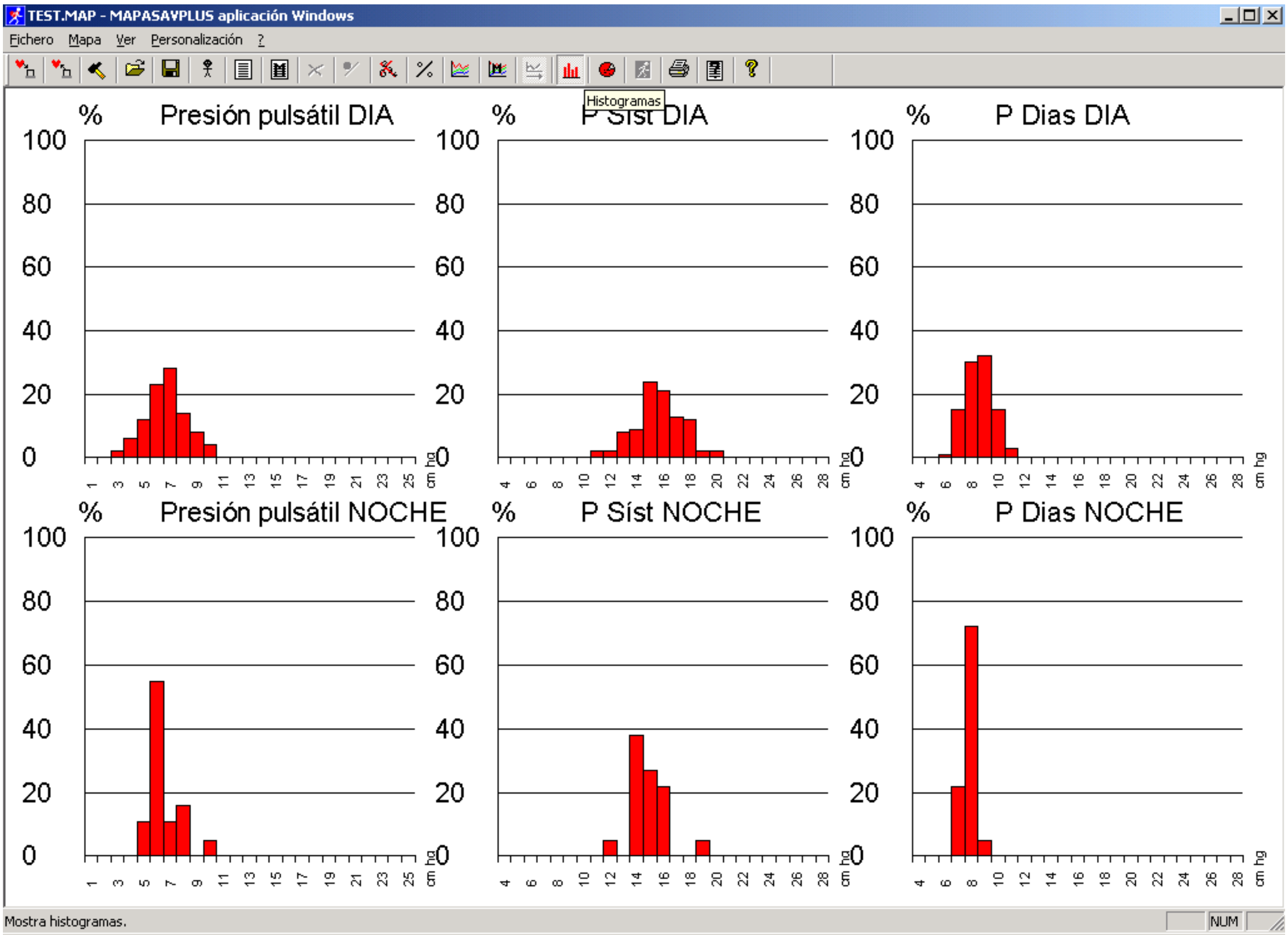




Clic este ícono para anunciar los histogramas en barra.

☞ Pulsar las teclas ALT y V al mismo tiempo para llamar la lista Ver y la tecla H para fijar los 'Histogramas' en barra.

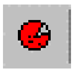
Entonces la pantalla se presenta de la siguiente manera:



Ventana 16

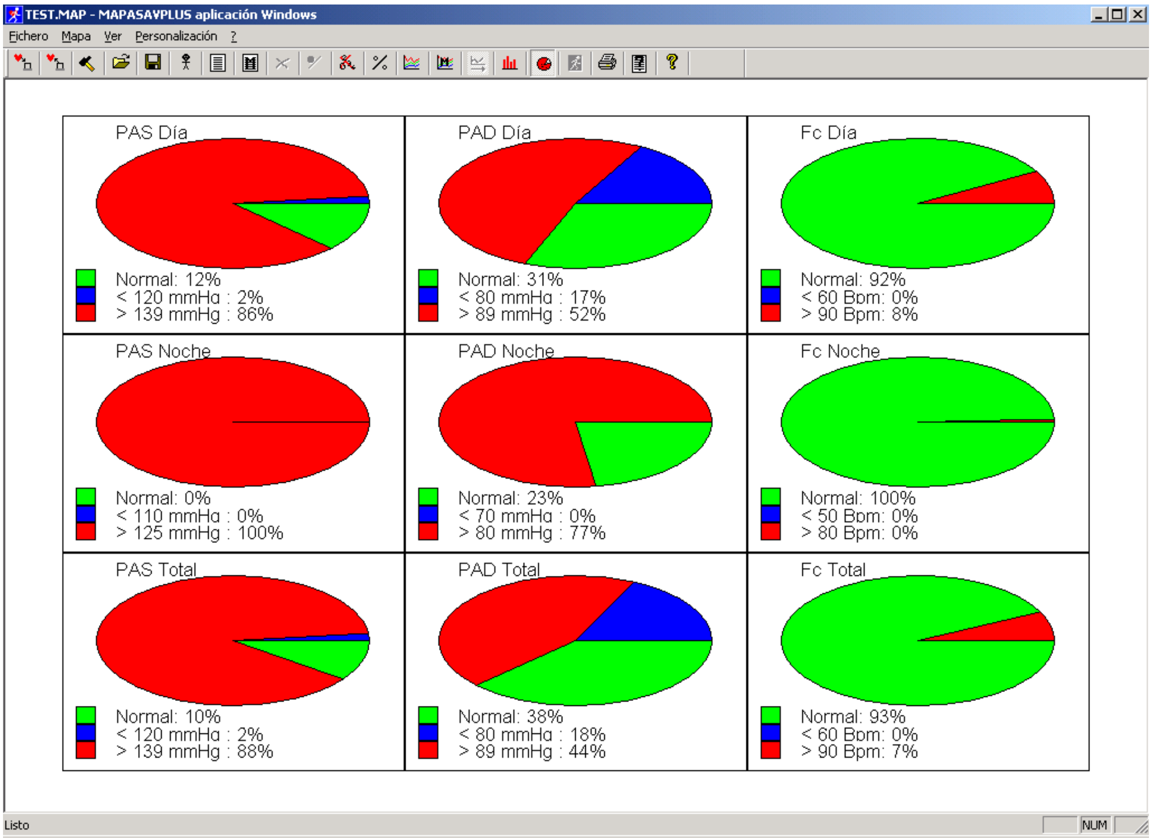
Los ejes horizontales están graduados en cmHg, los ejes verticales en %.
Los histogramas representan la repartición de las zonas de presiones en % de la totalidad de las medidas.

D/ *Los diagramas circulares o representaciones en sectores*



Clic este ícono para anunciar las gráficas sectoriales.

☞ Pulsar las teclas ALT y V al mismo tiempo para llamar la lista Ver y la tecla E de Sectores para fijar las gráficas sectoriales. Entonces la pantalla se presenta así:



Ventana 17

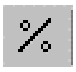
Los límites son modificables en la lista Personalización en el encuadrado ‘Gráficas sectoriales.

Los parámetros de presión sistólica, diastólica y de frecuencia de corazón aparecen en los tres períodos:

- medidas por el día
- medidas por la noche
- totalidad de las medidas

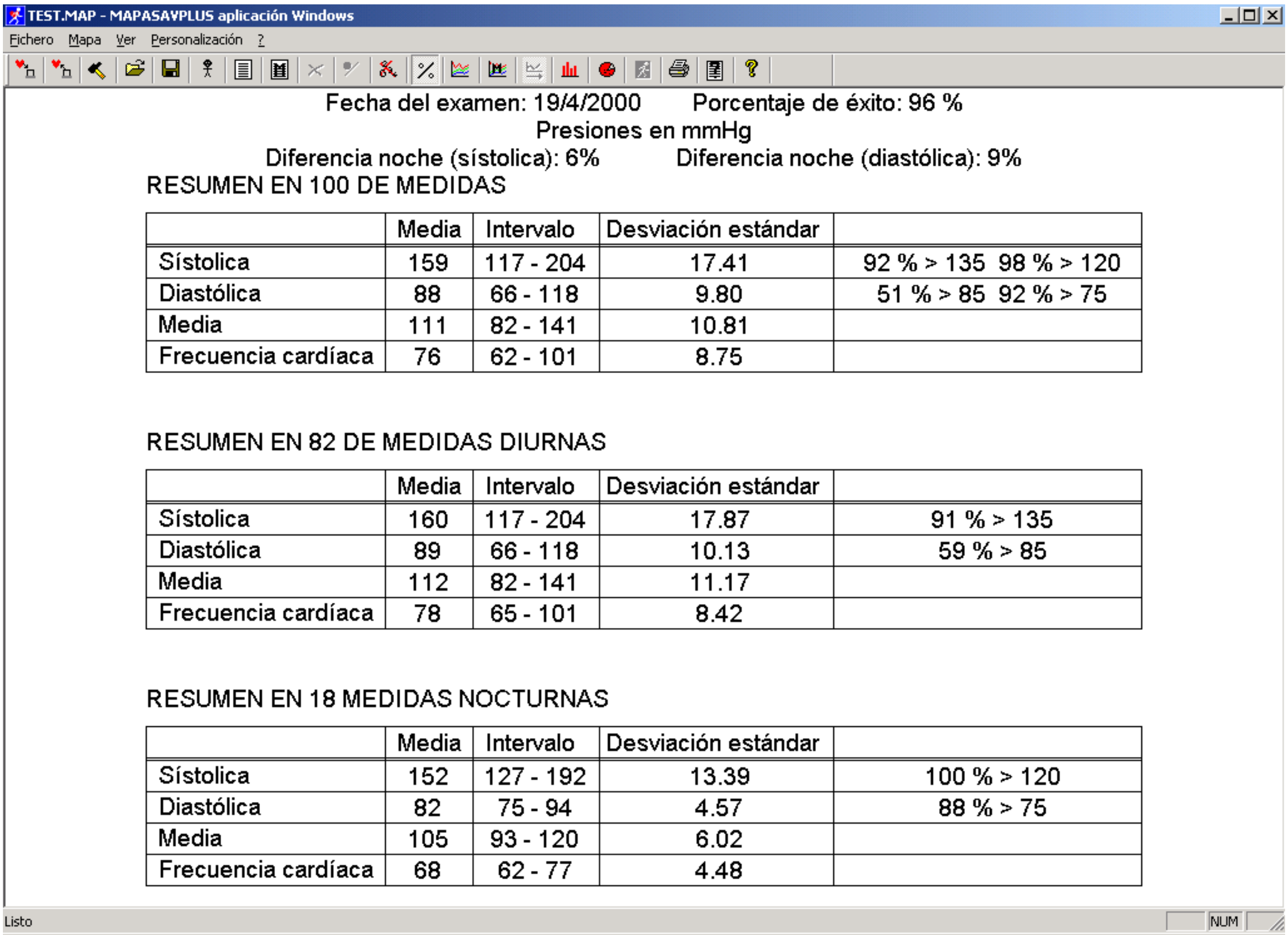
Los límites consisten en precisar un valor máximo y un valor mínimo para cada parámetro, los valores incluídos entre estos 2 límites están considerados como normales.

V-4. El cuadro de las estadísticas



Clic en este ícono para anunciar el cuadro de las estadísticas.

☞ Pulsar las teclas ALT y V al mismo tiempo para llamar la lista Ver y la tecla S para fijar el cuadro Estadísticas. Entonces la pantalla se presneta de la siguiente manera:



TEST.MAP - MAPASAVPLUS aplicación Windows

Fichero Mapa Ver Personalización ?

Fecha del examen: 19/4/2000 Porcentaje de éxito: 96 %

Presiones en mmHg

Diferencia noche (sístolica): 6% Diferencia noche (diastólica): 9%

RESUMEN EN 100 DE MEDIDAS

	Media	Intervalo	Desviación estándar	
Sístolica	159	117 - 204	17.41	92 % > 135 98 % > 120
Diastólica	88	66 - 118	9.80	51 % > 85 92 % > 75
Media	111	82 - 141	10.81	
Frecuencia cardíaca	76	62 - 101	8.75	

RESUMEN EN 82 DE MEDIDAS DIURNAS

	Media	Intervalo	Desviación estándar	
Sístolica	160	117 - 204	17.87	91 % > 135
Diastólica	89	66 - 118	10.13	59 % > 85
Media	112	82 - 141	11.17	
Frecuencia cardíaca	78	65 - 101	8.42	

RESUMEN EN 18 MEDIDAS NOCTURNAS

	Media	Intervalo	Desviación estándar	
Sístolica	152	127 - 192	13.39	100 % > 120
Diastólica	82	75 - 94	4.57	88 % > 75
Media	105	93 - 120	6.02	
Frecuencia cardíaca	68	62 - 77	4.48	

Listo NUM

Ventana 18

A la izquierda encima del primer cuadro, la tasa de variación de la presión media de las presiones sistólicas del período día respecto al período noche está fijada. A la derecha, la tasa de variación de la presión media de las presiones diastólicas del período día respecto al período noche está fijada.

Tres períodos están otra vez presentados:

- el período que incluye la totalidad de las medidas
- el período que no toma en cuenta las medidas efectuadas de día
- el período de las medidas efectuadas de noche

Cuatro tipos de cálculos están realizados:

- la media
- el intérvalo de variación del parámetro, es decir el valor mínimo y el valor máximo proporcionados
- la diferencia típica (ver definición matemática en el anexo 1)
- porcentajes de medidas superiores a un valor

Los valores límites utilizados son los de las gráficas horarias y son pués personalizables en el encuadrado 'Gráficas horarias' de la ventana de Personalización.

☞ Pulsar las teclas ALT y P al mismo tiempo para llamar la lista Personalización y la tecla P para abrir la ventana de Personalización.

VI - MANDOS

En la lista Fichero, 3 posibilidades para guardar los datos están abiertas:

- Guardar
- Guardar como…
- Exportación

VI-1. El mando 'Guardar'

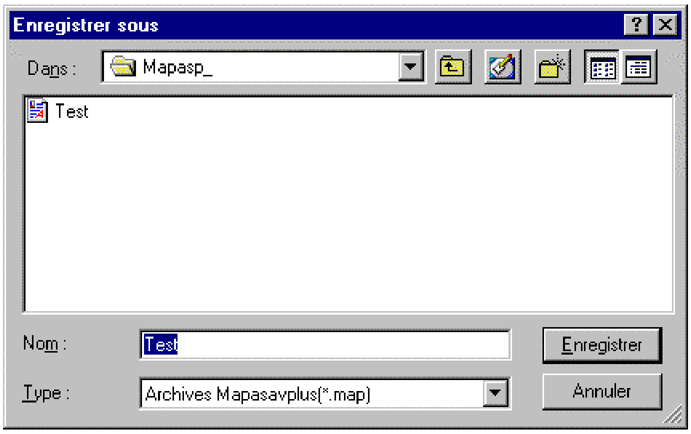
☞ Pulsar las teclas ALT y F al mismo tiempo para llamar la lista Fichero y la tecla G para utilizar el mando Guardar.

El mando entonces está automáticamente desviado en 'guardar como…' para proponer al usuario cambiar el nombre del fichero. El nombre del fichero por defecto es el nombre del paciente entrado en la ventana de personalización.

VI-2. El mando 'Guardar como…'

Esta función permite cambiar el nombre de fichero (o eventualmente el camino de ventanas informes-lectores) antes de su grabación. Si la extensión '.map' está omitida, el software la añadirá automaticamente.

☞ Pulsar las teclas ALT y F al mismo tiempo para llamar la lista Fichero y la tecla U para utilizar el mando 'Guardar como…''.



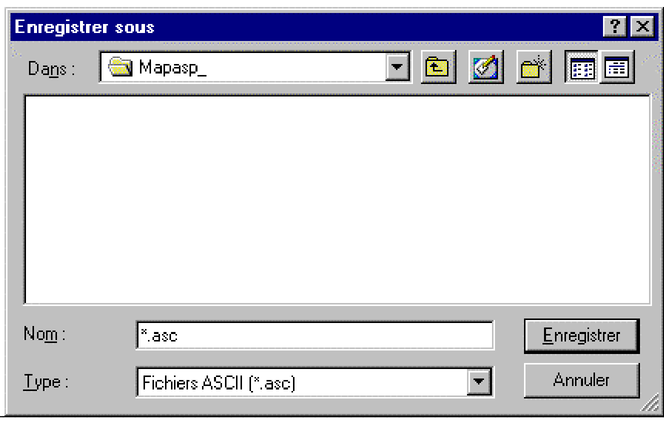
Ventana 19

☞ Para mover en la ventana, utilizar la tecla de TABULACIÓN.
Para desenrollar las listas en los encuadrados provistos de flechas, utilizar las teclas ↑ ↓.
Para validar un fichero, un tipo de fichero, un informe o un lector que está seleccionado, pulsar la tecla ENTRADA

VI-3. El mando 'exportación'

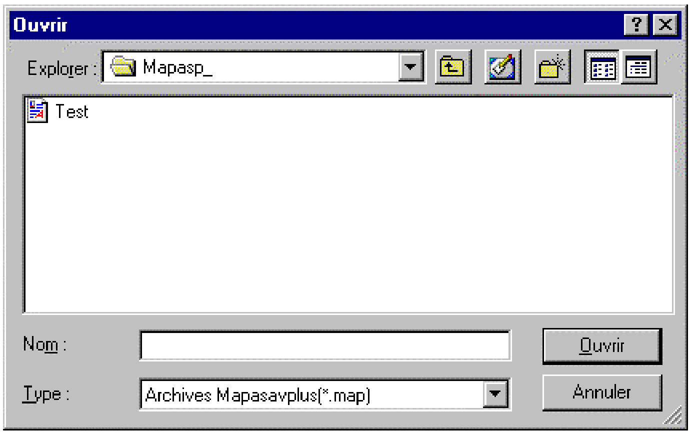
Permite recuperar las datos del MAPA en un fichero del tamaño ASCII. Eso permitirá utilizar el examen efectuado con otro sotfware que MAPASAV PLUS, un cuadro por ejemplo.
☞ Pulsar las teclas ALT y F al mismo tiempo para llamar la lista Fichero y la tecla X para utilizar el mando Exportación.

VI-4. El mando 'Abrir…' un fichero



Ventana 20

La pantalla se presenta así:



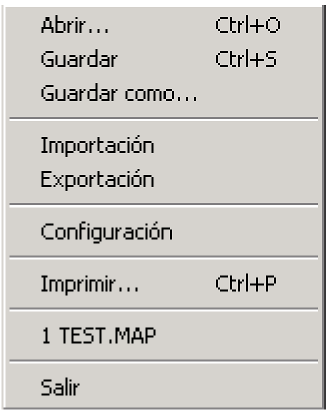
Ventana 21

Escribir el nombre del fichero que recargar en la ventana 'Nombre de fichero' o seleccionarlo en la lista de los ficheros grabados. Si el fichero no está en la lista, verificar que el camino (ventana Informe) y el lector están correctos.
Validar seleccionando el botón OK.

Nota:
Cuando se selecciona en la lista dos veces el nombre del fichero, éste se recarga automáticamente.
☞ Pulsar las teclas ALT y F al mismo tiempo para llamar la lista Fichero y la tecla A o las teclas CTRL et O para utilizar el mando 'Abrir'.
Para desplazarse en la ventana, utilizar la tecla de TABULACIÓN.
Para desenrollar las listas en los encuadrados provistos de flechas, utilizar las teclas ↑ ↓.
Para validar un fichero, un tipo de fichero, un informe o un lector que está seleccionado, pulsar la tecla ENTRADA.

Si un fichero utilizado no está guardado o si modificaciones que han sido hechas en el fichero no están protegidas, un mensaje aparecerá en la pantalla para advertirlo.
En efecto, cada cargamento de fichero empieza a borrar los datos del fichero presente en la pantalla.
Entonces, este aviso permite al usuario confirmar su acción o cancelar en caso de olvido.

Cuando se efectúa la instalación del software, un fichero 'Test.map' se vuelve a copiar en el disco duro de su ordenador.
Este fichero está disponible para acostumbrar el usuario con los mandos del software.
En la lista Fichero, una zona contiene los 4 últimos ficheros utilizados, seleccionar el fichero concernido.



Ventana 22

VI-5. El mando ‘Importación’

La lista Fichero tiene el mando importación que abre la misma ventana que el mando exportación.

☞ Pulsar las teclas ALT y F al mismo tiempo para llamar la lista Fichero y la tecla M para utilizar el mando ‘Importación’.

Este mando permite cargar un fichero cuyo tamaño no es compatible con los ‘.map’ y que fue anteriormente exportado en un tamaño binario o Ascii (ver el mando ‘exportación’).

VI-6. El mando ‘Imprimir’

Salida del informe de la impresora.

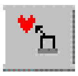
☞ Pulsar las teclas ALT y F al mismo tiempo para llamar la lista Fichero y la tecla I para utilizar el mando ‘Imprimir’.

El informe está publicado según la selección efectuada en el tablero de configuración (lista Fichero, mando Configuración). Referirse al párrafo que explica las funciones del tablero de configuración.

Si ninguna página está seleccionada, un aviso aparecerá en la pantalla.

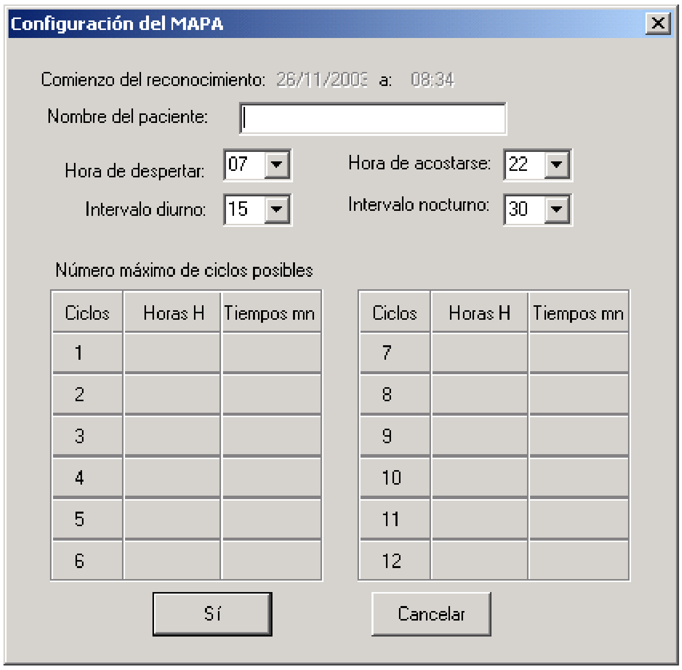
VI-7. El mando ‘Programar’

Conectar el MAPA al PC y pasar en modo comunicación PC (ver capítulo IV-3).



Clic este ícono o seleccionar el mando Programar en el menú MAPA para programar el MAPA.

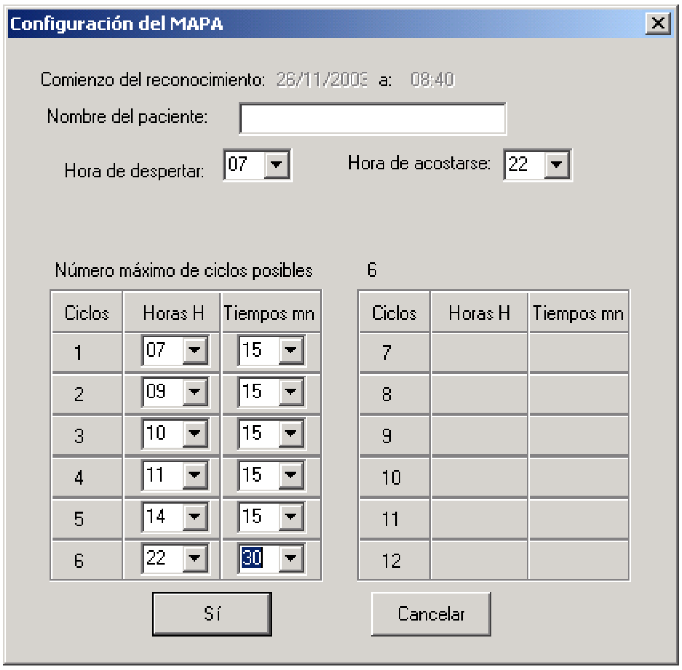
Según la versión del MAPA, la ventana de programación difiere. En el caso del MAPA33 versión simple :



Ventana 23

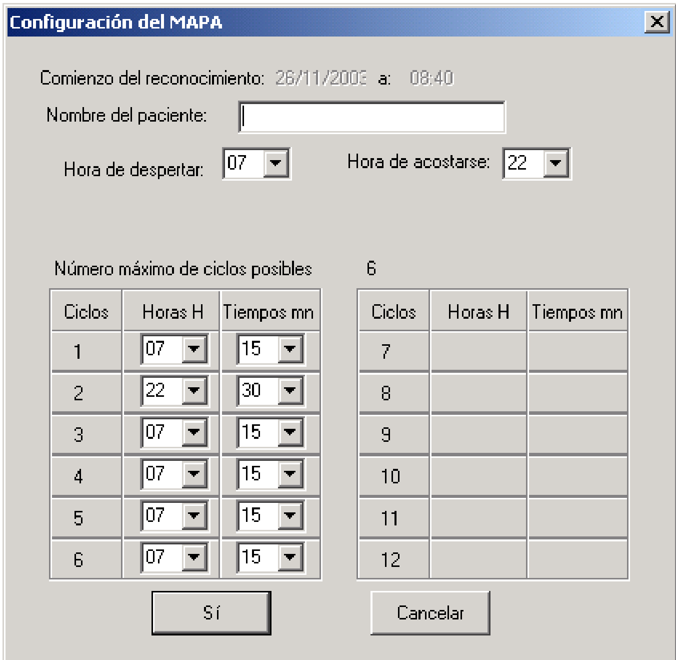
Arriba, parece la fecha y la hora de comienzo del examen que está programado en el MAPA y que corresponden a la reloj y al fecha interna de su ordenador. El usario utilizara las herramientas Windows para eventualmente volver a poner al día estos parámetros.
El campo ‘Nombre del paciente’ debe ser informado con 32 letras maximum.
4 ventanas de arreglo están también propuestas para ajustar ‘la hora del despertar’ estimada del paciente y a partir de la cual las medidas se efectuarán al ritmo indicado en esta última ventana.
Los dos tiempos de ciclos se arreglan por tojada de 5 minutos pulsando en la pequeña fecha a la derecha del valor propuesto. Otros campos no son accesibles.

En el caso del MAPA33 versión multiciclos:



Ventana 24

Es idéntico al precedente salvo la noción de 'ciclo día' o' ciclo noche ya no existe pero el MAPA puede aceptar hasta 12 ciclos según la versión.
En la ventana arriba, 6 ciclos son accesibles y significa para este ejemplo que el aparato efectuará medidas todos los 15 minutos a partir de las 07 h, 09 h, 10 h, 11 h y 14 h y medidas todos los 30 minutos a partir de las 22 horas.
Se cambian los valores de las ventanas de arreglo pulsando con el ratón la flecha a la izquierda de las cifras.
Si el usario no quiere solamente un tiempo de ciclo, puede invalidar los otros seleccionando el símbolo 'XX' en la casilla 'comienzo H' de los ciclos concernidos. En los 5 de 6 ciclos, la hora 'comienzo H' está arreglada a las 07 h y el intérvalo de medida a 15 minutos.



Ventana 25

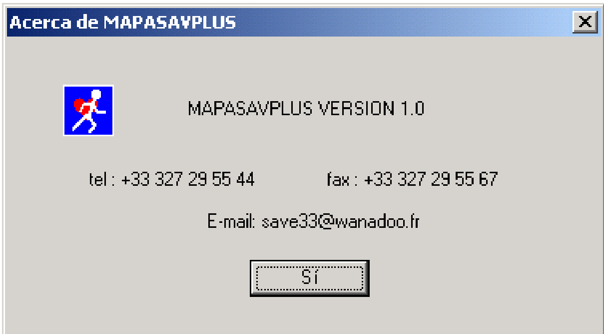
El ciclo 1 no puede ser utilizado, porque el MAPA necesita menos 1 valor para dar cadencia a las medidas automáticamente. Otros campos quedan idénticos, el nombre del paciente es obligatorio (con 32 letras al máximo) y la hora del despertar y el acosto permiten determinar los diferentes periodos de la jornada utiles para los gráficos y los cuadros estadísticos. La fecha y la hora son las del PC y serán transfiguradas al MAPA durante el clic en el botón OK.
Los diferentes parámetros configurados en esta ventana son tranfigurados al MAPA desde que el usario selecciona el botón OK. Entonces el MAPA emite 3 bips indicando que los parámetros han sido recibidos. El usuario entonces saca el cordón de transferencia del MAPA que emite inmediatamente un largo bip indica que el cuadro de medida eventualmente presente en memoria ha sido borrado y que efectuara su primera medida automáticamente al final del tiempo del primer ciclo.

☞ Pulsar las teclas ALT y M al mismo tiempo para llamar la lista Mapa y la tecla P para utilizar el mando Programar'.
Para mover en la ventana, utilizar la tecla de TABULACION.
Para desenrollar las listas en los encuadrados provistos de flechas, utilizar las teclas ↑ ↓.
Para validar, pulsar la teclar ENTRADA

VI-8. Versión del software y dirección de SAVE33

Clic este ícono o seleccionar 'A cerca de MAPASAV PLUS…' en la lista '?' para anunciar la versión del software y la dirección de SAVE 33.

☞ Pulsar las teclas ALT y SHIFT y ? al mismo tiempo para llamar la lista ? y la tecla C para utilizar el mando 'Acerca de MAPASAV PLUS…'



Ventana 26

Esta ventana permite obtener todas las informaciones necesarias para ponerse en contacto con la sociedad SAVE33

ANEXO 1

Las preguntas frecuentemente hechas

Imposible leer los datos del MAPA33

- verificar que el MAPA33 está en comunicación PC. El aparato debe fijar el mensaje ‘Comunicación PC’
- verificar que el cable interface está correctamente conectado sobre el aparato y sobre el ordenador
- verificar que usted ha seleccionado correctamente el puerto serie de comunicación en su ordenador. Seleccionar la lista Fichero, mando ‘Configurar’.

Qué es una diferencia típica ?

La diferencia típica permite apreciar la dispersión de una serie de datos respecto a la media.

Por definición matemática, la diferencia típica es la raíz cuadrada de la fluctuación de una serie estadística, escrita V^2.

La fluctuación es la media de los cuadrados disminuida del cuadrado de la media.

$$V^2 = (X^2) - (X)^2$$

$$\text{Diferencia típica} = \sqrt{V^2}$$

Anexo N° 5g Rutinas de control

```
/*********************************************************************
 PROGRAMA QUE CONTROLA LA CONVERSIÓN ANALOGO DIGITAL DEL PIC A LA COMPUTADORA POR EL PUERTO PARALELO

*********************************************************************/

//declarar las librerias a usar
#include <stdio.h>
#include <stdlib.h>
#include <conio.h>
#include <string.h>
#ifdef__cplusplus		#define __CPPARGS ...
#else			#define __CPPARGS
#endif
//declaración de variables globales
int	DATA=0x0378;
	//bidireccional
int	STATUS=0x0379;
	//entrada a la PC
int	CONTROL=0x037A;
	//salida de la PC
//declarar las funciones
/* EL MANEJO DEL PUERTO PARALELO ESTA DISPUESTO DE ESTA FORMA
PIN	PORT	DIREC	BIT	ADC
1	CONTROL		OUT	C0\	CS\
2	DATO	BI	D0	Dato0
3	DATO		D1	Dato1
4	DATO		D2	Dato2
5	DATO		D3	Dato3
6	DATO		D4	Dato4
7	DATO		D5	Dato5
8	DATO		D6	Dato6
9	DATO		D7	Dato7
10	STATUS	IN	S6\	Dato10\	OJO es negado...!!!
11	STATUS	IN	S7	Dato11
12	STATUS	IN	S5	Dato9
13	STATUS	IN	S4	Dato8
14	CONTROL OUT	C1\	WR\
15	STATUS	IN	S3\	INT\
16	CONTROL OUT	C2	bit para controlar la valvula on-off
17	CONTROL OUT	C3\	RD\
18-25					*/
void writeadc(int palabra)
{
	int dato,mando;
	dato=inportb(CONTROL);
	mando=dato|0x01;
	//Activo CS\
	outportb(CONTROL,mando);
	dato=inportb(CONTROL);
	mando=dato|0x02;
	//Activo WR\
	outportb(CONTROL,mando);
	outportb(DATA,palabra);
	//Escribo la palabra en el ADC
	dato=inportb(CONTROL);
	mando=dato&0xFD;
	//Desactivo WR\
	outportb(CONTROL,mando);
	dato=inportb(CONTROL);
	mando=dato&0xFE;
	//Desactivo CS\
	outportb(CONTROL,mando);
}

int conv(int dato)
{
	int tempo,tempo2,final;
	tempo=dato&0xF0;
	tempo2=0;
	if (tempo==0x40)  tempo2=0 ;
	if (tempo==0x50)  tempo2=0x100 ;
	if (tempo==0x60)  tempo2=0x200 ;
	if (tempo==0x70)  tempo2=0x300 ;
	if (tempo==0x00)  tempo2=0x400 ;
	if (tempo==0x10)  tempo2=0x500 ;
	if (tempo==0x20)  tempo2=0x600 ;
	if (tempo==0x30)  tempo2=0x700 ;
	if (tempo==0xC0)  tempo2=0x800 ;
	if (tempo==0xD0)  tempo2=0x900 ;
	if (tempo==0xE0)  tempo2=0xA00 ;
	if (tempo==0xF0)  tempo2=0xB00 ;
	if (tempo==0x80)  tempo2=0xC00 ;
	if (tempo==0x90)  tempo2=0xD00 ;
	if (tempo==0xA0)  tempo2=0xE00 ;
	if (tempo==0xB0)  tempo2=0xF00 ;
	final=tempo2;
	return final;
}

int readadc(void)
{
	int dato,mando,tempo,numero;
	dato=inportb(CONTROL);
	mando=dato|0x01;
	//Activo CS\
	outportb(CONTROL,mando);
	dato=inportb(CONTROL);
	mando=dato|0x08;
	//Activo RD\
	outportb(CONTROL,mando);
	numero=0;
	dato=inportb(DATA);
	numero=dato;
	dato=inportb(STATUS);
	tempo=conv(dato);
	dato=inportb(CONTROL);
	mando=dato&0xF7;
	//Desactivo RD\
	outportb(CONTROL,mando);
```

```
	dato=inportb(CONTROL);
	mando=dato&0xFE;
	//Desactivo CS\
	outportb(CONTROL,mando);
	numero=numero+tempo;
	return tempo;
}


void finconv(void)
{
	int tempo;
	tempo=0;
	while (tempo==0)		//queda en
el bucle
	{			//hasta que ocurra
la
		tempo=inportb(STATUS);
//la interrupcion
		tempo=tempo&0x08;
	}
}


int configadc(void)
{
	int opc,mando;
	printf("\n Seleccione el modo en que
desea hacer funcionar el ADC \n");
	printf(" [1] Modo de   0v  a  5v \n");
	printf(" [2] Modo de   0v  a 10v \n");
	printf(" [3] Modo de  -5v  a  5v \n");
	printf(" [3] Modo de -10v  a 10v \n");
	opc=getche();
	mando=0;
	if (opc==1) mando=0x40;
	//01000000
	if (opc==2) mando=0x48;
	//01001000
	if (opc==3) mando=0x50;
	//01010000
	if (opc==4) mando=0x58;
	//01011000
	return mando;
}

//comienzo del programa principal

void main (void)
{
	int inip,cont,conf,dato;
	char archi1[40];
	char archi2[40];
	FILE *p_arch1;
	FILE *p_arch2;
	clrscr();
	inip=inportb(CONTROL);
	//Salvo dato del puerto de control
	inip=inip&0xF0;		//Desactivo
CS\ WR\ VALV RD\
	outportb(CONTROL,inip);
	//Inicializo el puerto de control
	printf("\n Ingrese el numero de datos
deseados: ");
	scanf("%d",&cont);
	printf("\n");
	printf("\n Nombre del archivo de
presion sin filtro: ");
	scanf("%s",&archi1);
	printf("\n");
	printf("\n Nombre del archivo de
presion con filtro: ");
	scanf("%s",&archi2);
	printf("\n");
	p_arch1=fopen(archi1,"w");
	p_arch2=fopen(archi2,"w");
	if((p_arch1==NULL)||(p_arch2==NUL
L))
	{
		printf("\n Archivo no
valido....! \n");
	}
	else
	{
		conf=configadc();
		while(cont>0)
		{
			writeadc(conf+0);
		//Leo canal 0
			finconv();
			dato=readadc();

	fwrite(&dato,sizeof(int),1,p_arch1);
			writeadc(conf+1);
		//Leo canal 1
			finconv();
			dato=readadc();

	fwrite(&dato,sizeof(int),1,p_arch1);
			cont=cont-1;
		}
		fclose(p_arch1);
		fclose(p_arch2);
	}
}
/***************************************
*******************************
 PROGRAMA DE COMUNICACION Y DE
ENVIO DE PROGRAMAS ENTRE  LA
COMPUTADORA Y EL PIC

**************************************
******************************/
//declarar las librerias a usar
#include <stdio.h>
#include <stdlib.h>
#include <conio.h>
#include <string.h>
#ifdef__cplusplus		#define __CPPARGS
...
```

```
#else                          #define __CPPARGS
#endif
//declaración de variables globales
int     DATA=0x0378;
        //bidireccional
int     STATUS=0x0379;
        //entrada a la PC
int     CONTROL=0x037A;
        //salida de la PC
//declarar las funciones
void paralelosalida(void)
{
        int dato_ant,numero;
        dato_ant=inportb(CONTROL);
        //Salvo dato del puerto de control
        numero=dato_ant&0xDF;
        //Coloco en 0 solo el bit 5
        outportb(CONTROL,numero);
//aseguro que el puerto sea de salida
}

int conv(char CAR)
{
        int Num;
        Num=0;
        if (CAR=='1') Num=1;
        if (CAR=='2') Num=2;
        if (CAR=='3') Num=3;
        if (CAR=='4') Num=4;
        if (CAR=='5') Num=5;
        if (CAR=='6') Num=6;
        if (CAR=='7') Num=7;
        if (CAR=='8') Num=8;
        if (CAR=='9') Num=9;
        if (CAR=='A') Num=0x0A;
        if (CAR=='B') Num=0x0B;
        if (CAR=='C') Num=0x0C;
        if (CAR=='D') Num=0x0D;
        if (CAR=='E') Num=0x0E;
        if (CAR=='F') Num=0x0F;
        return Num;
}

int conv2(char B1, char B0)
{
        int N1,N0,Num;
        N1=conv(B1);
        N0=conv(B0);
        Num=N0+N1*0x10;
        return Num;
}

void paralelcom(int nbytes, int l_dir, char *pal)
{
        int j,numero,dato_ant;
        outportb(DATA,l_dir);
        //Flag para envio de direccion de 4 o 6
        dato_ant=inportb(CONTROL);
        //Salvo dato del puerto de control
        dato_ant=dato_ant&0xF0;
        //Enmascaro los bits reservados
        numero=dato_ant|0x0A;
        //Defino: Ingreso,DFP\,NDP\
        outportb(CONTROL,numero);
        //Mando esto al puerto de control
        do
        {
                dato_ant=inportb(STATUS);
                dato_ant=dato_ant&0x10;
        //enmascaro para recibir solo ROKH
        } while (dato_ant!=0x10);
        dato_ant=inportb(CONTROL);
        //Salvo dato del puerto de control
        dato_ant=dato_ant&0xF0;
        //Enmascaro los bits reservados
        numero=dato_ant|0x0F;
        //Desactivo: DFP\,NDP\
        outportb(CONTROL,numero);
        //Mando esto al puerto de control
        do
        {
                dato_ant=inportb(STATUS);
                dato_ant=dato_ant&0x10;
        //enmascaro para recibir solo ROKH
        } while (dato_ant!=0);
        //espero la desactivacion de ROKH
        for (j=2; j<=nbytes; j++)
        {

        numero=conv2(pal[2*j],pal[2*j+1]);
        //conversion
                outportb(DATA,numero);
        //envio la data

        dato_ant=inportb(CONTROL);
        //Salvo dato del puerto de control
                dato_ant=dato_ant&0xF0;
        //Enmascaro los bits reservados
                numero=dato_ant|0x0E;
        //Defino: Ingreso,NDP\
                outportb(CONTROL,numero);
        //Mando esto al puerto de control
                do
                {

        dato_ant=inportb(STATUS);

        dato_ant=dato_ant&0x10; //enmascaro
para recibir solo ROKH
                } while (dato_ant!=0x10);
//espero hasta recibir ROKH

        dato_ant=inportb(CONTROL);
        //Salvo dato del puerto de control
                dato_ant=dato_ant&0xF0;
        //Enmascaro los bits reservados
                numero=dato_ant|0x0F;
        //Desactivo: DFP\,NDP\
```

```
		outportb(CONTROL,numero);
	//Mando esto al puerto de control
		do
		{

	dato_ant=inportb(STATUS);

	dato_ant=dato_ant&0x10; //enmascaro
para recibir solo ROKH
		} while (dato_ant!=0);
	//espero la desactivacion de ROKH
	}
}

void transarchivo(char *nombre_arch, int
n_lineas) // Transforma el formato del archivo
{
	FILE *ptr_arch1;
	int i,j,nb_dir,nume,dato_a;
	int n_byte;			//numero de
bytes que tiene la linea
	int direc;			//direccion
de inicio de la linea de prog
	char arch_tx[40];
	char li[255];		//arreglo de
caracteres de la linea
	ptr_arch1=fopen(nombre_arch, "r");
	for (i=1; i<=n_lineas; i++)
	{
		if ((i==1)||(i==n_lineas))
fscanf(ptr_arch1,"%s",li);
		else
		{

	fscanf(ptr_arch1,"%s",li);
			if (li[1]=='1')
			{

	n_byte=conv2(li[2],li[3]);

	paralelcom(n_byte,0x04,li);
				printf("\n
Linea Transmitida");
			}
			if (li[1]=='2')
			{

	n_byte=conv2(li[2],li[3]);

	paralelcom(n_byte,0x06,li);
				printf("\n
Linea Transmitida");
			}
		}
	}
	outportb(DATA,0xAA);	//Coloco flag
para fin de transmision
	dato_a=inportb(CONTROL);
	//Salvo dato del puerto de control
	dato_a=dato_a&0xF0;
	//Enmascaro los bits reservados
	nume=dato_a|0x0A;
	//Defino: Ingreso,DFP\,NDP\
	outportb(CONTROL,nume);
	//Mando esto al puerto de control
	do
	{
		dato_a=inportb(STATUS);
		dato_a=dato_a&0x10;
	//enmascaro para recibir solo ROKH
	} while (dato_a!=0x10);
	dato_a=inportb(CONTROL);
	//Salvo dato del puerto de control
	dato_a=dato_a&0xF0;
	//Enmascaro los bits reservados
	nume=dato_a|0x07;
	//Desactivo: DFP\,NDP\ y DATA IN
	outportb(CONTROL,nume);
	//Mando esto al puerto de control
	fclose(ptr_arch1);
/*	do
	{
		dato_a=inportb(STATUS);
		dato_a=dato_a&0x10;
	//enmascaro para recibir solo ROKH
	} while (dato_a!=0);  */
}

int leearchivo(char *nombre_arch) //Lee el
numero de lineas del archivo
{
	FILE *ptr_arch;
	int n_lineas;
	char cosa[255];
	n_lineas=0;
	ptr_arch=fopen(nombre_arch, "r");
	if (ptr_arch==NULL)
	{
		n_lineas=1;
	}
	else
	{
		while(!feof(ptr_arch))
		{

	fscanf(ptr_arch,"%s",cosa);
			n_lineas++;
		}
	}
	fclose(ptr_arch);
	return n_lineas;
}

//comienzo del programa principal

void main (void)
{
	int lineas,lineastx,inip;
	char archivo[40];
```

```
	clrscr();
	paralelosalida();	//Habilito el puerto
paralelo de data out
	lineas=0;
	inip=inportb(CONTROL);
	//Salvo dato del puerto de control
	inip=inip&0xF0;		//Enmascaro
los bits reservados
	inip=inip|0x0F;		//Desactivo
todo DFP\,NDP\,ROKP\
	outportb(CONTROL,inip);
	//Inicializo el puerto de control
	printf("\n Ingrese el nombre del archivo
*.H68: ");
	scanf("%s",&archivo);
	printf("\n");
	printf("\n El archivo ingresado es %s
",archivo);
	printf("\n");
	lineas=leearchivo(archivo);
	if (lineas==1)
	{
		printf(" Error al leer el
archivo");
	}
	else
	{
		lineas=lineas-1;
		lineastx=lineas-2;
		printf(" El n£mero de l¡neas a
transmitir es: %d", lineastx);
		transarchivo(archivo,lineas);
		printf("\n -...Transmisi¢n
finalizada...!");
	}
}


/*************************************
******************************
 PROGRAMA DE TRASMISION SERIAL
ENTRE  LA COMPUTADORA Y EL PIC

*************************************
******************************/
//Declaro librerías a usar
#include <conio.h>
#include <stdio.h>
#include <dos.h>
//Declaro las variables globales
FILE *p;
long cont=0;
int carr,dato,datolisto,car;
int INTS=0x0b;
int PORTB=0x2f8;
int MASC=0xf7;
//Declaro las funciones a usar
void interrupt (*oldserial)();
long filesize(FILE *stream);
void menu(void);
```

```
void chat(void);
void enviar(void);
void recep(void);
void recibo(int masc);
//Empieza el programa
void interrupt newserial()
{
dato=inp(PORTB);		//cojo el dato del
puertoB
datolisto=1;		//digo la bandera de 1
outp(0x20,0x20);		//escribir en el PIC
(interrupciones)
}

void menu (void)
 {
 clrscr();
 printf ("\n MENU \n \n");
 printf("[1]: Comunicaci¢n entre dos PCs\n");
 printf("[2]: Env¡o de Archivo a una PC\n");
 printf("[3]: Recepci¢n de Archivo de una
PC\n");
 printf("[4]: Recibo datos del PIC18F242 por
serial\n");
 return;
 }

void chat(void)
 {
 while(1)
  {
  if(datolisto==1)
   {
   datolisto=0;
   printf("%c",dato);
   if(dato==13)printf("\n");
   }

  if(kbhit())
   {
   carr=getch();
   if(carr==0x1b) break;
   while(!(inp(PORTB + 5)&0x20)); //pues es
transmision por sensado...
   outp(PORTB,carr);
   printf("%c",carr);
   if(carr==13) printf("\n");
   }
  }
 }

long filesize(FILE *stream)
 {
 long curpos, length;

 curpos = ftell(stream);
 fseek(stream, 0L, SEEK_END);
 length = ftell(stream);
 fseek(stream, curpos, SEEK_SET);
 return length;
```

```
 }

void enviar(void)
 {
 char *nombre,b1,b2,b3,b4,car;
 FILE *nombre1;
 long tamano,t;

 printf("escribe el nombre del archivo a enviar
");
 gets(nombre);
 nombre1=fopen(nombre,"rb");
 tamano=filesize(nombre1);
 t=tamano;
 b1=tamano%256;
 tamano=tamano/256;
 b2=tamano%256;
 tamano=tamano/256;
 b3=tamano%256;
 tamano=tamano/256;
 b4=tamano%256;

 while(!(inp(PORTB + 5)&0x20));
 outp(PORTB,b4);
 while(!(inp(PORTB + 5)&0x20));
 outp(PORTB,b3);
 while(!(inp(PORTB + 5)&0x20));
 outp(PORTB,b2);
 while(!(inp(PORTB + 5)&0x20));
 outp(PORTB,b1);

 while(t>0)
  {
  t--;
  car=getc(nombre1);
  if(car==0x1b) break;
  while(!(inp(PORTB + 5)&0x20));
  outp(PORTB,car);
  }
 fclose(nombre1);
 }

void recibo(int masc)
{
 char *nombre;
 FILE *nombre1;
 int t;
 t=0;
 printf("\n Escribe el nombre del archivo: ");
 gets(nombre);
 nombre1=fopen(nombre,"wb");
 while (datolisto==0);
 datolisto=0;
 if (dato==0xAA) printf("\n Inicio de
transmision...!");
 if (!(dato==0xAA)) printf("\n Error en bandera
de inicio de tx..!");
 do
  {
  while (datolisto==0);
  datolisto=0;
  fputc(dato,nombre1);   //escribo el dato en el
archivo
  while (datolisto==0);
  datolisto=0;
  if (dato==0xEE) t=1;    //si el caracter bandera
es EE finaliza todo
  }
 while (t==0);
 outp(0x21,masc);             //restauro mascara del
PIC
 setvect(INTS,oldserial);   //restauro vector
original
 fclose(nombre1);
 printf("\n Fin de transmisioon....!");
}

void recep(void)
 {
 int i=0;
 clrscr();
 p=fopen("C:\\nuevo.txt","w");
 while(1)
  {
  if (datolisto==1)
   {
   datolisto=0;
   switch(i)
    {
    case 0: cont=dato*256*256*256; i++; break;
    case 1: cont=cont+dato*256*256; i++; break;
    case 2: cont=cont+dato*256; i++; break;
    case 3: cont=cont+dato; i++; break;
    case 4: fputc(dato,p);
               cont--;
               printf("%c",dato);
               if (dato==13) printf("\n");
               if (cont==0)
                {
                fclose(p);
                menu();
                return;
                }
    }
   }
  }
 }

int main(void)
{
int car,masc;
unsigned char car1,n;
menu();
while (inp(PORTB + 5)& 0x01 ) inp (PORTB);
oldserial=getvect(INTS);
setvect(INTS,newserial);
outp(PORTB + 3,0x80);
outp(PORTB, 12);
outp(PORTB + 1,0);
outp(PORTB + 3, 0x03);
```

```
car1 = inp(PORTB + 4)|0x08;
outp(PORTB + 4,car1);
outp(PORTB + 1,0x01);
masc=inp(0x21);
car1=masc&MASC;
outp(0x21,car1);
while(1)
 {
 n=getch();
 switch(n)
  {
  case '1': chat(); break;
  case '2': enviar(); break;
  case '3': recep(); break;
  case '4': recibo(masc); break;
  case 27:  outp(0x21,masc);            //restauro
mascara del PIC
                  setvect(INTS,oldserial);
              //restauro vector original
                  return 0;
  }
 }
}
```

TONOPORT V

Firmware Version FW1.4
Hardware Version HW1.2

Servicing Instructions

2001589-023 (ENG) Revision F

GE Medical Systems
Information Technologies

Caution:
During repairs/service interventions, observe the protective measures against damage due to ESD.

- ***GE Medical Systems*** *Information Technologies* ***(GEMS IT)*** considers itself responsible for the effects on safety, reliability, and performance of the equipment, only if:
  - assembly operations, extensions, readjustments, modifications, or repairs are carried out by
    GE Medical Systems *Information Technologies* ***(GEMS IT)*** or by persons authorized by ***GE Medical Systems*** *Information Technologies*,
  - the electrical installation of the relevant room complies with the applicable national and local requirements, and
  - the instrument is used in accordance with the instructions for use.
- This manual contains service information; operating instructions are provided in the operator's manual of the instrument.
- This manual is in conformity with the instrument at printing date.
- All rights are reserved for instruments, circuits, techniques, and names appearing in the manual.

CONTENTS

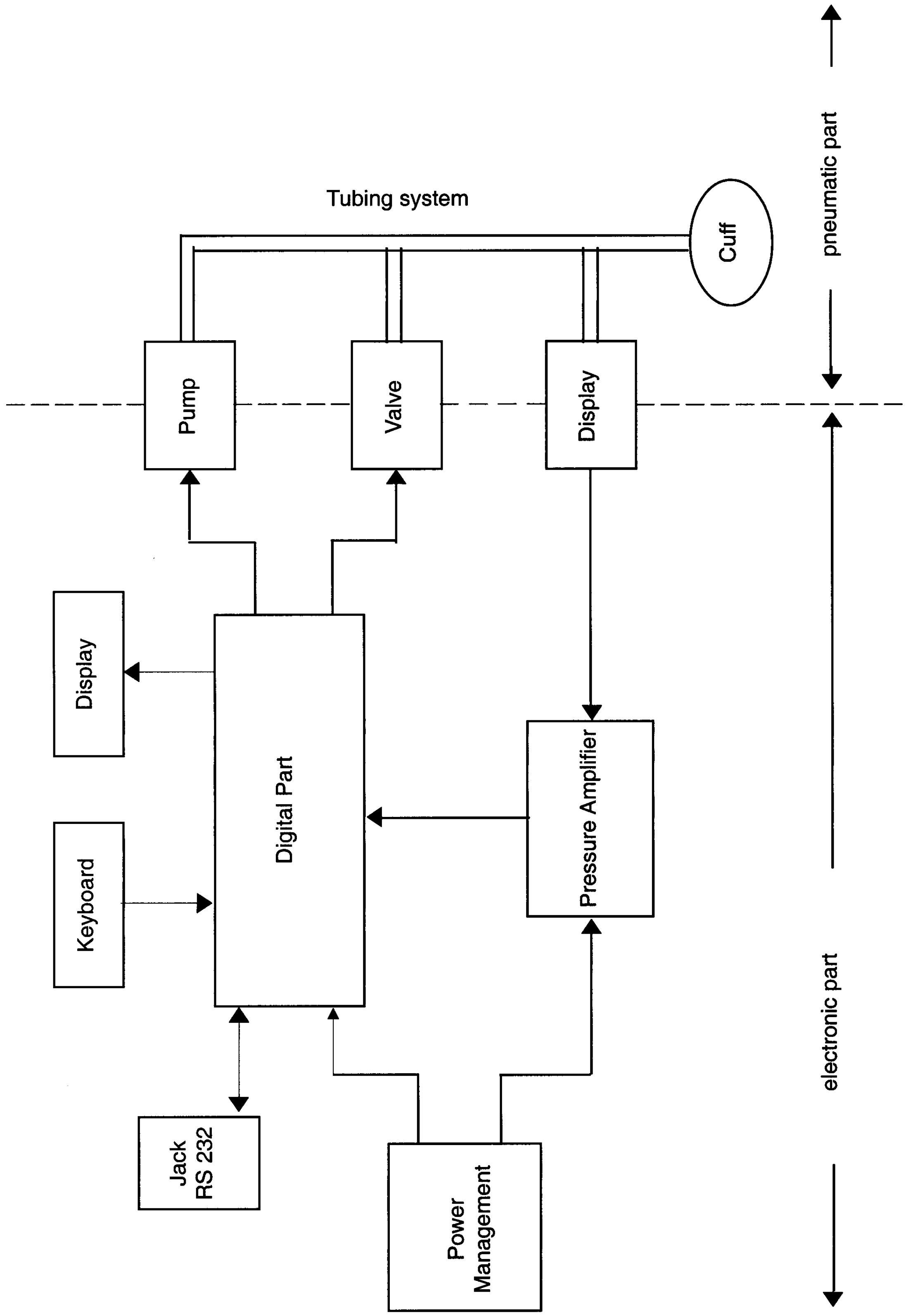
Revision History

This manual is subject to the ***GE Medical Systems*** *Information Technologies (GEMS IT)* change order service. The revision code, a letter that follows the document part number, changes with every update of the manual. The initial version of the manual has the letter A.

Part No./Revision Code	Date	Comment
2001589-023 Rev A	2000-03	Initial Release
2001589-023 Rev B	2001-01	ECO 066338; Update due to Release of Firmware V 1.1
2001589-023 Rev C	2001-04	ECO 066834
2001589-023 Rev D	2001-06	ECO 067061, Firmware V 1.2
2001589-023 Rev E	2001-10	ECO 068207, Firmware V 1.3
2001589-023 Rev F	2002-07	ECO 071404, FW1.4/HW1.2;

Changes are on the following pages:
Page 6: 13:01 replaced with 14:01
Page 10: Table completed
Page 14: new picture with HW 1.2
Page 14: Second sentence in the grey table removed
Page 14: In the table: in the row of step 4 "BOOT ERASE = OK** replaced
Page 19: New picutre with HW 1.2
Page 21: changes by "weight"
Page 23: Changes in Parts Lists
New drawings in the Appendix

1 Block Diagram



2 Functional Description

Button / Switch	**Display**	**Button**	**Display**	**Info**
ON	All segments			Self-Test
	A100			A= Accu 100 = 100%
	Clock			
Info	H 1	Start/Start	LLLL	Delete Record
Info	H 2	Start	YYYY MM DD Hour Min	Date Time
Info	H 3	Start/Start Info	LLLL P1 P2 P3	Internal Programs
Info	H 4	Start	50	Pressure Offset
		Start	0	Calibration Mode (Manometer)
Info	H 5	Start	14:01	14: = FW1.4 01 = German 02 = English 03 = French 04 = Italian 05 = Spanish
Info	H 6	Start	AAAA	Accu
		Info	bbbb	Battery

Measurement limits
- Max. cuff inflation time 100s
- Max. measurement time after measurement begins = 180s

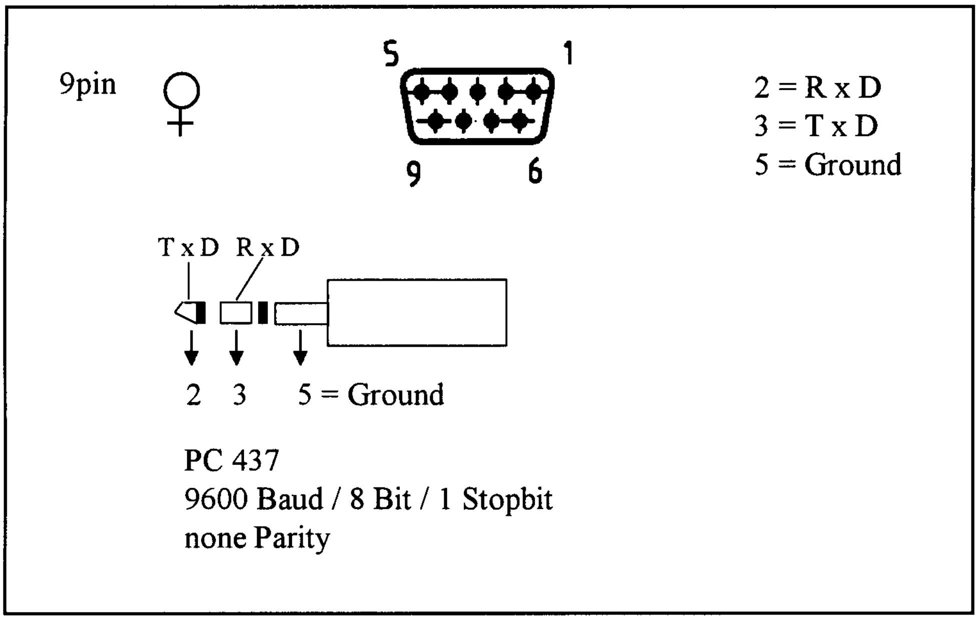
3 Names of Signals

n/a

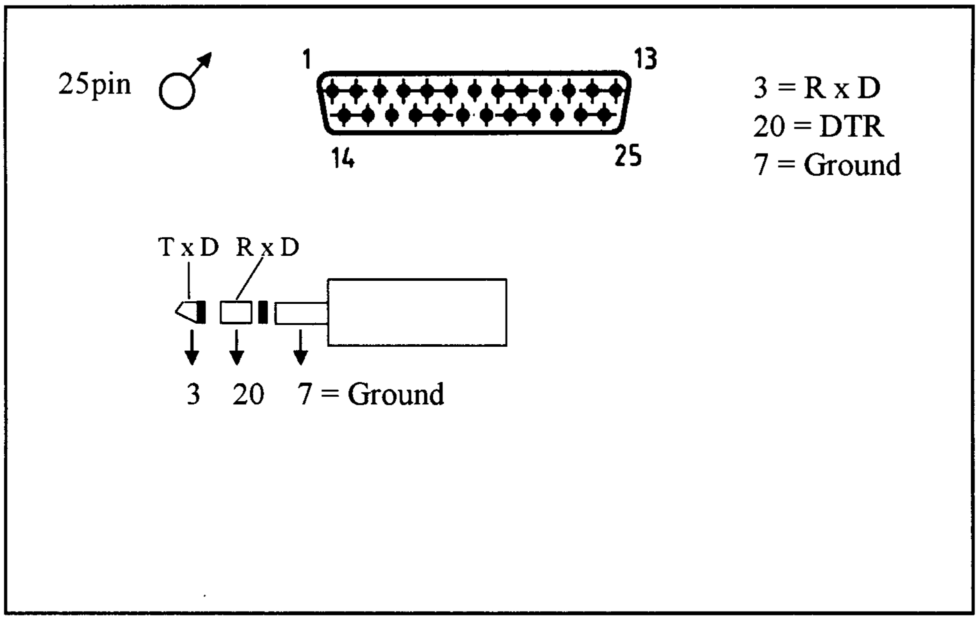
4 Pin Connections

See diagram

Cable TONOPORT V - PC
2001589-011



Cable TONOPORT V - Printer
2001589-012



5 Instrument Options (none)

6 Instrument Versions

The instrument is available in one version only. However, the printout can be programmed in 5 different languages. These languages are:

old versions

- 2001589-001 TONOPORT V (GER) German
- 2001589-002 TONOPORT V (ENG) English
- 2001589-003 TONOPORT V (FRE) French
- 2001589-004 TONOPORT V (ITA) Italian
- 2001589-005 TONOPORT V (SPA) Spanish

new version

- 2001589-001 TONOPORT V

Displaying the firmware version

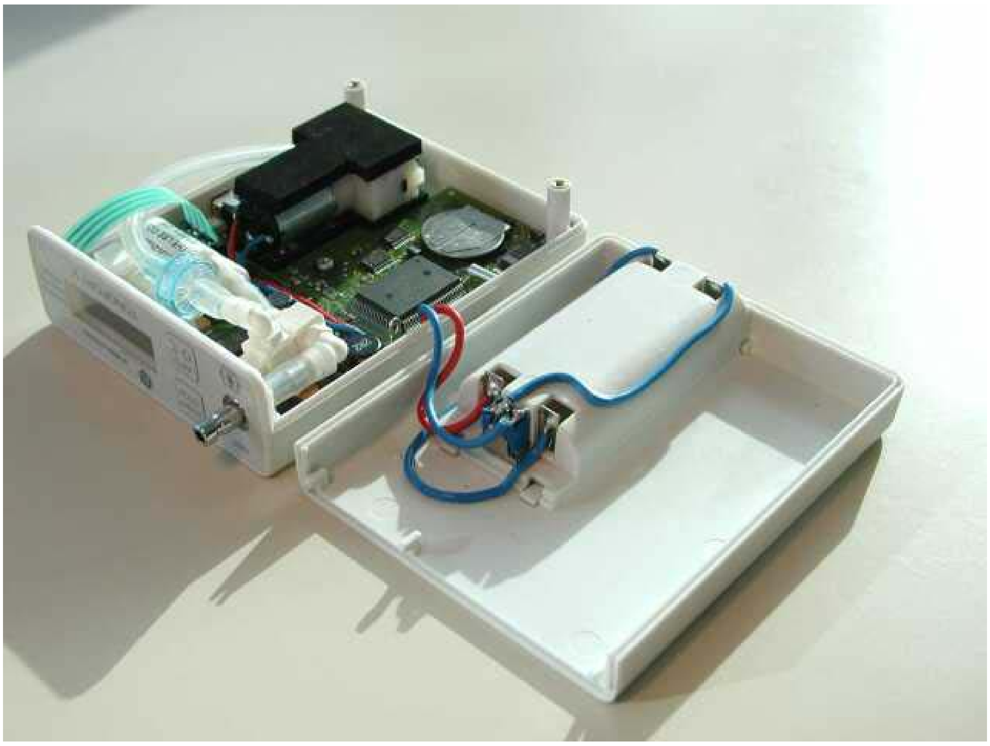
- Switch TONOPORT V on and wait until **the time** appears on the screen
- Press **INFO** five times: Display shows **"H 5".**

Press **START**: firmware version is now displayed, e.g.,

- From firmware FW1.3 the language can be changed by pressing INFO until the required language code is displayed. Pressing START finishes the language setting.

FirmwareVersion : Language Code	Language
10 : 01	German
10 : 02	English
10 : 03	French
10 : 04	Italian
10 : 05	Spanish
11 : 01	German
11 : 02	English
11 : 03	French
11 : 04	Italian
11 : 05	Spanish
12 : 01	German
12 : 02	English
12 : 03	French
12 : 04	Italian
12 : 05	Spanish
13 : 01	German
13 : 02	English
13 : 03	French
13 : 04	Italian
13 : 05	Spanish
14 : 01	German
14 : 02	English
14 : 03	French
14 : 04	Italian
14 : 05	Spanish

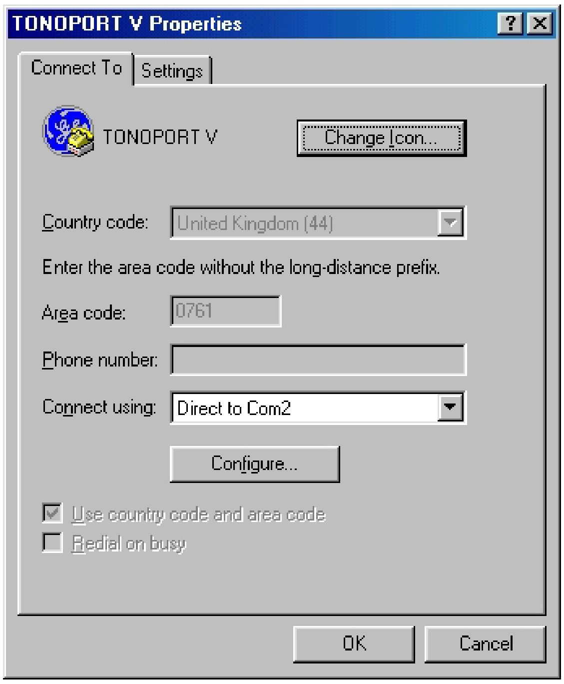
7 Pictures

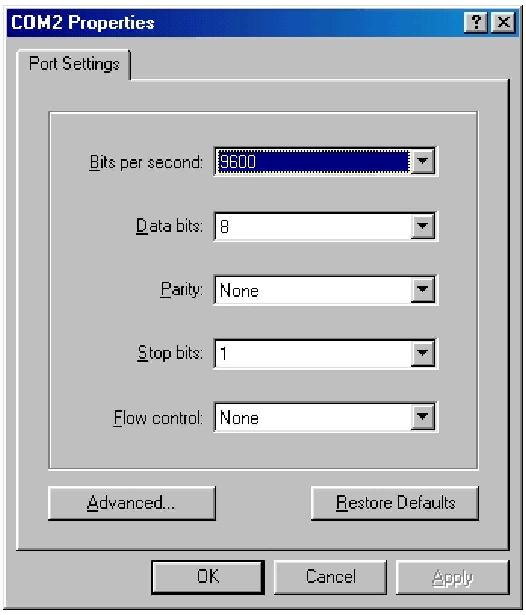


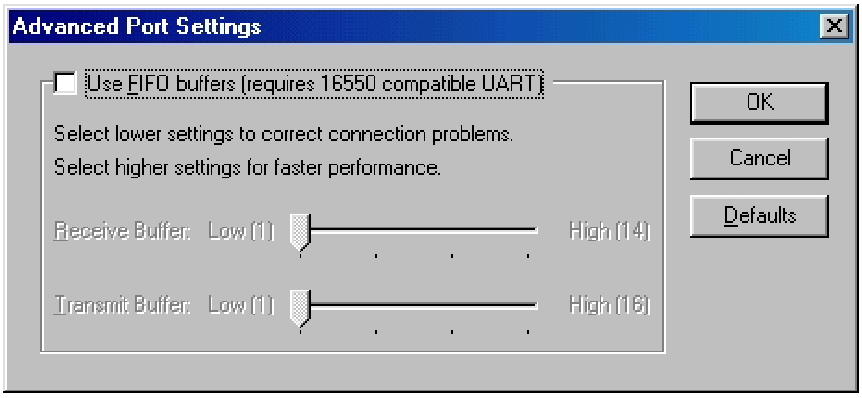
8 Firmware Loading Procedure

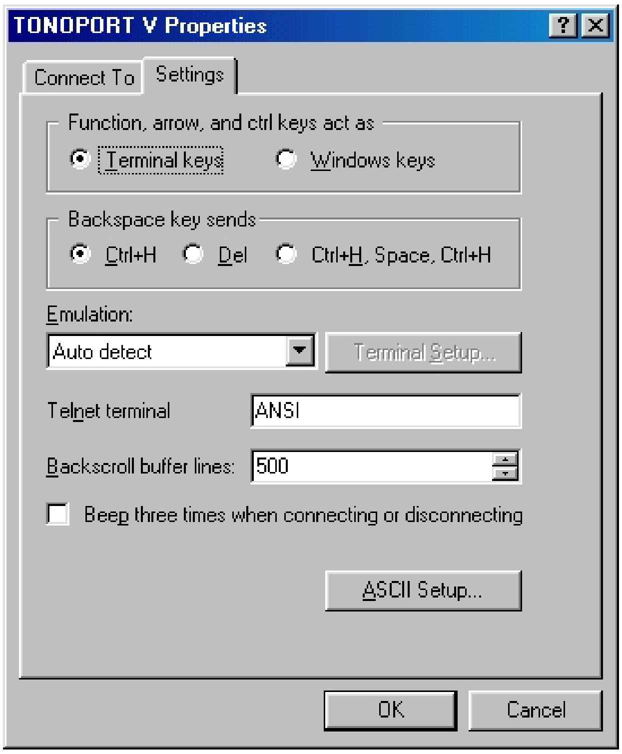
8.1.1 Settings for Hyperterminal under Windows 95/98SE/NT4.0/2000 (in this example with Windows 95SE)

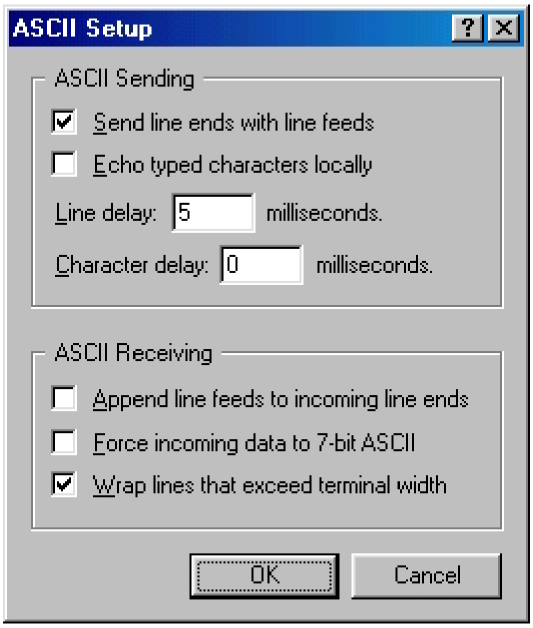
- Start Hypertrm.exe
– Type in the name: TONOPORT V
– Type in any Phone Number and click to <OK>
- Go to FILE -→ PROPERTIES and make the same configurations as shown in the pictures
- Go to "Transfer" -→ "Send Text File..." to transfer files to TONOPORT






Advanced Port Settings
Use FIFO buffers (requires 16550 compatible UART)
Select lower settings to correct connection problems.
Select higher settings for faster performance.
Receive Buffer: Low (1)
High (14)
Transmit Buffer: Low (1)
High (16)
OK
Cancel
Defaults


TONOPORT V Properties
Connect To
Settings
Function, arrow, and ctrl keys act as
Terminal keys
Windows keys
Backspace key sends
Ctrl+H
Del
Ctrl+H, Space, Ctrl+H
Emulation:
Auto detect
Terminal Setup...
Telnet terminal
ANSI
Backscroll buffer lines:
500
Beep three times when connecting or disconnecting
ASCII Setup...
OK
Cancel


ASCII Setup
ASCII Sending
Send line ends with line feeds
Echo typed characters locally
Line delay: 5 milliseconds.
Character delay: 0 milliseconds.
ASCII Receiving
Append line feeds to incoming line ends
Force incoming data to 7-bit ASCII
Wrap lines that exceed terminal width
OK
Cancel

8.1.2 Settings for Telix for Windows (Hyperterminal for NT does not work)

- Extract all TONOPORT V, FW1.4 Firmware files into one directory (e.g. C:\tonoport\V1.4)
- by starting: FIRMWARE TONOPORT V FW14.exe
- Load all files from the Telix program into the same directory on the Hard Disk
- Start the Telix program (\telix.exe)..
  Remarks:
  Enter <ALT> + <p> to select the COM port
  Enter <ALT> + <o> to select Ascii transfers. Select F - Line pacing 2
  Enter <ALT> + <s> and select ASCII to transfer files to TONOPORT
  Delete screen with <ALT> + <c>
  Telix can be terminated with <ALT> + <x>

8.2 Loading Procedure

- Connect inactive TONOPORT to PC COM port via serial cable.
- Start Hyperterminal or Telix on the PC
- Note: After TONOPORT V has been switched on updating can only be carried out within the first 10 minutes. After 10 minutes TONOPORT V enters a power down mode and can be reactivated by switching on and off.
- Follow steps 1...6.
  * Note down the "LANGUAGE" (DEUTSCH, ENGLISH, FRANCAIS, ITALIANO, ESPAÑOL) which is installed on TONOPORT V (Step1)

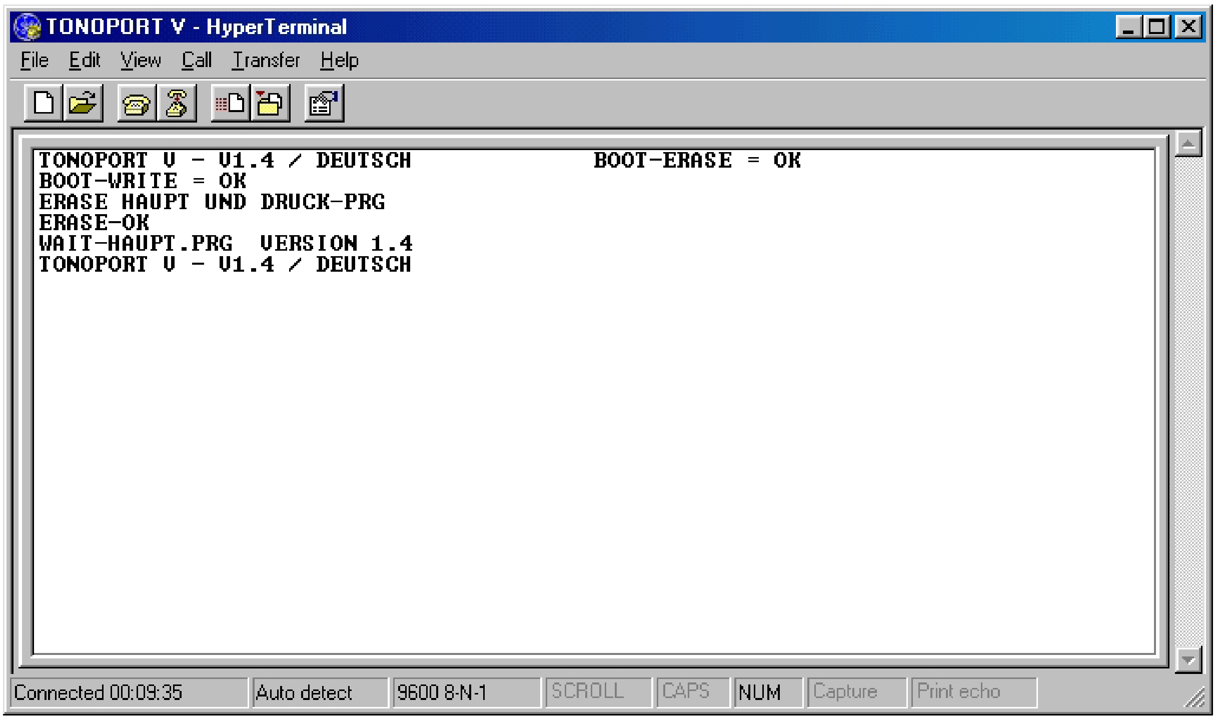
**	Steps 2 and 3 are not applicable if V 1.3 or 1.4 is installed on TONOPORT V. ~~In this case "BOOT-ERASE = OK" is not displayed on the PC Monitor~~

Step	**Action**		**Duration (approox.)**	**Display**	
	TONOPORT V	PC	Telix Hyperterminal	PC-Monitor	TONO-PORT V LCD
1	Switch on TONOPORT V		8 sec 8 sec	TONOPORT V - V1.0*, TONOPORT V - V1.1 or TONOPORT V- V 1.2 or TONOPORT V - V 1.3 / "LANGUAGE" TONOPORT V - V 1.4 / "LANGUAGE"	HH:MM (time)
** 2		Transfer ERASE.INT	2 sec 2 sec		LLLL (flashing)
** 3	Press "START"		3 sec 3 sec	WAIT-BOOT.*	0000
4		Transfer BOOT14.PRG	50 sec 25 sec	~~BOOT-ERASE = OK**~~ BOOT-WRITE = OK ERASE HAUPT UND DRUCK-PRG	LLLL (flashin)
5	Press "INFO"		11 sec 11 sec	ERASE-OK WAIT-HAUPT.PRG VERSION 1.4	all segments on
6		Transfer HAUPT14.PRG	15 min	TONOPORT V-FW1.4/DEUTSCH	HH.MM (time)

- Switch off TONOPORT V
- Disconnect TONOPORT V from PC
- Check the correct Firmware version on TONOPORT V and set the correct language:

Step	Action	Display
1	Switch on TONOPORT V	HH : MM (time)
2	Press "INFO" 5 times	H 5
3	Press "START"	14 : 01 (14 = Version FW 1.4 01 = language German)
4	Press "INFO" to select the correct language (which was displayed at Step 1 of the Loading Procedure)	14 : 01 (German) 14 : 02 (English) 14 : 03 (French) 14 : 04 (Italian) 14 : 05 (Spanish)
5	Press "START" to save the language setting	HH : MM (time)

Screenshot of a successful loading procedure with Hyper Terminal:



9 Diagnosis Codes / Error Codes

"E 02": Battery depleted. Code is displayed to indicate that the battery charge level is insufficient for further measurements. The recorder differentiates between two states: the memory has just been cleared (i.e., the battery test is performed with a higher power consumption to ensure that a fresh battery will be inserted at the beginning of the measurement) or measurements have already been taken.

"E 03": Measurement time over. Code is displayed when a measurement is not taken within 60 seconds (excluding cuff inflation time).

"E 06": Inflation time over. The max. inflation time of 60 s has elapsed. This condition indicates a leak in the cuff or tubing, or a defective gasket.

"E 07": The pump will not increase the cuff pressure any further. Code is displayed when no systolic reading could be found although the cuff pressure was already increased twice. The measuring system waits until the next measurement is due.

"E 08": 200 pressure measurements taken; storage capacity exhausted.

"E 14": Diastolic reading below 40 mmHg. Code appears when the cuff pressure has dropped to 40 mmHg and diastole could not be identified (TONOPORT does not measure diastolic pressures below 40 mmHg).

"E 15": Motion artifact during diastole detection.

"E 17": Internal hardware error (inform service center).

"E 18": Systolic pressure outside measuring range.

"E 19": Diastolic pressure outside measuring range.
(These codes are displayed when the systolic and diastolic values are outside the range in which oscillations have been detected. Tighten the cuff slightly.)

"E 21": Difference between systolic and diastolic pressure too small (10 mmHg or less).

"E 22": Motion artifact during systole detection.

"E 24": No systole detected in the provided time frame.

"E 26": Systolic pressure below 60 mmHg.

"E 27": Systolic pressure above 260 mmHg. Max. measuring range exceeded.

"E 29": Insufficient number of oscillations detected: For a correct measurement, the system must detect at least 8 oscillations. Tighten the cuff so that one finger, but not two, can be inserted between the patient's arm and the cuff. At the same time the device switches to a deflation rate of 4 mmHg/s. When it detects more than 13 oscillations later on, the rate is changed to 6 mmHg/s.

10 Adjustment Instructions

Only the pressure amplifier needs to be calibrated. This is done by switching on the TONOPORT V and waiting until the time is displayed on the LCD.
Measure the direct voltages at TP2 and TP3. This is done by turning the trimming potentiometer R59 with a screwdriver until the voltages at TP2 and TP3 are 2.0 ±0.2 V and 1.8±0.1 V, respectively.
Press "INFO" four times, LCD indicates "H 4".
Press "START" once, a 2-digit figure is displayed on the LCD.
Use a screw driver to turn the trimming potentiometer R53 until the LCD indicates a value of approx. 50.
Connect a reference pressure gauge, a rubber bulb and air container (1 l) to the TONOPORT pressure connector and press "START".
Using the rubber bulb generate a pressure of 100 mmHg in the tubing system and watch the LCD.
Using a screwdriver, turn the trimming potentiometer R40 until the LCD indicates a value of 100.
Also check the values indicated on the LCD at pressures of 50 mmHg, 150 mmHg and 200 mmHg. No deviations may exceed ±3 mm Hg.
Switch the TONOPORT off.

10.1 Interior View

11 Jumper Table

not applicable as there are none

12 Technical Specifications

Microprocessor
P80C558EFB
Storage capacity
128 x 8 bit (= 1 Megabit) EEPROM
512 x 8 bit (= 4 Megabit) EEPROM

Measuring range

Systolic pressure:	60 ... 260 mmHg
Diastolic pressure:	40 ... 220 mmHg
Mean pressure:	50 ... 260 mmHg
Pulse rate (HR):	35 ... 240 min-1

Recording period
30 h or 200 measurements max.

Battery
2 Mignon (size AA) NiMH batteries, 1.2 V, ≥1500 mA (HR-3U SANYO) or
2 Mignon (size AA) alkaline batteries
Battery charging time
2 ... 3 h
Max. cuff pressure
300 mmHg
Measuring method
oscillometric

Ambient conditions
Operation
Temperature +10...+ 40 oC
Relative humidity 30...75 %, no condensation
Atmospheric pressure 700...1060 hPa
Transport and storage
Temperature -10...+ 70 oC
Relative humidity 10...90 %, no condensation
Atmospheric pressure 500...1060 hPa
Dimensions and weight
Height 99 mm
Width 80 mm
Depth 27 mm
Weight :
147 g; 195 g, incl. Batteries; 199 incl. Accus

13 Technical Inspections

The non-invasive pressure measurement system must be verified every 2 years.

These inspections should be referred to independent persons with adequate training and experience.

"Technical inspections" involve checking the pneumatic system for leaks and the accuracy of the values indicated on the display.

To achieve this, activate the calibration mode.

* Connect a rubber bulb and a suitable pressure gauge between pressure hose and a fixed volume of 1 liter (e.g. glass bottle), using a T-adapter.
* Switch off device and switch it on again after a few seconds.
* Wait until display indicates **the time**.
* Press **INFO** four times: display indicates **"H 4".**
* Press **START**: display indicates internal value, which must lie between 25 and 100. If the value lies outside this range, the TONOPORT V must be sent in for inspection.
* Press **START** again: display indicates **"0"** (the display now indicates the pressure in mmHg).
* Generate a test pressure of 200 mmHg and, after waiting for at least 30 seconds, measure the pressure decrease (pressure decreases between 3 and 5 mmHg are typical, when the pressure decrease exceeds 6 mmHg, there must be a leak and the system needs to be repaired).
* This completes the test on the system for leaks.
* Using the rubber bulb, exert pressures of 50, 100, 150, 200 and 250 mmHg on the device. No deviations may exceed +/- 3 mmHg.
* Press **START** to exit the calibration mode.

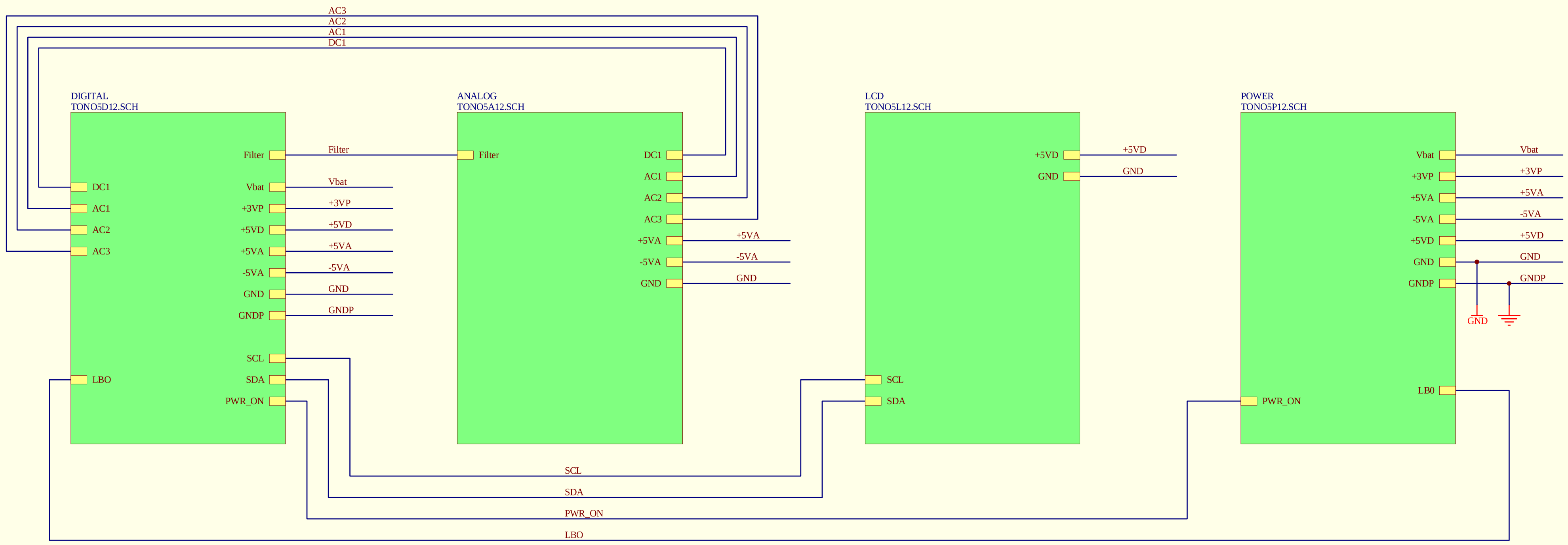
14 Parts Lists

Order No:	**Description**
Manuals	
2001589-023	Service Manual (only in English)
2001589-006	Users Manual Ger.
2001589-007	Users Manual Eng.
2001589-008	Users Manual Fre
2001589-009	Users Manual Ita.
2001589-010	Users Manual Spa.
Accessories	
2001589-011	Cable RS232 TONOPORT V ———> PC (with CARDIOSOFT V4.14 or higher Version)
2001589-012	Cable RS232 TONOPORT V ———> Printer (LQ-Emulation)
2001589-015	Carrying Bag
2001589-016	Bag Belt
2001589-013	Battery Charger NiMH + NiCd
2001589-014	Rechargeable Battery NiMH Size AA
73700008	Alkaline Battery 1,5 V Mignon Size AA
2001589-017	BP Cuff Adult Small 17-26 cm
2001589-018	BP Cuff Adult Standard 24-32 cm
2001589-019	BP Cuff Adult Large 32-42 cm
Spare Parts	
2002857-001	Cover Battery Skip
2002858-001	Cover Bottom with Switch and Cable
2002859-001	Cover Top with Keypad
2002860-001	Battery Buttom Cell Lithium CR2016 PCB 3V, 90mAh
2002861-001	Keypad
2002862-001	Battery Contact
2002863-001	Switch On / Off
2002864-001	Hose Connector (Luer)
2002865-001	Pump
2002865-002	Pump (low noise)
2002866-001	PCB with Honeywell Valve and LCD Display
2002866-002	PCB with Motorola Valve and LCD Display
2002866-003	PCB HW1.2 with low noise pump
2006591-001	Label for Calibration: “Nächste MTK” (only for Germany)

Exchange Units

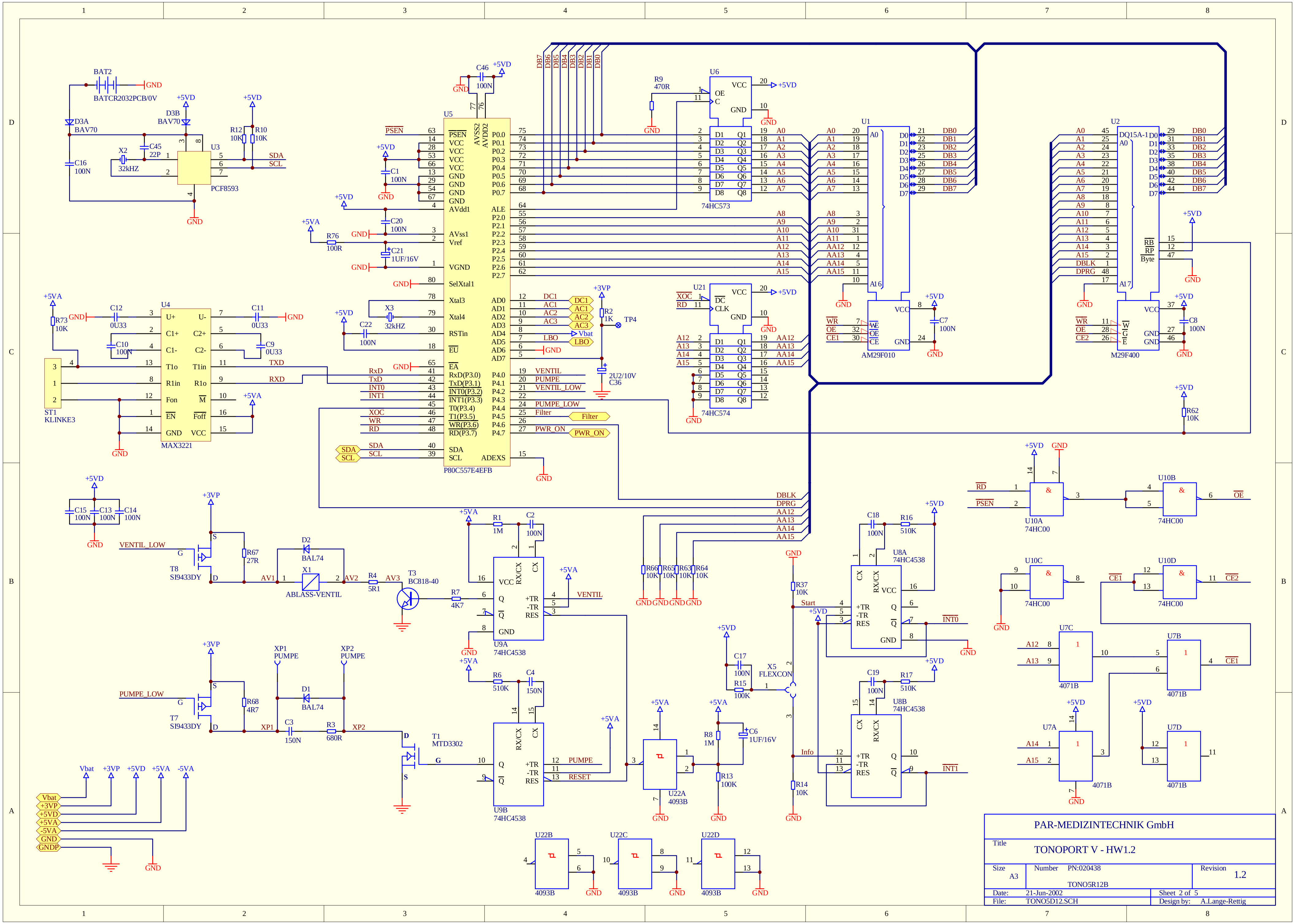
2003386-001	Exchange Recorder ABP TONOPORT V German
2003387-001	Exchange Recorder ABP TONOPORT V English
2003388-001	Exchange Recorder ABP TONOPORT V French
2003389-001	Exchange Recorder ABP TONOPORT V Italien
2003390-001	Exchange Recorder ABP TONOPORT V Spanish

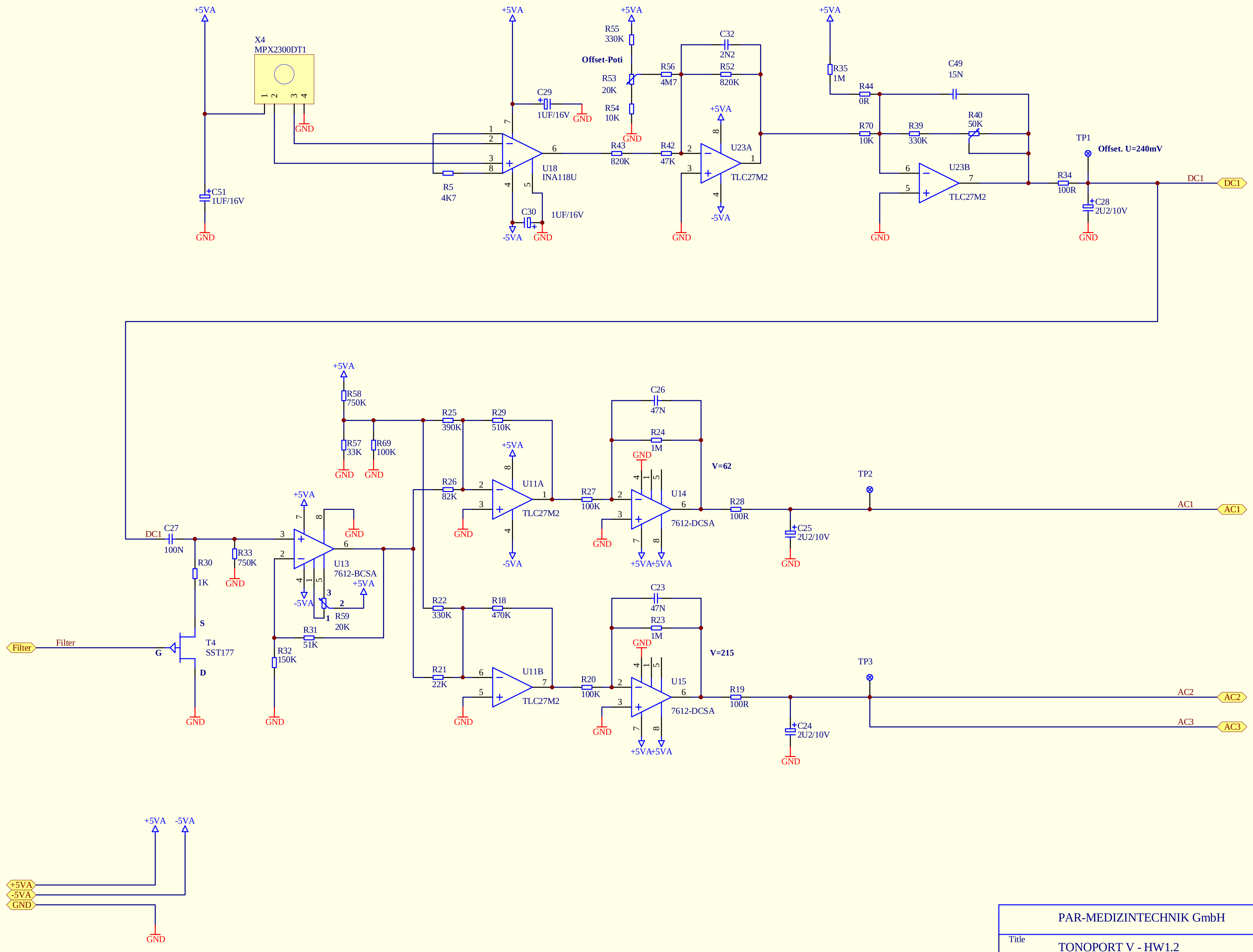
15 Appendix: Drawings



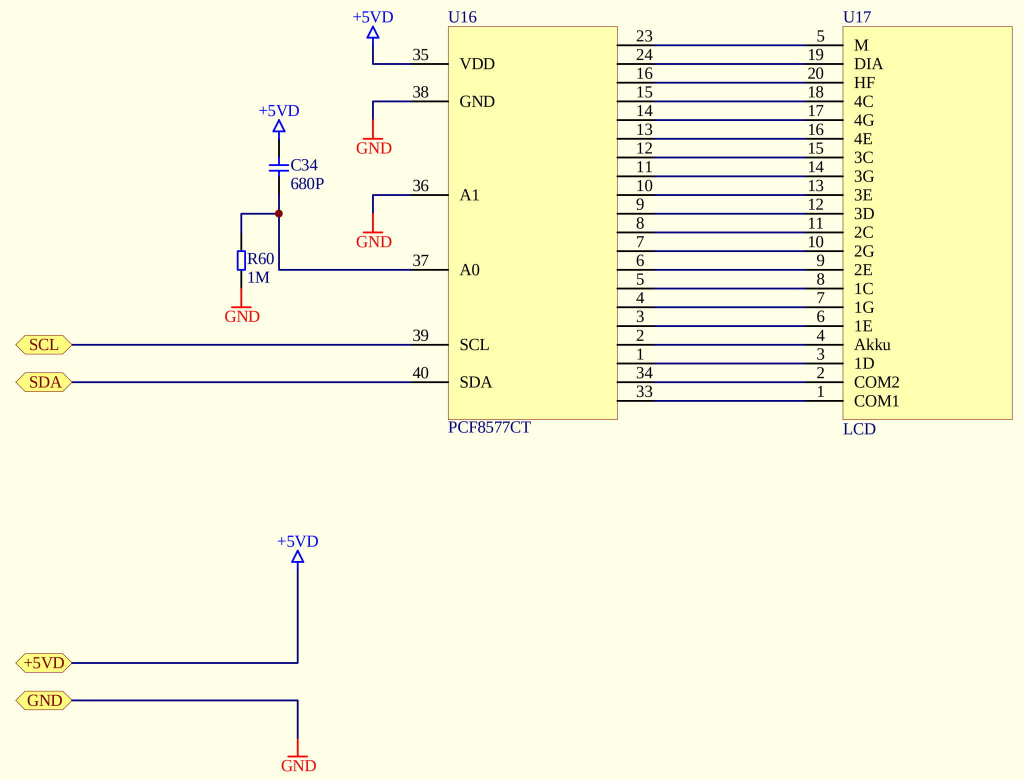
PAR-MEDIZINTECHNIK GmbH

Title	TONOPORT V - HW1.2	
Size A3	Number PN:020438 TONO5R12B	Revision 1.2
Date: 21-Jun-2002		Sheet 1 of 5
File: TONO5R12B.SCH		Design by: A.Lange-Rettig

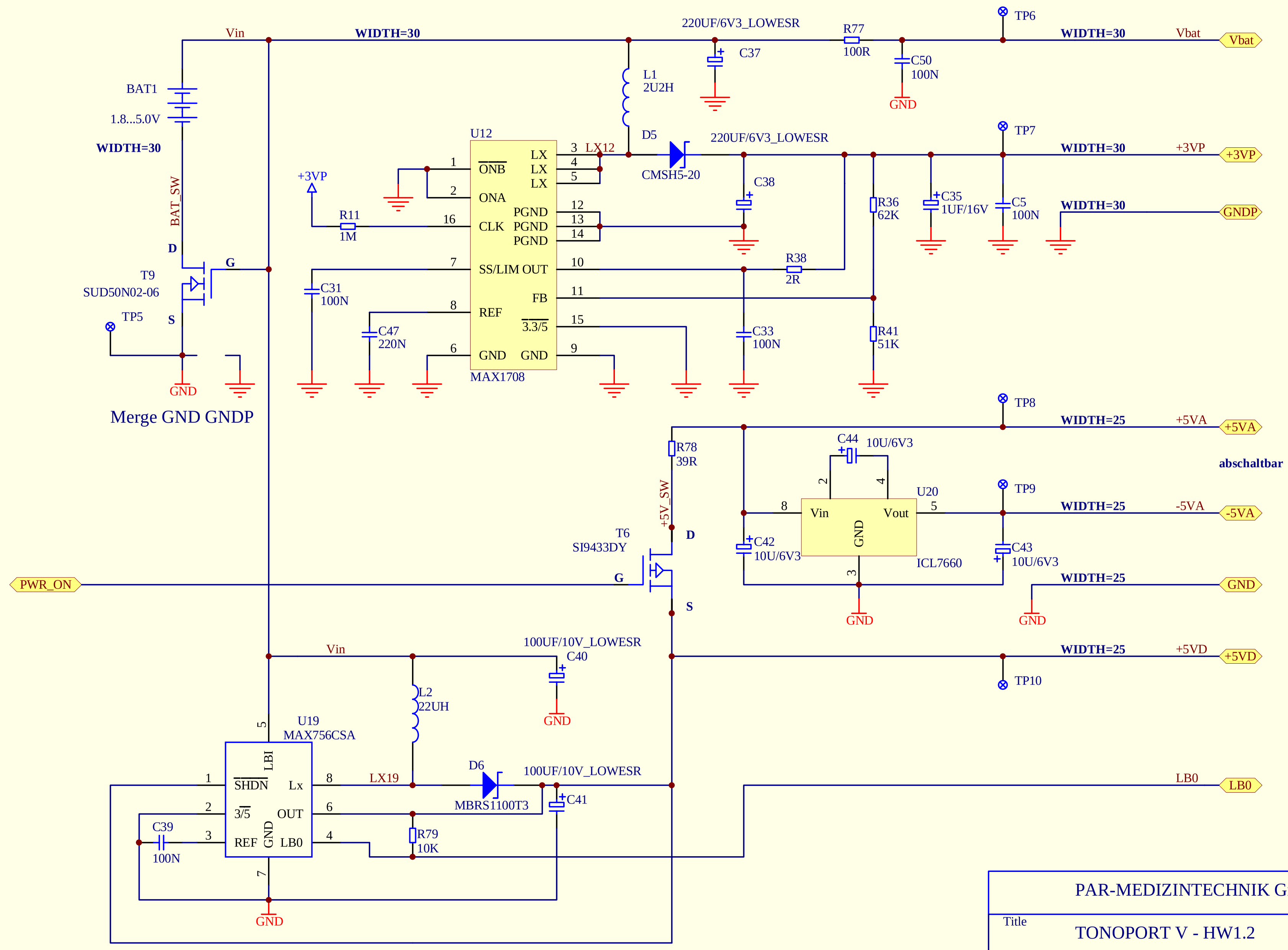

PAR-MEDIZINTECHNIK GmbH
Title
TONOPORT V - HW1.2
Size
A3
Number
PN:020438
TONO5R12B
Revision
1.2
Date:
21-Jun-2002
Sheet 2 of 5
File:
TONO5D12.SCH
Design by:
A.Lange-Rettig



PAR-MEDIZINTECHNIK GmbH		
Title: TONOPORT V - HW1.2		
Size: A3	Number: PN:020438 TONO5R12B	Revision: 1.2
Date: 21-Jun-2002		Sheet 3of 5
File: TONO5A12.SCH		Design by: A.Lange-Rettig

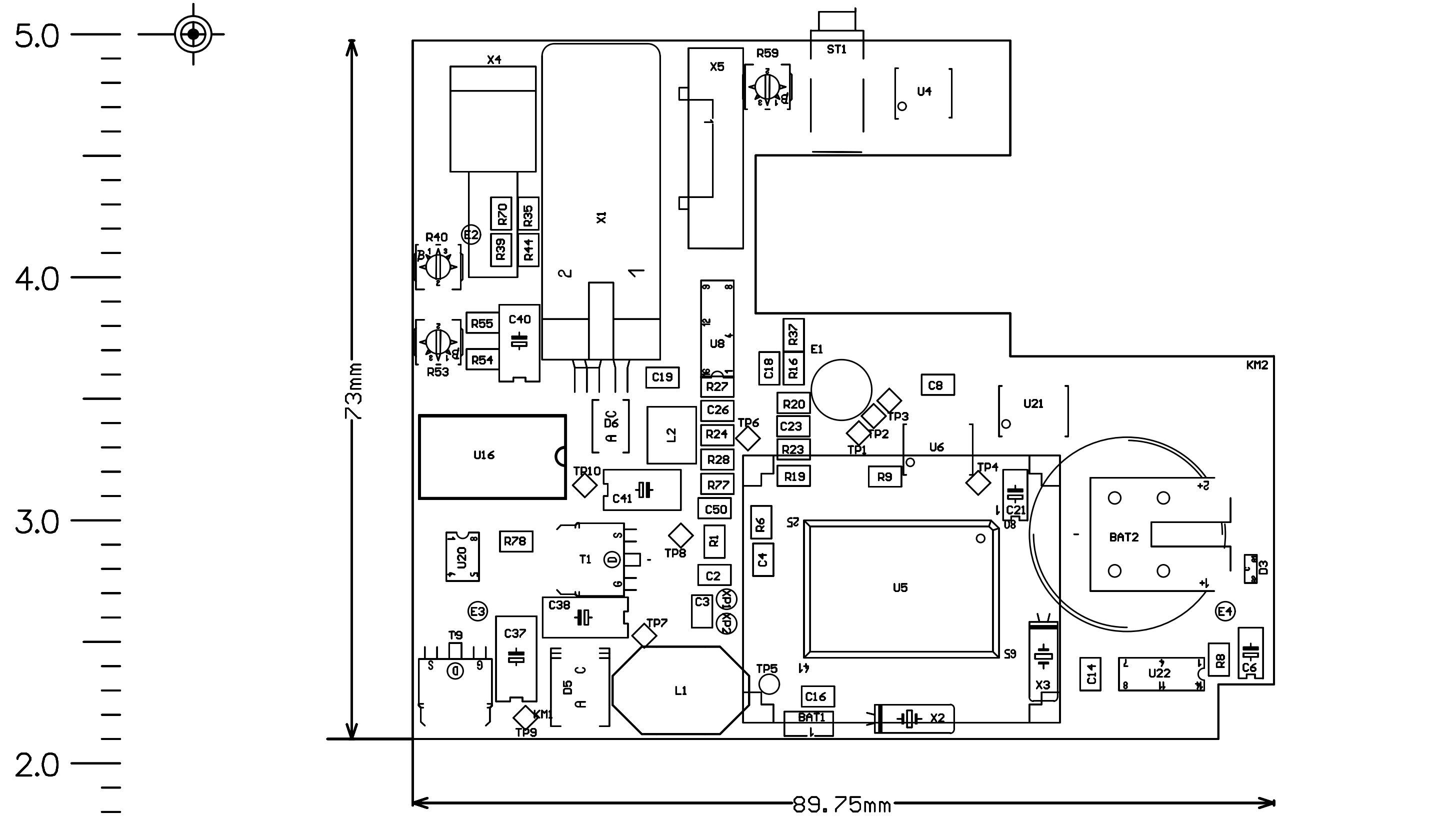


PAR-MEDIZINTECHNIK GmbH			
Title	TONOPORT V - HW1.2		
Size A4	Number PN:020438 TONO5R12B		Revision 1.2
Date:	21-Jun-2002	Sheet 4of 5	
File:	TONO5L12.SCH	Design by:	A.Lange-Rettig

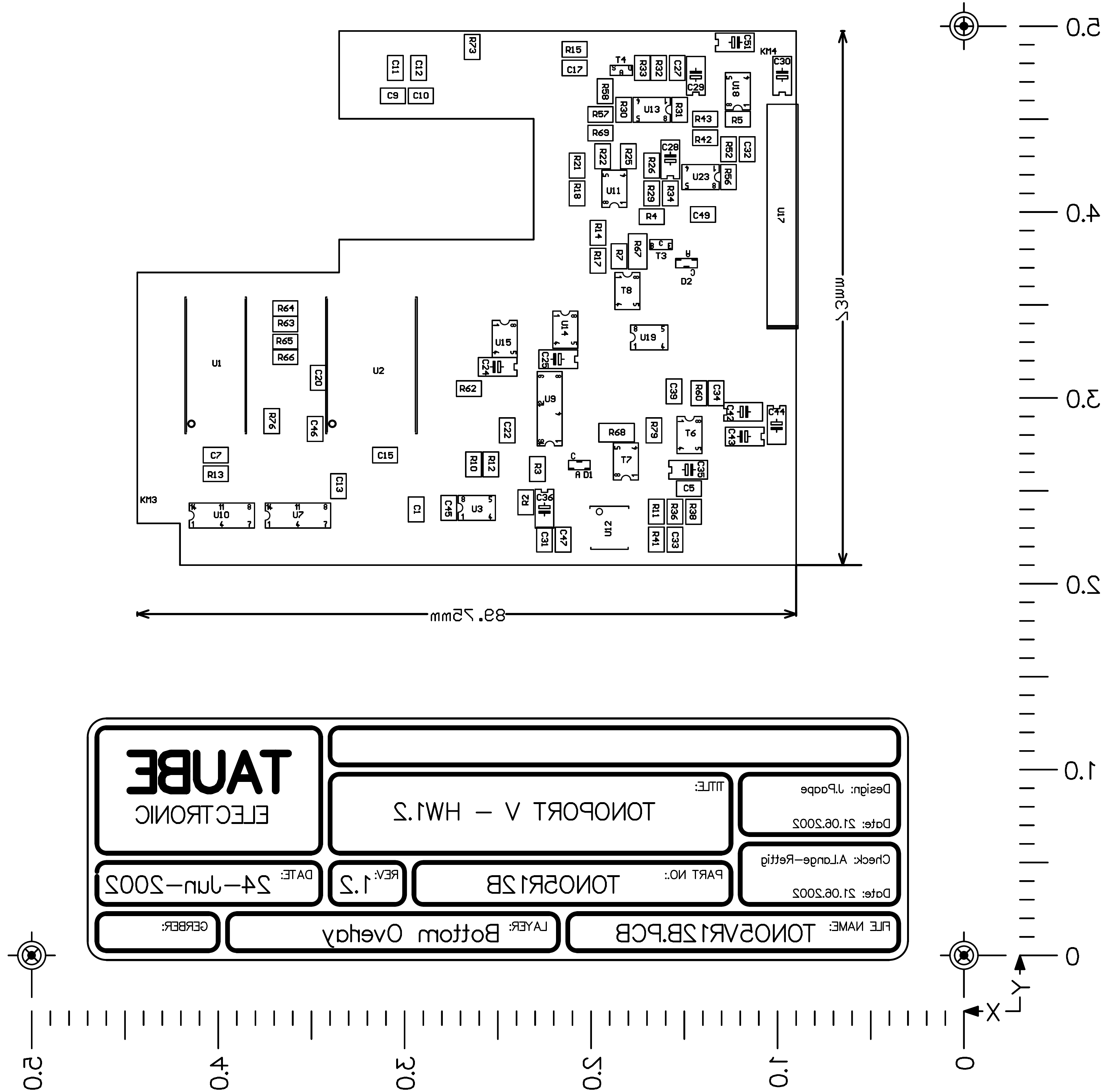


PAR-MEDIZINTECHNIK GmbH

Title	TONOPORT V - HW1.2		
Size A3	Number PN:020438 TONO5R12B		Revision 1.2
Date:	21-Jun-2002	Sheet 5of 5	
File:	TONO5P12.SCH	Design by:	A.Lange-Rettig



Design: J.Paape Date: 21.06.2002	TITLE: TONOPORT V – HW1.2		TAUBE ELECTRONIC
Check: A.Lange–Rettig Date: 21.06.2002	PART NO.: TONO5R12B	REV: 1.2	DATE: 24–Jun–2002
FILE NAME: TONO5VR12B.PCB	LAYER: Top Overlay		GERBER: .GTO



TAUBE
ELECTRONIC
TITLE: TONOPORT V – HW1.2
Design: J.Paape
Date: 21.06.2002
Check: A.Lange-Rettig
Date: 21.06.2002
DATE: 24-Jun-2002
REV: 1.2
PART NO.: TONO5R12B
FILE NAME: TONO5VR12B.PCB
LAYER: Bottom Overlay
GERBER:
73mm
89.75mm

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ABC of hypertension: Blood pressure measurement

Gareth Beevers, Gregory Y H Lip and Eoin O'Brien

BMJ 2001;322;1043-1047
doi:10.1136/bmj.322.7293.1043

ABC of hypertension

Blood pressure measurement

Part II—Conventional sphygmomanometry: technique of auscultatory blood pressure measurement

Gareth Beevers, Gregory Y H Lip, Eoin O'Brien

The measurement of blood pressure in clinical practice by the century-old technique of Riva-Rocci/Korotkoff is dependent on the accurate transmission and interpretation of a signal (Korotkoff sound or pulse wave) from a subject via a device (the sphygmomanometer) to an observer. Errors in measurement can occur at each of these interactionary points of the technique, but by far the most fallible component is the observer.

This article has been adapted from the newly published 4th edition of ABC of Hypertension. *The book is available from the BMJ bookshop and at www.bmjbooks.com*

Observer error

In 1964, Geoffrey Rose and his colleagues classified observer error into three categories.[1]

Rose classification of observer error

- Systematic error
- Terminal digit preference
- Observer prejudice

Systematic error
This leads to both intraobserver and interobserver error. It may be caused by lack of concentration, poor hearing, confusion of auditory and visual cues, etc. The most important factor is failure to interpret the Korotkoff sounds accurately, especially for diastolic pressure.

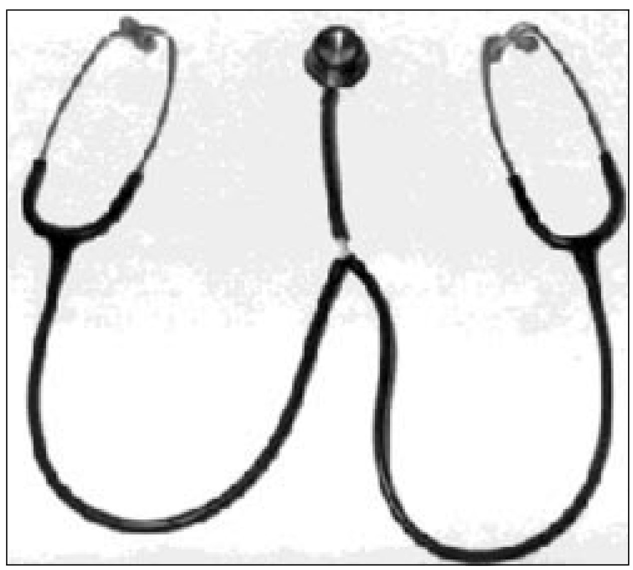
Terminal digit preference
This refers to the phenomenon whereby the observer rounds off the pressure reading to a digit of his or her choosing, most often to zero. Doctors may have a 12-fold bias in favour of the terminal digit zero; this has grave implications for decisions on diagnosis and treatment, although its greatest effect is in epidemiological and research studies in which it can distort the frequency distribution curve and reduce the power of statistical tests.[2]

Observer training techniques

- Direct instruction by an experienced observer
- Instruction manuals and booklets
- Audiotapes
- Video films
- CD Rom presentations

Observer prejudice or bias
This is the practice whereby the observer simply adjusts the pressure to meet his or her preconceived notion of what the pressure should be. It usually occurs when there has been recording of an excess of pressures below the cut-off point for hypertension and it reflects the observer's reluctance to diagnose hypertension. This is most likely to occur when an arbitrary division is applied between normal and high blood pressure, for example 140/90 mm Hg. An observer might tend to record a favourable measurement in a young healthy man with a borderline increase in pressure, but categorise as hypertensive an obese, middle aged man with a similar reading. Likewise, there might be observer bias in overreading blood pressure to facilitate recruitment for a research project, such as a drug trial. Observer prejudice is a serious source of inaccuracy, as the error cannot usually be demonstrated.[3]

Overcoming error by observer training
The technique of auscultatory blood pressure measurement is a complicated one that is often taken for granted. Instruction to medical students and nurses has not always been as comprehensive as it might be, and assessment for competence in measuring blood pressure has been a relatively recent development.[4] Ironically, these methods of achieving much needed improvement in performing the auscultatory technique have arrived as the mercury sphygmomanometer is under threat and as automated devices move in to replace the observer; these have included: direct instruction using a



Binaural stethoscope used for instruction in ausculatory blood pressure measurement binaural stethoscope; the use of manuals, booklets, and published recommendations; audiotape training methods; videofilm methods, and, most recently, CD Rom methods. The CD Rom produced by the Working Party on Blood Pressure Measurement of the British Hypertension Society in 1998[5] incorporates instruction, with examples of blood pressure measurement using a falling mercury column with Korotkoff sounds and a means for the student to assess competence in the technique using a series of examples. The CD is accompanied by the British Hypertension Society booklet *Blood pressure measurement: recommendations of the British Hypertension Society*.[6]

Overcoming error with instrumentation

As mentioned earlier, blood pressure measurement is subject to observer prejudice and terminal digit preference, introducing an error that is unacceptable for research work. Careful training of observers can reduce but not abolish these sources of error, some of which cannot be easily demonstrated. Because accuracy of measurement is particularly desirable in research, efforts have been made to devise devices that would minimise or abolish observer error.

Measuring blood pressure

Assuming the observer has been trained and shown to be proficient in the technique there are then a number of factors that may affect the performance of the technique.[5 6] Some of these factors are described below.

Attitude of observer

Before taking the blood pressure, the observer should be in a comfortable and relaxed position, because if hurried the pressure will be released too rapidly, resulting in underestimation of systolic and overestimation of diastolic pressures. If any interruption occurs the exact measurement may be forgotten and an approximation made, so the blood pressure should always be written down as soon as it has been measured.

Mercury and aneroid sphygmomanometers

The mercury sphygmomanometer is a reliable device, but all too often its continuing efficiency has been taken for granted, whereas the aneroid manometer, which is not generally as accurate, is often assumed to be as reliable. These devices have certain features in common; each has an inflation-deflation system, and occluding bladder encased in a cuff, and both devices measure blood pressure by auscultation using a stethoscope.[6]

Inflation-deflation system

The inflation-deflation system consists of an inflating and deflating mechanism connected by rubber tubing to an occluding bladder. The standard mercury and aneroid sphygmomanometers used in clinical practice are operated manually, with inflation being effected by means of a bulb compressed by hand and deflation by means of a release valve, which is also controlled by hand. The pump and control valve are connected to the inflatable bladder and thence to the sphygmomanometer by rubber tubing.

Rubber tubing

Leaks due to cracked or perished rubber make accurate measurement of blood pressure difficult because the fall in mercury cannot be controlled. The rubber should be in a good condition and free from leaks. The minimum length of tubing between the cuff and the manometer should be 70 cm and

Recommendations for observer training

Training observers in clinical practice: nursing and medical students, doctors, paramedical personnel
- Instruction in the theory of hypertension and blood pressure measurement
- Booklet for reading, eg BHS *Recommendations on blood pressure measurement*
- Tutorial sessions with demonstrations using a binaural or multiaural stethoscope
- CD Rom demonstration using, eg, the BHS CD Rom
- CD Rom assessment
- Repeat CD Rom assessment until level of accuracy achieved
- Reassessment using BHS CD Rom every two years

Training observers in research
- Measurement of blood pressure—highest possible standard
- Level of accuracy—90% of SBP and DBP within 5 mm Hg
  —100% within 10 mm Hg of an expert observer
- Instruction in the theory of hypertension and blood pressure measurement
- Audiogram to check auditory acuity
- Booklet for reading, eg BHS *Recommendations on blood pressure measurement*
- Tutorial sessions with demonstrations using a binaural or multiaural stethoscope
- CD Rom demonstration using, eg the BHS CD Rom
- CD Rom assessment
- Repeat CD Rom assessment until level of accuracy achieved
- Training and assessment repeated at least every three months

Relaxed subject

Mercury sphygmomanometer

between the inflation source and the cuff the tubing should be at least 30 cm in length. Connections should be airtight and easily disconnected.

Control valve
A very common source of error in sphygmomanometers is the control valve, especially when an air filter rather than a rubber valve is used. Defective valves cause leakage, making control of pressure release difficult; this leads to underestimation of systolic and overestimation of diastolic pressures. Faults in the control valve may be corrected easily by simply cleaning the filter or replacing the control valve. It is helpful to have a checklist of possible faults and the means of rectifying these.

Hazards of mercury
The mercury sphygmomanometer is a simple and accurate device, which can be easily serviced, but there are rightly concerns about the toxicity of mercury for individuals using mercury sphygmomanometers, and for those who have to service them. Users should be alert therefore to the hazards associated with handling mercury.[7]

However, the greatest concern about mercury is its toxic effects on the environment. The call to have mercury removed from hospitals comes from the environmental lobby, which, quite correctly, sees mercury as a toxic, persistent, and bioaccumable substance. What happens, they ask, to the many tons of mercury supplied for the manufacture of sphygmomanometers and then distributed throughout the world to hospitals and countless individual doctors? Quite simply it finds its way back into the environment through evaporation, sewage, or in solid waste, most seriously damaging the marine environment, and it accumulates in soil and in sediments thereby entering the food chain.

The mercury thermometer has been replaced in many countries, and in Sweden and the Netherlands the use of mercury is no longer permitted in hospitals. However, in other European countries, including the UK and Ireland, the move to ban mercury from hospital use has not been received with enthusiasm on the grounds that there is no accurate alternative device to the mercury sphygmomanometer. None the less, the fear of mercury toxicity is making it difficult to get mercury sphygmomanometers serviced, and the precautions recommended for dealing with a mercury spill are influencing purchasing decisions. Indeed, this is what central governmental policy in many countries would favour—the gradual disappearance of mercury from hospitals should a ban become operative.[8–10]

Preparing for the end of the mercury sphygmomanometer
Although it will be some years before any move is made to replace the millimetre of mercury, we must prepare for changes in clinical sphygmomanometry. Several simple measures can be instigated immediately. Healthcare providers are being encouraged to phase out mercury sphygmomanometers and replace them only with devices that have been independently validated against the relevant protocols. Automated devices should provide blood pressures in both millimetres of mercury and kilopascals, so that users can become familiar with kilopascals. Finally, the medical and nursing professions, which constitute the clinical market for blood pressure measuring devices, must ensure that manufacturers provide us with accurate devices designed to our specifications, rather than accepting, as we have done in the past, devices in which these considerations are secondary to the commercial success of the product.[11]

Aneroid manometers
Aneroid sphygmomanometers register pressure through a bellows and lever system, which is mechanically more intricate

Consequences of defects in the control valve

Pumping control valve	little or no effort required
Excessive squeeze on the pump	*filter blocked*
With valve closed	mercury at level steady
Falling mercury	*leak in inflation system*
With valve released	controlled fall of mercury
Failure to control mercury fall	*leak in inflation system*

Advice to be included in the instructions accompanying a sphygmomanometer using a mercury manometer
(from European Standard EN 1060-2)

B1 Guidelines and precautions
A mercury-type sphygmomanometer should be handled with care. In particular, care should be taken to avoid dropping the instrument or treating it in any way that could result in damage to the manometer. Regular checks should be made to ensure that there are no leaks from the inflation system and to ensure that the manometer has not been damaged so as to cause a loss of mercury.

B2 Health and safety when handling mercury
Exposure to mercury can have serious toxicological effects; absorption of mercury results in neuropsychiatric disorders and, in extreme cases, nephrosis. Therefore precautions should be taken when carrying out any maintenance to a mercury-type sphygmomanometer.

When cleaning or repairing the instrument, it should be placed on a tray having a smooth, impervious surface which slopes away from the operator at about 10° to the horizontal, with a water filled trough at the rear. Suitable gloves (eg of latex) should be worn to avoid direct skin contact. Work should be carried out in a well ventilated area, and ingestion and inhalation of the vapour should be avoided.

For more extensive repairs, the instrument should be securely packed with adequate packing, sealed in a plastic bag or container, and returned to a specialist repairer. It is essential that a high standard of occupational hygiene is maintained in premises where mercury containing instruments are repaired. Chronic mercury absorption is known to have occurred in individuals repairing sphygmomanometers.

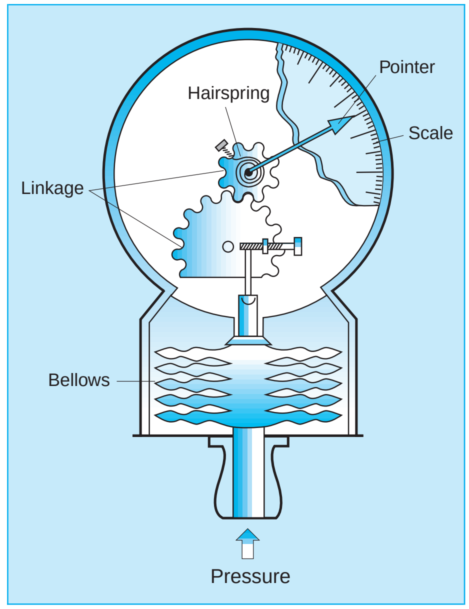
B3 Mercury spillage
When dealing with a mercury spillage, wear latex gloves. Avoid prolonged inhalation of mercury vapour. Do not use an open vacuum system to aid collection. Collect all the small droplets of spilt mercury into one globule and immediately transfer all the mercury into a container, which should then be sealed.

After removal of as much of the mercury as practicable, treat the contaminated surfaces with a wash composed of equal parts of calcium hydroxide and powdered sulfur mixed with water to form a thin paste. Apply this paste to all the contaminated surfaces and allow to dry. After 24 h, remove the paste and wash the surfaces with clean water. Allow to dry and ventilate the area.

B4 Cleaning the manometer tube
To obtain the best results from a mercury-type sphygmomanometer, the manometer tube should be cleaned at regular intervals (eg under the recommended maintenance schedule). This will ensure that the mercury can move up and down the tube freely, and respond quickly to changes in pressure in the cuff.

During cleaning, care should be taken to avoid the contamination of clothing. Any material contaminated with mercury should be sealed in a plastic bag before disposal in a refuse receptacle.

than the mercury reservoir and column. The jolts and bumps of everyday use affect their accuracy; they lose accuracy over time, usually leading to falsely low readings with the consequent underestimation of blood pressure. They are therefore less accurate in use than mercury sphygmomanometers. When calibrated against a mercury sphygmomanometer a mean difference of 3 mm Hg is considered to be acceptable; however, 58% of aneroid sphygmomanometers have been shown to have errors greater than 4 mm Hg, with about one third of these having errors higher than 7 mm Hg.[12] Moreover, aneroid sphygmomanometry is prone to all the problems of the auscultatory technique, namely observer bias and terminal digit preference.



Mechanism of an aneroid sphygmomanometer

Position of manometer

The observer should take care when positioning the manometer:

- The manometer should be no further than three feet (92 cm) away so that the scale can be read easily.
- The mercury column should be vertical (some models are designed with a tilt) and at eye level—this is achieved most effectively with stand mounted models, which can be easily adjusted to suit the height of the observer.
- The mercury manometer has a vertical scale and errors will occur unless the eye is kept close to the level of the meniscus. The aneroid scale is a composite of vertical and horizontal divisions and numbers, and must be viewed straight on with the eye on a line perpendicular to the centre of the face of the gauge.


Correct placement of cuff and bladder

Placing the cuff

The cuff should be wrapped around the arm ensuring that the bladder dimensions are accurate. If the bladder does not completely encircle the arm its centre must be over the brachial artery. The rubber tubes from the bladder are usually placed inferiorly, often at the site of the brachial artery, but it is now recommended that they should be placed superiorly or, with completely encircling bladders, posteriorly, so that the antecubital fossa is easily accessible for auscultation. The lower edge of the cuff should be 2-3 cm above the point of brachial artery pulsation.


Palpating artery

Palpatory estimation of blood pressure

The brachial artery should be palpated while the cuff is rapidly inflated to about 30 mm Hg above the point where the pulse disappears; the cuff is then slowly deflated, and the observer notes the pressure at which the pulse reappears. This is the approximate level of the systolic pressure. Palpatory estimation is important because phase I sounds sometimes disappear as pressure is reduced and reappear at a lower level (the auscultatory gap), resulting in systolic pressure being underestimated unless already determined by palpation. The palpatory technique is useful in patients in whom auscultatory endpoints may be difficult to judge accurately—for example, pregnant women, patients in shock, or those taking exercise. (The radial artery is often used for palpatory estimation of the systolic pressure, but by using the brachial artery the observer also establishes its location before auscultation.)

Auscultatory measurement of systolic and diastolic pressures

- Place the stethoscope gently over the brachial artery at the point of maximal pulsation; a bell end-piece gives better sound reproduction, but in clinical practice a diaphragm is easier to secure with the fingers of one hand and covers a larger area.
- The stethoscope should be held firmly and evenly but without excessive pressure—too much pressure might distort the artery, producing sounds below diastolic pressure. The stethoscope end-piece should not touch the clothing, cuff, or rubber tubes to avoid friction sounds.
- The cuff should then be inflated rapidly to about 30 mm Hg above the palpated systolic pressure and deflated at a rate of 2-3 mm Hg per pulse beat (or per second), during which the auscultatory phenomena will be heard.
- When all sounds have disappeared the cuff should be deflated rapidly and completely before repeating the measurement to prevent venous congestion of the arm. The phases shown in the box, which were first described by Nicolai Korotkoff and later elaborated by Witold Ettinger, can be heard.[13]

Diastolic dilemma

For many years recommendations on blood pressure measurement have been uncertain about the diastolic endpoint—the so called diastolic "dilemma." Phase IV (muffling) may coincide with or be as much as 10 mm Hg higher than phase V (disappearance), but usually the difference is less than 5 mm Hg; phase V correlates best with intra-arterial pressure. There has been resistance to general acceptance of the silent endpoint until recently, because the silent endpoint can be greatly below the muffling of sounds in some groups of patients—children, pregnant women, anaemic or elderly patients. In some patients sounds may even be audible when cuff pressure is deflated to zero. There is now a general consensus that disappearance of sounds (phase V) should be taken as diastolic pressure except in those subjects mentioned above (as originally recommended by Korotkoff in 1910).[13]

Recording blood pressure

The points to be noted when measuring blood pressure are listed in the box opposite.

Number of measurements

One measurement should be taken carefully at each visit, with a repeat measurement if there is uncertainty or distraction; do not make a number of hurried measurements.

As a result of the variability of measurements of casual blood pressure, decisions based on single measurements will result in erroneous diagnosis and inappropriate management. Reliability of measurements is improved if repeated measurements are made. The alarm reaction to blood pressure measurement may persist after several visits, so for patients in whom sustained increases of blood pressures are being assessed, a number of measurements should be made on different occasions over a number of weeks or months before diagnostic or management decisions are made.

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Auscultatory sounds

- *Phase I*—The first appearance of faint, repetitive, clear tapping sounds which gradually increase in intensity for at least two consecutive beats is the systolic blood pressure
- *Phase II*—A brief period may follow during which the sounds soften and acquire a swishing quality
- *Auscultatory gap*—In some patients sounds may disappear altogether for a short time
- *Phase III*—The return of sharper sounds, which become crisper to regain, or even exceed, the intensity of phase I sounds. The clinical significance, if any, to phases II and III has not been established
- *Phase IV*—The distinct abrupt muffling of sounds, which become soft and blowing in quality
- *Phase V*—The point at which all sounds finally disappear completely is the diastolic pressure

What to note when measuring blood pressure

- The blood pressure should be written down as soon as it has been recorded
- Measurements of systolic and diastolic pressure should be made to the nearest mm Hg
- Pressures should not be rounded off to the nearest 5 or 10 mm Hg—digit preference
- The arm in which the pressure is being recorded and the position of the subject should be noted
- Pressures should be recorded in both arms on first attendance
- In obese patients the bladder size should be indicated
- If a "standard cuff" containing a bladder with the dimensions 23 × 12 cm has to be used, it is best to state this together with the measurement so that the presence of "cuff hypertension" can be taken into account in diagnostic and management decisions and arrangements can be made for a more accurate measurement
- In clinical practice the diastolic pressure should be recorded as phase V, except in those patients in whom sounds persist greatly below muffling; this should be clearly indicated
- In hypertension research both phases IV and V should be recorded
- If the patient is anxious, restless, or distressed a note of this should be made with the blood pressure
- The presence of an auscultatory gap should always be indicated
- In patients taking blood pressure lowering drugs the optimal time for control of blood pressure will depend on the timing of the drugs; when assessing the effect of antihypertensive drugs the time of drug ingestion should be noted in relation to the time of measurement

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Ambulatory blood pressure monitoring

Barry P McGrath, and on behalf of the National Blood Pressure Advisory Committee of the National Heart Foundation of Australia

THE DEVELOPMENT OF NON-INVASIVE ambulatory blood pressure monitoring (ABPM) devices has been a great impetus to clinical hypertension research, and ABPM is now widely used in clinical practice. This position statement examines the evidence to support the use of ABPM, and provides guidance on how and when it should be applied in practice and how to interpret an ambulatory blood pressure (ABP) profile.

Rationale for use of ABPM in clinical practice

A range of indicators have been used to examine the relationship between increased 24-hour ABP and end-organ damage. Most studies have shown that the end-organ damage associated with hypertension is more strongly correlated with ABP than with clinic blood pressure measurements. There is a stronger relationship between left ventricular hypertrophy (LVH) and 24-hour ambulatory systolic blood pressure than clinic or casual systolic blood pressure [E3][1] (see Box at the end of this article for an explanation of levels of evidence). In a study of 206 patients with essential hypertension, regression of left ventricular hypertrophy (LVH) was predicted much more closely by changes in ABP than in clinic or home blood pressure measurements [E3]).[2] A pivotal study with a mean of eight years' follow-up reported a progressive rise in risk of cardiovascular morbidity and mortality (stroke, myocardial infarct) with increasing levels of ABP.[3] A review of published outcome studies conducted in untreated and treated patients with hypertension in the general population concluded that there was good evidence for the clinical usefulness of ABPM for refinement of cardiovascular risk stratification [E3].[4]

Two prospective studies have reported that ABP measurements give better prediction of clinical outcomes compared with conventional clinic or office blood pressure measurements.[5,6] The first involved 1542 subjects of Ohasama, Japan, who were followed up for a mean of 6.2 years. ABP measurements better predicted mortality than did casual blood pressure measurements [E3].[5] More recently, in a study of 808 older participants (aged over 60 years) with isolated systolic hypertension followed up for a mean of 4.4 years, ambulatory systolic blood pressure was a significantly better predictor of cardiovascular events than conventional blood pressure measurement [E3].[6] Although this was a large randomised controlled study, treatment was based on office blood pressure recordings. There is a need for randomised controlled studies which compare outcomes in patients with hypertension who are treated on the basis of ABP versus casual blood pressure measurements.

See also pages 571 and 580

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ABSTRACT

- End-organ damage associated with hypertension is more closely related to ambulatory blood pressure (ABP) than clinic or casual blood pressure measurements.
- ABP measurements give better prediction of clinical outcome than clinic or casual blood pressure measurements.
- The technique of ABP monitoring (ABPM) is specialised; validated monitors and appropriate quality control measures should be used.
- Interpretation of ABP profile should include mean daytime, night-time (sleep) and 24-hour measurements, and consideration of diary information and time of drug treatment. Reports may also include ABP "loads" (percentage area under the blood pressure curve above set limits) for daytime and night-time periods.
- Normal blood pressure values for adults are <135/85 mmHg for daytime, <120/75 mmHg for night-time, and <130/80 mmHg for 24 hours.
- ABPM is indicated to exclude "white coat" hypertension and has a role in assessing apparent drug-resistant hypertension, symptomatic hypotension or hypertension, in the elderly, in hypertension in pregnancy, and to assess adequacy of control in patients at high risk of cardiovascular disease.
- White coat hypertension requires continued surveillance; patients who display this phenomenon may, in time, develop established hypertension.
- Appropriate use of ABPM may result in cost savings.
- Randomised controlled trials comparing management based on clinic or casual versus ABP measurements are needed.

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Technical aspects of non-invasive ambulatory blood pressure monitoring (ABPM)

The first device for non-invasive ambulatory blood pressure monitoring was developed in 1962. It used a microphone taped over the brachial artery, an occlusive cuff inflated by the patient, and a magnetic tape recorder for recording cuff pressures, electrocardiogram and Korotkoff sounds. A modified version was used by Sokolow and colleagues in a classic study published in 1966,[7] which showed that end-organ damage was related to average ABP measurements.

New measurement techniques (see Box 1) and the ability to handle large volumes of data with computer-assisted analysis have led to studies that challenge entrenched views on diagnosis, prognosis and management of hypertension. A new language has emerged, with such terms as blood pressure load, nocturnal dipping (a significant day–night difference in blood pressure of more than 10% or more than 10/5 mmHg) and non-dipping, "white-coat" (or "isolated clinic") hypertension, "white-coat" effect, "reversed white-coat" hypertension, trough-to-peak ratio, and blood pressure variability. Health professionals now have to adjust and incorporate this new knowledge into their practice.

Practical aspects of ABPM

Current ABP monitors are generally lightweight, easy to wear, accurate, quiet, programmable and computer-interactive. Only devices validated to international standards (British Hypertension Society [BHS[8]] or the American Association for the Advancement of Medical Instrumentation [AAMI][9]) should be used. Recent reviews of validation studies have shown that about two-thirds of ABPM devices tested could be recommended, as they fulfilled the AAMI criteria for both systolic and diastolic pressure (denoted as "passed") and received a grade of A or B under the BHS protocol for measuring both systolic and diastolic blood pressures.[10,11,12]

There are important principles for the application of ABP monitors that are often overlooked in current practice. The British guidelines[8] emphasise observer training and assessment, calibration testing and an ongoing schedule of in-use evaluation of equipment. Patients should be monitored on a normal work day, rather than a rest day, to provide a better predictor of end-organ damage. At least two concomitant sphygmomanometer readings should be recorded at the time the device is fitted; a Y-tube should be used, and average values for ABPM and mercury column readings should not differ by more than 5 mmHg. Each participant should receive verbal and written information on the monitoring procedure and a diary to record times of sleep and medication, posture, activity and symptoms. The arm should be kept immobile at the time of measurements.

Some patients find the cuff pressure intolerable, particularly those with very high blood pressure and who have frequent repeat readings. Patients need to have a mobile phone number or pager number of a nurse or technician who can give advice if there are problems or technical difficulties during the monitoring period. ABPM is uncommonly associated with any complications. Petechiae of the upper arm and sometimes bruising under the inflating cuff may occur, and sleep disturbance is fairly common.

In general, ABP may not be accurate during exercise or when driving, or when the cardiac rate is irregular, as in atrial fibrillation. There may be technical reasons why ambulatory readings fail in some patients (eg, problems with cuff fitting in patients with conical-shaped arms, movement artefact, tremor, weak or irregular pulse, auscultatory gap). Although movement and physical activity often result in invalid readings, machines that rely on detection of Korotkoff sounds with simultaneous ECG recording to validate the signal ("gating") offer some advantages in detecting movement artifact. Most devices are programmed to take additional readings if a likely erroneous reading is recorded. A generally accepted rule is that an ABPM recording is not acceptable if fewer than 85% of readings are suitable for use in the analysis. The detection of artefactual recordings and handling of outlying values have been debated, but editing should be kept to a minimum.[10]

Studies that have looked at the day-to-day variability in ABP profiles have generally reported good reproducibility, but some have found significant variation. ABP profiles should be interpreted cautiously in relation to activity and sleep patterns.

There is no consensus on the summary measures that should be used in clinical decision making. All experienced monitoring centres report the mean values for daytime, night-time (sleep), and 24 hours. Many also report blood pressure "loads", defined as the percentage area under the blood pressure curve above set limits. This concept was first described by White in 1989, who showed that blood pressure load was a better predictor of cardiac target-organ effects than the corresponding mean ABP values.[13] A careful visual assessment of the ABP profile should also be made in relation to diary information and the timing of drug therapy.

1: Ambulatory blood pressure monitoring devices

A variety of devices are now available for ambulatory blood pressure monitoring (ABPM), and their pressure detection relies on one or more of three principles.

- *Auscultation* with detection of the onset and disappearance of Korotkoff sounds by a microphone placed over an artery distal to a deflating compression cuff.
- *Cuff oscillometry*, which relies on detection of cuff pressure oscillations. Systolic and diastolic pressures correspond to cuff pressures at which oscillations first increase (systolic) and cease to decrease (diastolic). The end-points are approximated by analysis of oscillation amplitudes and cuff pressures. Different algorithms are used by different manufacturers, creating a potential source of variability.
- *Volumetric oscillometry*, usually of a finger, with detection of volume pulsations under a cuff. Systolic and mean pressures are estimated as the cuff pressures at which finger volume oscillations commence and become maximal, respectively, while diastolic pressure is derived.

These three detection methods for ABPM incorporate techniques relying on different vascular phenomena during arterial pressure waveform transmission. Auscultatory methods depend on flow and may underestimate systolic pressure. Oscillometric methods may overestimate systolic pressure because of transmitted cuff pressure oscillations. Finger pressure has a variable relationship to brachial pressure, and there are also problems inherent in assessing diastolic blood pressure by finger oscillometry.

Day–night blood pressure differences

There is now extensive literature on day–night ambulatory blood pressure differences. Some investigators suggest night-time blood pressure is more important than daytime blood pressure in predicting outcome, particularly in individuals whose nocturnal (sleep) blood pressure remains high (ie, less than 10% lower than the daytime average — "non-dippers").[14] In older patients with isolated systolic hypertension, the Syst-Eur study found that cardiovascular risk increased with a higher night : day ratio of systolic blood pressure (ie, in

2: Why use ambulatory blood pressure monitoring?

- To exclude "white coat" hypertension.
- End-organ damage is more closely correlated with ambulatory blood pressure (ABP) than with clinic blood pressure readings.
- ABP may be a better predictor of cardiovascular events and mortality than clinic blood pressure readings.
- Patients with hypertension whose nocturnal (sleep) blood pressure remains high (< 10% lower than daytime average) may have a worse prognosis.
- ABP provides a 24-hour profile, allowing assessment of clinic effects, drug effects, work influence, etc.

patients more likely to be non-dippers) independent of the average 24-hour blood pressure, with a 10% increase in the ratio giving a hazards ratio for cardiovascular end-points of 1.41 (95% CI, 1.03–1.94) [E3].[6] In contrast, in the SAMPLE study, night-time ABP did not improve on the prediction of LVH regression provided by daytime ABP, suggesting that daytime ABP suffices.[2] Moreover, the Ohasama study found that mean daytime ABP is a better predictor of mortality than night-time ABP.[5] Thus, the jury is still out on the relative importance of night-time (sleep) and daytime ABP measurements. A practical problem is that it is very difficult to differentiate "non-dippers" from "non-sleepers" without monitoring brainwave activity.

Is 24-hour control of blood pressure important?

It is a widely held view that optimal BP control requires a smooth reduction in the 24-hour BP profile. In the United States, it is a Food and Drug Administration requirement that a claim for 24-hour efficacy of a drug must be substantiated with 24-hour ABPM studies. However, it has yet to be determined which particular component of the blood pressure profile (24-hour mean, daytime mean, night-time mean, ambulatory blood pressure load, day–night difference, blood pressure variability) is the best predictor of prognosis. The blood pressure measured during a patient's workday is a good predictor of left ventricular hypertrophy, and there is supporting evidence for a carryover of high daytime ABP into the evening period in patients with "high demand, low control" types of work [E3].[15]

Application of ABPM

The importance of ABPM in managing hypertension has been acknowledged in hypertension guidelines,[16,17] and a number of authoritative bodies have now issued guidelines on the use of ABP.[10,18,19] A taskforce of participants at the 1999 Consensus Conference on ABP monitoring, sponsored by the International Society of Hypertension, suggested that:

> "ABPM should be performed only with properly validated devices as an accessory to conventional measurement of BP [blood pressure]. ABPM requires considerable investment in equipment and training and its use for screening purposes cannot be recommended. ABPM is most useful for identifying patients with white-coat hypertension (WCH), also known as isolated clinic hypertension. ABPM or equivalent methods for tracing the white-coat effect should become part of the routine diagnostic and therapeutic procedures applied to treated and untreated patients with elevated clinic blood pressures. Results of long-term outcome trials should better establish the advantage of further integrating ABPM as an accessory to conventional sphygmomanometry into the routine care of hypertensive patients and should provide more definite information on the long-term cost-effectiveness."[20]

Reasons for using ABPM are summarised in Box 2.

ABPM should be considered in the following scenarios:

- To exclude "white coat" hypertension in patients with newly discovered hypertension with no evidence of end-organ damage;[10,18,19]
- In patients with borderline or labile hypertension;[10,18,19]
- To assist blood pressure management in patients whose blood pressure is apparently poorly controlled, despite using appropriate antihypertensive therapy;[10,18,19]
- In patients with worsening end-organ damage, despite adequate blood pressure control on office blood pressure measurements;[10,18,19]
- To assess adequacy of blood pressure control over 24 hours in patients at particularly high risk of cardiovascular events, in whom rigorous control of blood pressure is essential (eg, diabetes, past stroke);[10]
- In deciding on treatment for elderly patients with hypertension;[10]
- In patients with suspected syncope or orthostatic hypotension;[10,18,19]
- In patients with symptoms or evidence of episodic hypertension;[18,19] and
- In hypertension in pregnancy.[10,18,19]

The role of ABPM in monitoring antihypertensive therapy

There is fairly good evidence that antihypertensive therapy based on ABPM rather than regular office measurements may be advantageous in that the amount of medication required to achieve the target blood pressure is reduced [E3].[21] ABPM may also be a sensitive indicator of loss of BP control.[22] "White-coat" hypertension does not appear to respond to standard drug therapy, but large-scale controlled trials are needed to examine this issue.[10,23]

Normal values for ABP profiles in adults

There are large studies in normal adult populations which have provided suitable normative data for ambulatory blood pressures. Staessen and colleagues[24] collated data from an international database of 24 research groups, including one Australian centre. The database was drawn from 4577 participants with repeated normal casual blood pressure readings of less than 140/90 mmHg. In these normotensive participants, the 95th centiles for 24-hour ambulatory blood pressure were 133 mmHg systolic and 82 mmHg diastolic. Data from this large, unbiased sample of a general population showed that home and 24-hour or daytime average blood pressures were much lower than clinic blood pressures. The upper limit of "normality" for both home and ambulatory blood pressures was in the range 120–130 mmHg systolic and 78–81 mmHg diastolic, compared with the upper limits for clinic blood pressure of 140/90 mmHg. In the Italian PAMELA study, clinic, home and ambulatory blood pressure measurements were compared in 1438 adults.[25] Data from both the international database and the PAMELA study are shown in Box 3.

3: Comparisons of ambulatory, home and clinic blood pressures (mmHg, mean ± SD)

Blood pressure	International database*	PAMELA study†
Systolic		
24-hour	116 ± 10	118 ± 11
Day	122 ± 11	123 ± 11
Night	106 ± 11	108 ± 16
Home	—	119 ± 17
Clinic	—	128 ± 17
Diastolic		
24-hour	70 ± 7	74 ± 7
Day	75 ± 8	79 ± 8
Night	61 ± 8	65 ± 7
Home	—	75 ± 10
Clinic	—	82 ± 10

* 4577 participants with repeated casual (clinic) blood pressure readings less than 140/90 mmHg.

† Randomised population sample of 1438 participants aged 24–64 years not receiving antihypertensive therapy.

Ohkubo and colleagues derived reference values for 24-hour ABP based on a prognostic criterion in the Ohasama study, and reported that the optimal blood pressure range predicting the best prognosis for risk of cardiovascular mortality was 120–133 mmHg for systolic ABP and 65–78 mmHg for diastolic ABP.[26]

Deciding what constitutes normal versus abnormal ABP is controversial, but commonly used values for adults are less than 135/85 mmHg during the day, less than 120/75 mmHg during the night, and less than 130/80 for 24 hours.[10,16,18,19] Normative data for children[27] and pregnant women[28] are available from smaller studies. Normal values for adults and information on interpreting an ABPM profile are shown in Box 4.

It should be emphasised that blood pressure values obtained by ABPM or home blood pressure monitoring are several mmHg lower than those obtained by clinic measurements, with a 24-hour ABP of 125/80 mmHg corresponding to a clinic reading of 140/90 mmHg.[25] The difference is even more exaggerated for systolic blood pressure in older patients with isolated systolic hypertension [E2].[29]

"White-coat" ("isolated clinic") hypertension

This is a condition in which blood pressure is persistently elevated in the presence of a doctor, but falls to normal values when the patient leaves the medical environment [E2].[23,30] Measurement of blood pressure by nurses or trained non-medical staff may reduce, but not necessarily abolish, this effect. The condition can only be detected by ABPM or by self-monitoring. There are no known predisposing factors such as personality type, reactivity to stress, biochemical or physiological variables. The definition has been variable in published series and there may be selection bias.[31] Initially thought to be benign, there is increasing evidence that the prognosis for patients with "white-coat" hypertension is intermediate between that of those who have normotension and those with established hypertension.[1,23,32] However, in an older Japanese population followed for an average of 42 months, among those with "white coat" hypertension (defined according to American Society of Hypertension criteria [clinic blood pressure, >140/90 mmHg; 24 h ABP, <130/80 mmHg]) the incidence of stroke was similar to that of normotensive participants, and the risk of stroke was a quarter that for patients with sustained hypertension.[33] Further large-scale definitive outcome studies are needed. Appropriate management requires careful exclusion of end-organ damage and cardiovascular risk factor management, appropriate lifestyle changes, as well as the introduction of self-monitoring and repeat ABPM at one-year to two-year intervals, or both. Important points about "white coat" hypertension are summarised in Box 5.

4: How to interpret ambulatory blood pressure (ABP) profile

- ABP profiles should be inspected in relation to diary information and time of drug treatment.
- Normal ABP values for adults (non-pregnant) are < 135/85 mmHg during the day, < 120/75 mmHg during the night, and < 130/80 mmHg over 24 hours.
- Daytime and night-time ABP "loads"* should be < 20% above normal values.
- Mean day-time and night-time (sleep) ABP measurements should differ by > 10%.

* Percentage area under the blood pressure curve above set limits.

The only alternative to ABPM for diagnosing "white-coat" hypertension is home or self-monitoring. However, only about a fifth of self-recording devices evaluated in recent reviews have met acceptable criteria,[11,12] so care should be exercised in choosing the home monitoring device. A recent review of self-monitoring suggests that ABPM may be better for the initial diagnosis of hypertension and for predicting prognosis, but that home blood pressure monitoring may be of more value for long term follow-up.[34] In a separate paper, the National Heart Foundation of Australia outlines the value of blood pressure self-monitoring for promoting patient understanding and improving compliance, and provides guidelines for valid self-measurement of blood pressure.[35]

The mirror image phenomenon of "reversed white-coat" hypertension — when the blood pressure reading is normal when measured in the clinic but raised on ABP — also occurs and is not an uncommon phenomenon.[5] The cause and implications of this are unknown at present.

Cost effectiveness

The evidence on cost effectiveness of ABPM is limited. Appropriate use of ABPM in selected patient groups to

5: "White-coat" ("isolated clinic") hypertension

- Can only be detected by ambulatory blood pressure monitoring (ABPM) or self-monitoring.
- May not be benign; definitive outcome studies are needed.
- Requires continued surveillance, involving self-monitoring and repeat ABPM at 1–2-year intervals.
- Does not respond to standard drug therapy.

Background and evidence basis of recommendations

This Position Statement on Ambulatory Blood Pressure Monitoring was written by Professor Barry McGrath on behalf of the National Blood Pressure Advisory Committee of the National Heart Foundation of Australia, which comprises Professor L Wing (Chair), Dr A Boyden, Professor A Dart, Associate Professor K Duggan, Professor G Hankey, Dr M Nelson, Professor I Puddey, Dr M Stowasser, and Dr J Vial. The draft Statement was circulated for comment to the above members of the committee, who have clinical and research expertise or interests in hypertension and blood pressure monitoring. All comments were incorporated into the final document, which was ratified by the Heart Foundation's Cardiovascular Health Advisory Committee. All available evidence from controlled observational studies and clinical trials was combined with clinical experience to provide recommendations according to the National Health and Medical Research Council quality-of-evidence ratings.[37]

Levels of evidence:

- E1 Level I: Evidence obtained from a systematic review of all relevant randomised controlled trials.
- E2 Level II: Evidence obtained from at least one properly designed randomised controlled trial.
- E3 Level III: Evidence obtained from all well-designed controlled trials without randomisation, well-designed cohort or case–control analytical studies, preferably from more than one centre or research group, or from multiple time series with or without the intervention. Dramatic results in uncontrolled experiments (such as the results of the introduction of penicillin treatment in the 1940s) could also be regarded as this type of evidence.
- E4 Level IV: Opinions of respected authorities, based on clinical experience, descriptive studies, or reports of expert committee.

National Health and Medical Research Council, 1995.

improve diagnosis and reduce unnecessary drug therapy may result in significant cost savings [E3].[36]

Conclusions

The rationale for the use of ABPM in clinical practice is soundly based. The technique is specialised and quality control measures have been defined for service providers. ABPM is indicated to exclude “white coat” hypertension and has a role in assessing apparent drug-resistant hypertension, the elderly, hypertension in pregnancy, during symptomatic episodes of hypotension or hypertension, and in monitoring adequacy of blood pressure control in patients at high risk of cardiovascular disease. Definitive outcome studies are needed in the form of randomised controlled trials comparing management of hypertension based on office blood pressure measurement versus ABPM.

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Automated Ambulatory Blood Pressure Monitoring: Clinical Utility in the Family Practice Setting

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Although the percentage of patients who are treated for hypertension has increased, the percentage of those who demonstrate control of blood pressure has declined. As a result of this trend, clinicians may increasingly rely on ambulatory blood pressure monitoring to improve the diagnosis and treatment of hypertension. Studies confirm that ambulatory blood pressure monitoring devices more accurately reflect a patient's blood pressure and correlate more closely with end-organ complications than blood pressure levels measured in the physician's office. Discriminate use of this technology in specific clinical circumstances assists in identifying patients at risk for hypertension and may result in improved outcomes in this subset of patients. Ambulatory blood pressure monitoring may be particularly helpful in clinical situations such as borderline hypertension, white-coat hypertension, apparent drug resistance, hypotensive symptoms from medications or autonomic dysfunction, episodic hypertension, and evaluation of antihypertensive efficacy. (Am Fam Physician 2003;67:2343-50,2353-4. Copyright© 2003 American Academy of Family Physicians.)

A patient information handout on blood pressure monitoring, written by the authors of this article, is provided on page 2353.

See page 2241 for definitions of strength-of-evidence levels.

See editorial on page 2262.

Ambulatory blood pressure monitoring (ABPM), although previously considered only a research instrument, may be useful in the management of some of the nearly 50 million adults in the United States with hypertension.[1] With ABPM, multiple automatic measurements of blood pressure are obtained at specific intervals throughout a 24- to 48-hour period, enabling the clinician to assess the level of blood pressure control under conditions of a normally active day.[2] Although ABPM is not applicable to all hypertensive patients, it is particularly useful in patients with borderline hypertension, white-coat hypertension, suspected autonomic dysfunction, and episodic hypertension. It also is useful in the evaluation of drug resistance and medication compliance.[3]

Indications for use of ambulatory blood pressure monitoring include white-coat hypertension, borderline hypertension, and resistant hypertension.

Accurate in-office blood pressure readings, obtained in compliance with the American Heart Association guidelines, remain the gold standard for decision-making in the diagnosis and treatment of hypertension.[1,4] Recent studies, however, indicate that ABPM data may more accurately reflect a patient's actual blood pressure than casual or in-office blood pressure measurements and may improve the physician's ability to predict cardiovascular risk.[2,5] The best possible use for ABPM data, then, is to further evaluate and fine-tune treatment in conjunction with in-office pressure assessment.

Ambulatory Blood Pressure Monitoring Techniques

Since the introduction of ABPM, increasingly automated, lightweight, and accurate measurement devices have emerged. They are typically battery-powered, belt-worn, and of a size and shape similar to that of a Sony Walkman radio *(Figure 1)*. ABPM units indirectly measure blood pressure through auscultation (of Korotkoff's sounds) with piezoelectric microphones, through oscillometric measure-

FIGURE 1. Ambulatory blood pressure monitor and cuff (Model 90207, SpaceLabs Medical, Inc., Issaquah, Wash.).

ment of the vibratory signals associated with blood flow in the brachial artery, or through the combined use of both technologies.[3,6] Auscultatory devices record both systolic and diastolic pressures, whereas the oscillatory units record systolic and mean pressure and then calculate diastolic pressure through a variety of algorithms. Validation testing against mercury sphygmomanometry and intra-arterial measurement has confirmed the accuracy of these technologies. Studies indicate that there is a discrepancy of less than 5 mm Hg between ambulatory devices and readings taken by trained human observers.[2]

The process of selecting a monitoring device for the office includes an assessment of the validation of the equipment performed by an independent laboratory or association, as shown in *Table 1*.[7] Data are collected at 15- to 30-minute intervals (and when triggered at the patient's request) throughout the monitoring period and are stored in the unit's memory chip. The clinician downloads the system's memory to a personal computer for organization and interpretation. The simultaneous advantage and challenge of ABPM interpretation lies in coping with the volume of data. However, software simplifies this interpretation and, when combined with review of the patient's diary of daily activities, allows interpretation of the results.

TABLE 1
Selection of Monitors Validated by the U.S. Association for the Advancement of Medical Instrumentation

Manufacturer	*Model and validation information*
A & D Engineering, Inc. 1555 McCandless Dr. Milpitas, CA 95035 408-263-5333	TM-2420 and TM-2421; validated at rest
SpaceLabs Medical, Inc. 15220 N.E. 40th St. P.O. Box 97013 Redmond, WA 98073 800-251-9910	SpaceLabs 90207; validated at rest,* in pregnancy, in elderly patients with postural effect SpaceLabs 90217; validated at rest
Sun Tech Medical Instruments 8917 Glenwood Ave. Raleigh, NC 27617 919-782-3005	Accutracker II; validated at rest

**—Validated for high, medium, and low pressure ranges.*

Adapted with permission from O'Brien E, Coats A, Owens P, Petrie J, Padfield PL, Littler WA, et al. Use and interpretation of ambulatory blood pressure monitoring: recommendations of the British hypertension society. BMJ 2000;320:1129.

Daily Blood Pressure Variability

The literature describes a normal diurnal variation in blood pressure readings, an effect frequently chronicled by ambulatory pressure records. Peak pressures are typically encountered around 6 a.m. and herald the characteristic higher daytime blood pressures. In the normotensive patient, daytime pressures taper to lower levels during the evening hours and fall even further at night. The pressure nadir ("dip") typically occurs between 2 and 4 a.m.[2] *(Figure 2)*. This dip in nocturnal pressure may have prognostic implications. The absence of this decline may place patients at an increased risk of cardiovascular disease, particularly elderly patients, and has been identified as an early marker of microalbuminuria in diabetic patients[8-10] *(Figure 3)*. Diurnal variation in blood pressure has been attributed to changes in physical activity, changes in environmental conditions, and variations in the hormonal milieu.[2,11]

Typical Diurnal Blood Pressure Rhythm in a "Dipper"

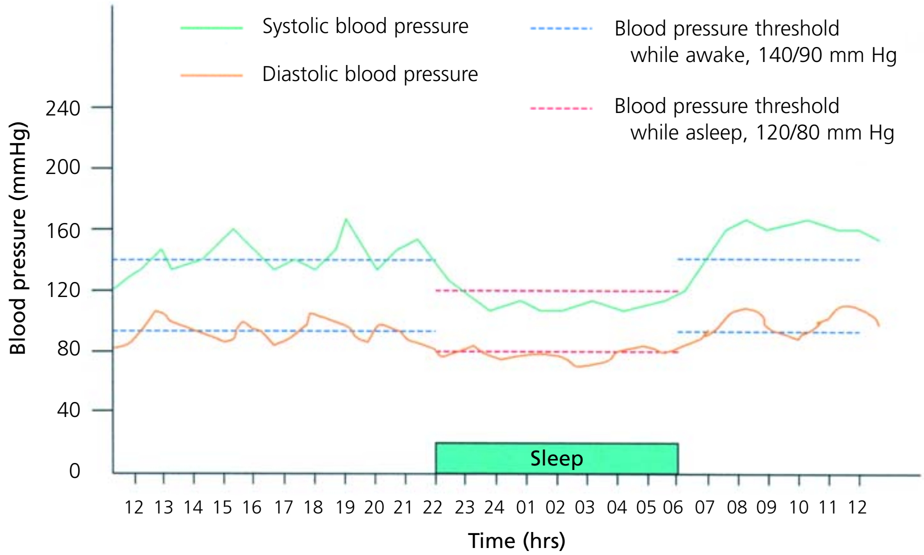

FIGURE 2. Ambulatory blood pressure report of a hypertensive patient who is a "dipper."

Diurnal Blood Pressure Rhythm in a "Nondipper"

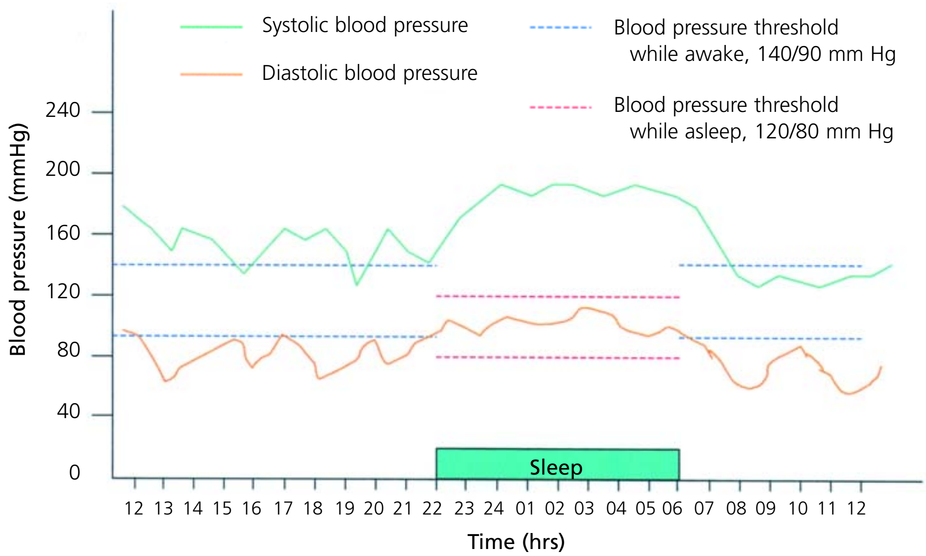

FIGURE 3. Ambulatory blood pressure report of a hypertensive patient who is not a "dipper."

TABLE 2
Situations in Which Ambulatory Blood Pressure Monitoring Might Be Useful

Evaluation of newly diagnosed hypertensive patients with or without target-organ damage
White-coat hypertension
Evaluation of drug-resistance or resistant hypertension
Evaluation of pregnancy-induced hypertension
Evaluation of treatment
Episodic hypertension associated with symptoms
Autonomic neuropathy
Orthostatic hypotension

Information from references 1, 3, and 12.

Indications for ABPM

Research indicates that clinical management may be simplified by using ABPM in certain situations *(Table 2)*.[1,3,12]

WHITE-COAT HYPERTENSION

Hypertensive patients frequently demonstrate their highest recorded levels in a clinical setting, with subsets of patients who demonstrate hypertensive blood pressures only in the physician's office.[13] To manage these white-coat hypertensive patients, it is first necessary to identify them and then to stratify their cardiovascular risk status.[12,14] Historical appraisal and review of self-recorded blood pressures can aid in the identification of these patients, but stratifying their risk solely on the basis of office measurement of blood pressure is more difficult.

Recent studies suggest that ABPM data can clarify the clinical situation, since 20 to 30 percent of patients who are hypertensive in the office are normotensive at other times[2] *(Figure 4)*. Recognition and proper management of this subgroup allows a reduction in antihypertensive medication use and a decrease in related side effects.[12] Accumulat-

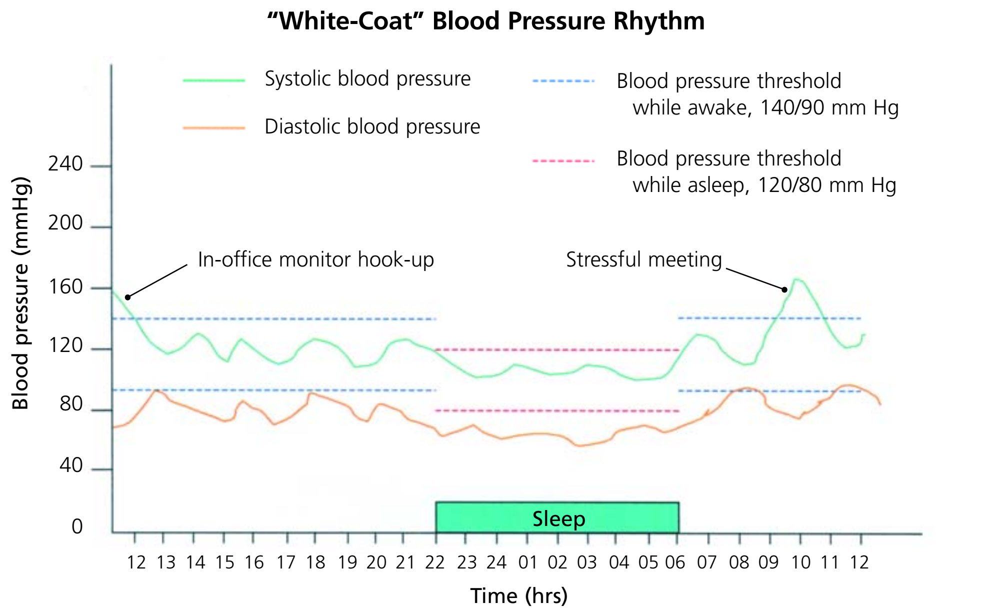

FIGURE 4. Ambulatory blood pressure report of a patient with white-coat hypertension.

ing ABPM data suggest that patients with white-coat hypertension who maintain low ambulatory blood pressures (less than 130 to 135/80 mm Hg) have a low cardiovascular risk status and no demonstrable end-organ damage.[14]

Armed with ABPM control data, the clinician can make rational recommendations about continued or expanded lifestyle modifications or progressive use of antihypertensive medications.

BORDERLINE HYPERTENSION WITHOUT END-ORGAN DAMAGE

The decision to initiate pharmacotherapy in patients with stage 1 (mild) hypertension can be difficult, particularly in patients without identified end-organ damage, a family history of hypertension, or a secondary etiology. Pharmacotherapy decisions traditionally depend on sequential office blood pressure readings and review of patient-supplied home recordings.

Accuracy of at-home recordings can be improved by calibration of the home instrument with a known standard, but even so, a lower threshold for treatment is recommended (i.e., less than 135/85 mm Hg), because of inaccuracies in home measurements and the tendency for home readings to be lower than office readings *(Table 3)*.[1,12] ABPM data may help refine decision-making by rectifying discrepancies between in-office and home measurements and by quantifying the patient's overall level of control. Armed with this control data, the clinician can make rational recommendations about continued or expanded lifestyle modifications or progressive use of antihypertensive medications.

RESISTANT HYPERTENSION

Resistant hypertension is the term applied when adequate blood pressure control cannot be achieved despite the use of appropriately combined antihypertensive therapies in proper dosages for a sufficient duration.[3] This clinical dilemma arises in true drug-resistant hypertension, cases of patient noncompliance, white-coat hypertension, and cases of pseudohypertension (where brachial artery calcification precludes collapse by the pressure cuff, leading to spuriously high readings). These patients typically have persistently elevated clinic pressures and normal or equivocal home or ABPM readings but fail to demonstrate any evidence of target-organ damage.[12]

Sleep apnea and other sleep disorders are noteworthy etiologies of resistant hypertension. It is critical to identify an underlying disorder, given the cardiovascular risks associated with failure to diagnose and treat such disorders.[15] Patients with sleep apnea and other sleep disorders demonstrate sporadic hypertensive episodes, coincident with apneic spells, and often fail to demonstrate the nocturnal physiologic dip in blood pressure. ABPM data may help the clinician determine whether inadequate therapy or true drug resistance underlies the failure to control hypertension. Of course, excluding noncompliance as the cause requires skilled interpretation by the clinician.

TABLE 3
Ambulatory Blood Pressure vs. Clinic Blood Pressure—Thresholds for Treatment

Hypertension	*Clinic blood pressure (mm Hg)*	*Ambulatory blood pressure (mm Hg)*
Daily[1]	140/90	135/85
Nighttime[12]	125/80	120/75
With diabetes[1]	130/85	†
With renal disease[1]	130/85 125/75*	†

**—Blood pressure goal in patients with renal disease who have proteinuria in excess of 1 g per 24 hours.[1]*

†—Although daytime and nighttime hypertensive blood pressure thresholds have been established for clinic and ambulatory readings, thresholds for specific disease states (e.g., diabetes, renal disease) have not been established.

Information from references 1 and 12.

Excluding noncompliance as the cause of failure to control hypertension requires skilled interpretation by the clinician.

HYPERTENSION IN PREGNANCY

Research supports the use of ABPM for the evaluation of hypertension during pregnancy. Reference values have been established for this clinical setting.[16] Hypertensive disease complicates nearly 10 percent of pregnancies in the United States, with white-coat hypertension affecting an additional 30 percent of patients.[7] Because ABPM can more accurately identify hypertensive risk in these subgroups than office readings, it may be particularly helpful in reducing unwarranted hospitalizations or medication use in pregnancy.[17] [Evidence level B, nonrandomized clinical trial]

EVALUATION OF HYPOTENSIVE SYMPTOMS

Transient hypotensive episodes, whether related to antihypertensive therapy or to autonomic dysfunction, are difficult to assess with standard clinic blood pressure measurements but are readily recorded on ABPM monitoring. Identification of these episodes can clarify diagnostic strategies and medication management. This step may be particularly important in elderly or debilitated patients.[3,12]

EVALUATION OF TREATMENT EFFICACY

Previous reluctance to use ABPM devices in the routine management of patients with hypertension may change following the results of a comparative study of conventional and ABPM measurements.[18] This study compared cost, symptoms, left ventricular hypertrophy (LVH), and intensity of pharmacotherapy in patients followed by conventional clinic monitoring and by ABPM. The results failed to demonstrate any differences in cost, incidence of LVH, or level of reported symptoms between the two study groups. Antihypertensive therapy could be discontinued in 26 percent of the ABPM patients, compared with 7.3 percent ($P < 0.001$) of the patients in the clinic-monitoring group. In addition, hypertension was controlled with single-drug therapy in 27.2 percent of the ABPM patients. Multiple-drug therapy was required in 42.7 percent ($P < 0.007$) of the clinic-monitoring patients.[17] Despite the simplification or elimination of drug therapy and the reduction in the number of physician visits in the ABPM group, the study showed that cost savings were offset by the costs of ABPM equipment.

Interpretation of ABPM Results

Hypertension (defined as 140/90 mm Hg or higher) is difficult to apply to ABPM data because studies indicate that ambulatory pressures tend to be lower than clinic pressures, even in patients with hypertension.[1,19] The challenge is complicated further by the attempted application of treatment guidelines designed for clinic monitoring to the ABPM setting. Revised definitions of hypertension for the ambulatory setting have simplified diagnosis, and careful data interpretation and software manipulation appear to simplify treatment recommendations.

Mean systolic and diastolic pressures over the monitoring period are assessed to determine elevation above normal limits (140/90 mm Hg

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awake, 120/80 mm Hg during sleep) and the total duration that the patient's pressure remains above acceptable limits.[3] Combined use of these parameters defines the concept of "blood pressure load" (correlated with cardiac changes secondary to hypertension) and enables the clinician to assess the quality and quantity of overall blood pressure control.[2]

A Look at the Evidence

Epidemiologic and clinical studies correlate office-based blood pressure management with reductions in cardiovascular end points and surrogate markers of target-organ damage (e.g., LVH, proteinuria).[8] The identification and subsequent regression of these markers allows clinicians to better gauge long-term risks and monitor influences afforded by antihypertensive therapy.[20] An extensive and consistent body of evidence demonstrates that managing hypertension with ABPM rather than office-based readings significantly reduces these risks.[10,20] [Reference 10—Evidence level B, uncontrolled clinical trial]

Cost Issues

Ambulatory blood pressure technology does not come cheaply, with monitoring equipment and software estimated to cost approximately $4,500 to $5,500 for a fully equipped office. Clinician cost for a single-patient study ranges from $60 to $100, including staff time and supplies. The patient's cost ranges from $100 to $300 (with the addition of patient education, equipment hook-up, and data interpretation costs).[12] Although third-party reimbursement is variable, as would be expected for emerging technology, the Centers for Medicare and Medicaid Services has recently approved reimbursement for ABPM in patients with suspected white-coat hypertension.[21]

Opponents to the use of ABPM for routine clinical management cite an overall increase in cost, but proponents are quick to point out that careful patient selection is key to successful application of this technology.[22] Within carefully selected populations, ABPM may simplify or eliminate drug therapy, reducing medication consumption and its attendant potential complications, resulting in an overall cost savings.

The estimated cost of monitoring equipment and software to fully equip a physician's office for ambulatory blood pressure monitoring is $4,500 to $5,500.

Reduction in or simplification of pharmacotherapeutic regimens and increased use of lifestyle modifications to treat hypertension offer a potential for cost-effective use of this technology. Further research is warranted to link this promising tool to an overall improvement in morbidity and mortality in hypertensive patients.

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ARTÍCULO DE REVISIÓN

Automedida de Presión Arterial (AMPA)

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INTRODUCCIÓN

La medida de la presión arterial (PA) forma parte de la actividad cotidiana del médico de familia. A diario tomamos decisiones clínicas sobre diagnóstico, cambios de estilos de vida, inicio o modificación de tratamientos farmacológicos, realización de pruebas complementarias e interconsultas, basadas en las lecturas obtenidas mediante el esfigmomanómetro de mercurio, método más frecuentemente utilizado para medir la PA.

Sin embargo, una serie de hechos ponen de manifiesto limitaciones y deficiencias en esta forma de actuar:

— La gran variabilidad de la PA en cada individuo exige realizar múltiples determinaciones en diferentes situaciones.[1,2,3]

— Un porcentaje no despreciable de pacientes presenta en consulta cifras de PA significativamente más elevadas que en su ambiente habitual, por lo que los valores obtenidos pueden no ser adecuados para tomar decisiones.[1,3,4]

— Existen recomendaciones internacionales sobre la progresiva desaparición de los aparatos que utilicen el mercurio, por su potencial toxicidad y poder contaminante, lo que hace prever su sustitución por aparatos electrónicos.[1,5]

— Hay un creciente interés de los pacientes por medir su PA, lo que ha propiciado la aparición y rápida difusión de equipos de automedida de presión arterial (AMPA), con los que el paciente puede determinar su PA en el domicilio o ambiente laboral.[1]

La automedida de la presión arterial es la lectura de la PA efectuada por el paciente, sus allegados o familiares fuera del ámbito sanitario, generalmente en el domicilio[3].

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Los aparatos de AMPA electrónicos no utilizan el mercurio para medir la presión, de modo que su impacto sobre el medio ambiente es mínimo. Por otro lado, no requieren un alto nivel de habilidad (aunque sí cierto entrenamiento y supervisión),[1,6] por lo que la mayoría de los pacientes o sus familiares pueden emplearlos sin dificultad.[4,7] El hecho de poder hacer medidas en las condiciones «reales» de vida del paciente (fuera de la consulta y de la influencia del personal sanitario) hace que estas mediciones sean más representativas de la PA de cada sujeto.[1,4]

Es importante que el médico de familia conozca las indicaciones de la AMPA, los aparatos disponibles en el mercado capaces de medir con suficiente precisión y exactitud y la manera de utilizarlos estos dispositivos, con los que cada vez habremos de estar más familiarizados.

En la presente revisión se abordan aspectos referentes a los aparatos de AMPA existentes en el mercado, así como los protocolos de validación aceptados; se detallarán los dispositivos que han pasado dichos protocolos y se expondrán las ventajas e inconvenientes derivados del uso de estos equipos.

APARATOS DE AUTOMEDIDA DE PRESIÓN ARTERIAL

En los últimos años, las ventas de aparatos de AMPA han sufrido un aumento considerable, con la proliferación de múltiples modelos, que utilizan diferentes métodos para medir la PA.[1,4,6-9] Nos encontramos así con dispositivos que emplean métodos auscultatorios, incorporando un pequeño micrófono que capta las pulsaciones de la arteria previamente comprimida, al igual que lo haría un fonendoscopio, junto a otros aparatos que utilizan el método oscilométrico. Éstos últimos, que constituyen la gran mayoría de los aparatos,[4,9] analizan la onda de pulso que se produce al liberar la compresión de la arteria. Existen aparatos de mercurio y aneroides para automedida[4] cuyo uso es muy inferior a los electrónicos (debido al nivel de habilidad requerido), por lo que en adelante nos referiremos sólo a éstos últimos.

Hay aparatos que miden la PA a nivel de la arteria braquial, junto a otros que se ajustan en la muñeca o en un dedo de la mano. Los hay que utilizan un compresor eléctrico para inflar el manguito, denominados dispositivos automáticos, y otros que incorporan una perilla similar a la del esfigmomanómetro clásico (semiautomáticos). Por último, los podemos encontrar con un mecanismo de impresión de las medidas registradas y algunos también tienen capacidad de almacenar los datos de múltiples mediciones, y exportarlos después a un ordenador para su posterior análisis.

VALIDACIÓN DE LOS APARATOS DE AMPA

Ante tanta diversidad, cabe preguntarse si todos los equipos miden con suficiente precisión y exactitud la PA, o más bien, cuáles de estos aparatos muestran la validez requerida.

Dos organizaciones se han encargado de realizar protocolos de validación de dispositivos de medida de PA, tanto de AMPA como de monitorización ambulatoria de PA (MAPA): la Sociedad Británica de Hipertensión (BHS)[10] y la Asociación para el Progreso de la Instrumentación Médica (AAMI) [11]. Ambas han establecido unos estrictos criterios que han de superar estos aparatos para ser considerados válidos.

La BHS[10] los clasifica en grados de exactitud que van desde A hasta D, siendo el aparato que más se aproxima al «patrón oro» (el esfigmomanómetro de mercurio) el que obtiene el grado A, y el más alejado el que tiene grado D. Estos grados se basan en el porcentaje acumulado de medidas que se encuentran dentro de una diferencia máxima de 5, 10 o 15 mm Hg con respecto al «patrón oro». Para que un aparato de AMPA pase los criterios de la BHS debe obtener al menos un grado B. (Tabla 1).

TABLA 1

CRITERIOS DE VALIDACIÓN DE APARATOS DE MEDIDA DE LA PRESIÓN ARTERIAL DE LA BRITISH HYPERTENSION SOCIETY

	Diferencias absolutas entre el aparato evaluado y el esfigmomanómetro de mercurio (%)		
Grado	≤5 mm Hg	≤10 mm Hg	≤15 mm Hg
A	60	85	95
B	50	75	90
C	40	65	85
D	Peores que C		

Cada grado representa el porcentaje acumulado de lecturas con diferencias menores de 5, 10 y 15 mm Hg respecto al esfigmomanómetro de mercurio. Los porcentajes deben ser iguales o mayores a los expuestos para cada categoría.

La AAMI[11] exige que el 85% de las diferencias obtenidas al comparar el aparato de AMPA con el esfigmomanómetro de mercurio no sea superior a 5 mm Hg y el 95% no supere los 10 mm Hg, o la desviación estándar no sea superior a 8 mm Hg.

En ambos casos se requiere un mínimo de 85 individuos a los que se les realizarán 3 mediciones con ambos métodos, el aparato en estudio y el manómetro de mercurio.

Recientemente, la 1.ª Conferencia Internacional de Consenso para el uso de la AMPA ha propuesto un protocolo de validación reducido que requiere sólo 33 individuos.[1]

Previamente al período de validación los dispositivos de AMPA deben haber sido prevalidados. Esta fase podría obviarse si todos los aparatos superan los requisitos de certificación de la Unión Europea sobre evaluación de calidad y seguridad de equipos médicos (directiva 93/42/CEE).[1,6]

Los equipos de AMPA deberán calibrarse con una periodicidad anual, conectándolos mediante un tubo en «T» a un esfigmomanómetro de mercurio.[3,12]

Los dispositivos existentes en el mercado que hasta la fecha han pasado los criterios de la BHS[10] y de la AAMI[11] se exponen en la tabla 2.[1,8]

EFECTO DE BATA BLANCA (HIPERTENSIÓN Y FENÓMENO DE BATA BLANCA)

Un porcentaje nada despreciable de pacientes (se estima alrededor del 20-30%[13,14,15]) tiene en presencia del personal sanitario (especialmente del médico[16]) unos valores de PA superiores a los que mantiene en su ambiente habitual. Este fenómeno, denominado efecto de bata blanca[14], se atribuye a una respuesta presora del paciente provocada por el hecho de medirle la PA,[3] relacionada más con el ambiente clínico que con determinadas características psicofisiológicas del sujeto y no predecible por criterios clínicos, psicológicos o de reactividad tensional[17,18]. Se ha observado que esta circunstancia es más frecuente con PA moderadamente elevadas que en formas severas de hipertensión arterial (HTA), en mujeres y en individuos de mayor edad, y más acusada para la PA sistólica (PAS).[14]

Cuando el efecto de bata blanca es clínicamente relevante (diferencias entre PA de consulta y ambulatorias mayores de 20 mmHg de sistólica y/o 10 mmHg de diastólica), se habla de fenómeno de bata blanca (FBB)[19]. La hipertensión de bata blanca (HBB) o hipertensión clínica aislada consiste en la detección en consulta de valores de PA compatibles con HTA siendo normales fuera del ámbito sanitario[2,14].

TABLA 2
APARATOS DE AUTOMEDIDA DE PRESIÓN ARTERIAL VALIDADOS POR LA BHS Y POR LA AAMI (TOMADO DE O´BRIEN ET AL.[8])

Recomendados

	Método	Manguito	Comentario
Omrom HEM-705 CP	Oscilométrico	Braquial	
Omrom HEM-706/711	Oscilométrico	Braquial	
Omrom HEM-722 C	Oscilométrico	Braquial	Validado en ancianos
Omrom HEM-735 C	Oscilométrico	Braquial	Validado en ancianos
Omrom HEM-713 C	Oscilométrico	Braquial	
Omrom HEM-737			
Intellisense	Oscilométrico	Braquial	

Recomendación cuestionable

	Método	Manguito	Comentario
Omrom HEM-703 CP	Oscilométrico	Braquial	No se aplicaron los criterios BHS
Omrom M4	Oscilométrico	Braquial	Sólo disponible resumen del trabajo
Omrom MX2	Oscilométrico	Braquial	Sólo disponible resumen del trabajo

BHS: Sociedad Británica de Hipertensión.
AMMI: Asociación para el Progreso de la Instrumentación Médica.

La historia natural de la HBB y, por lo tanto, su pronóstico, no se conocen bien y no está claro que sea una condición benigna.[14] Estudios que analizan morbimortalidad en hipertensos de bata blanca observan un aumento de la misma respecto a los normotensos, aunque menor que en hipertensos. También se ha sugerido que podría tratarse de una condición intermedia que evolucionará posteriormente hacia una hipertensión establecida.[1,14,20]

El método de elección para diagnosticar HBB es la MAPA[2,13]: el paciente lleva consigo durante 24 horas un monitor que automáticamente realizará mediciones a intervalos prefijados. El paciente apunta la hora de acostarse y de levantarse en un diario que se le suministra al efecto. De este modo obtenemos multitud de medidas realizadas en las condiciones habituales de vida del paciente, incluyendo el período de sueño. Los datos, acumulados en la memoria del aparato, se exportan después a un ordenador, donde un programa especialmente diseñado (suministrado normalmente por el fabricante) analizará los resultados. Los pacientes con efecto de bata blanca (HBB o FBB) tendrán en consulta valores significativamente más elevados que en su domicilio.

El problema de la MAPA estriba fundamentalmente en su limitada accesibilidad[3]: son aparatos caros (alrededor de 900.000 pesetas el sistema completo), por lo que sólo se pueden encontrar, por lo general, en el nivel especializado y en contados centros de salud.

La AMPA, dado su bajo coste, surge entonces como una alternativa a la MAPA[1], si bien requiere mayor entrenamiento y colaboración por parte del paciente. Es importante recordar que sólo podremos recoger mediciones en período diurno.

Comas et al.[21] encuentran una buena correlación entre los valores de PA obtenidos mediante AMPA y MAPA en hipertensos, si bien el trabajo adolece de ciertas limitaciones (usa aparatos de AMPA sin memoria y existe un sesgo de selección). En cualquier caso sus hallazgos confirman los de otros autores[4].

Aunque una de las principales indicaciones de la AMPA es la detección de EBB (hipertensión y fenómeno de bata blanca), su utilidad real para ello está aún por aclarar. En un reciente estudio llevado a cabo por Stergiou et al[22] en 189 hipertensos, se llega a la conclusión que la AMPA no es apropiada como alternativa a la MAPA para el diagnóstico de EBB, obteniendo una sensibilidad del 57 % y una especificidad del 85 %. Otros autores[23] consiguen resultados algo mejores (sensibilidad del 84 % y especificidad del 82 %), concluyendo que la AMPA permite sospechar fenómeno de bata blanca aunque debería confirmarse mediante MAPA.

DIAGNÓSTICO DE HIPERTENSIÓN ARTERIAL

Al medir la PA con un aparato diferente al esfigmomanómetro de mercurio es razonable plantearse si podemos seguir utilizando los mismos umbrales de PA sistólica y diastólica para el diagnóstico de hipertensión, especialmente cuando se ha comprobado que los valores fuera del ámbito sanitario son menores.[1,6] La arbitrariedad del punto de corte establecido para las mediciones con el esfigmomanómetro convencional (140 mm Hg para la PAS y 90 mm Hg para la PAD) complica aun más este aspecto.

Los trabajos que se han realizado para aclarar esta cuestión han utilizado procedimientos estadísticos, sea a través de percentiles, tomando como valores umbral el percentil 95 de las automedidas realizadas en normotensos, y/o a través de sus medias obtenidas +/— 2DE, o bien mediante regresión de los valores de AMPA sobre mediciones convencionales. Para el primer método el punto de corte más aceptado es 135/85; para el segundo, 130/85. En general, y hasta que no se lleven a cabo estudios que aporten mayor información, niveles de PA ambulatoria inferiores a 135/85 mm Hg son los más aceptados como «normales».[1,3,4,6,9,14,24]

UTILIZACIÓN DE APARATOS DE AMPA

Las medidas deben realizarse en las mismas condiciones que las determinaciones con esfigmomanómetro convencional.[1] Son importantes el reposo previo y utilizar el brazo control (brazo dominante), manteniéndolo a la altura del corazón y empleando un manguito de tamaño adecuado al perímetro braquial. Deben evitarse movimientos durante la lectura.[3,12]

En los modelos semiautomáticos debe advertirse al paciente que infle el manguito 30 mm Hg por encima de la PAS esperada y que descienda lentamente para que dé tiempo a que desaparezca el efecto presor del trabajo muscular al comprimir la perilla.[7]

El modelo a utilizar debería ser oscilométrico y de manguito braquial,[4] validado por la BHS y por la AAMI. Los dispositivos de muñeca y dedo son poco exactos y no son recomendables: la flexo-extensión de la muñeca o la vasoconstricción periférica pueden afectar la medición, así como la posición del miembro respecto al corazón.[4,6,8,9] Yarows y Brook[25] encontraron suficiente exactitud en varios aparatos de muñeca y dedo, pero no utilizaron protocolos de validación internacionalmente aceptados (BHS y AAMI).

En cuanto al número de medidas a efectuar, dependerá, como es lógico, de cada paciente y del grado de control de su PA. Éste es un aspecto importante, pues se ha sugerido que la principal ventaja de la AMPA es que permite realizar un elevado número de mediciones, más que el hecho de efectuarlas en el domicilio del paciente[7]. En cualquier caso, se recomienda un mínimo de dos medidas por la mañana y dos por la noche, al menos durante tres días laborables.[1,26]

Se ha encontrado un porcentaje significativo de errores al comunicar cifras de PA por parte de los pacientes, especialmente cuando los registros son demasiado altos o bajos.[1,4,6,27] Por este motivo, se recomienda utilizar aparatos con impresora, o bien con memoria, para pasar después los datos a un ordenador y, una vez excluidas las determinaciones en consulta, calcular los valores medios de PA.

AMPA Y RIESGO CARDIOVASCULAR

La AMPA introduce dos elementos fundamentales a la hora de medir la PA: la medición efectuada en el ambiente del individuo, fuera del ámbito sanitario (por lo que obviamos el efecto de bata blanca), y las mediciones múltiples, que facilitan una mayor correlación entre los valores obtenidos y la afectación de órganos diana.[1,9] El poder predictivo de mortalidad (total y cardiovascular) es mayor que el que poseen las tomas aisladas de PA en consulta.[1,4,14] La masa ventricular izquierda se relaciona mejor con mediciones múltiples de PA realizadas con AMPA, que con lecturas clínicas aisladas, con una correlación similar a la que presenta con las cifras obtenidas mediante MAPA[9,28]. Las cifras de PA obtenidas mediante AMPA predicen también mejor la progresión de la nefropatía diabética.[4]

De este modo, la AMPA se equipara a la MAPA en cuanto a predicción de episodios cardiovasculares.[1,28]

INDICACIONES Y VENTAJAS DE LA AMPA

Las indicaciones y las ventajas de la AMPA son fundamentalmente las siguientes:

— Diagnóstico y seguimiento a largo plazo de la HBB[1,3,6,12], dado que efectúa mediciones en el ambiente habitual del paciente y que se trata de un método más accesible que la MAPA. Si se dispone de ésta, la AMPA podría utilizarse como método de cribado de HBB, confirmándose después por MAPA.

— Estudio de HTA en ancianos[1,6], donde la prescripción de medicación antihipertensiva debe ser especialmente cuidadosa, debido a la frecuencia y severidad de efectos secundarios en estos pacientes. En los ancianos, además, la PAS de consulta suele ser como media 20 mm Hg superior a la detectada fuera del contexto clínico, por lo que el uso de la AMPA podría evitar un sobrediagnóstico de hipertensión arterial sistólica aislada.

— Estudio de hipertensión resistente[1,3,6,12], ya que en ocasiones podría tratarse en realidad de pacientes con efecto de bata blanca. Las mediciones domiciliarias permiten diferenciar ambas situaciones.

— Control de PA en el embarazo[1,6]: hasta un 30% de las gestantes pueden presentar HBB. Con el uso de la AMPA se podrían evitar tratamientos e ingresos hospitalarios innecesarios.

— Control de la PA en diabéticos: las PA domiciliarias predicen mejor la progresión de la nefropatía diabética, que las tomas en consulta[1,3,6].

— Detección de episodios hipotensivos[3,12]: en especial en ancianos en tratamiento con fármacos antihipertensivos.

— Control de la PA de hipertensos en tratamiento farmacológico[3,4,6,12], aportando una mayor información que las PA en consulta sobre la respuesta terapeútica en diferentes momentos del día.

— Para mejorar la adhesión al tratamiento[1,6,9,12]. Los pacientes que se miden la PA en su domicilio o centro de trabajo se implican más en el control de su enfermedad, y, en general, se muestran más cumplidores que aquéllos controlados sólo en consulta.

— Para la realización de estudios de investigación[1,3,4,12], puesto que las tomas de PA mediante AMPA son más reproducibles que las realizadas en consulta[1], requiriéndose muestras mucho menores (en pocos individuos se realizan multitud de mediciones). También permite estimar la duración de la acción de los fármacos antihipertensivos y su efecto máximo.

— La AMPA parece reducir los costes en el manejo de la HTA[4,9,12].

LIMITACIONES E INCONVENIENTES

Las limitaciones e inconvenientes de la AMPA son:

— La mayoría de los dispositivos no se someten a los protocolos de validación y una parte importante de los que lo hacen no los superan[3,4].

— Los niveles de PA obtenidos por AMPA utilizados para definir HTA se han establecido, provisionalmente, mediante procedimientos estadísticos[3,4].

— No está bien delimitado el comportamiento de la PA medida por AMPA, MAPA y esfigmomanómetro clásico en relación con la edad, el sexo, la raza y el tratamiento recibido[4].

— No se ha demostrado el beneficio del tratamiento antihipertensivo en función de las cifras estimadas por AMPA[3].

— Está por concretar el número óptimo de mediciones a realizar[4].

— La reducción del coste en el manejo de la HTA atribuida a la AMPA, sólo se ha comprobado por ahora en Estados Unidos[4]. No se sabe si esta reducción de costes sería aplicable a otros sistemas sanitarios diferentes.

— Las automediciones son difíciles de llevar a cabo en pacientes con retinopatía diabética, enfermedad cerebrovascular, demencia o arritmias cardiacas, lo que ocasiona dependencia de familiares y allegados[3].

— En personas hipocondriacas podría provocar mayor ansiedad, ante las fluctuaciones fisiológicas de la PA durante el día[3].

— Se necesita un adiestramiento inicial y supervisión periódica por parte del personal sanitario[3].

— Podría generarse un exceso de confianza, riesgo de automedicación y olvidos por parte del personal sanitario en el control de la HTA y otros factores de riesgo[3].

— Finalmente, debemos tener presente que se trata de una técnica complementaria. Las automedidas de PA deben integrarse con las lecturas de consulta, teniendo en cuenta la posible morbilidad asociada a la HBB, condición que no detectaríamos realizando sólo automediciones en el domicilio.

En resumen, podemos concluir que existen ventajas indiscutibles en el uso de los dispositivos de AMPA, principalmente derivadas de las múltiples mediciones que se pueden realizar en diferentes situaciones. Aunque se pueden encontrar multitud de aparatos en el mercado, sólo algunos han pasado los protocolos exigibles para su validación, siendo en todos los casos equipos de manguito braquial. El médico de familia debe acostumbrarse al uso de estos equipos, para aconsejar e instruir correctamente a los pacientes en su utilización, interpretando adecuadamente los resultados de las mediciones.

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BRAUN

Blood Pressure Measurement

The following is a detailed description of the main techniques used for measuring human blood pressure. Possible sources of error and influences on measurement are discussed, with an emphasis on the oscillometric method and how Braun has adapted it to improve measurement results.

Influence of the measurement site on blood pressure values

Many people think that the blood pressure in the aorta is equivalent to that in the brachial artery. However, there are differences between the central aortic blood pressure and the invasively obtained peripheral blood pressure. In general, the more peripheral the measurement site, the higher the systolic blood pressure and the greater the pulse pressure, i.e. the difference between the systolic and diastolic pressure [1].

The differences between invasively obtained aortic and brachial (upper arm) systolic pressure values in young, healthy adults are usually about 5 mm Hg [2]. In elderly people, these differences can rise to 20 mm Hg [2]. The pulse pressure in young people is up to 50% greater in the brachial artery than in the aorta [2]. The pulse pressure in the elderly is approximately 5–20 mm Hg greater in the brachial artery [2], while the diastolic blood pressure is about the same in both the aorta and brachial artery [3], [2], differing by only about 1 mm Hg.

There are possible pressure differences between the brachial artery and the radial artery. In general, these differences are small, in the range of 1–4 mm Hg [2]. However, in patients with arterial abnormalities (stenosis, atherosclerosis, etc.), these differences can vary greatly in both directions. With a stenosis proximal to the measurement site, the blood pressure is significantly lowered according to the degree of stenosis.

Invasive blood pressure measurement

In order to obtain blood pressure values invasively, a catheter (a sterile, flexible tube with a diameter of about 0.66–2 mm) must be inserted into an artery. This procedure is performed under local anesthetic using aseptic methods, as in an operation. This “gold standard” of blood pressure measurement is used almost exclusively in diagnostic procedures such as heart catheterization, or for monitoring patients during operations and in critical care. The pressure transducer is usually outside the patient's body and connected to the fluid-filled catheter. The pressure waves are transmitted to the transducer via the saline solution in the catheter. As a result, the measurement is sensitive to the elastic properties of, and friction in the catheter, which cause damping of the signal.

A small air bubble in the catheter can lead to very low pressure signals. Moreover, the entire system must have a resonance frequency of above 16 Hz in order to avoid a marked distortion of the intra-arterial pressure signal.
There is a difference of 2–3 mm Hg between systolic pressure recordings with the catheter opening perpendicular to the direction of the bloodstream (recording “lateral pressure” only) and recordings with the catheter opening directly against the direction of the bloodstream (adding “impact pressure” to the lateral pressure).
Minor blood clotting at the tip of the catheter is a further source of error, damping the signal. A visual inspection will usually reveal the problem, which can be solved by flushing the system, without danger to the patient.
If the catheter is positioned inside the artery in constant contact with the wall of the vessel, early and pronounced blood clotting will result, disturbing the signal. The longer a catheter is in the artery, the greater the likelihood of a disturbed signal. A severe atherosclerosis in the vessel may also obstruct the tip of the catheter if it is positioned too close to a plaque.

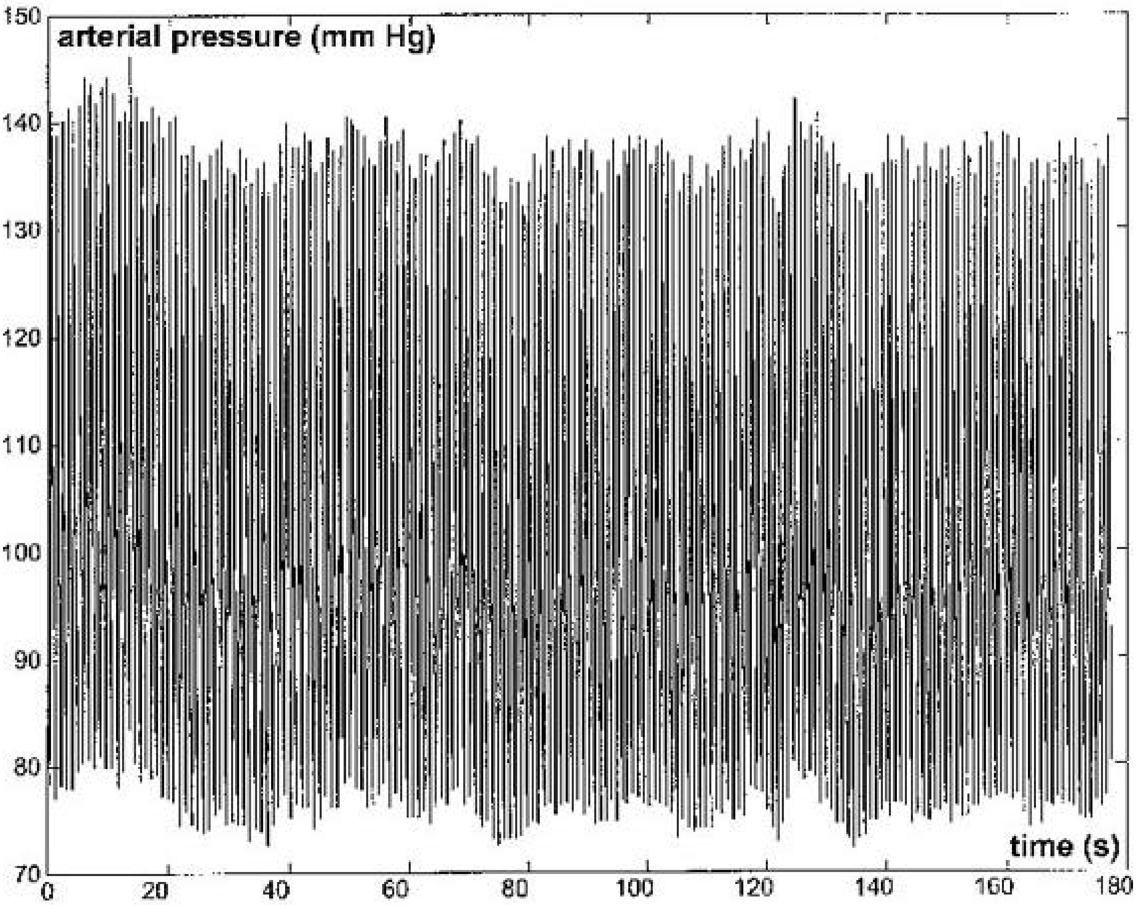

Figure 1: Invasively measured blood pressure.

The main causes of error in intra-arterial measurements, as they have been described above, are systematic. The statistical errors of the transducers and the electronics used are, by law, less than 1 mm Hg and negligible. In short, the intra-arterial signal is correct to within 1 mm Hg, or otherwise completely unreliable. Unfortunately, the determination of reliability is not always easy.

Auscultatory blood pressure measurement

The non-invasive, quantitative measurement of blood pressure was introduced by Riva-Rocci in 1896, and refined by the auscultatory method of Korotkoff in 1905.

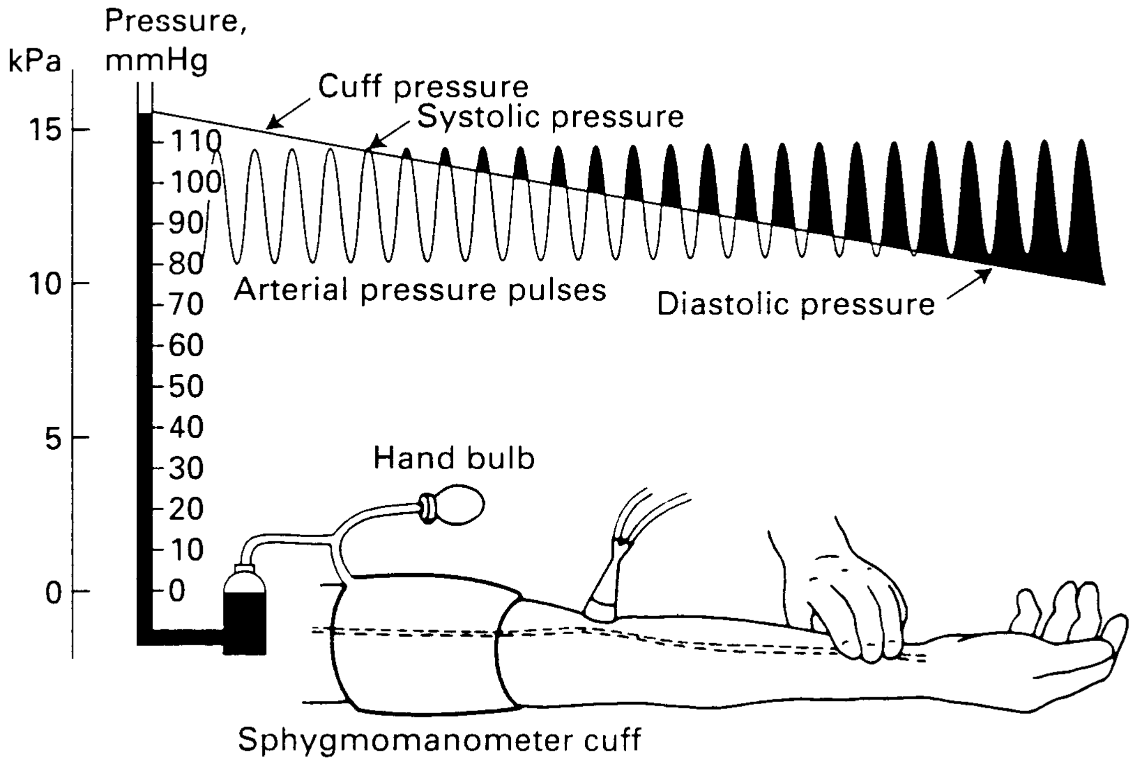

Figure 2: The principle of auscultatory blood pressure measurement.

The recommended procedure today is as follows:
The patient must have been at rest for at least five minutes. The upper arm must be positioned level with the heart, i.e. next to the chest.

1. Wrap the appropriately sized cuff snugly around the bare upper arm, with the lower edge about 1.5 cm above the inner skin fold at the elbow. The cuff must be centered level with the heart.
2. Quickly inflate the cuff to 100 mm Hg and more, while palpating the radial pulse. Inflate to about 20 mm Hg higher than the pressure at which the radial pulse is no longer palpable.
3. Place the stethoscope over the brachial/cubital artery below the cuff.
4. Deflate the cuff at a rate of 2–3 mm Hg/s. Auscultate for Korotkoff sounds in order to determine systolic pressure with the manometer upon the appearance of the first Korotkoff sound and diastolic pressure at the *end* of phase 4 Korotkoff sounds, i.e. the onset of silence. Then, quickly deflate the cuff's bladder.

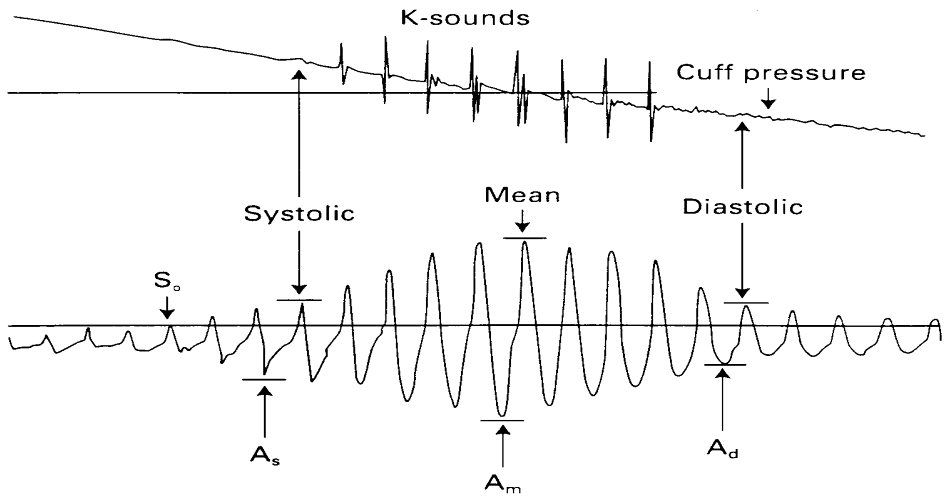

Figure 3: Korotkoff sounds and oscillations in the cuff.

It should be noted that the systolic and diastolic blood pressures do not correspond to the same heartbeat.
The diastole is measured 10–20 seconds after the systole. The physiological variation of blood pressure depicted in Figure 1 demonstrates the variation in auscultatory readings over a range of 10 mm Hg. Remember, the changing readings are not due to the person who is doing the measurement, but rather to principal variation in the subject and the limitations of the method.

The repeatability of this method is greater for systolic values than for diastolic pressure, since it is easier to detect the onset of quite marked sounds (about 40–600 Hz) than it is to judge the end of fading sounds at diastole. The error of trained auscultation observers corresponds to a standard deviation of about 1–3 mm Hg, as compared with a standard deviation of less than 1 mm Hg for invasive measurements.

Differences between auscultation and invasive blood pressure measurement

Numerous authors [1], [2], [4], [5], [6], [7] have reported differences between invasive and non-invasive blood pressure measurements. At the brachial artery (upper arm), overestimation of the diastolic pressure of up to 20 mm Hg has been reported in a large number of hypertensive patients, using both auscultation and oscillometry [4], [7]. The reported ranges are between 0.8 and 18 mm Hg, mostly around 4mm Hg. Case reports describe even larger overestimations [7]. Today, the American Heart Association recommends using the cessation of Korotkoff sounds (end of phase 4) for determining diastolic pressure. This pressure is somewhat lower than the invasively obtained diastolic pressure in healthy patients. The error in hypertensive patients remains a problem.
The systolic pressure is often underestimated by up to 5 mm Hg, in some cases even more. More important is the problem of “pseudohypertension” [7] in the elderly, with overestimation of systolic pressure of up to 30 mm Hg [8]. Hence, in some people,

the non-invasively obtained blood pressure values do not represent a direct equivalent of invasively obtained values. On the other hand, invasive blood pressure measurement is only available at special medical sites or during certain diagnostic procedures.
In clinical practice, it is assumed that blood pressure is approximately equal at all measurement sites and at the central arteries. Moreover, there is only little concern in clinical medicine about differences between invasive and non-invasive blood pressure values.

General description of the oscillometric blood pressure monitor

An introduction to the field of non-invasive blood pressure monitoring using oscillometric devices can be found in [9], [10], [11], and [12].

As in auscultatory measurement, an artery must be compressed over a sufficiently long segment, usually by means of an inflatable cuff. Once the artery wall's transmural pressure (pressure difference between the inside and outside of the artery) is zero, the cuff pressure corresponds to the intra-arterial blood pressure. Since this pressure varies with time, oscillations of the cuff pressure will occur. The amplitude of these oscillations is related to both the cuff pressure and blood pressure.

There are several factors that oppose the applied pressure of the cuff:

- Hydrostatic pressure difference between the cuff and heart levels
- Compressible tissues, including veins
- Non-compressible tissues, e.g. bone
- Stiffness of the arterial wall
- The intra-arterial blood pressure, which varies with time.

The aim here is to determine the intra-arterial blood pressure. It is known that the effect of compressible and non-compressible tissues influences the choice of cuff, which must be large enough to compress an arterial segment of sufficient length. Other aspects of the tissues' opposing forces are usually negligible, except in the blood pressure measurement of severely obese patients.
The hydrostatic pressure difference plays an important role in blood pressure measurement at the wrist, since not holding the cuff at heart level changes the blood pressure. You can notice for example a positive difference if the wrist is lower and a negative one if the wrist is higher than heartlevel. To ensure the proper position of the forearm and wrist, blood pressure monitors of the Braun BP 2000 range feature an inclination sensor that gives the user feedback on the correct position. The suggested user posture is seated upright with the arms crossed. The forearm with the device is then raised to the angle indicated by the inclination sensor of the BP2000, as shown in the display.

The arterial wall stiffness is dependent on its thickness, diameter, and composition, which change with age and as a result of disease. This is one reason for many of the differences between intra-arterial and non-invasive blood pressure measurements.

A typical measurement cycle of an oscillometric device is shown in Figure 4.

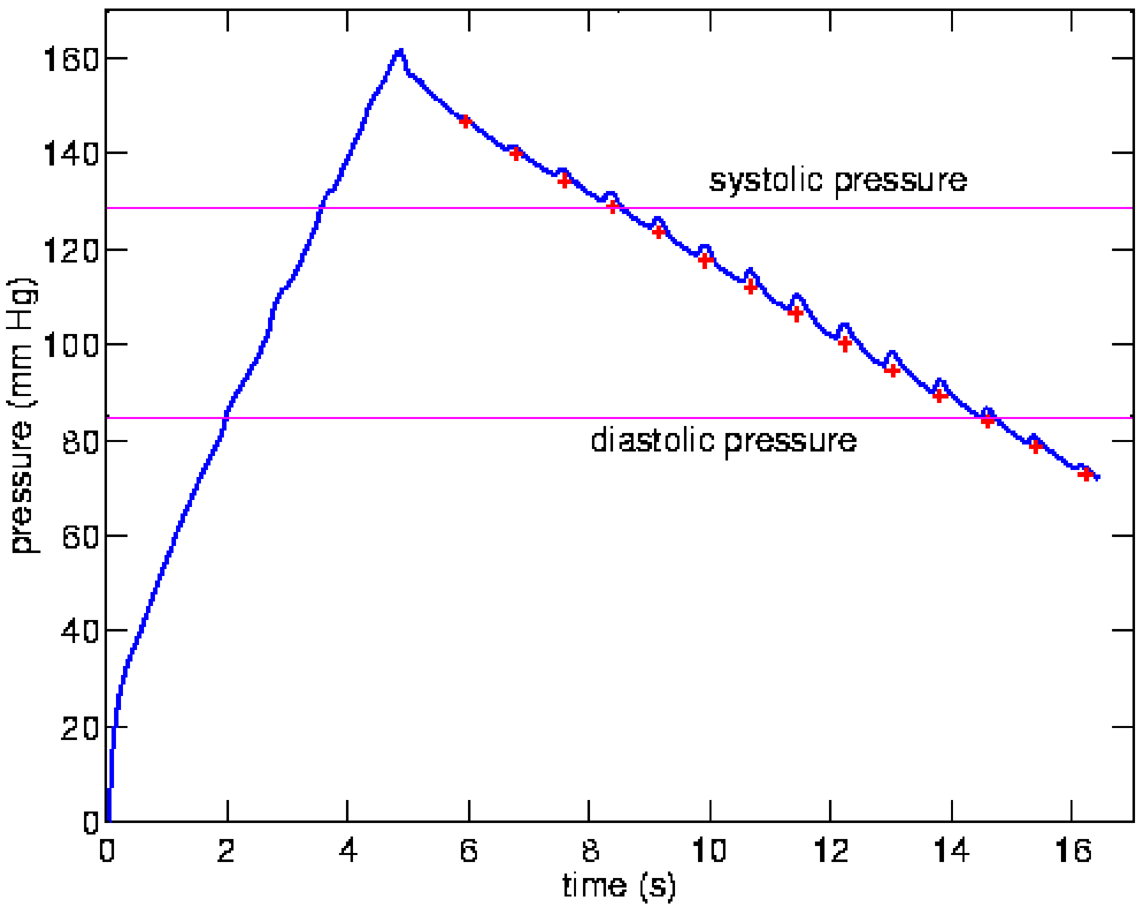

Figure 4: Typical measurement cycle of an oscillometric blood pressure monitor. The cuff is quickly inflated to a certain pressure, as shown by the pressure-time curve in the diagram. Then, the cuff is slowly deflated and arterial pulsations are detected (red crosses). For orientation, systolic and diastolic blood pressures are indicated by horizontal lines.

With inflation of the cuff, the external pressure on the artery rises, and hence the artery is increasingly compressed. At pressures exceeding the systolic blood pressure, the artery will be occluded. Only blood pulsations that are closely proximal to the occluded segment will be transmitted to the edge of the cuff, causing small oscillations in the cuff pressure. However, when the cuff is slowly deflated, the cuff pressure, and hence the external pressure on the artery will be lowered to that of the systolic blood pressure. Now, the artery is no longer continuously occluded. At systolic blood pressure, small amounts of blood pass through the compressed artery segment and cause changes in the artery volume, conducted to the cuff. This leads to pressure oscillations in the cuff. These oscillations increase with lower cuff pressure values, as more blood passes through the compressed artery. The maximum oscillation amplitude is reached around the mean intra-arterial blood pressure.

Here, the amplitude is about 1–10 mm Hg. As the falling cuff pressure approaches the diastolic blood pressure, the oscillation amplitude decreases and remains at a low level below diastolic pressure (see Figure 5)

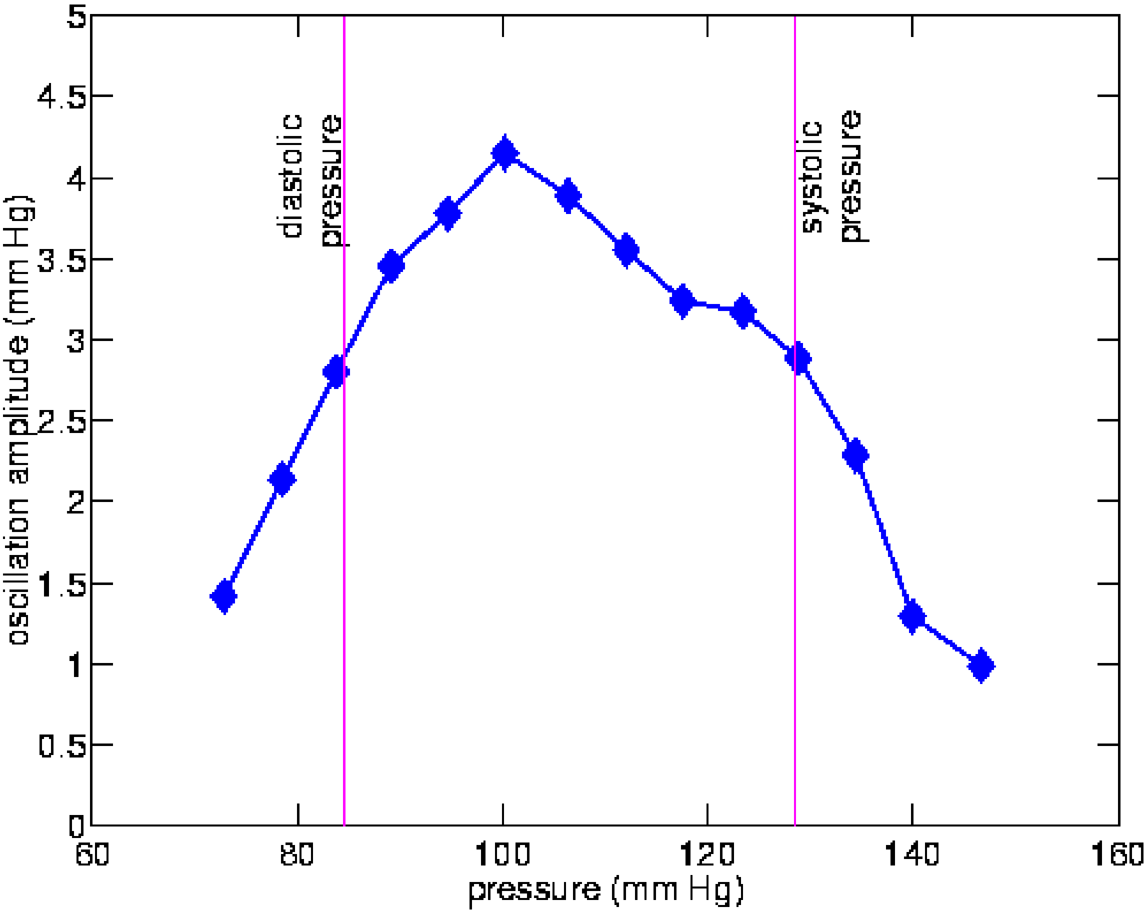

Figure 5: The amplitude of the cuff pressure oscillations is dependent on the cuff pressure itself. This relation is associated with the blood pressure, as shown by the vertical lines. The diamonds in the diagram correspond to the oscillations depicted in Figure 4.

The systolic, mean, and diastolic blood pressures can be characterized and measured by the cuff pressure at different oscillation amplitudes. This is usually done by means of a pressure transducer to measure the cuff pressure, a signal amplifier, the control unit with an algorithm to calculate blood pressure from the recorded oscillations, and a display for the result. The major components of an oscillometric blood pressure monitor are shown in Figure 6.

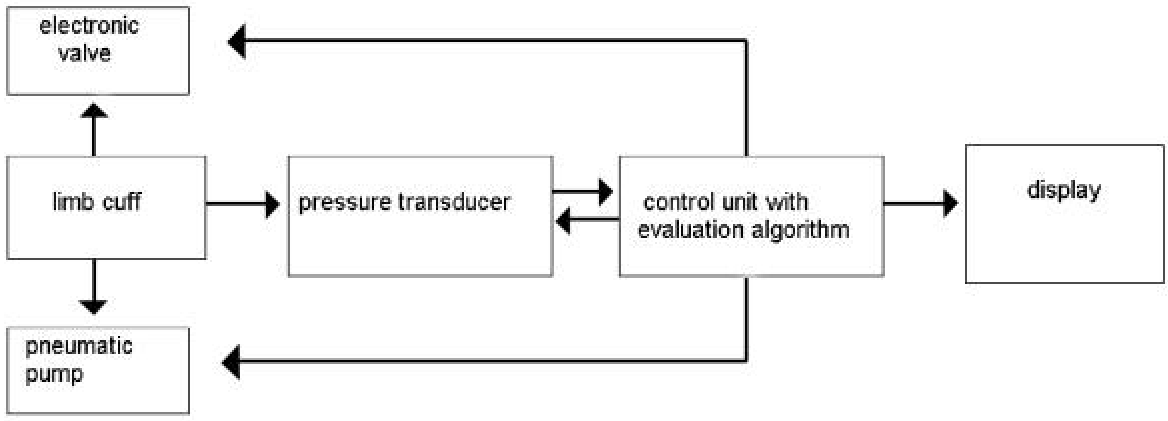

Figure 6: Major components of oscillometric blood pressure monitors.

There are several methods of calculating the blood pressure values from the measured oscillations. All these need to determine the so-called “envelope of amplitudes” from the measured oscillation amplitudes. On the basis of this curve, the blood pressure is calculated with an algorithm and experimentally obtained coefficients.

The Braun PrecisionSensor Device

The Braun PrecisionSensor uses the oscillometric method to determine blood pressure. The basic data for the blood pressure calculation are taken from the so-called “envelope curve” shown in Figure 5, giving the relation between cuff pressure and arterial pulsation.

First-generation oscillometric devices used fixed amplitude ratios to determine the systolic and diastolic pressure from the envelope curve. This was done, more or less, by determining the maximum amplitude of the envelope, calculating the systolic and diastolic amplitudes from fixed ratios, and reading off the systolic and diastolic pressure from the envelope curve as those pressures whereby the pulsating amplitude was the calculated systolic and diastolic one, respectively.

A great number of clinical studies during the course of the device’s development, and also the literature [9] showed that the fixed ratios described above are inadequate for a sufficiently accurate determination of blood pressure over all pressure ranges. Put more simply, the blood pressure to be determined is dependent on more than just two single points of the envelope curve. The Braun PrecisionSensor makes unique use of this finding for its blood pressure calculating algorithm.

Another point worth mentioning is the Braun PrecisionSensor’s adaptable inflation and deflation control. As mentioned above, the most important input for the blood pressure calculation is the envelope curve, shown in Figure 5. From this diagram, it is easy to conclude that only a certain number of pulses are necessary, i.e. heartbeats around the maximal pulsation. Excessive (with respect to the blood pressure) or inadequate inflation of the cuff yields an envelope curve that contains more or less data points than necessary. Excessive cuff inflation leads to patient discomfort and prolongs the measurement procedure unduly. Inadequate cuff inflation leads to a re-inflation of the device that often stresses the user, in turn influencing the blood pressure. Hence, this re-inflation regularly occurs in hypertensive users. The Braun PrecisionSensor has a “smart” inflation control that estimates the blood pressure during the inflation phase and stops inflation at an appropriate pressure, so that re-inflation of the cuff is very rare.

Another lesson to be learned from the envelope curve is that only a certain number of heartbeats need to be detected by the device. This means that the measurement time should be heart-rate dependent. At a higher heart rate, the necessary number of pulsations occurs over a shorter time interval, and vice versa. Hence, the Braun PrecisionSensor estimates the heart rate during inflation and controls the deflation process according to this estimate. Normally, the measurement time must be adapted to the slowest specified heart rate measured by the device, meaning that the total measurement time is unnecessarily long.

The dependence of the measurement cycle on blood pressure and heart rate is illustrated in Figure 7.

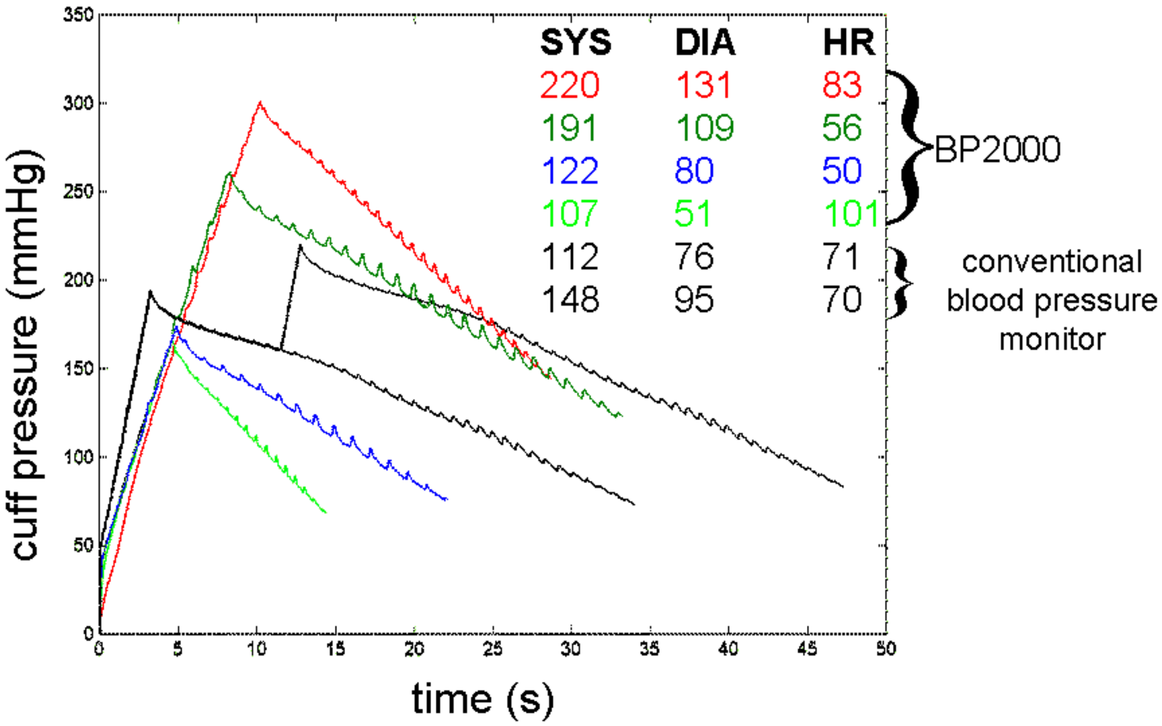

Figure 7: Comparison of measument cycles between monitors of the Braun BP2000 range (colored lines) and conventional blood pressure monitors (black lines).

Mechanical design

The oscillometric blood pressure measurement device consists of the components shown in Figure 6. The size of the cuff depends on where it is to be applied (upper arm, wrist, or finger). The recommended ratio of the cuff's air chamber width to limb circumference is 0.4, while the length to circumference ratio should be 0.8. However, it must be mentioned that the above ratios are based on experience with upper arm devices. At the wrist, for example, they may be inapplicable, since the position of the respective arteries (arteriae radialis and ulnaris) relative to the skin where the cuff is applied differs from that at the upper arm (arteria brachialis). At the upper arm, the artery is surrounded by far more damping tissue than at the wrist. The cuff consists of an inflatable PVC or polyurethane air chamber and surrounding fabric, with a Velcro securing strap.

The measurement site also determines the size of the pneumatic pump for inflating and deflating the cuff, and the housing for the electrical and mechanical components. In a wrist or finger device, the housing is directly attached to the cuff, while in an upper arm measurement device it is connected to the cuff by a long tube.

Differences between results from auscultation and the oscillometric method

As demonstrated in Figure 3, the determination of the systolic, and especially the diastolic values from the oscillations must be adapted to either the somewhat different auscultation or the intra-arterial measurement. The limits of agreement are defined by guidelines. Since the determination of blood pressure using the oscillometric method is dependent on calculations, and not just measurements, the calculations must be adapted to fit the values of the chosen reference method.

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MEDICAL DEVICES AGENCY

DEVICE

BULLETIN

Blood Pressure Measurement Devices – Mercury and Non-mercury

MDA DB2000(03)
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CONTENTS

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MDA wishes to thank all those who have contributed to this Device Bulletin, in particular Prof. Eoin O'Brien, Dr. Philip Bickford Smith and Prof. Alan Murray.

1. SCOPE

The purpose of this document is to provide information and guidance to all involved with the use, purchase and management of non-invasive blood pressure measurement devices. This document reviews the current situation regarding the use of mercury, and the issues associated with electronic blood pressure measuring devices, which should ensure the most appropriate technology is selected for use.

2. SUMMARY

The measurement of blood pressure is important in the monitoring of a wide range of clinical conditions. The mercury sphygmomanometer is currently seen as the "gold standard" and is often used as a reference for determining the accuracy of automated devices. However, such devices are not without problems and their long-term future is uncertain due to a number of environmental concerns.

Although at present no ban has been imposed on the use of medical devices containing mercury in the UK, it is recommended that consideration is given to the selection of mercury-free products when the opportunity arises.

The automatic-cycling non-invasive blood pressure (NIBP) monitor, although designed for clinical use, is an expensive alternative. However, provided that accuracy can be assured, it may have a useful role throughout a healthcare facility.

The low-cost automated NIBP device, although originally designed for home use, is now being increasingly purchased for clinical practice, particularly those devices that have been validated against clinical trial protocols. It is expected that in time, the reliability of these products will improve, leading to an increase in user confidence and a further reduction in the use of the mercury sphygmomanometer.

It is important that health service personnel involved in purchasing or replacing blood pressure measuring devices seek and take into account the views of clinical and technical staff; the pros and cons of the different devices; and ensure that these products deliver the performance required for the optimal management of the patient conditions being investigated.

3. CURRENT POSITION OF MERCURY DEVICES IN THE UK AND EUROPE

Mercury-in-glass thermometers and mercury sphygmomanometers have served the medical profession well over the last 100 years. However, environmental concerns regarding mercury mean the long-term future for these devices is now uncertain. These concerns have led to the imposition of bans in some European countries.

Although at present no ban has been imposed on the use of medical devices containing mercury in the UK, it is possible that this may change in the future. The introduction of the Control Of Substances Hazardous to Health (COSHH) Regulations has resulted in a decline in the use of these medical devices. It is therefore recommended that consideration is given to the selection of mercury-free products when the opportunity arises.

4. BLOOD PRESSURE MEASUREMENT EQUIPMENT AVAILABLE

- Mercury Sphygmomanometer - This includes a mercury manometer, an upper arm cuff, a hand inflation bulb with a pressure control valve and requires the use of a stethoscope to listen to the Korotkoff sounds. Relies on the auscultatory technique.

- Aneroid Sphygmomanometer - As for a mercury sphygmomanometer, except an aneroid gauge replaces the mercury manometer. The aneroid gauge may be desk mounted or attached to the hand bulb. Relies on the auscultatory technique.

- Semi-automated Device - This includes an electronic monitor with a pressure sensor, a digital display, an upper arm cuff and a hand bulb. The pressure is raised manually using the hand bulb. The device automatically deflates the cuff and displays the systolic and diastolic values. Pulse rate may also be displayed. Battery powered. Uses the oscillometric technique.

- Automated Device - This includes an electronic monitor with a pressure sensor, a digital display and an upper arm cuff. An electrically driven pump raises the pressure in the cuff. Devices may have a user-adjustable set inflation pressure or they will automatically inflate to the appropriate level, about 30 mmHg above the predicted systolic reading. On operation of the start button the device automatically inflates and deflates the cuff and displays the systolic and diastolic values. Pulse rate may also be displayed. Devices may also have a memory facility that stores the last measurement or up to 10 or more previous readings. Battery powered. Uses the oscillometric technique.

- Wrist Device - This includes an electronic monitor with a pressure sensor, an electrically driven pump and a wrist cuff, or the device itself may be attached to the wrist. Function is similar to the automated device above. Battery powered. Uses the oscillometric technique.

- Finger Device - This includes an electronic monitor and a finger cuff, or the device itself may be attached to the finger. Generally battery powered. Uses oscillometric, pulse-wave or plethysmographic methods.

- Automatic-cycling Non-Invasive Blood Pressure (NIBP) Monitor – This is a more sophisticated version of the automated device above, with the addition of an automatic-cycling facility to record the patient's blood pressure at set time intervals. There may also be an option to measure temperature or SpO_2. Alarm limits can usually be set to alert nursing staff when one or more patient functions have exceeded the limits. Mains and battery powered. Uses the oscillometric technique.

- Ambulatory Blood Pressure Monitor – This includes an upper arm cuff and an electronic monitor with a pressure sensor and an electrically driven pump that attaches to the patient's belt. The unit is programmed to record the patient's blood pressure over a 24-hour period during normal activities and stores the data for future analysis. Battery powered. Uses auscultatory and oscillometric techniques.

The majority of non-invasive automated blood pressure measuring devices currently available use the oscillometric method.

The oscillometric method relies on detection of variations in pressure oscillations due to arterial wall movement beneath an occluding cuff. Empirically derived algorithms are employed, which calculate systolic and diastolic blood pressure.

Manufacturers develop their own algorithms by studying a population group and may validate the stated accuracy by performing a clinical trial in accordance with one of the protocols referenced in Section 8.2.2. The American and German protocols allow validation of the test device against either intra-arterial measurements or non-invasive measurements. The British Hypertension Society protocol only specifies non-invasive methods, i.e. comparison with a mercury sphygmomanometer.

There are other methods of blood pressure measurement, but these are not commonly available. They may include palpatory, infrasound, ultrasound, volume oscillometric, vascular unloading, arterial tonometry, pulse-wave velocity and plethysmographic methods.

Generic types of equipment available

Equipment	Advantages	Disadvantages
Mercury Sphygmomanometer Price £35 to £45	"Gold standard", transportable, well understood by users, can be used on most patients.	Contains toxic substance leading to maintenance problems, although safe in normal use. Can be prone to observer bias.
Aneroid Sphygmomanometer Price £25 to £55	Mercury-free, easily transported, well understood by users, easy to check calibration, can be used on most patients.	Can be prone to observer bias. Wear and mechanical shock to mechanism may result in incorrect readings. Requires regular calibration check.
Semi-automated and Automated Device Price £50 to £140.	Mercury-free, lightweight, compact, portable, easy to use, no observer bias.	Originally designed for home use, and may not be suitable for all patients, particularly those with arrhythmias. May be difficult to calibrate. Some cuffs cannot be washed or decontaminated.
Wrist Device Price £80 to £120	As above, with increased patient comfort.	As above. Readings are dependent on the relative positioning of the wrist to the heart.
Finger Device Price £100 to £120	As above.	As above. May not be suitable for patients with narrow or cold fingers.
Automatic-cycling Non-Invasive Blood Pressure Monitor Price £2,000 to £3,000.	Mercury-free, no observer bias, transportable, easy to use, designed for clinical use, may have motion artefact rejection.	Cost is likely to restrict acceptability as a direct replacement for the mercury sphygmomanometer for all applications.
Ambulatory Blood Pressure Monitor Price £1,000 to £2,000	Mercury-free, lightweight, compact, designed for clinical use, records 24-hour blood pressure trend.	Cost and function is likely to restrict acceptability as a direct replacement for the mercury sphygmomanometer for all applications.

5. SOURCES OF ERROR AND OTHER ISSUES

Manual

Manual techniques may suffer from observer bias. Differences in auditory acuity between observers may lead to consistent bias. Digit preference is common, with observers recording a disproportionate number of readings ending in five or zero. The observer may be influenced by the knowledge they have of the patient, such as earlier readings, effect of drug therapy, gender, age, race and weight.

However, formal training in blood pressure measurement can improve this situation, and the observer may obtain additional useful information about the general health of the patient, such as the regularity and strength of the pulse, skin condition and any tremors. Concern has been expressed that the skills for manual techniques may be lost by those clinical staff using automated devices.

Automated

Users should be aware that for patients experiencing muscle tremors, abnormal heart rhythms, weak pulse or low blood pressure due to shock, some automated blood pressure devices may fail to obtain a reading or may give unreliable results.

Differences in blood pressure readings can occur between products validated by reference to intra-arterial measurements and with those validated by non-invasive measurements.

Manual and automated

Incorrect cuff size is a major source of error for both automated blood pressure measuring devices and mechanical sphygmomanometers. An under-sized cuff tends to over-estimate blood pressure, while an over-sized cuff may under-estimate.

The blood pressure recorded using either manual or automated techniques may be influenced by behavioural factors that are related to the effects of the observer on the patient, such as "white-coat hypertension".

Other problems such as ulnar nerve palsy and venous haemostasis, can be caused by both automated blood pressure measuring devices and mechanical sphygmomanometers and depend on factors such as cuff placement, pressure and duration of inflation.

6. PURCHASE, TRAINING AND MAINTENANCE

Staff responsible for purchasing should take into account any relevant local policy, and ensure that the product meets the requirements of clinical staff and the accuracy is adequate for the clinical situation. Relevant information should be obtained from the manufacturer before purchase, including standards complied with, manuals available, warranty details, availability of training for users, and maintenance contracts. It is also important to estimate total costs, including training, consumables and maintenance.

Purchasers will be aware that blood pressure monitors for clinical use should be CE marked to show compliance with the Medical Devices Directive 93/42/EEC. This CE mark will be accompanied by the number of the Notified Body involved in the conformity assessment. However, some blood pressure monitors are supplied as an aid to exercise or diet programmes and may not be classified as medical devices. These may be CE marked against another Directive, such as EMC 89/336/EEC and are not recommended for clinical use.

When new medical devices are introduced it is important that staff are trained to ensure they are aware of the equipment’s limitations and can recognise artefacts. General advice on the selection, purchasing, maintenance and the need for user training are given in Device Bulletin MDA DB 9801.

All blood pressure measuring equipment should be regularly maintained and calibrated in accordance with the manufacturer’s instructions. However, it should be noted that those originally designed for home-use may be difficult to calibrate without returning to the supplier.

7. MERCURY ISSUES

Environmental concerns arise from the fact that once mercury is released into the environment it can accumulate and possibly contaminate the food chain. Direct exposure to mercury is also a health risk via inhalation of vapour and absorption through the skin.

The Health and Safety Executive (HSE) first issued the Regulations for the Control of Substances Hazardous to Health COSHH in 1988 (last updated in 1999). They have also produced several guidance documents in order to protect personnel and limit the amount of mercury reaching the environment (EH 17 & MS 12). Occupational Exposure Limits are now contained within EH40/99.

The COSHH Regulations provide a comprehensive and systematic approach to the control of hazardous substances at work and require employers to: (a) assess risks to health arising from exposure to hazardous substances; (b) prevent or adequately control exposure; (c) ensure control measures are used, maintained, examined and tested; (d) in some instances monitor exposure and carry out appropriate health surveillance; (e) inform, instruct and train employees.

For medical devices containing mercury the question needs to be asked, “are these products needed?” If the answer is yes, then control measures should be implemented and staff should be trained to ensure safe handling:

- during normal use and storage;
- in the event of a mercury spillage;
- during maintenance of mercury sphygmomanometers, if performed in-house;
- in the event of mercury disposal or when a complete instrument is discarded.

This can result in extra costs associated with the use of devices containing mercury, when compared with non-mercury types.

In a particular example a hospital’s maintenance laboratory was closed after a safety check revealed that the mercury vapour present exceeded the occupational exposure limit of 0.025 mg/m^3 (EH40/99). This resulted in a decision being made to replace mercury sphygmomanometers throughout the hospital.

8. BIBLIOGRAPHY

8.1 Health and Safety Executive documents (available from HMS0)

a) EH 17 (Revised) Mercury and its inorganic divalent compounds 1996.
b) MS12 (Revised) Mercury – medical guidance notes 1996.
c) Control of Substances Hazardous to Health Regulations 1999. (General COSHH and Carcinogens and Biological agents Approved Codes Of Practice.)
d) EH40/99 Occupational Exposure Limits, 1999.

8.2 Standards (available from BSI)

a) EN 60601-1 Medical Electrical Equipment, General requirements for safety.
b) EN 60601-1-2 Medical Electrical Equipment, Electromagnetic compatibility.
c) EN 60601-2-30 Medical Electrical Equipment, Particular requirements for the safety of automatic cycling indirect blood pressure monitoring equipment.
d) EN 1060-1 Non-invasive sphygmomanometers, General requirements.
e) EN 1060-2 Non-invasive sphygmomanometers, Supplementary requirements for mechanical sphygmomanometers.
f) EN 1060-3 Non-invasive sphygmomanometers, Supplementary requirements for electro-mechanical blood pressure measuring systems.

8.2.1 Accuracy

a) EN 1060-1 states that the limit of error of the cuff pressure indication shall be ±3 mmHg.
b) EN 1060-3 states the overall system accuracy values shall apply: maximum mean error of measurement ±5 mmHg, maximum experimental standard deviation 8 mmHg.

8.2.2 Clinical trial protocols

EN 1060-3 Annex A recommends a clinical investigation to demonstrate compliance and refers to three protocols.

a) The British Hypertension Society protocol for the evaluation of blood pressure measuring devices. Journal of Hypertension 1993, 11 (Suppl 2): S43-S62, O'Brien E. et al.
b) E DIN 58130 : 1995, Non-invasive sphygmomanometers - Clinical investigation.
c) ANSI/AAMI SP10, American National Standard for electronic or automated sphygmomanometer 1992 (Currently under revision).

8.3 MDA Publications

Device Bulletin MDA DB 1999 (03) October 1999 – MDA warning notices issued before 1995, section 8.2 Mercury contamination of baby incubators: The need for vigilance SAB (93) 41.

Device Bulletin MDA DB9801 January 1998 – Medical Device and Equipment Management for Hospital and Community-based Organisations.

Device Bulletin MDA DB9801 Supplement 1, December 1999 – Checks and tests for newly-delivered medical devices.

Safety Notice June 1998, SN 9822 – Mercury Sphygmomanometer: Yamasu desk models UN600 and UN605P, mercury leakage and possible sluggish performance.

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Medical Devices Agency
An Executive Agency of the Department of Health

Shyam Rithalia, et. al.. "Blood Pressure Measurement."

Blood Pressure Measurement

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75.1 Introduction

Blood pressure measurements have been part of the basic clinical examination since the earliest days of modern medicine. The origin of blood pressure is the pumping action of the heart, and its value depends on the relationship between cardiac output and peripheral resistance. Therefore, blood pressure is considered as one of the most important physiological variables with which to assess cardiovascular hemodynamics. Venous blood pressure is determined by vascular tone, blood volume, cardiac output, and the force of contraction of the chambers of the right side of the heart. Since venous blood pressure must be obtained invasively, the term *blood pressure* most commonly refers to arterial blood pressure, which is the pressure exerted on the arterial walls when blood flows through the arteries. The highest value of pressure, which occurs when the heart contracts and ejects blood to the arteries, is called the systolic pressure (SP). The diastolic pressure (DP) represents the lowest value occurring between the ejections of blood from the heart. Pulse pressure (PP) is the difference between SP and DP, i.e., PP = SP – DP. The period from the end of one heart contraction to the end of the next is called the cardiac cycle. Mean pressure (MP) is the average pressure during a cardiac cycle.

Mathematically, MP can be decided by integrating the blood pressure over time. When only SP and DP are available, MP is often estimated by an empirical formula:

$$MP \approx DP + PP/3 \tag{75.1}$$

Note that this formula can be very inaccurate in some extreme situations. Although SP and DP are most often measured in the clinical setting, MP has particular importance in some situations, because it is the driving force of peripheral perfusion. SP and DP can vary significantly throughout the arterial system whereas MP is almost uniform in normal situations.

The values of blood pressure vary significantly during the course of 24 h according to an individual's activity [1]. Basically, three factors, namely, the diameter of the arteries, the cardiac output, and the state or quantity of blood, are mainly responsible for the blood pressure level. When the tone increases in the muscular arterial walls so that they narrow or become less compliant, the pressure becomes higher than normal. Unfortunately, increased blood pressure does not ensure proper tissue perfusion, and in some instances, such as certain types of shock, blood pressure may seem appropriate when peripheral tissue perfusion has all but stopped. Nevertheless, observation or monitoring of blood pressures affords dynamic tracking of pathology and physiology affecting the cardiovascular system. This system in turn has profound effects on the other organs of the body.

75.2 Measurement Techniques

The basis of any physiological measurement is the biological signal, which is first sensed and transduced or converted from one form of energy to another. The signal is then conditioned, processed, and amplified. Subsequently, it is displayed, recorded, or transmitted (in some ambulatory monitoring situations). Blood pressure sensors often detect mechanical signals, such as blood pressure waves, to convert them into electric signals for further processing or transmission. They work on a variety of principles, for example, resistance, inductance, and capacitance. For accurate and reliable measurements a sensor should have good sensitivity, linearity, and stability [2].

75.3 Indirect Blood Pressure Measurement

Indirect measurement is often called noninvasive measurement because the body is not entered in the process. The upper arm, containing the brachial artery, is the most common site for indirect measurement because of its closeness to the heart and convenience of measurement, although many other sites may have been used, such as forearm or radial artery, finger, etc. Distal sites such as the wrist, although convenient to use, may give much higher systolic pressure than brachial or central sites as a result of the phenomena of impedance mismatch and reflective waves [3]. An occlusive cuff is normally placed over the upper arm and is inflated to a pressure greater than the systolic blood pressure. The cuff is then gradually deflated, while a detector system simultaneously employed determines the point at which the blood flow is restored to the limb. The detector system does not need to be a sophisticated electronic device. It may be as simple as manual palpation of the radial pulse. The most commonly used indirect methods are auscultation and oscillometry, each is described below.

Auscultatory Method

The auscultatory method most commonly employs a mercury column, an occlusive cuff, and a stethoscope. The stethoscope is placed over the blood vessel for auscultation of the Korotkoff sounds, which defines both SP and DP. The Korotkoff sounds are mainly generated by the pulse wave propagating through the brachial artery [4]. The Korotkoff sounds consist of five distinct phases. The onset of Phase I Korotkoff sounds (first appearance of clear, repetitive, tapping sounds) signifies SP and the onset of Phase V Korotkoff sounds (sounds disappear completely) often defines DP [5].

Observers may differ greatly in their interpretation of the Korotkoff sounds. Simple mechanical error can occur in the form of air leaks or obstruction in the cuff, coupling tubing, or Bourdon gage. Mercury can leak from a column gage system. In spite of the errors inherent in such simple systems, more mechanically complex systems have come into use. The impetus for the development of more elaborate detectors has come from the advantage of reproducibility from observer to observer and the convenience of automated operation. Examples of this improved instrumentation include sensors using plethysmographic principles, pulse-wave velocity sensors, and audible as well as ultrasonic microphones [6].

The readings by auscultation do not always correspond to those of intra-arterial pressure. [5]. The differences are more pronounced in certain special occasions such as obesity, pregnancy, arteriosclerosis,

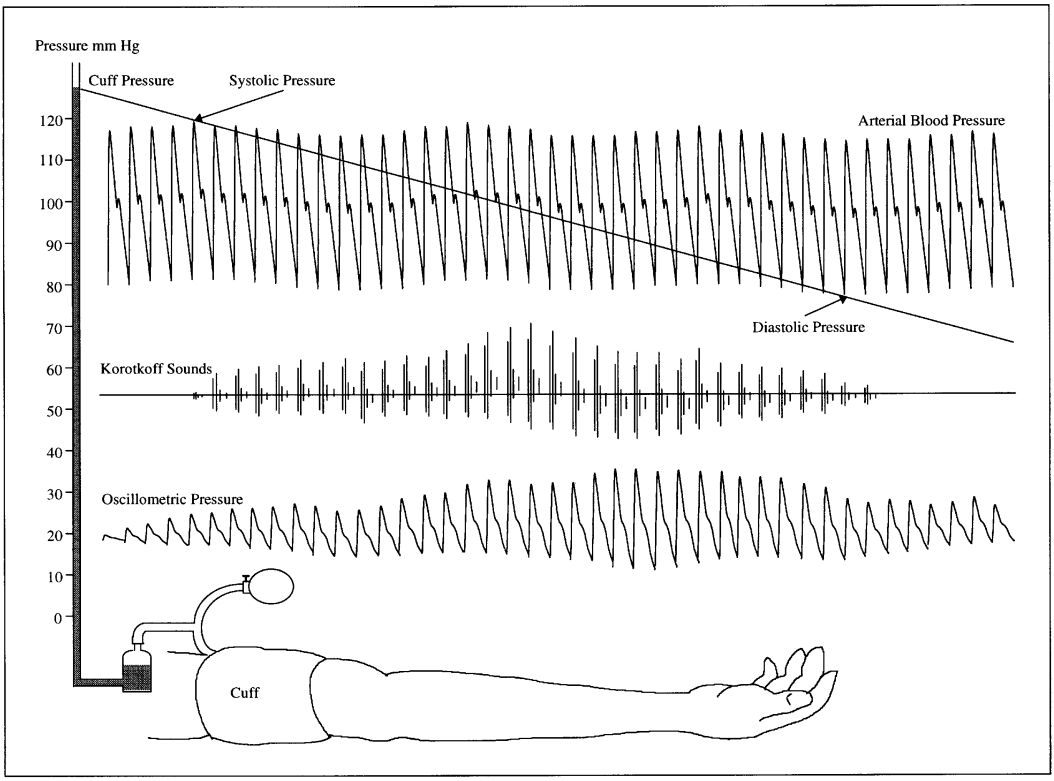

FIGURE 75.1 Indirect blood pressure measurements: oscillometric measurement and auscultatory measurement. (Adapted from Current technologies and advancement in blood pressure measurements — review of accuracy and reliability, *Biomed. Instrum. Technol.,* AAMI, Arlington, VA (publication pending). With permission.)

shock, etc. Experience with the auscultation method has also shown that determination of DP is often more difficult and less reliable than SP. However, the situation is different for the oscillometric method where oscillations caused by the pressure pulse amplitude are interpreted for SP and DP according to empirical rules [7].

Oscillometric Method

In recent years, electronic pressure and pulse monitors based on oscillometry have become popular for their simplicity of use and reliability. The principle of blood pressure measurement using the oscillometric technique is dependent on the transmission of intra-arterial pulsation to the occluding cuff surrounding the limb. An approach using this technique could start with a cuff placed around the upper arm and rapidly inflated to about 30 mmHg above the systolic blood pressure, occluding blood flow in the brachial artery. The pressure in the cuff is measured by a sensor. The pressure is then gradually decreased, often in steps, such as 5 to 8 mmHg. The oscillometric signal is detected and processed at each step of pressure. The cuff pressure can also be deflated linearly in a similar fashion as the conventional auscultatory method.

Figure 75.1 illustrates the principle of oscillometric measurement along with auscultatory measurement. Arterial pressure oscillations are superimposed on the cuff pressure when the blood vessel is no longer fully occluded. Separation of the superimposed oscillations from the cuff pressure is accomplished by filters that extract the corresponding signals. Signal sampling is carried out at a rate determined by the pulse or heart rate [7]. The oscillation amplitudes are most often used with an empirical algorithm to estimate SP and DP. Unlike the Korotkoff sounds, the pressure oscillations are detectable throughout the whole measurement, even at cuff pressures higher than SP or lower than DP. Since many oscillometric devices use empirically fixed algorithms, variance of measurement can be large across a wide range of blood pressures [8]. Significantly, however, MP is determined by the lowest cuff pressure of maximum oscillations [9] and has been strongly supported by many clinical validations [10, 11].

Self-Measurement

From the growing number of publications on the topic in recent years, it is evident that the interest in self-measurement of blood pressure has increased dramatically. There is also evidence that the management of patients with high blood pressure can be improved if clinic measurements are supplemented by home or ambulatory monitoring. Research has shown that blood pressure readings taken in the clinic can be elevated, by as much as 75 mmHg in SP and 40 mmHg in DP, when taken by a physician. The tendency for blood pressure to increase in certain individuals in the presence of a physician due to stress response is generally known as “white-coat” hypertension [12]. When reasonably priced and easy to use, oscillometric devices became commonly available in the early 1970s, public interest in the self-measurement of blood pressure increased and this has made it possible for greater patient involvement in the detection and management of hypertension [13]. Health care costs may also be reduced by home monitoring. Indeed, a recent study found that costs were almost 30% lower for patients who measured their own blood pressure than those who did not [14]. Measurements taken at patient’s home are more highly correlated to 24-h blood pressure levels than clinic readings are. It has also been shown that most patients are able to monitor their blood pressure and may be more relaxed as well as assured by doing so, particularly when experiencing symptoms [15].

Ambulatory Monitoring

There is great significance for ambulatory monitoring of blood pressure. Over a period of 24 h, blood pressure is subject to numerous situational and periodic fluctuations [1]. The pressure readings have a pronounced diurnal rhythm in an individual, with a decrease of 10 to 20 mmHg during sleep and a prompt increase on getting up and walking in the morning. Readings tend to be higher during working hours and lower at home and they depend on the pattern of activity. After a bout of vigorous exercise or strenuous work, blood pressure may be reduced for several hours. The readings may be raised if the patient is talking during the measurement period. Smoking a cigarette and drinking coffee, especially if they are combined, may both raise the pressure [16]. When assessing the efficacy of antihypertensive drugs, ambulatory blood pressure monitoring can provide considerable information and validation of the drug treatment [17].

Although the technique of noninvasive ambulatory blood pressure monitoring was first described more than three decades ago, it has only recently become accepted as a clinically useful procedure for evaluation of patients with abnormal regulation of blood pressure. It gives the best evaluation for patients who have white-coat hypertension. Technical advances in microelectronics and computer technology have led to the introduction of ambulatory monitors with improved accuracy and reliability, small size, quiet operation, and reasonable low price. They can take and store several hundred readings over a period of 24 h while patients may not be compromised with their normal activities, thus becoming usable for purposes of clinical diagnosis [18]. Theoretically, ambulatory monitoring can provide information about the level and variability covering the full range of blood pressure experienced during day-to-day activities. It is now recognized to be a very useful procedure in clinical practice since blood pressure varies significantly during the course of 24 h, especially useful in detecting white-coat hypertension. However, many studies have found that accuracy of monitoring using current ambulatory monitors is acceptable only when patients are at rest but not during physical activity [19] or under truly ambulatory conditions. Report of error codes during operation in the latter situations is much higher [20].

TABLE 75.1 AHA Acceptable Bladder Dimensions for Arm of Different Sizes[a]

Cuff	Bladder Width (cm)	Bladder Length (cm)	Arm Circumference Range at Midpoint (cm)
Newborn	3	6	≤6
Infant	5	15	6–15[b]
Child	8	21	16–21[b]
Small adult	10	24	22–26
Adult	13	30	27–34
Large adult	16	38	35–44
Adult thigh	20	42	45–52

[a] There is some overlapping of the recommended range for arm circumferences in order to limit the number of cuffs; it is recommended that the larger cuff be used when available.

[b] To approximate the bladder width:arm circumference ratio of 0.40 more closely in infants and children, additional cuffs are available.

Adapted from the *Recommendations for Human Blood Pressure Determination by Sphygmomanometers,* Dallas: American Heart Association, 1993. With permission.

Cuff Size

Both the length and width of an occluding cuff are important for accurate and reliable measurement of blood pressure by indirect methods. A too-short or too-narrow cuff results in false high blood pressure readings. Several studies have shown that a cuff of inappropriate size in relation to the patient's arm circumference can cause considerable error in blood pressure measurement [21]. The cuff should also fit around the arm firmly and comfortably. Some manufacturers have designed cuffs with a fastener spaced so that a cuff of appropriate width only fits an arm of appropriate diameter. With this design, the cuff will not stay on the arm during inflation unless it fits accordingly.

According to American Heart Association (AHA) recommendations [5], the width of the cuff should be 40% of the midcircumference of the limb and the length should be twice the recommended width. Table 75.1 presents the AHA cuff sizes covering from neonates to adults.

Recommendations, Standards, and Validation Requirements

The AHA has published six editions of the AHA recommendations for indirect measurement of arterial blood pressure. The most recent edition [5] included the recommendations of the joint national committee on the diagnosis, evaluation, and treatment of hypertension for classifying and defining blood pressure levels for adults (age 18 years and older) [22], as shown in Table 75.2. The "Report of the Second Task Force on Blood Pressure Control in Children" [23] offered classification of hypertension in young age groups from newborns to adolescents, as shown in Table 75.3.

The AHA recommendations provide a systemic step-by-step procedure for measuring blood pressure, including equipment, observer, subject, and technique. It extends considerations of blood pressure recording in special populations such as infants and children, elderly, pregnant and obese subjects, etc. It also provides recommendations of self-measurement or home measurement of blood pressure, as well as ambulatory blood pressure measurement.

The Association for the Advancement of Medical Instrumentation (AAMI) and American National Standard Institute (ANSI) published and revised a national standard [24, 25] for evaluating electronic or automated sphygmomanometers. This standard established labeling requirements, safety and performance requirements, and referee test methods for electronic or automated sphygmomanometers used in indirect measurement of blood pressure. Specific requirements for ambulatory blood pressure monitors were also included. Recently, AAMI/ANSI amended this SP10 standard to include neonatal devices as well [26]. Some of the specific requirements, procedures, and limits were modified to fit neonatal

TABLE 75.2 Recommendations of the Joint National Committee on the Diagnosis, Evaluation, and Treatment of Hypertension for Classifying and Defining Blood Pressure Levels for Adults (age 18 years and older)[a]

Category	Systolic Pressure (mm Hg)	Diastolic Pressure (mm Hg)
Normal[b]	<130	<85
High normal	130–139	85–89
Hypertension[c]		
Stage 1 (mild)	140–159	90–99
Stage 2 (moderate)	160–179	100–109
Stage 3 (severe)	180–209	110–119
Stage 4 (very severe)	≥210	120

[a] Not taking antihypertensive drugs and not acutely ill. When systolic and diastolic pressures fall into different categories, the higher category should be selected to classify the individual's blood pressure status. For instance, 160/92 mmHg should be classified as stage 2, and 180/120 mmHg should be classified as stage 4. Isolated systolic hypertension is defined as a systolic blood pressure of 140 mmHg or more and a diastolic blood pressure of less than 90 mmHg and staged appropriately (e.g., 170/85 mmHg is defined as stage 2 isolated systolic hypertension). In addition to classifying stages of hypertension on the basis of average blood pressure levels, the clinician should specify presence or absence of target-organ disease and additional risk factors. For example, a patient with diabetes and a blood pressure of 142/94 mmHg plus left ventricular hypertrophy should be classified as having "stage 1 hypertension with target-organ disease (left ventricular hypertrophy) and with another major risk factor (diabetes)." This specificity is important for risk classification and management.

[b] Optimal blood pressure with respect to cardiovascular risk is less than 120 mmHg systolic and less than 80 mmHg diastolic. However, unusually low readings should be evaluated for clinical significance.

[c] Based on the average of two or more readings taken at each of two or more visits after an initial screening.

Adapted from *The fifth report of the Joint National Committee on Detection, Evaluation, and Treatment of High Blood Pressure (JNCW), Arch. Intern. Med.*, 153, 154–183, 1993.

applications, such as the maximum cuff pressure, ranges of age and weight, reference standards for validation, minimum sample size of data, etc. The overall system efficacy for both neonatal and adult devices requires that for systolic and diastolic pressures treated separately, the mean difference between the paired measurements of the test system and the reference standard shall be ±5 mmHg or less, with a standard deviation of 8 mmHg or less.

For manual or nonautomated indirect blood pressure measuring devices, ANSI/AAMI SP9 standard [27] applies.

The British Hypertension Society (BHS) also published and revised a protocol for assessing accuracy and reliability of blood pressure measurement using automatic and semiautomatic devices [28, 29]. Many automatic and semiautomatic devices, including ambulatory devices, have been evaluated according to the BHS protocol. Such evaluation provided a quality-control mechanism for manufacturers and an objective comparison for customers. However, there are many more devices available on the market, which have not been accordingly evaluated. Different from the AAMI SP10 standard in which either indirect or direct blood pressure may be used as a reference standard, the BHS protocol relies exclusively on references of sphygmomanometric blood pressure measurement, and does not recommend comparison with intra-arterial blood pressure values [30]. This could make accurate validation of ambulatory devices difficult because sphygmomanometric measurements during exercise and under ambulatory conditions are not accurate [31].

Significantly, the BHS protocol emphasized the need on special-group validation, such as children, pregnancy, and the elderly for the intended use. It also emphasized the need for validation under special circumstances, such as exercise and posture. The accuracy criteria use a grading system based on the percentages of test instrument measurements differing from the sphygmomanometric measurements by ≤5, ≤10, and ≤15 mmHg for systolic and diastolic blood pressure, respectively, as shown in Table 75.4.

TABLE 75.3 Classification of Hypertension in the Young by Age Group[a]

Age Group	High Normal (90–94th percentile) mmHg	Significant Hypertension (95–99th percentile) mmHg	Severe Hypertension (>99th percentile) mmHg
Newborns (SBP)		96–105	≥106
7 d	—	104–109	≥110
8–30 d	—		
Infants (≥2 y)			
SBP	104–111	112–117	≥118
DBP	70–73	74–81	82
Children			
3–5 y			
SBP	108–115	116–123	≥124
DBP	70–75	76–83	≥84
6–9 y			
SBP	114–121	122–129	≥130
DBP	74–77	78–85	≥86
10–12 y			
SBP	122–125	126–133	≥134
DBP	78–81	82–89	≥90
13–15 y			
SBP	130–135	136–143	≥144
DBP	80–85	86–91	≥92
Adolescents (16–18 y)			
SBP	136–141	142–149	≥150
DBP	84–91	92–97	≥98

[a] SBP indicates systolic blood pressure; DBP, diastolic blood pressure.

Adapted from the Report of the Second Task Force on Blood Pressure Control in Children — 1987, *Pediatrics*, 79, 1–25, 1987. With permission.

TABLE 75.4 Grading Criteria of the 1993 British Hypertension Society Protocol[a,b]

Grade	Absolute Difference between Standard and Test Device (mmHg) ≤5	≤10	≤15
	Cumulative Percentage of Readings		
A	60	85	95
B	50	75	90
C	40	65	85
D	Worse than C		

[a] Grades are derived from percentages of readings within 5, 10, and 15 mmHg. To achieve a grade all three percentages must be equal to or greater than the tabulated values.

[b] Grading percentages changed from the 1990 British Hypertension Society protocols due to changes in sequential assessment of blood pressure references.

Manufacturer, Product, Price, Efficacy, and Technology

The annual publication of the *Medical Device Register* is a comprehensive reference work that provides a wealth of detailed information on U.S. and international medical devices, medical device companies, OEM suppliers, and the key personnel in the industry. Blood pressure devices are listed in the sphygmomanometer directory. Price information of specific models for some providers is also published. For example, A&D Engineering, Inc. listed price from $51.95 (model UA701) to $179.95 (model UA-751) for a whole line of sphygmomanometers in the 1997 *Medical Device Register* [32]. Since technology and market can change rapidly, models, features, specifications, and prices may change accordingly. More specific and updated information may be available by contacting the manufacturers or distributors directly.

Table 75.5 lists only a limited number of indirect blood pressure devices from a literature review. Many of the listed blood pressure devices have multiple evaluation studies and only a few study results are presented here. In view of reference standards for comparison, although direct and indirect methods yield similar measurements, they are rarely identical because the direct method measures pressure and the indirect method is more indicative of flow [5]. Egmond et al. [33] evaluated the accuracy and reproducibility of 30 home blood pressure devices in comparison with a direct brachial arterial standard. They found average offsets of all tested devices amounted to –11.7 mmHg for systolic and 1.6 mmHg for diastolic blood pressure, which were close to those of the mercury sphygmomanometer (–14.2 mmHg for systolic and –0.1 mmHg for diastolic pressure), indicating a significant difference between the two assessment standards. When selecting a blood pressure device for a specific application, the evaluation using the reference that is of a common practice in the intended population or environment may be practically more informative, since that reference has been the common basis for decision making in blood pressure diagnosis and treatment.

Different evaluation results for the same brand product can also be due to different versions of a model used for validation, where a later version may have performance improvement over the earlier one [34]. Another source of discrepancies can come from utilizing different study protocols or only partially following the same protocols. It is recommended that the original clinical evaluation report be carefully examined in determining the desired efficacy that may meet the users' requirements. If the devices were FAD approved for marketing in the U.S., one may request a copy of their clinical validation report directly from the manufacturer.

In addition to the fundamental categories such as intended use, efficacy, and acquisition technology, listed in Table 75.5, many other categories are also very important in evaluating, selecting, purchasing, using, and maintaining blood pressure devices. These include but are not limited to the following items: measurement range of each pressure (systolic, diastolic, and mean) for each mode of intended use (i.e., neonates, children, adults); maximum pressure that can be applied by the monitor and cuff for each mode of intended use; cuff size range for the target population of the intended use; cost; measurement and record failure rate; noise and artifact rejection capability; mode of operation (manual, automatic, semiautomatic); data display; recording, charting, reporting, and interfacing; physical size and weight; power consumption; operation manual; service manual; labels and warnings; etc.

Advancement of Indirect Blood Pressure Measurement

Since the introduction of Dinamap™, an automated blood pressure monitor based on the oscillometric principle [9], many variants of oscillometric algorithms were developed. However, the fixed or variable fractions of the maximum oscillations are still the fundamental algorithms of the oscillometry [10, 53, 54]. Typically, mean blood pressure was determined by the lowest cuff pressure with greatest average oscillation [11]. Systolic and diastolic blood pressure were determined by the cuff pressure with the amplitude of oscillation being a fixed fraction of the maximum. Performance of the algorithms may be improved by introducing a greater level of complexity or variables into considerations. The Dinamap™ 1846SX (Critikon, Tampa, FL) oscillometric device offered two measurement modes. The normal mode uses two matching pulse amplitudes at each cuff pressure step to establish an oscillometric envelope or curve. Therefore, measurement time is heart rate dependent. The second mode, which the manufacturer refers to as "stat mode," is capable of faster determination by disabling the dual pulse-matching algorithm which was designed for artifact rejection. The stat mode does not appear to compromise accuracy in anesthetized patients [55], in which rapid measurement of blood pressure is often more desirable, particularly during induction and management of anesthesia.

TABLE 75.5 Survey of Indirect Blood Pressure Device Manufacturer, Product, Intended Use, and Efficacy

				Efficacy								
				Reference Standard	BHS Protocol Grading		AAMI SP10 Comparison (Device – Reference) mmHg		Other Validations (Device -Reference) mmHg			
Manufacturer	Model	Technology	Intended Use	MC/AC[a]	SBP	DBP	SBP	DSP	SBP	DBP	MBP	Ref.
A&D, Tokyo, Japan	TM-2420/ TM-2020	Korotkoff	Health Care: Ambulatory	MC	D	D	–4 ± 11	–2 ± 11				35
	TM-2420 Version 7	Korotkoff	Health Care: Ambulatory	MC	B	B	–1.8 ± 5.0	–3.5 ± 6.8				36
Colin Medical Instruments, Plainfield, NJ	ABPM 630	Korotkoff (primary mode) Oscillometry (backup mode)	Health Care: Ambulatory Health Care: Ambulatory	AC MC AC MC					1.4 ± 7.1 –0.4 ± 4.6 4.5 ± 6.6 1.9 ± 4.0	–0.1 ± 5.6 –6.0 ± 5.9 –1.2 ± 6.3 –6.9 ± 5.1		37
Del Mar Avionics, Irvine, CA	Pressurometer IV	Korotkoff (ECG R-wave gating)	Health Care: Ambulatory	MC MC	C	D	–2 ± 11	–3 ± 11	 1.2 ± 7.3	 –2.2 ± 5.7		38 39
Disetronic Medical Systems AG Burgdorf, Switzerland	CH-Druck/Pressure Scan ERKA	Korotkoff	Health Care: Ambulatory	MC	A	A	–3 ± 4	–2 ± 4				40
Novacor, France	DIASYS 200	Korotkoff	Health Care: Ambulatory	MC	C	C	–1 ± 8	0 ± 8				41
Oxford Medical, Abingdon, Oxford, U.K.	Medilog ABP	Korotkoff	Health Care: Ambulatory	AC MC			–8 ± 8 –4 ± 6	6 ± 6 –2 ± 8				42
Disetronic Medical Systems AG, Burgdorf, Switzerland	Profilomat	Korotkoff	Health Care: Ambulatory	MC	B	A	–3 ± 5	–1 ± 5				43
SpaceLabs Medical, Redmond, WA	90207	Oscillometry	Health Care: Ambulatory	MC	B	B	–1 ± 7	–3 ± 6				44
Suntech Medical Instruments, Raleigh, NC	Accutracker II (v30/23)	Korotkoff (ECG R-wave gating)	Health Care: Ambulatory	MC	A	C	–1.3 ± 6.5	–4.5 ± 7.3				45[b]
Tycos-Welch-Allyn, Arden, NC	QuietTrack	Korotkoff	Health Care: Ambulatory				0.3 ± 5.0	–1.5 ± 7.5				46[c]
Colin Medical Instruments, San Antonio, TX	BP8800MS	Oscillometry Oscillometry	Health Care: Children Health Care: Adults	MC MC			3.2 ± 6.0 2.8 ± 5.4	–0.8 + 5.2 0.0 ± 4.9				47

TABLE 75.5 (continued) Survey of Indirect Blood Pressure Device Manufacturer, Product, Intended Use, and Efficacy

				Efficacy								
				Reference Standard	BHS Protocol Grading		AAMI SP10 Comparison (Device – Reference) mmHg		Other Validations (Device -Reference) mmHg			
Manufacturer	Model	Technology	Intended Use	MC/AC[a]	SBP	DBP	SBP	DSP	SBP	DBP	MBP	Ref.
Critikon, Tampa, FL	Dinamap 1846SX	Oscillometry	Health Care: Neonates, Children, Adults	AC					–8.8 ± 11.2	1.6 ± 8.9	–1.8 ± 9.7	48
	Dinamap portable monitor	Oscillometry	Health Care: Neonates, Children, Adults	MC	B	D	–1 ± 7	–6 ± 7				49[d]
SpaceLabs Medical, Redmond, WA	Oscillometric Blood Pressure Monitor	Oscillometry	Health Care: Neonates,	AC	B	B	0.1 ± 4.3	2.7 ± 4.8				50[e]
			Health Care: Children, Adults	MC	B	B	–0.6 ± 5.9	0.9 ± 6.4				
Ohmeda, Denver, CO	Finapres 3700	Volume-clamping	Health Care: Continuous Monitoring	AC					–8.4 ± 8.6	–1.1 ± 7.0	–6.8 ± 6.7	48
Terumo, Tokyo, Japan	ES-H51[f]	Korotkoff (primary mode)	Health Care: Routine	MC	A	A	0.7 ± 2.9	0.3 ± 2.6				51[g]
		Oscillometry (backup mode)	Clinical	MC	B	A	–0.3 ± 5.7	–0.3 ± 4.3				

Matsushita, Osaka, Japan	Denko EW 160	Oscillometry	Self Care: Home Measurement	MC	1.8 ± 5.2	–1.7 ± 5.5	52
Nissei, Tokyo, Japan	DS 91[f]	Korotkoff	Self Care: Home Measurement	MC	–2.5 ± 7.4	2.8 ± 10.8	52
Omron, Tokyo, Japan	HEM 439[f]	Korotkoff	Self Care: Home Measurement	MC	–0.2 ± 5.3	6.2 ± 9.9	52
	HEM 719K	Korotkoff	Self Care: Home Measurement	MC	–2.3 ± 5.6	2.4 ± 4.7	52
	401C[f]	Oscillometry	Self Care: Home Measurement	MC	–1.6 ± 7.7	2.4 ± 6.1	52
Sharp, Osaka, Japan	MB 305H[f]	Korotkoff	Self Care: Home Measurement	MC	0.5 ± 4.5	9.6 ± 14.3	52
	MB 500A	Oscillometry	Self Care: Home Measurement	MC	–1.8 ± 6.7	0.7 ± 6.3	52
A&D, Tokyo, Japan	Takeda UA 751	Oscillometry	Self Care: Home Measurement	MC	–4.1 ± 5.6	0.4 ± 7.8	52

[a] MC: mercury column; AC: arterial catheter.
[b] Data quoted for the standing position; grading was the same as for pooled data of three positions (supine, seated, and standing).
[c] Data quoted for the three positions of supine, seated, and standing.
[d] Efficacy quoted was determined in adult population.
[e] Efficacy quoted was determined in neonate and adult populations, respectively.
[f] Semiautomatic; all other listed are automatic.
[g] Only partially followed AAMI and BHS protocol and only validated one size (median) of three cuffs (small, median, large).

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Another variant of the oscillometric algorithm was developed by Protocol Systems [56]. In addition to using pulse amplitude for primary artifact rejection, it further calculated impulse value, a principal area of pulse waveform, in constructing an oscillometric curve. This curve is smoothed by employing a Kalman filter that also provides an expected mean and acceptable upper and lower bounds of prediction for the principal area of subsequent pulse waveform. Smoothing of the oscillometric curve is accomplished by using the difference between the predicted and calculated area data of pulse waveform for each cuff pressure step. Blood pressures are derived from the final smoothed oscillometric curve.

In more recent study, oscillometric algorithms using an artificial neural network have been reported to produce better estimates of reference blood pressures than the standard oscillometric algorithm [57]. By using neural network training and processing, subtle features and nonlinear relationships of the oscillometric envelope have been modeled. Empiricism of the oscillometric fixed fraction criteria is overcome and variances of measurements are greatly reduced.

Because of its low risk and cost, noninvasive continuous blood pressure monitoring represents another need in critical-care monitoring to supplement invasive arterial catheterization. A significant development in this field is the arterial counterpulsation principle, proposed by Penaz [58], and further developed by two major groups of people [59, 60]. Finapres™, a continuous finger arterial blood pressure monitor was engineered and developed by Ohmeda, Denver, CO. Many clinical evaluation reports of these devices have been published since then.

Recently, a number of other continuous blood pressure monitors have been made commercially available. Examples of these are Cortronic APM770 [61], which monitors pulsation of the brachial artery with a slightly pressurized arm cuff and calibrates it to a continuous pressure waveform; Sentinel ARTRAC 7000 [62], which monitors pulse transit time and correlates that to pressure change; Colin CBM-3000 and JENTOW (Colin Electronics, Komaki, Japan) [63, 64] and Nellcor NCAT N-500 (Nellcor, Hayward, CA) [65], which are tonometric devices monitoring the radial artery pulse waveform by a matrix pressure sensor. All of these monitors require a frequent calibration reference. Except for a few favorable reports with the tonometric method and devices, many reports so far are unfavorable. Nevertheless, noninvasive continuous monitoring represents an important and growing field of biomedical sensor and instrumentation research and development. Continuous monitors, which maintain cuff pressure, must periodically relieve pressure to prevent the risk of venous congestion, edema, swelling, and tissue damage.

75.4 Direct Blood Pressure Measurement

Direct measurement is also called invasive measurement because bodily entry is made. For direct arterial blood pressure measurement an artery is cannulated. The equipment and procedure require proper setup, calibration, operation, and maintenance [66]. Such a system yields blood pressures dependent upon the location of the catheter tip in the vascular system. It is particularly useful for continuous determination of pressure changes at any instant in dynamic circumstances. When massive blood loss is anticipated, powerful cardiovascular medications are suddenly administered, or a patient is induced to general anesthesia, continuous monitoring of blood pressures becomes vital.

Most commonly used sites to make continuous observations are the brachial and radial arteries. The femoral or other sites may be used as points of entry to sample pressures at different locations inside the arterial tree, or even the left ventricle of the heart. Entry through the venous side of the circulation allows checks of pressures in the central veins close to the heart, the right atrium, the right ventricle, and the pulmonary artery. A catheter with a balloon tip carried by blood flow into smaller branches of the pulmonary artery can occlude flow in the artery from the right ventricle so that the tip of the catheter reads the pressure of the left atrium, just downstream. These procedures are very complex and there is always concern of risk of hazard as opposed to benefit [67].

Invasive access to a systemic artery involves considerable handling of a patient. The longer a catheter stays in a vessel, the more likely an associated thrombus will form. The Allen's test can be performed by pressing on one of the two main arteries at the wrist when the fist is clenched, then opening the hand to see if blanching indicates inadequate perfusion by the other artery. However, it has proved an equivocal predictor of possible ischemia [68]. In the newborn, when the arterial catheter is inserted through an umbilical artery, there is a particular hazard of infection and thrombosis, since thrombosis from the catheter tip in the aorta can occlude the arterial supply to vital abdominal organs. Some of the recognized contraindications and complications include poor collateral flow, severe hemorrhage diathesis, occlusive arterial disease, arterial spasm, and hematoma formation [69].

In spite of well-studied potential problems, direct blood pressure measurement is generally accepted as the gold standard of arterial pressure recording and presents the only satisfactory alternative when conventional cuff techniques are not successful. This also confers the benefit of continuous access to the artery for monitoring gas tension and blood sampling for biochemical tests. It also has the advantage of assessing cyclic variations and beat-to-beat changes of pressure continuously, and permits assessment of short-term variations [70, 71].

Catheter–Tubing–Sensor System

A large variety of vascular catheters exist. Catheter materials have undergone testing to ensure that they have a minimal tendency to form blood clots on their surface. The catheter chosen may be inserted percutaneously over a hollow stylet into the blood vessel. Guide wires can be useful to facilitate longer or larger-diameter catheters into vessels, after the guide wires have been placed through a smaller catheter or needle. Less often, entry to a vessel requires a "cutdown," a direct exposure of the vessel after a skin incision. Ultrasonic devices may assist locating the vessels not readily apparent at the skin surface.

Although pressure sensors can be located at the catheter tip, this presents a problem for calibration if left in place and a clot forms near the tip of the catheter, damping the pressure signal. Instead, most catheters connect to an external pressure sensor via fluid-filled low-compliance tubing. The signal from the sensor then undergoes transformation for display or recording. The sensor may take one of several forms, from a variable resistance diaphragm to a silicon microchip. A basic system can consist of an intravascular catheter connected to a rigid fluid-filled catheter and tubing which communicates the pressure to an elastic diaphragm, the deflection of which is detected electrically. There is a direct relationship between the deflection of the diaphragm and the voltage. The higher the voltage, the greater the pressure. Continuous low-rate infusion of heparinized saline is carried out to keep the catheter patent or free from coagulation. The advent of disposable sensor kits have greatly simplified the clinical use of intravascular monitoring [72]. With the cost continually being lowered with the development of semiconductor industry, disposable sensors become more and more cost-effective.

Although direct recording is considered the most accurate method, its accuracy may be limited by variations in the kinetic energy of the fluid in the catheter or dynamic frequency response of the measurement system. The hydraulic link between the patient and the sensor is the major source of potential errors and hazard for the monitoring. Damping and degrading the system's natural frequency, caused by trapped air bubbles, small catheters, various narrow connections, compliant and too long tubing, and too many components connected, are the two characteristic problems with a pressure sensor system. Extreme care should be exercised to eliminate all air bubbles from the fluid to provide adequate dynamic response. The sensor should be zeroed at the level of the heart to eliminate hydrostatic error [73]. A fast flush testing is easy to use for inspection of the dynamic response of the whole system of catheter–tubing–sensor. It can also help direct adjustments for the system to minimize dynamic artifacts [74, 75].

75.5 Reproducibility, Accuracy, and Reliability Issues and Recommendations for Corrective Measures

For each blood pressure assay technique, there is an issue of reproducibility of measurements given approximately similar conditions. Reproducibility quantifies the internal uncertainty of an individual method and instrument, whereas accuracy quantifies the external uncertainty when compared with a reference. Table 75.6 presents estimated uncertainties of reproducibility for three blood pressure–measuring techniques: auscultation, oscillometry, and umbilical arterial catheter [50]. When dealing with

TABLE 75.6 Estimated Uncertainties of Reproducibility for Blood Pressure Measuring Techniques of Auscultation, Oscillometry, and Umbilical Arterial Catheter[a]

	Auscultation	Oscillometry[b]	Umbilical Arterial Catheter
Neonate			
Systolic pressure (mmHg)	N/A	3.3	2.2
Diastolic pressure (mmHg)	N/A	3.4	1.8
Adult			
Systolic pressure (mmHg)	2.8	3.2	N/A
Diastolic pressure (mmHg)	2.2	3.5	N/A

[a] From Reference 50.
[b] Evaluated from SpaceLabs Medical Oscillometric monitor [50].

blood pressure measurement, it is important to bear in mind that even for standard methods, there is a certain amount of nonrepeatable random error. Consequently, taking the average of repeated measurements or multiple readings is always advised before any serious recommendation or management is made.

Table 75.7 presents a review of common problems associated with accuracy and reliability in both indirect and direct blood pressure measurements. Consequences of these problems are analyzed and recommendation of preventive action or alternative solutions are provided. Hazard or safety analyses and review are also very important.

75.6 Blood Pressure Impact, Challenge, and Future

Hypertension is one of the most common and important risk factors of health in industrialized countries [82]. It is the leading cause of death in the U.S. It is treatable by a variety of effective medications. It can cause serious damage to the heart and arteries leading to cardiac infarct, stroke, or renal failure. Significant sudden changes in blood pressure may also precede a major physiological catastrophe such as cardiac arrest. There is now almost universal acceptance that basic physiological parameters such as blood pressure should always be monitored in the clinical setting.

There has been increasing interest in automatic blood pressure monitoring devices in recent years and some clinicians are now advising patients to record their blood pressure at home over a period of up to 3 months before starting antihypertensive medication [83]. Self-monitoring of blood pressure has become very common with the development of microchip technology and oscillometric monitors. The patients no longer have to learn how to listen for Korotkoff sounds. This has also removed bias and observer errors, allowing more accurate measurement than by conventional techniques using a stethoscope and a mercury sphygmomanometer [84].

Special populations have unique blood pressure assessment requirements. Newborns require miniaturized equipment. The act of taking a blood pressure in a newborn may stimulate a series of movements causing motion artifact. The very obese may be hard to fit properly with a cuff at the upper arm, if the upper arm is too conical rather than cylindrical. In pregnancy, auscultatory and oscillometric methods, although useful to follow trends, may correspond poorly with central pressures [85] and even the proper Korotkoff sound (IV or V) to designate as diastolic pressure is uncertain [86].

Observing blood pressures has limitations. It may suggest what is happening with blood volume, but sometimes does not reveal that blood volume has become inadequate until circulatory collapse has occurred. Venous and left atrial pressures are often used in an attempt to clarify blood volume problems but with uncertain results [87]. Similarly, a satisfactory blood pressure does not always indicate adequate tissue perfusion. Some medications that increase blood pressure can do so at the expense of general perfusion. Since blood pressure is measured at specific sites in the arterial tree, if circulation has become nonhomogeneous, such as can happen in arteriosclerosis, the region distal to the arteriosclerosis can be compromised without warning from blood pressure readings sampled at another site. Even mean blood pressure, so useful otherwise, can fail in these circumstances.

TABLE 75.7 Common Issues of Accuracy and Reliability in Blood Pressure Measurement and Recommendations of Preventive Action or Alternative Solution in Both Indirect and Direct Measurements

Source	Problem	Result	Recommendation
		Indirect Measurement	
Subject	Obesity, peripheral edema, peripheral vascular disease	Weak Korotkoff sounds and diminished sound transmission may reduce the accuracy and reliability of auscultatory measurement; oscillometric measurement may also be affected	Verify with a second indirect method such as oscillometry; direct blood pressure measurement may be elected to use in severe conditions that indirect measurement does not warrant sufficient accurate and reliable measurement
	Shock, severe peripheral vasoconstriction, diminished peripheral circulation resulting from shunting of blood to central organs; Korotkoff sounds and pulses may be absent even in presence of normal pressure [76]	Any of the indirect methods, including auscultatory, oscillometric and Doppler techniques may not provide accurate and reliable reading; indirect measurement may be impossible or may give misleading results	Direct measurement should be considered
	Arrhythmias, respiratory effect	Pronounced variation in beat-to-beat blood pressure and waveform	Take multiple measurements and average
	Subject shivering, pain, anxiety, discomfort, motion artifact	Shivering and motion artifact may cause either false high or false low reading, whereas pain, anxiety, and discomfort may cause false high reading	Minimize pain, anxiety, and discomfort; reduce shivering and movement
	Physical activity within 5 min of measurement; talking, moving, arm unsupported, back unsupported, legs dangling, and any other isometric activities	False high reading that does not reflect subject's resting blood pressure	Subject should rest at least 5 min in the same position that blood pressure is going to be taken; subject should not talk and involve any isometric activities during measurement; arm should be supported at heart level
	Arm supported at above heart level	Hydrostatic pressure causes false low reading by 0.78 mmHg for each centimeter of offset [77]	Support the arm with midpoint of upper arm at heart level
	Arm supported at below heart level	Hydrostatic pressure causes false high reading by 0.78 mmHg for each centimeter of offset	Support the arm with midpoint of upper arm at heart level
	White-coat hypertension during clinical measurement	Psychological or stress response causes blood pressure temporarily elevated and unrepresentative of subject's true condition	Take multiple self-measurements at home or ambulatory monitoring as desired and provide record to care providers
	"Pseudo-hypertension" with calcified or stiffened arteries	Reduced arterial compliance, often occurring in the elderly, causes cuff blood pressure falsely too high or unable to be measured accurately	Use Osler maneuver for screening; direct method is recommended for those who test positive [78,79]
Operator	Hose kinked	Will cause reading error or operation failure	Rearrange hose to avoid kink
	Cuff used too narrow for arm	Will cause false high reading	Select appropriate cuff size that its width encircles 40% of arm circumference
	Cuff used too wide for arm	May cause false low reading; may not fit on arm	Select appropriate cuff size that its width encircles 40% of arm circumference

TABLE 75.7 (continued) Common Issues of Accuracy and Reliability in Blood Pressure Measurement and Recommendations of Preventive Action or Alternative Solution in Both Indirect and Direct Measurements

Source	Problem	Result	Recommendation
	Cuff wrapped too loosely	Will cause false high reading; may introduce artifact of inter cuff–arm abrasion if placed for long-term monitoring	Cuff should be snugly applied; one should not be able to insert two fingers between the cuff and arm for adult
	Cuff wrapped too tightly	May cause false low reading; will restrict and impair limb circulation if placed for long-term monitoring	Cuff should be snugly but not restrictively applied; one should be able to insert one finger between the cuff and arm for adults
	Cuff pressure inflated too high	Patient discomfort; may induce increase in systolic blood pressure during inflation period, so called "cuff-inflation hypertension" [80]	Inflate cuff pressure to 30 mmHg above palpatory blood pressure
	Cuff pressure inflated too low	Will either miss or have false low systolic pressure reading	Inflate cuff pressure to 30 mmHg above palpatory blood pressure
	Cuff pressure deflated too fast	May degrade the accuracy of the reading	Deflate cuff pressure at 2–4 mmHg per heart beat or 3 mmHg/s
	Cuff pressure deflated too slow	May cause discomfort or forearm congestion	Deflate cuff pressure at 2–4 mmHg per heart beat or 3 mmHg/s
	Repeated cuff pressure measurement too frequently	May cause discomfort and forearm congestion	A sufficient time should elapse (at least 60 s) before the next reading to allow the return of normal circulation
	Miss identifying auscultatory gap between systolic and diastolic pressure	Will cause false low systolic or false high diastolic pressure	Listen to Korotkoff sounds carefully for a wide pressure deflation range or use oscillometric method
	Stethoscope head or sensor not over the brachial artery	Will not hear clear sounds or detect sufficient signal for blood pressure determination	Place the stethoscope head or sensor over the brachial artery at least 1.5 cm above the antecubital fossa
	Noise and artifact created by accidentally touching or bumping the cuff, hose, stethoscope, or sensor	May cause inaccurate reading or failure of reading	Avoid incidence of extraneous noise and artifact
Equipment	Leaky hose, bladder/cuff, or pneumatic components	Will cause inaccurate reading or failure in operation	Require service or replace equipment
	Faulty valves	Will cause inaccurate reading or failure in operation	Require service or replace equipment
	Limited selection for different size of cuffs	Will cause false low or false high reading if cuff is too large or too small, respectively	Manufacturer should provide appropriate label/labeling for the intended use and arm size; blood pressure measurement beyond the intended use of the device should be warned against and prohibited
	Device zero-shifted, out of calibration	Will create systematic bias or uncertainty in blood pressure reading	Require routine calibration and maintenance
		Direct Measurement	
Subject	Subject position change (e.g., body position change, bed lowered or elevated, etc.) in relation to pressure sensor	Subject heart level change in relation to pressure sensor will introduce bias of hydrostatic pressure in blood pressure recording	Move the sensor zero port to the heart level and zero the sensor/monitor
	Catheter whip in pulmonary artery, catheter impact in aorta or ventricle	Catheter whip can result in superimposed waves of ±10 mmHg; catheter impact can cause high-frequency transients to occur in waveform [81]	Catheter whip and catheter impact are difficult to prevent; evaluation of pressure waveform and reading should consider the effect of these events

TABLE 75.7 (continued) Common Issues of Accuracy and Reliability in Blood Pressure Measurement and Recommendations of Preventive Action or Alternative Solution in Both Indirect and Direct Measurements

Source	Problem	Result	Recommendation
	Subject severe shivering, pain, anxiety, discomfort, moving	Severe shivering and moving may cause artifact on blood pressure waveform whereas pain, anxiety, and discomfort may elevate blood pressure	Minimize pain, anxiety, and discomfort, reduce shivering and moving
Operator	Tubing kinked	Will change dynamic response of tubing system and distort pressure waveform	Use short and low compliant tubing, and place tubing appropriately to avoid kink
	Sensor zero port higher than heart level when zeroing	Hydrostatic pressure causes false low pressure measurement by 0.78 mmHg for each centimeter of offset	Move the sensor zero port to heart level and zero the sensor/monitor
	Sensor zero port lower than heart level when zeroing	Hydrostatic pressure causes false high pressure measurement by 0.78 mmHg for each centimeter of offset	Move the sensor zero port to heart level and zero the sensor/monitor
	Air bubbles entrapped in the tubing system	Air bubbles will decrease natural frequency and increase damping coefficient; therefore they damp and distort the waveform, causing high-frequency components to loss in pressure waveform	Eliminate air in both tubing system and flush solution bag; light tapping while fluid is filling the tubing system is an effective method for removing air
	Tubing too long, too thin, and with too many components	All of these will degrade the system dynamic response and result in distorted waveform and erroneous reading	Use tubing of large inner diameter, short length, and reduce the number of components as much as possible
	Connectors not tightly connected	Will decrease natural frequency of tubing system and cause pressure waveform to be distorted	Check loose luer-lock connection and cracked connection; replace cracked components and secure tight connection of all components
	Failure to flush the arterial line adequately after blood draw	May cause the catheter tip partially clotted by the blood and pressure waveform over damped and distorted	Flush the arterial line adequately; may need to replace with a new catheter if dynamic response cannot be improved to meet the minimum requirement
	Failure to zero the sensor/monitor after subject position change in relation to pressure sensor	Subject heart level change in relation to pressure sensor will introduce bias of hydrostatic pressure in blood pressure recording	Move the sensor zero port to the heart level and zero the sensor/monitor
	Failure to provide constant infusion of anticoagulation/saline solution	May cause catheter tip partially clotted by the blood and pressure waveform overdamped and distorted	Check the constant infusion device to have sufficient flow rate; flush the arterial line adequately; may need to replace with a new catheter if dynamic response cannot be improved to meet the minimum requirement
	Failure to test dynamic response at least once a shift and anytime after blood draw or component change	This leaves the system dynamic performance unknown, which may affect the accuracy of systolic pressure the most, diastolic pressure the second; mean pressure is hardly affected	Routinely perform the fast flush test to evaluate the dynamic response visually according to Gardner's chart of natural frequency vs. damping coefficient [73]
Equipment	Not equipped with an appropriate flush device	May not be able to generate quality test waveform to evaluate the adequacy of dynamic response of the catheter–tubing–sensor system	Select appropriate flush device that permits fast flush test for the system dynamic response
	Tubing or component not transparent	Unable to see entrapped air bubbles	Use transparent tubing and components

TABLE 75.7 (continued) Common Issues of Accuracy and Reliability in Blood Pressure Measurement and Recommendations of Preventive Action or Alternative Solution in Both Indirect and Direct Measurements

Source	Problem	Result	Recommendation
	Tubing, sensor, or constant flush device too compliant	Will decrease natural frequency of the system and cause pressure waveform to be distorted	Use only high-quality and low-compliance tubing, sensor, and constant flush device
	Stopcocks not tightly sealed	Will decrease natural frequency of the system and cause pressure waveform to be distorted	Replace with tightly sealed, high-quality stopcocks
	Monitor failure to zero the sensor electronically, sensor zero drift, or pressure amplifier zero drift	Will introduce unknown offset or bias in pressure measurement	Require service or replacement of the equipment
	Natural frequency and damping coefficient of the catheter–tubing–sensor system failure to meet minimum dynamic response requirement	Fidelity of pressure waveform recording suffers and accuracy of systolic and diastolic pressure measurement degrades	Need to optimize the catheter–tubing–sensor system by replacing part or all of the components; use low-compliance pressure sensor, tubing, and all other components; use short and large tubing and reduce the number of components as much as possible
	Blood pressure monitor failure to identify special events such as sensor zeroing, fast flush testing, blood drawing, as well as artifacts	Blood pressure monitor displays false digital reading of blood pressure without warning sign or error message	Health care provider needs to exercise care in viewing the digital results with waveform display; quality control or screening process is needed in dealing with monitoring database

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In spite of inherent problems, observation of blood pressure through both old and new technologies retains more than enough usefulness to have remained an essential aspect of patient care. The promise of improved technology to solve problems such as those of motion artifacts, noninvasive continuous monitoring, long-distance telemetry, rapid analysis of accumulated or concurrent data, and assessment of new inaccessible regions of blood flow represent continued challenges for future biomedical research and development.

Recently, exciting research has revealed that comparing pressures taken at the arm and the ankle results in a simple but extremely useful index for assessment of lower extremity vascular disease, with implications for general cardiovascular risk factors [88]. The possibility of obtaining noninvasive blood pressures from arteries in the forehead by stick-on oscillometric patches has also been proved. At least in anesthetized patients, the forehead noninvasive blood pressure corresponded reasonably well with central arterial pressures [89]. Finger blood pressure monitors have found some applications in continuous ambulatory and sleep blood pressure assessments [90]. A technology that is capable of continuously monitoring brachial or even central blood pressure continues to be a clinical demand and future challenge.

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Casual blood pressure and ambulatory blood pressure measurement in children

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Invited Review

ABSTRACT

Some epidemiological studies on blood pressure among children and adolescents have revealed that blood pressure levels in childhood are the strongest predictors of adult blood pressure levels. In the adult population, hypertension causes a two to threefold increase in an individual's risk of cardiovascular morbidity. Cardiovascular risk depends on blood pressure itself, coexistent risk factors and whether there is hypertensive end-organ damage. Therefore, accuracy in determining blood pressure is essential and a standardized protocol should be considered for blood pressure measurement, which would make the comparison of results obtained by different studies in different countries possible. This article reviews the main determinants of accuracy for casual and ambulatory blood pressure measurements in children.

KEY WORDS: Blood. Pressure. Methodology. Children. Adolescent.

Cardiovascular diseases are the main causes of death in Brazil. Stroke mortality rates among Brazilians are high, reflecting the burden of hypertension. Some international epidemiological studies on blood pressure among children and adolescents have revealed that blood pressure levels in childhood are the strongest predictor of adult blood pressure levels.[1-3] In the adult population, hypertension causes a two to threefold increase in an individual's risk of cardiovascular morbidity.[4,5] The relationship between hypertension and cardiovascular disease seems to be continuous: cardiovascular risk depends on blood pressure itself, coexistent risk factors and whether there is hypertensive end-organ damage.

As accuracy in determining blood pressure is essential, a standardized protocol should be considered for blood pressure measurement, which would make the comparison of results obtained by different studies in different countries possible. Observers should be trained and certified to minimize measurement bias. Homogeneous decisions should be taken regarding equipment factors such as an appropriate cuff bladder size or the alternative use of mercury manometers or oscillometric devices. Technical factors such as the recording of fourth, fifth or both Korotkoff sounds for diastolic blood pressure need to be taken into consideration. Also, the number of measurements needed for estimating a child's blood pressure and the influence on its measured value of environmental factors such as the time of the day and ambient temperature must be considered.[6] Some of these factors will be discussed separately in the next paragraphs.

The cuff

Classically, to obtain an accurate blood pressure measurement, a cuff bladder width of approximately 40% of the upper arm circumference should be chosen because it most closely approximates intra-arterial readings.[7] The bladder length should be at least 90% of arm circumference to avoid overestimation of blood pressure, especially in children.[8] Another less-known effect of the cuff size change occurs when, in accordance with the abovementioned instructions for cuff selection, the cuff size is changed to a larger one. In this case, the cuff change leads to an abrupt fall in the value of measured blood pressure that is not arm-dependent, but cuff-dependent.[9] This very inconvenient effect may be responsible for two issues: 1. Any association between blood pressure and arm circumference, such as body mass, will be biased towards zero. 2. In longitudinal studies, when changing to a larger cuff, measured blood pressure is lower than previous readings, which could lead to inappropriate inverse correlations of blood pressure with chronological age or height. In 1999, Arafat and Mattoo[10] reviewed commercially available blood pressure cuffs and detected that the sizes of available cuffs, labeled as infant, pediatric, small adult, adult and large adult were heterogeneous among the different manufacturers. These authors concluded that cuff sizes need to be standardized and indicate bladder size, and suggested that they should be color-coded for convenience.

Number of measurements needed

Another important issue to consider is the number of measurements that should be repeated within a visit and between visits in order to determine a child's blood pressure. The work by Gillman and Cook (1993)[6] demonstrated that it depends on the instrument and technique. For auscultatory equipment, using a mercury manometer or random zero manometer, among 162 children aged 8 to 12 years, the systolic blood pressure values obtained after four weekly visits with three measurements per visit leveled off after about 2-3 measurements per visit, but the difference between visits was large until about the third or fourth visit. For oscillometric equipment, using the Dinamap model 845XT, among 106 children aged 9 to 13 years, the systolic blood pressure values obtained after three weekly visits with four measurements per visit demonstrated that for the Dinamap device the first of several measurements during one particular visit was generally higher than the following ones. The values obtained started to level off after 4-5 measurements within a visit, with the "first measurement effect" reproducible even after 3 consecutive visits.

The diastolic dilemma

There has been an ongoing controversy over whether the muffling (Korotkoff 4- K4) or disappearance of sounds (Korotkoff 5- K5) should be preferentially considered for the measurement of diastolic blood pressure in children.[11] Neither value correctly defines intra-arterial diastolic blood pressure, since K5 is approximately 9 mmHg higher than direct diastolic blood pressure and K5 is easier for the human ear to discern than K4[12]. Current recommendations therefore favor the use of K5.

The stethoscope diaphragm versus the bell

The bell is preferred for blood pressure auscultation in adults. This issue is still controversial in children, since placing the bell adequately in small children may compress the artery and produce falsely low diastolic values. Thus, some authors advocate the use of the diaphragm for small children,[13] while others suggest that the bell, when properly used, should accomplish better auscultatory results.[11]

Time of the day and ambient temperature

It is clear from ambulatory blood pressure studies that blood pressure varies over the 24 hours of the day, presenting lower values during sleep and higher values during wakefulness, with a peak in the morning and another in late afternoon.[14] There is a negative relationship between blood pressure and temperature. An increase of 10°C leads to a fall of approximately 5-7 mmHg in systolic and in diastolic blood pressure.[15,16]

Do we have normative blood pressure data for children?

Unfortunately we don't have normative blood pressure data for the pediatric population. Table 1 shows the lack of homogeneous methodology in nine studies that made up the Second Task Force of Blood Pressure Measurement in Children, reviewed by Rosner et al. in 1993.[17,18] The Update of the Second Task Force of Blood Pressure Measurement in Children added a tenth study to this list (National Health and Nutrition Examination Survey — NHANES III).[19] Table 2 shows the same lack of methodological homogeneity in the six studies from which the European pediatric blood pressure normative data is at present derived.[20]

It is important to emphasize that this lack of homogeneity is not a consequence of carelessness but rather of the multiple difficulties involved in performing epidemiological studies in the pediatric age group. Unfortunately, according to Nielsen et al. (1989)[21], "confusion concerning the most suitable cuff… is responsible for at least some of the scatter between blood pressure studies". Arafat and Mattoo (1999),[10] referring to the Update of the Second Task Force of Blood Pressure Measurement in Children, suggested that "a new multicenter study, using uniform criteria for cuff selection, may be necessary to establish the accuracy of the published nomogram on normal blood pressure in children".

What blood pressure measuring device should be used in the future?

The mercury manometer is our old friend. It is simple, accurate and easy to service. Standard Hg readings are the main basis for blood pressure-disease associations and, although

Table 1. Methodology parameters of the nine studies that made up the Second Task Force of Blood Pressure Measurement in Children[17,18]

Source	Age (years)	Instrument	Cuff width	Cuff length	Number of observers	Place of measurement
NIH	6 - 17	Mercury column	9.5 x 13	-	Multiple – physicians	Vans
Pittsburgh	1 - 5	Doppler	-	≥ 75% AC	-	Home
Dallas	13 - 17	Random zero	Multiple AC	Most of AC	Multiple	School
Bogalusa	1 - 17	Mercury column	4 cuffs AC	≥ 50% AC	3	School
Houston	3 - 17	Mercury column	2/3 arm length	≥ 75% AC	Multiple	Clinic
South Carolina	4 - 17	Mercury column	Multiple AC	-	Multiple	School
Iowa	5 - 17	Doppler Random zero	4 cuffs	-	Multiple	School
Providence	1 - 3	Random zero	2/3 arm length	-	Multiple	Clinic
Minnesota	9 - 17	Mercury column	5 cuffs AC	≥ 90% AC	4	School

NIH: National Institutes of Health; AC: arm circumference.

Table 2. Methodology parameters for the six studies that made up the European pediatric blood pressure normative data[19]

Source	Age (years)	Instrument	Cuff (cm)	Position	Place of measurement
Berlin-Bremen	11 - 17	Random zero	9 x 18 12 x 23 14 x 28	Sitting, Right arm	school
Cologne	15 - 19	LSH	12.5 x 28	Sitting, Right arm	school
Copenhagen	6 - 18	Random zero	6 x 20 9 x 28 12 x 35	Sitting, Right arm	school
Essen	4 - 18	LSH	2/3 arm length 8 x 2010 x 25	Sitting, Right arm	school/open
Nancy	4 - 17	Mercurycolumn	2/3 arm length9 x 22 12 x 26	Supine, Left arm	open
Zoetermeer	5 - 19	Random zero	10 x 23 14 x 23	Sitting, Left arm	open

LSH: London School of Hygiene equipment.

blood pressure readings with this instrument are subject to terminal digit preference and observer bias, observer training could possibly eliminate this problem. Unfortunately, mercury has toxic effects on the environment and the mercury manometer will have to be gradually replaced.

The aneroid sphygmomanometer registers blood pressure through a mechanically intricate system. Its accuracy is affected by everyday use. When calibrated against a mercury manometer a mean difference of 3 mmHg is acceptable, although up to 30% have errors of more than 7 mmHg. Readings are also subject to terminal digit preference and observer bias[22].

What about automated sphygmomanometry? The most widely used oscillometric devices are manufactured under the name "Dinamap". Several models have been developed, each with an updated algorithm. Validation data has to be obtained separately for each model. Systolic and diastolic blood pressures are calculated as a function of the mean arterial pressure, which is the point of maximal oscillation and are calibrated to be equivalent to intra-aortic pressures. The devices are easy to use and strongly correlated to intra-arterial readings. Accuracy is affected by arm movement and measurements are affected by the "first-reading effect".[23]

Automated oscillometric devices have to be validated before they can be recommended for clinical use. Validation protocols based on comparative measurements between oscillometric equipment and the mercury manometer were devised by the British Hypertension Society and the American Association of Medical Instruments.[24] The two protocols have now been reconciled and are used in association to validate oscillometric devices. Table 3 presents the instruments currently validated and recommended for hospital use and self-measurement (home blood pressure).[25,26]

Is it possible to use auscultatory and oscillometric devices interchangeably? Unfortunately not, as Korotkoff is approximately 3 mmHg lower than direct systolic blood pressure and, as we mentioned earlier, K5 is approximately 9 mmHg higher than direct diastolic blood pressure[12]. Park et al. (2001)[27]tested the Dinamap 8100 against the standard mercury manometer and found that the equipment detected mean systolic and diastolic blood pressure values significantly above auscultatory readings. On the other hand, Barker et al. (2000)[28] tested the Omron M1 against the standard mercury manometer and concluded that the Omron M1 overestimates higher pressures and underestimates lower pressures. There is a lack of validated and approved automated devices for use in clinical and epidemiological setting for the pediatric age group.[29]

Ambulatory blood pressure monitoring in children

The current general indications for ambulatory blood pressure monitoring are: identification of white coat hypertension, borderline hypertension, identification of nocturnal hypertension, drug resistant hypertension, indication of antihypertensive medication, hypertension of pregnancy and identification of hypotension.[30] Among the current issues for ambulatory blood pressure monitoring use in pediatrics, the main problem is the lack of definite normative data. The methodology is promising, since recordings show good accuracy and reproducibility in children.[31] Up-to-date definitions of sleep/wake periods, using actigraphy or a detailed diary of daily activities, are necessary for accurately determining the sleep blood pressure decline.[32] The white coat effect (white coat hypertension or white coat normotension) known within the literature relating to adults has also been confirmed in the pediatric population. In the same way as for adults, the left ventricular mass index and left ventricular hypertrophy are more closely related in children to 24-hour systolic blood pressure than with casual systolic blood pressure.[33] According to Kapuku et al. (1999),[34] left ventricular

Table 3. Automated oscillometric blood pressure measuring devices recommended for hospital use and self measurement (upper arm)[23]

DEVICE	AAMI	BHS	USE
HOSPITAL USE			
Datascope Accutorr Plus	Passed	A/A	At rest
CAS Model 9010	Passed	-	At rest (adults)In neonates
SELF MEASUREMENT			
Omron HEM 705 CP	Passed	B/A	At rest
Omron HEM 722 C	Passed	A/A	At rest (elderly people)
Omron HEM 735 C	Passed	B/A	At rest (elderly people)
Omron HEM 713 C	Passed	B/B	At rest
Omron HEM 737 Intellisense	Passed	B/B	At rest

AAMI: Association for the Advancement of Medical Instruments; BHS: British Hypertension Society: A and B represent grading criteria for evaluating the devices proposed by the BHS for systolic/diastolic pressure. Criteria for fulfilling protocol are that the mean difference between the standard sphygmomanometer and the device being validated should be within < 5 mmHg (SD < 8 mmHg). Grades represent the cumulative percentage of readings in agreement with 5 mm Hg, 10 mm Hg, and 15 mm Hg of the mercury standard. Grade A denotes greatest agreement with mercury standard and D denotes least agreement. A=best agreement (recommended for clinical use); B=good agreement (recommended); C=poor agreement (not recommended); D=worst agreement (not recommended).[25]

Table 4. List of some large pediatric ambulatory blood pressure monitoring studies showing methodological heterogeneity

Study	Device	Casual BP	Methodology	Interval between measurements	Data Analysis
Lurbe[32]	Spacelabs 90207	Mean of 3 mercury column	O	20 - 20' day 30 - 30' night	linear
Harshfied[33] Accutracker II	Spacelabs 5200	Mean of 10 Dinamap	O A	20 - 20' day 60 - 60' night 20 - 20'	linear
Reichert[35]	Spacelabs 90207Medilog	-	OA	15 - 15' day 30 - 30' night	linear
Lurbe[34]	Spacelabs 90207	Mean of 3 mercury column	O	20 - 20' day 30 - 30' night	Fourier
Soergel[36]	Spacelabs 90207Meditech		OO	15 – 20' day 30 – 50' night	linear
O'Sullivan[37]	TM2421	Mean of 4TM2421	O/A	30 - 30' day 60 - 60' night	linear

A = auscultatory ; O = oscillometric.

hypertrophy can be predicted by initial ambulatory systolic parameters.

In a recent study,[35] our group compared casual blood pressure and ambulatory blood pressure monitoring parameters among normotensive and hypertensive adolescents. Casual blood pressure was measured by two trained observers in two different and separate environments (clinic and ambulatory blood pressure monitoring unit). For systolic and diastolic blood pressure, in both normotensive and hypertensive populations, an alarm reaction was demonstrated during exposure to an unknown environment and observer (the ambulatory blood pressure monitoring unit). It should also be noted that, contrary to findings in adult populations, the mean casual systolic/diastolic blood pressure measured in the clinic was lower than the mean ambulatory blood pressure monitoring parameters while awake, for normotensive and hypertensive adolescents. The same study compared findings from casual auscultatory measurements (in the clinic and ambulatory blood pressure monitoring unit) and ambulatory blood pressure monitoring parameters among hypertensive adolescents. The parameters included systolic and diastolic ambulatory blood pressure monitoring methods, systolic and diastolic blood pressure descent during sleep (systolic/diastolic sleep blood pressure descent), systolic and diastolic blood pressure load. This led us to conclude that, although normality parameters are still under development for ambulatory blood pressure monitoring in the pediatric age range, ambulatory blood pressure monitoring is a promising tool for the follow-up of pediatric hypertensive patients. In this respect it seems superior to casual blood pressure evaluation, since it uncovers the white coat effect.

Ambulatory blood pressure monitoring device validation data for children is scarce. The Spacelabs 90207, widely used in pediatric studies, and the TM 2421, used in a recent large pediatric study[36] are equipment that has not scored well enough to be recommended according to the protocols of the British Hypertension Society and the American Association of Medical Instruments. At present, the only device recommended for children, according to these protocols, is the QuietTrak[37] Amazingly, this is a piece of auscultatory equipment, a type of device generally not adopted in pediatric studies because the noise of children in movement interferes with the accuracy of the microphone determination of the measured blood pressure value. Table 4 shows a list of some large pediatric ambulatory blood pressure monitoring studies[36,38-42] and demonstrates that, as for casual blood pressure, studies are being performed without methodological homogeneity. Different devices, with different measurement protocols, cannot be considered together to generate norms.

In conclusion, as of today, the main problem for the diagnosis and management of hypertension in children is the lack of good normative data for casual and ambulatory blood pressure values. The only solution for this issue is to propose a multicenter study with a homogenous protocol, in order to obtain normal multiethnic casual and ambulatory pediatric blood pressure values. Only then will studies to correlate blood pressure level and hypertensive end-organ damage be possible.

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RESUMO

Estudos epidemiológicos envolvendo medida de pressão arterial em crianças e adolescentes têm demonstrado que o valor da medida de pressão arterial na infância constitui-se no maior preditor dos níveis pressóricos do adulto. A hipertensão arterial no adulto eleva em duas a três vezes o risco individual de desenvolvimento de morbidade cardiovascular. O risco cardiovascular depende da pressão arterial propriamente dita, de fatores coexistentes e da presença de lesão instalada de órgãos-alvo. A acurácia na determinação da pressão arterial é, portanto, mandatória e um protocolo estruturado e padronizado para sua obtenção deveria ser estabelecido, possibilitando a comparação de resultados de estudos realizados em diferentes países. Este artigo discute os maiores determinantes da precisão de medida da pressão arterial casual e ambulatorial na criança.

PALAVRAS-CHAVE: Pressão. Arterial. Metodologia. Criança. Adolescente.

CLINICAL VIGNETTE

Common Problems in Blood Pressure Measurement

Hawkin Woo, M.D.

"The cuff of Riva-Rocci is placed on the middle third of the upper arm; the pressure within the cuff is quickly raised up to complete cessation of circulation below the cuff. Then, letting the mercury of the manometer fall one listens to the artery just below the cuff with a children's stethoscope. At first no sounds are heard. With the falling of the mercury in the manometer down to a certain height, the first short tones appear; their appearance indicates the passage of part of the pulse wave under the cuff. It follows that the manometric figure at which the first tone appears corresponds to the maximal pressure. With the further fall of the mercury in the manometer one hears the systolic compression murmurs, which pass again into tones (second). Finally, all sounds disappear. The time of the cessation of sounds indicates the free passage of the pulse wave; in other words at the moment of the disappearance of the sounds the minimal blood pressure within the artery predominates over the pressure in the cuff. It follows that the manometric figures at this time correspond to the minimal blood pressure."

- Nikolai Korotkov,
Presentation at the St. Petersburg
Imperial Military Academy, 1905[1]

Case Report

A 77-year-old female presented for evaluation of an elevated blood pressure reading. She has chronic hypertension and diabetes type II, stable on benazepril and metformin. She was scheduled to undergo an outpatient urologic procedure when the nurse found a blood pressure of 188/110 mm Hg. Because of the elevated reading, the nurse told the patient that the procedure would be canceled and that she should see her primary care physician. The patient asked if the nurse could repeat the blood pressure measurement without the thick sweater over her arm as he had done. He replied that the sweater made no difference. She decided to check her own blood pressure with a digital self-blood pressure monitor carried in her bag. Without an intervening sweater, she found a pressure of 144/86 mm Hg, and showed the finding to the nurse. He refused to acknowledge the reading and proceeded to escort her over to the urgent care center in the same building. The evaluating physician measured a blood pressure of 138/88 mm Hg by auscultation with an aneroid sphygmomanometer on her bare upper arm. Despite the evaluation, the patient was unable to complete the urological procedure that day.

Discussion

Blood pressure measurement is an important skill to master because improper measurement can lead to far reaching implications for a patient. For example, a patient may be incorrectly diagnosed with hypertension and treated unnecessarily with medications; or they may be denied a livelihood because of an elevated blood pressure reading during a commercial driver's license examination. As in the case report, improper blood pressure measurement can lead to a waste of resources. Recognizing common problems in blood pressure measurement will help health care providers reduce such important errors.

<u>Background and Types of Sphygmomanometers</u>

The era of blood pressure measurement began in the 1780s when the reverend and biologist Steven Hales cannulated a horse's artery.[2] While direct intra-arterial catheter measurement remains the gold standard for blood pressure measurement, this technique is obviously invasive and not widely applicable. The indirect method involves measuring the pressure needed to collapse an artery. In 1896, Dr. Scipione Riva-Rocci introduced a method that remains the foundation of modern indirect blood pressure measurement.[1] He invented a sphygmomanometer with an inflatable bladder and a column of mercury to measure systolic blood pressure by the cessation of the palpable distal pulse. In 1905, Dr. Nikolai Korotkov introduced the auscultatory method of indirect blood pressure measurement.[3] By using a stethoscope and a mercury sphygmomanometer, an examiner can determine systolic and diastolic blood pressure by the sounds that bear Dr. Korotkov's name. Because the indirect method involves determination of blood flow rather than pressure per se, the direct method is inherently more accurate. However, the direct and indirect methods generally yield similar readings.[4]

Innovations in the equipment have been made since the time of Dr. Korotkov. The aneroid sphygmomanometer is made up of a metal-like spring device with a needle pressure pointer instead of a column of mercury. More affordable and portable, the aneroid sphygmomanometer can be found all over health care sites mounted on walls and mobile stands. Because of the more complex components, the aneroid device is more prone to malfunction than a mercury sphygmomanometer.[5] Some devices have small pressure dials that can be more challenging to read exactly. If the needle at rest is not at the zero point, the device needs calibration. With regular calibration, the aneroid sphygmomanometer is just as accurate as the gold standard mercury sphygmomanometer for the indirect measurement of blood pressure.[6] However, regular calibration does not happen often at many practices.[7]

Introduced in 1984, the oscillometric sphygmomanometer is gaining in popularity, as it is the technology behind most of the automated digital devices purchased by the general public. An oscillometric device senses the oscillations in the artery wall, which reach their maximum at the mean arterial pressure. A proprietary algorithm then calculates the systolic and diastolic pressures. Easy to use and widely available, oscillometric machines can also reduce human error because of the digital displays and printed reports. However, some machines may be inaccurate.[8] Because of the vast market, not all machines can be independently tested against the standard protocols put forth by the American Association for the Advancement of Medical Instrumentation or the British Hypertension Society. Nevertheless, a number of devices have passed independent testing for accuracy.[9]

<u>A Method for Examiners</u>

Proper blood pressure measurement begins with the examiner taking an adequate amount of time to perform the measurement. If in a hurry, the examiner may release the pressure from the bladder too rapidly, leading to underestimation of systolic blood pressure and overestimation of diastolic pressure.[10] The examiner can be a source of many other errors, such as terminal digit bias. Physicians have a 12-fold preference for recording blood pressure results ending in zeroes.[10] Examiners may also be influenced by expectations of what a patient's blood pressure should be, subtly underestimating or overestimating values.[10]

The patient should be relaxed in a sitting position. Sitting or standing blood pressure values tend to be higher than supine readings.[11] A rest period of 3 to 5 minutes is advised prior to measurement to allow the patient to become comfortable to the environment and attenuate any effects of recent physical activity. The subject's feet should be resting on a surface and the back supported because isometric exertion can increase the blood pressure.[4] Avoiding verbal communication is also important for accuracy. Talking on the patient's part can cause an elevation as much as 10 mg Hg in the systolic and diastolic pressures.[12] Telling a patient that their pressure should be higher or lower can also influence their readings in the respective directions.[12] Other factors that can raise blood pressure include pain, cigarettes, caffeine, alcohol, decongestant medication, aspirin, and licorice.[13]

Select a cuff of the appropriate size for the person's arm. Technically what really matters is the size of the bladder inside the cuff. Generally the bladder is the same width as the overlying cuff, but it may not be as long as the cuff. The medical pioneers quickly realized that certain bladder sizes were of inadequate width or length to properly transmit the bladder pressure through the arm tissues to occlude the brachial artery.[14] Bladders that are too narrow or short for an arm, also termed "undercuffing," tend to overestimate the true blood pressure. Conversely, a bladder that is too wide or long, termed "overcuffing," tends to underestimate blood pressure.[15] The American Heart Association (AHA) recommends the bladder's width to be 40% of the arm's circumference, and the bladder's length to be able to encircle 80% of the arm.[4]

The choice of arm normally does not affect blood pressure readings. Multiple studies have not found a consistent inter-arm difference.[12] An inter-arm difference may represent pathology such as an aortic dissection. If the inter-arm difference is more than 20 mm Hg systolic or 10 mm Hg diastolic, consider referral for cardiovascular evaluation.[11] For hypertensive patients, the AHA recommends recording the higher inter-arm blood pressure.

Locate the brachial artery by palpation with your finger and position the bladder's midline, which is marked on many cuffs, over the pulsation. The cuff should be placed directly on the arm without intervening clothes, which can increase the arm circumference and cause the "undercuffing" error of overestimating blood pressure as in the case report.[14] The cuff should be snug on the arm because loose cuffs can lead to falsely elevated readings.[4] Leave a few centimeters between the lower edge of the cuff and the antecubital fossa for the stethoscope head to rest.

Position the arm horizontally at the patient's heart level, which is about midsternum. Placing the arm below heart level leads to elevated blood pressure readings, while placing the arm above heart level leads to underestimated readings. The arm should be supported on a surface or by the examiner. Without support, the arm has isometric tone, which can raise diastolic blood pressure by as much as 10%.[11]

Estimate the systolic blood pressure by the palpatory method. Palpate the radial pulse with your finger and inflate the cuff until the pulse disappears. Deflate the cuff carefully and note the pressure when the radial pulse reappears to palpation. This technique of estimating the systolic blood pressure helps in avoiding errors made from underinflation of the cuff in patients with an auscultatory gap.

Place the head of the stethoscope over the brachial pulse. The bell is preferred for optimal transmission of the low-pitched Korotkov sounds. However, the diaphragm is generally easier to hold in place. Also many examiners tend to press too firmly when using the bell and effectively convert it into a diaphragm anyway.[14] Avoid touching the stethoscope head against the cuff, which may lead to extraneous friction noises.

Inflate the bladder rapidly and steadily to about 20 to 30 mm Hg above the estimated systolic pressure from the palpatory method. Deflate the pressure gradually at about 2 to 3 mm Hg per second and listen for the repetitive auditory phenomena known as the Korotkov sounds. Note the level of pressure at the first appearance of repetitive clear tapping sounds, which gradually increase in intensity. This is Korotkov Phase I and corresponds to systolic blood pressure. Continue to steadily deflate the bladder and note the pressure when the sounds disappear. This is Korotkov Phase V and corresponds to the diastolic blood pressure. After the last Korotkov sound, continue gradual deflation for another 10 mm Hg to ensure that there are no more sounds. Then the bladder may be deflated rapidly and completely. Avoid too slow deflation rates during auscultation because it can cause forearm blood congestion and overestimate the diastolic pressure.[4] Record the measurements promptly.

Special Situations

Certain clinical situations deserve special mention. Elderly patients sometimes have stiff sclerotic vessels that are not readily compressed by a cuff. This can lead to falsely elevated systolic and diastolic blood pressure measurements, also termed "pseudohypertension."[4] Osler's maneuver is one way to assess if stiff vessels may be an issue.[16] In the maneuver, palpate an arterial pulse with your finger. Then proximally occlude the artery's flow with another finger or by inflating a cuff. The distal pulse should disappear. However, in a patient with stiff sclerotic vessels, the distal pulse will continue uninterrupted. Although more invasive, another method to rule out pseudohypertension is to look for a discrepancy between indirect and direct intra-arterial blood pressure measurement.

Obese patients can pose a challenge because a large arm may not fit the available cuffs. Every effort should be made to use a cuff of the appropriate size to avoid the problem of undercuffing. Otherwise, the patient may be falsely labeled hypertensive and be unnecessarily treated with antihypertensive medications.

Sometimes the Korotkov sounds can be heard at very low pressures, even all the way down to zero. This situation arises especially in children under age 12, pregnant women and patients with high cardiac output states, such as anemia, hyperthyroidism, febrile illness, aortic insufficiency and arteriovenous fistulas.[4,10] For these patients, the diastolic pressure should be recorded during Korotkov Phase IV, when the sounds become muffled, less distant and softer.[4,10]

Cardiac arrhythmias can cause errors in blood pressure measurement as well. Atrial fibrillation may cause systolic blood pressure to vary beat to beat because of the varying stroke volumes. Slower bladder deflation and multiple measurements should be made and averaged.[4] In bradyarrhythmias, deflation should be slower in order to avoid the problem of underestimating systolic and overestimating diastolic blood pressure.[10]

Conclusion

Many variables affect proper blood pressure measurement. Each of the three major types of sphygmomanometer (mercury, aneroid and oscillometric) has certain limitations in their accuracy. However, by using a systematic approach, one can minimize the errors and measure blood pressure more accurately.

The field of blood pressure measurement continues to evolve. The future of the mercury sphygmomanometers is in jeopardy. Because of concerns about safety, the Environmental Protection Agency and the AHA have targeted 2005 to "virtually eliminate" mercury.[5] As mercury sphygmomanometers are phased out and disappear, an interesting question is whether or not to continue measurement of blood pressure in units of mm Hg. Some experts have already recommended measuring blood pressure with the kilopascal.[17]

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AN1571

Digital Blood Pressure Meter

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INTRODUCTION

This application note describes a Digital Blood Pressure Meter concept which uses an integrated pressure sensor, analog signal–conditioning circuitry, microcontroller hardware/software and a liquid crystal display. The sensing system reads the cuff pressure (CP) and extracts the pulses for analysis and determination of systolic and diastolic pressure. This design uses a 50 kPa integrated pressure sensor (Motorola P/N: MPX5050GP) yielding a pressure range of 0 mmHg to 300 mmHg.

CONCEPT OF OSCILLOMETRIC METHOD

This method is employed by the majority of automated non–invasive devices. A limb and its vasculature are compressed by an encircling, inflatable compression cuff. The blood pressure reading for systolic and diastolic blood pressure values are read at the parameter identification point.

The simplified measurement principle of the oscillometric method is a measurement of the amplitude of pressure change in the cuff as the cuff is inflated from above the systolic pressure. The amplitude suddenly grows larger as the pulse breaks through the occlusion. This is very close to systolic pressure. As the cuff pressure is further reduced, the pulsation increase in amplitude, reaches a maximum and then diminishes rapidly. The index of diastolic pressure is taken where this rapid transition begins. Therefore, the systolic blood pressure (SBP) and diastolic blood pressure (DBP) are obtained by identifying the region where there is a rapid increase then decrease in the amplitude of the pulses respectively. Mean arterial pressure (MAP) is located at the point of maximum oscillation.

HARDWARE DESCRIPTION AND OPERATION

The cuff pressure is sensed by Motorola's integrated pressure X–ducer™. The output of the sensor is split into two paths for two different purposes. One is used as the cuff pressure while the other is further processed by a circuit. Since MPX5050GP is signal–conditioned by its internal op–amp, the cuff pressure can be directly interfaced with an analog–to–digital (A/D) converter for digitization. The other path will filter and amplify the raw CP signal to extract an amplified version of the CP oscillations, which are caused by the expansion of the subject's arm each time pressure in the arm increases during cardiac systole.

The output of the sensor consists of two signals; the oscillation signal ($\approx$ 1 Hz) riding on the CP signal ($\leq$ 0.04 Hz). Hence, a 2–pole high pass filter is designed to block the CP signal before the amplification of the oscillation signal. If the CP signal is not properly attenuated, the baseline of the oscillation will not be constant and the amplitude of each oscillation will not have the same reference for comparison. Figure 1 shows the oscillation signal amplifier together with the filter.

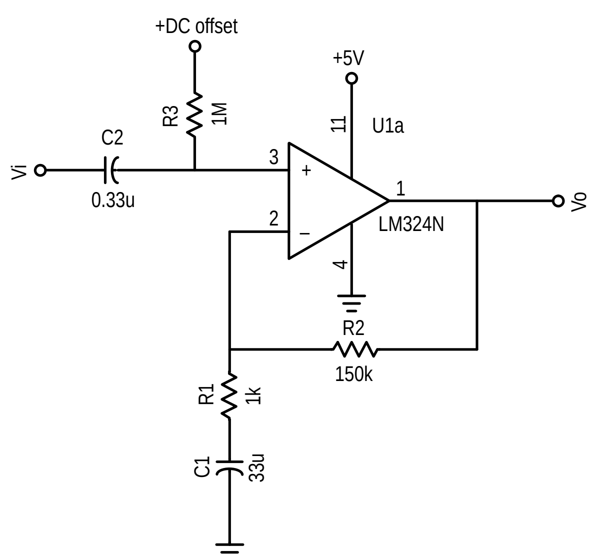

Figure 1. Oscillation Signal Amplifier

The filter consists of two RC networks which determine two cut–off frequencies. These two poles are carefully chosen to ensure that the oscillation signal is not distorted or lost. The two cut–off frequencies can be approximated by the following equations. Figure 2 describes the frequency response of the filter. This plot does not include the gain of the amplifier.

$$f_{P1} = \frac{1}{2\pi R_1 C_1}$$

$$f_{P2} = \frac{1}{2\pi R_3 C_2}$$

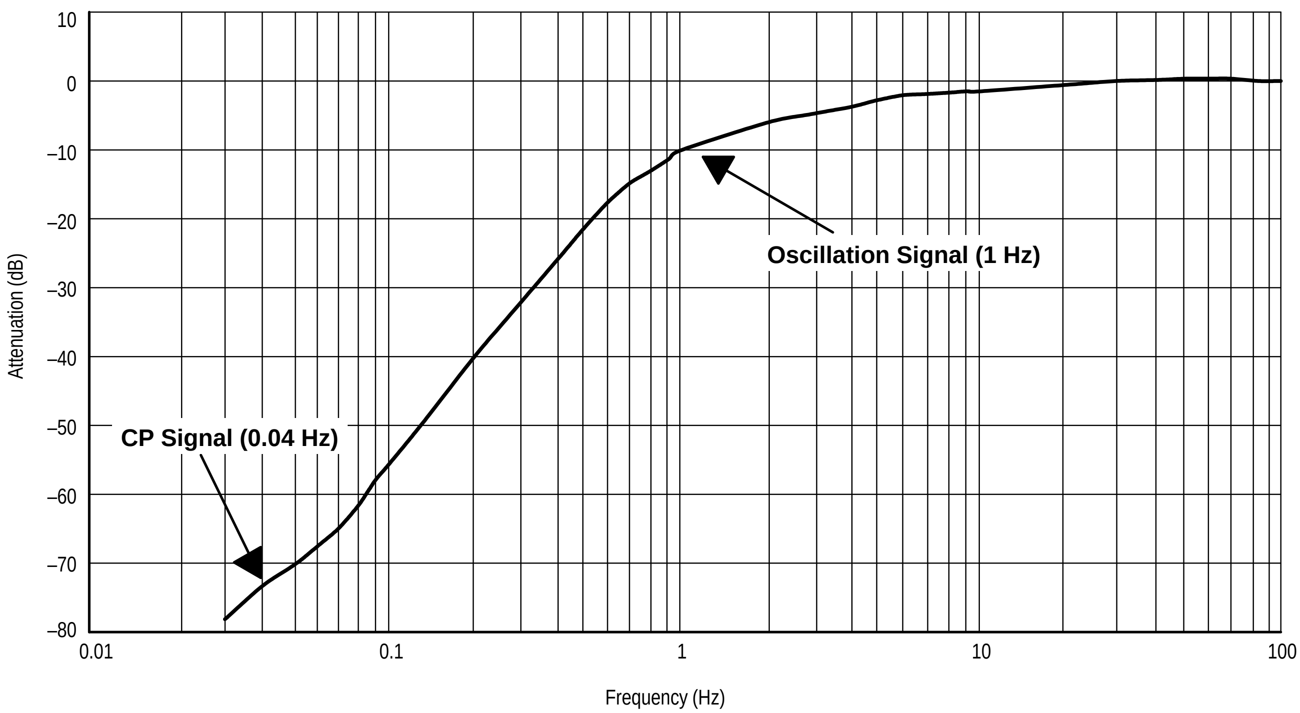

Figure 2. Filter Frequency Response

The oscillation signal varies from person to person. In general, it varies from less than 1 mmHg to 3 mmHg. From the transfer function of MPX5050GP, this will translate to a voltage output of 12 mV to 36 mV signal. Since the filter gives an attenuation of 10 dB to the 1 Hz signal, the oscillation signal becomes 3.8 mV to 11.4 mV respectively. Experiments indicate that, the amplification factor of the amplifier is chosen to be 150 so that the amplified oscillation signal is within the output limit of the amplifier (5 mV to 3.5 V). Figure 3(a) shows the output from the pressure sensor and Figure 3(b) shows the extracted oscillation signal at the output of the amplifier.

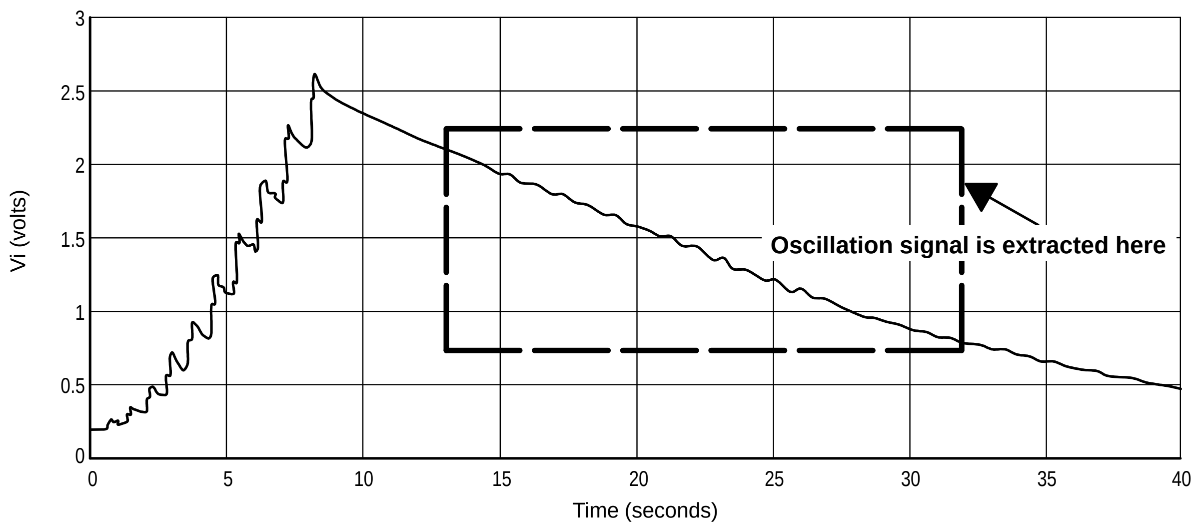

Figure 3. CP signal at the output of the pressure sensor

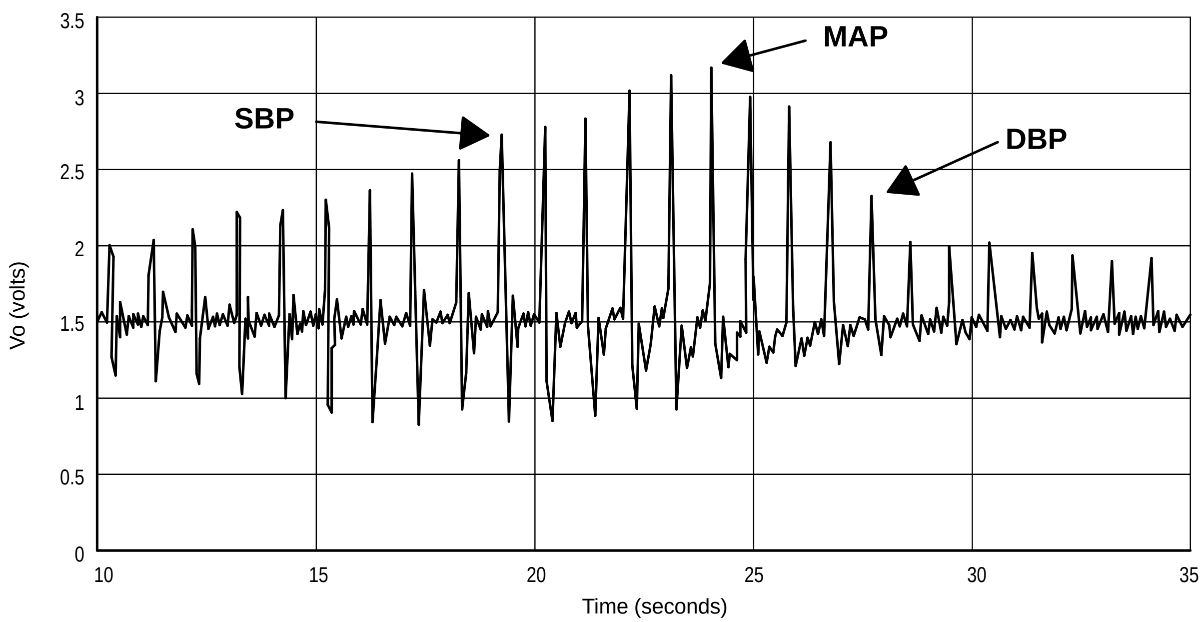

Figure 3b. Extracted oscillation signal at the output of amplifier

Referring to the schematic, Figure 4, the MPX5050GP pressure sensor is connected to PORT D bit 5 and the output of the amplifier is connected to PORT D bit 6 of the microcontroller. This port is an input to the on–chip 8–bit analog–to–digital (A/D) converter. The pressure sensor provides a signal output to the microprocessor of approximately 0.2 Vdc at 0 mmHg to 4.7 Vdc at 375 mmHg of applied pressure whereas the amplifier provides a signal from 0.005 V to 3.5 V. In order to maximize the resolution, separate voltage references should be provided for the A/D instead of using the 5 V supply. In this example, the input range of the A/D converter is set at approximately 0 Vdc to 3.8 Vdc. This compresses the range of the A/D converter around 0 mmHg to 300 mmHg to maximize the resolution; 0 to 255 counts is the range of the A/D converter. V_{RH} and V_{RL} are the reference voltage inputs to the A/D converter. The resolution is defined by the following:

$$\text{Count} = [(V_{Xdcr} - V_{RL})/(V_{RH} - V_{RL})] \times 255$$

The count at 0 mmHg = [(0.2 – 0)/(3.8 – 0)] x 255 ≈ 14

The count at 300 mmHg = [(3.8 – 0)/(3.8 – 0)] x 255 ≈ 255

Therefore the resolution = 255 – 14 = 241 counts. This translates to a system that will resolve to 1.24 mmHg.

The voltage divider consisting of R5 and R6 is connected to the +5 volts powering the system. The output of the pressure sensor is ratiometric to the voltage applied to it. The pressure sensor and the voltage divider are connected to a common supply; this yields a system that is ratiometric. By nature of this ratiometric system, variations in the voltage of the power supplied to the system will have no effect on the system accuracy.

The liquid crystal display (LCD) is directly driven from I/O ports A, B, and C on the microcontroller. The operation of a LCD requires that the data and backplane (BP) pins must be driven by an alternating signal. This function is provided by a software routine that toggles the data and backplane at approximately a 30 Hz rate.

Other than the LCD, there are two more I/O devices that are connected to the pulse length converter (PLM) of the microcontroller; a buzzer and a light emitting diode (LED). The buzzer, which connected to the PLMA, can produce two different frequencies; 122 Hz and 1.953 kHz tones. For instance when the microcontroller encounters certain error due to improper inflation of cuff, a low frequency tone is alarm. In those instance when the measurement is successful, a high frequency pulsation tone will be heard. Hence, different musical tone can be produced to differential each condition. In addition, the LED is used to indicate the presence of a heart beat during the measurement.

The microcontroller section of the system requires certain support hardware to allow it to function. The MC34064P–5 provides an undervoltage sense function which is used to reset the microprocessor at system power–up. The 4 MHz crystal provides the external portion of the oscillator function for clocking the microcontroller and provides a stable base for time based functions, for instance calculation of pulse rate.

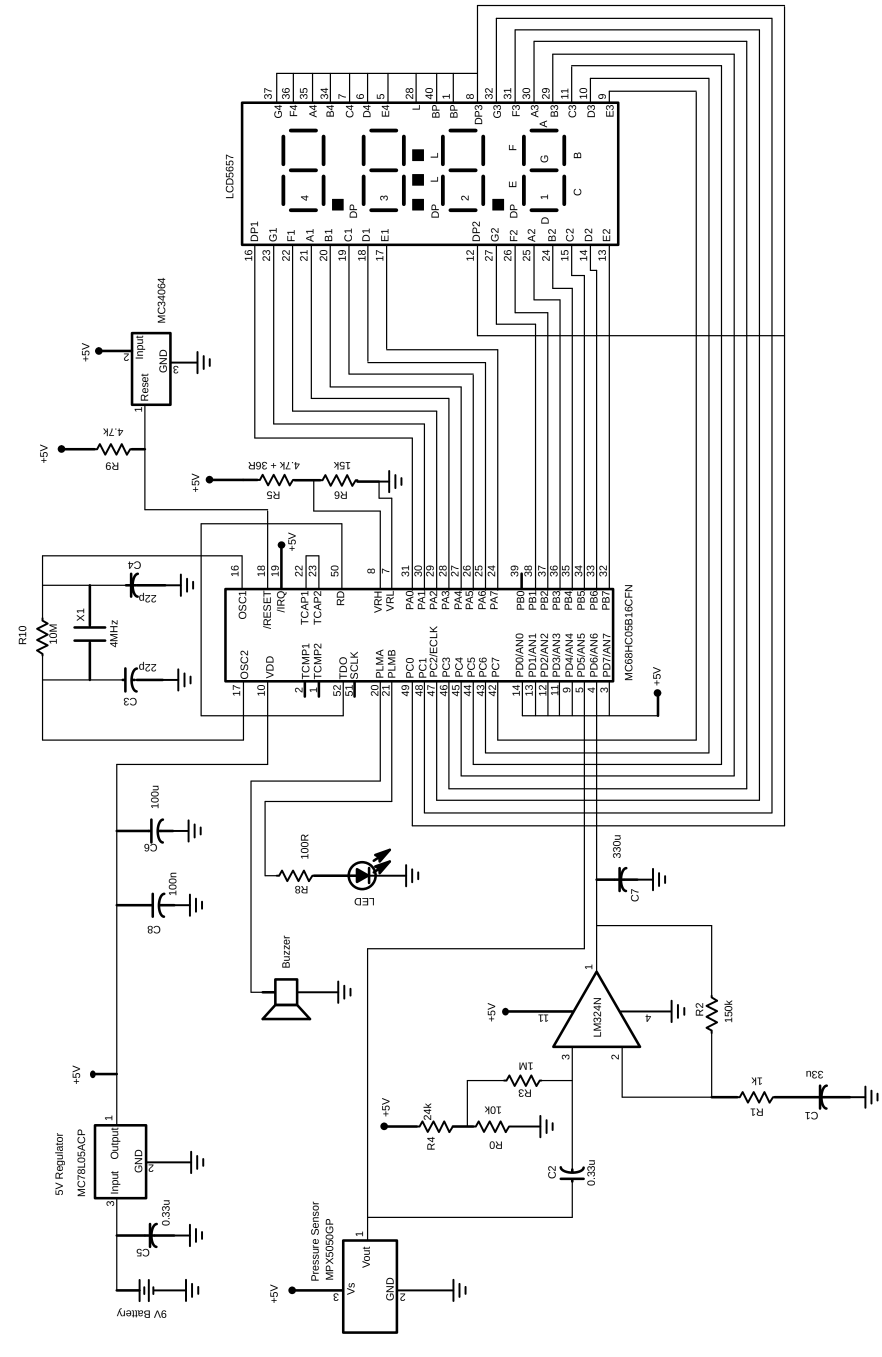

Figure 4. Blood Pressure Meter Schematic Drawing

SOFTWARE DESCRIPTION

Upon system power–up, the user needs to manually pump the cuff pressure to approximately 160 mmHg or 30 mmHg above the previous SBP. During the pumping of the inflation bulb, the microcontroller ignores the signal at the output of the amplifier. When the subroutine TAKE senses a decrease in CP for a continuous duration of more than 0.75 seconds, the microcontroller will then assume that the user is no longer pumping the bulb and starts to analyze the oscillation signal. Figure 5 shows zoom–in view of a pulse.

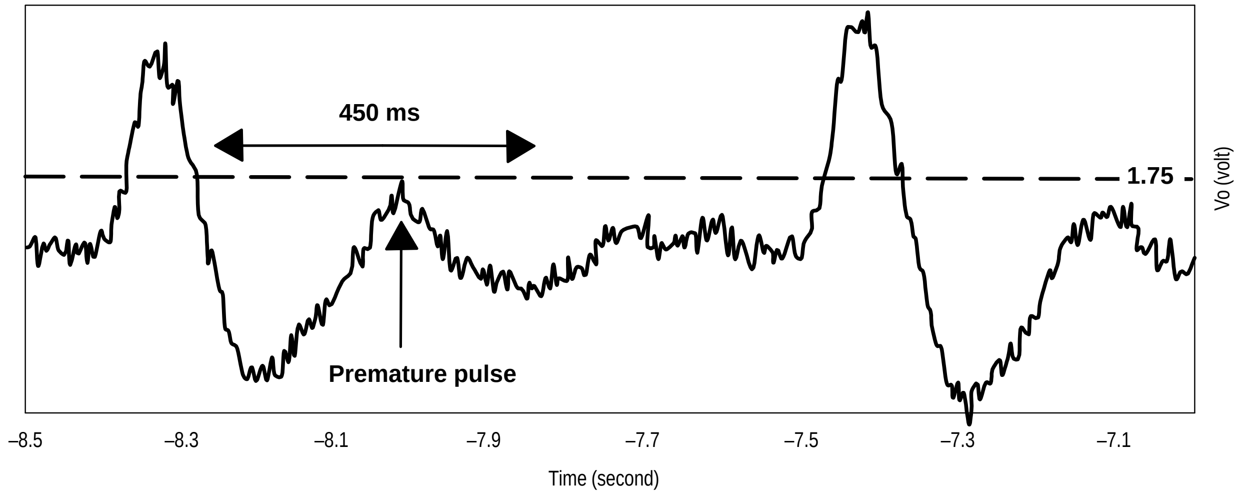

Figure 5. Zoom–in view of a pulse

First of all, the threshold level of a valid pulse is set to be 1.75 V to eliminate noise or spike. As soon as the amplitude of a pulse is identified, the microcontroller will ignore the signal for 450 ms to prevent any false identification due to the presence of premature pulse ”overshoot” due to oscillation. Hence, this algorithm can only detect pulse rate which is less than 133 beats per minute. Next, the amplitudes of all the pulses detected are stored in the RAM for further analysis. If the microcontroller senses a non–typical oscillation envelope shape, an error message (“Err”) is output to the LCD. The user will have to exhaust all the pressure in the cuff before re–pumping the CP to the next higher value. The algorithm ensures that the user exhausts all the air present in the cuff before allowing any re–pumping. Otherwise, the venous blood trapped in the distal arm may affect the next measurement. Therefore, the user has to reduce the pressure in the cuff as soon as possible in order for the arm to recover. Figure 6 is a flowchart for the program that controls the system.

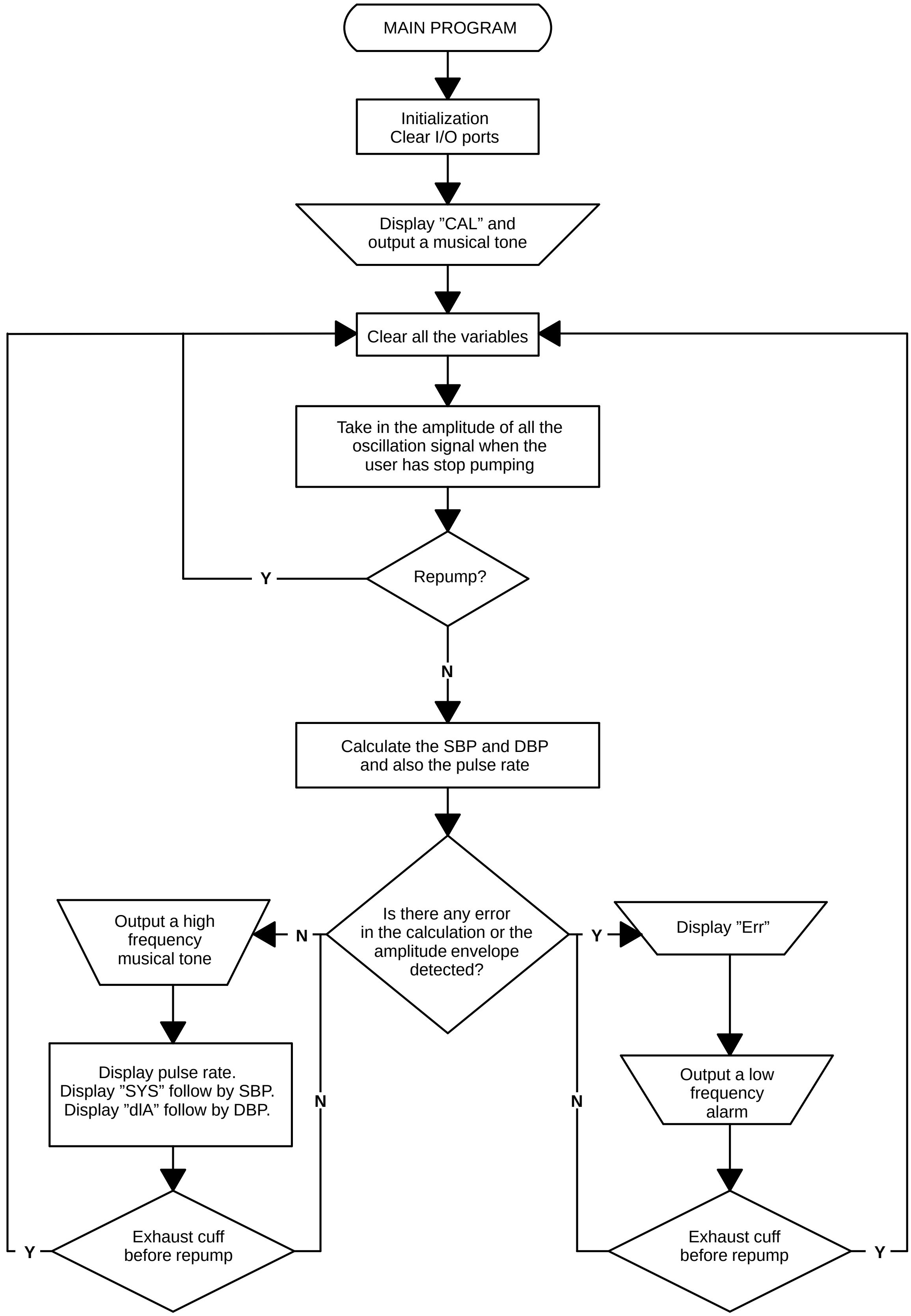

Figure 6. Main program flowchart

SELECTION OF MICROCONTROLLER

Although the microcontroller used in this project is MC68HC05B16, a smaller ROM version microcontroller can also be used. The table below shows the requirement of microcontroller for this blood pressure meter design in this project.

Table 1. Selection of microcontroller

On–chip ROM space 2 kilobytes
On–chip RAM space 150 bytes
2–channel A/D converter (min.)
16–bit free running counter timer
LCD driver
On–chip EEPROM space 32 bytes
Power saving Stop and Wait modes

CONCLUSION

This circuit design concept may be used to evaluate Motorola pressure sensors used in the digital blood pressure meter. This basic circuit may be easily modified to provide suitable output signal level. The software may also be easily modified to provide better analysis of the SBP and DBP of a person.

REFERENCES

Lucas, Bill (1991). "An Evaluation System for Direct Interface of the MPX5100 Pressure Sensor with a Microprocessor," Motorola Application Note AN1305.

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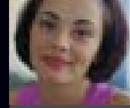

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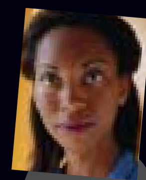
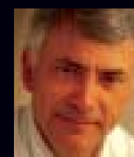
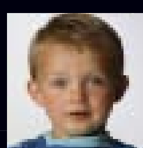
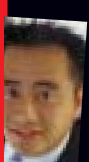
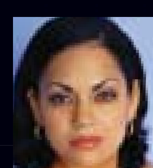


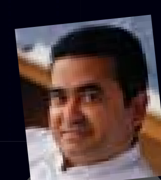




Heart Disease and Stroke Statistics — 2005 Update







Our guide to current statistics and the supplement to our "Heart and Stroke Facts"

Statistical Fact Sheets

Information for the population groups and risk factors listed below is available at **americanheart.org**. Click on "Publications & Resources," then "Statistics," then "Statistical Fact Sheets."

Populations

African Americans and Cardiovascular Diseases — Statistics
American Indians or Alaska Natives and Cardiovascular Diseases — Statistics
Asian or Pacific Islanders and Cardiovascular Diseases — Statistics
Baby Boomers and Cardiovascular Diseases — Statistics
Hispanics or Latinos and Cardiovascular Diseases — Statistics
International Cardiovascular Disease Statistics [includes death rates by country]
Men and Cardiovascular Diseases — Statistics
Older Americans and Cardiovascular Diseases — Statistics
Whites and Cardiovascular Diseases — Statistics
Women and Cardiovascular Diseases — Statistics
Youth and Cardiovascular Diseases — Statistics

Risk Factors

Diabetes Mellitus — Statistics
High Blood Cholesterol and Other Lipids — Statistics
High Blood Pressure — Statistics
Metabolic Syndrome — Statistics
Overweight and Obesity — Statistics
Physical Inactivity — Statistics
Tobacco — Statistics

Miscellaneous

Cardiovascular Procedures — Statistics
Congenital Cardiovascular Defects — Statistics
Death Rates by State — Statistics
Hospital Discharges for Cardiovascular Diseases — Statistics
Leading Causes of Death — Statistics
Nutrition and Cardiovascular Diseases — Statistics
Out-of-Hospital Cardiac Deaths by State — Statistics
Peripheral Arterial Disease — Statistics
Sudden Deaths From Cardiac Arrest — Statistics
(Throughout this publication, statistics relating to sudden death from cardiac arrest are highlighted in pink.)
Understanding and Using American Heart Association Statistics
Venous Thromboembolism — Statistics

Check Our Web Sites

For more information on cardiovascular diseases including stroke, see **americanheart.org** and **StrokeAssociation.org**.

Table of Contents

About These Statistics

All statistics are for the most recent year available. Prevalence, mortality and hospitalizations are computed for 2002 unless otherwise noted. Incidence estimates come from specific studies and remain the same until new studies become available. “Total mention mortality” is for 2001. Economic costs are for 2005. Due to late release of mortality data, some mortality are not updated to 2002. **U.S. and state death rates and prevalence rates are age-adjusted (unless otherwise specified) per 100,000 population using the 2000 U.S. standard as the base.**

Do not compare the prevalence or incidence statistics with those in past issues of this publication. It can lead to serious misinterpretation of time trends.

If you have questions about statistics or any points made in this booklet, please contact the Biostatistics Program Coordinator at the National Center, Nancy.Haase@heart.org, 214-706-1423. Direct media inquiries to News Media Relations at inquiries@heart.org or 214-706-1173.

We do our utmost to ensure that this booklet is error-free. If we discover errors after publication, we’ll provide corrections at our Web site, **americanheart.org**. Click on “Publications & Resources,” then “Statistics,” then “Heart Disease and Stroke Statistics — 2005 Update.”

Acknowledgement

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1 Statistical Highlights

Overweight and Obesity

Now commonly described as modern epidemics, overweight and obesity together represent the No. 2 preventable cause of death in the United States, second only to cigarette smoking. Today, nearly seven of every 10 U.S. adults are overweight, and about three of every 10 are obese. And among children, overweight and obesity are also rising at an alarming rate.

- Since 1991, the prevalence of obesity has increased 75 percent.
- Obesity has increased among every ethnic group.
- The estimated annual cost of obesity-related diseases in the United States is about $100 billion.

For more information on overweight and obesity, see page 39.

Physical Inactivity

Physical inactivity, a risk factor for cardiovascular disease (CVD), is becoming increasingly prevalent. More than ever, Americans are turning down or missing out on important opportunities to stay in shape. And while our level of activity declines, our rates of heart disease increase.

- 38.6 percent of United States adults report no leisure-time physical activity.
- The relative risk of coronary heart disease associated with physical inactivity ranges from 1.5 to 2.4, which is comparable to high blood cholesterol, high blood pressure or cigarette smoking.

For more information on physical inactivity, see page 37.

Women and Cardiovascular Disease

According to an American Heart Association survey, only 13 percent of women consider CVD their greatest health risk. But statistics show that no disease, not even cancer, claims as many women's lives as CVD. It causes about a death a minute among females —nearly half a million female lives every year. That's more lives than are claimed by the next six causes of death combined.

Information on women and cardiovascular disease is included throughout this publication.

Stroke

About 700,000 Americans will have a stroke this year — that's someone every 45 seconds. Stroke is our nation's No. 3 killer and a leading cause of severe, long-term disability. Some population groups, including African Americans, American Indians or Alaska Natives, and Mexican Americans, have a higher than average risk. Recent studies also indicate that the risk of stroke may be higher in women during pregnancy and the six weeks following childbirth.

For more information on stroke, see page 16.

Children and Cardiovascular Disease

CVD ranks as the No. 2 cause of death (behind certain accidents) for children under age 15. And in 2002 about 210,000 cardiovascular procedures were performed on people age 15 or younger.

Thousands of babies are born each year with congenital cardiovascular defects. These defects claim more lives than any other kind of congenital defects — about 2,200 lives a year of children under age 15. About 1 million Americans alive today have congenital cardiovascular defects — and about 25 percent are children.

Most CVD in children is due to congenital cardiovascular malformations. However, more and more children are also developing many preventable risk factors for cardiovascular diseases — such as high blood pressure (page 21), smoking (page 32), high blood cholesterol (page 35), physical inactivity (page 37), overweight (page 39), and the metabolic syndrome (page 44).

For more information on congenital cardiovascular defects, see page 24.

Cardiovascular Diseases

(ICD/9 390–459, 745–747) (ICD/10 I00–I99, Q20–Q28; see Glossary for details and definitions)

Population Group	Prevalence 2002	Mortality 2002#	Hospital Discharges 2002	Cost 2005
Total population	70,100,000 (34.2%)	927,448	6,373,000	$393.5 billion
Total males	32,500,000 (34.4%)	433,825 (46.8%)*	3,209,000	—
Total females	37,600,000 (33.9%)	493,623 (53.2%)*	3,164,000	—
White males	34.3%	375,392	—	—
White females	32.4%	428,461	—	—
Black males	41.1%	48,993	—	—
Black females	44.7%	56,721	—	—
Mexican-American males	29.2%	—	—	—
Mexican-American females	29.3%	—	—	—

Note: (—) = data not available.

* These percentages represent the portion of total mortality that is males vs. females.

Sources: ***Prevalence:*** *NHANES (1999–02), CDC/NCHS and NHLBI; data for white and black males and females are for non-Hispanics. Total population data include children; percentages for racial/ethnic groups are age-adjusted for Americans age 20 and older.These data are based on self reports.* ***Mortality:*** *CDC/NCHS; data for white and black males and females include Hispanics; data include congenital cardiovascular disease.* ***Hospital discharges:*** *CDC/NCHS; data include people both living and dead. Cost: NHLBI; data include direct and indirect costs for 2005.*

— Preliminary mortality.

Prevalence

Of the 70,100,000 Americans with one or more types of cardiovascular disease (CVD), 27,000,000 are estimated to be age 65 or older. (National Health and Nutrition Examination Survey [NHANES 1999–2002], CDC/NCHS. Bullet points below are also from NHANES 1999–2002 unless otherwise noted.)

The following are the latest estimates of prevalence for these conditions. Due to overlap, it is not possible to add these conditions to arrive at a total.

- High blood pressure (HBP) — 65,000,000. (Defined as systolic pressure 140 mm Hg or greater and/or diastolic pressure 90 mm Hg or greater, taking antihypertensive medication or being told at least twice by a physician or other health professional that you have high blood pressure.)
- Coronary heart disease — 13,000,000.
  - — Myocardial infarction (heart attack) — 7,100,000.
  - — Angina pectoris (chest pain) — 6,400,000.
- Congestive heart failure — 4,900,000.
- Stroke —5,400,000.
- Congenital cardiovascular defects — 1,000,000. (Unpublished NHIS survey data, 1993–95, CDC/NCHS)
- 1 in 4 males and females has some form of CVD. (NHANES 2001–02, CDC/NCHS)
- The following prevalences are for people age 18 and older: (NHIS [2001], CDC/NCHS, *Vital and Health Statistics*, Series 10, No. 219, Feb. 2004)
  - — Among whites only, 12.2 percent have heart disease, 20.1 percent have hypertension and 2.4 percent have had a stroke.
  - — Among blacks or African Americans only, 9.6 percent have heart disease, 26.7 percent have hypertension and 2.9 percent have had a stroke.
  - — Among Hispanics or Latinos, 6.1 percent have heart disease, 14.5 percent have hypertension and 1.8 percent have had a stroke.
  - — Among Asians, 5.4 percent have heart disease, 13.5 percent have hypertension and 2.2 percent have had a stroke.
  - — Among Native Hawaiians or other Pacific Islanders, 1.6 percent have heart disease, 14.5 percent have hypertension and 6.3 percent have had a stroke.
  - — Among American Indians or Alaska Natives, 12.6 percent have heart disease, 25.0 percent have hypertension and 1.1 percent have had a stroke.

Incidence

- Based on the NHLBI's Framingham Heart Study (FHS) in its 44-year follow-up of participants and the 20-year follow-up of their offspring… (Hurst W. *The Heart, Arteries and Veins.* 10th ed. New York, NY: McGraw-Hill; 2002)
  - — The average annual rates of first major cardiovascular events rise from 7 per 1,000 men at ages 35–44 to 68 per 1,000 at ages 85–94. For women, comparable rates occur 10 years later in life. The gap narrows with advancing age.
  - — Under age 75, a higher proportion of CVD events due to coronary heart disease (CHD) occur in men than in women, and a higher proportion of events due to congestive heart failure (CHF) occur in women than in men.
- The aging of the population will undoubtedly result in an increased incidence of chronic diseases, including coronary artery disease, heart failure and stroke. *(Circulation* 2002;106:1602–5)
  - — The U.S. Census estimates that there will be 40 million Americans age 65 and older in 2010.

- — There's been an explosive increase in the prevalence of obesity and type 2 diabetes. Their related complications — hypertension, hyperlipidemia and atherosclerotic vascular disease — also have increased.
- — An alarming increase in unattended risk factors in the younger generations will continue to fuel the cardiovascular epidemic for years to come.

- Among American Indian men ages 45–74, the incidence of CVD ranges from 1.5 to 2.8 percent. Among women it ranges from 0.9 to 1.5 percent. *(Strong Heart Study Data Book,* NIH, NHLBI, Nov. 2001)
- Among American Indians ages 65–74, the annual rates per 1,000 population of new and recurrent heart attacks are 6.8 for men and 2.2 for women (SHS[1991–98], NHLBI)

Mortality

CVD accounted for 38.0 percent of all deaths or 1 of every 2.6 deaths in the United States in 2002. CVD mortality was nearly 60 percent of "total mortality." This means that of over 2,400,000 deaths from all causes, CVD was listed as a primary or contributing cause on about 1,400,000 death certificates.

- Since 1900 CVD has been the No. 1 killer in the United States every year but 1918. Nearly 2,600 Americans die of CVD each day, an average of 1 death every 34 seconds. CVD claims about as many lives each year as the next 5 leading causes of death combined, which are cancer, chronic lower respiratory diseases, accidents, diabetes mellitus, and influenza and pneumonia.
- Other causes of death in 2002 — cancer 557,271; accidents 106,742; Alzheimer's disease 58,866; HIV (AIDS) 14,095.
- The 2002 preliminary CVD death rates were 380.4 for males and 273.4 for females. Cancer death rates were 238.9 for males and 163.1 for females. Breast cancer claimed the lives of 41,514 females in 2002; lung cancer claimed 67,542. The death rates were 25.6 for breast cancer and 41.6 for lung cancer. 1 in 30 female deaths is from breast cancer, while 1 in 2.5 is from CVD.
- Over 150,000 Americans killed by CVD each year are under age 65. In 2002, 32 percent of deaths from CVD occurred prematurely (i.e., before age 75, the approximate average life expectancy in that year).
- The 2002 overall preliminary death rate from CVD was 320.5. The rates were 373.8 for white males and 492.5 for black males; 265.6 for white females and 368.1 for black females. From 1992 to 2002 death rates from CVD (ICD/10 I00–I99) declined 18.0 percent. In the same 10-year period actual CVD deaths increased 0.8 percent.
- Based on revised 2000 population data, the average life expectancy of people born in the United States is now 77.3 years. According to the CDC/NCHS, if all forms of major CVD were eliminated, life expectancy would rise by almost 7 years. If all forms of cancer were eliminated, the gain would be 3 years. According to the same study, the probability at birth of eventually dying from major CVD (I00–I78) is 47 percent, and the chance of dying from cancer is 22 percent. Additional probabilities are 3 percent for accidents, 2 percent for diabetes and 0.7 percent for HIV. *(U.S. Decennial Life Tables for 1989–91,* Vol. 1, No. 4, Sept. 1999)
- The CDC estimates that each year 400,000 to 460,000 people die of heart disease in an emergency department or before reaching a hospital, which accounts for over 60 percent of all cardiac deaths. Heart disease death in this study included deaths from all forms of heart disease (Diseases of the Heart) and congenital malformations of the heart (I00–I09, I11, I13, I20–I51, Q20–Q24). *(Morbidity and Mortality Weekly Report [MMWR],* Vol. 51, No. 6, Feb. 15, 2002, CDC/NCHS) See the **Out-of-Hospital Cardiac Deaths by State** fact sheet, instructions on page 1a.
- In 2001, the number of premature deaths (<65 years) from diseases of the heart (I00–I09, I11, I13, I20–I51) was greatest among American Indians or Alaska Natives (36 percent) and blacks (31.5 percent) and lowest among whites (14.7 percent). Premature death was higher for Hispanics (23.5 percent) than non-Hispanics (16.5 percent), and for males (24 percent) than females (10 percent). Hispanic whites (23.3 percent) had lower proportions than Hispanic blacks (27.5 percent), and non-Hispanic whites (14.4 percent) had lower proportions than non-Hispanic blacks (31.5 percent). (Behavioral Risk Factor Surveillance System, CDC/NCHS, *MMWR,* Vol. 53, No. 6, Feb. 20, 2004, CDC/NCHS)
- Yearly totals of out-of-hospital death (ICD/9 codes: 390–398, 402, and 404–429) in people ages 15 to 34 rose from 2,719 in 1989 to 3,000 in 1996. Alarmingly, though the numbers are very small, the death rate increased by 30 percent in young women. Death rates were also higher among young African Americans than among Caucasians. *(Sudden Cardiac Death in U.S. Young Adults, 1989–96,* CDC, 2001)
- Age-adjusted death rates for Diseases of the Heart from 1990 to 1998 declined 15 percent for non-Hispanic whites, 11 percent for non-Hispanic blacks, 17 percent for Hispanics, 14 percent for Asian or Pacific Islanders and 8 percent for American Indians or Alaska Natives. In 1998 the rate for non-Hispanic blacks was 2.8 times the rate for Asian or Pacific Islanders. *(Healthy People 2000, Statistical Notes,* No. 23, CDC/NCHS, Jan. 2002)

Risk Factors

For statistics on individual CVD risk factors, see Chapter 9 beginning on page 32.

- Among adults age 18 and older, the prevalence of 2 or more risk factors increased from 23.6 percent in 1991 to 27.9 percent in 1999. It increased significantly for both men and women and for all race, ethnic, age and education groups. (BRFSS, CDC/NCHS, *Arch Intern Med* 2004;164:181–8)
  - — Among persons with 2 risk factors in 1999, the most common combination was HBP and high cholesterol (23.9 percent).
  - — Among those with 3 risk factors, the most common combination was HBP, high cholesterol and obesity (32.5 percent).

- — Among those with 4 risk factors, about 43 percent had the combination of HBP, high cholesterol, obesity and smoking. Another 40 percent had HBP, high cholesterol, obesity and diabetes. These risk factor combinations were also the most common combinations in earlier years.
- Black and Mexican-American women have higher prevalence of CVD risk factors than white women of comparable socioeconomic status (SES). (NHANES III [1988–94], CDC/NCHS, *JAMA* 1998;280:356–62)
- Among American Indians or Alaska Natives age 18 and older, 63.7 percent of men and 61.4 percent of women have one or more CVD risk factors (hypertension, current cigarette smoking, high blood cholesterol, obesity or diabetes). If data on physical inactivity had been included in this analysis, the prevalence of risk factors probably would have been higher. (BRFSS [1997], CDC/NCHS)
- Data from the BRFSS survey on adults 18 and older, from 1991–2001, showed the prevalence of reported HBP, high cholesterol, diabetes and obesity increased. The prevalence of smoking remained nearly the same, and the prevalence of no known risk factors for diseases of the heart and stroke declined. As a result, the national burden of Diseases of the Heart and stroke is expected to increase. (MMWR, Vol. 53(01);4–7, CDC/NCHS)
- Data from the BRFSS study of the CDC/NCHS showed that young women and men, ages 18 to 24, had poor health profiles and experienced adverse changes from 1990 to 2000. After adjustment for education and income, these young people had the highest prevalence of smoking (34–36 percent current smokers among whites); the largest increases in smoking (10–12 percent among whites and 9 percent among Hispanic women); large increases in obesity (4–9 percent increase in all groups). All groups had high levels of sedentary behavior (approximately 20–30 percent) and low vegetable or fruit intake (approximately 35–50 percent). In contrast, older Hispanics and older black men, ages 65–74, showed some of the most positive changes. They had the largest decreases in smoking (Hispanic women), largest decreases in sedentary behavior (Hispanic women and black men), and largest increases in vegetable or fruit intake (Hispanic women and black men). *(Am J Health Promot* 2004;19[1]:19–27)
- Data from the Chicago Heart Association Detection Project (1967–73) showed that in younger women (age 18–39) with favorable levels for all five major risk factors (blood pressure, serum cholesterol, BMI, diabetes and smoking), CHD and CVD are rare, and long-term and all-cause mortality are much lower compared with others. (JAMA 2004;292:1588-92)

Hospital/Physician/Nursing Home Visits

- From 1979 to 2002 the number of Americans discharged from short-stay hospitals with CVD as the first listed diagnosis increased 30 percent. In 2002 CVD ranked highest among all disease categories in hospital discharges. (National Hospital Discharge Survey: 2001, CDC/NCHS)
- In 2002 there were 80,092,000 physician office visits with a primary diagnosis of CVD. (National Ambulatory Medical Care Survey, 2002 Summary, CDC/NCHS)
- In 2002 there were 4,648,000 visits to emergency departments with a primary diagnosis of CVD. (National Hospital Ambulatory Medical Care Survey, 2002 Emergency Department Summary. CDC/NCHS)
- In 1999, 23 percent of nursing home residents age 65 or older had a primary diagnosis of CVD at admission. This was the highest disease category for these residents. (1999 National Nursing Home Survey, USDHHS, June 2002)
- In 2002 there were 6,024,000 outpatient department visits with a primary diagnosis of CVD. (National Hospital Ambulatory Medical Care Survey, 2002 Outpatient Department Summary. CDC/NCHS)

Cost

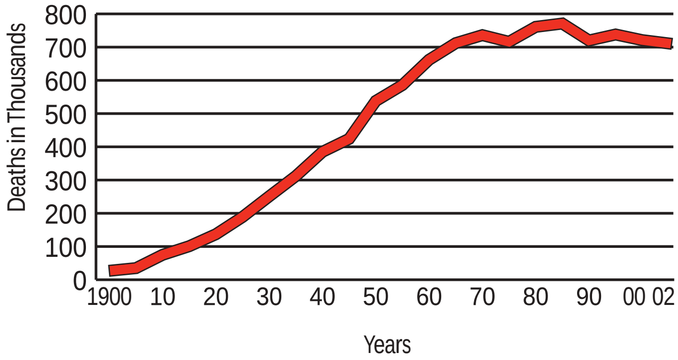
- In 2005 the estimated direct and indirect cost of CVD is $393.5 billion. See page 53 for more detailed information.
- In 1999, $26.3 billion in program payments were made to Medicare beneficiaries discharged from short-stay hospitals, with a principal diagnosis of cardiovascular disease. That was an average of $7,883 per discharge. *(Health Care Financing Review, 2001 Medicare and Medicaid Statistical Supplement*, CMS, April 2003)
- A study of the 1987 National Medicaid Expenditure Survey and the 2000 Medical Expenditure Panel Survey, Household Component, showed the 15 most costly medical conditions, and the estimated percent increase in total healthcare spending for each condition from 1987–2000. The following are some of the top 15 conditions, by order of rank, and their percentage impact on health care spending:

  heart disease (1) +8.06 percent; cancer (4) +5.36 percent; hypertension (5) +4.24 percent; cerebrovascular disease (7) +3.52 percent; diabetes (9) +2.37 percent; and kidney disease (15) +1.03 percent.

Operations and Procedures

- In 2002 an estimated 6,813,000 inpatient cardiovascular operations and procedures were performed in the United States; 4.0 million were performed on males and 2.8 million were performed on females. For more data, see pages 51 and 52. (CDC/NCHS)

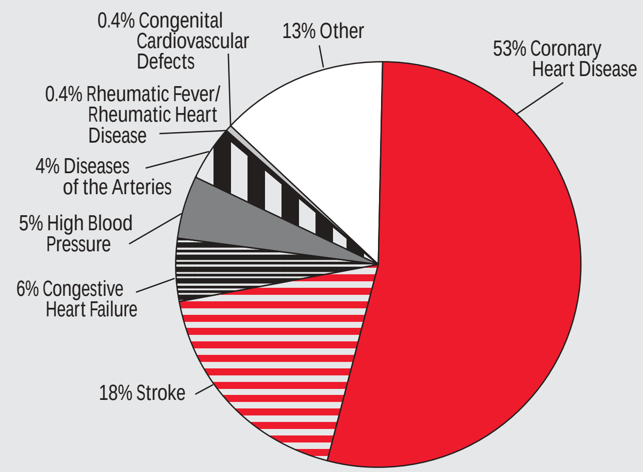
Deaths From Diseases of the Heart
United States: 1900–2002



Note: See Glossary on page 58 for an explanation of "Diseases of the Heart." Total cardiovascular disease data are not available for much of the period covered by this chart.

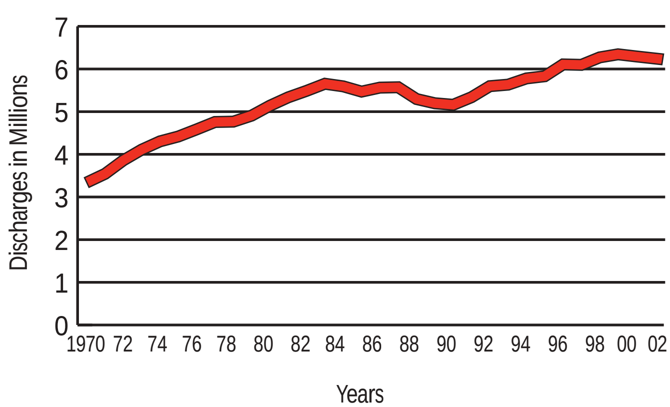
Source: CDC/NCHS.

Percentage Breakdown of Deaths From Cardiovascular Diseases
United States: 2002 Preliminary



Source: CDC/NCHS .

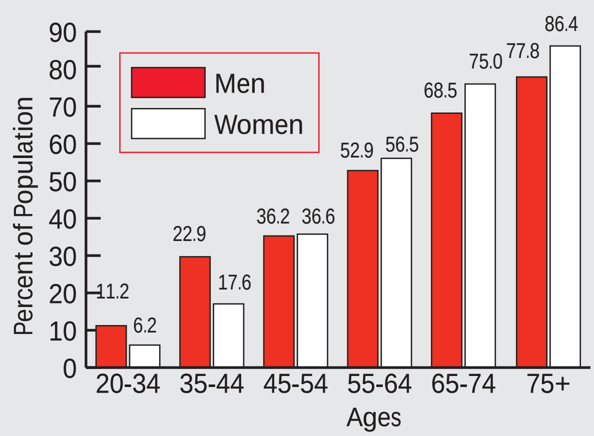
Hospital Discharges for Cardiovascular Diseases
United States: 1970–2002



Note: Hospital discharges include people both living and dead.

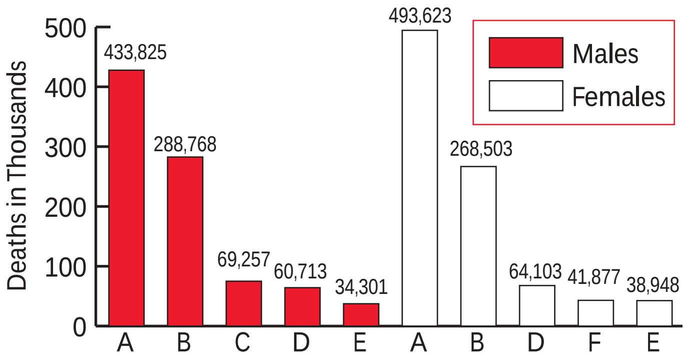
Source: CDC/NCHS.

Prevalence of Cardiovascular Diseases in Americans Age 20 and Older by Age and Sex
NHANES: 1999–2002



Source: CDC/NCHS and NHLBI. These data include CHD, CHF, stroke and hypertension.

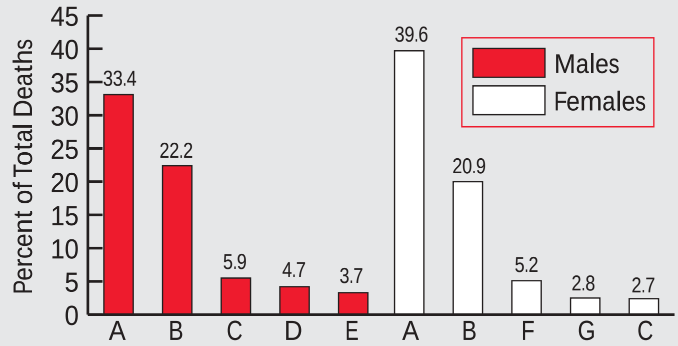
Leading Causes of Death for All Males and Females
United States: 2002



A Total CVD (Preliminary)
B Cancer
C Accidents
D Chronic Lower Respiratory Diseases
E Diabetes Mellitus
F Alzheimer's Disease

Source: CDC/NCHS.

Leading Causes of Death for Black or African-American Males and Females
United States: 2002

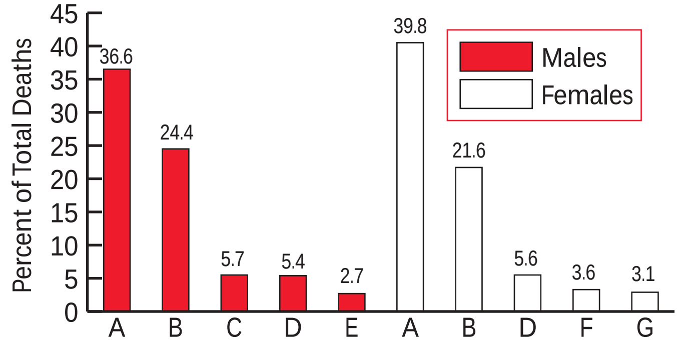


A Total CVD (Preliminary)
B Cancer
C Accidents
D Assault (Homicide)
E HIV (AIDS)
F Diabetes Mellitus
G Nephritis, Nephrotic Syndrome and Nephrosis

Note: Using "Diseases of the Heart, and Stroke," which do not constitute total CVD, the percentages of the "A" bars would be 30.6 for males and 36.0 for females.

Source: CDC/NCHS.

Leading Causes of Death for White Males and Females
United States: 2002

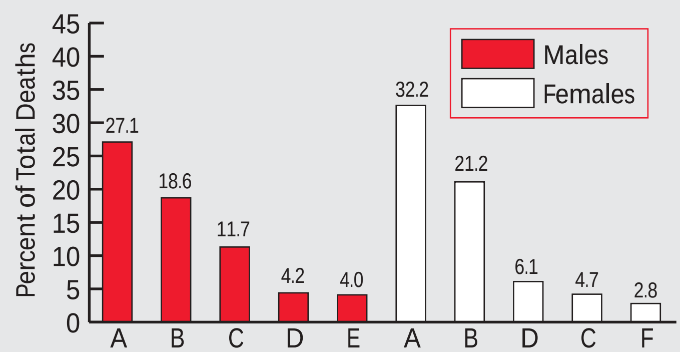


A Total CVD (Preliminary)
B Cancer
C Accidents
D Chronic Lower Respiratory Diseases
E Diabetes Mellitus
F Alzheimer's Disease
G Influenza and Pneumonia

Note: Using "Diseases of the Heart, and Stroke," which do not constitute total CVD, the percentages of the "A" bars would be 34.1 for males and 36.8 for females.

Source: CDC/NCHS.

Leading Causes of Death for Hispanic or Latino Males and Females
United States: 2002

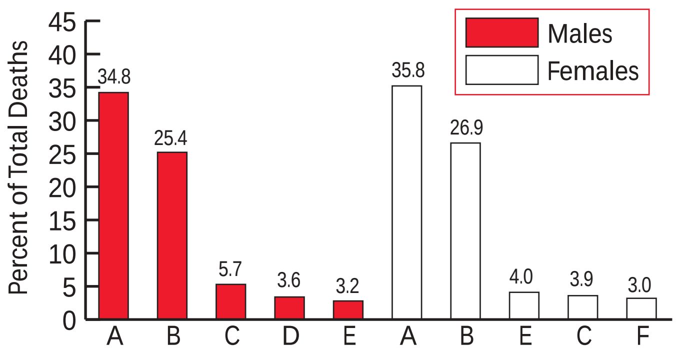


A Diseases of the Heart, and Stroke
B Cancer
C Accidents
D Diabetes Mellitus
E Assault (Homicide)
F Chronic Lower Respiratory Disease

Source: CDC/NCHS.

2

Leading Causes of Death for Asian or Pacific Islander Males and Females
United States: 2002

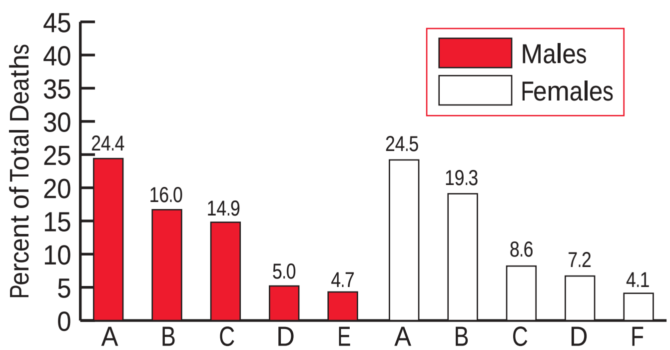


A Diseases of the Heart, and Stroke
B Cancer
C Accidents
D Chronic Lower Respiratory Diseases
E Diabetes Mellitus
F Influenza and Pneumonia

Note: "Asian or Pacific Islander" is a heterogeneous category that includes people at high CVD risk (South Asian) and people at low CVD risk (Japanese). More specific data on these groups aren't available.

Source: CDC/NCHS.

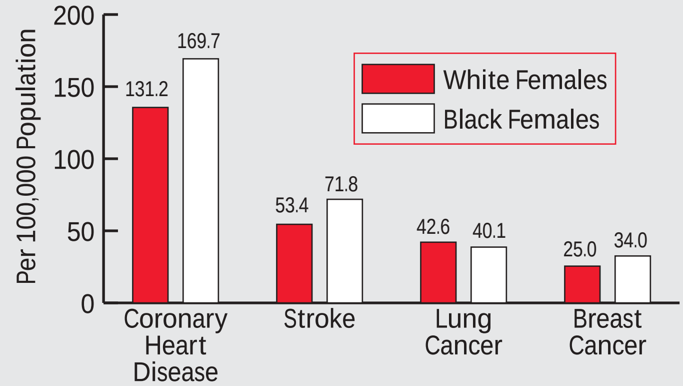
Leading Causes of Death for American Indian or Alaska Native Males and Females
United States: 2002



A Diseases of the Heart, and Stroke
B Cancer
C Accidents
D Diabetes Mellitus
E Chronic Liver Disease and Cirrhosis
F Chronic Lower Respiratory Diseases

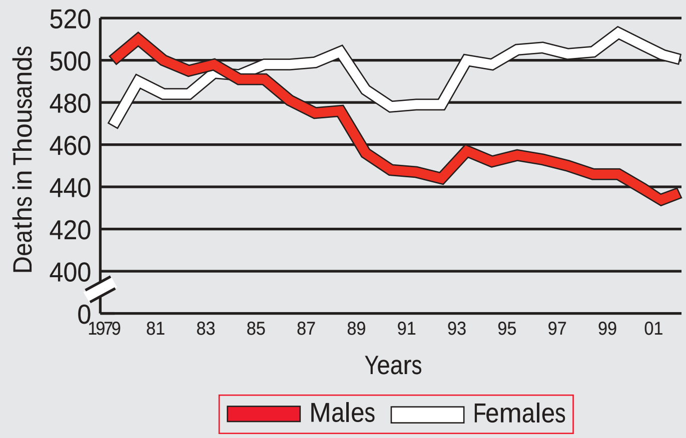
Source: CDC/NCHS.

Age-Adjusted Death Rates for Coronary Heart Disease, Stroke, and Lung and Breast Cancer for White and Black Females
United States: 2002



Source: CDC/NCHS

Cardiovascular Disease Mortality Trends for Males and Females
United States: 1979-2002



Source: CDC/NCHS.

2001 Age-Adjusted Death Rates for Total Cardiovascular Disease, Coronary Heart Disease and Stroke by State (includes District of Columbia and Puerto Rico)

Maps showing age-adjusted death rates by state for cardiovascular disease, coronary heart disease and stroke are available in the **Death Rates by State** fact sheet at **americanheart.org.** See page 1a for instructions.

	Total Cardiovascular Disease*			Coronary Heart Disease**			Stroke#		
State	Rank##	Death Rate	Percent Change+ 1991 to 2001	Rank##	Death Rate	Percent Change+ 1991 to 2001	Rank##	Death Rate	Percent Change+ 1991 to 2001
Alabama	49	379.4	–14.2	22	154.8	–22.2	44	66.0	–10.0
Alaska	9	276.8	–14.3	5	118.7	–30.2	23	57.4	+2.0
Arizona	6	272.6	–19.2	18	151.7	–24.2	6	48.2	–10.6
Arkansas	45	377.5	–11.9	39	186.0	–23.8	52	75.9	–11.5
California	27	313.9	–18.5	33	180.3	–24.4	34	61.2	–12.6
Colorado	5	267.9	–19.0	6	121.9	–35.4	16	53.9	–8.2
Connecticut	12	285.5	–21.5	13	146.5	–26.7	9	49.6	–12.0
Delaware	30	325.6	–22.5	43	192.9	–23.8	8	49.2	–18.2
District of Columbia	47	379.0	–8.7	50	218.1	+18.8	3	46.4	–30.6
Florida	21	300.8	–15.8	35	181.5	–21.2	5	47.6	–14.7
Georgia	43	364.0	–16.8	19	153.1	–31.0	46	67.4	–12.8
Hawaii	2	256.2	–18.0	1	101.7	–29.2	31	59.8	–7.9
Idaho	15	289.4	–17.8	11	136.8	–27.3	40	64.7	–11.1
Illinois	31	331.3	–21.7	31	178.9	–30.0	27	58.4	–13.3
Indiana	39	346.1	–17.7	29	174.4	–27.7	37	63.8	–11.6
Iowa	23	305.7	–19.6	30	177.3	–24.4	28	58.8	–7.9
Kansas	26	310.1	–15.8	14	148.7	–26.7	32	60.3	–6.2
Kentucky	48	379.0	–13.3	41	191.2	–21.9	39	64.4	–8.8
Louisiana	44	368.5	–19.8	36	182.3	–30.2	41	64.8	–13.2
Maine	20	296.8	–22.3	21	153.5	–29.9	17	54.7	–4.5
Maryland	32	332.0	–14.7	38	184.5	–19.1	30	59.6	+0.1
Massachusetts	10	280.2	–20.7	12	139.9	–32.2	7	48.6	–13.5
Michigan	42	357.0	–16.6	46	201.9	–26.2	26	58.2	–11.9
Minnesota	1	247.5	–27.2	3	113.2	–39.8	14	52.5	–23.1
Mississippi	52	424.2	–16.0	45	197.8	–25.2	48	70.5	–9.1
Missouri	41	355.9	–14.1	42	192.2	–20.7	35	61.6	–6.8
Montana	8	274.4	–19.5	4	116.2	–29.9	25	57.7	–14.4
Nebraska	18	292.7	–22.9	7	124.9	–37.2	22	57.3	–10.6
Nevada	34	336.3	–20.7	23	156.7	–31.8	18	55.1	–1.0
New Hampshire	24	307.2	–17.4	32	180.1	–21.6	12	52.0	–14.2
New Jersey	28	315.5	–19.7	40	187.2	–24.8	2	44.2	–20.0
New Mexico	7	273.4	–18.3	16	150.9	–21.4	10	49.6	–11.9
New York	36	340.0	–22.4	52	227.6	–27.5	1	38.4	–25.3
North Carolina	35	339.5	–20.1	28	170.6	–28.2	49	71.3	–12.5
North Dakota	19	296.0	–13.9	27	162.9	–18.3	33	60.4	–11.9
Ohio	40	352.5	–16.8	44	193.5	–23.8	24	57.4	–6.1
Oklahoma	51	391.6	–8.7	51	220.6	–9.2	43	65.6	–2.9
Oregon	13	285.8	–17.4	8	128.5	–34.9	47	69.5	–3.0
Pennsylvania	33	334.0	–19.6	34	180.4	–28.3	19	55.5	–10.6
Puerto Rico	4	265.8	—	9	130.1	—	13	52.2	—
Rhode Island	25	309.5	–17.8	47	202.5	–16.7	4	47.4	–18.4
South Carolina	38	344.1	–22.8	26	160.4	–30.4	51	75.0	–15.3
South Dakota	14	288.9	–22.4	24	158.2	–31.0	15	52.5	–5.4
Tennessee	46	377.7	–13.6	49	211.9	–19.2	50	72.3	–11.6
Texas	37	340.8	–13.1	37	183.8	–20.5	38	63.8	–8.0
Utah	3	262.7	–20.7	2	108.0	–35.4	21	56.4	–8.5
Vermont	17	292.6	–20.5	25	158.5	–31.6	11	50.2	–11.7
Virginia	29	317.5	–22.5	15	150.4	–28.7	42	65.4	–11.0
Washington	16	290.3	–18.5	17	151.2	–23.8	45	67.2	–7.1
West Virginia	50	382.6	–16.1	48	209.7	–21.6	29	59.4	–5.4
Wisconsin	22	304.4	–19.9	20	153.1	–29.9	36	61.7	–11.3
Wyoming	11	282.5	–16.9	10	136.2	–24.0	20	56.1	–15.1
Total United States		**328.1**	**–18.8**		**177.8**	**–25.6**		**57.9**	**–11.4**

Note: (—) = data not available.

* Total cardiovascular disease is defined here as ICD/10 I00–I99.

** Coronary heart disease is defined here as ICD/10 I20–I25.

\# Stroke is defined here as ICD/10 I60–I69.

\## Rank is lowest to highest.

\+ Percent change is based on log linear slope of rates for each year, 1990–2001. For computing percent change, the death rates in 2001 were comparability modified using the comparability ratio 1.0588 for stroke.

Source: NCHS compressed mortality file for the years 1979 to 2001.

Charts showing death rates for total cardiovascular disease, coronary heart disease, stroke and total deaths in selected countries are included in the **International Cardiovascular Disease Statistics** fact sheet at **americanheart.org.** See page 1a for instructions.

3 Coronary Heart Disease, Acute Coronary Syndrome and Angina Pectoris

Coronary Heart Disease

(ICD/9 410–414, 429.2) (ICD/10 I20–I25; see Glossary for details and definitions)

Population Group	Prevalence CHD 2002	Prevalence MI 2002	New and Recurrent Heart Attacks and Fatal CHD	New and Recurrent MI	Mortality CHD 2002	Mortality MI 2002	Hospital Discharges CHD 2002	Cost CHD 2005
Total population	13,000,000 (6.9%)	7,100,000 (3.5%)	1,200,000	865,000	494,382	179,514	2,125,000	$142.1 billion
Total males	7,100,000 (8.4%)	4,100,000 (5.0%)	715,000	520,000	252,760 (51.1%)*	93,830 (52.3%)*	1,249,000	—
Total females	5,900,000 (5.6%)	3,000,000 (2.3%)	485,000	345,000	241,622 (48.9%)*	85,684 (47.7%)*	875,000	—
White males	8.9%	5.1%	650,000	—	223,262	83,288	—	—
White females	5.4%	2.4%	425,000	—	211,908	74,634	—	—
Black males	7.4%	4.5%	65,000	—	24,322	8,680	—	—
Black females	7.5%	2.7%	60,000	—	25,852	9,642	—	—
Mexican-American males	5.6%	3.4%	—	—	—	—	—	—
Mexican-American females	4.3%	1.6%	—	—	—	—	—	—
Hispanics or Latinos**	4.8%	—	—	—	—	—	—	—
Asians**	5.0%	—	—	—	—	—	—	—
American Indians or Alaska Natives**	3.6%	—	—	—	—	—	—	—

Note: CHD = coronary heart disease; includes acute myocardial infarction, other acute ischemic (coronary) heart disease, angina pectoris, atherosclerotic cardiovascular disease, and all other forms of heart disease. MI = myocardial infarction (heart attack). (—) = data not available.

* These percentages represent the portion of total mortality that is males vs. females.

** NHIS (2002) — data are for Americans age 18 and older.

Sources: ***Prevalence:*** *NHANES (1999–02), CDC/NCHS and NHLBI; data for white and black males and females are for non-Hispanics. Total population data are for Americans age 20 and older; percentages for racial/ethnic groups are age-adjusted for age 20 and older. These data are based on self report.* ***Incidence:*** *ARIC (1987–2000), NHLBI.* ***Mortality:*** *CDC/NCHS; data for white and black males and females include Hispanics.* ***Hospital discharges:*** *CDC/NCHS; data include people both living and dead.* ***Cost:*** *NHLBI; data include direct and indirect costs for 2005.*

Prevalence

- Coronary heart disease rates in women after menopause are 2–3 times those of women the same age before menopause. (FHS, NHLBI, 44-year follow-up of participants and 20-year follow-up of their offspring)
- Among Americans ages 40–74, NHANES data found the age-adjusted prevalence of self-reported MI and ECG-MI (verified by electrocardiogram) to be higher among men than women, but angina prevalence to be higher in women than men. Age-adjusted rates of self-reported MI increased among African-American men and women and Mexican-American men, but decreased among white men and women. (Ethnicity & Disease, Vol. 13, p. 85–93, Winter 2003.)

Incidence

- This year an estimated 700,000 Americans will have a new coronary attack. About 500,000 will have a recurrent attack. (Atherosclerosis Risk in Communities [ARIC, 1987–2000, NHLBI] It is estimated that an additional 175,000 silent first heart attacks occur each year.)
- The estimated incidence of myocardial infarction (MI) (ICD/9 410) (ICD/10 I21, I22) is 565,000 new attacks and 300,000 recurrent attacks annually. (ARIC, 1987–2000, NHLBI)
- The average age of a person having a first heart attack is 65.8 for men and 70.4 for women. (ARIC and CHS, NHLBI)
- Based on the NHLBI's FHS in its 44-year follow-up of participants and the 20-year follow-up of their offspring: (Hurst W. *The Heart, Arteries and Veins.* 10th ed. New York, NY: McGraw-Hill; 2002)
  - CHD comprises more than half of all cardiovascular events in men and women under age 75.
  - The lifetime risk of developing CHD after age 40 is 49 percent for men and 32 percent for women.
  - The incidence of CHD in women lags behind men by 10 years for total CHD and by 20 years for more serious clinical events such as MI and sudden death.
- In the NHLBI's ARIC study, average age-adjusted CHD incidence rates per 1,000 person-years were: white men, 12.5; black men, 10.6; white women, 4.0; and black women, 5.1. Incidence rates excluding revascularization procedures were: white men, 7.9; black men, 9.2; white women, 2.9; and black women, 4.9. Hypertension was a particularly powerful risk factor for CHD in black persons, especially in black women. Diabetes was a weaker predictor of CHD in black than in white persons. *(Arch Intern Med* 2002;162:2565–71)
- The annual rates per 1,000 population of new heart attack (MI or CHD death) in non-black men are 19.2 for ages 65–74, 28.3 for ages 75–84, and 50.6 for age 85 and older. For non-black women in the same age groups the rates are 6.8, 14.2 and 33.2, respectively. For black men the rates are 21.6, 27.9 and 57.1, and for black women the rates are 8.6, 17.6 and 24.8, respectively. (CHS [1989–2000], NHLBI)
- Combining the rates for possible and definite CHD shows that 17 to 25 of every 100 American Indian men ages 45 to 74 had some evidence of heart disease. *(Strong Heart Study Data Book,* NIH, NHLBI, Nov. 2001)
- Among American Indians ages 65–74, the annual rates per 1,000 population of new and recurrent heart attacks are 6.8 for men and 2.2 for women. (SHS [1991–98], NHLBI)

Mortality

Coronary heart disease caused 1 of every 5 deaths in the United States in 2002. CHD total mention mortality — 656,000. MI total mention mortality — 225,000.

- CHD is the *single* largest killer of American males and females. About every 26 seconds an American will suffer a coronary event, and about every minute someone will die from one. About 41 percent of the people who experience a coronary attack in a given year, will die from it.
- About 335,000 people a year die of CHD in an emergency department or before reaching a hospital. Most of these are sudden deaths caused by cardiac arrest, usually resulting from ventricular fibrillation. (See also Arrhythmias, page 28.)
- A study of 1,275 HMO enrollees aged 50 to 79 years, who had cardiac arrest (CA), showed the incidence of out-of-hospital CA was 6.0/1,000 subject-years in subjects with any clinically recognized heart disease compared to 0.8/1,000 subject-years in subjects without heart disease. In subgroups with heart disease, incidence was 13.6/1,000 subject-years in subjects with prior MI and 21.9/1,000 subject-years in subjects with heart failure. *(Am J Cardiol* 2004;93:1455–60)
- An analysis of data from the FHS from 1950 to 1999 showed that overall CHD death rates decreased by 59 percent. Nonsudden CHD death decreased by 64 percent, and sudden cardiac death fell by 49 percent. These trends were seen in men and women, in subjects with and without a prior history of CHD, and in smokers and nonsmokers. *(Circulation* 2004;110:522–7)
- From 1992 to 2002 the death rate from CHD declined 26.5 percent, but the actual number of deaths declined only 9.9 percent. In 2002 the overall CHD death rate was 170.8 per 100,000 population. The death rates were 220.5 for white males and 250.6 for black males, and 131.2 for white females and 169.7 for black females. 1999 death rates for CHD were 138.4 for Hispanics, 123.9 for American Indians or Alaska Natives and 115.5 for Asian or Pacific Islanders. (CDC/NCHS)
- Over 83 percent of people who die of CHD are age 65 or older. (CDC/NCHS)
- The estimated average number of years of life lost due to a heart attack is 11.5. (NHLBI)
- Based on data from the FHS study of the NHLBI: (Hurst W. *The Heart, Arteries and Veins.* 10th ed. New York, NY: McGraw-Hill; 2002)
  - 25 percent of men and 38 percent of women will die within 1 year after having an initial recognized MI. In part because women have heart attacks at older ages than men do, they're more likely to die from them within a few weeks. Almost half of men and women under age 65 who have a heart attack (MI) die within 8 years.
  - 50 percent of men and 64 percent of women who died suddenly of CHD had no previous symptoms of this disease.
  - Between 70 and 89 percent of sudden cardiac deaths

3

occur in men, and the annual incidence is 3 to 4 times higher in men than in women. However, this disparity decreases with advancing age.

— People who've had a heart attack have a sudden death rate that's 4–6 times that of the general population.

— Sudden cardiac death accounts for 19 percent of sudden deaths in children between 1 and 13 years of age and 30 percent between 14 and 21 years. The overall incidence is low, 600 cases per year.

- According to data from the National Registry of Myocardial Infarction (NRMI), (www.nrmi.org/nrmi_data.html)
  - From 1990–1999, in-hospital AMI mortality declined from 11.2 percent to 9.4 percent. *(J Am Coll Cardiol* 2000;2056–63)
  - Mortality increases for every 30 minutes that elapse before a patient with ST-segment elevation is recognized and treated. *(Am J Cardiol* 2000;85:5B–9B)
  - Women under 50 are twice as likely to die after an AMI than men in the same age group. *(NEJM* 1999;341:217–25)

Risk Factors

- A study of men and women in three prospective cohort studies found that antecedent major CHD risk factor exposures were very common among those who developed CHD. About 90 percent of the CHD patients have prior exposure to at least one of these major risk factors, which include high total blood cholesterol levels or current medication with cholesterol-lowering drugs, hypertension or current medication with blood pressure-lowering drugs, current cigarette use, and clinical report of diabetes. *(JAMA* 2003;290:891–7)
- According to a study of 52 countries (INTERHEART), nine easily measured and potentially modifiable risk factors account for over 90 percent of the risk of an initial acute MI. The effect of these risk factors is consistent in men and women, across different geographic regions, and by ethnic group, making the study applicable worldwide. These nine risk factors include cigarette smoking, abnormal blood lipid levels, hypertension, diabetes, abdominal obesity, a lack of physical activity, low daily fruit and vegetable consumption, alcohol overconsumption, and psychosocial index. *(Lancet* 2004;364:937–52)
- A study of over 3,000 members of the FHS offspring cohort without CHD showed that among men with 10-year predicted risk for CHD of ≥ 20 percent, failure to reach target heart rate and ST-segment depression both more than doubled the risk of an event, and each MET (metabolic equivalent) increment in exercise capacity reduced risk by 13 percent. *(Circulation* 2004;110:1920–5)
- Low CHD risk is defined as blood pressure less than 120/80 mm Hg, cholesterol less than 200 mg/dL and not currently smoking. Age-adjusted prevalence was estimated in nondiabetic persons without a history of MI participating in four NHANES surveys conducted in 1971–75, 1976–80, 1988–94, and 1999–2000. (Manolio TA, et al. U.S. trends in prevalence of low coronary risk. National Health and Nutrition Examination Surveys. *Circulation* 2004;109:32. Abstract P108.)
  - The prevalence of low risk rose from 6 percent in 1971–75 to 17 percent in 1988–94 and 1999–2000.
  - Prevalence of low risk was about twice as high in women as in men throughout the period.
  - Prevalence was initially higher in whites than in blacks (7 percent vs. 3 percent in 1971–75); it increased more with time in blacks (17 percent vs. 15 percent in 1999–2000).
  - Prevalence of low risk in 1999–2000 was lowest in those ages 65–74 (3 percent) and was progressively greater at younger ages (29 percent at ages 25–34), with similar increases in prevalence over time across age groups.
  - The greatest changes in the components of low risk from 1971 to 2000 were in prevalence of favorable diastolic blood pressure (38 to 71 percent), compared to favorable systolic blood pressure (32 to 47 percent), nonsmoking (60 to 79 percent), and favorable cholesterol (33 to 46 percent).
- Taking into account CHD risk factors in combination provides a very potent predictor of 10-year risk of CHD compared with individual risk factors. Among participants age 20–79 in the NHANES III study of the CDC/NCHS, without self-reported CHD, stroke, peripheral vascular disease and diabetes, 81.7 percent had a 10-year risk for CHD of <10 percent, 15.5 percent had a risk of 10–20 percent, and 2.9 percent had a risk of >20 percent. 40.3 percent of men and 8.2 percent of women age 60 and over were at "intermediate risk (10–20 percent)." The proportion of participants with a 10-year risk of CHD of >20 percent increased with advancing age and was higher among men than women but varied little with race or ethnicity. *(J Am Coll Cardiol* 2004;43:1791–6)

Aftermath

- Depending on their gender and clinical outcome, people who survive the acute stage of a heart attack have a chance of illness and death that's 1.5–15 times higher than that of the general population. The risk of another heart attack, sudden death, angina pectoris, heart failure and stroke — for both men and women — is substantial. (FHS, NHLBI) (Hurst W. *The Heart, Arteries and Veins.* 10th ed. New York, NY: McGraw-Hill; 2002)
- A study conducted by the Mayo Clinic found that cardiac rehabilitation after a heart attack is underused, particularly in women and the elderly. Women were 55 percent less likely than men to participate in cardiac rehabilitation, and older study patients were less likely than younger participants. Only 32 percent of men and women aged 70 or older participated in cardiac rehabilitation, in comparison to 66 percent of 60- to 69-year-olds and 81 percent of those under age 60. *(J Am Coll Cardiol* 2004;44(5):988–96)

- Within 6 years after a recognized heart attack (MI)… (FHS, NHLBI) (Hurst W. *The Heart, Arteries and Veins.* 10th ed. New York, NY: McGraw-Hill; 2002)
  - 18 percent of men and 35 percent of women will have another heart attack.
  - 7 percent of men and 6 percent of women will experience sudden death.
  - About 22 percent of men and 46 percent of women will be disabled with heart failure.
  - 8 percent of men and 11 percent of women will have a stroke.

Hospital Discharges

- From 1979 to 2002 the number of Americans discharged from short-stay hospitals with CHD as the first listed diagnosis increased 22 percent. (CDC/NCHS)
- From 1990–1999, the median duration of hospital stay related to acute myocardial infarction dropped from 8.3 days to 4.3 days, according to an analysis of the NRMI. Findings were similar for both patients receiving primary PTCA and those receiving thrombolytic therapy. *(J Am Coll Cardiol* 2000;2056–63)

Cost

- In 2005 the estimated direct and indirect cost of CHD is $142.1 billion. See page 53 for more detailed information.
- In 1999, $10.7 billion was paid to Medicare beneficiaries for CHD ($10,336 per discharge for acute MI; $11,270 per discharge for coronary atherosclerosis; and $3,472 per discharge for other CHD). *(Health Care Financing Review, 2001 Medicare and Medicaid Statistical Supplement,* CMS, April 2003)

Operations and Procedures

- In 2002 an estimated 1,204,000 angioplasty procedures, 515,000 bypass procedures, 1,463,000 diagnostic cardiac catheterizations, 63,000 implantable defibrillators and 199,000 pacemaker procedures were performed in the United States. For more data, see pages 51 and 52. (CDC/NCHS)

Acute Coronary Syndrome

(ICD/9 codes 410, 411)

The term 'acute coronary syndrome' (ACS) is increasingly used to describe patients who present with either acute myocardial infarction or unstable angina (UA). (Unstable angina is chest pain or discomfort that's unexpected and usually occurs while at rest. The discomfort may be more severe and prolonged than typical angina or be the first time a person has angina.)

- 942,000 is a conservative estimate for the number of people with ACS discharged from hospitals in 2002. Of these, an estimated 543,000 are male and 399,000 are female. This estimate is derived by adding the first listed hospital discharges for myocardial infarction (818,000) to those for unstable angina (124,000). (CDC/NCHS)
- When including secondary discharge diagnoses, the corresponding number of hospital discharges was 1,673,000 unique hospitalizations for ACS, 973,000 for MI and 728,000 for UA (28,000 hospitalizations received both diagnoses). (CDC/NCHS)

Decisions regarding medical and interventional treatments are based on specific findings noted when a patient presents with ACS. Such patients are classified clinically into one of three categories according to the presence or absence of ST segment elevation on the presenting electrocardiogram and abnormal ("positive") elevations of myocardial enzymes such as troponins, as follows:

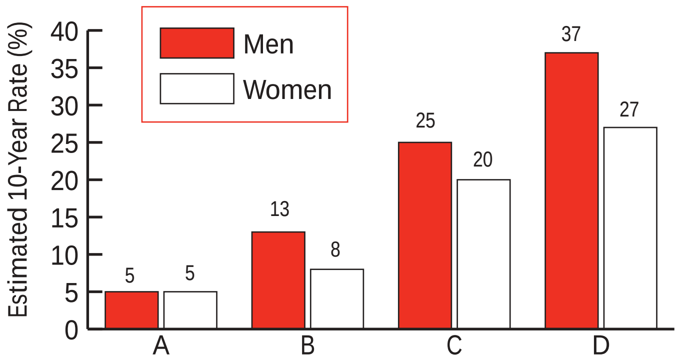
- ST elevation myocardial infarction (STEMI)
- non-ST elevation myocardial infarction
- unstable angina

Studies evaluating the percentage of ACS patients who have STEMI range from 30 to 45 percent. (NRMI-4 Steering Committee; *J Am Coll Cardiol* 2003;41[suppl. A]:365A–366A)

These are only preliminary estimates, in part because of dramatically changing practices in the unstable angina discharge diagnosis in the past decade. Factors affecting the UA diagnosis include changes in reimbursement policies, the advent of more sensitive assays for myocardial injury (leading to increased diagnosis of MI over unstable angina), and greater care of patients in same-day "chest pain units" and same-day catheterization procedures.

3

Estimated 10-Year CHD Risk in 55-Year-Old Adults According to Levels of Various Risk Factors
Framingham Heart Study

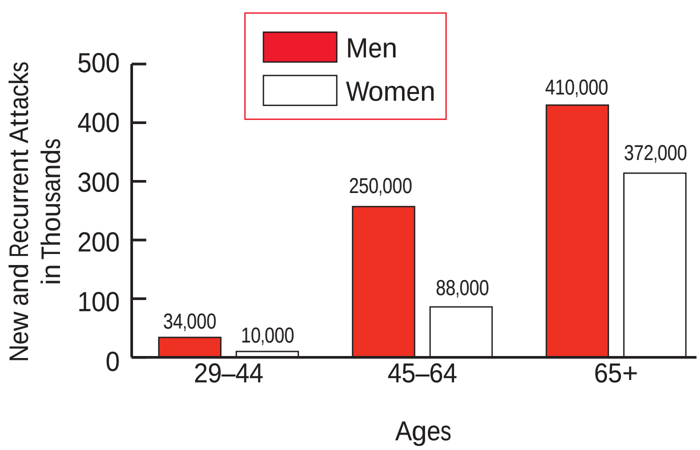


	A	B	C	D
Blood Pressure (mm Hg)	120/80	140/90	140/90	140/90
Total Cholesterol (mg/dL)	200	240	240	240
HDL Cholesterol (mg/dL)	50	50	40	40
Diabetes	No	No	Yes	Yes
Cigarettes	No	No	No	Yes

mm Hg = millimeters of mercury
mg/dL = milligrams per deciliter of blood

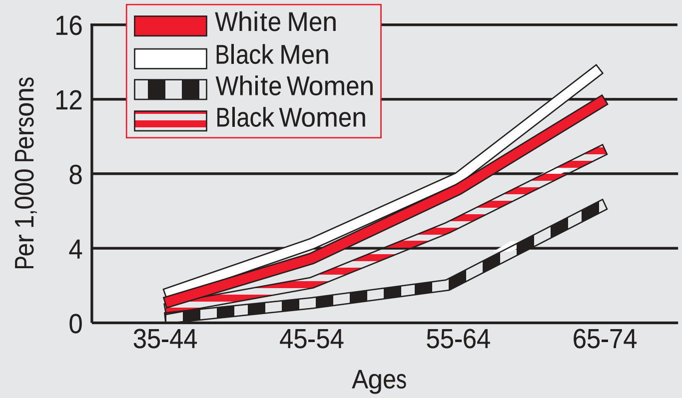
Source: Wilson PWF, et al. Prediction of coronary heart disease using risk factor categories. Circulation. *1998;97:1837–1847.*

Annual Number of Americans Having Diagnosed Heart Attack by Age and Sex
ARIC: 1987–2000



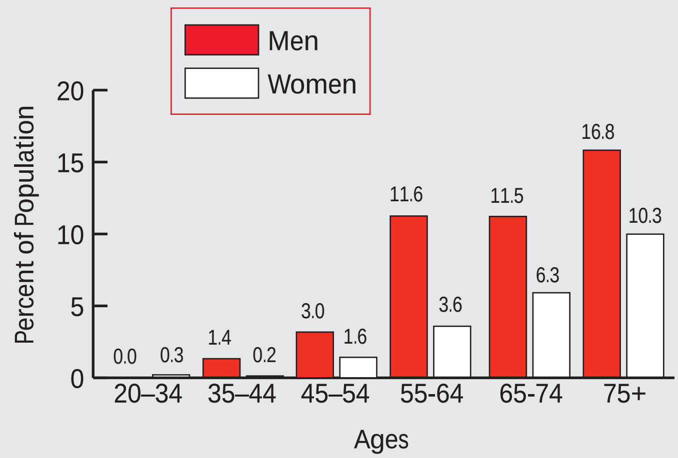
Source: Extrapolated from rates in the NHLBI's ARIC surveillance study, 1987–2000. These data don't include silent MIs.

Annual Rate of First Heart Attacks by Age, Sex and Race
ARIC: 1987–2000



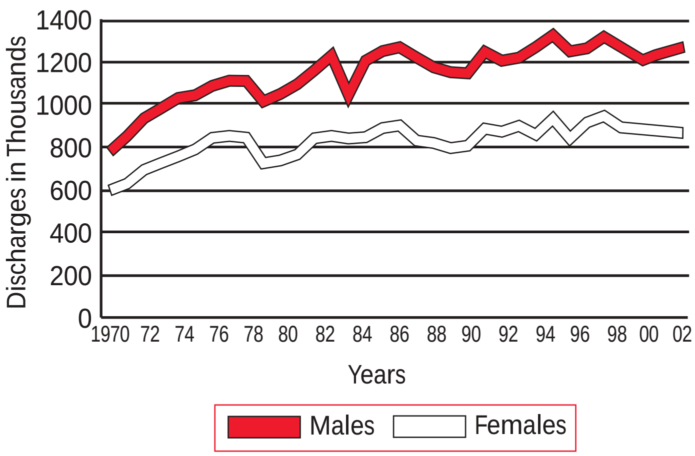
Source: NHLBI's ARIC surveillance study, 1987–2000.

Prevalence of Coronary Heart Disease by Age and Sex
NHANES: 1999–2002



Source: CDC/NCHS and NHLBI.

Hospital Discharges for Coronary Heart Disease by Sex
United States: 1970–2002



Note: Hospital discharges include people both living and dead.

Source: CDC/NCHS.

Angina Pectoris

(ICD/9 413) (ICD/10 I20)

Population Group	Prevalence 2002	Incidence of Stable Angina	Hospital Discharges — 2002*
Total population	6,400,000 (3.8%)	400,000	58,000
Total males	3,100,000 (4.2%)	—	23,000
Total females	3,300,000 (3.6%)	—	35,000
White males	4.5%	—	—
White females	3.5%	—	—
Black males	3.1%	—	—
Black females	4.7%	—	—
Mexican-American males	2.4%	—	—
Mexican-American females	2.2%	—	—

Note: Angina pectoris is chest pain or discomfort due to insufficient blood flow to the heart muscle. Stable angina is predictable chest pain on exertion or under mental or emotional stress.

(—) = data not available.

Sources: ***Prevalence:*** *NHANES (1999–02), CDC/NCHS and NHLBI; data for white and black males and females are for non-Hispanics; percentages for racial/ethnic groups are age-adjusted for Americans age 20 and older.* ***Incidence:*** *FHS, NHLBI.* ***Hospital discharges:*** *CDC/NCHS; data include people both living and dead.*

* There were 166,000 days of care for discharges from short-stay hospitals in 2001.

Prevalence

- A study of four national cross-sectional health examination studies found that, among Americans ages 40–74, the age-adjusted prevalence of angina pectoris (AP) was higher among women than men. Increases in the prevalence of AP occurred for Mexican-American men and women, and African-American women, but were not statistically significant for the latter. *(Ethnicity & Disease* 2003;13:85–93)

Incidence

- Only 20 percent of coronary attacks are preceded by long-standing angina. (44-year follow-up of participants and 20-year follow-up of their offspring, FHS, NHLBI) (Hurst W. *The Heart, Arteries and Veins* 10th ed. New York, NY: McGraw-Hill; 2002)
- The annual rates per 1,000 population of new and recurrent episodes of angina for non-black men are 44.3 for ages 65–74, 56.4 for ages 75–84, and 42.6 for age 85 and older. For non-black women in the same age groups the rates are 18.8, 30.8 and 19.8, respectively. For black men the rates are 26.1, 52.2 and 43.5, and for black women the rates are 29.4, 37.7 and 15.2, respectively. (CHS, NHLBI)

Mortality

A small number of deaths due to coronary heart disease are coded as being from angina pectoris. These are included as a portion of total deaths from CHD.

4 Stroke

(ICD/9 430–438) (ICD/10 I60–I69)

Population Group	Prevalence 2002	Incidence New and Recurrent Attacks	Mortality 2002	Hospital Discharges 2002	Cost 2005
Total population	5,400,000 (2.6%)	700,000	162,672	942,000	$56.8 billion
Total males	2,400,000 (2.5%)	327,000 (47%)*	62,622 (38.5%)*	432,000	—
Total females	3,000,000 (2.6%)	373,000 (53%)*	100,050 (61.5%)*	509,000	—
White males	2.3%	277,000	52,959	—	—
White females	2.6%	312,000	86,760	—	—
Black males	4.0%	50,000	7,828	—	—
Black females	3.9%	61,000	11,028	—	—
Mexican-American males	2.6%	—	—	—	—
Mexican-American females	1.8%	—	—	—	—
Hispanic or Latino**	2.4%	—	—	—	—
Asian**	2.4%	—	—	—	—
American Indian or Alaska Native**	4.6%	—	—	—	—

Note: (–) = data not available.

* These percentages represent the portion of total incidence or mortality that is males vs. females.

** NHIS (2002) — data are for Americans age 18 and older.

Sources: ***Prevalence:*** *NHANES (1999–2002), CDC/NCHS and NHLBI; data for white and black males and females are for non-Hispanics. Total population data include children; percentages for racial/ethnic groups are age-adjusted for Americans age 20 and older. These data are based on self report.* ***Incidence:*** *FHS, GCNKSS, ARIC.* ***Mortality:*** *CDC/NCHS; data for white and black males and females include Hispanics.* ***Hospital discharges:*** *CDC/NCHS; data include people both living and dead.* ***Cost:*** *NHLBI; data include direct and indirect costs for 2005.*

Prevalence

- From the early 1970s to early 1990s, the estimated number of noninstitutionalized stroke survivors increased from 1.5 million to 2.4 million. (*Stroke* 2002;33:1209–13)
- The prevalence of transient ischemic attacks (TIA) in men is 2.7 percent for ages 65–69 and 3.6 percent for ages 75–79. (A TIA, or transient ischemic attack, is a mini-stroke that lasts less than 24 hours.) For women, TIA prevalence is 1.6 percent for ages 65–69 and 4.1 percent for ages 75–79. (*Ann Epidemiol* 1993;3:504–7) (CHS, NHLBI)
- The prevalence of stroke in American Indian men ages 45–74 ranges from 0.2 to 1.4 percent and in women from 0.2 to 0.7 percent. (*Strong Heart Study Data Book,* NIH, NHLBI, Nov. 2001)
- The prevalence of silent cerebral infarction between ages 55 to 64 is about 11 percent. This prevalence increases to 22 percent between ages 65 to 69, 28 percent between ages 70 to 74, 32 percent between ages 75 to 79, 40 percent between ages 80 to 85, and 43 percent above age 85. Applying these rates to 1998 U.S. population estimates results in an estimated 13 million people with prevalent silent stroke. (*Stroke* 1998;29:913–7; *Radiology* 2002;202:47–54)

Incidence

- On average, every 45 seconds someone in the United States has a stroke.
- Each year about 700,000 people experience a new or recurrent stroke. About 500,000 of these are first attacks, and 200,000 are recurrent attacks. (GCNKSS, FHS, ARIC)
- Each year about 40,000 more women than men have a stroke. (CHS, NHLBI)
- Men's stroke incidence rates are 1.25 times greater than women's. The difference in incidence rates between the sexes is somewhat larger at younger ages but nonexistent at older ages. The male/female incidence was 1.59 for ages 65–69; 1.46 for ages 70–74; 1.35 for ages 75–79 and 0.74 for age 80 and older. (CHS, NHLBI)
- Of all strokes, 88 percent are ischemic, 9 percent are intracerebral hemorrhage, and 3 percent are subarachnoid hemorrhage. (GCNKSS, FHS, ARIC)
- Blacks have almost twice the risk of first-ever stroke compared with whites. The age-adjusted stroke incidence rates (per 100,000) for first-ever strokes are 167 for white males, 138 for white females, 323 for black males and 260 for black females. (GCNKSS, FHS, ARIC)
- The Brain Attack Surveillance in Corpus Christi project (BASIC) clearly demonstrated an increased incidence of stroke among Mexican Americans compared with non-Hispanic whites in this community. The crude cumulative incidence was 168/10,000 in Mexican Americans and 136/10,000 in non-Hispanic whites. Specifically, Mexican Americans have an increased incidence of intracerebral hemorrhage and subarachnoid hemorrhage than non-Hispanic whites adjusted for age, as well as an increased incidence of ischemic stroke and TIA at younger ages when compared with non-Hispanic whites. (*Am J Epidemiol* 2004;160:376–83)

- The age-adjusted annual incidence rate (per 1,000) for total stroke in Japanese-American men has declined markedly from 5.1 to 2.4; for thromboembolic stroke, from 3.5 to 1.9; and for hemorrhagic stroke, from 1.1 to 0.6. The estimated average annual declines are 5 percent for total stroke, 3.5 percent for thromboembolic stroke, and 4.3 percent for hemorrhagic stroke. The decline in stroke mortality in the HHP target population was similar to that reported for U.S. white males ages 60–69 during the same period. (During the 1969–88 follow-up period of the Honolulu Heart Program, NHLBI)
- Among American Indians ages 65–74, the annual rates per 1,000 population of new and recurrent strokes are 15.2 for men and 7.9 for women. (SHS [1991–98], NHLBI)

Mortality

Stroke accounted for more than 1 of every 15 deaths in the United States in 2002. About 50 percent of these deaths occurred out of hospital. Total mention mortality — about 275,000.

- When considered separately from other cardiovascular diseases, stroke ranks No. 3 among all causes of death, behind diseases of the heart and cancer. (CDC/NCHS)
- On average, every 3 minutes someone dies of a stroke.
- 8–12 percent of ischemic strokes and 37–38 percent of hemorrhagic strokes result in death within 30 days. *(Stroke* 1999;30:736–43; *Stroke* 1999;30:2517–22)
- From 1992 to 2002 the stroke death rate fell 13.8 percent, but the actual number of stroke deaths rose 6.9 percent. (CDC/NCHS)
- The 2002 overall death rate for stroke was 56.2. Death rates were 54.2 for white males and 81.7 for black males; and 53.4 for white females and 71.8 for black females. 1999 death rates for stroke were 40.0 for Hispanics, 52.4 for Asian or Pacific Islanders, and 39.7 for American Indians or Alaska Natives. (CDC/NCHS)
- Because women live longer than men, more women than men die of stroke each year. Women accounted for 61.5 percent of U.S. stroke deaths in 2002.
- From 1995 to 1998 age-standardized mortality rates for ischemic stroke, subarachnoid hemorrhage and intracerebral hemorrhage were higher among blacks than whites. Death rates from intracerebral hemorrhage were also higher among Asian or Pacific Islanders than among whites. All minority populations had higher death rates from subarachnoid hemorrhage than did whites. Among adults ages 25–44, blacks and American Indians or Alaska Natives had higher risk ratios than did whites for all three stroke subtypes. *(Am J Epidemiol* 2001;154:1057–63)

Risk Factors

- In 2000, 70 percent of respondents correctly named at least one established stroke warning sign vs. 57 percent in 1995. 72 percent correctly named at least one established risk factor vs. 68 percent in 1995. Groups of people with the highest risk and incidence of stroke — i.e., persons at least 75 years old, blacks and men — were the least knowledgeable about warning signs and risk factors. *(JAMA* 2003;289:343–6)
- TIAs carry a substantial short-term risk of stroke, hospitalization for cardiovascular events and death. Of 1,707 TIA patients evaluated in the emergency department (ED) of a large health care plan, 180 patients or 10 percent developed stroke within 90 days. 91 patients or 5 percent did so within 2 days. Predictors of stroke: more than 60 years of age, having diabetes mellitus, focal symptoms of weakness or speech impairment, and TIA lasting longer than 10 minutes. *(JAMA* 2000;284:2901–6)
- The relative risk of stroke in heavy smokers (more than 40 cigarettes a day) is twice that of light smokers (less than 10 cigarettes per day). Stroke risk decreases significantly after two years and is at the level of nonsmokers by five years after cessation of cigarette smoking. *(JAMA* 1988;259:1025–9)
- Atrial fibrillation (AF) is an independent risk factor for stroke, increasing risk about 5-fold. For details, see Arrhythmias on page 28. *(Stroke* 1991;22:983–8)
- In adults over 55, the lifetime risk for stroke is greater than 1 in 6. Women have a higher risk than men, perhaps due to their survival advantage. Blood pressure (BP) is a powerful determinant of stroke risk. Subjects with BP less than 120/80 mm Hg have about half the lifetime risk of stroke, compared to subjects with hypertension. (FHS, NHLBI, Seshadri, et al. *Lifetime Risk of Stroke: Results from the Framingham Study)*

Physical Activity

- Physical activity reduces stroke risk. Results from the Physicians' Health Study showed a lower stroke risk associated with vigorous exercise among men (relative risk [RR] of total stroke = 0.86 for exercise 5 times a week or more). *(Stroke* 1999;30:1–6) The Harvard Alumni Study showed a decrease in total stroke risk in men who were highly physically active (RR = 0.82). *(Stroke* 1998;29:2049–54)
- For women in the Nurses' Health Study, RR for total stroke from the lowest to the highest physical activity levels were: 1.00 (reference), 0.98, 0.82, 0.74 and 0.66, respectively. *(JAMA* 2000;283:2961–7)
- The Northern Manhattan Study — which included whites, blacks and Hispanics, and men and women in an urban setting — showed a decrease in ischemic stroke risk associated with physical activity levels across all racial/ethnic and age groups, and for each gender (odds ratio = 0.37). *(Stroke* 1998;29:380–7)

4

Pregnancy and Stroke

- The Baltimore-Washington Cooperative Young Stroke Study found the risk of ischemic stroke or intracerebral hemorrhage during pregnancy and the first six weeks postpartum was 2.4 times greater than for nonpregnant women of similar age and race. The risk of ischemic stroke during pregnancy was not increased during pregnancy per se, but was increased 8.7-fold during the six weeks postpartum. Intracerebral hemorrhage showed a small relative risk (RR) of 2.5 during pregnancy, but increased dramatically to an RR of 28.3 in the six weeks postpartum. The excess risk of stroke (all types except subarachnoid hemorrhage) attributable to the combined pregnant/post-pregnant period was 8.1 per 100,000 pregnancies. *(NEJM* 1996;335:768–74)
- Using Swedish administrative data, it was found that ischemic stroke and intracerebral hemorrhage, including subarachnoid hemorrhage, are increased in association with pregnancy. The postpartum period and particularly the three days surrounding delivery were times of increased risk. However, overall risks for stroke in association with pregnancy was low. (Sources were used to compare the risk of stroke among women in the third trimester of pregnancy, around delivery [from 2 days before to 1 day after delivery], and the puerperium [from 2 days to 6 complete weeks after delivery] to the risk of stroke among nonpregnant and early pregnant [up to the first 27 gestational weeks] women. Subarachnoid hemorrhage, as well as ischemic stroke and intracerebral hemorrhage, are increased in association with pregnancy. The postpartum period and particularly the three days surrounding delivery were times of increased risk.) *(Epidemiology* 2001;12:456–60)
- Data from the HHP found that in elderly Japanese men ages 71–93, low concentrations of HDL cholesterol were more likely to be associated with a future risk of thromboembolic stroke than were high concentrations. *(Am J Epidemiol* 2004;160:150–7)

Aftermath

- Stroke is a leading cause of serious, long-term disability in the United States. *(MMWR,* Vol. 50, No.7, Feb. 23, 2001, CDC/NCHS)
- The median time from stroke onset to arrival in an ER is between 3 and 6 hours, according to a study of at least 48 unique reports of prehospital delay time for patients with stroke, TIA or stroke-like symptoms. The study included data from 17 countries, including the United States. Improved clinical outcome at 3 months was seen for patients with acute ischemic stroke when intravenous thrombolytic treatment was started within 3 hours of the onset of symptoms. (*NEJM* 1995;333:1581–7)
- In 1999 more than 1,100,000 American adults reported difficulty with functional limitations, activities of daily living, etc., resulting from stroke. *(MMWR,* Vol. 50, No. 7, Feb. 23, 2001, CDC/NCHS)
- According to the NHLBI's FHS… (Hurst W. *The Heart, Arteries and Veins.* 10th ed. New York, NY: McGraw-Hill; 2002)
  - — 14 percent of persons who survive a first stroke or TIA will have another one within 1 year.
  - — 22 percent of men and 25 percent of women who have an initial stroke die within a year. This percentage is higher among people age 65 and older.
  - — 51 percent of men and 53 percent of women under age 65 who have a stroke die within 8 years.
  - — The length of time to recover from a stroke depends on its severity. 50 to 70 percent of stroke survivors regain functional independence, but 15 to 30 percent are permanently disabled. 20 percent require institutional care at three months after onset.
- In the NHLBI's FHS, among ischemic stroke survivors who were at least 65 years old, these disabilities were observed at 6 months post-stroke: *(J Stroke Cerebrovasc Dis* 2003;12:119–26)
  - — 50 percent had some hemiparesis.
  - — 30 percent were unable to walk without some assistance.
  - — 26 percent were dependent in activities of daily living.
  - — 19 percent had aphasia.
  - — 35 percent had depressive symptoms.
  - — 26 percent were institutionalized in a nursing home.

Hospital Discharges

- From 1979 to 2002 the number of Americans discharged from short-stay hospitals with stroke as the first listed diagnosis increased 26 percent. (CDC/NCHS)
- During 1988–97 the age-adjusted stroke hospitalization rate increased 18.6 percent (from 560 to 664 per 100,000), while total hospitalizations increased 38.6 percent (from 592,811 to 821,760). Hospitalization rates did not change for ages 35–64 but increased for persons age 65 and older. This increase was greater for men than for women. The average length of hospital stay fell from 11.1 to 6.2 days. Total person-days in hospital decreased 22 percent. *(Stroke* 2001;32:2221–6. Stroke in this study includes ICD/9 431–434 and 436–438. The American Heart Association uses 430–438.)
- Between 1980 and 1999 the hospital discharge rates for stroke increased for blacks and whites; the in-hospital mortality rates decreased for both black and white patients. Generally, the risk of a stroke hospitalization was more than 70 percent greater for blacks than for whites. Both groups were similar in terms of in-hospital mortality rates. *(Neuroepidemiology* 2002;21:131–41)

Cost

- In 2005 the estimated direct and indirect cost of stroke was $56.8 billion. See page 53 for more detailed information.

- In 1999, $3.4 billion ($5,692 per discharge) was paid to Medicare beneficiaries discharged from short-stay hospitals for stroke. *(Health Care Financing Review, 2001 Medicare and Medicaid Statistical Supplement*, CMS, April 2003)
- The mean lifetime cost of ischemic stroke in the United States is estimated at $140,048. This includes inpatient care, rehabilitation and follow-up care necessary for lasting deficits. (All numbers converted to 1999 dollars using the medical component of CPI.) *(Stroke* 1996;27:1459–66)
- In a population study of stroke costs within 30 days of an acute event, the average cost was $13,019 for mild ischemic strokes and $20,346 for severe ischemic strokes (4 or 5 on the Ranking Disability Scale). *(Neurology* 1996;46:861–9)
- Inpatient hospital costs for an acute stroke event account for 70 percent of the first-year post-stroke costs. *(Stroke* 1996;27:1459–66)
- The largest components of acute care costs were room charges (50 percent), medical management (21 percent) and diagnostic costs (19 percent). *(Stroke* 1999;30:724–8)
- Mortality within seven days, subarachnoid hemorrhage, and stroke while hospitalized for another condition are associated with higher costs in the first year. Conversely, lower costs are associated with mild cerebral infarctions or residence in a nursing home prior to the stroke. *(Neurology* 1996;46:861–9)
- Demographic variables (age, sex and insurance status) are not associated with stroke cost. Severe strokes (NIHSS score greater than 20) cost twice as much as mild strokes, despite similar diagnostic testing. Co-morbidities such as ischemic heart disease and atrial fibrillation predict higher costs. *(Stroke* 1999;30:724–8; *Arch Intern Med* 2003;163)

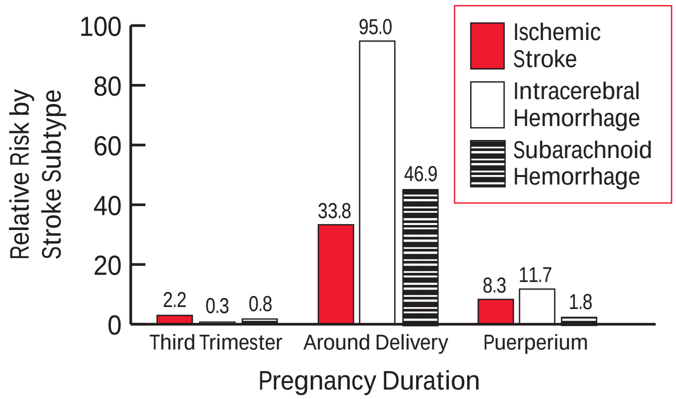
Operations and Procedures

- In 2002 an estimated 134,000 endarterectomy procedures were performed in the United States. Carotid endarterectomy is the most frequently performed surgical procedure to prevent stroke. For more data, see pages 51 and 52. (CDC/NCHS)

Stroke in Children

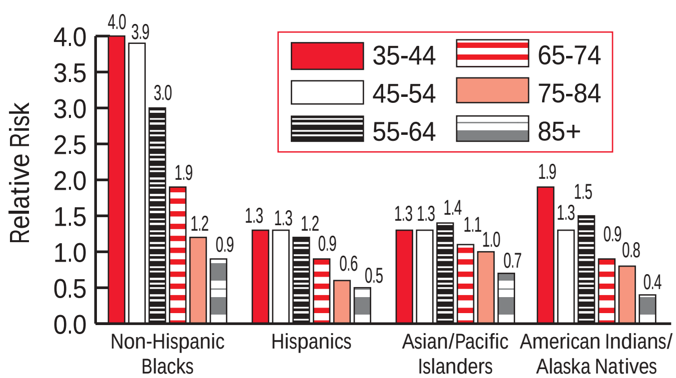
- Stroke in children has a peak in the perinatal period. In the National Hospital Discharge Survey from 1980–1998, the rate of stroke for infants less than 30 days old (per 100,000 live births per year) was 26.4, with rates of 6.7 for hemorrhagic stroke and 17.8 for ischemic stroke *(Pediatrics* 2002;109[1]:116–23)
- The Greater Cincinnati/Northern Kentucky Stroke Study found the stroke rate per 100,000 for children ages 1–14 was 2.7. The rate of ischemic stroke and intracerebral hemorrhage is similar in this age group. *(J Child Neurol* 1993;8[3]:250–5; *Neurology* 1998;51[1]:169–76)
- Stroke in childhood and young adulthood has a disproportionate impact on the affected patients, their family and society, compared to stroke at older ages. Outcome of childhood stroke was a moderate or severe deficit in 42 percent of cases. *(J Child Neurol* 2000;15[5]:316–24)
- Compared to the stroke risk of white children, black children have a higher relative risk of 2.12, Hispanics a lower relative risk of 0.76, and Asians have a similar risk. Boys have a 1.28-fold higher risk of stroke than girls. There are no ethnic differences in stroke severity or case-fatality, but boys have a higher case-fatality rate for ischemic stroke. The increased risk among blacks is not explained by the presence of sickle cell disease, nor is the excess risk among boys explained by trauma. *(Neurology* 2003;61[2]:189–94)
- Despite current treatment, 1 out of 10 children with ischemic stroke will have a recurrence within 5 years. *(Lancet* 2002;360:1540–5)
- Cerebrovascular disorders are among the top 10 causes of death in children, with rates highest in the first year of life. Stroke mortality in children under 1 year of age has remained the same over the last 40 years. *(Pediatrics* 2002;109[1]:116–23)
- From 1979 to 1998 in the United States, childhood mortality from stroke declined by 58 percent overall, with reductions in all major subtypes. *(Neurology* 2002;59:34–9)
  - — Ischemic stroke decreased by 19 percent, subarachnoid hemorrhage (SAH) by 79 percent, and intracerebral hemorrhage (ICH) by 54 percent.
  - — Black ethnicity was a risk factor for mortality from all stroke types.
  - — Male sex was a risk factor for mortality from SAH and ICH but not from ischemic stroke.
- Sickle cell disease is the most important cause of ischemic stroke among African-American children. The Stroke Prevention Trial in Sickle Cell Anemia (STOP) demonstrated the efficacy of blood transfusions for primary stroke prevention in high-risk children with sickle cell disease in 1998. First admission rates for stroke in California among persons under age 20 with sickle cell disease showed a dramatic decline subsequent to the publication of the STOP study. For the study years 1991–1998, 93 children with sickle cell disease were admitted to California hospitals with a first stroke; 92.5 percent were ischemic and 7.5 percent were hemorrhagic. The first-stroke rate was 0.88 per 100 person-years during 1991–1998, compared to 0.50 in 1999 and 0.17 in 2000 ($p < 0.005$ for trend). *[Neurology* 1998;51(1):169–76] [Blood 2004;103(6):2391–6]

Risk of Stroke in Women in the Third Trimester, Peri- and Post-Partum Period Versus Risk of Nonpregnant Women and Women in the First 2 Trimesters



Source: Epidemiology 2001;12:456–60.

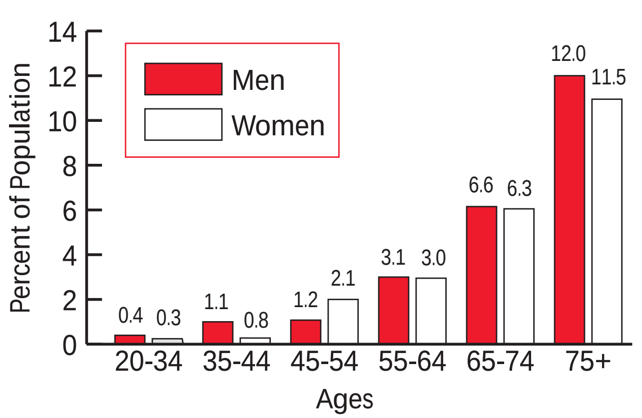
Risk for Stroke Mortality Among Racial/Ethnic Groups Compared With Non-Hispanic Whites, by Age
United States: 1997



Note: Values greater than 1.0 indicate populations with higher relative risks. Values less than 1.0 indicate lower relative risks.

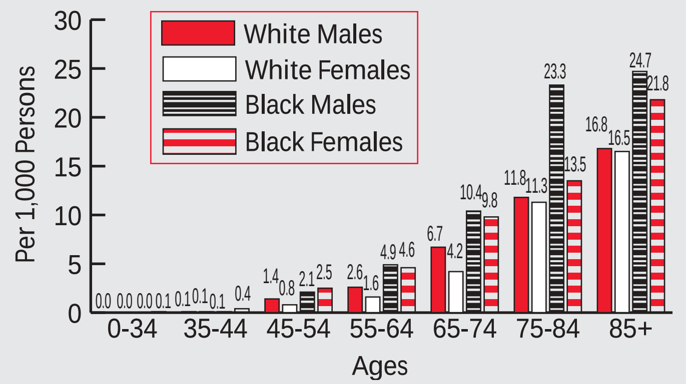
Source: Age-specific excess deaths associated with stroke among racial/ethnic minority populations – United States, 1997, MMWR, Vol. 49, No. 5, Feb.11, 2000, CDC/NCHS and NHLBI.

Prevalence of Stroke by Age and Sex
NHANES: 1999–2002



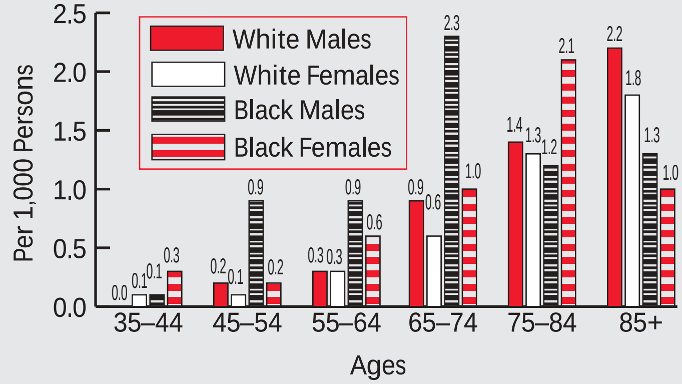
Source: CDC/NCHS and NHLBI.

Annual Rate of First Cerebral Infarction by Age, Sex and Race
Greater Cincinnati/Northern Kentucky Stroke Study: 1993–94



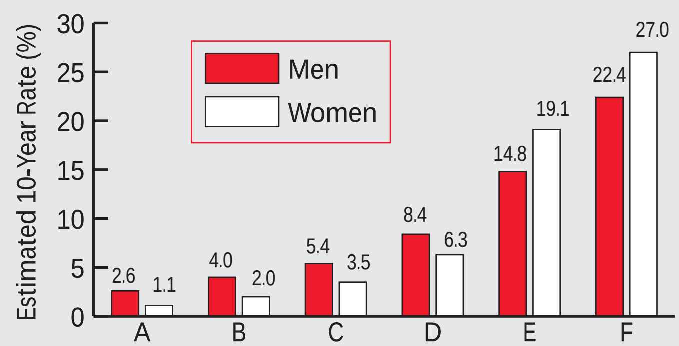
Source: Unpublished data from the GCNKSS.

Annual Rate of First Intracerebral Hemorrhage by Age, Sex and Race
Greater Cincinnati/Northern Kentucky Stroke Study: 1993–94



Source: Stroke 2004;35:426–431.

Estimated 10-Year Stroke Risk in 55-Year-Old Adults According to Levels of Various Risk Factors
Framingham Heart Study



	A	B	C	D	E	F
Systolic BP*	95–105	130–148	130–148	130–148	130–148	130–148
Diabetes	No	No	Yes	Yes	Yes	Yes
Cigarettes	No	No	No	Yes	Yes	Yes
Prior Atrial Fibrillation	No	No	No	No	Yes	Yes
Prior CVD	No	No	No	No	No	Yes

* Blood pressures are in millimeters of mercury (mm Hg).

Source: Stroke. *1991;22:312–318.*

High Blood Pressure 5

(ICD/9 401–404) (ICD/10 I10–I15)

Population Group	Prevalence 2002	Mortality 2002	Hospital Discharges 2002	Cost 2005
Total population	65,000,000 (32.3%)	49,707	535,000	$59.7 billion
Total males	29,400,000 (31.5%)	20,512 (41.3%)*	224,000	—
Total females	35,600,000 (32.8%)	29,195 (58.7%)*	312,000	—
White males	30.6%	14,713	—	—
White females	31.0%	22,329	—	—
Black males	41.8%	5,268	—	—
Black females	45.4%	6,311	—	—
Mexican-American males	27.8%	—	—	—
Mexican-American females	28.7%	—	—	—
Hispanic or Latino**	18.2%	—	—	—
Asian**	16.7%	—	—	—
American Indians or Alaska Natives**	21.2%	—	—	—

Note: (–) = data not available.

* These percentages represent the portion of total mortality that is males vs. females.

Sources: ***Prevalence:*** *NHANES (1999–2002),* (Hypertension. *2004;44:398–404) and NHLBI; data are age-adjusted for age 20 and older. Rates are for non-Hispanics.** NHIS (2002), CDC/NCHS; data are for Americans age 18 and older.* ***Mortality:*** *CDC/NCHS; data for white and black males and females include Hispanics.* ***Hospital discharges:*** *CDC/NCHS; data include people both living and dead.* ***Cost:*** *NHLBI; data include direct and indirect costs for 2005.*

Prevalence

- High blood pressure (HBP) is defined as:
  - — systolic pressure of 140 mm Hg or higher, or diastolic pressure of 90 mm Hg or higher
  - — taking antihypertensive medicine
  - — being told at least twice by a physician or other health professional that you have high blood pressure
- "Prehypertension" is systolic pressure of 120–139 mm Hg, or diastolic pressure of 80–89 mm Hg, and both not taking antihypertensive medication, or not being told on two occasions by a doctor or other health professional that you have hypertension.
- Nearly 1 in 3 adults has HBP. *(Hypertension* 2004;44:398–404)
- About 28 percent of American adults age 18 and older or about 59 million people, have "prehypertension." (NHANES 1999–2002, CDC/NCHS, NHLBI)
- Overall, 39 percent of persons were normotensive, 31 percent were prehypertensive, and 29 percent were hypertensive. The age-adjusted prevalence of prehypertension was greater in men (39 percent) than in women (23.1 percent). African Americans aged 20 to 39 years had a higher prevalence of prehypertension (37.4 percent) than whites (32.2 percent) and Mexican Americans (30.9 percent), but their prevalence was lower at older ages because of a higher prevalence of hypertension. *(Arch Intern Med* 2004;164:2113–8)
- Of those with HBP, 30 percent don't know they have it; 34 percent are on medication and have it controlled; 25 percent are on medication but don't have their HBP under control; and 11 percent aren't on medication. (JNC 7; NHANES III)
- A higher percentage of men than women have HBP until age 55. After that a much higher percentage of women have HBP than men do. (CDC/NCHS)
- HBP is 2–3 times more common in women taking oral contraceptives, especially in obese and older women, than in women not taking them. (Fifth and Sixth Reports of the JNC [JNC 5 and 6])
- About half of people who have a first heart attack and two-thirds who have a first stroke have blood pressure higher than 160/95 mm Hg. (FHS, NHLBI) (Hurst W. *The Heart, Arteries and Veins.* 10th ed. New York, NY: McGraw-Hill; 2002)
- People with systolic blood pressure of 160 mm Hg or higher and/or diastolic blood pressure of 95 mm Hg or higher have a relative risk for stroke about 4 times greater than for those with normal blood pressure. *(Hypertens Res* 1994;17[suppl. 1]:S23–S32)
- The prevalence of HBP among blacks and whites in the southeastern United States is greater and death rates from stroke are higher than among those in other regions. (JNC 5 and 6)
- Hypertension precedes the development of congestive heart failure (CHF) in 91 percent of cases. HBP is associated with 2–3 times higher risk for developing CHF. (FHS, NHLBI, *JAMA* 1996;275:1557–62)

Race/Ethnicity and HBP

- The prevalence of hypertension in blacks in the United States is among the highest in the world. Compared with whites, blacks develop HBP earlier in life and their average blood pressures are much higher. As a result, compared with whites, blacks have a 1.3 times greater rate of nonfatal stroke, a 1.8 times greater rate of fatal stroke, a 1.5 times greater rate of heart disease death and a 4.2 times greater rate of end-stage kidney disease. (JNC 5 and 6)

- Within the African-American community, rates of hypertension vary substantially. (NHANES III [1988–94], *Prev Med* 2002;35:303–12)
  - — Those with the highest rates are more likely to be middle-aged or older, less educated, overweight or obese, physically inactive, and to have diabetes.
  - — Those with the lowest rates are more likely to be younger, but also overweight or obese.
  - — Those with uncontrolled HBP who are not on antihypertensive medication tend to be male, younger and have infrequent contact with a physician.
- Compared with white women, black women have an 85 percent higher rate of ambulatory medical care visits for HBP. (Utilization of Ambulatory Medical Care by Women: United States, 1997–98, NCHS, 2001)
- The awareness, treatment and control of HBP among those in the Cardiovascular Health Study (CHS) age 65 and older improved during the 1990s. The percentages who were aware of and treated for HBP were higher among blacks than among whites. Prevalences with HBP under control were similar. For both groups combined, the control of BP to lower than 140/90 mm Hg increased from 37 percent in 1990 to 49 percent in 1999. Improved control was achieved by an increase in antihypertensive medications per person and by increasing the proportion of the CHS population treated for hypertension from 34.5 percent to 51.1 percent. (CHS, NHLBI, *Arch Intern Med* 2002;162:2325–32)
- A study of children and adolescents from 1988–94 to 1999–2000, among ages 8 through 17 showed that among non-Hispanic blacks, mean systolic blood pressure (BP) levels increased 1.6 mm Hg among girls and 2.9 mm Hg among boys, when compared with non-Hispanic whites. Among Mexican Americans, girls' systolic BP increased 1.0 mm Hg and boys' increased 2.7 mm Hg higher when compared with non-Hispanic whites. *(JAMA* 2004;291:2107–13)

Mortality

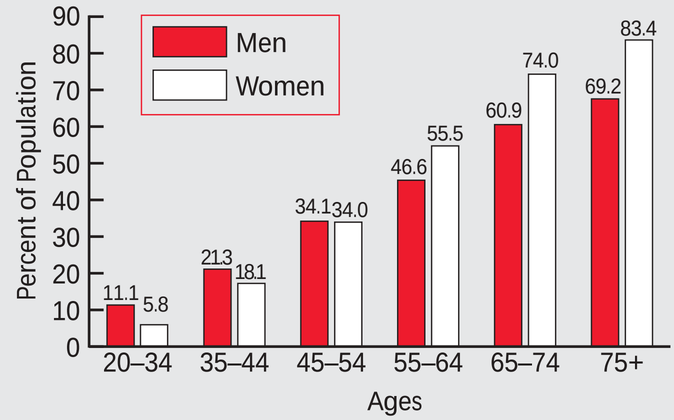
Total mention mortality — HBP was listed as a primary or contributing cause of death in about 261,000 of over 2,400,000 U.S. deaths in 2002.

- From 1992 to 2002 the age-adjusted death rate from HBP increased 26.8 percent, and the actual number of deaths rose 56.6 percent.
- The 2002 overall death rate from HBP was 17.1. Death rates were 14.4 for white males, 49.6 for black males, 13.7 for white females and 40.5 for black females.
- As many as 30 percent of all deaths in hypertensive black men and 20 percent of all deaths in hypertensive black women may be due to HBP. (JNC 5 and 6)

Cost

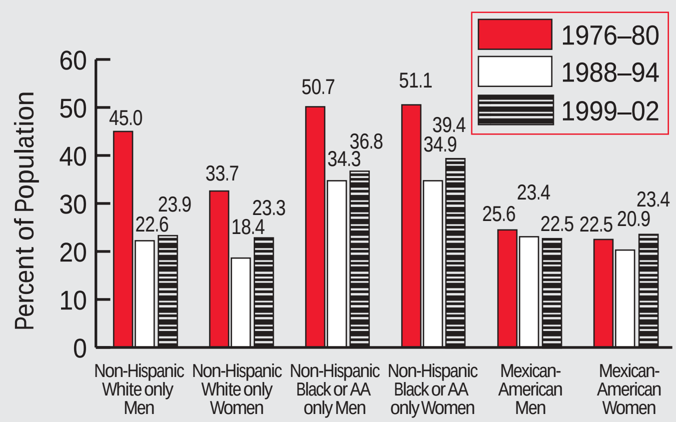
- In 2005 the estimated direct and indirect cost of high blood pressure is $59.7 billion. See page 53 for more detailed information.

Prevalence of High Blood Pressure in Americans by Age and Sex
NHANES: 1999–2002



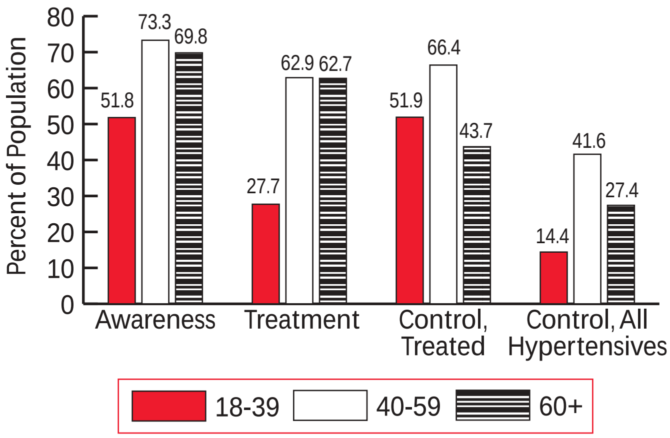
Source: CDC/NCHS and NHLBI.

Age-Adjusted Prevalence Trends for High Blood Pressure in Americans Ages 20–74 by Race/Ethnicity, Sex and Survey
NHANES: 1976–80, 1988–94 and 1999–2002



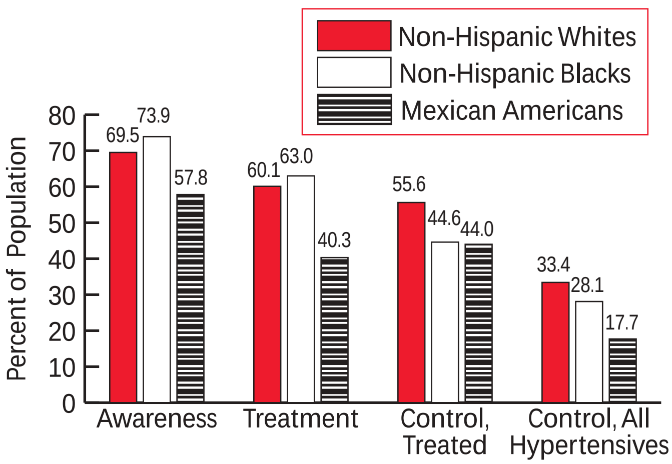
Source: CDC/NCHS . Data based on a single measure of blood pressure.

Extent of Awareness, Treatment and Control of High Blood Pressure by Age
NHANES: 1999–2000



Source: Trends in prevalence, awareness, treatment, and control of hypertension in the United States, 1988–2000. JAMA. *2003;290:199–206.*

Extent of Awareness, Treatment and Control of High Blood Pressure by Race/Ethnicity
NHANES: 1999–2000



Source: Trends in prevalence, awareness, treatment, and control of hypertension in the United States, 1988–2000. JAMA. *2003;290:199–206.*

End-Stage Renal Disease (ESRD)

(ICD/10 N18.0)

ESRD (also called end-stage kidney disease) is a condition closely related to high blood pressure, and occurs when the kidneys can no longer function normally on their own. When this happens, patients are required to undergo treatment such as kidney dialysis or a kidney transplant. ESRD morbidity rates vary dramatically among different age, race, ethnicity and sex population groups. Morbidity rates tend to increase with age, then fall off for the oldest age group. The age group with the highest incidence rate is ages 75–79; for prevalence rates, it's ages 70–74. Chronic kidney disease (categorized in stages by level of estimated glomerular filtration rate and urine proteins) which eventually progresses to ESRD is also a substantial public health burden in the United States. The excess CVD risk in people with chronic renal disease is caused, in part, by a higher prevalence of CVD risk factors in this group than in the general population. The main factors include older age, high blood pressure, high blood cholesterol and lipids, diabetes and physical inactivity. An independent, graded association was observed between a reduced estimated glomerular filtration rate (GFR, an indicator of kidney function) and the risk of death, cardiovascular events, and hospitalization in a large, community-based population of over 1 million men and women. (*NEJM* 2004;351:1296–305)

- The incidence of reported ESRD has almost doubled in the past 10 years. (NHLBI from usrds.org Web site)
- In 2002, 100,359 new cases of ESRD were reported.
- Over 424,000 patients were being treated for ESRD by the end of 2002.
- 79,812 patients died from ESRD in 2002.
- More than 15,700 kidney transplants were performed in 2002.
- Diabetes continues to be the most common reported cause of ESRD.
- An estimated 11 percent or 19.2 million American adults have between stage 1–4 chronic kidney disease. *(Am J Kidney Dis* 2003;41(1):1–12)
- 3.2 percent of the Medicare population had a diagnosis of chronic kidney disease between 1996 and 1997, representing 63.6 percent of persons who progressed to ESRD after one year. (Kidney International Supplement 2003;(87):S24–S31)

Age, Sex, Race and Ethnicity

- The average incidence rates for pediatric ESRD are more than twice as high among children ages 15–19 as for children ages 10–14. The rates are more than 3 times higher than those for children ages 0–4 and 5–9.
- Children with pediatric ESRD have high transplantation rates. More than 44 percent of children starting therapy received a transplant during the first year of therapy, compared with 10 percent of patients ages 20–64 at ESRD incidence.
- The median age of the prevalent population is 58.1 years (59.2 for whites, 56.1 for blacks, 56.7 for Hispanics, 58.9 for Asians and 57.5 for Native Americans). (USRDS 2004 Annual Data Report. NIH, NIDDK)
- Treatment of ESRD is more common in men than in women.
- Blacks and Native Americans have much higher rates of ESRD than whites and Asians. Blacks represent 29 percent of treated ESRD patients.

6

Congenital Cardiovascular Defects

(ICD/9 745–747) (ICD/10 Q20–Q28)

Population Group	Mortality 2001	Hospital Discharges 2002
Total population	4,109	51,000
Total males	2,199 (53.5%)*	25,000
Total females	1,910 (46.5%)*	25,000
White males	1,759	—
White females	1,493	—
Black males	363	—
Black females	339	—

Note: (–) = data not available.

* These percentages represent the portion of total mortality that is males vs. females.

Sources: ***Mortality:*** *CDC/NCHS; data for white and black males and females include Hispanics.* ***Hospital discharges:*** *CDC/NCHS; data include people both living and dead.*

Congenital cardiovascular defects, also known as congenital heart defects, are structural problems arising from abnormal formation of the heart or major blood vessels. At least 15 distinct types of congenital defects are recognized, with many additional anatomic variations.

Defects range in severity from tiny pinholes between chambers that are nearly irrelevant and often resolve spontaneously, to major malformations that result in fetal loss or death in infancy or childhood. Common complex defects include:

- tetralogy of Fallot (9–14 percent)
- transposition of the great arteries (10–11 percent)
- atrioventricular septal defects (4–10 percent)
- coarctation of the aorta (8–11 percent)
- hypoplastic left heart syndrome (4–8 percent)
- ventricular septal defects (VSDs), the most common defect. Many close spontaneously, but VSDs still account for 14–16% of defects requiring an invasive procedure within the first year of life. *(Perspectives in Pediatric Cardiology,* Vol. 6, Futura Publishing Company, Armonk, N.Y., 1998)

Prevalence

About 1 million Americans, or 3.4 per 1,000, reported being told by a physician that they had a congenital cardiovascular defect, according to a national interview survey in 1993–95. The current prevalence is likely to be higher, since both diagnosis and treatment for all types of defects have improved substantially over the past decade, and since some patients may have been unaware of their diagnosis at the time of the survey. (CDC/NCHS, HIS Survey, 1993–95. Unpublished data.)

Incidence

Major defects are usually apparent in the neonatal period, but minor defects may not be detected until adulthood. Thus, true measures of incidence for congenital heart disease would need to record new cases of defects presenting anytime in fetal life through adulthood. However, estimates are only available for new cases detected between birth and 30 days of life, known as birth prevalence, or as new cases detected in the first year of life only. Both of these are typically reported as cases per 1,000 live births per year, and do not distinguish between tiny defects that resolve without treatment and major malformations. To distinguish more serious defects, some studies also report new cases of sufficient severity to undergo an invasive procedure or result in death within the first year of life. Despite the absence of true incidence figures, some data are available, and are shown in the Table on the next page.

- According to the CDC, 1 in every 110 babies in the metropolitan Atlanta area was born with a congenital heart defect, including some infants with tiny defects that resolved without treatment. Some defects occur more commonly in males or females, or in whites or blacks. (MACDP, *Pediatrics* 2001;107)
- 9.0 defects per 1,000 live births are expected, or 36,000 babies per year in the United States. Of these, several studies suggest that 9,200, or 2.3 per 1,000 live births, require invasive treatment or result in death in the first year of life. (BWIS; Moller, 1998)
- Estimates are also available for bicommisural aortic valves, occurring in 13.7 per 1,000 people; these defects may not require treatment in infancy, but can cause problems later in adulthood. *(J Am Coll Cardiol* 2002;39:1890–900; *Am J Cardiol* 1984;53:849–55)
- Some studies suggest that as many as 5 percent of newborns, or 200,000 per year, are born with tiny muscular ventricular septal defects, almost all of which close spontaneously. *(J Am Coll Cardiol* 1995;26:1545–8; *Arch Dis Child Fetal Neonatal Ed* 1999;81:F61–F63) These defects nearly never require treatment, so they aren't included in the Table on the next page.

Annual Incidence of Congenital Cardiovascular Defects

Type of Presentation	Rate per 1,000 Live Births	Number
Fetal loss	Unknown	Unknown
Invasive procedure during first year	2.3	9,200
Detected during first year*	9.0	36,000
Bicommisural aortic valve	13.7	54,800
Other defects detected after first year	Unknown	Unknown
Total	Unknown	Unknown

* Includes stillbirths and pregnancy termination at less than 20 weeks gestation; includes some defects that resolve spontaneously or don't require treatment.

Mortality

- Total mention mortality — 6,100.
- Congenital cardiovascular disease is the most common cause of infant death from birth defects; 1 in 3 infants who die from a birth defect have a heart defect. (NVSS Final Data for 2000)
- The 2001 overall death rate for congenital cardiovascular defects was 1.5. Death rates were 1.6 for white males, 2.0 for black males, 1.4 for white females and 1.6 for black females. Crude infant death rates (under 1 year) were 44.0 for white babies and 56.2 for black babies.
- In 2000, 213,000 life years were lost before age 65 due to deaths from congenital cardiovascular disease. This is nearly equivalent to the life years lost from leukemia, prostate cancer and Alzheimer's disease combined. (CDC/NCHS; NHLBI)
- In 2000 over 25,000 cardiovascular operations for congenital heart disease were performed on children less than 20 years of age. Inpatient mortality after all types of cardiac surgery was 4.7 percent. However, mortality risk varies substantially for different defect types, from 0.3 percent for atrial septal defect repair to 20.1 percent for first stage palliation for hypoplastic left heart syndrome. 54 percent of operations were performed in males. In unadjusted analyses, mortality after cardiac surgery was somewhat higher for females than for males (4.8 percent versus 4.6 percent). (Healthcare Cost and Utilization Project, HCUP KID2000)
- Mortality from congenital defects has been declining. From 1979–97 age-adjusted death rates from all defects declined 39 percent, and deaths tended to occur at progressively older ages. However, 43 percent of deaths still occurred in infants less than 1 year old. Mortality varies considerably according to type of defect. (*Circulation* 2001;103:2376–81)
- From 1991 to 2001 death rates for congenital cardiovascular defects declined 27.1 percent, while the actual number of deaths declined 26.1 percent.

Hospitalizations

In 2000 over 130,000 hospitalizations, as a primary or secondary diagnosis, occurred in infants or children with congenital cardiovascular disease; hospital charges were $6.5 billion. (HCUP KID2000)

7 Congestive Heart Failure

(ICD/9 428.0) (ICD/10 I50.0)

Population Group	Prevalence 2002	Incidence (New Cases)	Mortality 2001	Hospital Discharges 2002	Cost 2005
Total population	4,900,000 (2.3%)	550,000	52,828	970,000	$27.9 billion
Total males	2,400,000 (2.6%)	—	19,805 (37.5%)*	441,000	—
Total females	2,500,000 (2.1%)	—	33,023 (62.5%)*	529,000	—
White males	2.5%	—	17,782	—	—
White females	1.9%	—	29,942	—	—
Black males	3.1%	—	1,802	—	—
Black females	3.5%	—	2,797	—	—
Mexican-American males	2.7%	—	—	—	—
Mexican-American females	1.6%	—	—	—	—

Note: (–) = data not available.

* These percentages represent the portion of total mortality that is males vs. females.

Sources: ***Prevalence:*** *NHANES (1999–2002), CDC/NCHS and NHLBI; data for white and black males and females are for non-Hispanics; percentages are age-adjusted for Americans age 20 and older. These data are based on self reports.* ***Incidence:*** *FHS, NHLBI.* ***Mortality:*** *CDC/NCHS; data for white and black males and females include Hispanics.* ***Hospital discharges:*** *CDC/NCHS; data include people both living and dead.* ***Cost:*** *NHLBI; data include direct and indirect costs for 2005.*

Prevalence

- In a study conducted in Minnesota, 20.8 percent of the population had mild diastolic dysfunction, 6.6 percent had moderate diastolic dysfunction and 0.7 percent had severe diastolic dysfunction. 5.6 percent had moderate or severe diastolic dysfunction with normal ejection fraction (EF). The prevalence of any systolic dysfunction was 6.0 percent and moderate or severe systolic dysfunction was 2.0 percent. Congestive heart failure (CHF) was much more common among those with systolic or diastolic dysfunction than in those with normal ventricular function. Even among those with moderate or severe diastolic or systolic dysfunction, less than half had recognized CHF. Mild diastolic dysfunction and moderate or severe diastolic dysfunction were predictive of all-cause mortality. *(JAMA* 2003;289:194–202)

Incidence

- Based on the 44-year follow-up of the NHLBI's FHS… (Hurst W. *The Heart, Arteries and Veins.* 10th ed. New York, NY: McGraw-Hill; 2001)
  - — CHF incidence approaches 10 per 1,000 population after age 65.
  - — 75 percent of CHF cases have antecedent hypertension.
  - — About 22 percent of male and 46 percent of female heart attack (MI) victims will be disabled with heart failure within 6 years.
- Based on 1971 to 1996 data from the NHLBI's FHS… *(Circulation* 2002;106:3068–72)
  - — At age 40, the lifetime risk of developing CHF for both men and women is 1 in 5.
  - — At age 40, the lifetime risk of CHF occurring without antecedent MI is 1 in 9 for men and 1 in 6 for women.
  - — The lifetime risk doubles for people with blood pressure greater than 160/90 mm Hg vs. those with pressure less than 140/90 mm Hg.
- The annual rates per 1,000 population of new and recurrent CHF events for non-black men are 21.5 for ages 65–74, 43.3 for ages 75–84, and 73.1 for age 85 and older. For non-black women in the same age groups the rates are 11.2, 26.3 and 64.9, respectively. For black men the rates are 21.1, 52.0 and 66.7, and for black women the rates are 18.9, 33.5 and 48.4, respectively. (CHS, NHLBI)
- A community-based cohort study conducted in Olmsted County, Minn., showed that the incidence of heart failure (ICD9/428) has not declined during two decades, but survival after onset had increased overall, with less improvement among women and elderly persons. *(JAMA* 2004;292:344–50)

Risk Factors

- A study of the predictors of heart failure among women with CHD found that diabetes was the strongest risk factor. Diabetic women with elevated BMI or depressed creatinine clearance were at highest risk with annual incidence rates of 7 and 13 percent respectively. Among nondiabetic women with no risk factors, the annual incidence rate was 0.4 percent. The rate increases with each additional risk factor, and nondiabetic women with 3 or more risk factors had an annual incidence of 3.4 percent. Among diabetic participants with no additional risk factors, the annual incidence of heart failure was 3.0 percent compared with 8.2

percent among diabetics with at least 3 additional risk factors. Diabetics with fasting glucose >300 mg/dL had a threefold adjusted risk of developing heart failure, compared with diabetics with controlled fasting blood sugar levels. *(Circulation* 2004;110:1424–30)

Mortality

Total mention mortality — 264,900.

- Based on the 44-year follow-up of the NHLBI's FHS…
  - — 80 percent of men and 70 percent of women under age 65 who have CHF will die within 8 years.
  - — After CHF is diagnosed, survival is poorer in men than in women, but fewer than 15 percent of women survive more than 8–12 years. The 1-year mortality rate is high, with 1 in 5 dying.
  - — In people diagnosed with CHF, sudden cardiac death occurs at 6–9 times the rate of the general population.
- From 1992 to 2002, deaths from heart failure (ICD 428) increased 35.3 percent. In the same time period, the death rate increased 7.7 percent.
- The 2001 overall death rate for CHF was 18.7. Death rates were 19.6 for white males, 21.7 for black males, 18.1 for white females and 18.8 for black females.

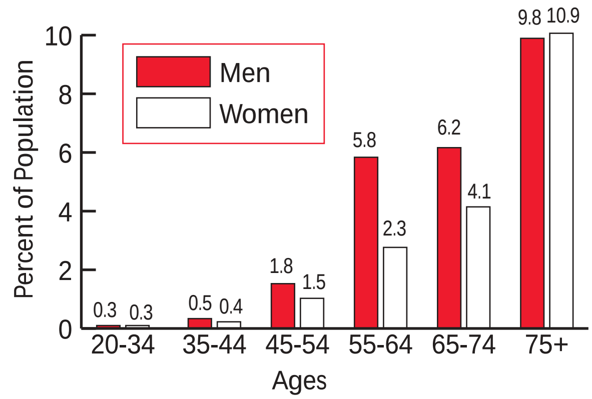
Hospital Discharges

- Hospital discharges for CHF rose from 377,000 in 1979 to 970,000 in 2002, an increase of 157 percent.

Cost

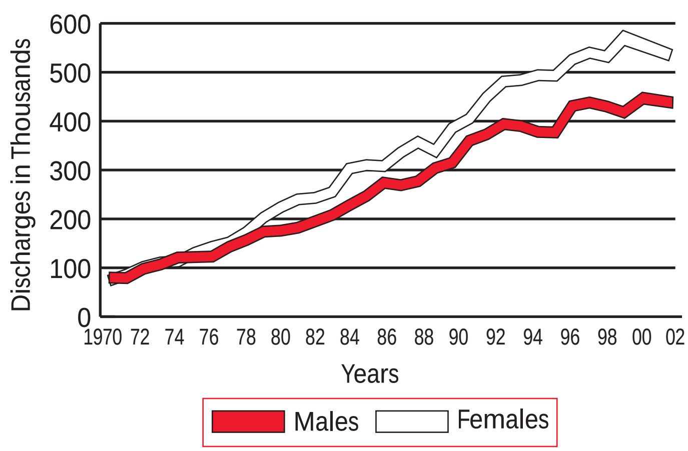
- In 2005 the estimated direct and indirect cost of CHF in the United States is $27.9 billion. See page 53 for details.
- In 1999, $3.6 billion ($5,456 per discharge) was paid to Medicare beneficiaries for CHF. *(Health Care Financing Review, 2001 Medicare and Medicaid Statistical Supplement*, CMS, April 2003)

Prevalence of Congestive Heart Failure by Sex and Age
NHANES: 1999–2002



Source: CDC/NCHS and NHLBI.

Hospital Discharges for Congestive Heart Failure by Sex
United States: 1970–2002



Note: Hospital discharges include people both living and dead.

Source: CDC/NCHS.

8

Other Cardiovascular Diseases

Mortality, prevalence and death rate data in this section are for 2001 or 2002. Total mention mortality is for 2001. Hospital discharge data are based on ICD/9 codes.

Arrhythmias (Disorders of Heart Rhythm)

(ICD/9 426, 427) (ICD/10 I46–I49)

Mortality — 37,892. Total mention mortality — 480,400 of over 2,400,000 U.S. deaths. Hospital discharges — 858,000. In 1999, $2.2 billion ($6,041 per discharge) was paid to Medicare beneficiaries for cardiac dysrhythmias. *(Health Care Financing Review, 2001 Medicare and Medicaid Statistical Supplement,* CMS, April 2003)

Atrial fibrillation and flutter (ICD/9 427.3) (ICD/10 I48). Mortality — 9,451. Total mention mortality — 73,300. Prevalence — about 2,200,000. *(MMWR,* Vol. 52, No. 7, Feb. 21, 2003, CDC/NCHS) Hospital discharges — 465,000.

- In the FHS study, the lifetime risk for development of AF is 1 in 4 for men and women 40 years of age and older. Lifetime risks for AF are high (1 in 6), even in the absence of antecedent CHF or MI. *(Circulation* 2004;110:1042–6)
- Data from the National Hospital Discharge Survey (from 1996 to 2001) on cases that included AF as a primary discharge diagnosis found that: *(Am J Cardiol* 2004;94:500–4)
  - — About 44.8 percent of patients were men.
  - — The mean age for men was 66.8 years vs. 74.6 for women.
  - — The racial breakdown for admissions was 71.2 percent white, 5.6 percent black, and 2.0 percent other races. 20.8 percent were not specified.
  - — African-American patients were much younger than patients of other races.
  - — The incidence in men ranged from 20.58/100,000 persons per year for patients ages 15 to 44 to 1,077.39/100,000 persons per year for patients ages 85 and older. In women the incidence ranged from 6.64/100,000 persons per year for patients ages 15 to 44 years to 1,203.7/100,000 persons per year for those ages 85 and older.
  - — From 1996 to 2001, hospitalizations with AF as the first-listed diagnosis, increased 34 percent.
- Age-adjusted death rates for AF were highest among whites (25.7) and blacks (16.4) and higher for men (34.7) than women (22.8). *(MMWR,* Vol. 52, No. 7, Feb. 21, 2003, CDC/NCHS)
- The most common diseases listed as the **primary** diagnosis for persons hospitalized with AF were congestive heart failure (11.8 percent), followed by AF (10.9 percent), CHD (9.9 percent), and stroke (4.9 percent). *(MMWR,* Vol. 52, No. 7, Feb. 21, 2003, CDC/NCHS)
- AF is an independent risk factor for stroke, increasing risk about 5-fold. The risk for stroke attributable to AF increases with age. *(Stroke* 1991;22:983–8)
- AF is responsible for about 15–20 percent of all strokes. *(JAMA* 2001;285:2370–5)
- AF is also an independent risk factor for stroke recurrence and stroke severity. A recent report showed people who had AF and were not treated with anticoagulants had a 2.1-fold increase in risk for recurrent stroke and a 2.4-fold increase in risk for recurrent severe stroke. *(Am J Med* 2003;114:206–10)
- People who have strokes caused by AF have been reported as 2.23 times more likely to be bedridden compared to those who have strokes from other causes. *(Neuroepidemiology* 2003;22:118–23)
- Participants in the FHS Offspring Study of the NHLBI were examined between 1984 to 1987 and monitored for 10 years. Data show that symptoms of anger and hostility were predictive of 10-year incidence of AF in men. *(Am J Epidemiol* 2004;159:950–8)
- Participants in the FHS study of the NHLBI were followed from 1968–1999. At age 40, lifetime risks for AF were 26.0 percent for men and 23.0 percent for women. At 80 years, lifetime risks for AF were 22.7 percent for men and 21.6 percent for women. In further analysis, counting only those who had development of AF without prior or concurrent congestive heart failure or MI, lifetime risk for AF was approximately 16 percent. *(Circulation* 2004;110:1042–6)
- **Tachycardia** (ICD/9 427.0,1,2) (ICD/10 I47.0,1,2,9). Mortality — 6,496. Total mention mortality — 7,500. Hospital discharges — 87,000.
- **Paroxysmal supraventricular tachycardia** (ICD/9 427.0) (ICD/10 I47.1). Mortality — 137. Hospital discharges — 30,000.

Ventricular fibrillation (ICD/9 427.4) (ICD/10 I49.0). Mortality — 1,406. Total mention mortality — 14,500. Hospital discharges — 8,000. Ventricular fibrillation is listed as the cause of relatively few deaths, but the overwhelming number of sudden cardiac deaths from coronary disease (estimated at about 335,000 per year) is thought to be from ventricular fibrillation.

Arteries, Diseases of

(ICD/9 440–448) (ICD/10 I70–I79) (Includes peripheral arterial disease)

Mortality — 38,748 Total mention mortality — 118,300. Hospital discharges — 272,000.

Aortic aneurysm (ICD/9 441) (ICD/10 I71). Mortality — 15,234. Total mention mortality — 21,100. Hospital discharges — 61,000.

Atherosclerosis (ICD/9 440) (ICD/10 I70) is a process that leads to a group of diseases characterized by a thickening of artery walls. Mortality — 14,086. Total mention mortality — 68,900. Hospital discharges — 111,000. Atherosclerosis causes many deaths from heart attack and stroke and accounts for nearly three-fourths of all deaths from CVD. (FHS, NHLBI)

- In 1999 U.S. community hospitals billed $26.2 billion for coronary atherosclerosis, more than for any other condition. (AHRQ Electronic Newsletter, June 14, 2002)

Other diseases of arteries (ICD/9 442–448) (ICD/10 I72–I78). Mortality — 10,084. Hospital discharges — 100,000.

- Kawasaki disease (ICD/9 446.1) (ICD/10 M30.3). Total mention mortality — 6. Up to 2,500 cases of Kawasaki disease are diagnosed yearly. Hospital discharges — 6,000, primary plus secondary diagnoses. *[Pediatr Infect Dis J* 1994;13(8)]
  - About 80 percent of Kawasaki disease patients are under age 5; most are under age 2. Children older than 8 years are rarely affected. (*NEJM* 1998;339:93–104)
  - Kawasaki disease occurs more often among boys (63 percent) and among those of Asian ancestry. *(Pediatr Infect Dis J* 1994;13:8)
  - The highest incidence in the United States is in Hawaii. A hospitalization rate of 47.7 per 100,000 children under age 5 was reported during the mid-1990s. In the continental United States, the estimated incidence is from 9 to 19 per 100,000 children. *(Pediatrics* 2003;112:495–501)

Peripheral arterial disease (PAD) affects 8 to 12 million Americans and is associated with significant morbidity and mortality. *(JAMA* 2001;286:1317–24; *NEJM* 1992;326:381–6)

- A study from the NHANES 1999–2000 data found that PAD affects about 5 million adults. Prevalence increases dramatically with age and disproportionately affects blacks *(Circulation* 2004;110:738–43). However, the measurement of systolic blood pressure utilizing the right arm only and the omission of queries for surgical procedures to correct PAD in this study led to an underestimate of the true PAD prevalence. Experts in the field generally agree that PAD affects approximately 8 to 12 million Americans *(JAMA* 200;286:1317–24; *NEJM* 1992;326:381–6).
- PAD affects 12–20 percent of Americans age 65 and older (4.5–7.6 million). By 2050 the prevalence could reach 9.6–16 million among those age 65 and older and 19 million overall. Despite its prevalence and cardiovascular risk implications, only 25 percent of PAD patients are undergoing treatment. *(J Vasc Interv Radiol* 2002;13:7–11)
- Based on current epidemiologic projections, 27 million people in Europe and North America have PAD. An estimated 10.5 million are symptomatic and 16.5 million are asymptomatic. The prevalence of asymptomatic PAD was estimated in one study to be as high as 20 percent of the adult population. *(Arch Intern Med* 2003;163)
- In the general population, only about 10 percent of persons with PAD have the classic symptoms of intermittent claudication (IC). About 40 percent do not complain of leg pain, while the remaining 50 percent have a variety of leg symptoms different from classic claudication. *(JAMA* 2001;286:11, 1317–24; *Circulation* 1985;71:516–22)
- The risk factors for PAD are similar to those for CHD, although diabetes and cigarette smoking are particularly strong risk factors for PAD. *(Am J Epidemiol* 1989;129:1110–9)
- Persons with PAD have impaired function and quality of life. This is true even for persons who do not report leg symptoms. Furthermore, PAD patients, including those who are asymptomatic, experience significant decline in lower extremity functioning over time. *(Ann Intern Med* 2002;136:873–83; *JAMA* 2004;292:453–61)
- PAD is a marker for systemic atherosclerotic disease. Persons with PAD, compared to those without, have 4–5 times the risk of dying of a CVD event, resulting in 2–3 times higher total mortality risk. *(NEJM* 1992;326:381–6; *JAMA* 1993;270:487–9)
- In the Framingham Heart Study (FHS), the incidence of PAD was based on symptoms of IC in subjects ages 29–62. Annual incidence of IC per 10,000 subjects at risk rose from 6 in men and 3 in women ages 30–44 to 61 in men and 54 in women ages 65–74. *(Clin Cornerstone* 2002;4:1–15)
- Several studies have evaluated both symptomatic and asymptomatic PAD using the ABI. The prevalence of asymptomatic PAD was 25.5 percent among 1,537 participants of the Systolic Hypertension in the Elderly Program (SHEP). *(Clin Cornerstone* 2002;4:1–15)
- In the FHS the annual mortality rate was almost 4 times greater in subjects with IC. In a major cohort study, investigators observed a 3.1 times higher risk for all-cause mortality compared with patients without PAD. In addition, PAD patients had a 5.9 times higher risk for death from CVD complications and a 6.6 times higher risk for death from CHD specifically. *(Clin Cornerstone* 2002;4:1–15; *NEJM* 1992;326:381–6)
- In the Genetic Epidemiology Network of Arteriopathy (GENOA) study of the NHLBI, a comparison between African Americans and non-Hispanic whites found that after

adjusting for age, African Americans had a greater prevalence of PAD (women 34 percent vs. 22 percent; men 33 percent vs. 11 percent). *(Vasc Med* 2003 Nov;8(4):237–42)

- Data from NHANES, 1999–2000 (CDC/NCHS), show that even low blood levels of lead and cadmium may increase the risk of PAD. Exposure to these two metals is possible through cigarette smoke. The risk was 2.8 for high levels of cadmium and 2.9 for high levels of lead. The odds ratio of PAD for current smokers was 4.13 compared to people who had never smoked. *(Circulation* 2004;109:3196–201)

Bacterial Endocarditis

(ICD/9 421.0) (ICD/10 I33.0)

Total mention mortality — 2,421. Hospital discharges — 17,000, primary plus secondary diagnoses.

Cardiomyopathy

(ICD/9 425) (ICD/10 I42)

Mortality — 26,863. Total mention mortality — 54,600. Hospital discharges — 36,000.

- 87 percent of cases are congestive or dilated cardiomyopathy. 50 percent of patients with dilated cardiomyopathy are alive 5 years after their initial diagnosis; 25 percent are alive 10 years after the diagnosis. (Facts About Cardiomyopathy, NIH, NHLBI, 1995)
- Mortality from cardiomyopathy is highest in older persons, men and blacks. (FHS, NHLBI)
- Tachycardia-induced cardiomyopathy develops slowly and appears reversible, but recurrent tachycardia causes rapid decline in left ventricular function and development of heart failure. Sudden death is possible. *(Circulation* 2004;110:247–52)
- Since 1996 the NHLBI's Pediatric Cardiomyopathy Registry has collected data on all children with newly diagnosed cardiomyopathy in New England and the Central Southwest (Texas, Oklahoma and Arkansas). *(NEJM* 2003;348:1647–55)
  - — The overall incidence of cardiomyopathy is 1.13 cases per 100,000 in children younger than age 18.
  - — In children under 1 year the incidence is 8.34 and in children from 1 year to age 18 it's 0.70 per 100,000.
  - — The annual incidence is lower in white than black children; higher in boys than girls; higher in New England (1.44 per 100,000) than in the Central Southwest (0.98 per 100,000).
- Studies show that 36 percent of young athletes who die suddenly have probable or definite hypertrophic cardiomyopathy. *(JAMA* 1996;276:199–204)

Rheumatic Fever/Rheumatic Heart Disease

(ICD/9 390–398) (ICD/10 I00–I09)

Population Group	Mortality 2002	Hospital Discharges 2002
Total population	3,579	52,000
Total males	1,078 (30.1%)*	19,000
Total females	2,501 (69.9%)*	33,000
White males	950	—
White females	2,254	—
Black males	93	—
Black females	159	—

Note: (–) = data not available.

* These percentages represent the portion of total mortality that is males vs. females.

Sources: ***Mortality:*** *CDC/NCHS; data for white and black males and females include Hispanics.* ***Hospital discharges:*** *CDC/NCHS; data include people both living and dead.*

Incidence

- Many operations on heart valves are related to rheumatic heart disease (RHD).
- The incidence of rheumatic fever (RF) remains higher in African Americans, Puerto Ricans, Mexican Americans and American Indians. (Hurst W. *The Heart, Arteries and Veins.* 10th ed. New York, NY: McGraw-Hill; 2001)

Mortality

- Total mention mortality —6,975
- In 1950 about 15,000 Americans (adjusted for changes in ICD codes) died of RF/RHD compared with about 3,500 today.
- From 1992 to 2002 the death rate from RF/RHD fell 23.5 percent, while actual deaths declined 39.1 percent.
- The 2002 overall death rate for RF/RHD was 1.2. Death rates were 0.9 for white males and 0.8 for black males, 1.5 for white females and 1.0 for black females.

Valvular Heart Disease

(ICD/9 424) (ICD/10 I34–I38)

Mortality — 19,737. Total mention mortality — 42,060. Hospital discharges — 98,000.

- Aortic valve disorders (ICD/9 424.1) (ICD/10 I35). Mortality — 12,380. Total mention mortality — about 26,200. Hospital discharges — 56,000.
- Mitral valve disorders (ICD/9 424.0) (ICD/10 I34). Mortality — 2,865. Total mention mortality — about 7,000. Hospital discharges — 39,000.
  — The NHLBI's FHS reports that among people ages 26–84, prevalence is about 1–2 percent and equal between women and men.
- Pulmonary valve disorders (ICD/9 424.3) (ICD/10 I37). Mortality — 12. Total mention mortality — 34.
- Tricuspid valve disorders (ICD/9 424.2) (ICD/10 I36). Mortality — 3. Total mention mortality — 46.

Operations and Procedures

- In 2002 an estimated 93,000 valve procedures were performed in the United States. For more data, see pages 51 and 52. (CDC/NCHS)

Venous Thromboembolism

- Venous thromboembolism (VTE) occurs for the first time in about 100 persons per 100,000 each year in the United States. About one-third of patients with symptomatic VTE manifest pulmonary embolism (PE), whereas two-thirds manifest deep vein thrombosis (DVT) alone. *(Circulation* 2003;107:I-4–I-8)
- Caucasians and African Americans have a significantly higher incidence than Hispanics and Asian or Pacific Islanders. *(Circulation* 2003;107:I-4–I-8)
- In studies conducted in Worcester, Mass., and Olmsted County, Minn., the incidence of VTE was about 1 in 1,000. In both studies VTE was more common in men; for each 10-year increase in age, the incidence doubled. By extrapolation, it's estimated that more than 250,000 patients are hospitalized annually with VTE. *(NEJM* 1998;339:93–104)
- The crude incidence rate per 1,000 person-years was 0.80 in the ARIC study, 2.15 in CHS and 1.08 in the combined cohort. Half of the participants who developed incident VTE were women and 72 percent were white. *(Am J Med* 2002;113:636–42)
- Over 200,000 new cases of VTE occur annually. Of these, 30 percent die within three days; one-fifth suffer sudden death due to PE. About 30 percent develop recurrent VTE within 10 years. Independent predictors for recurrence include increasing age, obesity, malignant neoplasm and extremity paresis. *(Seminars in Thrombosis and Hemostasis.* Vol. 28, Suppl. 2, 2002)
- Data from the ARIC study of the NHLBI showed the 28-day fatality from DVT is 9 percent; from PE, 15 percent; from idiopathic DVT or PE, 5 percent; from secondary non-cancer-related DVT or PE, 7 percent; and secondary cancer-related DVT or PE, 25 percent. *(Am J Med* 2004;117(1):19–25)
- **Deep vein thrombosis** (ICD/9 451.1) (ICD/10 I80.2). Mortality — 2,730. Total mention mortality — 10,200. Hospital discharges — 8,000.
- A review of nine studies conducted in the United States and Sweden showed that the mean incidence of first DVT in the general population was 5.04 per 10,000 person-years. The incidence was similar in males and females and increased dramatically with age from about 2–3 per 10,000 person-years at ages 30–49 to 20 at ages 70–79. *(Eur J Vasc Endovasc Surg* 2003;25:1–5)
- Death occurs in about 6 percent of DVT cases within one month of diagnosis. *(Circulation* 2003;107:I-4–I-8)
- **Pulmonary embolism** (ICD/9 415.1) (ICD/10 I26). Mortality — 8,627. Total mention mortality — 26,400. Hospital discharges — 99,000.
- In the Nurses Health Study, nurses age 60 or older in the highest BMI quintile had the highest rates of pulmonary embolism. (BMI is body mass index; see Glossary on page 58 for definition.) Heavy cigarette smoking and high blood pressure were also identified as risk factors for PE. *(NEJM* 1998;339:93–104)
- Death occurs in about 12 percent of PE cases within one month of diagnosis. *(Circulation* 2003;107:I-4–I-8)
- A study of Medicare recipients age 65 and older reported 30-day case fatality rates in patients with PE. Overall, men had higher fatality rates than women (13.7 percent vs. 12.8 percent), and blacks had higher fatality rates than whites (16.1 percent vs. 12.9 percent). *(NEJM* 1998;339:93–104)
- In the International Cooperative Pulmonary Embolism Registry, the three-month mortality rate was 17.5 percent. In contrast, the overall three-month mortality rate in the Prospective Investigation of Pulmonary Embolism Diagnosis was 15 percent, but only 10 percent of deaths during one year of follow-up were ascribed to PE. *(NEJM* 1998;339:93–104)
- The age-adjusted rate of deaths from **pulmonary thromboembolism** (PTE) decreased from 191 per million in 1979 to 94 per million in 1998 overall, decreasing 56 percent for men and 46 percent for women. During this time the age-adjusted mortality rates for blacks were consistently 50 percent higher than those for whites, and those for whites were 50 percent higher than those for people of other races (Asian, American Indian, etc.). Within racial strata, mortality rates were consistently 20 to 30 percent higher among men than among women. *(Arch Intern Med* 2003;163:1711–7)

9 Risk Factors

Tobacco

Cigarette Smoking, Overall Prevalence

Population Group	Prevalence 2002
Total population	48,500,000 (22.5%)
Total males	26,300,000 (25.2%)
Total females	21,200,000 (20.0%)
White males	25.2%
White females	20.7%
Black or African-American males	27.0%
Black or African-American females	18.5%
Hispanic or Latino males #	23.2%
Hispanic or Latino females #	12.5%
Asian only males #	21.3%
Asian only females #	6.9%
American Indian or Alaska Native only males #	32.0%
American Indian or Alaska Native only females #	36.9%

Note: Data are crude percentages for age 18 and older.

— Data are for 1999–2001.

Source: Health, United States, 2003 & 2004, CDC/NCHS.

Cigarette Smoking, Prevalence by Race/Ethnicity, Age and Sex

Population Group	Ages 12–17 Males	Ages 12–17 Females	Age 18 and older Males	Age 18 and older Females
Non-Hispanic:				
White	14.9%	17.2%	29.1%	25.9%
Black	8.2%	5.9%	30.1%	22.2%
Hispanic:	11.4%	10.2%	29.2%	17.3%
Mexican	11.4%	10.6%	29.8%	15.6%
Puerto Rican	11.2%	10.4%	34.2%	27.3%
Central or South American	9.9%	9.3%	26.3%	16.9%
Cuban	14.3%	10.0%	21.1%	17.5%
Asian:	8.8%	7.3%	24.1%	9.1%
Chinese	6.3%	5.4%	19.3%	5.9%
Filipino	5.8%	8.9%	—	6.9%
Japanese	—	—	18.3%	—
Asian Indian	10.1%	6.8%	20.0%	3.0%
Korean	13.8%	7.3%	—	—
Vietnamese	—	8.0%	—	—
American Indian or Alaska Native	29.5%	26.3%	40.9%	40.0%
Hawaiian or Other Pacific Islander	7.0%	NR	NR	NR
TOTAL	13.3%	14.2%	29.2%	24.1%

Note: (—) = data not available; NR = data considered unreliable.

Source: Percentage of persons ages 12–17 and age 18 and older reporting cigarette use during the preceding month, by race/ethnicity and sex: National Survey on Drug Use and Health, U.S., 1999–2001, MMWR, Vol. 53, No. 3, Jan. 30, 2004, CDC/NCHS.

Prevalence

Youth

- In 2003 for grades 9–12, 30.3 percent of male students and 24.6 percent of female students reported current tobacco use; 19.9 percent of males and 9.4 percent of females reported current cigar use; and 11.0 percent of males and 2.2 percent of females reported current smokeless tobacco use. (Youth Risk Behavior Surveillance [YRBS], United States, 2003, *MMWR,* Vol. 53, No. SS-2, May 21, 2004, CDC/NCHS)
- About 80 percent of people who use tobacco begin before age 18. The most common age of initiation is 14 to 15. *(MMWR*, Vol. 48, No. 31, Aug. 1999, CDC/NCHS)
- White youths ages 18–24 from families with lower educational attainment report substantially higher smoking rates than black and Mexican-American youths from families with similar educational attainment. 77 percent of young white men and 61 percent of young white women are smokers compared with 35 percent of minority youth. *(JAMA* 1999;281:1006–13)
- From 1980 to 2002 the percentage of high school seniors who smoked in the past month decreased 12.5 percent. This percentage decreased by 2.2 percent in males, 23.7 percent in females, 0.3 percent in whites and 55.2 percent in blacks or African Americans. *(Health, United States*, 2003, CDC/NCHS)
- An estimated 150,000–300,000 children younger than 18 months of age have respiratory tract infections because of exposure to secondhand smoke. (CDC/NCHS)
- Children's exposure to secondhand smoke, as indicated by cotinine levels, dropped between 1988–94 and 1999–2000. Overall, 64 percent of children ages 4–11 had cotinine in their blood in 1999–2000, down from 88 percent in 1988–94. In 1999–2000, 86 percent of non-Hispanic black children ages 4–11 had cotinine in their blood compared to 63 percent of non-Hispanic white children and 49 percent of Mexican-American children. The percentage of homes with children under age 7 in which someone smokes on a regular basis decreased from 29 percent in 1994 to 19 percent in 1999. *(America's Children: Key National Indicators of Well-Being*, 2003. Federal Interagency Forum on Child and Family Statistics, Washington, D.C.: U.S. Government Printing Office)

- Among children under age 18, an estimated 22 percent are exposed to secondhand smoke in their homes, with estimates ranging from 11.7 percent in Utah to 34.2 percent in Kentucky. *(MMWR,* Vol. 46, No. 44, 1997, CDC/NCHS)

Adults

- Since 1965 smoking in the United States has declined by 47 percent among people age 18 and older. *(Health, United States*, 2004, CDC/NCHS)
- Among Americans age 18 and older, 25.2 percent of men and 20.0 percent of women are smokers, putting them at increased risk of heart attack and stroke. *(Health, United States*, 2004, CDC/NCHS)
- Use of any tobacco product in 2001 was 31.3 percent for white only, 27.7 for black or African-American only, 44.9 for American Indian or Alaska Native only, 28.5 for Native Hawaiian or other Pacific Islander only, 13.6 for Asian only and 22.9 for Hispanic or Latino, any race. *(Health, United States*, 2003, CDC/NCHS)
- Smoking prevalence is higher among those with 9–11 years of education (35.4 percent) compared with those with more than 16 years of education (11.6 percent). It's highest among persons living below the poverty level (33.3 percent) compared with other income groups. *(MMWR,* Vol. 48, No. 43, 1999, CDC/NCHS)
- About 60 percent of people in the U.S. have biological evidence of secondhand smoke exposure. *(Second National Report on Human Exposure to Environmental Chemicals: Tobacco Smoke.* CDC/NCHS 2003:80)
- Data from the BRFSS study of the CDC/NCHS show that more than one-third of white men and women ages 18–24 smoked, the highest rate among all the groups covered in the survey in 2000. Those young people and Hispanic women the same age had the largest increases in smoking rates from 1990–2000. More than half of men and women ages 18–24 from all ethnic groups failed to quit smoking in 2000. Younger white women and men ages 18–44 had higher overall risk levels for noncommunicable diseases, probably due to increased smoking and obesity. *(Am J Health Promot* 2004;19(1):19)
- According to the World Health Organization (WHO), 1 year after quitting, the risk of CHD decreases by 50 percent. Within 15 years, the relative risk of dying from CHD for an ex-smoker approaches that of a long-time (lifetime) nonsmoker. (World No-Tobacco Day 1998, www.who.ch/ntday/ntday98)

Incidence

- A survey conducted in 2002 found that an estimated 1.4 million Americans began smoking cigarettes daily in 2001. This translates to close to 4,000 new regular smokers per day, including more than 2,000 youths under age 18. (National Survey on Drug Use and Health, samhsa.gov)
- Information from the CDC Health Effects of Cigarette Smoking Fact Sheet, February 2004:
  - — Cigarette smokers are 2–4 times more likely to develop CHD than nonsmokers.
  - — Cigarette smoking approximately doubles a person's risk for stroke.
  - — Cigarette smokers are more than 10 times as likely as nonsmokers to develop peripheral vascular disease (PVD).

Mortality

- From 1995 to 1999 an average of 442,398 Americans died each year of smoking-related illnesses. 33.5 percent of these deaths were cardiovascular-related. *(MMWR,* Vol. 51, No. 14, 2002, CDC/NCHS)
- About 35,000 nonsmokers die from CHD each year as a result of exposure to environmental tobacco smoke. *(MMWR,* Vol. 51, No. 14, 2002, CDC/NCHS)
- On average, male smokers die 13.2 years earlier than male nonsmokers, and female smokers die 14.5 years earlier than female nonsmokers(Surgeon General's Health Consequences of Smoking 2004)
- Current cigarette smoking is a powerful independent predictor of sudden cardiac death in patients with CHD. (Arch Intern Med 2003;163:2301–5)
- Cigarette smoking results in a 2-to-3 fold risk of dying from CHD. (Tobacco-Related Mortality, Fact Sheet. CDC.gov/tobacco. Feb. 2004)

Health Consequences

- Data from *The Health Consequences of Smoking, 2004 — A Report of the Surgeon General* (CDC/NCHS): A study of women younger than 44 years of age found there was a strong dose-relationship for MI, with a risk of 2.5 for those smoking 1 to 5 cigarettes per day, rising to 74.6 for those smoking more than 40 cigarettes per day, compared with nonsmokers.
- Another study on female smokers found the highest risk (6.8) for MI was in women younger than 55 years of age.
- One-third of those who receive percutaneous coronary artery vascularization are current smokers, and 50 to 60 percent continue to smoke after the procedure.
- Cigarette smoking remains a major cause of stroke in the U.S. The evidence is sufficient to infer a causal relationship between smoking and subclinical atherosclerosis.
- From 61.3 percent to 82.1 percent of adults report that their workplace has a smoke-free policy. (BRFSS [1999], CDC/NCHS)
- The 2004 Health Consequences of Smoking Report of the Surgeon General states that the risk of stroke decreases steadily after smoking cessation. Former smokers have the same risk as nonsmokers after 5 to 15 years. (www.cdc.gov/tobacco/sgr/sgr_2004/Factsheets/3.htm)

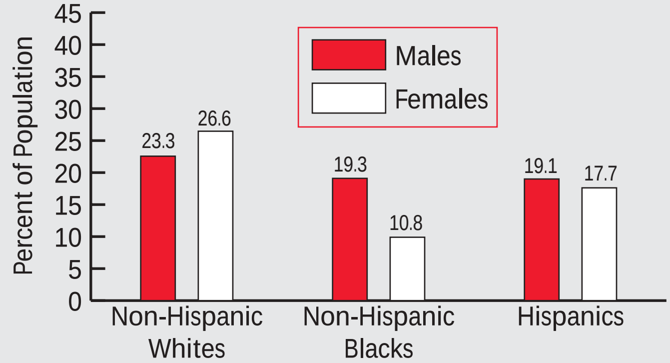
Chewing Tobacco

- About 5 million American men and women use chewing tobacco. (NHANES III [1988–94], CDC/NCHS)
  - — Rates are highest in the South and rural areas.
  - — Men use chewing tobacco at 10 times the rate for women. For men, the percentages who use chewing tobacco are 6.8 for whites, 3.1 for blacks, 1.5 for Hispanics, 1.2 for Asian or Pacific Islanders and 7.8 for American Indians or Alaska Natives.
  - — For women the percentages are 0.3 for whites, 2.9 for blacks, 0.1 for Hispanics, almost none for Asian or Pacific Islanders and 1.2 for American Indians or Alaska Natives.
  - — Use rates increase as years of education decrease for both men and women.

Cost

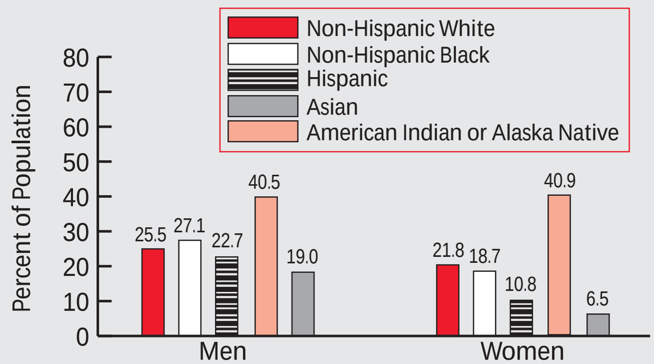
- Direct medical costs and lost productivity costs associated with smoking total an estimated $155 billion per year. (CDC/NCHS)

Prevalence of High School Students In Grades 9–12 Reporting Current Cigarette Smoking by Sex and Race/Ethnicity
YRBS: 2003



Source: MMWR, Vol. 53, (23); 499–502, June 18, 2004, CDC/NCHS.

Prevalence of Current Smoking for Americans Age 18 and older By Race/Ethnicity and Sex
NHIS: 2002



Source: MMWR, Vol. 53, (20); 427–431, May 28, 2004, CDC/NCHS.

High Blood Cholesterol and Other Lipids

Population Group	Prevalence of Total Cholesterol 200 mg/dL or higher 2002	Prevalence of Total Cholesterol 240 mg/dL or higher 2002	Prevalence of LDL Cholesterol 130 mg/dL or higher 2002	Prevalence of HDL Cholesterol less than 40 mg/dL 2002
Total population*	106,900,000 (50.7%)	37,700,000 (18.3%)	95,000,000 (45.8%)	54,700,000 (26.4%)
Total males*	50,400,000 (50.4%)	16,900,000 (17.2%)	48,600,000 (48.5%)	39,000,000 (39.0%)
Total females*	56,500,000 (50.9%)	20,800,000 (19.1%)	46,400,000 (43.3%)	15,900,000 (14.9%)
White males**	51.0%	17.8%	49.6%	40.5%
White females**	53.6%	19.9%	43.7%	14.5%
Black males**	37.3%	10.6%	46.3%	24.3%
Black females**	46.4%	17.7%	41.6%	13.0%
Mexican-American males	54.3%	17.8%	43.6%	40.1%
Mexican-American females	44.7%	13.9%	41.6%	18.4%
Total Hispanics#	—	25.6%	—	—
Total Asian or Pacific Islanders#	—	27.3%	—	—
Total American Indians or Alaska Natives, Alaska#	—	26.0%	—	—
Total American Indians or Alaska Natives, Oklahoma#	—	28.6%	—	—
Total American Indians or Alaska Natives, Washington#	—	26.5%	—	—

Note: mg/dL = milligrams per deciliter of blood. Prevalence of Total Cholesterol 200 mg/dL or higher includes people with total cholesterol of 240 mg/dL or higher. In adults, levels of 200–239 mg/dL are considered borderline-high risk. Levels of 240 mg/dL or higher are considered high risk.

(—) = data not available.

* Total population data for total cholesterol are for Americans age 20 and older. Data for LDL cholesterol, HDL cholesterol and all racial/ethnic groups are age-adjusted for age 20 and older.

** Data for 240 mg/dL for whites are white only and for blacks are black or African-American only.

BRFSS (1997), MMWR, Vol. 49, No. SS-2, March 24, 2000, CDC/NCHS; data are for Americans age 18 and older.

Source for total cholesterol 200 mg/dL or higher: NHANES (1999 to 2000), Circulation. *2003;107:2185–2189; 240 mg/dL or higher data from* Health, United States, 2003, *CDC/NCHS; LDL and HDL cholesterol: NHANES III (1988–94), CDC/NCHS.*

Prevalence

For information on dietary cholesterol, total fat, saturated fat and other factors that affect blood cholesterol levels, see Nutrition, pages 46–47.

Youth

- Among children and adolescents ages 4–19 years (NHANES III [1988–94], CDC/NCHS):
  - — Females have significantly higher average total cholesterol and low-density lipoprotein (LDL) cholesterol (bad cholesterol) than do males.
  - — Non-Hispanic black children and adolescents have significantly higher mean total cholesterol, LDL (bad) cholesterol and HDL (good) cholesterol levels when compared with non-Hispanic white and Mexican-American children and adolescents.
- Among children and adolescents ages 4–19, the mean total blood cholesterol level is 165 mg/dL. For boys it's 163 mg/dL and for girls it's 167 mg/dL. The racial/ethnic breakdown is (NHANES III [1988–94], CDC/NCHS):
  - — For non-Hispanic whites, 162 mg/dL for boys and 166 mg/dL for girls.
  - — For non-Hispanic blacks, 168 mg/dL for boys and 171 mg/dL for girls.
  - — For Mexican Americans, 163 mg/dL for boys and 165 mg/dL for girls.
- About 10 percent of adolescents ages 12–19 have total cholesterol levels exceeding 200 mg/dL. (NHANES III [1988–94], CDC/NCHS)

Adults

- Beginning at age 45, a higher percentage of women than men have total blood cholesterol of 200 mg/dL or higher. (NHANES [1999–2000], CDC/NCHS)

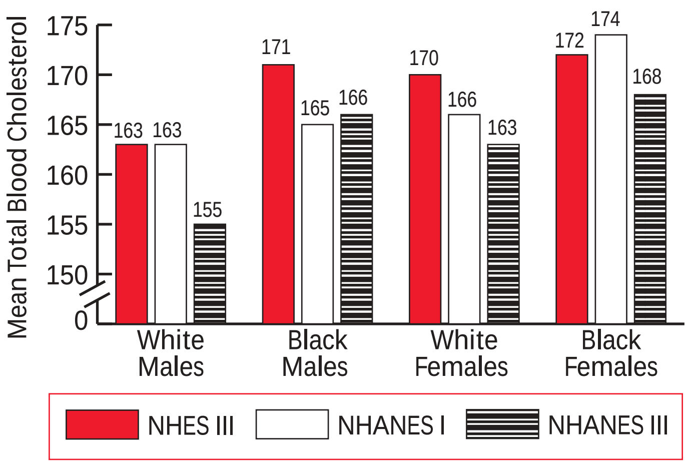
- The prevalence of cholesterol screening during the preceding 5 years increased from 67.3 percent in 1991 to 70.8 percent in 1999. The age-standardized prevalence of high blood cholesterol awareness among persons screened increased from 25.7 percent in 1991 to 28.6 percent in 1999. (BRFSS, *MMWR*, Vol. 50, No. 35, Sept. 7, 2001, CDC/NCHS)
- A 10-percent decrease in total cholesterol levels (population-wide) may result in an estimated 30-percent reduction in the incidence of CHD. (*MMWR*, Vol. 49, No. 33, Aug. 25, 2000, CDC/NCHS)

Adherence

Based on data from the Third Report of the Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III [ATP III], NHLBI):

- Less than half of persons who qualify for any kind of lipid-modifying treatment for CHD risk reduction are receiving it.
- Less than half of even the highest-risk persons, those who have symptomatic CHD, are receiving lipid-lowering treatment.
- Only about a third of treated patients are achieving their LDL goal; less than 20 percent of CHD patients are at their LDL goal.
- Only about half of the people who are prescribed a lipid-lowering drug are still taking it six months later; after 12 months this falls to 30–40 percent. This is especially troubling, because it takes six months to one year before a benefit from treatment becomes apparent.

Trends in Mean Total Blood Cholesterol Among Adolescents Ages 12–17 by Race, Sex and Survey
NHES III: 1966–70, NHANES I & III: 1971–74, 1988–94



Source: CDC/NCHS. Prev Med. 1998;27:879–890.

LDL (Bad) Cholesterol

Youth

- Mean LDL cholesterol levels among children and adolescents ages 12–19 are (NHANES III [1988–94], CDC/NCHS):
  - — Among non-Hispanic whites, 91 mg/dL for boys and 100 mg/dL for girls.
  - — Among non-Hispanic blacks, 99 mg/dL for boys and 102 mg/dL for girls.
  - — Among Mexican Americans, 93 mg/dL for boys and 92 mg/dL for girls.

Adults

- The mean level of LDL cholesterol for American adults age 20 and older is 127 mg/dL. Levels of 130–159 mg/dL are considered borderline high. Levels of 160–189 mg/dL are classified as high, and levels of 190 mg/dL and higher are very high. (NHANES III [1988–94], CDC/NCHS)
  - — Among non-Hispanic whites, 20.4 percent of men and 17.0 percent of women have an LDL cholesterol level of 160 mg/dL or higher.
  - — Among non-Hispanic blacks, 19.3 percent of men and 18.8 percent of women have an LDL cholesterol level of 160 mg/dL or higher.
  - — Among Mexican Americans, 16.9 percent of men and 14.0 percent of women have an LDL cholesterol level of 160 mg/dL or higher.

HDL (Good) Cholesterol

The higher a person's HDL cholesterol level is, the better. Less than 40 mg/dL in adults is low HDL cholesterol, a risk factor for heart disease and stroke.

Youth

- Mean HDL cholesterol levels among children and adolescents ages 4–19 are (NHANES III [1988–94], CDC/NCHS):
  - — Among non-Hispanic whites, 48 mg/dL for boys and 50 mg/dL for girls.
  - — Among non-Hispanic blacks, 55 mg/dL for boys and 56 mg/dL for girls.
  - — Among Mexican Americans, 51 mg/dL for boys and 52 mg/dL for girls.

Adults

- The mean level of HDL cholesterol for American adults age 20 and older is 50.7 mg/dL. (NHANES III [1988–94], CDC/NCHS)
- Men and women who have low HDL cholesterol and high total cholesterol levels have the highest risk of heart attack. However, men with HDL levels of 37 mg/dL or lower or women whose levels are 47 mg/dL or lower are at a high risk regardless of their total cholesterol level. Conversely, those with high levels of total cholesterol have lower risks of heart attack when they also have higher levels of HDL cholesterol (53 mg/dL or greater in men and 67 mg/dL or greater in women). (FHS, NHLBI)

Physical Inactivity

Population Group	Prevalence 1999–2001
Total Population	38.6%
Total Males	35.8%
Total Females	41.0%
White only males	34.4%
White only females	38.3%
Black or African-American males	45.1%
Black or African-American females	55.1%
American Indian or Alaska Native only males	42.5%
American Indian or Alaska Native only females	55.5%
Hispanic or Latino males	52.6%
Hispanic or Latino females	57.2%
Asian only males	33.4%
Asian only females	42.6%
Native Hawaiian or other Pacific Islander males	38.5%
Native Hawaiian or other Pacific Islander females	27.1%

Note: Prevalence is the percentage of population who report no leisure-time physical activity.

Source: NHIS (1999–2001), CDC/NCHS; data are age-adjusted for Americans age 18 and older.

Prevalence

Youth

- In 2003, 58.5 percent of male and 52.8 percent of female high school students, grades 9–12, were enrolled in physical education (PE) classes. 30.5 percent of males and 26.4 percent of females attended classes daily and 84.5 percent of males and 75.3 percent of females exercised or played sports during an average PE class. *(MMWR,* Vol. 53, No. SS-2, May 21, 2004, CDC/NCHS)
- 2002 data from the Youth Media Campaign Longitudinal Study (YMCLS) of the CDC showed that 61.5 percent of children ages 9–13 don't participate in any organized physical activity (PA) during their nonschool hours and that 22.6 percent don't engage in any free-time PA. Non-Hispanic black and Hispanic children are significantly less likely than non-Hispanic white children to report involvement in organized activities, as are children with parents who have lower incomes and education levels. *(MMWR,* Vol. 52, No. 33, Aug. 22, 2003, CDC/NCHS)
- By the age of 16 or 17, 31 percent of white girls and 56 percent of black girls report no habitual leisure-time activity. *(NEJM* 2002;347:709–15)
  - — Lower levels of parental education are associated with greater decline in activity for white girls at both younger and older ages. For black girls, this association is seen only at the older ages.
  - — Cigarette smoking is associated with decline in activity among white girls. Pregnancy is associated with decline in activity among black girls but not among white girls.
  - — A higher BMI is associated with greater decline in activity among girls of both races.

Adults

Prevalences of no leisure-time physical activity by race and sex, in adults age 18 and older: (BRFSS [2002], *MMWR*, Vol. 53, No. 4, Feb. 6, 2004, CDC/NCHS)

Population Group	Men	Women
Non-Hispanic whites	19.2	23.2
Non-Hispanic blacks	27.7	36.0
Hispanics	35.2	40.1
Asian or Pacific Islanders	19.9	28.0
American Indians or Alaska Natives	26.3	29.8

- 2001–2003 data from the BRFSS study of the CDC/NCHS showed that among Asians and Native Hawaiian or Other Pacific Islanders, 21.2 percent of men and 27.0 percent of women reported no leisure-time physical activity. Of these, 21.5 percent were overweight (BMI 25.0–29.9) and 23.8 were obese (BMI 30.0 and over). *(MMWR*, Vol. 53, No. 33; 756–760, August 27, 2004)
- Based on data from the 1999–2001 NHIS survey of the CDC/NCHS… *(Vital and Health Statistics*, Series 10, No. 219, Feb. 2004)
  - — 31.3 percent of U.S. adults age 18 and older engage in any regular leisure-time physical activity (PA).
  - — Men (64.2 percent) were more likely than women (59.0 percent) to engage in at least some leisure-time PA.
  - — Engaging in any PA declined steadily with age from 39.7 percent of adults ages 18–24 to 15.6 percent age 75 and older.
  - — Engaging in any regular leisure-time PA was more prevalent among white adults (32.7 percent) than among Asian adults (27.8 percent) and black adults (23.9 percent).
  - — Non-Hispanic white adults (65.7 percent) were more likely than non-Hispanic black adults (49.3 percent) and Hispanic adults (45.0 percent) to engage in at least some leisure-time PA.
  - — Adults with a graduate degree (80.6 percent) were about twice as likely as adults with less than a high school diploma (41.0 percent) to engage in at least some leisure-time PA.
  - — Adults who had incomes four times the poverty level or more (39.9 percent) were about twice as likely as adults with incomes below the poverty level (22.6 percent) to engage in any regular PA.
  - — Widowed adults (23.6 percent) were less likely than

never-married adults (33.0 percent), married adults (31.1 percent), and divorced or separated adults (29.1 percent) to engage in regular PA.

— Adults living in the West (65.3 percent) were more likely than adults living in the South (56.4 percent) to engage in at least some leisure-time PA.

- The relative risk of CHD associated with physical inactivity ranges from 1.5 to 2.4, an increase in risk comparable to that observed for high blood cholesterol, high blood pressure or cigarette smoking. (*JAMA* 1995;273:402–7)
- A recent study of over 72,000 female nurses indicates that moderate-intensity physical activity such as walking is associated with a substantial reduction in risk of total and ischemic stroke. (*JAMA* 2000;283:2961–7)
- The prevalence of physical inactivity during leisure time among Mexican Americans is higher than in the general population. (NHANES III [1988–94], CDC/NCHS, *Am J Public Health* 2001;91:1254–7)

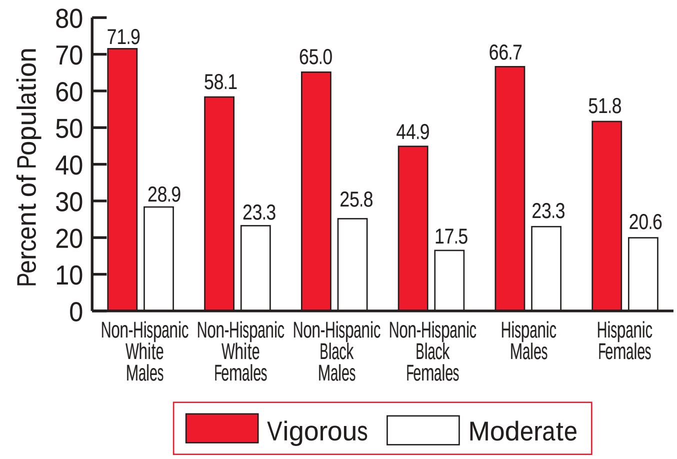
— The prevalence of physical inactivity among those whose main language is English is 15 percent of men and 28 percent of women. This is similar to that of the general population (17 percent of men and 27 percent of women).

— Those whose main language is Spanish have the highest prevalence of physical inactivity (38 percent of men and 58 percent of women).

Cost

- The annual estimated cost for diseases associated with physical inactivity in 2000 was $76 billion. (CDC)

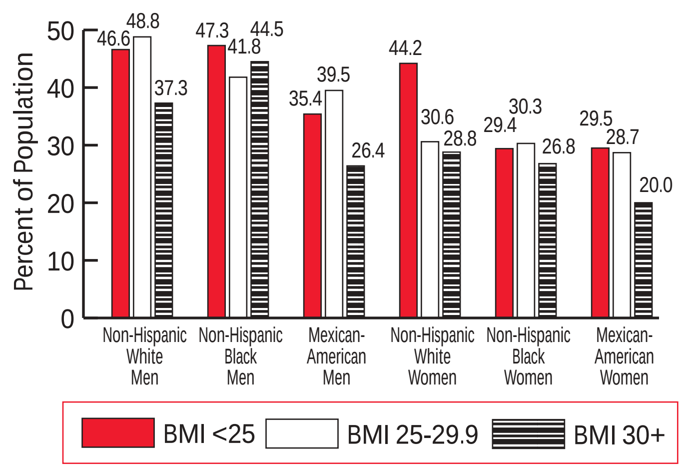
Prevalence of Students in Grades 9–12 Who Participated in Sufficient Vigorous or Moderate Physical Activity During the Past 7 Days by Race/Ethnicity and Sex
YRBS: 2003



Note: "Vigorous activity" is defined as activity causing sweating and hard breathing for at least 20 minutes on 3 or more of the 7 days. "Moderate activity" is defined as activities such as walking or bicycling lasting for at least 30 minutes on 5 or more of the 7 days.

Source: MMWR, Vol. 53, No. SS-2, May 21, 2004, CDC/NCHS.

Prevalence of Moderate or Vigorous Physical Activity in Americans Age 20 and Older by Race/Ethnicity, Sex, and BMI
NHANES III: 1988–94



Note: BMI indicates body mass index: weight in kilograms divided by height in meters squared (kg/m^2).

Source: CDC/NCHS.

Overweight and Obesity

Population Group	Prevalence of Overweight in Children Ages 6–11 2002	Prevalence of Overweight in Adolescents Ages 12–19 2002	Prevalence of Overweight and Obesity in Adults 2002	Prevalence of Obesity in Adults 2002
Total population	3,890,000 (15.8%)	5,290,000 (16.1%)	134,750,000 (65.1%)	63,120,000 (30.4%)
Total males	2,130,000 (16.9%)	2,820,000 (16.7%)	68,590,000 (68.8%)	27,480,000 (27.6%)
Total females	1,760,000 (14.7%)	2,470,000 (15.4%)	66,160,000 (61.6%)	35,640,000 (33.2%)
White males	14.0%	14.6%	69.4%	28.2%
White females	13.1%	12.7%	57.2%	30.7%
Black males	17.0%	18.7%	62.9%	27.9%
Black females	22.8%	23.6%	77.2%	49.0%
Mexican American males	26.5%	24.7%	73.1%	27.3%
Mexican American females	17.1%	19.9%	71.7%	38.4%
Hispanics or Latinos*	—	—	65.2%	25.4%
Asians*	—	—	34.5%	7.0%
American Indians or Alaska Natives*	—	—	61.7%	31.3%

Note: BMI (body mass index) = weight in kilograms divided by height in meters squared (kg/m^2).
Data for white, black or African-American, and Asian or Pacific Islander males and females are for non-Hispanics.
(—) = data not available.
Overweight in adults is BMI 25 and higher. Obesity in adults is BMI 30.0 or higher. Overweight in children is BMI 95th percentile or higher of the CDC 2000 growth chart.

* *NHIS (2002), CDC/NCHS; data are for Americans age 18 and older.*

Sources: NHANES (1999–2002), (JAMA. *2004;291:2847–50); CDC/NCHS data in adults are for age 20 and older. Data are for non-Hispanics.*

Prevalence

Youth

- An estimated 9,180,000 children and adolescents ages 6–19 are considered overweight or obese, based on the 95th percentile or higher of body mass index (BMI) values in the 2000 CDC growth chart for the United States. (NHANES [1999–2002], CDC/NCHS)
- Based on data from NHANES (1999–2002), the prevalence of overweight in children ages 6–11 increased from 4.2 percent to 15.8 percent compared with data from 1963–65. The prevalence of overweight in adolescents ages 12–19 increased from 4.6 percent to 16.1 percent. (CDC/NCHS)
- Over 10 percent of preschool children between the ages of 2 and 5 are overweight, up from 7 percent in 1994. (NHANES [1999–2002], CDC/NCHS; *JAMA* 2004;291:2847–50)
  - — Among preschool children, the following are overweight: 8.6 percent of non-Hispanic whites, 8.8 percent of non-Hispanic blacks and 13.1 percent of Mexican Americans.
  - — Among children ages 6–11, the following are overweight: 13.5 percent of non-Hispanic whites, 19.8 percent of non-Hispanic blacks and 21.8 percent of Mexican Americans.
  - — Among adolescents ages 12–19, the following are overweight: 13.7 percent of non-Hispanic whites, 21.1 percent of non-Hispanic blacks and 22.5 percent of Mexican Americans.
  - — In addition, the data show that another 31 percent of children and teens ages 6 to 19 are considered at risk of becoming overweight (BMI from the 85th to the 95th percentile).

Adults

- The age-adjusted prevalence of overweight (BMI of 25.0 or higher) increased from 55.9 percent in NHANES III (1988–94) to 65.1 percent in NHANES (1999–2002). The prevalence of obesity (BMI of 30.0 or higher) also increased during this period from 22.9 percent to 30.4 percent. Extreme obesity (BMI of 40.0 or higher) increased from 2.9 percent to 4.9 percent. *(JAMA* 2004;291:2847–50)
- Since 1991 the prevalence of those who are obese increased 75 percent. Among states in 2001, Mississippi had the highest rate of obesity and Colorado had the lowest. (BRFSS, CDC/NCHS)
- Data from the BRFSS study of the CDC/NCHS showed that in participants ages 18–24, studied from 1990–2000, obesity increased among every ethnic group, especially in black women. Almost 20 percent of black women were obese by ages 18–24, increasing to over 35 percent by ages 25–44. Between one-third and one-half of those surveyed ate fewer than three servings of fruit and vegetables a day, although older black men and older Hispanic men and women improved dramatically in that regard between 1990 and 2000. *(Am J Health Promot* 2004;19(1):19)
- Abdominal obesity is an independent risk factor for ischemic stroke in all race ethnic groups with an odds ratio about 3 times greater when comparing the first and fourth quartiles. This effect was larger for those under age 65 (OR=4.4) than over age 65 (OR=2.2). (NOMASS) *(Stroke* 2003;34:1586–92)
- Among American Indians or Alaska Natives, single-race adults, age 18 and older, the following are overweight or obese: (NHIS [1999–2001], CDC/NCHS, *Vital and Health Statistics*, Series 10, No. 219, Feb. 2004)
  - — 76.6 percent of men and 61.1 percent of women are overweight (BMI of 25 or more).
  - — Overall, 34.6 percent are overweight but not obese and 34.2 percent are obese. Among these, 38.0 and 38.6 percent respectively were men and 31.3 and 29.7 percent respectively were women.

9

- A recent comparison of risk factors in both the HHP and FHS showed a BMI increase around 3 kg/m^2 raised the risk of hospitalized thromboembolic stroke by 10–30 percent. (*Stroke* 2002;33:230–7)
- In 1998–99, surveys of people in 8 states and the District of Columbia by the BRFSS study of the CDC/NCHS indicated that obesity rates are significantly higher among people with disabilities, especially blacks and those ages 45–64. (*MMWR*, Vol. 51, No. 36, Sept. 13, 2002, CDC/NCHS)
- Data from the FHS showed that overweight and obesity were associated with large decreases in life expectancy. Forty-year-old female nonsmokers lost 3.3 years and 40-year-old male nonsmokers lost 3.1 years of life expectancy because of overweight. In 40-year-old nonsmokers, females lost 7.1 years and males lost 5.8 years due to obesity. Obese female smokers lost 7.2 years and obese male smokers lost 6.7 years when compared to normal-weight nonsmokers. (*Ann Intern Med* 2003;138:24–32)

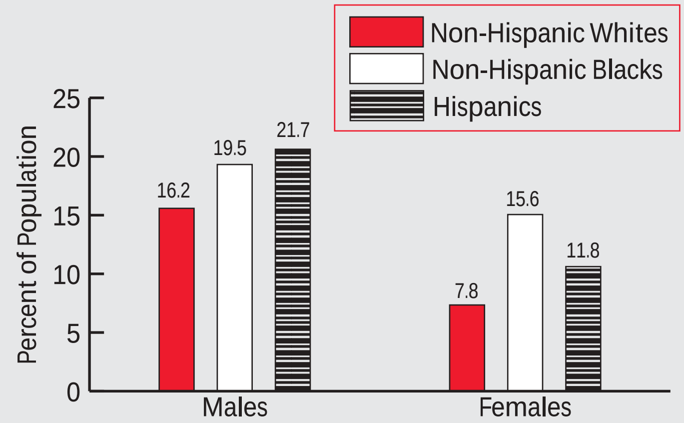
Mortality

- Each year an estimated 300,000 U.S. adults die of causes related to obesity. (*JAMA* 1999;282:1530–8)
- Obesity profoundly affects life span. A 20-year-old white male with a BMI greater than 45 is estimated to have 13 years of life lost (YLL) due to obesity. A 20-year-old white woman with a BMI greater than 45 is estimated to have 8 YLL due to obesity. For black men the estimate is 20 YLL and for black women the estimate is 5 YLL. (*JAMA* 2003;289:187–93)

Cost

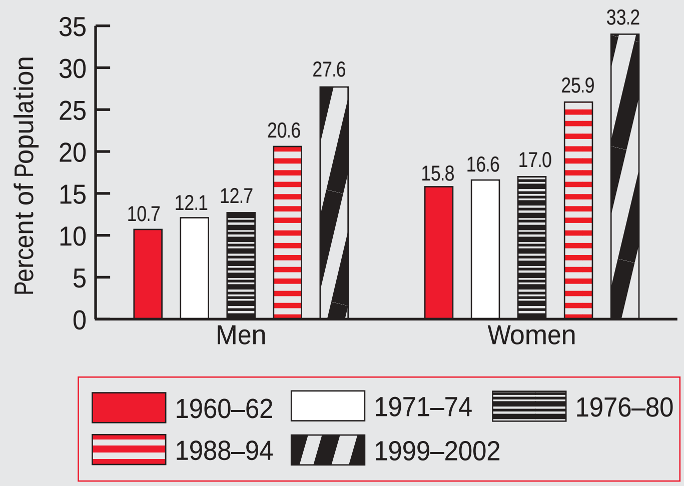
- Nationally, the estimated annual cost attributable to obesity-related diseases is about $100 billion. (*MMWR*, Vol. 51, No. 36, Sept. 13, 2002, CDC/NCHS)
- Among children and adolescents, annual hospital costs related to obesity were $127 million during 1997–99. (CDC) ("Preventing Obesity and Chronic Diseases Through good Nutrition and Physical Activity," www.cdc.gov/nccdphp/pe_factsheets)

Prevalence of Overweight Among Students in Grades 9–12 by Sex and Race/Ethnicity
YRBS: 2003



Source: BMI 95th percentile or higher by age and sex of the CDC 2000 growth chart. MMWR, *Vol. 53, No. SS-2, May 21, 2004, CDC/NCHS.*

Age-Adjusted Prevalence of Obesity in Americans Ages 20–74 by Sex and Survey
NHES 1960–62; NHANES: 1971–74, 1976–80, 1988–94 and 1999–2002



Note: Obesity is defined as a BMI of 30.0 or higher.

Source: CDC/NCHS.

Diabetes Mellitus

(ICD/9 250) (ICD/10 E10–E14)

Population Group	Prevalence of Physician-Diagnosed Diabetes — 2002	Prevalence of Undiagnosed Diabetes — 2002	Prevalence of Pre-Diabetes 2002	Incidence of Diagnosed Diabetes	Mortality 2002	Hospital Discharges 2002
Total population	13,900,000 (6.7%)	5,900,000 (2.8%)	14,500,000 (7.0%)	1,300,000	73,249	577,000
Total males	6,800,000 (7.2%)	2,900,000 (2.9%)	8,500,000 (8.9%)	—	34,301 (46.8%)*	283,000
Total females	7,000,000 (6.3%)	3,000,000 (2.7%)	6,000,000 (5.4%)	—	38,948 (53.2%)*	294,000
White males	6.2%	3.0%	8.6%	—	28,110	—
White females	4.7%	2.7%	4.6%	—	30,349	—
Black males	10.3%	1.3%	8.3%	—	5,207	—
Black females	12.6%	6.1%	5.9%	—	7,480	—
Mexican-American males	10.4%	3.5%	8.7%	—	—	—
Mexican-American females	11.3%	1.8%	7.2%	—	—	—
Hispanics or Latinos**	9.4%	—	—	—	—	—
Asians**	6.3%	—	—	—	—	—
American Indians or Alaska Natives**	16.0%	—	—	—	—	—

Note: Undiagnosed diabetes is defined here for those whose fasting glucose is 126 mg/dL or higher but who did not report being told they had diabetes by a health care provider. Pre-diabetes is a fasting blood glucose of 100 to less than 126 mg/dL (impaired fasting glucose). Pre-diabetes also includes impaired glucose tolerance.

(—) = data not available.

* These percentages represent the portion of total mortality that is males vs. females.

** NHIS (2002), CDC/NCHS; data are for Americans age 18 and older.

Sources: ***Prevalence:*** *NHANES [1999–2002], CDC/NCHS and NHLBI; data for white and black males and females are for non-Hispanics; percentages for racial/ethnic groups are age-adjusted for Americans age 20 and older.* ***Incidence:*** *NIDDK estimates.* ***Mortality:*** *CDC/NCHS; data for white and black males and females include Hispanics.* ***Hospital discharges:*** *CDC/NCHS; data include people both living and dead.*

Prevalence

- The prevalence of diabetes increased by 8.2 percent from 2000 to 2001. Since 1990 the prevalence of those diagnosed with diabetes increased 61 percent. In 2001 Alabama had the highest rate of diagnosed diabetes (10.5 percent) and Minnesota had the lowest (5.0 percent). *(JAMA* 2003;289:76–9)
- During 1994–2002 the age-adjusted prevalence of diabetes increased 54.0 percent for U.S. adults, from 4.8 to 7.3 percent, and increased 33.2 percent from 11.5 to 15.3 percent among American Indian or Alaska Native adults. The overall age-adjusted prevalence for American Indian or Alaska Native adults was more than twice that of U.S. adults overall. *(MMWR,* Vol. 52, No. 30, Aug. 1, 2003, CDC/NCHS)
- Based on data from the NHANES studies of the CDC/NCHS, in 1976–80, total diabetes prevalence in African Americans ages 40 to 74 was 8.9 percent; in 1988–94 the rate was 18.2 percent, a doubling of the rate in just 12 years. In 1988–94 among people ages 40 to 74, the prevalence rate was 18.2 percent for African Americans compared to 11.2 percent for whites. *(Diabetes Care* 1998;21:518–24)
- Data from the NHANES (1999–2000) study of the CDC/NCHS showed a disproportionately high prevalence of diabetes in non-Hispanic blacks and Mexican Americans when compared to non-Hispanic whites. For previously diagnosed diabetes the percentage was 11.7 for non-Hispanic blacks and 9.6 for Mexican Americans compared to 4.8 for non-Hispanic whites. For undiagnosed diabetes the percentages were 3.2, 2.4 and 2.6, respectively. For impaired fasting glucose the percentages were 6.3, 6.7 and 5.7, respectively. *(MMWR,* Vol. 52(35);833–7, CDC/NCHS)
- In the NHANES III study of the CDC/NCHS, prevalence in Hispanic Americans ages 40 to 74, the rate was 11.2 percent for non-Hispanic whites, but 20.3 percent for Mexican Americans. (niddk.nih.gov, 2004)
- BRFSS data in selected areas, 1998–2002, showed that diabetes disproportionately affects Hispanics in the U.S. and Puerto Rico. Hispanics were twice as likely to have diabetes as non-Hispanic whites of similar age (9.8 percent vs. 5.0 percent). This disparity, however, varied by geographic location — it was lowest in Florida and higher in California, Texas, and Puerto Rico. Among Hispanic adults in California, Florida, Illinois, New York/New Jersey, Puerto Rico and Texas, the overall prevalence of diabetes was 7.4 percent; it ranged from 6.2 percent in Illinois and New York/New Jersey to 9.3 percent in Puerto Rico. *(MMWR* 2004;53(40):941–4)

- About 15 percent of American Indians or Alaska Natives who receive care from the Indian Health Service have been diagnosed with diabetes. On average, American Indians or Alaska Natives are 2.6 times as likely to have diagnosed diabetes as non-Hispanic whites of the same age. (niddk.nih.gov, 2004)
- The prevalence of diabetes for all age groups worldwide was estimated to be 2.8 percent in 2000 and a projected 4.4 percent in 2030. The total number of people with diabetes is projected to rise from 171 million in 2000 to 366 million in 2030. [*Diabetes Care* 2004;27(5)]
- Type 2 diabetes may account for 90 to 95 percent of all diagnosed cases of diabetes. (niddk.nih.gov, 2004)
- In April 2004, the USDHHS announced that about 40 percent of U.S. adults ages 40–74, or 41 million, currently have pre-diabetes, a condition that raises a person's risk of developing type 2 diabetes, heart disease and stroke. Many don't know that they are at risk or that they have pre-diabetes. (National Diabetes Education Program, May 2004 E-Newsletter).
- In the U.S. each year, over 13,000 children are diagnosed with type 1 diabetes. Increasingly, healthcare providers are finding more and more children and teens with type 2 diabetes. Some clinics report that one-third to one-half of all new cases of childhood diabetes are now type 2. African American, Hispanic or Latino and American Indian children who are obese and have a family history of type 2 diabetes are at especially high risk for this type of diabetes. (niddk.nih.gov, 2004)
- The risk of diabetes for Mexican Americans and non-Hispanic blacks is almost twice that for non-Hispanic whites. (NHANES III [1988–94], CDC/NCHS, *Diabetes Care* 1998;21:518–24)
- Analysis of data collected in Hawaii from 1996 to 2000 showed that Native Hawaiians were 2.5 times more likely to have diabetes than non-Hispanic white residents of similar age. (niddk.nih.gov, 2004)
- Diabetes is twice as common in Mexican American and Puerto Rican adults as in non-Hispanic whites. The prevalence of diabetes in Cuban Americans is lower, but still higher than that of non-Hispanic whites. (niddk.nih.gov, 2004)

Mortality

Total mention mortality — 218,100.

- The 2002 overall death rate from diabetes was 25.4. Death rates were 26.8 for white males, 49.4 for black males, 20.3 for white females and 48.6 for black females.
- From two-thirds to three-fourths of people with diabetes mellitus die of some form of heart or blood vessel disease.
- Heart disease death rates among adults with diabetes are 2 to 4 times higher than the rates for adults without diabetes. (diabetes.niddk.nih.gov)
- Death rates for people with diabetes are 27 percent higher for African Americans compared with whites. (niddk.nih.gov, 2004)

Aftermath

- The age-adjusted prevalence of major CVD for women with diabetes is twice that for women without diabetes, and the age-adjusted major CVD hospital discharge rate for women with diabetes is almost four times the rate for women without diabetes. (*MMWR,* Vol. 50, No. 43, Nov. 2, 2001, CDC/NCHS)
- A population-based study of over 13,000 men and women in Denmark showed that in people with type 2 diabetes, the relative risk (RR) of first, incident and admission for MI was increased 1.5–4.5 fold in women and 1.5–2 fold in men. The RR of first, incident and admission for stroke was increased 2–6.5 fold in women and 1.5–2 fold in men, with a significant difference between the sexes. In both men and women the RR of death was increased 1.5–2 times. (*Arch Intern Med* 2004;164:1422–6)
- Diabetes increases the risk of stroke, with the RR ranging from 1.8 to almost 6.0. (*Stroke* 2001;32:280–99)
- Diabetes is one of the most important risk factors for stroke in women. In the FHS and in several European studies, the impact of diabetes on stroke risk is greater in women than in men. (*Stroke* 2001;32:280–99; *Neuroepidemiology* 1999;18:1–14)
- Compared with white women, black women have a 138 percent higher rate of ambulatory medical care visits for diabetes. (Utilization of Ambulatory Medical Care by Women: United States, 1997–98. NCHS, 2001)
- Based on data from the CDC Diabetes Surveillance System, 1997–2000:
  - — In 2000 the age-standardized prevalence of any self-reported CV condition among persons with diabetes age 35 and older was 37.5 percent for white men, 32.2 percent for white women, 31.4 percent for black men, 34.0 percent for black women, 23.9 percent for Hispanic men and 22.9 percent for Hispanic women.
  - — In 2000 the self-reported prevalence of any CV condition was 28.8 per 100 diabetic population among persons ages 35–64, 45.7 per 100 among persons ages 65–74, and 53.5 per 100 persons age 75 and older.
  - — In 2000, among persons with diabetes age 35 and older, 37.2 percent reported being diagnosed with a CV condition, (i.e., CHD, stroke or other CV condition).
  - — In 2000, among persons with diabetes age 35 and older, the age-standardized prevalence of self-reported CHD, angina or heart attack, was almost three times that of self-reported stroke (22.1 percent vs. 8.0 percent).

— In 2000, 4.4 million persons age 35 and older with diabetes reported being diagnosed with a CV condition. 2.9 million were diagnosed with CHD (i.e., self-reported CHD, angina or heart attack) and 1.1 million reported being diagnosed with a stroke.

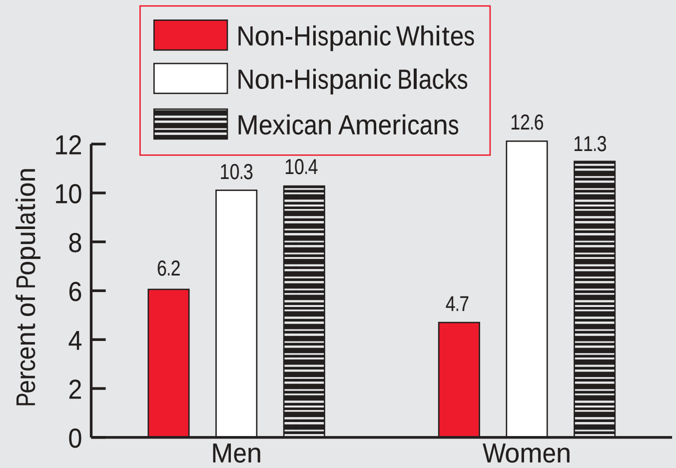
Risk

- Among U.S. adults with diabetes, data from the NHANES surveys from 1971–74 to 1999–2000, showed that mean total cholesterol declined from 5.95 mmol/liter to 5.48 mmol/liter. The proportion with high cholesterol decreased from 72 to 55 percent. Mean blood pressure declined from 146/86 mm Hg to 134/72 mm Hg. The proportion with HBP decreased from 64 to 37 percent, and smoking prevalence decreased from 32 to 17 percent. Although these trends are encouraging, still one of two people with diabetes had high cholesterol, one of three had HBP, and one of six was a smoker. *(Am J Epidemiol* 2004;160:531–9)
- Data from the National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK) of the NIH stated:
  - — Heart disease is the leading cause of diabetes-related death. Adults with diabetes have heart disease death rates about 2 to 4 times higher than adults without diabetes.
  - — The risk for stroke is 2 to 4 times higher among people with diabetes.
  - — About 73 percent of adults with diabetes have blood pressure greater than or equal to 130/80 mm Hg or use prescription medication for hypertension.
  - — An estimated 49–69 million adults in the United States may have insulin resistance. (Personal communication with Earl Ford, MD, CDC/NCHS, 2003) One in four of them will develop type 2 diabetes. (ndep.nih.gov)

Cost

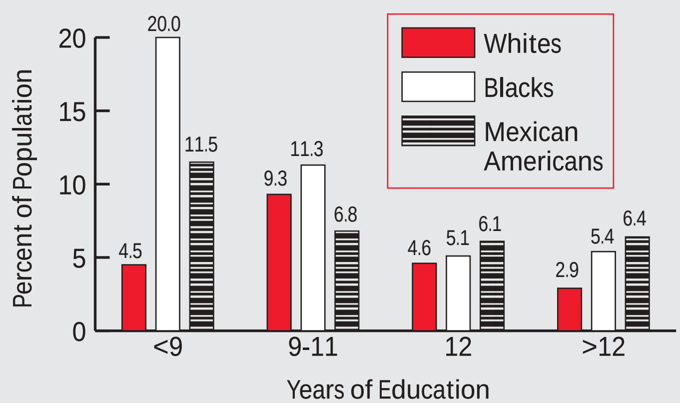
- In 2002, the direct and indirect cost of diabetes was $132 billion. *(The Burden of Chronic Diseases and Their Risk Factors,* CDC/NCHS, Feb. 2004)

Age-Adjusted Prevalence of Physician-Diagnosed Diabetes in Americans Age 20 and Older by Sex and Race/Ethnicity
NHANES: 1999–2002



Source:CDC/NCHS and NHLBI.

Prevalence of Non-Insulin-Dependent (Type 2) Diabetes in Women* Ages 25–64 by Race/Ethnicity and Education
NHANES III: 1988–94



* Findings for men are similar but of lower magnitude. See: Pathways by which SES and ethnicity influence cardiovascular disease risk factors. *Annals New York Academy of Science.* 1999;896:191–209.

Source: JAMA. 1998;280:356–362.

10 Metabolic Syndrome

The Third Report of the National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (ATP III, NHLBI) defines the metabolic syndrome (MetS) as three or more of the following abnormalities:

- Waist circumference greater than 102 cm (40 inches) in men and 88 cm (35 inches) in women.
- Serum triglyceride level of 150 mg/dL or higher.
- High-density lipoprotein (HDL) cholesterol level less than 40 mg/dL in men and less than 50 mg/dL in women.
- Blood pressure of 130/85 mm Hg or higher.
- Fasting glucose level of 110 mg/dL or higher.

People with MetS are at increased risk for developing diabetes and cardiovascular disease as well as increased mortality from CVD and all causes.

Prevalence of Metabolic Syndrome Among Adolescents:

The prevalence of MetS among 12–19 year old U.S. adolescents was estimated in an analysis of NHANES III data, by applying a modification of the ATP III definition for adults. MetS during adolescence was defined as three or more of the following abnormalities:

- Serum triglyceride level of 110 mg/dL or higher.
- High-density lipoprotein (HDL) cholesterol level of 40 mg/dL or lower.
- Elevated fasting glucose of 110 mg/dL or higher.
- Blood pressure at or above the 90th percentile for age, sex and height.
- Waist circumference at or above the 90th percentile for age and sex (NHANES III data set)

An estimated 1 million 12–19 year old adolescents in the U.S. have the MetS, or 4.2 percent overall (6.1 percent of males; 2.1 percent of females). [Cook S, et al. *Arch Pediatr Adol Med* 2003;157:821–7]

- Of adolescents with MetS, 73.9 percent were overweight (BMI ≥ 95th percentile of the CDC Growth Chart), and 25.2 percent were at risk of overweight (BMI 85–94th percentile).
- The mean BMI of adolescents with the MetS (30.1 percent) was just above the 95th percentile of the CDC Growth Chart; thus they are likely to represent a fairly common clinical problem in pediatrics.
  - — MetS was present in 28.7 percent of overweight adolescents (BMI ≥ 95th percentile of CDC Growth Chart) compared with 6.8 percent of at-risk of overweight adolescents, and 0.1 percent of those with BMI below the 85th percentile (P<.001).
  - — Among adolescents with MetS, 40.9 percent had ≥ 1 criterion; 14.2 percent had ≥ 2 criteria; 4.2 percent had ≥ 3 criteria and 0.9 percent had ≥ 4 criteria for MetS. For overweight adolescents, 88.5 percent had ≥ 1 criterion; 54.4 percent had ≥ 2 criteria; 28.7 percent had ≥ 3 criteria and 5.8 percent had ≥ 4 criteria for MetS.
- Among more than 3,400 children examined in one study, 1 in 10 had the MetS. (De Ferranti, et al. *Circulation* 2003;108:17:IV-727, Meeting Abstract #3286)
- Using a sample of adolescents from NHANES III, the overall prevalence of the MetS in moderately obese subjects was 38.7 percent and 49.7 percent in severely obese subjects. The prevalence of the MetS in severely obese black subjects was 39 percent. (*NEJM* 2004;350:2362–74)

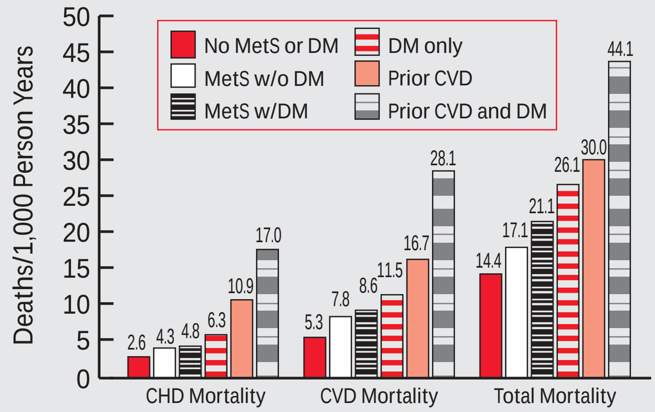
Prevalence of Metabolic Syndrome Among Adults

- An estimated 47 million U.S. residents have the MetS. (NHANES III [1988–94], CDC/NCHS; *JAMA* 2002;287:356–9)
- The age-adjusted prevalence of the MetS for adults is 23.7 percent. (NHANES III [1988–94], CDC/NCHS; *JAMA* 2002;287:356–9)
  - — The prevalence ranges from 6.7 percent among people ages 20–29 to 43.5 percent for ages 60–69 and 42.0 percent for those age 70 and older.
  - — The age-adjusted prevalence is similar for men (24.0 percent) and women (23.4 percent).
  - — Mexican Americans have the highest age-adjusted prevalence of the MetS (31.9 percent). The lowest prevalence is among whites (23.8 percent), African Americans (21.6 percent) and people reporting an "other" race or ethnicity (20.3 percent).
  - — Among African Americans, women had about a 57 percent higher prevalence than men. Among Mexican Americans, women had a 26 percent higher prevalence than men did.
- The prevalences of people with the MetS are 24.3, 13.9 and 20.8 percent for white, black and Mexican-American men, respectively. For women the percents are 22.9, 20.9 and

27.2, respectively. (NHANES III [1988–94], CDC/NCHS; *Arch Intern Med* 2003;163)

- In a study of over 15,000 men and women, ages 45 to 64, in the ARIC study, MetS prevalence was 30 percent and 27 percent using ATP III and modified WHO definitions with substantial variation across race and gender subgroups. CHD prevalence was greater in those with than without the MetS (ATP III 7.4 percent vs. 3.6 percent; WHO 7.8 percent vs. 3.6 percent, both p<0.0001). Using either definition, subjects with the MetS were about two times more likely to have prevalent CHD than those without the syndrome after adjustment for established risk factors. Among individuals free of CVD, the average age, sex, and race/center-adjusted intima-media thickness (IMT) was greater among individuals with the syndrome [ATP III 747 vs. 704, WHO 750 vs. 705 micrometers, both p<0.0001]. These data suggest that MetS was significantly associated with the presence of CHD and carotid IMT. *(Am J Cardiol* 2004;94:1249–54)
- A follow-up study of over 19,000 men found that those with the MetS who were fit were less likely to die during the study. The total person-years of follow-up is over 190,000. Those who were deemed to be out of shape were twice as likely as those who were fit to die of CVD or any other cause. An additional study of 2,200 diabetic men found that those who were overweight yet fit had a risk similar to that of their fit, healthy peers. They estimated that moderate exercise, such as walking for 30 minutes five times per week, would be enough to achieve protective fitness levels. *(Arch Intern Med* 2004;164:1092–7)

Total Mortality Rates in U.S. Adults, Ages 30–75, With Metabolic Syndrome (MetS), With and Without Diabetes Mellitus (DM) and Pre-Existing CVD
NHANES II 1976–80 Follow-Up Study*



Source: Circulation *2004;110:1245–50.*

* Average of 13 years of follow-up.

11 Nutrition

Mean Dietary Intake of Energy and 10 Key Nutrients for Public Health	Total Population	Males	Females
Energy (kcal)	2,146	2,475	1,833
Protein, percent of calories	14.7%	14.9%	14.6%
Carbohydrate, percent of calories	51.9%	50.9%	52.8%
Total fat, percent of calories	32.7%	32.7%	32.6%
Saturated fat, percent of calories	11.2%	11.2%	11.1%
Cholesterol (mg)	265	307	225
Calcium (mg)	863	966	765
Folate micrograms (mcg)	361	405	319
Iron (mg)	15.2	17.2	13.4
Zinc (mg)	11.4	13.3	9.7
Sodium (mg)	3,375	3,877	2,896

Source: NHANES (1999–2000), CDC/NCHS, 2003. (Advance Data, Vital and Health Statistics, No. 334, April 17, 2003.)

- The Economic Research Service of the USDA suggests that the average daily calorie consumption in the United States in 2000 was 12 percent, or roughly 300 calories, above the 1985 level. Of that increase, grains (mainly refined grains) accounted for 46 percent, added fats 24 percent, added sugars 23 percent, fruits and vegetables 8 percent, and the meat and dairy groups together declined 1 percent. Per capita availability of total dietary fat, after remaining steady from 1985 to 1999, jumped 6 percent in 2000. American diets are also low in whole grains and other nutritious foods. (ers.usda.gov/briefing/consumption)
- Between 1965 and 1991 among U.S. adults age 18 and older, total daily calories declined from 2,049 to 1,807, but then rebounded to 2,000 calories in 1996. This contributed to the marked increase in obesity levels in the past decade. *(Prev Med* 2001;32:245–54)
- In 1999–2000, among children ages 2 to 6, 20 percent had a good diet, 74 percent had a diet that needed improvement, and 6 percent had a poor diet. For those ages 7 to 12, 8 percent had a good diet, 79 percent had a diet that needed improvement, and 13 percent had a poor diet. (America's Children: Key National Indicators of Well-Being, 2003. Federal Interagency Forum on Child and Family Statistics, Washington, DC: U.S. Government Printing Office)

Fat/Meat Consumption

- Between 1965 and 1996 among adults, total fat as a proportion of daily calorie intake fell steadily from 39.1 to 33.1 percent. Saturated fat fell from 14.4 to 11.0 percent. However, total calorie intake increased between 1991 and 1996. Over the same period daily total fat consumption rose from 70.9 grams (g) to 74.8 g. *(Prev Med* 2001;32:245–54)
- The average daily intake of total fat in the United States is 81.4 grams (96.5 g for males and 67.3 g for females). (NHANES III [1988–94], CDC/NCHS)
  - — For non-Hispanic whites the average is 82.7 grams (99.0 g for males and 67.4 g for females).
  - — For non-Hispanic blacks the average is 82.0 grams (94.6 g for males and 71.2 g for females).
  - — For Mexican Americans the average is 77.6 grams (88.0 g for males and 66.5 g for females).
- The average daily intake of saturated fat in the United States is 27.9 grams (33.1 g for males and 23.0 g for females). (NHANES III [1988–94], CDC/NCHS)
  - — For non-Hispanic whites the average is 28.4 grams (34.1 g for males and 23.1 g for females).
  - — For non-Hispanic blacks the average is 27.5 grams (31.7 g for males and 23.8 g for females).
  - — For Mexican Americans the average is 26.7 grams (30.1 g for males and 23.1 g for females).
- The proportion of fat calories from beef, pork, dairy products and eggs fell from 50 percent in 1965 to 33 percent in 1994–96. The proportion of fat calories from poultry increased from 4 percent to 7 percent. Calories from fruits and vegetables rose from 8 percent to 13 percent. *(Prev Med* 2001;32:245–54)
- In 1994–96, pizza, Mexican food, Chinese food, hamburgers, French fries and cheeseburgers accounted for 10.8 percent of total fat intake. These six foods accounted for only 1.9 percent of fat intake in 1965. *(Prev Med* 2001;32:245–54)
- The major sources of saturated fat in the diet are red meat, butter, whole milk and eggs. Intake of these foods has fallen markedly since 1965. The decline in whole milk consumption from 21.3 gallons in 1972–76 to 8.2 gallons in 1997 accounts for most of the reduction in saturated fat. *(Prev Med* 2001;32:245–54)
- According to USDA data, in 2001 total meat consumption (red meat, poultry and fish) amounted to 194 pounds per person, 16 pounds above the level in 1970. Each American consumed an average of 21 pounds less red meat (mostly beef) than in 1970, 34 pounds more poultry and 3.4 pounds more fish. (ers.usda.gov/briefing/consumption)

Cholesterol

- The average daily intake of dietary cholesterol in the United States is 269.6 mg. For males it's 323.5 mg and for females it's 218.9 mg. (NHANES III [1988–94], CDC/NCHS)
  - — For non-Hispanic whites the average is 259.3 milligrams (312.6 mg for males and 209.1 mg for females).
  - — For non-Hispanic blacks the average is 297.9 milligrams (358.8 mg for males and 245.6 mg for females).
  - — For Mexican Americans the average is 316.2 milligrams (365.9 mg for males and 263.8 mg for females).

Fiber

- The recommended daily intake of dietary fiber is 25 grams or more. Americans consume a daily average of 15.6 grams of dietary fiber (17.8 g for males and 13.6 g for females). (NHANES III [1988–94], CDC/NCHS)
  - — For non-Hispanic whites the average is 15.8 grams (18.1 g for males and 13.7 g for females).
  - — For non-Hispanic blacks the average is 13.4 grams (15.0 g for males and 12.0 g for females).
  - — For Mexican Americans the average is 18.5 grams (21.0 g for males and 15.9 g for females).
- Analysis of participants in the Cardiovascular Health Study (CHS) showed that cereal fiber consumption late in life was associated with lower risk of incident CVD, supporting recommendations for elderly people to increase consumption of dietary cereal fiber. *(JAMA* 2003;289:1659–66)

Fruits/Vegetables

- In 2000, 81 percent of men and 73 percent of women reported eating fewer than five servings of fruits and vegetables a day. More than 60 percent of young people eat too much fat, and less than 20 percent eat the recommended five or more servings of fruits and vegetables each day. (CDC/NCHS, BRFSS, 2000)
- Only 22.7 percent of adults consumed fruits and vegetables at least 5 times a day in 1996. This was an increase from 19.0 percent in 1990. (BRFSS [1990–96], CDC/NCHS)
- The highest proportion of adults who consumed fruits and vegetables at least 5 times a day were those age 65 and older, whites, college graduates, those actively engaged in leisure-time physical activity, and nonsmokers. *(Prev Med* 2001;32:245–54)
- The percentage of men who consumed fruits and vegetables at least 5 times a day increased from 16.5 percent in 1990 to 19.1 percent in 1996. The percentage of women increased from 21.3 percent in 1990 to 26.2 percent in 1996. *(Am J Public Health* 2000;90:777–81)
- From 1990 to 1996 the percentage of obese adults who consumed at least 5 servings of fruits and vegetables a day dropped from 16.8 percent to 15.4 percent. *(Prev Med* 2001;32:245–54)
- Recent studies support the intake of up to 9 servings of fruits and vegetables per day. *(NEJM* 1997;336:1117–24)
- In 2003, the percentage of students in grades 9–12 who reported eating fruits and vegetables 5 or more times per day was 23.6 percent for males and 20.3 percent for females. (YRBS, U.S., 2003, MMWR, Vol. 53, No. SS-2, May 21, 2004, CDC/NCHS)
  - — Black students (24.5 percent) were more likely than white students (20.2 percent) to have eaten 5 or more servings per day. This racial/ethnic difference was significantly higher for male students.

Costs

- Each year over $33 billion in medical costs and $9 billion in lost productivity due to heart disease, cancer, stroke and diabetes are attributed to diet. (CDC)

12 Quality of Care

The Institute of Medicine defines quality of care as "the degree to which health services for individuals and populations increase the likelihood of desired health outcomes and are consistent with current professional knowledge." ***(Crossing the quality chasm: a new health system for the 21st century. National Academy Press, 2001.)*** **This section of the Update highlights national data on rates of compliance with quality measures for several cardiovascular conditions.**

National Medicare and Medicaid Data

In 2003 the Centers for Medicare and Medicaid Services published national data on quality of cardiovascular care indicators for hospitalized Medicare beneficiaries in 2000–01. Only patients who were candidates for each quality indicator were considered (i.e., patients with contraindications to a given therapy were not considered).

Acute myocardial infarction	Percent of inpatients
Aspirin within 24 hours of admission	85%
Aspirin at discharge	86%
Beta blocker within 24 hours of admission	69%
Beta blocker at discharge	79%
ACE inhibitor for patients with LVEF <40%	74%
Smoking cessation advice given	43%
Median time for thrombolysis	45 minutes
Median time to primary angioplasty	107 minutes

Heart failure	Percent of inpatients
Evaluation of LVEF	70%
ACE inhibitor for patients with LVEF <40%	68%

Stroke	Percent of inpatients
Warfarin for atrial fibrillation	57%
Antithrombotic therapy for stroke or TIA	84%

Overall, the improvement for these specific quality indicators between 1998–99 and 2000–01 was very modest, 2–7 percent.

National Veterans Health Administration Data

The VA collects national quality performance data related to cardiovascular disease. Aggregate data from 158 VA hospitals from January 1, 2003 to January 1, 2004 are listed below ***(Office of Quality and Performance, Veterans Health Administration).*** **Only patients who were candidates for each quality indicator were considered (i.e., patients with contraindications to a given therapy were not considered).**

Acute myocardial infarction	Percent of inpatients
Aspirin within 24 hours of admission	96%
Aspirin at discharge	98%
Beta blocker within 24 hours of admission	94%
Beta blocker at discharge	98%
ACE inhibitor for patients with LVEF <40%	92%
Smoking cessation advice given	87%

Heart failure	Percent of inpatients
Documentation of LVEF	99%
ACE inhibitor for patients with LVEF <40%	92%
Complete discharge instructions	76%
Smoking cessation advice given	76%

Hypertension	Percent of inpatients
Blood pressure at goal (<140/90)	68%

Cholesterol	Percent of outpatients
Cholesterol screening in all patients	91%
Cholesterol measured after acute MI	94%
LDL cholesterol <130 mg/dL after acute MI	78%

National Managed Care Data

For 2003, the National Committee for Quality Assurance reported on 5 quality-of-care performance measures for cardiovascular disease prevention and treatment (The State of Health Care Quality 2003, Industry Trends and Analysis, NCQA). Note that NCQA data is reported voluntarily by participating managed care plans, and that performance data apply to patients receiving medical care from providers participating in specific managed care plans in the United States.

Use of beta blockers after a heart attack

- In 2002, 93.5 percent of heart attack survivors enrolled in commercial managed care plans were receiving a beta blocker at the time of discharge from the hospital, an increase from 62 percent in 1996. If all practices were performed at the 90th percentile level, an additional 1,726 deaths could be avoided each year.

Cholesterol screening in patients with coronary heart disease

- In 2002, 79 percent of patients enrolled in commercial managed care plans and hospitalized for heart attack, bypass surgery or angioplasty were screened for LDL cholesterol between 60 and 365 days after discharge. This proportion represented an increase from 59 percent in 1998.

Cholesterol control in patients with coronary heart disease

- In 2002, 61 percent of patients enrolled in commercial managed care plans and hospitalized for heart attack, bypass surgery or angioplasty were treated to an LDL cholesterol goal of less than 130 mg/dL. This proportion represented an increase from 45 percent in 1999. If all practices were performed at the 90th percentile level, 6,500 deaths could be avoided each year. Note that this treatment goal is less aggressive than the LDL goal of less than 100 mg/dL endorsed by the American Heart Association and the National Cholesterol Education Program.

Control of high blood pressure

- In 2002, 58 percent of adults enrolled in commercial managed care plans and diagnosed with high blood pressure were controlled to levels less than140/90 mm Hg. This proportion represented an increase from 40 percent in 1999. More than 28,000 lives could be saved and nearly 50,000 strokes could be prevented each year if everyone with diagnosed hypertension received care at rates seen at the 90th percentile (68 percent control).

Control of diabetes

- In 2002, 33 percent of adults enrolled in commercial managed plans and diagnosed with diabetes were poorly controlled (HbA1c >9.5 or not tested). This proportion represented a decrease from 38 percent in 1998. (The AHA diabetes management goal is to reduce HbA1c to less than 7 percent.)

Advising smokers to quit

- In 2002, 68 percent of smokers enrolled in commercial managed care plans were advised to quit, an increase from 59 percent in 1996. Nearly 2,700 lives could be saved each year if all Americans smokers were advised to quit at the rates seen in plans at the 90th percentile.

American Heart Association GWTG-CAD Program

*Get With The Guidelines*SM (GWTG) is a national quality improvement initiative of the American Heart Association to help hospitals redesign systems of care to improve guidelines adherence in patients admitted with a cardiovascular or stroke event.

The table below summarizes baseline pre-intervention performance on the selected quality indicators. These were collected from 30 consecutive patients from 398 hospitals.

Performance indicator	Percent of inpatients
Aspirin at discharge	91%
Beta blocker at discharge	79%
ACE inhibitor at discharge	57%
Lipid therapy at discharge	60%
Lipid therapy at discharge if LDL >100 mg/dL	72%
Blood pressure therapy at discharge	70%
Smoking cessation counseling	65%
Referral to cardiac rehabilitation	47%

These data demonstrate the treatment gaps for each of the quality-of-care indicators. GWTG aims to bridge these gaps in care. Information on GWTG can be found on this Web site.

National Heart Failure Data

The ADHERE (Acute Decompensated HEart Failure National REgistry) Registry is a national observational registry of patients hospitalized with acutely decompensated heart failure. Hospitals from all regions of the country participate, including community, tertiary and academic. The demographics of the 260 hospitals participating are representative of the nation's hospitals as a whole. The Joint Commission on Accreditation of Health Care Organizations (JCAHO) has created, tested and validated a set of heart failure core quality-of-care measures.

Mean performance of the JCAHO quality indicators from 40,046 patients enrolled August 2003 through July 2004 from these 260 U.S. hospitals was as follows:

JCAHO Performance indicators	Percent of inpatients
Complete set of discharge instructions	47%
Measure of LV function	87%
ACE inhibitor at discharge for patients with LVEF < 40 percent, no contraindications	74%
Smoking cessation counseling, current smokers	64%
Additional measures	
ACE inhibitor and/or ARB at discharge for patients with LVEF < 40 percent, no contraindications	82%
Beta blockers at discharge for patients with LVEF < 40 percent, no contraindications	73%

These patients were hospitalized with a primary diagnosis of heart failure. The mean age was 72.1 years and 52 percent of them were female. 58 percent of HF patients had a history of coronary artery disease. Mechanical ventilation was required in 4.0 percent of patients. In-hospital mortality was 3.8 percent and mean length of hospital stay was 5.8 days (median 4.3 days).

Further information on the ADHERE registry can be found at adhereregistry.com.

National Acute Coronary Syndrome Data

CRUSADE (Can Rapid Stratification of Unstable Angina Patients Suppress ADverse Outcomes with Early Implementation of the ACC/AHA Guidelines?) is a national quality improvement initiative designed to increase adherence to guideline-recommended care for patients hospitalized with non-ST-segment elevation myocardial infarction or unstable angina. Over 440 hospitals participate nationwide. Treatment measures from the CRUSADE registry from a data set of 40,530 patients who were enrolled in the registry from July 2003 through June 2004 are as follows:

Acute Medications* (within 24 hrs)	Overall	'Leading' Centers (Top 25%)	'Lagging' Centers (Bottom 25%)
Aspirin	94%	97%	89%
Beta blocker	85%	92%	76%
Heparin, Any	86%	92%	75%
Glycoprotein IIb-IIIa Inhibitor, Any	42%	57%	24%
Discharge Medications**			
Aspirin	92%	97%	83%
Clopidogrel	66%	73%	52%
Beta blocker	88%	93%	78%
ACE-I, Overall	60%	68%	48%
ACE-I, Among Recommended#	63%	71%	51%
Lipid-lowering Agent, Overall	74%	82%	60%
Lipid-lowering Agent, Recommended+	84%	89%	75%
Procedures***			
Cardiac Catheterization, Overall	73%	89%	59%
Cardiac Catheterization, Within 48 hours of Presentation	53%	69%	40%

* Excluding patients with contraindications to these therapies

** Excluding patients with contraindications, transfers out, and deaths

Including only patients with history of hypertension, diabetes, CHF, and LVEF<40%

+ Including only patients with history of hyperlipidemia or LDL>100mg/dL

*** Excluding patients with contraindications to cardiac catheterization

Note that not all of the treatment measures reported above are established quality indicators. Further information on the CRUSADE registry can be found at its Web site (www.CRUSADEQI.com).

Medical Procedures and Costs

From 1979 to 2002 the total number of cardiovascular operations and procedures increased 470 percent.

Cardiac Catheterization

- From 1979 to 2002 the number of cardiac catheterizations increased 389 percent.
- An estimated 1,463,000 inpatient cardiac catheterizations were performed in 2002.
- The average total charge for patients hospitalized for diagnostic cardiac catheterization increased from $11,232 in 1993 to $16,838 in 2000. The total number of patients increased from 626,690 to 693,472, while the average length of stay decreased from 4.7 days to 3.6 days. (Agency for Healthcare Research and Quality, Healthcare Cost and Utilization Project, HCUPnet, 2000. hcup.ahrq.gov)

Coronary Artery Bypass Surgery

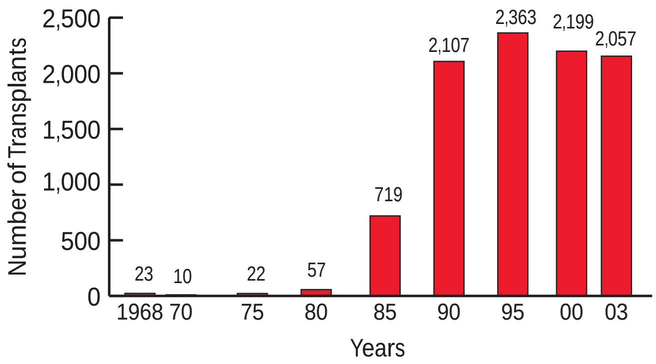
In the United States in 2002, the NCHS estimates that 515,000 of these procedures were performed on 306,000 patients.

Heart Transplants

In 2003, 2,057 heart transplants were performed in the United States. There are 291 organ transplant centers in the United States, 173 of which perform heart transplants.

- In the United States, 74 percent of heart transplant patients are male, 74 percent are white, 21 percent are ages 35–49, and 47 percent are ages 50–64.
- In 2002 the 1-year survival rate was 86.8 percent, and the 2-year rate was 80.9 percent. In 2003, the 1-year survival rate was 86.9 percent.
- As of 10/31/04, there were 3,366 heart patients on the transplant waiting list.

Trends in Heart Transplants
UNOS: 1968–2003



Source: United Network for Organ Sharing (UNOS), scientific registry data.

Percutaneous Transluminal Coronary Angioplasty (PTCA)

- An estimated 657,000 PTCA procedures were performed on 640,000 patients in 2002 in the United States. From 1987 to 2002 the number of procedures increased 324 percent.
- In 2002, 66 percent of PTCA procedures were performed on men; 50 percent were performed on people age 65 and older.
- The rate of coronary stent insertion increased 147 percent between 1996 and 2000. Among the elderly, this procedure increased 168 percent during the same period. The rate of stent insertion also more than doubled for the population 45–64 years of age, increasing from 157 to 318 per 100,000. (*Health Care in America: Trends in Utilization.* CDC/NCHS 2003.)

2002 National HCUP Statistics

Data from the latest Healthcare Cost and Utilization Project (HCUP) provide data for the mean charges and in-hospital death rate for the following (hcup.ahrq.gov):

Procedure	Mean Charges	In-Hospital Death Rate
Coronary artery bypass graft	$60,853	2.4%
PTCA	28,558	0.9%
Diagnostic cardiac catheterization	17,763	1.0%
Cardiac pacemaker or cardioverter defibrillator	40,852	1.7%
Endarterectomy, vessel of head and neck	16,890	0.4%
Heart valves	85,187	5.8%

2002 data from the Healthcare Cost and Utilization Project (HCUP) provide the national bill for the top 100 CCS (Clinical Classifications Software) diagnoses treated in U.S. hospitals (hcup.ahrq.gov):

Primary Diagnosis	Rank	National Bill
Coronary atherosclerosis	1	$38.4 billion
Acute MI	2	27.8 billion
Congestive HF, nonhypertensive	4	21.8 billion
Cardiac dysrhythmias	8	14.3 billion
Acute cerebrovascular disease	9	13.9 billion

Estimated* Inpatient Cardiovascular Operations, Procedures and Patient Data by Sex, Age and Region

United States: 2002 (in Thousands)

Operations/Procedures/Patients (ICD/9 Code)		Total	Sex: Male	Sex: Female	Age: <15	Age: 15–44	Age: 45–64	Age: 65+	Region#: Northeast	Region#: Midwest	Region#: South	Region#: West
Angioplasty (36.0)	Procedures	1,204	802	402	—	76	517	608	211	323	416	254
PTCA (36.01, .02, .05) **(a)**	Procedures	657	434	223	—	37	283	331	110	182	223	130
	Patients	640	423	217	—	41	278	321	112	175	221	132
Stenting (36.06)	Procedures	537	363	174	—	34	228	273	95	138	186	118
Cardiac Revascularization (Bypass) (36.1–36.3) **(b)**	Procedures	515	373	142	—	19	217	279	104	117	204	90
	Patients	306	219	88	—	12	128	166	60	68	125	54
Diagnostic Cardiac Catheterizations (37.2) **(a)**	Procedures	1,463	884	579	10	123	597	732	281	342	585	255
Endarterectomy (38.12)	Procedures	134	79	56	—	—	33	101	33	29	55	17
Implantable Defibrillators (37.94–.99)	Procedures	63	45	11	—	—	21	36	13	14	20	9
Open-Heart Surgery **(c)**	Procedures	709	476	233	30	41	261	368	160	150	258	127
Pacemakers (37.8) **(d)**	Procedures	199	101	99	—	—	21	172	50	36	78	36
Valves (35.1, .2, .99) **(e)**	Procedures	93	49	44	—	9	19	56	25	15	25	18
Total Vascular and Cardiac Surgery and Procedures (35–39)**		**6,813**	**3,967**	**2,845**	**210**	**681**	**2,384**	**3,538**	**1,370**	**1,463**	**2,601**	**1,378**

Note: (–) = data not available.

* Breakdowns are not available for some procedures, so entries for some categories don't add to totals. These data include codes where the estimated number of procedures is fewer than 5,000. Categories of such small numbers are considered unreliable by CDC/NCHS and in some cases may have been omitted.

** Totals include procedures not shown here.

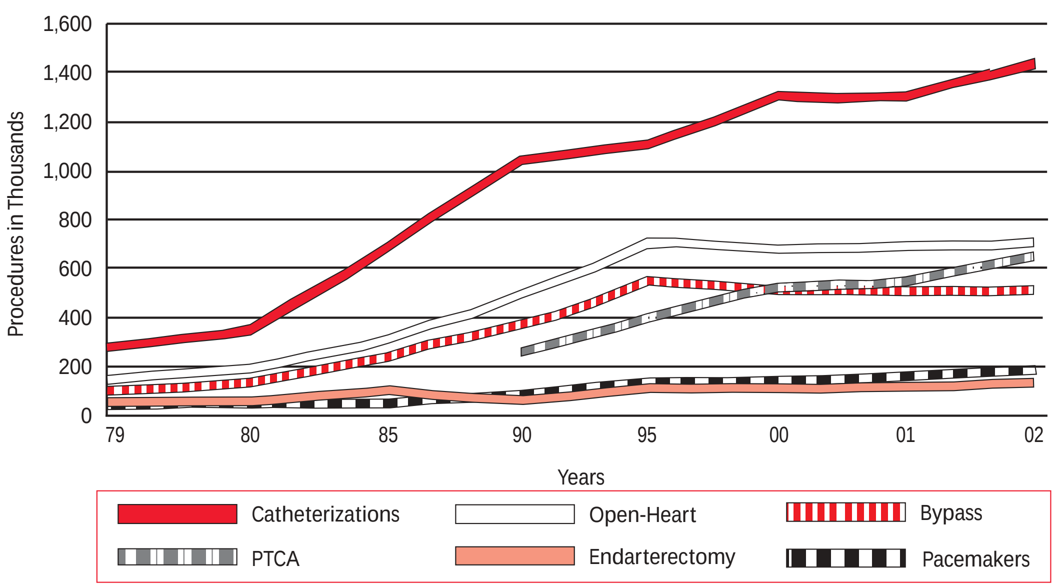
\# Regions: Northeast — Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont
Midwest — Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin
South — Alabama, Arkansas, Delaware, District of Columbia, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, West Virginia
West — Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, Wyoming

(a) — Does not include procedures in the outpatient or other non-hospitalized setting; thus, excludes some cardiac catheterizations and PTCAs.
(b) — Because one or more procedure codes are required to describe the specific bypass procedure performed, it's impossible from this (mixed) data to determine the average number of grafts per patient.
(c) — Includes valves, bypass and 101,000 "other" open-heart procedures. (Codes 35 [less 35.1–35.2, 35.4, 35.96, 35.99]; 36 [less 36.0–36.1]; 37.1, 37.3–37.5.)
(d) — There are additional insertions, revisions and replacements of pacemaker leads, including those associated with temporary (external) pacemakers.
(e) — Open heart valvuloplasty without replacement; replacement of heart valve; other operations on heart valves.

Source: Health Resources Utilization Branch, CDC/NCHS. Estimates are based on a sample of inpatient records from short-stay hospitals in the United States (National Hospital Discharge Survey).

Trends in Cardiovascular Operations and Procedures

United States: 1979–2002

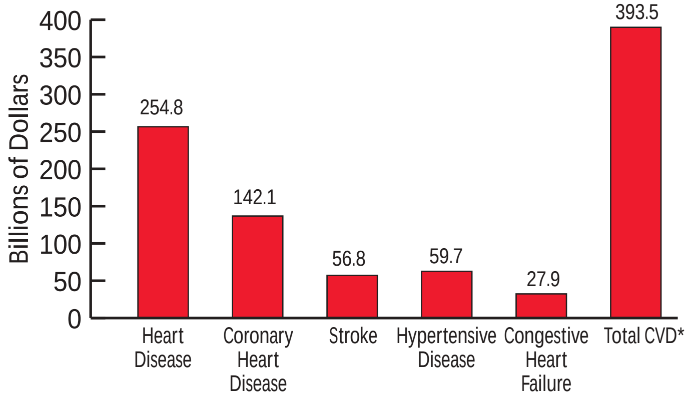


Source: CDC/NCHS.

Economic Cost of Cardiovascular Diseases

The cost of cardiovascular diseases and stroke in the United States in 2005 is estimated at $393.5 billion. This figure includes health expenditures (direct costs, which include the cost of physicians and other professionals, hospital and nursing home services, the cost of medications, home health care and other medical durables) and lost productivity resulting from morbidity and mortality (indirect costs). By comparison, in 2004 the estimated cost of all cancers was $190 billion ($69 billion in direct costs, $17 billion in morbidity indirect costs and $104 billion in mortality indirect costs). In 1999 the estimated cost of HIV infections was $28.9 billion ($13.4 billion direct and $15.5 billion indirect).

Estimated Direct and Indirect Costs (in Billions of Dollars) of Cardiovascular Diseases and Stroke
United States: 2005



Estimated Direct and Indirect Costs (in Billions of Dollars) of Cardiovascular Diseases and Stroke
United States: 2005

	Heart Diseases**	Coronary Heart Disease	Stroke	Hypertensive Disease	Congestive Heart Failure	Total Cardiovascular Disease*
Direct Costs						
Hospital	$77.7	$39.9	$14.8	$6.0	$14.7	$109.8
Nursing Home	19.1	10.0	13.2	3.9	3.6	39.3
Physicians/Other Professionals	18.5	10.4	2.9	10.4	1.9	36.0
Drugs/Other Medical Durables	19.4	9.0	1.2	22.3	2.9	45.9
Home Health Care	4.8	1.4	2.9	1.6	2.2	10.9
Total Expenditures*	**$139.5**	**$70.7**	**$35.0**	**$44.2#**	**$25.3**	**$241.9**
Indirect Costs						
Lost Productivity/Morbidity	21.4	9.4	6.3	7.5	—	34.8
Lost Productivity/Mortality##	93.9	62.0	15.5	8.0	2.6	116.8
Grand Totals*	**$254.8**	**$142.1**	**$56.8**	**$59.7**	**$27.9**	**$393.5**

Note: (–) = data not available.

* Totals do not add up due to rounding and overlap.

** This category includes coronary heart disease, congestive heart failure, part of hypertensive disease, cardiac dysrhythmias, rheumatic heart disease, cardiomyopathy, pulmonary heart disease, and other or ill-defined "heart" diseases.

\# Tom Hodgson and Liming Cai (*Medical Care* 2001) estimated that healthcare expenditures attributed to hypertension that could be allocated to cardiovascular complications and other diagnoses totaled $108 billion in 1997.

\## Lost future earnings of persons who will die in 2005, discounted at 3 percent.

Sources: *Hodgson TA, Cohen AJ. Medical care expenditures for selected circulatory diseases: opportunities for reducing national health expenditures. Medical Care. 1999;37:994–1012.*

National Health Expenditures Amounts, and Average Annual Percent Change, by Type of Expenditure: Selected Calendar Years 1990–2013 (cms.hhs.gov).

Rice DP, Hodgson TA, Kopstein AN. The economic costs of illness: a replication and update. Health Care Financ Rev. 1985;7:61–80.

Historic Income Tables — People (census.gov).

Deaths for 358 Selected Causes by 5-Year Age Groups, Race, and Sex, United States, 2001 (cdc.nchs/default/htm).

Rice, Max, Michel, and Sung. Present Value of Lifetime Earnings, U.S. 2001. Unpublished tables, Institute for Health and Aging, University of California, San Francisco, 2004.

All estimates prepared by Thomas Thom, NHLBI.

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At-a-Glance Summary Tables
Men and Cardiovascular Diseases

Diseases and Risk Factors	Total Population	Total Males	White Males	Black Males	Mexican-American Males
Total CVD					
Prevalence 2002	70.1 M (34.2%)	32.5 M (34.4%)	34.3%	41.1%	29.2%
Mortality 2002 (preliminary)	927.4K	433.8 K	375.4 K	49.0 K	—
Coronary Heart Disease					
Prevalence 2002 CHD	13.0 M (6.9%)	7.1 M (8.4%)	8.9%	7.4%	5.6%
Prevalence 2002 MI	7.1 M (3.5%)	4.1 M (5.0%)	5.1%	4.5%	3.4%
Prevalence 2002 AP	6.4 M (3.8%)	3.1 M (4.2%)	4.5%	3.1%	2.4%
New and recurrent CHD*	1.2 M	715.0 K	650.0 K	65.0 K	—
New and recurrent MI	865.0 K	520.0 K	—	—	—
Incidence AP (stable angina)	400.0 K	—	—	—	—
Mortality 2002 CHD	494.4 K	252.8 K	223.3 K	24.3 K	—
Mortality 2002 MI	179.5 K	93.8 K	83.3 K	8.7 K	—
Stroke					
Prevalence 2002	5.4 M (2.6%)	2.4 M (2.5%)	2.3%	4.0%	2.6%
New and recurrent attacks	700.0 K	327.0 K	277.0 K	50.0 K	—
Mortality 2002	162.7 K	62.6 K	53.0 K	7.8 K	—
High Blood Pressure					
Prevalence 2002	65.0 M (32.3%)	29.4M (31.5%)	30.6%	41.8%	27.8%
Mortality 2002	49.7 K	20.5 K	14.7 K	5.3 K	—
Congestive Heart Failure					
Prevalence 2002	4.9 M (2.3%)	2.4 M (2.6%)	2.5%	3.1%	2.7%
Mortality 2001	52.8 K	19.8 K	17.8 K	1.8 K	—
Tobacco					
Prevalence 2002	48.5 M (22.5%)	26.3 M (25.2%)	25.2%	27.0%	—
Blood Cholesterol					
Prevalence 2002:					
Total cholesterol 200 mg/dL+	106.9 M (50.7%)	50.4 M (50.4%)	51.0%	37.3%	54.3%
Total cholesterol 240 mg/dL+	37.7 M (18.3%)	16.9 M (17.2%)	17.8%	10.6%	17.8%
LDL cholesterol 130 mg/dL+	95.0 M (45.8%)	48.6 M (48.5%)	49.6%	46.3%	43.6%
HDL cholesterol <40 mg/dL	54.7 M (26.4%)	39.0 M (39.0%)	40.5%	24.3%	40.1%
Physical Inactivity					
Prevalence 1999–2001	38.6%	35.8%	34.4%	45.1%	—
Overweight and Obesity					
Prevalence 2002:					
Overweight BMI 25.0 or higher	134.8 M (65.1%)	68.6 M (68.8%)	69.4%	62.9%	73.1%
Obesity BMI 30.0 or higher	63.1 M (30.4%)	27.5 M (27.6%)	28.2%	27.9%	27.3%
Diabetes Mellitus					
Prevalence 2002:					
Physician-diagnosed diabetes	13.9 M (6.7%)	6.8 M (7.2%)	6.2%	10.3%	10.4%
Undiagnosed diabetes	5.9 M (2.8%)	2.9 M (2.9%)	3.0%	1.3%	3.5%
Pre-diabetes	14.5 M (7.0%)	8.5 M (8.9%)	8.6%	8.3%	8.7%
Incidence	1.3M	—	—	—	—
Mortality	73.2 K	34.3 K	28.1 K	5.2 K	—

Note: AP = angina pectoris (chest pain); BMI = body mass index; CHD = coronary heart disease; includes heart attack, angina pectoris (chest pain) or both; CVD = cardiovascular disease; K = thousands; M = millions; MI = myocardial infarction (heart attack); mg/dL = milligrams per deciliter; (—) = data not available.

* New and recurrent heart attacks and fatal CHD.

*Sources: See expanded version of the 2005 statistical update, at **americanheart.org/statistics**. For data on men in other ethnic groups, see other chapters and Statistical Fact*

At-a-Glance Summary Tables
Women and Cardiovascular Diseases

Diseases and Risk Factors	Total Population	Total Females	White Females	Black Females	Mexican-American Females
Total CVD					
Prevalence 2002	70.1 M (34.2%)	37.6 M (33.9%)	32.4%	44.7%	29.3%
Mortality 2002 (preliminary)	927.4 K	493.6 K	428.5 K	56.7 K	—
Coronary Heart Disease					
Prevalence 2002 CHD	13.0 M (6.9%)	5.9 M (5.6%)	5.4%	7.5%	4.3%
Prevalence 2002 MI	7.1 M (3.5%)	3.0 M (2.3%)	2.4%	2.7%	1.6%
Prevalence 2002 AP	4.8 M (3.8%)	3.3 M (3.6%)	3.5%	4.7%	2.2%
New and recurrent CHD*	1.2 M	485.0 K	425.0 K	60.0 K	—
New and recurrent MI	865.0 K	345.0 K	—	—	—
Incidence AP (stable angina)	400.0 K	—	—	—	—
Mortality 2002 CHD	494.4 K	241.6 K	211.9 K	25.9 K	—
Mortality 2002 MI	179.5 K	85.7 K	74.6 K	9.6 K	—
Stroke					
Prevalence 2002	5.4 M (2.6%)	3.0 M (2.6%)	2.6%	3.9%	1.8%
New and recurrent attacks	700.0 K	373.0 K	312.0 K	61.0 K	—
Mortality 2002	162.7 K	100.1 K	86.8 K	11.0 K	—
High Blood Pressure					
Prevalence 2002	65.0 M (32.3%)	35.6M (32.8%)	31.0%	45.4%	28.7%
Mortality 2002	49.7 K	29.2 K	22.3 K	6.3 K	—
Congestive Heart Failure					
Prevalence 2002	4.9 M (2.3%)	2.5M (2.1%)	1.9%	3.5%	1.6%
Mortality 2001	52.8 K	33.0 K	29.9 K	2.8 K	—
Tobacco					
Prevalence 2002	48.5 M (22.5%)	21.2 M (20.0%)	20.7%	18.5%	—
Blood Cholesterol					
Prevalence 2002:					
Total cholesterol 200 mg/dL+	106.9 M (50.7%)	56.5 M (50.9%)	53.6%	46.4%	44.7%
Total cholesterol 240 mg/dL+	37.7 M (18.3%)	20.8 M (19.1%)	19.9%	17.7%	13.9%
LDL cholesterol 130 mg/dL+	95.0 M (45.8%)	46.4 M (43.3%)	43.7%	41.6%	41.6%
HDL cholesterol <40 mg/dL	54.7 M (26.4%)	15.9 M (14.9%)	14.5%	13.0%	18.4%
Physical Inactivity					
Prevalence 1999–2001	38.6%	41.0%	38.3%	55.1%	—
Overweight and Obesity					
Prevalence 2002:					
Overweight BMI 25.0 or higher	134.8 M (65.1%)	66.2 M (61.6%)	57.2%	77.2%	71.7%
Obesity BMI 30.0 or higher	63.1 M (30.4%)	35.6 M (33.2%)	30.7%	49.0%	38.4%
Diabetes Mellitus					
Prevalence 2002:					
Physician-diagnosed diabetes	13.9 M (6.7%)	7.0 M (6.3%)	4.7%	12.6%	11.3%
Undiagnosed diabetes	5.9 M (2.8%)	3.0 M (2.7%)	2.7%	6.1%	1.8%
Pre-diabetes	14.5 M (7.0%)	6.0 M (5.4%)	4.6%	5.9%	7.2%
Incidence	1.3 M	—	—	—	—
Mortality	73.2 K	38.9 K	30.3 K	7.5 K	—

Note: AP = angina pectoris (chest pain); BMI = body mass index; CHD = coronary heart disease; includes heart attack, angina pectoris (chest pain) or both; CVD = cardiovascular disease; K = thousands; M = millions; MI = myocardial infarction (heart attack); mg/dL = milligrams per deciliter; (—) = data not available.

* New and recurrent heart attacks and fatal CHD.

Sources: See expanded version of the 2005 statistical update, at ***americanheart.org/statistics****. For data on women in other ethnic groups, see other chapters and Statistical Fact Sheets.*

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At-a-Glance Summary Tables
Ethnic Groups and Cardiovascular Diseases

Diseases and Risk Factors	Total Population	Whites Males	Whites Females	Blacks/African Americans Males	Blacks/African Americans Females	Mexican Americans Males	Mexican Americans Females	Hispanics/Latinos Males	Hispanics/Latinos Females
Total CVD									
Prevalence 2002	70.1 M (34.2%)	34.3%	32.4%	41.1%	44.7%	29.2%	29.3%	—	—
Mortality 2002 (preliminary)	927.4 K	375.4 K	428.5 K	49.0 K	56.7 K	—	—	—	—
Coronary Heart Disease									
Prevalence 2002 CHD	13.0 M (6.9%)	8.9%	5.4%	7.4%	7.5%	5.6%	4.3%	4.8%	
Prevalence 2002 MI	7.1 M (3.5%)	5.1%	2.4%	4.5%	2.7%	3.4%	1.6%	—	—
Prevalence 2002 AP	6.4 M (3.8%)	4.5%	3.5%	3.1%	4.7%	2.4%	2.2%	—	—
New and recurrent CHD*	1.2 M	650.0 K	425.0 K	65.0 K	60.0 K	—	—	—	—
Mortality 2002 CHD	494.4 K	223.3 K	211.9 K	24.3 K	25.9 K	—	—	—	—
Mortality 2002 MI	179.5 K	83.3 K	74.6 K	8.7 K	9.6 K	—	—	—	—
Stroke									
Prevalence 2002	5.4 M (2.6%)	2.3%	2.6%	4.0%	3.9%	2.6%	1.8%	2.4%	
New and recurrent attacks	700.0 K	277.0 K	312.0 K	50.0 K	61.0 K	—	—	—	—
Mortality 2002	162.7 K	53.0 K	86.8 K	7.8 K	11.0 K	—	—	—	—
High Blood Pressure									
Prevalence 2002	65.0 M (32.3%)	30.6%	31.0%	41.8%	45.4%	27.8%	28.7%	18.2%	
Mortality 2002	49.7 K	14.7 K	22.3 K	5.3 K	6.3 K	—	—	—	—
Congestive Heart Failure									
Prevalence 2002	4.9 M (2.3%)	2.5%	1.9%	3.1%	3.5%	2.7%	1.6%	—	—
Mortality 2001	52.8 K	17.8 K	29.9 K	1.8 K	2.8 K	—	—	—	—
Tobacco									
Prevalence 2002	48.5 M (22.5%)	25.2%	20.7%	27.0%	18.5%	—	—	23.2%**	12.5%**
Blood Cholesterol									
Prevalence 2002:									
Total cholesterol 200 mg/dL+	106.9 M (50.7%)	51.0%	53.6%	37.3%	46.4%	54.3%	44.7%	—	—
Total cholesterol 240 mg/dL+	37.7 M (18.3%)	17.8%	19.9%	10.6%	17.7%	17.8%	13.9%	25.6%	
LDL cholesterol 130 mg/dL+	95.0 K (45.8%)	49.6%	43.7%	46.3%	41.6%	43.6%	41.6%	—	—
HDL cholesterol <40 mg/dL	54.7 K (26.4%)	40.5%	14.5%	24.3%	13.0%	40.1%	18.4%	—	—
Physical Inactivity									
Prevalence 1999–2001	38.6%	34.4%	38.3%	45.1%	55.1%	—	—	52.6%	57.2%
Overweight and Obesity									
Prevalence 2002:									
Overweight BMI 25.0 or higher	134.8 M (65.1%)	69.4%	57.2%	62.9%	77.2%	73.1%	71.7%	65.2%	
Obesity BMI 30.0 or higher	63.1 M (30.4%)	28.2%	30.7%	27.9%	49.0%	27.3%	38.4%	25.4%	
Diabetes Mellitus									
Prevalence 2002:									
Physician-diagnosed diabetes	13.9 M (6.7%)	6.2%	4.7%	10.3%	12.6%	10.4%	11.3%	9.4%	
Undiagnosed diabetes	5.9 M (2.8%)	3.0%	2.7%	1.3%	6.1%	3.5%	1.8%	—	—
Pre-diabetes	14.5 M (7.0%)	8.6%	4.6%	8.3%	5.9%	8.7%	7.2%	—	—
Incidence	1.3 M	—	—	—	—	—	—	—	—
Mortality	73.2 K	28.1 K	30.3 K	5.2 K	7.5 K	—	—	—	—

Note: AP = angina pectoris (chest pain); BMI = body mass index; CHD = coronary heart disease; includes heart attack, angina pectoris (chest pain) or both; CVD = cardiovascular disease; K = thousands; M = millions; MI = myocardial infarction (heart attack); mg/dL = milligrams per deciliter; (—) = data not available.

* New and recurrent heart attacks and fatal CHD.

** Data are for 1999–2001.

*Sources: See expanded version of the 2005 statistical update, at **americanheart.org/statistics**. For data on other ethnic groups, see other chapters and Statistical Fact Sheets.*

At-a-Glance Summary Tables
Children, Youth and Cardiovascular Diseases

Diseases and Risk Factors	Total Population	Total Males	Total Females	Non-Hispanic Whites Males	Non-Hispanic Whites Females	Non-Hispanic Blacks Males	Non-Hispanic Blacks Females	Mexican Americans Males	Mexican Americans Females
Congenital Defects									
Mortality 2001 (all ages)	4.1 K	2.2 K	1.9 K	1.8 K	1.5 K	0.4 K	0.3 K	—	—
Mortality 2001 (< age 15)	2.1 K	1.2 K	1.0 K	—	—	—	—	—	—
Tobacco									
Prevalence ages 12–17: Current cigarette use 1999–2001	—	13.3%	14.2%	14.9%	17.2%	8.2%	5.9%	11.4%*	10.6%*
High school students (Grades 9-12):									
Current cigarette smoking 2003	—	21.8%	21.9%	23.3%	26.6%	19.3%	10.8%	19.1%*	17.7%*
Current cigar smoking 2003	—	19.9%	9.4%	21.3%	8.6%	19.5%	10.3%	14.9%*	12.2%*
Smokeless tobacco use 2003	—	11.0%	2.2%	13.2%	1.6%	4.1%	2.0%	6.1%*	3.3%*
Blood Cholesterol									
Ages 4–19:									
Mean total cholesterol mg/dL	165	163	167	162	166	168	171	163	165
Ages 4–19:									
Mean HDL cholesterol mg/dL	—	—	—	48	50	55	56	51	52
Ages 12–19:									
Mean LDL cholesterol mg/dL	—	—	—	91	100	99	102	93	92
Physical Inactivity									
Prevalence 2003 grades 9–12:									
Vigorous activity last 7 days	—	—	—	71.9%	58.1%	65.0%	44.9%	66.7%*	51.8%*
Moderate activity last 7 days	—	—	—	28.9%	23.3%	25.8%	17.5%	23.3%*	20.6%*
Overweight									
Prevalence 2002:									
Preschool children ages 2–5	>10%	—	—	8.6%		8.8%		13.1%	
Children ages 6–11	3.9 M (15.8%)	2.1 M (16.9%)	1.8 M (14.7%)	14.0%	13.1%	17.0%	22.8%	26.5%	17.1%
Adolescents ages 12–19	5.3 M (16.1%)	2.8 M (16.7%)	2.5 M (15.4%)	14.6%	12.7%	18.7%	23.6%	24.7%	19.9%
Students grades 9–12	—	—	—	16.2%	7.8%	19.5%	15.6%	21.7%*	11.8%*

Note: K = thousands; M = millions; mg/dL = milligrams per deciliter; overweight in children is body mass index (BMI) 95th percentile of the CDC 2000 growth chart; (—) = data not available.

* Hispanic.

Sources: See expanded version of the 2005 statistical update, at ***americanheart.org/statistics****. For more data on congenital defects, see pages 24-25, and our Statistical Fact Sheet,* **Congenital Cardiovascular Defects.**

16 Glossary

Age-Adjusted Rates — Used mainly to compare the rates of two or more communities, population groups or the nation as a whole, over time. We use a standard population (2000), so that these rates aren't affected by changes or differences in the age composition of the population.

Body Mass Index (BMI) — A mathematical formula to assess body weight relative to height. The measure correlates highly with body fat. Calculated as weight in kilograms divided by the square of the height in meters (kg/m2).

Centers for Disease Control and Prevention/National Center for Health Statistics (CDC/NCHS) — A division of the U.S. Department of Health and Human Services (USDHHS). The CDC conducts the:

- *Behavioral Risk Factor Surveillance System (BRFSS),* an ongoing study.

The NCHS conducted the:

- *National Health Examination Survey (NHES).*
- *National Health and Nutrition Examination Survey I (NHANES I, 1971–74).*
- *National Health and Nutrition Examination Survey II (NHANES II, 1976–80).*
- *National Health and Nutrition Examination Survey III (NHANES III, 1988–94).* Prevalence estimates for coronary heart disease, stroke and congestive heart failure are based on the self-reported questionnaire portion of this study. Exam-based estimates are being developed.
- *National Health and Nutrition Examination Survey (NHANES, 1999–2000).*

The NCHS also conducts these ongoing studies (among others):

- *National Health Interview Survey (NHIS)*
- *National Hospital Ambulatory Medical Care Survey*
- *National Home and Hospice Care Survey*
- *National Hospital Discharge Survey*

Centers for Medicare and Medicaid Services (CMS), formerly Health Care Financing Administration (HCFA) — The federal agency that administers the Medicare, Medicaid and Child Health Insurance Programs, which provide health insurance for more than 74 million Americans.

Comparability Ratio — Provided by the NCHS to allow time-trend analysis from one ICD revision to another. It compensates for the "shifting" of deaths from one causal code number to another. Its application to mortality based on one ICD revision means that mortality is "comparability-modified" to be more comparable to mortality coded to the other ICD revision.

Coronary Heart Disease (ICD/10 codes I20–I25) — This category includes acute myocardial infarction (I21–I22); other acute ischemic (coronary) heart disease (I24); angina pectoris (I20); atherosclerotic cardiovascular disease (I25.0); and all other forms of chronic ischemic heart disease (I25.1–I25.9).

Death Rate — The relative frequency with which death occurs within some specified interval of time in a population. National death rates are computed per 100,000 population. Dividing the mortality by the population gives a crude death rate. It's restricted because it doesn't reflect a population's composition with respect to such characteristics as age, sex, race or ethnicity. Thus rates calculated within specific subgroups, such as age-specific or sex-specific rates, are often more meaningful and informative. They allow you to look at well-defined subgroups of the total population.

Diseases of the Circulatory System — ICD codes (I00–I99); included as part of what the American Heart Association calls "Cardiovascular Disease." You can obtain mortality data for states from cdc.gov/nchs, by direct communication with the CDC/NCHS, or from our National Center Biostatistics Program Coordinator on request. (See "Total Cardiovascular Disease" in this Glossary.)

Diseases of the Heart — Classification the NCHS uses in compiling the leading causes of death. Includes acute rheumatic fever/chronic rheumatic heart diseases (I00–I09); hypertensive heart disease (I11) and hypertensive heart and renal disease (I13); coronary heart disease (I20–I25); pulmonary heart disease and diseases of pulmonary circulation (I26–I28); congestive heart failure (I50.0); and other forms of heart disease (I29–I49, I50.1–I51). "Diseases of the Heart" is not equivalent to "Total Cardiovascular Disease," which we prefer to use to describe the leading causes of death. "Diseases of the Heart" represents about three-fourths of "Total Cardiovascular Disease" mortality.

Health Care Financing Administration (HCFA) — See Centers for Medicare and Medicaid Services (CMS).

Hispanic Origin — In U.S. government statistics, "Hispanic" includes persons who trace their ancestry to Mexico, Puerto Rico, Cuba, Spain, the Spanish-speaking countries of Central or South America, the Dominican Republic or other Spanish cultures, regardless of race. It doesn't include people from Brazil, Guyana, Suriname, Trinidad, Belize and Portugal because Spanish is not the first language in those countries. Much of our data are for Mexican Americans or Mexicans, as reported by government agencies or specific studies. In many cases, data for all Hispanics are more difficult to obtain.

Hospital Discharges — The number of inpatients discharged from short-stay hospitals where some type of disease was the first listed diagnosis. Discharges include people both living and dead.

ICD and ICDA Codes — A classification system in standard use in the United States. The "International Classification of Diseases, Adapted" (ICDA) is based on the "International Classification of Diseases" (ICD) published by the World Health Organization. This system is reviewed and revised about every 10 to 20 years to ensure its continued flexibility and feasibility. We are in the tenth revision (ICD/10) with the release of 1999 final mortality data.

The ICD revisions can cause considerable change in the number of deaths reported for a given disease. The NCHS provides "comparability ratios" to compensate for the "shifting" of deaths from one ICD code to another. In this booklet we use the reported mortality when we want to show one year's data. When we want to compare the number or rate of deaths with that of an earlier year, then we use the "comparability-modified" number or rate.

Incidence — An estimate of the number of new cases of a disease that develop in a population in a one-year period. For some statistics, new and recurrent attacks or cases are combined. The incidence of a specific disease is estimated by multiplying the incidence rates reported in community- or hospital-based studies by the U.S. population. **The rates change only when new data are available; they are not computed annually.**

Major Cardiovascular Diseases — Disease classification commonly reported by the NCHS; represents ICD codes I00–I78. We don't use "Major CVD" for any calculations. See "Total Cardiovascular Disease" in this Glossary.

Morbidity — Incidence and prevalence rates are both measures of morbidity, that is, measures of various effects of disease on a population.

Mortality — The total number of deaths from a given disease in a population during a specific interval of time, usually a year. These data are compiled from death certificates and sent by state health agencies to the NCHS. The process of verifying and tabulating the data takes about two years. For example, 2002 mortality statistics, the latest available, didn't become available until late 2004. Mortality is "hard" data, so it's possible to do time-trend analysis and compute percent changes over time.

National Heart, Lung, and Blood Institute (NHLBI) — An institute in the National Institutes of Health in the U.S. Department of Health and Human Services. The NHLBI conducts such studies as the:

- *Framingham Heart Study (FHS) (1948 to date).*
- *Honolulu Heart Program (HHP) (1965–97).*
- *Cardiovascular Health Study (CHS) (1988 to date).*
- *Atherosclerosis Risk in Communities (ARIC) study (1985 to date).*
- *Strong Heart Study (SHS) (1989–92; 1991–98).*

The NHLBI also publishes the reports of the Joint National Committee on Prevention, Detection, Evaluation and Treatment of High Blood Pressure. JNC 7 is the most recent.

National Institute of Neurological Disorders and Stroke (NINDS) — An institute in the National Institutes of Health in the U.S. Department of Health and Human Services. The NINDS sponsors and conducts research studies such as these:

- *Greater Cincinnati/Northern Kentucky Stroke Study (GCNKSS)*
- *Rochester (Minnesota) Stroke Epidemiology Project*
- *Northern Manhattan Stroke Study (NOMASS)*
- *Brain Attack Surveillance in Corpus Christi (BASIC) Project*

Prevalence — An estimate of the total number of cases of a disease existing in a population at a specific point in time. Prevalence is sometimes expressed as a percentage of population. Rates for specific diseases are calculated from periodic health examination surveys that government agencies conduct. Annual changes in prevalence as reported in this booklet only reflect changes in the population; **rates do not change until there's a new survey.**

NOTE: In the data tables which precede the different disease and risk factor categories, if the percentages shown are age-adjusted, they will not add to the total.

Race and Hispanic Origin — Race and Hispanic origin are reported separately on death certificates. In this publication, unless otherwise specified, deaths of Hispanic origin are included in the totals for whites, blacks, American Indians or Alaska Natives and Asian or Pacific Islanders, according to the race listed on the decedent's death certificate. Data for Hispanic persons include all persons of Hispanic origin of any race. See "Hispanic Origin" in this Glossary.

Stroke (ICD/10 codes I60–I69) — This category includes subarachnoid hemorrhage (I60); intracerebral hemorrhage (I61); other nontraumatic intracranial hemorrhage (I62); cerebral infarction (I63); stroke, not specified as hemorrhage or infarction (I64); occlusion and stenosis of precerebral arteries, not resulting in cerebral infarction (I65); occlusion and stenosis of cerebral arteries, not resulting in cerebral infarction (I66); other cerebrovascular diseases (I67); cerebrovascular disorders in diseases classified elsewhere (I68) and sequalae of cerebrovascular disease (I69).

Total Cardiovascular Disease (ICD/10 codes I00–I99, Q20–Q28) — This category includes rheumatic fever/rheumatic heart disease (I00–I09); hypertensive diseases (I10–I15); ischemic (coronary) heart disease (I20–I25); pulmonary heart disease and diseases of pulmonary circulation (I26–I28); other forms of heart disease (I30–I52); cerebrovascular disease (stroke) (I60–I69); atherosclerosis (I70); other diseases of arteries, arterioles and capillaries (I71–I79); diseases of veins, lymphatics and lymph nodes, not classified elsewhere (I80–I89); and other and unspecified disorders of the circulatory system (I95–I99). When data are available, we include congenital cardiovascular defects (Q20–Q28).

Total Mention Mortality — The total number of times in a given year that a disease was listed on death certificates as an underlying or contributing cause of death.

16 Abbreviation Guide

ACE . . . . angiotensin-converting enzyme
ACS . . . . acute coronary syndrome
ADHERE . . . . Acute Decompensated HEart Failure National REgistry
AED . . . . automated external defibrillator
AF . . . . atrial fibrillation
AHA . . . . American Heart Association
AIDS . . . . acquired immune deficiency syndrome
AJC . . . . American Journal of Cardiology
AP . . . . angina pectoris
ARIC . . . . Atherosclerosis Risk in Communities
ATP . . . . Adult Treatment Panel
BMI . . . . body mass index
BP . . . . blood pressure
BRFSS . . . . Behavioral Risk Factor Surveillance System
BWIS . . . . Baltimore-Washington Infant Study
CAD . . . . coronary artery disease
CDC . . . . Centers for Disease Control and Prevention
CHD . . . . coronary heart disease
CHF . . . . congestive heart failure
CHS . . . . Cardiovascular Health Study
CMS . . . . Centers for Medicare and Medicaid Services
CPI . . . . Consumer Price Index
CPR . . . . cardiopulmonary resuscitation
CVD . . . . cardiovascular disease
DVT . . . . deep vein thrombosis
ED . . . . emergency department
EMS . . . . emergency medical services
ER . . . . emergency room
ESRD . . . . end-stage renal disease
FHS . . . . Framingham Heart Study
GCNKSS . . . . Greater Cincinnati/Northern Kentucky Stroke Study
GWTG . . . . Get With The Guidelines[SM]
HBP . . . . high blood pressure
HCFA . . . . Health Care Financing Administration
HCUP . . . . Healthcare Cost and Utilization Project
HDL . . . . high-density lipoprotein
HHP . . . . Honolulu Heart Program
HIV . . . . human immunodeficiency virus
ICD . . . . International Classification of Diseases
ICDA . . . . International Classification of Diseases, Adapted
ICH . . . . intracerebral hemorrhage
JACC . . . . Journal of the American College of Cardiology
JAMA . . . . Journal of the American Medical Association
JCAHO . . . . Joint Commission on Accreditation of Health Care Organizations
JNC . . . . Joint National Committee on Prevention, Detection, Evaluation and Treatment of High Blood Pressure
kcal . . . . kilocalories
LDL . . . . low-density lipoprotein
LV . . . . left ventricular
LVEF . . . . left ventricular ejection fraction
MACDP . . . . Metropolitan Atlanta Congenital Defects Program
MetS . . . . metabolic syndrome
mg/dL . . . . milligrams per deciliter
MI . . . . myocardial infarction
mm Hg . . . . millimeters of mercury
MMWR . . . . Morbidity and Mortality Weekly Report
NCEP . . . . National Cholesterol Education Program
NCHS . . . . National Center for Health Statistics
NCQA . . . . National Committee for Quality Assurance
NEJM . . . . New England Journal of Medicine
NHANES . . . . National Health and Nutrition Examination Survey
NHES . . . . National Health Examination Survey
NHIS . . . . National Health Interview Survey
NHLBI . . . . National Heart, Lung, and Blood Institute
NIHSS . . . . National Institutes of Health Stroke Scale
NINDS . . . . National Institute of Neurological Disorders and Stroke
NOMASS . . . . Northern Manhattan Stroke Study
NRMI . . . . National Registry of Myocardial Infarction
NVSS . . . . National Vital Statistics System
OR . . . . odds ratio
PA . . . . physical activity
PAD . . . . peripheral arterial disease
PTCA . . . . percutaneous transluminal coronary angioplasty
PE . . . . pulmonary embolism
PTE . . . . pulmonary thromboembolism
PVD . . . . peripheral vascular disease
RF . . . . rheumatic fever
RHD . . . . rheumatic heart disease
RR . . . . relative risk
SAH . . . . subarachnoid hemorrhage
SCD . . . . sudden cardiac death
SES . . . . socioeconomic status
SHS . . . . Strong Heart Study
STEMI . . . . ST elevation myocardial infarction
TIA . . . . transient ischemic attack
UA . . . . unstable angina
UNOS . . . . United Network for Organ Sharing
USDA . . . . United States Department of Agriculture
USDHHS . . . . United States Department of Health and Human Services
VF . . . . ventricular fibrillation
VSD . . . . ventricular septal defect
VTE . . . . venous thromboembolism
WHO . . . . World Health Organization
YLL . . . . years of life lost
YMCLS . . . . Youth Media Campaign Longitudinal Study
YRBS . . . . Youth Risk Behavior Surveillance

American Heart Association®

Learn and Live℠

American Stroke Association℠

A Division of American Heart Association

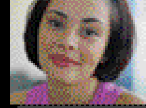
For heart- or risk-related information, call 1-800-AHA-USA1 (1-800-242-8721) or contact your nearest office. You can also visit us online at americanheart.org.

For stroke information, call our American Stroke Association at 1-888-4-STROKE (1-888-478-7653), or visit StrokeAssociation.org. For information on life after stroke, call and ask for the Stroke Family Support Network.

Your contributions will support research and educational programs that help reduce disability and death from America's No. 1 and No. 3 killers.

National Center
7272 Greenville Avenue
Dallas, Texas 75231-4596

1/05 KC-0078



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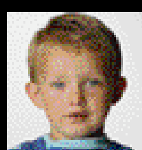
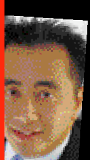
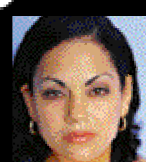
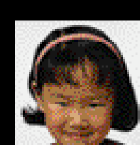


Know the Facts, **Get the Stats**


Our guide to heart disease, stroke and risks



Heart Attack

A heart attack occurs when the blood supply to part of the heart muscle (the myocardium) is severely reduced or stopped because one or more of the heart's arteries is blocked. The process usually begins with atherosclerosis, the buildup of fatty deposits (plaque) inside artery walls. The plaque can rupture, causing a blood clot to form and block the artery. If the blood supply is cut off for more than a few minutes, heart muscle cells suffer permanent injury or die. This can kill or disable someone, depending on how much heart muscle is damaged.

Warning Signs

Some heart attacks are sudden and intense, but most start slowly, with mild pain or discomfort. Often the people affected aren't sure what's wrong and wait too long before getting help. Here are some signs that can mean a heart attack is happening.

- **Chest discomfort. Most heart attacks involve discomfort in the center of the chest that lasts more than a few minutes, or that goes away and comes back. It can feel like uncomfortable pressure, squeezing, fullness or pain.**
- **Discomfort in other areas of the upper body. Symptoms can include pain or discomfort in one or both arms, the back, neck, jaw or stomach.**
- **Shortness of breath. May occur with or without chest discomfort.**
- **Other signs. These may include breaking out in a cold sweat, nausea or lightheadedness.**

If you or someone you're with has chest discomfort, especially with one or more of the other signs, don't wait longer than 5 minutes before calling for help. ***Call 9-1-1.***

Calling 9-1-1 is almost always the fastest way to get lifesaving treatment. Emergency medical services (EMS) staff can begin treatment when they arrive — up to an hour sooner than if someone gets to the hospital by car. The staff are trained to revive someone whose heart has stopped. You'll also get treated faster in the hospital if you come by ambulance.

Sudden Death From Cardiac Arrest

Cardiac arrest is the stopping of the heartbeat. When a person's heartbeat stops abruptly and unexpectedly, it's called **sudden cardiac arrest**. Death can occur within minutes after the victim collapses. This is called **sudden cardiac death** or SCD. The term "massive heart attack" is often mistakenly used to describe SCD. A heart attack may cause cardiac arrest and sudden death, but it's not the same thing.

The most common underlying cause of sudden cardiac arrest is a heart attack that results in ventricular fibrillation (VF) (quivering of the heart's lower chambers). This irregular heart rhythm causes the heart to suddenly stop pumping blood. No statistics are available for the exact number of sudden cardiac arrests that occur each year. However, about 335,000 people a year die of coronary heart disease (CHD) in an emergency department or before reaching a hospital. That's two-thirds of all deaths from CHD — more than 930 Americans each day. Most of these deaths are from sudden cardiac arrest.

When Minutes Count

A victim of VF sudden cardiac arrest suddenly collapses, is unresponsive to gentle shaking and stops breathing normally. Brain damage can start to occur in just 4 to 6 minutes after the heart stops pumping blood. Death may be prevented if the sudden cardiac arrest victim receives immediate bystander cardiopulmonary resuscitation (CPR) and defibrillation within a few minutes after collapse. CPR consists of mouth-to-mouth rescue breathing and chest compressions. It can help keep blood flowing to the heart and brain until emergency help arrives. Defibrillation can stop the abnormal, erratic rhythm and allow the heart to resume its normal rhythm. An automated external defibrillator (AED) provides an electric shock, which is the only way to defibrillate.

If no bystander CPR is provided, a victim's chances of survival are reduced by 7 to 10 percent with every minute of delay until defibrillation. The cardiac arrest survival rate is only about **5 percent** if a system for providing early defibrillation is not present in a community. In cities with "community AED programs," when bystanders provide **immediate** CPR and the first shock is delivered **within 3 to 5 minutes**, the reported survival rates from VF sudden cardiac arrest are as high as 48 to 74 percent.

Thousands of portable, computerized AEDs are now used in police and emergency vehicles and many public buildings. Lay rescuers can be trained to use them. If survival rates from sudden cardiac arrest increased from 5 percent to 20 percent, about 40,000 more lives could be saved each year.

- If symptoms last more than a few minutes, **call 9-1-1** or the er
and is unresponsive, **begin CPR** immediately. If you don't kno
the victim's heart, if an AED is available and if you're trained to u
of the start of a heart attack, they can minimize heart damage. If

Stroke

A stroke occurs when a blood vessel that brings oxygen and nutrients to the brain bursts or is clogged by a blood clot or some other particle. Because of this rupture or blockage, part of the brain doesn't get the blood and oxygen it needs. Deprived of oxygen, nerve cells in the affected area of the brain die within minutes.

There are two main types of stroke. One is caused by blood clots or other particles (ischemic strokes), and the other by bleeding from a burst blood vessel (hemorrhagic strokes). Ischemic strokes are the most common.

Cerebral thrombosis is the most common type of ischemic stroke. It occurs when a blood clot (thrombus) forms and blocks blood flow in an artery bringing blood to part of the brain. Blood clots usually form in arteries narrowed by fatty deposits called plaque. Cerebral embolism, another kind of ischemic stroke, occurs when a wandering clot or some other particle (an embolus) forms away from the brain, usually in the heart. The bloodstream carries the clot until it lodges and blocks blood flow in an artery leading to or in the brain.

A subarachnoid hemorrhage occurs when a blood vessel on the brain's surface ruptures and bleeds into the space between the brain and the skull (but not into the brain itself). Another type of hemorrhagic stroke occurs when a defective artery in the brain bursts, flooding the surrounding tissue with blood. This is a cerebral hemorrhage. Bleeding from an artery in the brain can be caused by a head injury or a burst aneurysm. Aneurysms are blood-filled pouches that balloon out from weak spots in the artery wall. They're often caused or made worse by high blood pressure. If an aneurysm bursts in the brain, it causes a hemorrhagic stroke.

After-Effects of Stroke

When brain cells injured by a stroke can't work, the part of the body they control can't work either. This is why a stroke can be so devastating. Brain injury from a stroke can affect the senses, motor activity, speech and the ability to understand speech. It can also affect a person's behavior and thought patterns, memory and emotions. Paralysis or weakness on one side of the body is common. These effects may be temporary or lasting, depending on the area of the brain affected and the extent of the brain injury.

Warning Signs

- **Sudden numbness or weakness of the face, arm or leg, especially on one side of the body.**
- **Sudden confusion, trouble speaking or understanding.**
- **Sudden trouble seeing in one or both eyes.**
- **Sudden trouble walking, dizziness, loss of balance or coordination.**
- **Sudden, severe headache with no known cause.**

Any of the above symptoms may be temporary and last only a few minutes. This may be due to a "mini-stroke" called a transient ischemic attack (TIA). TIAs are extremely important indicators of an impending stroke. Don't ignore them! If symptoms appear, ***call 9-1-1 to get medical attention immediately.***

Injured and dead brain cells can't heal or replace themselves. Recovery from a severe stroke usually takes months or years of medical treatment, rehabilitation therapy and determined effort by the stroke survivor. Many survivors never regain all their lost functions. Stroke is a leading cause of serious, long-term disability.

Preventing Stroke

Risk factors are traits and lifestyle habits that increase the risk of disease. The risk factors for stroke that you can control or treat are...

- high blood pressure
- tobacco use
- diabetes mellitus
- carotid or other artery disease
- atrial fibrillation or other heart disease
- a history of TIAs ("mini-strokes")
- a high red blood cell count
- sickle cell anemia
- high blood cholesterol
- physical inactivity
- overweight and obesity
- excessive alcohol intake
- some illegal drugs

Work with your healthcare provider to reduce or control as many risk factors as you can.

Rx for Survival

mergency medical services (EMS) immediately. Note the time that the first symptom started. • If someone collapses suddenly w how to do CPR, the EMS dispatcher can tell you what to do. **Use an automated external defibrillator** to shock use it. • **Clot-busting drugs** are a major advance in treating acute heart attack and stroke. If given within a few hours f given within 3 hours of the onset of a stroke caused by blood clots, they can reduce long-term disability.

Risk Reduction Checklist for Heart Attack and Stroke

What You Can Do on Your Own:

- Don't use tobacco — It's the No.1 preventable cause of serious illness such as heart disease, stroke, lung cancer and emphysema.
- Be physically active — It can build endurance, control blood pressure, reduce cholesterol levels, aid in weight control and reduce your risk of developing diabetes.
- Eat healthy foods — Foods high in saturated fat, trans fat and cholesterol contribute to atherosclerosis, a primary cause of heart attack and stroke. Consuming too much salt (sodium) can cause high blood pressure in some people.
- Watch your weight — Obesity is a major risk factor.
- Avoid excessive alcohol — One or two drinks a day may help increase "good" HDL cholesterol, but heavy drinking can contribute to high blood pressure, heart disease and stroke.

What You Can Do With Your Doctor's Help:

- Have regular checkups — A doctor can pinpoint major risk factors such as smoking, elevated cholesterol or blood pressure, excess weight and diabetes.
- Control your cholesterol — A simple blood test can show your blood cholesterol level. If it's too high, dietary changes, exercise, weight loss, and/or drug therapy can bring it down to a safer level.
- Keep tabs on your blood pressure — Even if it's less than 120/80 mm Hg, have it checked at least every two years. If it's 120/80 or above, have it checked more often, according to your doctor's recommendations.
- Keep diabetes in check — Your doctor can detect diabetes or a pre-diabetic condition and prescribe a program to minimize the risk.

Risks You Can't Control:

- Age — The risk gradually increases as people age, but this doesn't mean that younger people are immune. Advanced age significantly raises the risk of heart attacks or strokes.
- Sex — Before menopause, women have a much lower death rate from coronary attack than men. Women's risk rises sharply after menopause, but it still remains lower than men's in the same age group. Each year more women than men have a stroke.
- Heredity — Some families have a higher-than-normal genetic risk of heart attack and stroke. **African Americans are more likely than Caucasians to have high blood pressure, and they tend to have strokes earlier in life and with more severe results.**

2005 Heart Disease and Stroke Statistics

Coronary Heart Disease

- This year about 1.2 million Americans will have a first or recurrent coronary attack. About 494,000 of these people will die. Coronary heart disease is the nation's single leading cause of death.
- About 7.1 million Americans age 20 and older have survived a heart attack (myocardial infarction). About 6.4 million Americans have angina pectoris (chest pain or discomfort due to reduced blood supply to the heart).

Stroke

- Each year about 700,000 people suffer a new or recurrent stroke in the United States. Nearly 163,000 of these people die, making stroke the third leading cause of death.
- About 5.4 million U.S. stroke survivors are alive today, many of them with permanent stroke-related disabilities.
- Women account for more than 6 in 10 stroke deaths.

High Blood Pressure

- Data from NHANES 1999-2002 shows that the estimated prevalence of high blood pressure in adults age 20 and older in the U.S. is now 65.0 million.
- Of all people with high blood pressure, 30 percent are unaware of it, and only 34 percent are on medication and have it controlled. 25 percent are on medication but don't have it under control, and 11 percent aren't on medication. *(JNC7, NHANES III)*
- Up to 95 percent of high blood pressure cases stem from unknown causes, but the condition is easily detectable and most cases can be controlled with proper treatment. **Normal blood pressure in adults is below 120/80 mm Hg. High blood pressure is 140/90 mm Hg or higher.**

Tobacco

- An estimated 26 million men and 21 million women put themselves at increased risk of heart attack and stroke by smoking cigarettes.
- Each day about 4,000 people become regular smokers, more than 2,000 of them under age 18.

High Blood Cholesterol

- About 38 million American adults have cholesterol levels of 240 mg/dL or higher — the point at which it becomes a major risk factor for coronary heart disease and stroke. **Your total cholesterol should be below 200 mg/dL, and your HDL (good) cholesterol should be 40 mg/dL or higher.**

Physical Inactivity

- Data released by the Centers for Disease Control and Prevention show that more than 59 percent of American adults do not engage in periods of vigorous leisure-time physical activity lasting at least 10 minutes per week.

Overweight and Obesity

- About 65 percent of Americans age 20 and older are overweight or obese.

Diabetes Mellitus

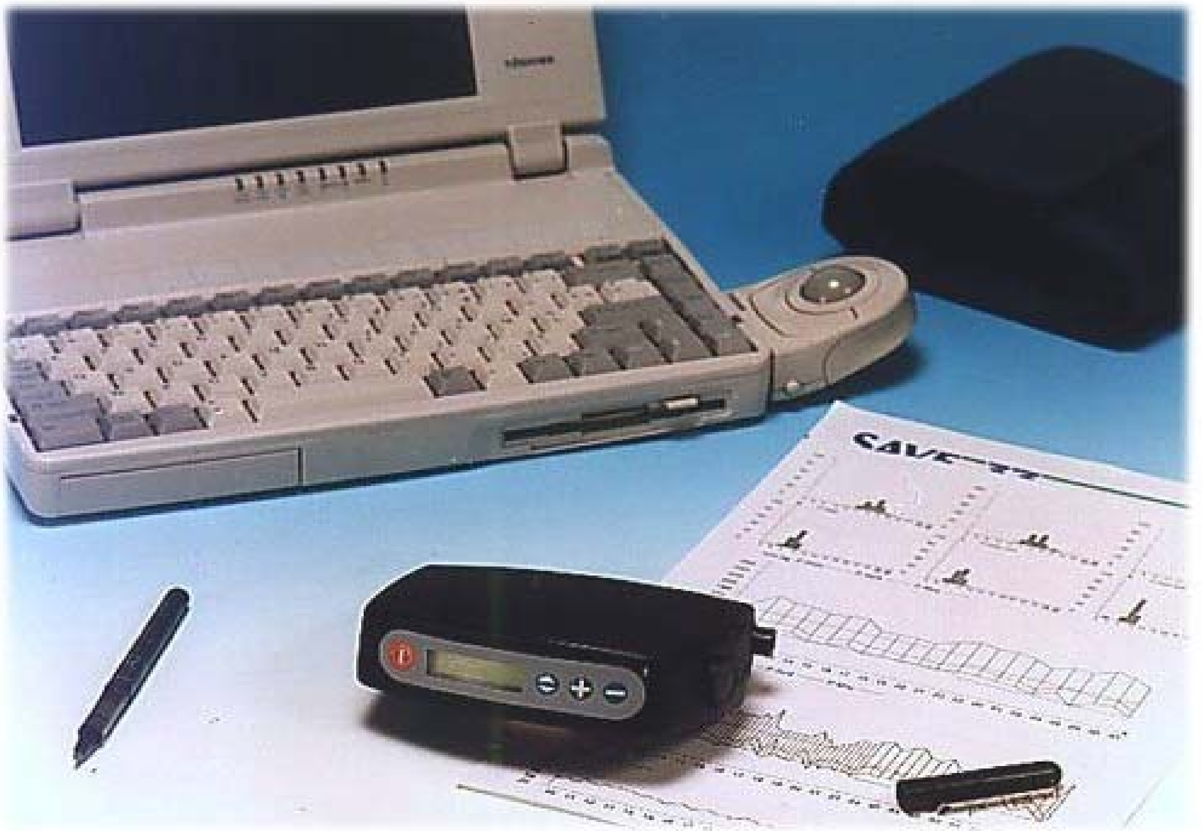
- From two-thirds to three-fourths of people with diabetes die of some form of heart or blood vessel disease.

For more information about heart disease and stroke or about the statistics in this publication, contact your nearest American Heart Association or call 1-800-AHA-USA1 (1-800-242-8721), or visit americanheart.org.

55-0586 12/04

MAPA 33

Medida ambulatoria de la presión arterial



Aparato validado según el protocolo B.H.S.

CE 0398

SAVE 33
ELECTRONIQUE MEDICALE

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Tel. : +33.(0)3.27.29.55.44
Fax : +33.(0)3.27.29.55.67
info@save33.fr - Web : www.save33.fr

CARACTERISTICAS

Método de medida: oscilometrica

Gama de medida: 40 - 280 mm Hg

Hinchado: micro pompa

Medida y almacenamiento de las presiones sistólica medio y diastólica y de la frecuencia cardiaca

Intervalos de medidas programable en 12 ciclos
(1, 2, 3, 4, 5, 6, 10 o 12 medidas por día)

LCD de presentación de: Psys, Pdia, Pmoy, FC
e informaciones paciente.

Programación sencillo por teclado integrado

Sistema de securidad, inflado y desinflado automatico

Rechazo automaticamente de las medidas

Posibilidad de mostrar las medidas durante el registro

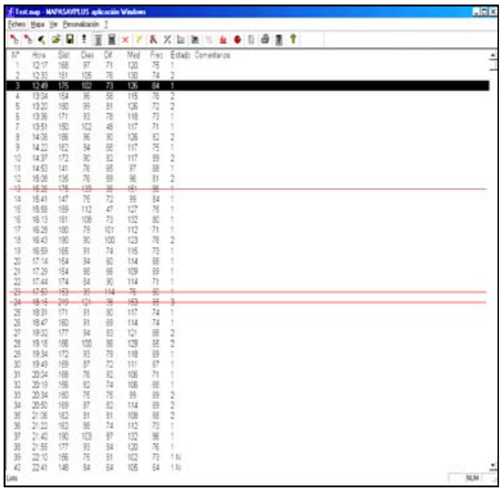
Peso grabadora: 290g

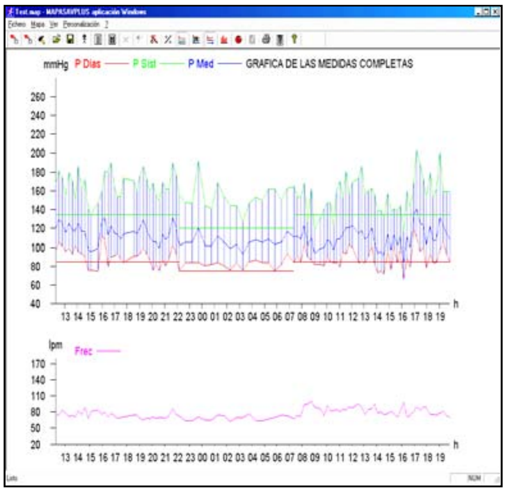
Alimentación: 4 pilas Alkaline 1,5V o baterías NiMh

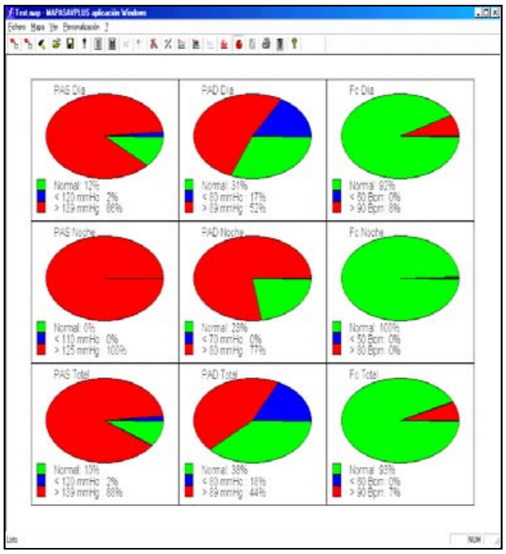
Autonomía: > 48h o 255 medidas

Dimensiones: 120 x 85 x 30 mm

3 tamaños de brazaletes (niño, adulto, odeso)







MAPASAV Plus Software

Software bajo Windows cualquiera versión

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Interface RS232 o USB

Programación and importación de los datos desde el grabador

Informe completo con curvas, histogramas, medidas
y comentarios, estadísticas.

Windows es una aplicación comercial de Microsoft corp.
Macintosh is una aplicación comercial de Apple Inc.
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ELECTRONIQUE MEDICALE

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Noninvasive Blood Pressure Measurement and Motion Artifact: A Comparative Study

December 3, 1998

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Abstract

Protocol Systems, Inc., a designer and manufacturer of patient monitoring instruments and systems, has introduced an advanced software filtering technology aimed at improving the performance of oscillometric noninvasive blood pressure (NIBP) measurement in the presence of motion artifact. Under the trade name of Smartcuf ™, Protocol Systems developed this technology to refine NIBP performance during vehicular transport or under conditions of shivering, tremors, or other sources of patient movement.

To assess the efficacy of the Smartcuf technology, Protocol Systems engineers created a new validation regimen and retained Revision Labs Inc.™ of Beaverton, Oregon to participate in a study of NIBP artifact tolerance and to confirm the scientific validity and objectivity of the data collection and analysis. The validation methods made possible performance comparisons between NIBP attempts with and without motion artifact repeatedly on the same patient profile and provided quantitative data on the disruptive effects of motion artifact on NIBP performance. This joint study lasted for approximately three months, required 1000 hours of labor, and documented NIBP performance data on accuracy, yield, measurement time, repumps, and false positive readings for a total of 6000 NIBP attempts. The experiment focused on side-by-side performance comparisons of a wide variety of patient monitors including the Propaq 200 with Smartcuf, the Propaq 200 without Smartcuf, the Hewlett Packard M3, the Datascope XG, the Dinamap Plus, and the MDE Escort. Monitor models included in this study represent medical devices commonly used in portable patient monitoring.

The results of this study clearly established the success of the Smartcuf technology in redefining performance expectations for NIBP under motion artifact conditions. The Propaq 200 monitor with Smartcuf had the best performance with 80% of its 900 NIBP attempts within +/-10% error. More significantly, the monitor returned < 1% of its readings in which errors exceeded 20%. In contrast the Propaq 200 without Smartcuf, generated 65% of its readings within a ± 10% error, but this configuration had errors greater than 20% 25 times more often than did the monitor with Smartcuf. The other four monitors struggled in the presence of artifact, with only 17 to 38% of their readings falling below a +/-10% error.

Introduction

Oscillometric blood pressure devices derive a patient's blood pressure by applying a cuff to an arm (or leg), inflating that cuff to an occlusive pressure, and then bleeding the pressure from the cuff in a controlled fashion. During the bleed-down phase, the device detects and measures the pressure oscillations in the cuff caused by the heart's pumping activity and then analyzes the pressure pulse data to determine the systolic (SYS), diastolic (DIA), and mean arterial (MAP) pressures. With quiet patients these noninvasive blood pressure (NIBP) devices provide clinically accurate readings in a wide variety of physiologic conditions. However, pressures oscillations impinging on the cuff from sources other than the heart (such as transport vibration, shivering, or tremors, to name a few), may seriously degrade NIBP performance. This degradation includes reduced accuracy, increased patient discomfort from prolonged measurement times and increased repumps, and readings ended before completion of a blood pressure determination. In addition, oscillometric NIBP devices regularly interpret pressure oscillations caused by motion artifact as patient pulses in cases where no patient pulses exists, such as misapplication of the cuff or cardiac arrest. That is to say, they can report blood pressures that do not reflect the patient's true condition. For these reasons most manufacturers warn clinicians not to use these devices in the presence of motion artifact.

Clinicians have generally failed to appreciate the extent of this problem for two primary reasons. First, NIBP displays no waveform. As a consequence, clinicians have no visualization of the magnitude of motion artifact as they would on the ECG or SpO_2 channels. Second, the very factors that produce motion artifact in the blood pressure cuff during transport also produce auditory noise and, thereby, prevent verification of NIBP accuracy through the traditional auscultatory measurement method with a stethoscope.

To minimize these disruptive effects of motion artifact on NIBP measurements, Protocol Systems has developed the Smartcuf technology. The technology synchronizes the ECG data and the NIBP data enabling the noncardiac pulses to be stripped from the artifact-contaminated cuff oscillations, leaving only the cardiac-derived pressure oscillations for analysis and blood pressure determination.

Methods

To assess and quantify the effectiveness of this ECG-dependent NIBP filter, Protocol Systems innovated a new analytical method. This method employed a commercially available NIBP simulator (Bio-Tek) with modifications to allow the injection of typical vehicular motion artifact signals from an Hewlett Packard Arbitrary Waveform Generator® onto the patient profile from the Bio-Tek simulator. The Bio-Tek NIBP simulator provided a mechanism to challenge an NIBP device with a repeatable patient blood pressure profile (e.g. 120/80 mmHg) and pulse rate (e.g. 150 BPM) that remained constant from one reading to the next. The new “method” consisted of comparing the NIBP pressure values obtained in the absence of artifact with those obtained in the presence of artifact. In addition to the pressure values, evaluators recorded measurement time, incidence of retries/repumps, and incidence of readings ending with no pressure values. By adjusting the size of the patient pulses to zero in the Bio-Tek simulator and continuing to inject artifact signals from the waveform generator, this methodology also provided quantification of the artifact-only performance. In the artifact-only tests, evaluators required no baseline readings because “no answer” constituted the correct response for these cases. All blood pressure readings in which pressure values were returned under artifact-only conditions fell into the category of “false-positive” readings.

Utilization of these analytical methods permitted comparisons of the Propaq 200 Smartcuf performance with the performance of the Propaq 200 without Smartcuf as well as with other monitor configurations including the Hewlett Packard M3, the Datascope XG, the MDE Escort, and the Dinamap Plus. Side-by-side comparisons of the tested NIBP devices encompassed accuracy, yield (incidence of values within specific error limits), measurement times, rates of retries/repumps, and frequency of false-positive readings under artifact-only conditions. Evaluators selected monitors for inclusion in this study on the basis of their potential importance in portable monitoring applications.

This report summarizes data collected for the blood pressure variables listed below in Table 1. These variables represent the ranges of conditions commonly present in patient transport.

Normotensive Profile 120/80 mmHg (93)	Hypertensive Profile 170/100 mmHg (123)	Hypotensive Profile 70/40 mmHg (50)
50 BPM	50 BPM	50 BPM
80 BPM	80 BPM	80 BPM
150 BPM	150 BPM	150 BPM

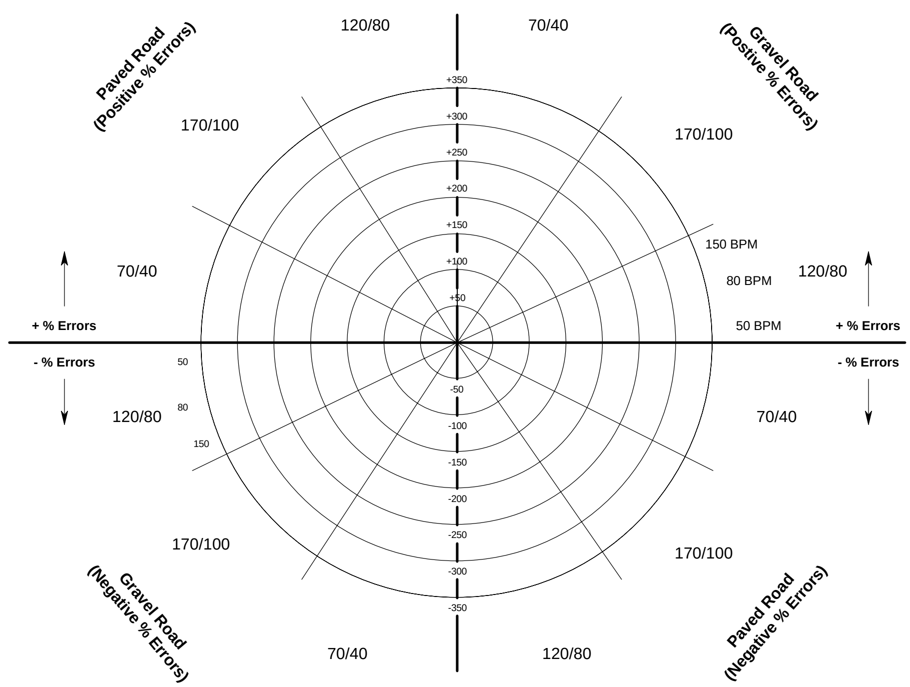
Table 1 Blood pressure profiles and heart rates tested for this report.

In addition to the pressure profile and heart rate variables in Table 1, the experimental design also varied the amplitude of artifact profiles over 5 levels. Expressed in terms of the Hewlett Packard Arbitrary Waveform Generator® settings, these amplitudes included 200, 400, 600, 800, and 1000 mV. These voltage levels simulated light to moderate motion artifact under typical transport conditions. The artifact tests also included two distinct road artifact profiles (a gravel road and a paved road) for all combinations of pressure profile, heart rate, and artifact amplitude level. Developers created the two road profiles by collecting vibration data to a lap-top computer from a Propaq monitor over the monitor’s communications port during vehicular transport on a gravel road or on a paved road. Artifact data contained no patient pulses. Analysis of the artifact data in MatLab® documented the spectral content of the two artifact profiles. Reformatting of the artifact data allowed importing of the two artifact profiles into the arbitrary waveform generator’s nonvolatile memory for superimposition on patient profiles or for artifact-only trials.

The following formula summarizes the experimental cases: 3 pressure profiles x 3 heart rates x 5 artifact levels x 2 artifact profiles x 10 readings for each combination of the preceding = 900 NIBP attempts for each NIBP monitor type. With three values possible for each attempt (SYS, DIA, MAP), each monitor had the potential to deliver 2700 blood pressure values in response to the combined patient/artifact profiles. In addition, artifact-only performance data were collected for 100 NIBP attempts in all models without an ECG-dependent filter and 300 NIBP attempts for the Propaq with Smartcuf (100 attempts for each heart rate).

Evaluators collected performance data to an Excel® spreadsheet. The data made possible calculation of the artifact-induced error by subtracting the artifact-free values from the pressure values for the combined artifact/patient profiles. These error values, expressed in mmHg were then converted to a percent value. For example, if an expected or artifact-free systolic value of 120 resulted in a reading of 90 due to artifact, the formula (90-120/120) x 100 expresses the percent error. In this example the calculation yields an error of - 25 percent. Artifact-only data recorded the incidence off attempts ending with blood pressure values.

The study's analysis plotted the error data for the combined artifact/patient profiles on a polar axis in which the readings for each experimental case (each combination of pressure profile, heart rate, artifact profile, and noise level) were plotted along a single diameter. Figure 1 portrays the mapping scheme for these error plots. Positive error data for the gravel road and for the paved road appear in the upper right and left quadrants of the plots, respectively. The negative error data for the gravel and paved roads appear in the lower left and right quadrants, respectively. The plots reveal both the central tendency of the errors and the variability of the data about that central tendency for the various monitor types. In the hypothetically perfect monitor, all 2700 values would lie exactly at the center of the polar plot. If a particular monitor always missed the expected value by 100 percent all data points would lie on the upper half of the second percent error ring.



Data Mapping Key for Polar Scatter Plots
NIBP Comparative Study

Figure 1 Polar Plot Data Map (Blood pressure measurement e.g. 170/100 is expressed in mmHg)

Results

Figures 2 to 7 compare the distribution patterns of percent errors in response to motion artifact for the six monitor types tested in this study. The data plots include all three pressure values (SYS, DIA, and MAP) for a total of 2700 potential values. The actual number of values returned by the NIBP devices appears in the description of the plot at the top of each graph. For example, Figure 2 for the HP M3 documents that this monitor achieved a yield of 2080 pressure values out of a total of 2700 possible values. Comparing Figure 7 with the Figures 2 through 6 establishes the superiority of the Smartcuf technology in producing a high yield of accurate blood pressure values in the presence of motion artifact. The four outliers in the Smartcuf data (the Propaq 200 with ECG) represent two circumstances. First, the three data points lying between 200 and 250 percent error rings resulted from a single NIBP attempt in which the heart rate and noise frequency aligned in a way that allowed the artifact to breach the Smartcuf filter. The Smartcuf filter has to permit waveform data at the heart rate to pass through the filter in order to ascertain the blood pressure reading. If the artifact has the same frequency as the heart rate or a multiple of the heart rate, the Smartcuf could fail to strip the artifact data from the incoming data. In the present study the heart rate did not vary throughout an NIBP attempt. In a human patient this invariability of the heart rate would not exist, reducing the likelihood that the heart rate and artifact would remain aligned at a problematical relationship long enough to breach the filter. The remaining outlier near the 100 percent ring represents an NIBP attempt in which the artifact failed to trigger the use of the Smartcuf. Consequently, this mean-only reading reflects the same type of errors made by the other monitor types.

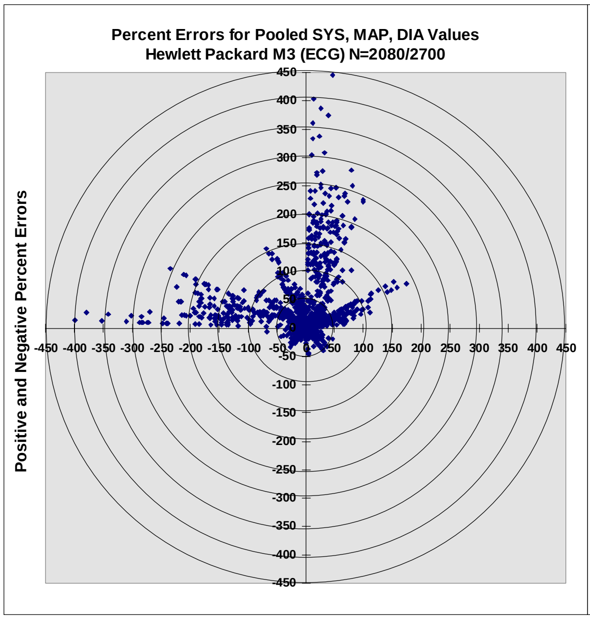


Figure 2 Hewlett Packard M3 data

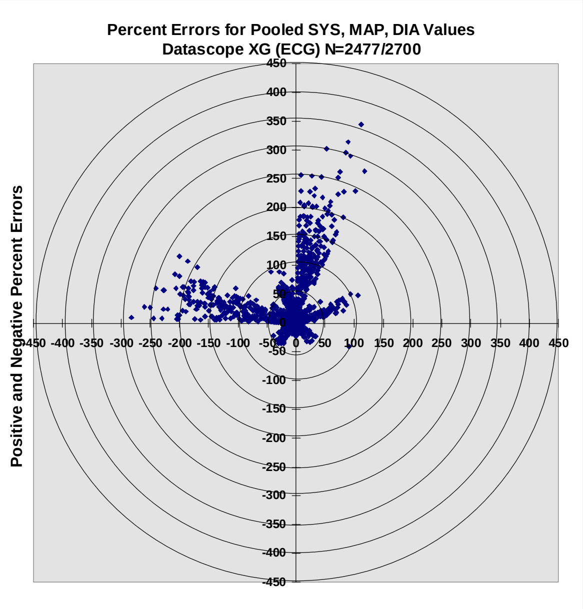


Figure 3 Datascope XG data

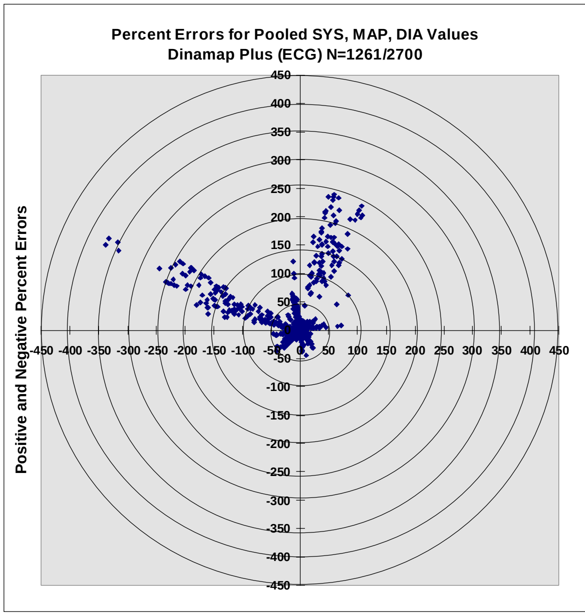


Figure 4 Dinamap Plus data

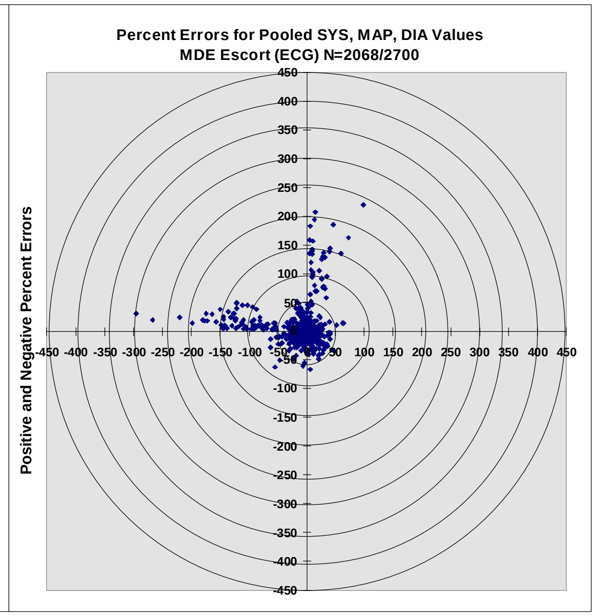


Figure 5 MDE Escort data

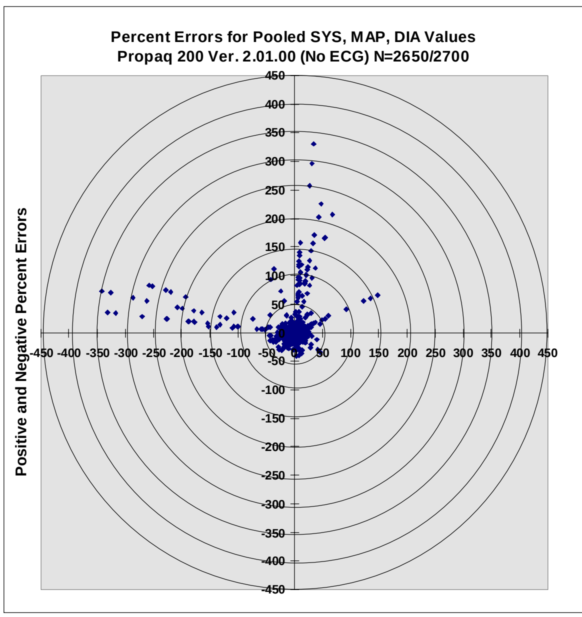


Figure 6 Propaq 200 without *Smartcuf*

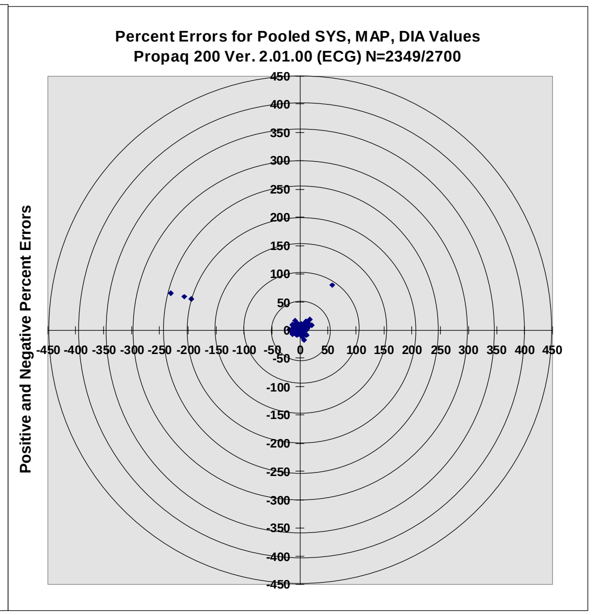


Figure 7 Propaq 200 with *Smartcuf*

Figure 8 summarizes the scatter plot data previously presented in Figures 2 through 7. This bar graph portrays the average percent errors over all pressure values (SYS, DIA, and MAP) ± the standard deviation for each monitor. The graph clarifies the relative accuracy and variability of the six monitors. The MDE Escort and the Propaq 200 without Smartcuf both had smaller average errors and standard deviations than did the Hewlett Packard M3, the Datascope XG, and the Dinamap Plus. The Propaq 200 with Smartcuf derived blood pressures with the lowest average error and contained the variability of the readings better than the other five monitor configurations.

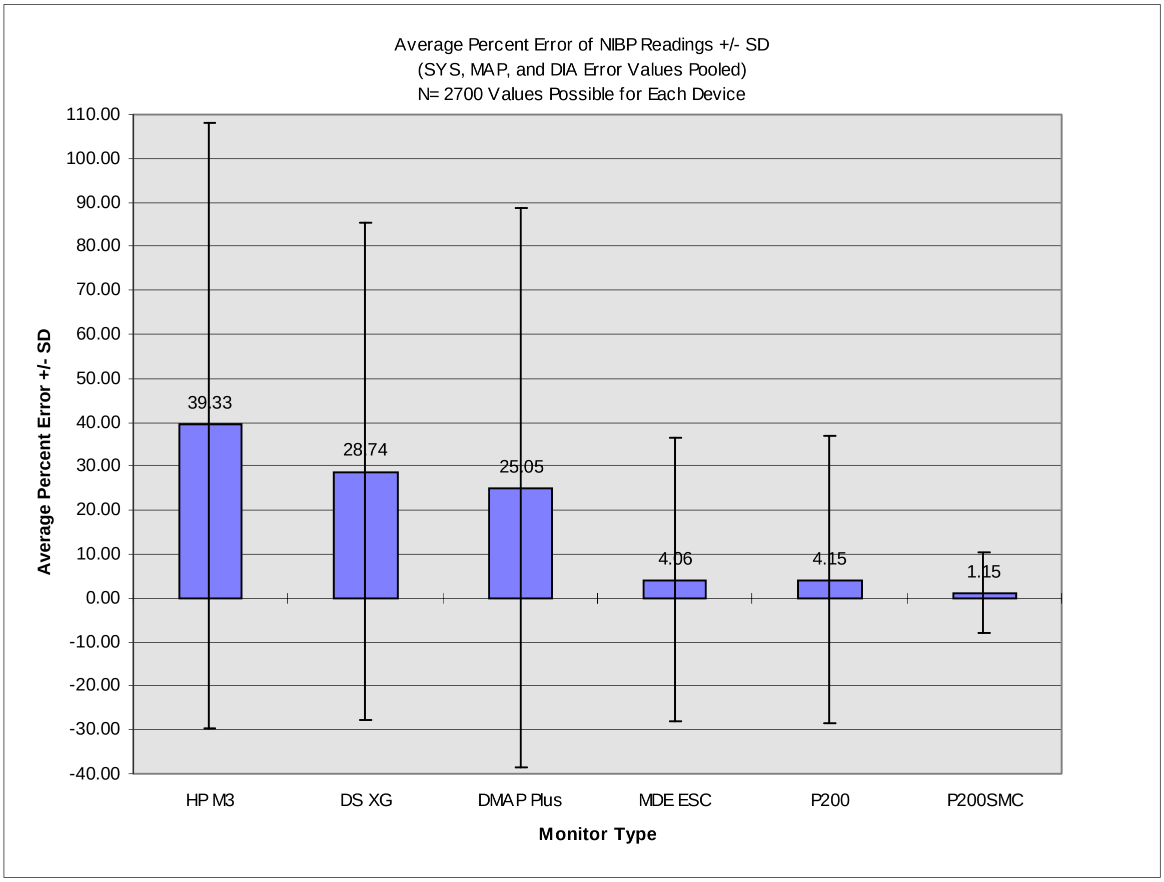


Figure 8 Summary of the average percent error data for the 6 monitor configurations tested (SMC = Smartcuf)

Figure 9 depicts the accuracy from another point of view. This stacked bar graph plots the relative incidences of errors in various categories; errors ≤ 10 percent, errors > 10 percent and ≤ 20 percent, errors > 20 percent, and readings ending with no values. In this analysis, a reading had to have no single value exceeding the category limit to qualify for inclusion in that category. Both Propaqs (with and without Smartcuf) outperformed the other monitors in the ≤ 10 percent category. For example, the Propaq 200 with Smartcuf attained 717 readings in the ≤ 10 percent. This meant that of these 717 readings, no single pressure value for SYS, DIA or MAP exceeded the 10 percent error limit. The Propaq 200 without Smartcuf attained the second highest incidence of readings ≤ 10 percent with 586 readings in that category. However, the Propaq 200 without Smartcuf also experienced twice as many values in the > 10 ≤ 20 percent category and 25 times as many values in the > 20 percent category as did the Propaq 200 with Smartcuf. The Smartcuf technology accomplished this increased reliability at the cost of a higher incidence of NIBP attempts ending with no answers. In other words, the Smartcuf succeeded more often than the Propaq without Smartcuf at detecting conditions of risk and disqualifying a reading for display. For monitors other than the Propaq 200 (both with and without Smartcuf), performance limitations resulted in greater than half of the NIBP attempts ending with errors > 20 percent.

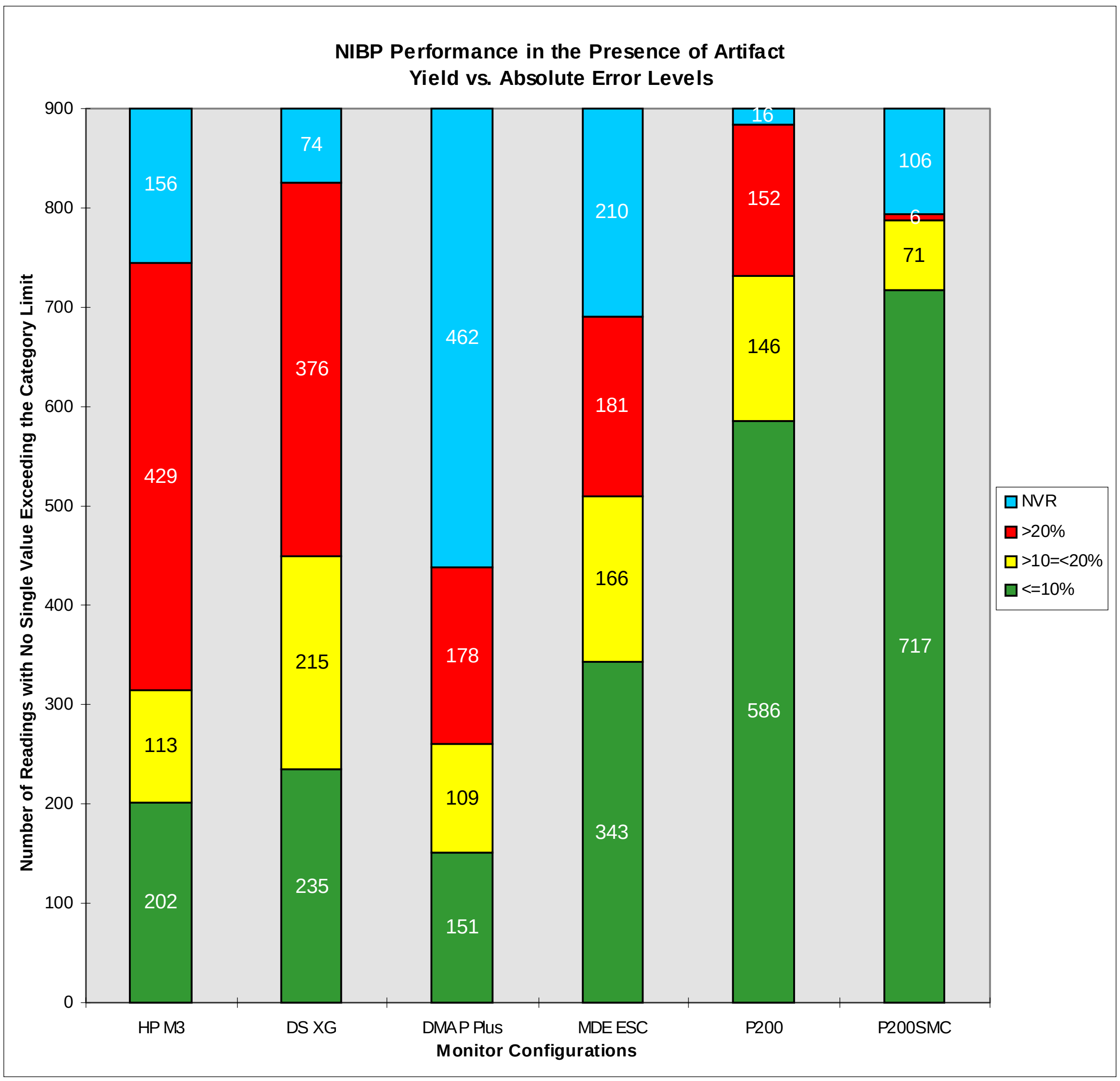


Figure 9 Yield data for error categories in the 6 monitor types tested (SMC = Smartcuf)

Figure 10 compares the average measurement times of the 6 monitor configurations (± standard deviation). Measurement time represents an important variable in NIBP performance for clinicians who must often make critical medical decisions promptly. Recognition of this fact raised concerns that the heavier filtering performed by the Smartcuf technology might prolong measurement times to unacceptable levels. The data in Figure 10 verify that the Smartcuf took about 15 to 20 seconds longer, on average, to complete readings than did the Propaq 200 without Smartcuf. This demonstrates the cost of attaining greater accuracy and reliability of blood pressure values in the Smartcuf system under artifact conditions. Despite the increased measurement time of the Smartcuf relative to the Propaq 200 without Smartcuf, the times for the Smartcuf are comparable to or faster than the other monitor configurations in this study. The analysis supports the conclusion that the modestly increased measurement times required to improve accuracy and reliability have not put the Smartcuf at a performance disadvantage relative to these other monitor configurations.

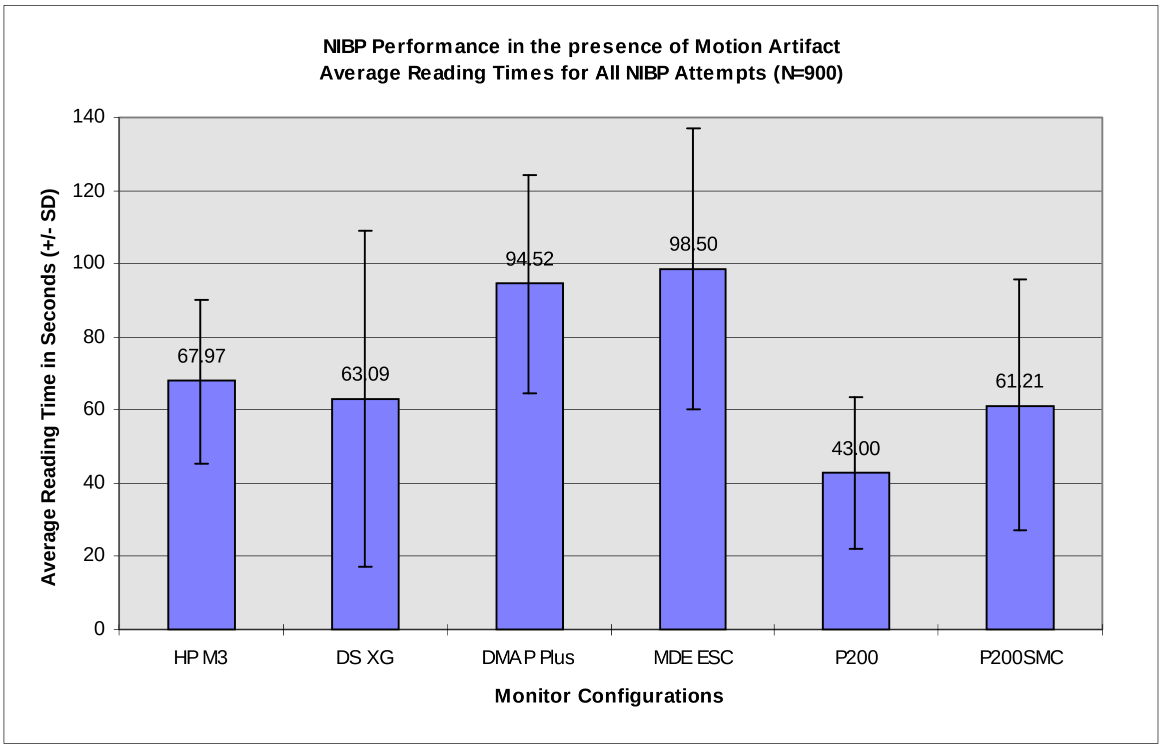


Figure 10 Comparison of the average reading times in the presence of motion artifact (SMC = Smartcuf)

Figure 11 compares the incidence of retries and repumps in the 6 monitor configurations tested. In this context, the term *retries* refers to cases in which the NIBP monitor bleeds the pressure to zero before reinflating the cuff during a single NIBP attempt. The term *repump* refers to cases in which the NIBP monitor need not bleed the cuff pressure to zero before reinflating to a higher pressure. Different monitors tend to employ one or the other and sometimes both schemes for gathering additional pulse data. These cuff reinflations tend to extend reading times and to increase patient discomfort. Therefore, the most efficient designs limit these reinflations to an absolute minimum. In some NIBP readings, reinflations of the cuff must occur even with no motion artifact in order to find the systolic pressure. For example, all of the tested monitors had default cuff inflation targets lower than the systolic pressure in the 170/100 mmHG patient profile. Consequently, all monitors should have performed cuff reinflations in at least 33 percent of the attempts in order to correctly identify the systolic pressure. Figure 11 demonstrates that the Dinamap Plus failed to perform correctly on the hypertensive profile with only 17 percent of reinflations over all NIBP attempts. All other monitors had repumps or retries in 33 percent or more of the attempts. Artifact also can cause reinflations if the NIBP attempt has, for example, found the MAP and the DIA but has been unable to determine the SYS because of the disruptive effects of motion artifact. Therefore, reinflation rates greater than 33 percent in this data did not necessarily represent improper performance.

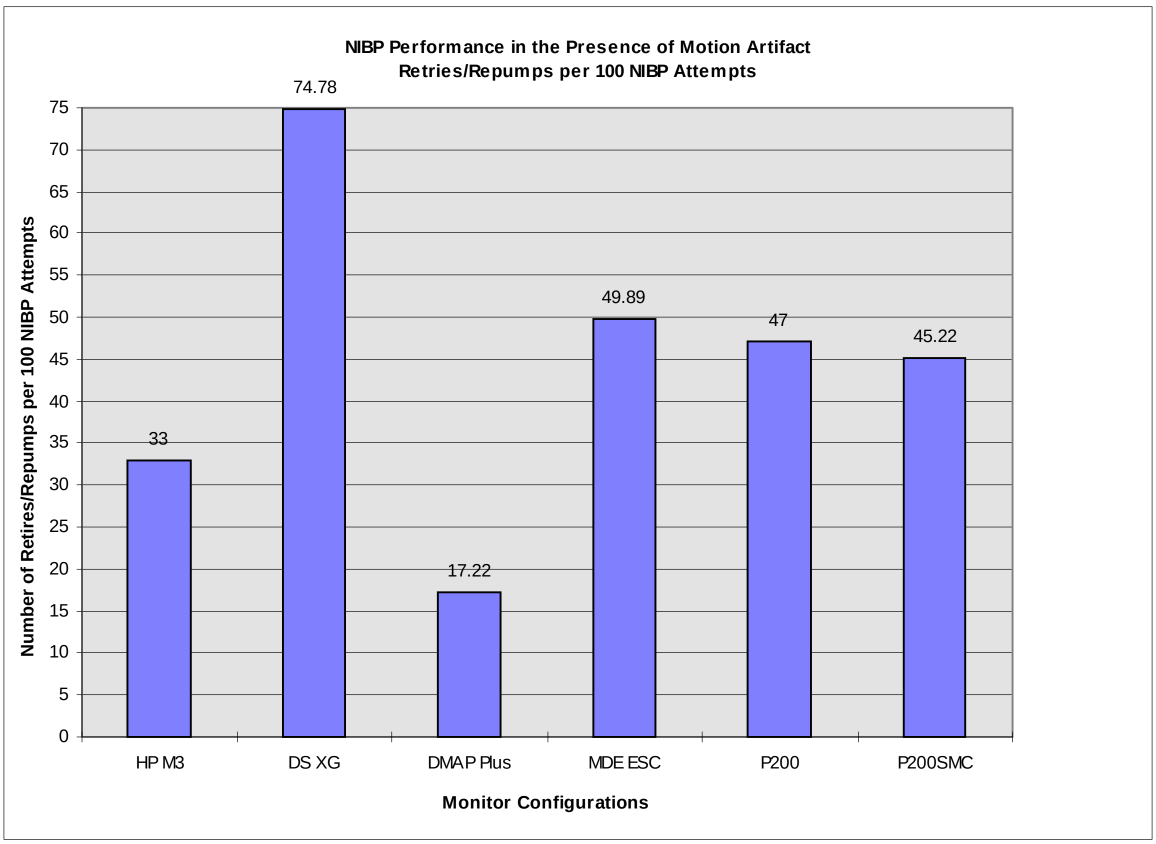


Figure 11 Comparison of the numbers of retries or repumps per 100 NIBP attempts in the presence of motion artifact (SMC = Smartcuf). (Note: Because one third of the NIBP attempts involved the 170/100 pressure profile, all monitors should have had at least a 33 percent incidence of retries)

Figure 12 compares the performance of the six monitors when exposed to motion artifact with no patient pulses. The Smartcuf technology surpassed all other monitor configurations in its ability to discern artifact-only pulses and displayed false positive readings in only 8 percent of attempts. The MDE Escort most closely approached this performance with a 31 percent incidence of false positive readings. The Datascope XG and the Dinamap Plus both returned false positives in 50 percent of the trials and the Hewlett Packard and the Propaq 200 without Smartcuf both experienced false positive readings in 80 percent of the trials.

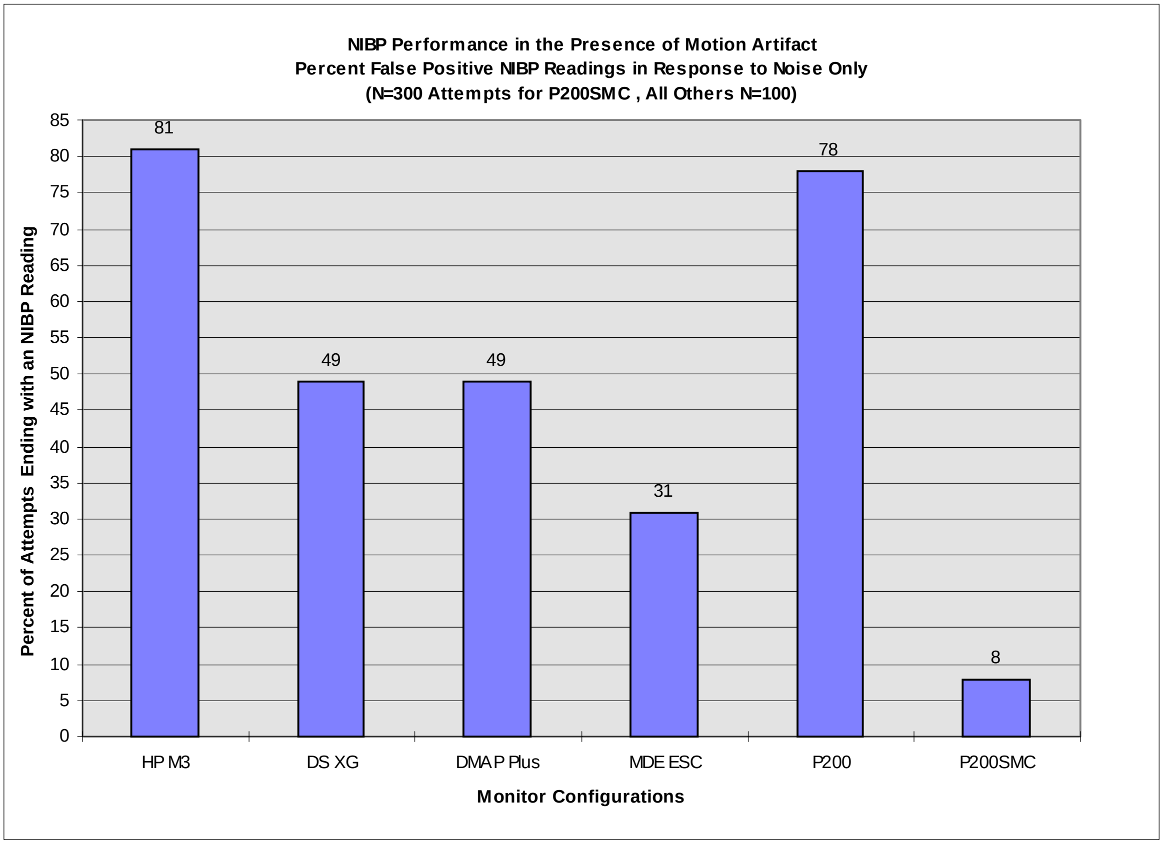


Figure 12 Comparison of the incidence of false positive NIBP readings on artifact-only NIBP attempts (SMC = Smartcuf)

Summary

The use of ECG synchronization to filter motion artifact from NIBP data in the Smartcuf technology produced a dramatic improvement in measurement accuracy/variability and in yield under artifact conditions. This increased accuracy did not produce a clinically unacceptable increase in times for the Smartcuf monitor compared to the measurement times of other monitor configurations included in this study. The Smartcuf technology had no adverse effects on the incidence of retries/repumps either when compared to the Propaq 200 without Smartcuf or when compared to the other four monitors. Furthermore, the Smartcuf technology surpassed all other monitor configurations in the ability to detect the absence of patient pulses in an artifact profile. This configuration had the lowest incidence of false-positive readings when patient pulses were not present in an artifact profiles.

NIBP Performance: Artifact Tolerance Comparison Summary						
Model	P200 (Smartcuf)	Propaq 200 (sans Smartcuf)	Hewlett Packard M3	Datascope XG	Dinamap Plus	MDE Escort
Average % Error	1.15	4.15	39.33	28.74	25.05	4.06
Standard Deviation	9.07	32.71	68.73	56.56	63.60	32.30
Average Measurement Time	61.21	43.00	67.97	63.09	94.52	98.50
Yield ≤10 %	717	586	202	235	151	343
Yield >10 ≤20 %	71	146	113	215	109	166
Yield > 20%	6	152	429	376	178	181
No Values Returned	106	16	156	74	462	210
Retries/100 Attempts	45.22	47	33	74.78	17.22	49.89
% False Positives	8.33	78	81	49	49	31

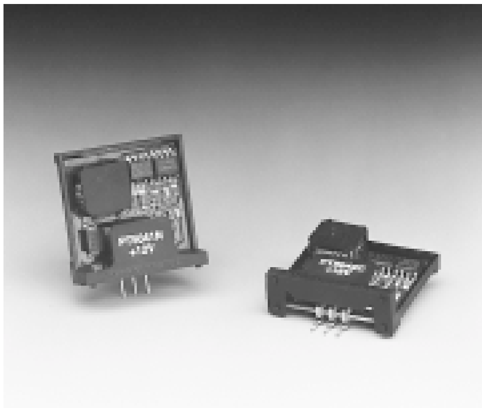
Table 2 NIBP Performance: Summary of numerical data for motion artifact tolerance

PT5040 Series

1-A Positive Step-up Integrated Switching Regulator

SLTS026B

(Revised 12/19/2001)



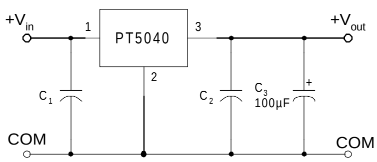
Features

- Wide Input Voltage Range
- 85% Efficiency
- Internal Over-Temperature Protection
- Laser-trimmed Output Voltage
- Soft Start
- 5-Pin Mount Option (Suffixes L & M)

Description

The PT5040 is a series of 3-pin boost-voltage Integrated Switching Regulators (ISRs). These ISRs are designed for use with +5V bus systems that require an additional regulated +8V to +20V with up to 1A of output current. These ISRs are packaged in the 3-pin, single in-line pin (SIP) package configuration.

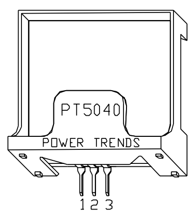
Standard Application



C_1 = Optional ceramic (1-5µF)
C_2 = Optional ceramic (1-5µF)
C_3 = Required Electrolytic (100µF)

Pin-Out Information

Pin	Function
1	V_{in}
2	GND
3	V_{out}



Ordering Information

PT5041☐ = +12 Volts
PT5042☐ = +15 Volts
PT5044☐ = +8 Volts
PT5045☐ = +9 Volts
PT5046☐ = +10 Volts
PT5047☐ = +18 Volts
PT5048☐ = +12.6 Volts
PT5049☐ = +20 Volts

PT Series Suffix (PT1234x)

Case/Pin Configuration	Order Suffix	Package Code *
Vertical	N	(EAD)
Horizontal	A	(EAA)
SMD	C	(EAC)
Horizontal, 2-pin Tab	M	(EAM)
SMD, 2-Pin Tab	L	(EAL)

** Previously known as package styles 100/110.*

(Reference the applicable package code drawing for the dimensions and PC board layout)

NOTE: Boost Topology ISRs are not Short-Circuit Protected.

Specifications

(Unless otherwise stated, T_a =25°C, V_{in} =5V, I_o =$I_o$max, C_3 =100µF)

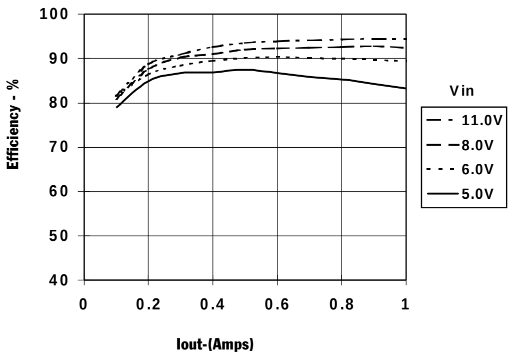
Characteristics	Symbol	Conditions		PT5040 SERIES Min	Typ	Max	Units
Output Current	I_o	Over V_{in} range	PT5049 PT5047 PT5041/48 PT5042 PT5044 PT5045/46	0.1 (1) 0.1 (1) 0.1 (1) 0.1 (1) 0.1 (1) 0.1 (1)	— — — — — —	0.5 0.6 1.0 0.75 1.5 1.2	A
Input Voltage Range	V_{in}	Over Io range	 PT5047/5049	4.75 4.75	— —	(V_o-1) 14	V
Output Voltage Tolerance	ΔV_o	Over V_{in} Range T_a= -20°C to SOA derating limit (3)		—	±1.5	±3.0	%V_o
Line Regulation	Reg_{line}	Over V_{in} range		—	±0.5	±1.0	%V_o
Load Regulation	Reg_{load}	$I_o$min ≤ I_o ≤ $I_o$max		—	±0.5	±1.0	%V_o
Efficiency	η	I_o=0.5A		—	85	—	%
V_o Ripple (pk-pk)	V_r	20MHz bandwidth		—	±2	±5	%V_o
Transient Response	t_{tr} V_{os}	25% load change V_o over/undershoot		— —	500 3.0	— 5.0	µSec %V_o
Current Limit	I_{lim}			—	150 (2)	—	%$I_o$max
Inrush Current	I_{ir} t_{ir}	On start up		— —	5.5 (3) 1	— —	A mSec
Switching Frequency	f_s	Over V_{in} and I_o ranges	V_o<15V V_o≥15V	500 650	650 800	800 950	kHz
Operating Temperature Range	T_a	—		-20	—	+85 (4)	°C
Thermal Resistance	θ_{ja}	Free Air Convection (40-60LFM)		—	40	—	°C/W
Storage Temperature	T_s			-40	—	+125	°C
Mechanical Shock		Per Mil-STD-883D, Method 2002.3 1 msec, Half Sine, mounted to a fixture	—	500	—	G's	
Mechanical Vibration Per Mil-STD-883D, 20-2000 Hz		Suffixes N, A, & C Suffixes L & M		— —	5 20 (5)	— —	G's
Weight		Suffixes N, A, & C Suffixes L & M		— —	4.5 6.5	— —	grams

Notes: *(1) The ISR will operate at no load with reduced specifications.*
(2) Boost topology ISRs are not short circuit protected.
(3) The inrush current stated is above the normal input current for the associated output load.
(4) See Safe Operating Area curves or consult the factory for the appropriate derating
(5) The tab pins on the 5-pin mount package types (suffixes L & M) must be soldered. For more information see the applicable package outline drawing.

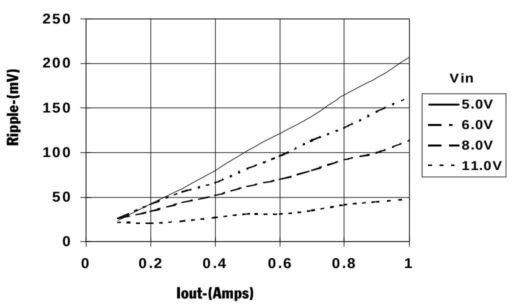
Typical Characteristics

PT5041, +12.0 VDC (See Note A)

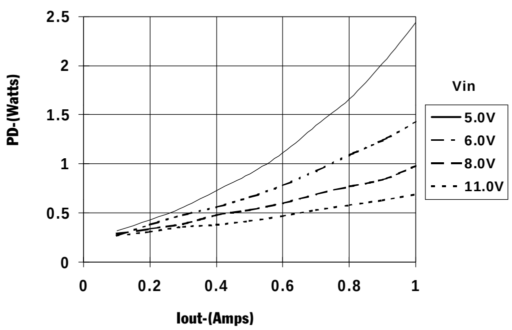
Efficiency vs Output Current



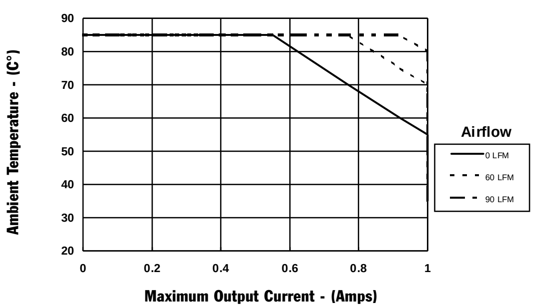
Ripple Voltage vs Output Current



Power Dissipation vs Output Current

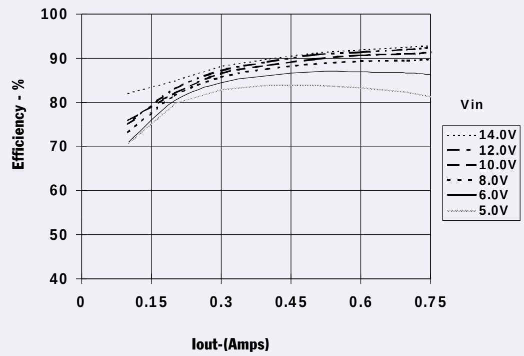


Safe Operating Area (V_{IN}=5V) (See Note B)

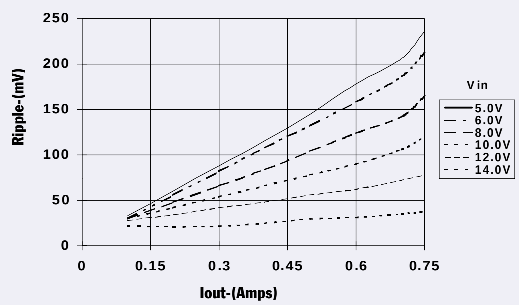


PT5042, +15.0 VDC (See Note A)

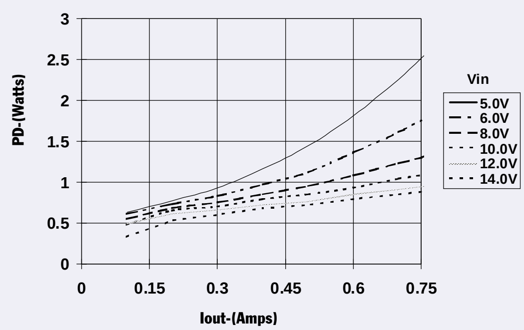
Efficiency vs Output Current



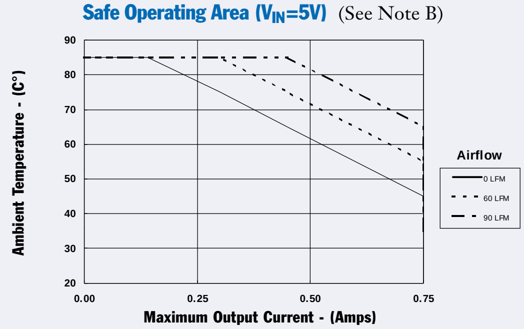
Ripple Voltage vs Output Current



Power Dissipation vs Output Current



Safe Operating Area (V_{IN}=5V) (See Note B)



Note A: *Characteristic data has been developed from actual products tested at 25°C. This data is considered typical data for the Converter.*
Note B: *Thermal derating graphs are developed in free-air convection cooling, which corresponds to approximately 40–60LFM of airflow.*

PACKAGING INFORMATION

Orderable Device	Status [1]	Package Type	Package Drawing	Pins	Package Qty	Eco Plan [2]	Lead/Ball Finish	MSL Peak Temp [3]
PT5041A	ACTIVE	SIP MOD ULE	EAA	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5041C	ACTIVE	SIP MOD ULE	EAC	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5041CT	ACTIVE	SIP MOD ULE	EAC	3	200	TBD	Call TI	Level-1-215C-UNLIM
PT5041H	ACTIVE	SIP MOD ULE	EAH	3	16	TBD	Call TI	Level-1-215C-UNLIM
PT5041J	ACTIVE	SIP MOD ULE	EAJ	3	16	TBD	Call TI	Level-1-215C-UNLIM
PT5041L	ACTIVE	SIP MOD ULE	EAL	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5041M	ACTIVE	SIP MOD ULE	EAM	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5041N	ACTIVE	SIP MOD ULE	EAD	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5041S	ACTIVE	SIP MOD ULE	EAF	3	16	TBD	Call TI	Level-1-215C-UNLIM
PT5042A	ACTIVE	SIP MOD ULE	EAA	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5042C	ACTIVE	SIP MOD ULE	EAC	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5042L	ACTIVE	SIP MOD ULE	EAL	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5042M	ACTIVE	SIP MOD ULE	EAM	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5042N	ACTIVE	SIP MOD ULE	EAD	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5044A	ACTIVE	SIP MOD ULE	EAA	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5044C	ACTIVE	SIP MOD ULE	EAC	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5044L	ACTIVE	SIP MOD ULE	EAL	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5044M	ACTIVE	SIP MOD ULE	EAM	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5044N	ACTIVE	SIP MOD ULE	EAD	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5045A	ACTIVE	SIP MOD ULE	EAA	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5045C	ACTIVE	SIP MOD ULE	EAC	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5045L	ACTIVE	SIP MOD ULE	EAL	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5046A	ACTIVE	SIP MOD ULE	EAA	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5046C	ACTIVE	SIP MOD ULE	EAC	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5046M	ACTIVE	SIP MOD ULE	EAM	3	35	TBD	Call TI	Level-1-215C-UNLIM

Orderable Device	Status [1]	Package Type	Package Drawing	Pins	Package Qty	Eco Plan [2]	Lead/Ball Finish	MSL Peak Temp [3]
PT5046N	ACTIVE	SIP MOD ULE	EAD	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5047A	ACTIVE	SIP MOD ULE	EAA	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5047C	ACTIVE	SIP MOD ULE	EAC	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5047H	ACTIVE	SIP MOD ULE	EAH	3	16	TBD	Call TI	Level-1-215C-UNLIM
PT5047N	ACTIVE	SIP MOD ULE	EAD	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5048A	ACTIVE	SIP MOD ULE	EAA	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5048C	ACTIVE	SIP MOD ULE	EAC	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5048N	ACTIVE	SIP MOD ULE	EAD	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5049A	ACTIVE	SIP MOD ULE	EAA	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5049C	ACTIVE	SIP MOD ULE	EAC	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5049L	ACTIVE	SIP MOD ULE	EAL	3	35	TBD	Call TI	Level-1-215C-UNLIM
PT5049N	ACTIVE	SIP MOD ULE	EAD	3	35	TBD	Call TI	Level-1-215C-UNLIM

[1] The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

[2] Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS) or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

[3] MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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Power Mgmt	power.ti.com	Optical Networking	www.ti.com/opticalnetwork
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Informe especial

Reunión de trabajo sobre la medición de la presión arterial: recomendaciones para estudios de población

Iniciativa Panamericana sobre la Hipertensión[1]

RESUMEN *Como parte de la Iniciativa Panamericana sobre la Hipertensión Arterial, la Organización Panamericana de la Salud y el Instituto Nacional del Corazón, los Pulmones y la Sangre, uno de los Institutos Nacionales de Salud de los Estados Unidos de América, llevaron a cabo una reunión de trabajo para examinar los métodos de medición de la presión arterial (PA) empleados en estudios de prevalencia y ensayos clínicos sobre la hipertensión arterial. El objetivo era desarrollar un protocolo para la medición de la PA que pudiera usarse en los estudios de prevalencia de hipertensión arterial que se realizan en las Américas. Ningún protocolo común de este tipo ha existido antes en la Región, y debido a ellos ha sido difícil comparar las estrategias de intervención y prevención en torno a la hipertensión arterial. Este artículo describe un método estándar que se ha propuesto para medir la PA en estudios de población en la Región de las Américas. El artículo examina todo lo que encierra la elaboración de un protocolo común para medir la PA, aspectos críticos de la medición de la PA en estudios nacionales, los procedimientos mínimos para la medición de la PA durante actividades de vigilancia y la evaluación de la calidad de la PA.*

Palabras clave Presión sanguínea, determinación de la presión sanguínea, hipertensión, pautas, vigilancia de la población.

Los días 12 y 13 de junio de 2000, el Instituto Nacional del Corazón, los Pulmones y la Sangre (*National Heart, Lung, and Blood Institute*) y la Organización Panamericana de la Salud llevaron a cabo una reunión de trabajo para discutir los métodos de medición de la presión arterial (PA) empleados en encuestas de prevalencia y ensayos clínicos de hipertensión arterial. Este taller es parte de la Iniciativa Panamericana sobre la Hipertensión Arterial (1). El objetivo de la reunión de trabajo fue elaborar un protocolo para la medición de la PA que pueda utilizarse en estudios sobre la prevalencia de la hipertensión arterial en las Américas. No ha habido nunca ningún protocolo común de este tipo en la Región, de tal manera que ha resultado difícil comparar las distintas estrategias de intervención y prevención de la hipertensión cuando las mediciones de la PA han sido obtenidas mediante diferentes procedimientos. Por ejemplo, algunos estudios sobre la prevalencia de PA definen la hipertensión a partir de 160/95 mm Hg, mientras que otros utilizan 140/90 mm Hg. Los estudios en general definen la presión diastólica como el quinto ruido de Korotkov (K5) escuchado, pero en algunos estudios se especifica que el criterio es la desaparición del ruido, mientras que en otros el criterio es el inicio del silencio, que es 2 mm Hg por debajo de K5. Además, los estudios difieren en cuanto al número de mediciones de la PA realizadas, el instrumental empleado, los métodos de entrenamiento y los procedimientos de verificación.

[1] Pan Americana Hypertension Initiative, Executive Secretariat, c/o Edward J. Roccella, National High Blood Pressure Education Program, National Heart, Lung, and Blood Institute, 31 Center Drive MSC 2480, Bethesda, Maryland 20892-2480, United States of America. Correo electrónico: roccella@nih.gov.

CONSIDERACIONES EN TORNO A LA ELABORACIÓN DE UN PROTOCOLO COMÚN PARA MEDIR LA PRESIÓN ARTERIAL

Las diferencias en la definición de la PA y en los criterios de medición pueden generar diferencias sustanciales en la prevalencia de la hipertensión arterial. Por lo tanto, los datos no pueden ser comparados ni combinados, y debido a ello se pierden las ventajas de examinar poblaciones con muestras muy grandes. Además, esto impide que los cambios o las mejorías en las tasas de control de la hipertensión o en los valores medios de PA se cuantifiquen a lo largo del tiempo. Por lo tanto, los programas y actividades de intervención comunitarios no se pueden evaluar. Por añadidura, es importante enseñarle al personal técnico a calibrar adecuadamente los equipos, a usar un manguito del tamaño adecuado y a evitar la preferencia de determinados valores durante la medición.

ASPECTOS CRÍTICOS ACERCA DE LA MEDICIÓN DE LA PRESIÓN ARTERIAL EN ESTUDIOS NACIONALES

Debido a que la PA puede variar en una misma persona en un lapso breve, es necesario medirla varias veces por lo menos en una ocasión. La PA debe medirse tres veces en una sesión, preferiblemente antes de un interrogatorio minucioso o un procedimiento, como la extracción de sangre, que también podrían ser parte de la encuesta.

Se debe emplear un esfigmomanómetro de mercurio estándar o un dispositivo automático certificado para medir la PA. Los esfigmomanómetros de mercurio han sido los dispositivos más usados para medir la PA, a pesar de que los están retirando de Europa y los Estados Unidos de América debido a inquietudes de tipo ambiental relacionadas con la posibilidad de que de un instrumento roto se derrame mercurio y haya que limpiarlo, cosa que es sumamente cara (2). Los dispositivos automáticos podrían llegar a usarse más en los estudios de vigilancia de la presión arterial y son los que se utilizan en la actualidad. Sin embargo, deben ser calibrados contra un estándar de mercurio o un medidor digital de presión validado, y deben satisfacer los estándares de la Sociedad Británica para el Estudio de la Hipertensión (3) o los de la Asociación para el Avance de la Instrumentación Médica (4). Los dispositivos diseñados para medir la PA en los dedos o en la muñeca son inadecuados para los estudios de vigilancia. Los esfigmomanómetros aneroides son menos confiables, pero, cuando se usan, tienen que calibrarse con frecuencia (5).

Los técnicos deben ser entrenados, certificados al inicio y certificados nuevamente con periodicidad en lo que respecta a los procedimientos para medir la PA y cuidar del instrumental. Debe haber disponibilidad de manguitos de diferentes tamaños, hasta cuatro en algunos casos. Si hace falta un estetoscopio, debe utilizarse un modelo con campana. Se debe aplicar un breve cuestionario para determinar si los participantes del estudio han recibido anteriormente un diagnóstico de hipertensión y si toman medicamentos antihipertensivos en el momento de la investigación. Para garantizar que las mediciones sigan teniendo la misma calidad, los técnicos deben ser evaluados con regularidad por supervisores y la calidad de su trabajo debe ser avalada periódicamente mediante tablas estadísticas para detectar sesgos en las mediciones. Puede ser necesario volver a entrenar al personal técnico para que no pierda las habilidades adquiridas.

PROCEDIMIENTOS MÍNIMOS PARA LA MEDICIÓN DE LA PRESIÓN ARTERIAL DURANTE LA VIGILANCIA

Los procedimientos para lograr una medición exacta de la PA son los siguientes:

1. El participante debe sentarse a una mesa sosegadamente, con ambos pies apoyados totalmente sobre el suelo y con la espalda contra un respaldo. La vejiga debe estar vacía. La habitación debe ser cómoda y poco ruidosa. No se deben haber consumido bebidas alcohólicas ni productos a base de tabaco ni cafeína durante los 30 minutos previos a la medición. Si esto no es posible, debe constar entre los datos anotados.
2. El brazo derecho, que debe estar desnudo, se coloca sobre la mesa (al nivel del corazón) ligeramente flexionado, con la palma de la mano hacia arriba. El investigador debe estar en una posición que le permita ver el manómetro a la altura de sus ojos.
3. Determine la circunferencia del brazo y escoja y coloque un manguito de tamaño adecuado. El borde inferior del manguito debe estar 2,5 cm por encima de la articulación del codo.
4. Espere 5 minutos.
5. Palpe el pulso radial e infle el manguito hasta llegar a 30 mm Hg por encima del nivel en el que desaparece el pulso radial (nivel de máxima inflación). Desinfle el manguito.
6. Espere 30 segundos antes de volver a inflar el manguito.
7. Infle el manguito hasta llegar al nivel de máxima inflación.
8. Desinfle el manguito a 2 mm Hg por segundo.
9. Registre la PA sistólica, la fase 1 de Korotkov (el primero de por lo menos dos ruidos regulares consecutivos). Anote el número par más cercano.
10. Registrar la PA diastólica, la fase 5 de Korotkov (el final del último ruido escuchado). Anote el número par más cercano.
11. Termine de desinflar el manguito, levante el brazo del participante por encima del nivel del corazón durante 15 segundos. Descanse un minuto y proceda a realizar la medición dos veces más. Utilice el valor medio de las últimas dos mediciones.

Cuando se utilizan dispositivos automáticos, es necesario observar los puntos 1, 2, 3, 4 y 11. El punto 5 depende de si el dispositivo automático mide la presión durante el inflado del manguito. Los otros puntos no son aplicables a estos dispositivos. Todos los puntos son aplicables cuando se utiliza un dispositivo manual de auscultación.

EVALUACIÓN DE LA CALIDAD DE LA PRESIÓN ARTERIAL

Antes de llevar a cabo un estudio se deben tener en cuanta los siguientes aspectos. El problema de los dígitos preferidos se asocia por lo general con los dispositivos manuales, aunque también se ha demostrado con el uso de dispositivos automáticos.

Los análisis de control de la calidad pueden identificar a los técnicos y procedimientos que necesitan medir mejor la presión. Como el desinflado del manguito se hace a 2 mm Hg por segundo y las lecturas se redondean al número par más cercano, se debe determinar si los dígitos pares son siempre uniformes. Esto se hace contando el número de mediciones observadas que terminan en cada uno de los dígitos pares y calculando un estadístico mediante la prueba de la ji al cuadrado, así como un puntaje que refleje la preferencia por cada dígito. Como se realizan como mínimo dos mediciones de PA, los técnicos que muestren diferencias extremas en estas dos mediciones o cuyas mediciones sean idénticas con más frecuencia de la esperada deben recibir un entrenamiento adicional. Puede que los técnicos no completen todas las mediciones de PA (esto puede verse en una tabla de datos incompletos), pero si esto se ve con más frecuencia en unos que en otros, entonces se necesita un mayor entrenamiento. Se deben calcular los valores promedio de PA en fechas secuenciales para determinar si hay desplazamientos (cambios repentinos) o deriva (cambios graduales) en los valores promedio a lo largo del tiempo. Esto presupone que los participantes se asemejan los unos a los otros mientras dura el estudio. Estos análisis del control de la calidad se describen detalladamente en un informe de la Organización Mundial de la Salud (6).

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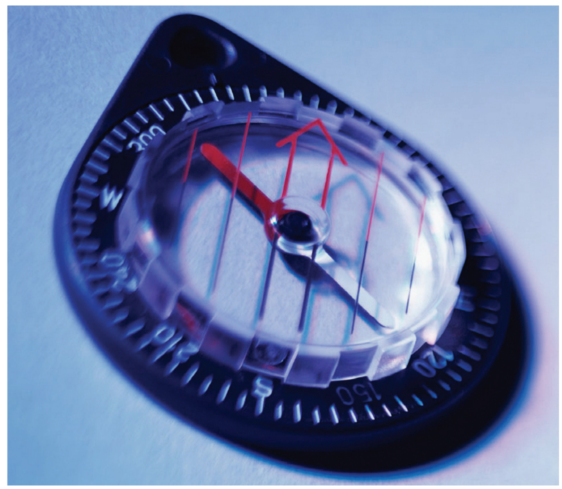
Sensor
Device Data



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Device Data

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Table of Contents

Section Four - Safety and Alarm Integrated Circuits Products

Section Five - Electric Field Sensor Products

Section One

Introduction

This version of the Sensor Products Device Data Handbook is organized to provide easy reference to sensor device information. We have organized the book based upon your recommendations with our goal to make designing in pressure, acceleration, safety and alarm ICs, and electric field sensing easy. If you do have a question, you will have access to the technical support you need.

The handbook is organized by product line, acceleration, pressure, safety and alarm ICs and electric field sensing. Once in a section, you will find a glossary of terms, a list of frequently asked questions, or other relevant data. If you have recommendations for improvement, please email us at support@freescale.com, as there will not be a comment card, especially electronically, and the hot line number is no longer valid.

General Information

NOTES

Quality and Reliability

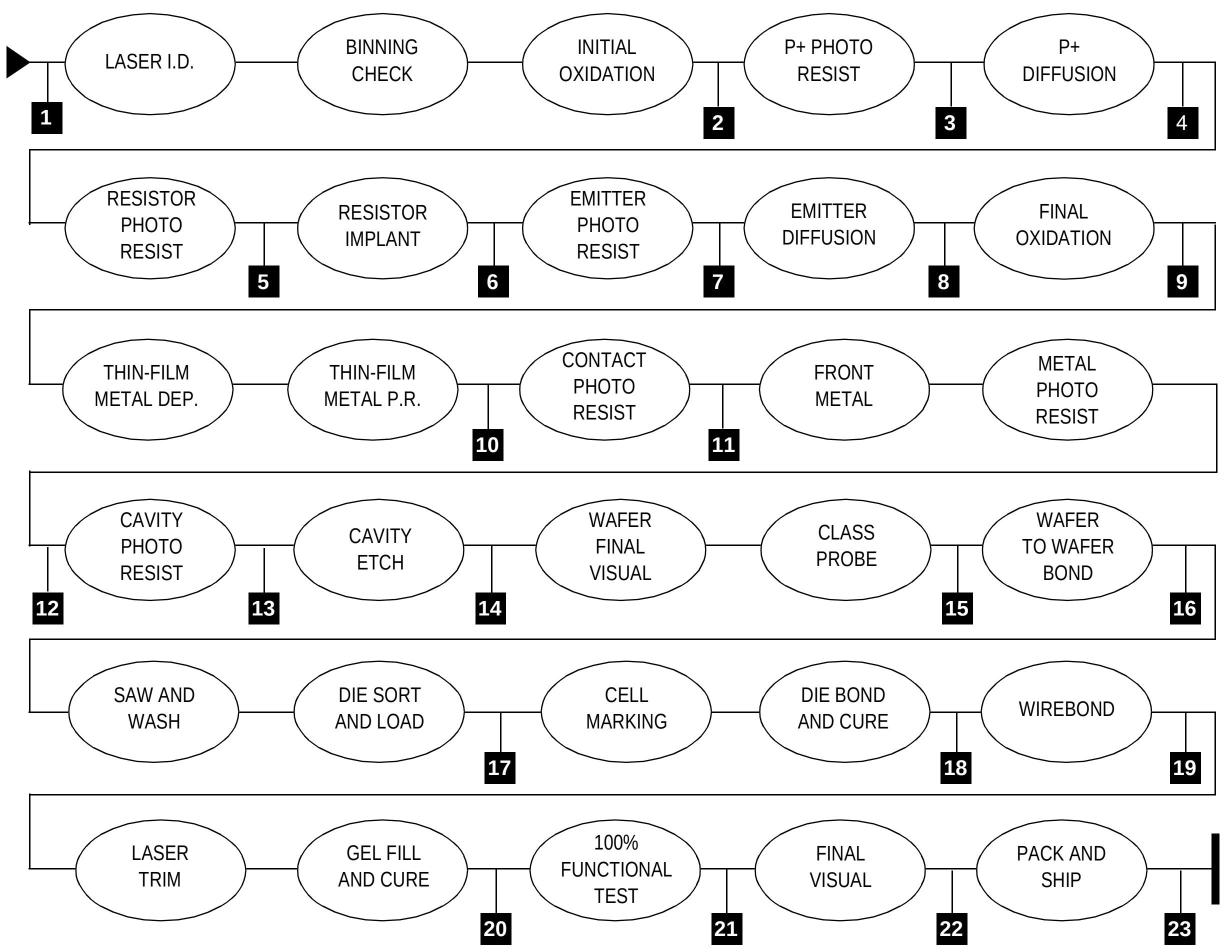
OVERVIEW

A Major Objective of the Production Cycle

From rigid incoming inspection of piece parts and materials, to stringent outgoing quality verification, the Freescale Semiconductor assembly and process flow is encompassed by an elaborate system of test and inspection stations; stations to ensure a step-by-step adherence to prescribed procedure. This produces the high level of quality for which Freescale Semiconductor is known from start to finish.

As illustrated in the process flow overview, every major manufacturing step is followed by an appropriate in-process quality inspection to insure product conformance to specification. In addition, Statistical Process Control (S.P.C.) techniques are utilized on all critical processes to insure processing equipment is capable of producing the product to the target specification while minimizing the variability. Quality control in wafer processing, assembly, and final test impart Freescale Semiconductor sensor products with a level of reliability that easily exceeds almost all industrial, consumer, and military requirements.

Compensated Sensor Flow Chart



RELIABILITY ISSUES FOR SILICON PRESSURE SENSORS

by: **Theresa Maudie and Bob Tucker**
Sensor Products Division
Revised June 9, 1997

ABSTRACT

Reliability testing for silicon pressure sensors is of greater importance than ever before with the dramatic increase in sensor usage. This growth is seen in applications replacing mechanical systems, as well as new designs. Across all market segments, the expectation for the highest reliability exists. While sensor demand has grown across all of these segments, the substantial increase of sensing applications in the automotive arena is driving the need for improved reliability and test capability. The purpose of this paper is to take a closer look at these reliability issues for silicon pressure sensors.

INTRODUCTION

Discussing reliability as it pertains to semiconductor electronics is certainly not a new subject. However, when developing new technologies like sensors how reliability testing will be performed is not always obvious. Pressure sensors are an intriguing dilemma. Since they are electromechanical devices, different types of stresses should be considered to insure the different elements are exercised as they would be in an actual application. In addition, the very different package outlines relative to other standard semiconductor packages require special fixtures and test set-ups. However, as the sensor marketplace continues to grow, reliability testing becomes more important than ever to insure that products being used across all market segments will meet reliability lifetime expectations.

RELIABILITY DEFINITION

Reliability is [1] the probability of a product performing its intended function over its intended lifetime and under the operating conditions encountered. The four key elements of the definition are probability, performance, lifetime, and operating conditions. Probability implies that the reliability lifetime estimates will be made based on statistical techniques where samples are tested to predict the lifetime of the manufactured products. Performance is a key in that the sample predicts the performance of the product at a given point in time but the variability in manufacturing must be controlled so that all devices perform to the same functional level. Lifetime is the period of time over which the product is intended to perform. This lifetime could be as small as one week in the case of a disposable blood pressure transducer or as long as 15 years for automotive applications. Environment is the area that also plays a key role since the operating conditions of the product can greatly influence the reliability of the product.

Environmental factors that can be seen during the lifetime of any semiconductor product include temperature, humidity, electric field, magnetic field, current density, pressure differential, vibration, and/or a chemical interaction. Reliability testing is generally formulated to take into account all of these potential factors either individually or in multiple combinations. Once the testing has been completed predictions can be made for the intended product customer base.

If a failure would be detected during reliability testing, the cause of the failure can be categorized into one of the following: design, manufacturing, materials, or user. The possible impact on the improvements that may need to be made for a product is influenced by the stage of product development. If a product undergoes reliability testing early in its development phase, the corrective action process can generally occur in an expedient manner and at minimum cost. This would be true whether the cause of failure was attributed to the design, manufacturing, or materials. If a reliability failure is detected once the product is in full production, changes can be very difficult to make and generally are very costly. This scenario would sometimes result in a total redesign.

The potential cause for a reliability failure can also be user induced. This is generally the area that the least information is known, especially for a commodity type manufacturer that achieves sales through a global distribution network. It is the task of the reliability engineer to best anticipate the multitudes of environments that a particular product might see, and determine the robustness of the product by measuring the reliability lifetime parameters. The areas of design, manufacturing, and materials are generally well understood by the reliability engineer, but without the correct environmental usage, customer satisfaction can suffer from lack of optimization.

RELIABILITY STATISTICS

Without standardization of the semiconductor sensor standards, the end customer is placed in a situation of possible jeopardy. If non-standard reliability data is generated and published by manufacturers, the information can be perplexing to disseminate and compare. Reliability lifetime statistics can be confusing for the novice user of the information, “let the buyer beware.”

The reporting of reliability statistics is generally in terms of failure rate, measured in FITs, or failure rate for one billion device hours. In most cases, the underlying assumption used in reporting either the failure rate or the MTBF is that the failures occurring during the reliability test follow an exponential life distribution. The inverse of the failure rate is the MTBF, or mean time between failure. The details on the various life distributions will not be explored here but the key concern about the exponential distribution is that the failure rate over time is constant. Other life distributions, such as the lognormal or Weibull can take on different failure rates over time, in particular, both distributions can represent a wear out or increasing failure rate that might be seen on a product reaching the limitations on its lifetime or for certain types of failure mechanisms.

The time duration use for the prediction of most reliability statistics is of relatively short duration with respect to the product's lifetime ability and failures are usually not observed. When a test is terminated after a set number of hours is achieved, or time censored, and no failures are observed, the failure rate can be estimated by use of the chi-square distribution which relates observed and expected frequencies of an event to established confidence intervals. The relationship between failure rate and the chi-square distribution is as follows:

$$\lambda_{L1} = \frac{\chi^2 (\alpha, d.f.)}{2t}$$

Where:

λ = failure rate
L1 = lower one side confidence limit
χ^2 = chi-square function
α = risk, (1-confidence level)
d.f. = degrees of freedom = 2 (r + 1)
r = number of failures
t = device hours

Chi-square values for 60% and 90% confidence intervals for up to 12 failures is shown in Table 1.

As indicated by the table, when no failures occur, an estimate for the chi-square distribution interval is obtainable. This interval estimate can then be used to solve for the failure rate, as shown in the equation above. If no failures occur, the failure rate estimate is solely a function of the accumulated device hours. This estimate can vary dramatically as additional device hours are accumulated.

As a means of showing the influence of device hours with no failures on the failure rate value, a graphical representation of cumulative device hours versus the failure rate measured in FITs is shown in Figure 1.

A descriptive example between two potential vendors best serves to demonstrate the point. If vendor A is introducing a new product and they have put a total of 1,000 parts on a high temperature storage test for 500 hours each, their corresponding cumulative device hours would be 500,000 device hours. Vendor B has been in the business for several years on the same product and has tested a total of 500,000 parts for 10 hours each to the same conditions as part of an in-line burn-in test for a total of 5,000,000 device hours. The corresponding failure rate for a 60% confidence level for vendor A would be 1,833 FITs, vendor B would have a FIT rate of 183 FITs.

Table 1. Chi-Square Table

Chi-Square Distribution Function			
60% Confidence Level		90% Confidence Level	
No. Fails	χ^2 Quantity	No. Fails	χ^2 Quantity
0	1.833	0	4.605
1	4.045	1	7.779
2	6.211	2	10.645
3	8.351	3	13.362
4	10.473	4	15.987
5	12.584	5	18.549
6	14.685	6	21.064
7	16.780	7	23.542
8	18.868	8	25.989
9	20.951	9	28.412
10	23.031	10	30.813
11	25.106	11	33.196
12	27.179	12	35.563

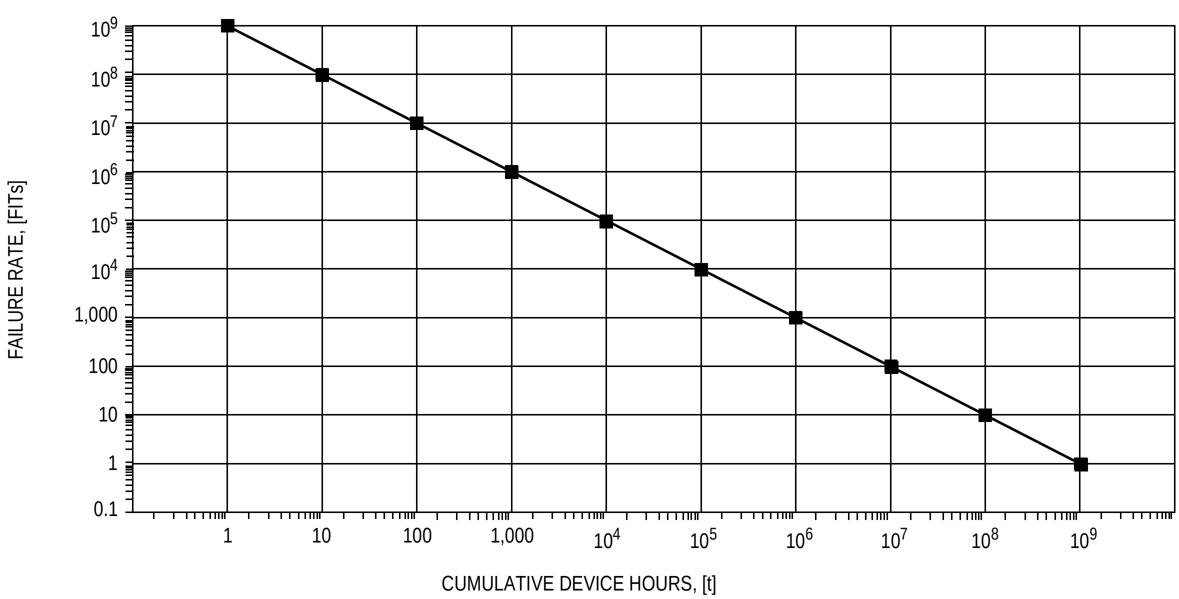


Figure 1. Depiction of the influence on the cumulative device hours with no failures and the Failure Rate as measured in FITs.

One could thus imply that the reliability performance indicates that vendor B has an order of magnitude improvement in performance over vendor A with neither one seeing an occurrence of failure during their performance.

The incorrect assumption of a constant failure rate over time can potentially result in a less reliable device being designed into an application. The reliability testing assumptions and test methodology between the various vendors needs to be critiqued to insure a full understanding of the product performance over the intended lifetime, especially in the case of a new product. Testing to failure and determination of the lifetime statistics is beyond the scope of this paper and presented elsewhere [2].

INDUSTRY RELIABILITY STANDARDS

Reliability standards for large market segments are often developed by “cross-corporation” committees that evaluate the requirements for the particular application of interest. It is the role of these committees to generate documents intended as guides for technical personnel of the end users and suppliers, to assist with the following functions: specifying, developing, demonstrating, calibrating, and testing the performance characteristics for the specific application.

One such committee which has developed a standard for a particular application is the Blood Pressure Monitoring Committee of the Association for the Advancement of Medical Instrumentation (AAMI) [3]. Their document, the “American National Standard for Interchangeability and Performance of Resistive Bridge Type Blood Pressure Transducers”, has an objective to provide performance requirements, test methodology, and terminology that will help insure that safe, accurate blood pressure transducers are supplied to the marketplace.

In the automotive arena, the Society of Automotive Engineers (SAE) develops standards for various pressure sensor applications such as SAE document J1346, “Guide to Manifold Absolute Pressure Transducer Representative Test Method” [4].

While these two very distinct groups have successfully developed the requirements for their solid-state silicon pressure sensor needs, no real standard has been set for the general industrial marketplace to insure products being offered have been tested to insure reliability under industrial conditions. Freescale Semiconductor has utilized MIL-STD-750 as a reference document in establishing reliability testing practices for the silicon pressure sensor, but the differences in the technology between a discrete semiconductor and a silicon pressure sensor varies dramatically. The additional tests that are utilized in semiconductor sensor reliability testing are based on the worst case operational conditions that the device might encounter in actual usage.

ESTABLISHED SENSOR TESTING

Freescale Semiconductor has established semiconductor sensor reliability testing based on exercising to detect failures by the presence of the environmental stress. Potential failure modes and causes are developed by allowing tests to run beyond the normal test times, thus stressing to destruction.

The typical reliability test matrix used to insure conformance to customers end usage is as follows [5]:

Pulsed Pressure Temperature Cycling with Bias (PPTCB)

This test is an environmental stress test combined with cyclic pressure loading in which the devices are alternately subjected to a low and high temperature while operating under bias under a cyclical pressure load. This test simulates the extremes in the operational life of a pressure sensor. PPTCB evaluates the sensor's overall performance as well as evaluating the die, die bond, wire bond and package integrity.

Typical Test Conditions: Temperature per specified operating limits (i.e., Ta = -40 to 125°C for an automotive application). Dwell time ≥ 15 minutes, transfer time ≤ 5 minutes, bias = 100% rated voltage. Pressure = 0 to full scale, pressure frequency = 0.05 Hz, test time = up to 1000 hours.

Potential Failure Modes: Open, short, parametric shift.

Potential Failure Mechanisms: Die defects, wire bond fatigue, die bond fatigue, port adhesive failure, volumetric gel changes resulting in excessive package stress. Mechanical creep of packaging material.

High Humidity, High Temperature with Bias (H^3TB)

A combined environmental/electrical stress test in which devices are subjected to an elevated ambient temperature and humidity while under bias. The test is useful for evaluating package integrity as well as detecting surface contamination and processing flaws.

Typical Test Conditions: Temperature between 60 and 85°C, relative humidity between 85 and 90%, rated voltage, test time = up to 1000 hours.

Potential Failure Modes: Open, short, parametric shift.

Potential Failure Mechanisms: Shift from ionic affect, parametric instability, moisture ingress resulting in excessive package stress, corrosion.

High Temperature with Bias (HTB)

This operational test exposes the pressure sensor to a high temperature ambient environment in which the device is biased to the rated voltage. The test is useful for evaluating the integrity of the interfaces on the die and thin film stability.

Typical Test Conditions: Temperature per specified operational maximum, bias = 100% rated voltage, test time = up to 1000 hours.

Potential Failure Modes: Parametric shift in offset and/or sensitivity.

Potential Failure Mechanisms: Bulk die or diffusion defects, film stability and ionic contamination.

High and Low Temperature Storage Life (HTSL, LTSL)

High and low temperature storage life testing is performed to simulate the potential shipping and storage conditions that the pressure sensor might encounter in actual usage. The test also evaluates the devices thermal integrity at worst case temperatures.

Typical Test Conditions: Temperature per specified storage maximum and minimum, no bias, test time = up to 1000 hours.

Potential Failure Modes: Parametric shift in offset and/or sensitivity.

Potential Failure Mechanisms: Bulk die or diffusion defects, mechanical creep in packaging components due to thermal mismatch.

Temperature Cycling (TC)

This is an environmental test in which the pressure sensor is alternatively subjected to hot and cold temperature extremes with a short stabilization time at each temperature in an air medium. The test will stress the devices by generating thermal mismatches between materials.

Typical Test Conditions: Temperature per specified storage maximum and minimum (i.e., -40 to +125°C for automotive applications). Dwell time ≥ 15 minutes, transfer time ≤ 5 minutes, no bias. Test time up to 1000 cycles.

Potential Failure Modes: Open, parametric shift in offset and/or sensitivity.

Potential Failure Mechanisms: Wire bond fatigue, die bond fatigue, port adhesive failure, volumetric gel changes resulting in excessive package stress. Mechanical creep of packaging material.

Mechanical Shock

This is an environmental test where the sensor device is evaluated to determine its ability to withstand a sudden change in mechanical stress due to an abrupt change in motion. This test simulates motion that may be seen in handling, shipping or actual use. MIL STD 750, Method 2016 Reference.

Typical Test Conditions: Acceleration = 1500 g's, orientation = X, Y, Z planes, time = 0.5 milliseconds, 5 blows.

Potential Failure Modes: Open, parametric shift in offset and/or sensitivity.

Potential Failure Mechanisms: Diaphragm fracture, mechanical failure of wire bonds or package.

Variable Frequency Vibration

A test to examine the ability of the pressure sensor device to withstand deterioration due to mechanical resonance. MIL STD 750, Method 2056 Reference.

Typical Test Conditions: Frequency - 10 Hz to 2 kHz, 6.0 G's max, orientation = X, Y, Z planes, 8 cycles each axis, 2 hrs. per cycle.

Potential Failure Modes: Open, parametric shift in offset and/or sensitivity.

Potential Failure Mechanisms: Diaphragm fracture, mechanical failure of wire bonds or package.

Solderability

In this reliability test, the lead/terminals are evaluated for their ability to solder after an extended time period of storage (shelf life). MIL STD 750, Method 2026 Reference.

Typical Test Conditions: Steam aging = 8 hours, Flux= R, Solder = Sn63, Pb37.

Potential Failure Modes: Pin holes, non-wetting, dewetting.

Potential Failure Mechanisms: Poor plating, contamination.

Over Pressure

This test is performed to measure the ability of the pressure sensor to withstand excessive pressures that may be encountered in the application. The test is performed from either the front or back side depending on the application.

Typical Test Conditions: Pressure increase to failure, record value.

Potential Failure Modes: Open.

Potential Failure Mechanisms: Diaphragm fracture, adhesive or cohesive failure of die attach.

A pressure sensor may be placed in an application where it will be exposed to various media that may chemically attack the active circuitry, silicon, interconnections and/or packaging material. The focus of media compatibility is to understand the chemical impact with the other environmental factors such as temperature and bias and determine the impact on the device lifetime. The primary driving mechanism to consider is permeation which quantifies the time for a chemical to permeate across a membrane or encapsulant corrosion can result.

Media related product testing is generally very specific to the application since the factors that relate to the product lifetime are very numerous and varied. An example is solution pH where the further from neutral will drive the chemical reaction, generally to a power rule relationship. The pH alone does not always drive the reaction either, the non-desired products in the media such as strong acids in fuels as a result of acid rain can directly influence the lifetime. It is recommended the customer and/or vendor perform application specific testing that best represents the environment. This testing should be performed utilizing *in situ* monitoring of the critical device parameter to insure the device survives while exposed to the chemical. The Sensor Products Division within Freescale Semiconductor has a wide range of media specific test capabilities and under certain circumstances will perform application specific media testing.

A sufficient sample size manufactured over a pre-defined time interval to maximize process and time variability is tested based on the guidelines of the matrix shown above. This test methodology is employed on all new product introductions and process changes on current products.

A silicon pressure sensor has a typical usage environment of pressure, temperature, and voltage. Unlike the typical bipolar transistor life tests which incorporate current density and temperature to accelerate failures, a silicon pressure sensor's acceleration of its lifetime performance is primarily based on the pressure and temperature interaction with a presence of bias. This rationale was incorporated into the development of the Pulsed Pressure Temperature Cycling with Bias (PPTCB) test where the major acceleration factor is the pressure and temperature component. It is also why PPTCB is considered the standard sensor operational life test.

To insure that silicon pressure sensors are designed and manufactured for reliability, an in-depth insight into what mechanisms cause particular failures is required. It is safe to say that unless a manufacturer has a clear understanding of everything that can go wrong with the device, it cannot design a device for the highest reliability. Figure 2 provides a look into the sensor operating concerns for a variety of potential usage applications. This information is utilized when developing the Failure Mode and Effects Analysis (FMEA). The FMEA then serves as the documentation that demonstrates all design and process concerns have been addressed to offer the most reliable approach. By understanding how to design products, control processes, and eliminate the concerns raised, a reliable product is achieved.

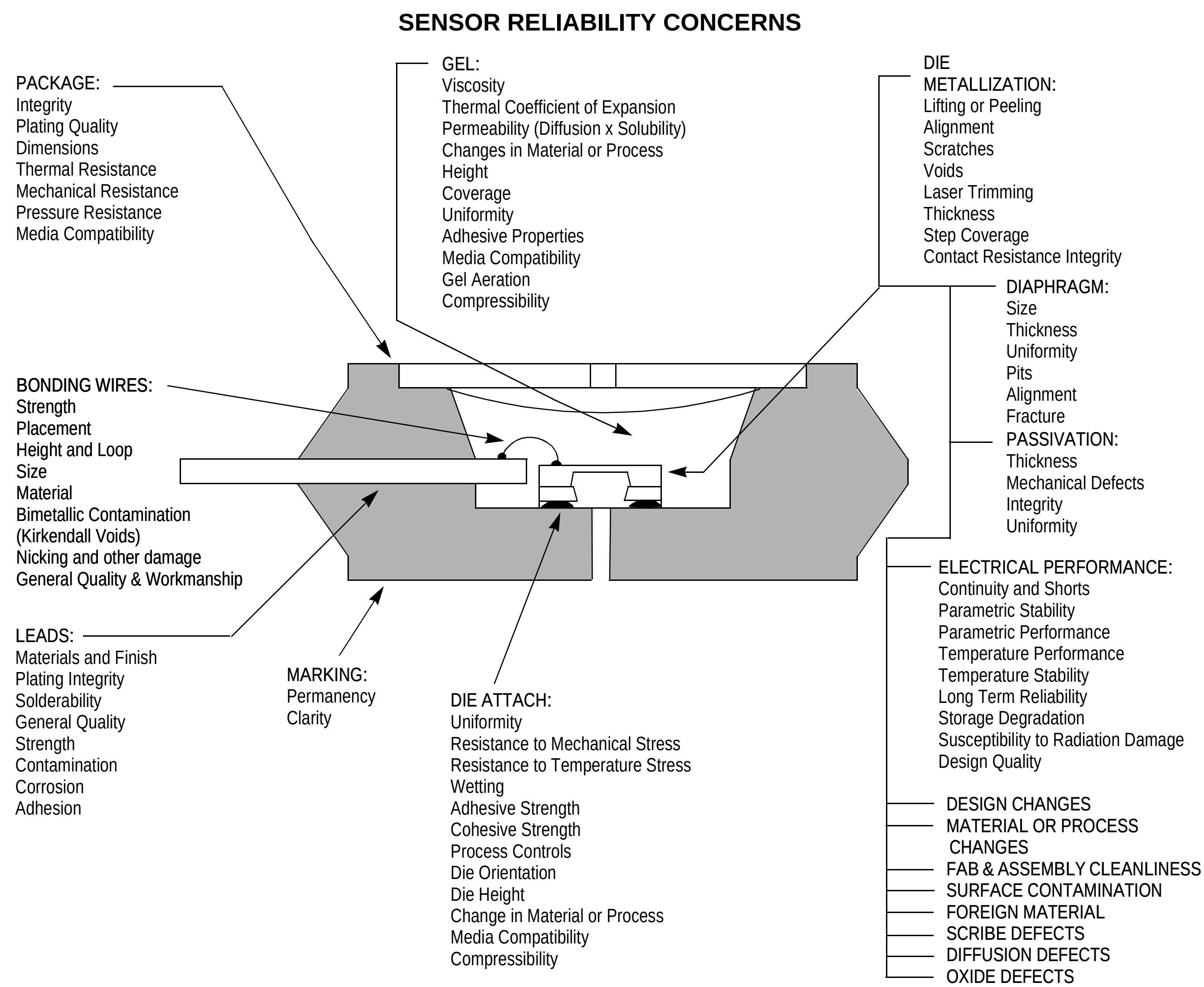


Figure 2. Process and Product Variability Concerns During Reliability Testing

ACCELERATED LIFE TESTING

It is very difficult to assess the reliability statistics for a product when very few or no failures occur. With cost as a predominant factor in any industrial setting and time of the utmost importance, the reliability test must be optimized. Optimization of reliability testing will allow the maximum amount of information on the product being tested to be gained in a minimum amount of time, this is accomplished by using accelerated life testing techniques.

A key underlying assumption in the usage of accelerated life testing to estimate the life of a product at a lower or nominal stress is that the failure mechanism encountered at the high stress is the same as that encountered at the nominal stress. The most frequently applied accelerated environmental stress for semiconductors is temperature, it will be briefly explained here for its utilization in determining the lifetime reliability statistics for silicon pressure sensors.

The temperature acceleration factor for a particular failure mechanism can be related by taking the ratio for the reaction rate of the two different stress levels as expressed by the Arrhenius type of equation. The mathematical derivation of the first order chemical reaction rate computes to:

$$AF = \frac{(R_T)_{HS}}{(R_T)_{LS}} = \frac{t_{HS}}{t_{LS}}$$

$$AF = \exp\left[\frac{Ea}{k}\left(\frac{1}{T_{LS}} - \frac{1}{T_{HS}}\right)\right]$$

Where:

AF = Acceleration Factor
R_T = Reaction Rate
t = time
T = temperature [°K]
Ea = activation energy of expressed in electron-volts [eV]
k = Boltzman's constant, 8.6171 x 10^{-5} eV/°K
LS = Low stress or nominal temperature
HS = High stress or test temperature

The activation energy is dependent on the failure mechanism and typically varies from 0.3 to 1.8 electron-volts. The activation energy is directly proportional to the degree of influence that temperature has on the chemical reaction rate. A listing of typical activation energies is included in reference [6] and [7].

An example using the Arrenhius equation will be demonstrated. A 32 device HTB test for 500 hours total and no failure was performed. The 125°C, 100% rated voltage test resulted in no failures. If a customer's actual usage conditions was 55°C at full rated voltage, an estimate of the lower one side confidence limit can be calculated. An assumption is made that the failure rate is constant thus implying the exponential distribution. The first step is to calculate the equivalent device hours for the customer's use conditions by solving for the acceleration factor.

From the acceleration factor above, if eA is assumed equal to 1,

$$AF = \exp\left[\frac{Ea}{k}\left(\frac{1}{T_{LS}} - \frac{1}{T_{HS}}\right)\right]$$

Where:

eA = 0.7 eV/°K (assumed)
T_{LS} = 55°C + 273.16 = 328.16°K
T_{HS} = 125°C + 273.16 = 398.16°K

then;

AF = 77.64

Therefore, the equivalent cumulative device hours at the customer's use condition is:

T_{LS} = AF x T_{HS} = (32 · 500) · 77.64

or

T_{LS} = 1,242,172 device hours

Computing the lower one sided failure rate with a 90% confidence level and no failures:

$$\lambda = \frac{\chi^2 (\alpha, d.f.)}{2t}$$

or

λ = 1.853E-06 failures per hour

or

λ = 1,853 FITs

The inverse of the failure, λ, or the Mean Time To Failure (MTTF) is:

$$MTTF = \frac{1}{\lambda}$$

or

MTTF = 540,000 device hours

CONCLUSION

Reliability testing durations and acceptance numbers are used as a baseline for achieving adequate performance in the actual use condition that the silicon pressure sensor might encounter. The baseline for reliability testing can be related to the current record high jump bar height. Just as athletes in time achieve a higher level of performance by improvements in their level of physical and mental fitness, silicon pressure sensors must also incorporate improvements in the design, materials, and manufacturability to achieve the reliability growth demands the future market place will require. This philosophy of never ending improvement will promote consistent conformance to the customer's expectation and production of a best in class product.

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[6] Wayne Nelson, “Accelerated Testing: Statistical Models,” *Test Plans, and Data Analyses,* John Wiley & Sons, Inc., New York, N.Y., 1990.
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SOLDERING PRECAUTIONS

The melting temperature of solder is higher than the rated temperature of the device. When the entire device is heated to a high temperature, failure to complete soldering within a short time could result in device failure. Therefore, the following items should always be observed in order to minimize the thermal stress to which the devices are subjected.

- Always preheat the device.
- The delta temperature between the preheat and soldering should be 100°C or less.*
- For pressure sensor devices, a no-clean solder is recommended unless the silicone die coat is sealed and unexposed. Also, prolonged exposure to fumes can damage the silicone die coat of the device during the solder reflow process.
- When preheating and soldering, the temperature of the leads and the case must not exceed the maximum temperature ratings as shown on the data sheet. When using infrared heating with the reflow soldering method, the difference should be a maximum of 10°C.
- The soldering temperature and time should not exceed 260°C for more than 10 seconds.
- When shifting from preheating to soldering, the maximum temperature gradient shall be 5°C or less.
- After soldering has been completed, the device should be allowed to cool naturally for at least three minutes. Gradual cooling should be used since the use of forced cooling will increase the temperature gradient and will result in latent failure due to mechanical stress.
- Mechanical stress or shock should not be applied during cooling.

*Soldering a device without preheating can cause excessive thermal shock and stress which can result in damage to the device.

Typical Solder Heating Profile

For any given circuit board, there will be a group of control settings that will give the desired heat pattern. The operator must set temperatures for several heating zones and a figure for belt speed. Taken together, these control settings make up a heating "profile" for that particular circuit board. On machines controlled by a computer, the computer remembers these profiles from one operating session to the next. Figure 3 shows a typical heating profile for use when soldering a surface mount device to a printed circuit board. This profile will vary among soldering systems, but it is a good starting point. Factors that can affect the profile include the type of soldering system in use, density and types of components on the board, type of solder used, and the type of board or substrate material being used. This profile shows temperature versus time. The line on the graph shows the actual temperature that might be experienced on the surface of a test board at or near a central solder joint. The two profiles are based on a high density and a low density board. The Vitronics SMD310 convection/infrared reflow soldering system was used to generate this profile. The type of solder used was 62/36/2 Tin Lead Silver with a melting point between 177-189°C. When this type of furnace is used for solder reflow work, the circuit boards and solder joints tend to heat first. The components on the board are then heated by conduction. The circuit board, because it has a large surface area, absorbs the thermal energy more efficiently, then distributes this energy to the components. Because of this effect, the main body of a component may be up to 30 degrees cooler than the adjacent solder joints.

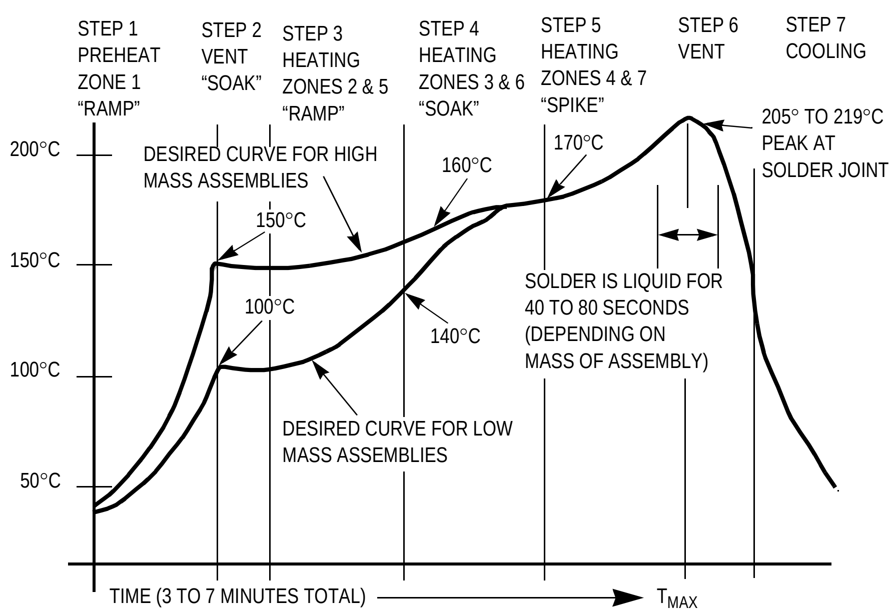


Figure 3. Typical Solder Heating Profile

ELECTROSTATIC DISCHARGE DATA

Electrostatic damage (ESD) to semiconductor devices has plagued the industry for years. Special packaging and handling techniques have been developed to protect these sensitive devices. While many of Freescale Semiconductor's semiconductors devices are not susceptible to ESD, all products are revered as sensitive and handled accordingly.

The data in this section was developed using the human-body model specified in MIL-STD-750C, Method 1020. The threshold values (Eth, kV) of ten devices was recorded, then the average value calculated. This data plus the device type, device source, package type, classification, polarity and general device description are supplied. Devices listed are mainly JEDEC registered 1N and 2N numbers. Military QPL devices and some customer specials are also in this database. The data in this report will be updated regularly, and the range will be added as new data becomes available.

The sensitivity classifications listed are as follows:

Class 1 . . . 1 to 1999 volts

Class 2 . . . 2000 to 3999 volts

Class 3 . . . 4000 to > 15500 volts

The code “N/S” signifies a non-sensitive device. “SEN” are considered sensitive and should be handled according to ESD procedures. Of the various products manufactured by the Communications, Power and Signal Technologies Group, the following examples list general device families by not sensitive to extremely sensitive.

Not sensitive . . . . FET current regulators

Least sensitive . . . . . . Zener diodes (on a square mil/millijoule basis)

Less sensitive . . . . Bipolar transistors

More sensitive. . . . . . . Bipolar darlington transistors

Very sensitive . . . . Power TMOS® devices

Extremely sensitive . . . Hot carrier diodes and MOSFET transistors without gate protection

The data supplied herein, is listed in numerical or alphabetical order.

Device	Line	Case	Class	Product Description
MPX10D	XL0010V1	344-15	3-SEN	Uncompensated
MPX10DP	XL0010V1	344C-01	3-SEN	Uncompensated
MPX10GP	XL0010V1	344B-01	3-SEN	Uncompensated
MPX12D	XL0012V1	344-15	3-SEN	Uncompensated
MPX12DP	XL0012V1	344C-01	3-SEN	Uncompensated
MPX12GP	XL0012V1	344B-01	3-SEN	Uncompensated
MPX2010D	XL2010V5	344-15	1-SEN	Temperature Compensated/Calibrated
MPX2010DP	XL2010V5	344C-01	1-SEN	Temperature Compensated/Calibrated
MPX2010GP	XL2010V5	344B-01	1-SEN	Temperature Compensated/Calibrated
MPX2010GS	XL2010V5	344E-01	1-SEN	Temperature Compensated/Calibrated
MPX2010GSX	XL2010V5	344F-01	1-SEN	Temperature Compensated/Calibrated
MPX2300DT1	XL2300C1,01C1	423-05	1-SEN	Temperature Compensated/Calibrated
MPX4100A	XL4101S2	867-08	1-SEN	Signal-Conditioned
MPX4100AP	XL4101S2	867B-04	1-SEN	Signal-Conditioned
MPX4100AS	XL4101S2	867E-03	1-SEN	Signal-Conditioned
MPX4101A	XL4101S2	867-08	1-SEN	Signal-Conditioned
MPX4115A	XL4101S2	867-08	1-SEN	Signal-Conditioned
MPX4115AP	XL4101S2	867B-04	1-SEN	Signal-Conditioned
MPX4115AS	XL4101S2	867E-03	1-SEN	Signal-Conditioned
MPX4250A	XL4101S2	867-08	1-SEN	Signal-Conditioned
MPX4250AP	XL4101S2	867B-04	1-SEN	Signal-Conditioned
MPX5010D	XL4010S5	867-08	1-SEN	Signal-Conditioned
MPX5010DP	XL4010S5	867C-05	1-SEN	Signal-Conditioned
MPX5010GP	XL4010S5	867B-04	1-SEN	Signal-Conditioned
MPX5010GS	XL4010S5	867E-03	1-SEN	Signal-Conditioned
MPX5010GSX	XL4010S5	867F-03	1-SEN	Signal-Conditioned
MPX5050D	XL4051S1	867-08	1-SEN	Signal-Conditioned

Device	Line	Case	Class	Product Description
MPX5050DP	XL4051S1	867C-05	1-SEN	Signal-Conditioned
MPX5050GP	XL4051S1	867B-04	1-SEN	Signal-Conditioned
MPX5100D	XL4101S1	867-08	1-SEN	Signal-Conditioned
MPX5100DP	XL4101S1	867C-05	1-SEN	Signal-Conditioned
MPX5100GP	XL4101S1	867B-04	1-SEN	Signal-Conditioned
MPX5700D	XL4701S1	867-08	1-SEN	Signal-Conditioned
MPX5700DP	XL4701S1	867C-05	1-SEN	Signal-Conditioned
MPX5700GP	XL4701S1	867B-04	1-SEN	Signal-Conditioned
MPX5999D	XL4999S1	867-08	1-SEN	Signal-Conditioned

Statistical Process Control

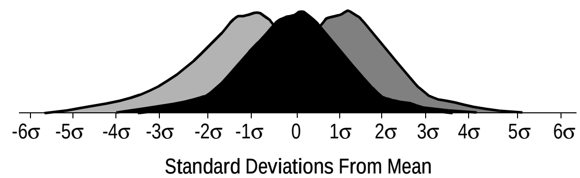
Freescale's Semiconductor Products Sector is continually pursuing new ways to improve product quality. Initial design improvement is one method that can be used to produce a superior product. Equally important to outgoing product quality is the ability to produce product that consistently conforms to specification. Process variability is the basic enemy of semiconductor manufacturing since it leads to product variability. Used in all phases of Freescale Semiconductor's product manufacturing, STATISTICAL PROCESS CONTROL (SPC) replaces variability with predictability. The traditional philosophy in the semiconductor industry has been adherence to the data sheet specification. Using SPC methods assures the product will meet specific process requirements throughout the manufacturing cycle. The emphasis is on defect prevention, not detection. Predictability through SPC methods requires the manufacturing culture to focus on constant and permanent improvements. Usually these improvements cannot be bought with state-of-the-art equipment or automated factories. With quality in design, process and material selection, coupled with manufacturing predictability, Freescale Semiconductor produces world class products.

The immediate effect of SPC manufacturing is predictability through process controls. Product centered and distributed well within the product specification benefits Freescale Semiconductor with fewer rejects, improved yields and lower cost. The direct benefit to Freescale Semiconductor's customers includes better incoming quality levels, less inspection time and ship-to-stock capability. Circuit performance is often dependent on the cumulative effect of component variability. Tightly controlled component distributions give the customer greater circuit predictability. Many customers are also converting to just-in-time (JIT) delivery programs. These programs require improvements in cycle time and yield predictability achievable only through SPC techniques. The benefit derived from SPC helps the manufacturer meet the customer's expectations of higher quality and lower cost product.

Ultimately, Freescale Semiconductor will have Six Sigma capability on all products. This means parametric distributions will be centered within the specification limits with a product distribution of plus or minus Six Sigma about mean. Six Sigma capability, shown graphically in Figure 1, details the benefit in terms of yield and outgoing quality levels. This compares a centered distribution versus a 1.5 sigma worst case distribution shift.

New product development at Freescale Semiconductor requires more robust design features that make them less sensitive to minor variations in processing. These features make the implementation of SPC much easier.

A complete commitment to SPC is present throughout Freescale Semiconductor. All managers, engineers, production operators, supervisors and maintenance personnel have received multiple training courses on SPC techniques. Manufacturing has identified 22 wafer processing and 8 assembly steps considered critical to the processing of semiconductor products. Processes, controlled by SPC methods, that have shown significant improvement are in the diffusion, photolithography and metallization areas.



Distribution Centered	Distribution Shifted ± 1.5
At ± 3σ 2700 ppm defective 99.73% yield	66810 ppm defective 93.32% yield
At ± 4σ 63 ppm defective 99.9937% yield	6210 ppm defective 99.379% yield
At ± 5σ 0.57 ppm defective 99.999943% yield	233 ppm defective 99.9767% yield
At ± 6σ 0.002 ppm defective 99.9999998% yield	3.4 ppm defective 99.99966% yield

Figure 1. AOQL and Yield from a Normal Distribution of Product With 6σ Capability

To better understand SPC principles, brief explanations have been provided. These cover process capability, implementation and use.

PROCESS CAPABILITY

One goal of SPC is to ensure a process is capable. Process capability is the measurement of a process to produce products consistently to specification requirements. The purpose of a process capability study is to separate the inherent random variability from assignable causes. Once completed, steps are taken to identify and eliminate the most significant assignable causes. Random variability is generally present in the system and does not fluctuate. Sometimes, these are considered basic limitations associated with the machinery, materials, personnel skills or manufacturing methods. Assignable cause inconsistencies relate to time variations in yield, performance or reliability.

Traditionally, assignable causes appear to be random due to the lack of close examination or analysis. Figure 2 shows the impact on predictability that assignable cause can have. Figure 3 shows the difference between process control and process capability.

A process capability study involves taking periodic samples from the process under controlled conditions. The performance characteristics of these samples are charted against time. In time, assignable causes can be identified and engineered out. Careful documentation of the process is key to accurate diagnosis and successful removal of the assignable causes. Sometimes, the assignable causes will remain unclear requiring prolonged experimentation.

Elements which measure process variation control and capability are Cp and Cpk respectively. Cp is the specification width divided by the process width or Cp = (specification width) / 6σ. Cpk is the absolute value of the closest specification value to the mean, minus the mean, divided by half the process width or Cpk = | closest specification $-\bar{X}/3\sigma$.

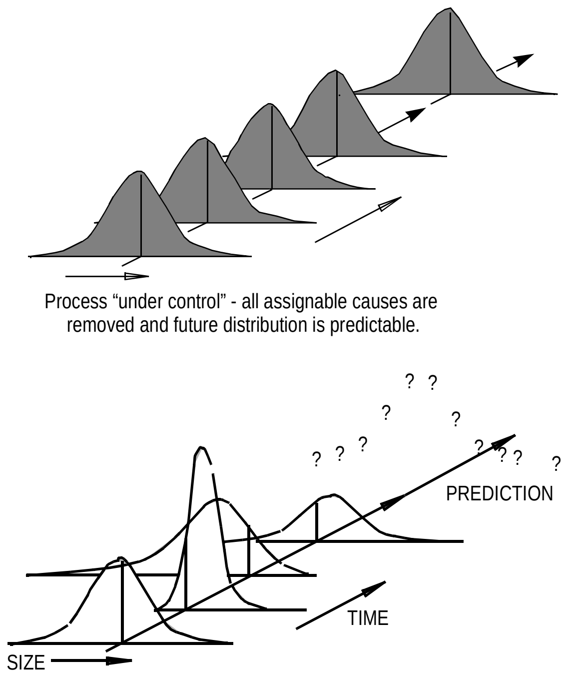


Figure 2. Impact of Assignable Causes on Process Predictable

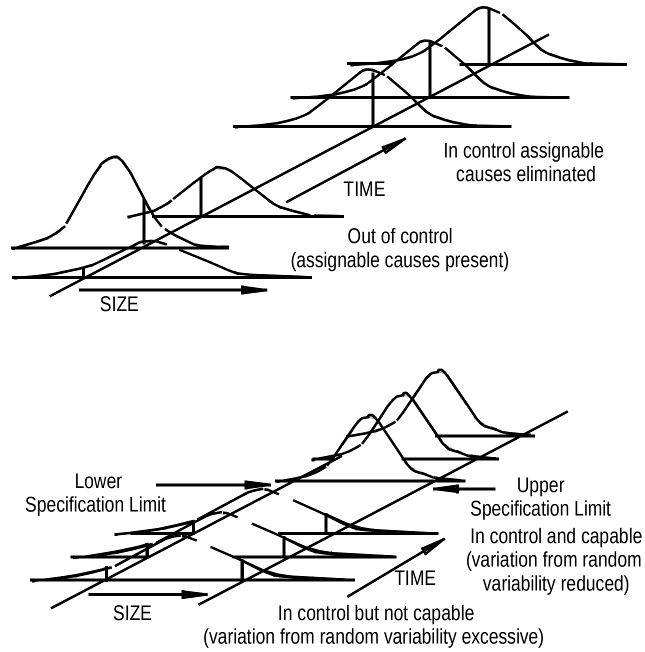


Figure 3. Difference Between Process Control and Process Capability

At Freescale Semiconductor, for critical parameters, the process capability is acceptable with a Cpk = 1.33. The desired process capability is a Cpk = 2 and the ideal is a Cpk = 5. Cpk, by definition, shows where the current production process fits with relationship to the specification limits. Off center distributions or excessive process variability will result in less than optimum conditions

SPC IMPLEMENTATION AND USE

DMTG uses many parameters that show conformance to specification. Some parameters are sensitive to process variations while others remain constant for a given product line. Often, specific parameters are influenced when changes to other parameters occur. It is both impractical and unnecessary to monitor all parameters using SPC methods. Only critical parameters that are sensitive to process variability are chosen for SPC monitoring. The process steps affecting these critical parameters must be identified also. It is equally important to find a measurement in these process steps that correlates with product performance. This is called a critical process parameter.

Once the critical process parameters are selected, a sample plan must be determined. The samples used for measurement are organized into RATIONAL SUBGROUPS of approximately 2 to 5 pieces. The subgroup size should be such that variation among the samples within the subgroup remain small. All samples must come from the same source e.g., the same mold press operator, etc. Subgroup data should be collected at appropriate time intervals to detect variations in the process. As the process begins to show improved stability, the interval may be increased. The data collected must be carefully documented and maintained for later correlation. Examples of common documentation entries would include operator, machine, time, settings, product type, etc.

Once the plan is established, data collection may begin. The data collected will generate $\bar{X}$ and R values that are plotted with respect to time. $\bar{X}$ refers to the mean of the values within a given subgroup, while R is the range or greatest value minus least value. When approximately 20 or more $\bar{X}$ and R values have been generated, the average of these values is computed as follows:

$$\bar{\bar{X}} = (\bar{X} + \bar{X}2 + \bar{X}3 + \ldots)/K$$

$$\bar{R} = (R1 + R2 + R3 + \ldots)/K$$

where K = the number of subgroups measured.

The values of $\bar{\bar{X}}$ and $\bar{R}$ are used to create the process control chart. Control charts are the primary SPC tool used to signal a problem. Shown in Figure 4, process control charts show $\bar{X}$ and R values with respect to time and concerning reference to upper and lower control limit values. Control limits are computed as follows:

R upper control limit = $UCL_R = D4\ \bar{R}$

R lower control limit = $LCL_R = D3\ \bar{R}$

$\bar{X}$ upper control limit = $UCL_{\bar{X}} = \bar{\bar{X}} + A2\ \bar{R}$

$\bar{X}$ lower control limit = $LCL_{\bar{X}} = \bar{\bar{X}} - A2\ \bar{R}$

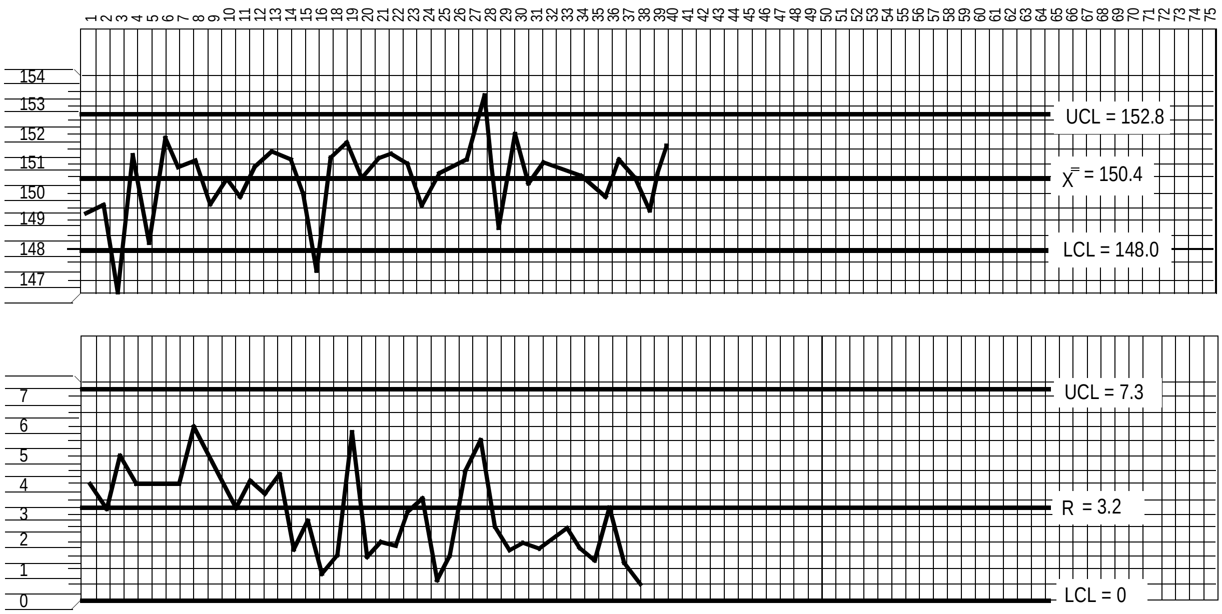


Figure 4. Example of Process Control Chart Showing Oven Temperature Data

Where D4, D3 and A2 are constants varying by sample size, with values for sample sizes from 2 to 10 shown in the following partial table:

n	2	3	4	5	6	7	8	9	10
D_4	3.27	2.57	2.28	2.11	2.00	1.92	1.86	1.82	1.78
D_3	*	*	*	*	*	0.08	0.14	0.18	0.22
A_2	1.88	1.02	0.73	0.58	0.48	0.42	0.37	0.34	0.31

* For sample sizes below 7, the LCL_R would technically be a negative number; in those cases there is no lower control limit; this means that for a subgroup size 6, six "identical" measurements would not be unreasonable.

Control charts are used to monitor the variability of critical process parameters. The R chart shows basic problems with piece to piece variability related to the process. The X chart can often identify changes in people, machines, methods, etc. The source of the variability can be difficult to find and may require experimental design techniques to identify assignable causes.

Some general rules have been established to help determine when a process is OUT-OF-CONTROL. Figure 5 shows a control chart subdivided into zones A, B, and C corresponding to 3 sigma, 2 sigma, and 1 sigma limits respectively. In Figure 6 through Figure 9, four of the tests that can be used to identify excessive variability and the presence of assignable causes are shown. As familiarity with a given process increases, more subtle tests may be employed successfully.

Once the variability is identified, the cause of the variability must be determined. Normally, only a few factors have a significant impact on the total variability of the process. The importance of correctly identifying these factors is stressed in the following example. Suppose a process variability depends on the variance of five factors A, B, C, D and E. Each has a variance of 5, 3, 2, 1 and 0.4 respectively.

Since:

$$\sigma\text{ tot} = \sqrt{\sigma A^2 + \sigma B^2 + \sigma C^2 + \sigma D^2 + \sigma E^2}$$

$$\sigma\text{ tot} = \sqrt{5^2 + 3^2 + 2^2 + 1^2 + (0.4)^2} = 6.3$$

Now if only D is identified and eliminated then;

$$\sigma\text{ tot} = \sqrt{5^2 + 3^2 + 2^2 + (0.4)^2} = 6.2$$

This results in less than 2% total variability improvement. If B, C and D were eliminated, then;

$$\sigma\text{ tot} = \sqrt{5^2 + (0.4)^2} = 5.02$$

This gives a considerably better improvement of 23%. If only A is identified and reduced from 5 to 2, then;

$$\sigma\text{ tot} = \sqrt{2^2 + 3^2 + 2^2 + 1^2 + (0.4)^2} = 4.3$$

Identifying and improving the variability from 5 to 2 gives us a total variability improvement of nearly 40%.

Most techniques may be employed to identify the primary assignable cause(s). Out-of-control conditions may be correlated to documented process changes. The product may be analyzed in detail using best versus worst part comparisons or Product Analysis Lab equipment. Multi-variance analysis can be used to determine the family of variation (positional, critical or temporal). Lastly, experiments may be run to test theoretical or factorial analysis. Whatever method is used, assignable causes must be identified and eliminated in the most expeditious manner possible.

After assignable causes have been eliminated, new control limits are calculated to provide a more challenging variability criteria for the process. As yields and variability improve, it may become more difficult to detect improvements because they become much smaller. When all assignable causes have been eliminated and the points remain within control limits for 25 groups, the process is said to be in a state of control.

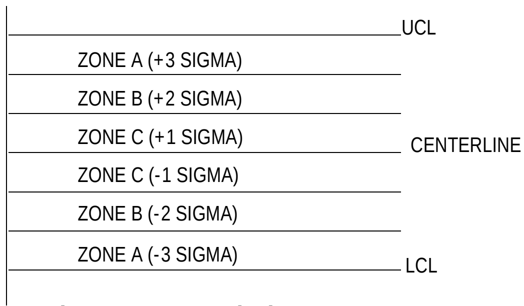


Figure 5. Control Chart Zones

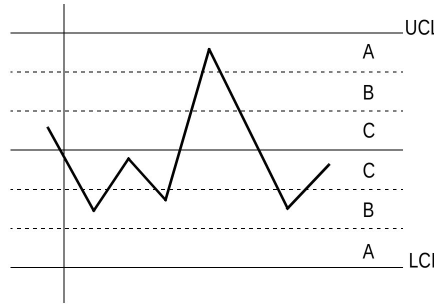


Figure 6. One Point Outside Control Limit Indicating Excessive Variability

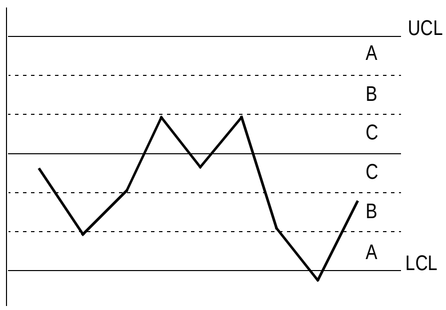


Figure 7. Two Out of Three Points in Zone A or Beyond Indicating Excessive Variability

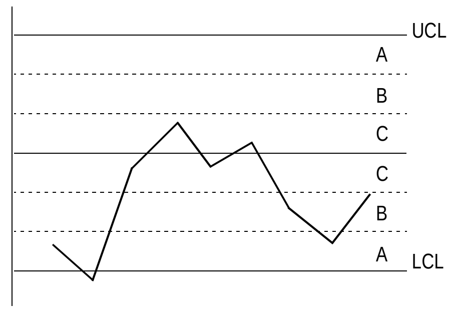


Figure 8. Four Out of Five Points in Zone B or Beyond Indicating Excessive Variability

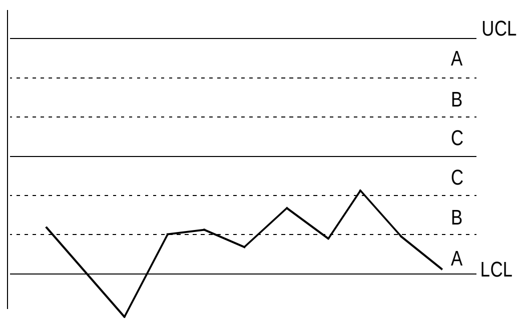


Figure 9. Seven Out of Eight Points in Zone C or Beyond Indicating Excessive Variability

SUMMARY

Freescale Semiconductor's commitment to statistical process controls has resulted in many significant improvements to processes. Continued dedication to the SPC culture will allow Freescale Semiconductor to reach beyond Six Sigma and zero defect capability goals. SPC will further enhance the commitment to Total Customer satisfaction.

MICROMACHINED ACCELEROMETER RELIABILITY TESTING RESULTS

LIFE AND ENVIRONMENTAL TESTING RESULTS

STRESS TEST	CONDITIONS	RESULTS FAILED/PASS
High Temperature Bias	T_A = 90°C, V_{DD} = 5.0 V t = 1000 hours, 12 minutes on, 8 seconds off	0/32
High Temperature/High Humidity Bias	T_A = 85°C, R_H = 85%, V_{DD} = 5.0 V, t = 2016	0/38
High Temperature Storage (Bake)	T_A = 105°C, t = 1000 hours	0/35
Temperature Cycle	–40 to 105°C, Air to Air, 15 minutes at extremes, ≤ 5 minutes transfer, 1000 cycles	0/23
Mechanical Shock	5 blows X1, X2, Y1, Y2, Z1, Z2 2.0 G's, 0.5 mS, T_A = –40°C, 25°C, 90°C	0/12
Vibration Variable Frequency with Temperature Cycle	10 - 1 Khz @ 50 G's max, 24 hours each axis, X1, X2, Y1, Y2, Z1, Z2, T_A = –40 to 90°C, Dwell = 1 Hour, transfer = 65 minutes	0/12
Autoclave	T_A = 121°C, R_H = 100% 15 P_{SIG}, t = 240 hours	0/71
Drop Test	10 Drops from 1.0 meters onto concrete, any orientation	0/12

PARAMETERS MONITORED

		LIMITS			
		INITIAL		END POINTS	
PARAMETER	CONDITIONS	MIN	MAX	MIN	MAX
Offset	V_{DD} = 5.0 V, 25, –40 & 90°C	2.15 V	2.95 V	2.15 V	2.95 V
Self Test	V_{DD} = 5.0 V, 25, –40 & 90°C	20G	30 G	20 G	30 G
Sensitivity	V_{DD} = 5.0 V, 25, –40 & 90°C	45 mV/G	55 mV/G	45 mV/G	55 mV/G

MEDIA COMPATIBILITY DISCLAIMER

Freescale Semiconductor has tested media tolerant sensor devices in selected solutions or environments and test results are based on particular conditions and procedures selected by Freescale Semiconductor. Customers are advised that the results may vary for actual services conditions. Customers are cautioned that they are responsible to determine the media compatibility of sensor devices in their applications and the foreseeable use and misuses of their applications.

SENSOR MEDIA COMPATIBILITY: ISSUES AND ANSWERS[1]

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ABSTRACT

As sensors and actuators are embedded deeper into electronic systems, the issue of media compatibility as well as sensor and actuator performance and survivability becomes increasingly critical. With a large number of definitions and even more explanations of what media compatibility is, there is a ground swell of confusion not only within the industry, but among end users as well. The sensor industry must respond to create a clear definition of what media compatibility is, then strive to provide a comprehensive understanding and industry wide agreement on what is involved in assessing media tolerance and compatibility. Finally, the industry must create a standard set of engineering parameters to design, evaluate, test, and ultimately qualify sensor and actuators functioning in various media conditions. This paper defines media compatibility, identifies pertinent compatibility issues, and recommends a path to industry standardization.

INTRODUCTION

Microelectromechanical System (MEMS) reliability in various media is a subject that has not yet received much attention in the literature yet [1-3], but does bring up many potential issues. The effects of long term media exposure to the silicon MEMS device and material still need answers [4]. Testing can result in predictable silicon or package related failures, but due to the complexity of the mechanisms, deleterious failures can be observed. The sensor may be exposed to diverse media in markets such as automotive, industrial, and medical. This media may include polar or nonpolar organic liquids, acids, bases, or aqueous solutions. Integrated circuits (ICs) have long been exposed to temperature extremes, humid environments, and mechanical tests to demonstrate or predict the reliability of the device for the application. Unlike a typical IC, a sensor often must exist in direct contact with a harsh environment. The lack of harsh media simulation test standardization for these direct contact situations necessitates development of methods and hardware to perform reliability tests.

The applicability of media compatibility affects all sensors to some degree, but perhaps none more dramatically than a piezoresistive pressure sensor. In order to provide an accurate, linear output with applied pressure, the media should come in direct contact with the silicon die. Any barrier provided between the die and the media, limits the device performance. A typical piezoresistive diaphragm pressure sensor manufactured using bulk micromachining techniques is shown in Figure 1. A definition for a media compatible pressure sensor will be proposed.

To ensure accurate media testing, the requirements and methods need to be understood, as well as what constitutes a failure. An understanding of the physics of failure can significantly reduce the development cycle time and produce a higher quality product [5,6]. The focus of the physics-of-failure approach includes the failure mechanism, accelerating environment, and failure mode. The requirement for a typical pressure sensor application involves long term exposure to a variety of media at an elevated temperature and may include additional acceleration components such as static or cyclic temperature and pressure.

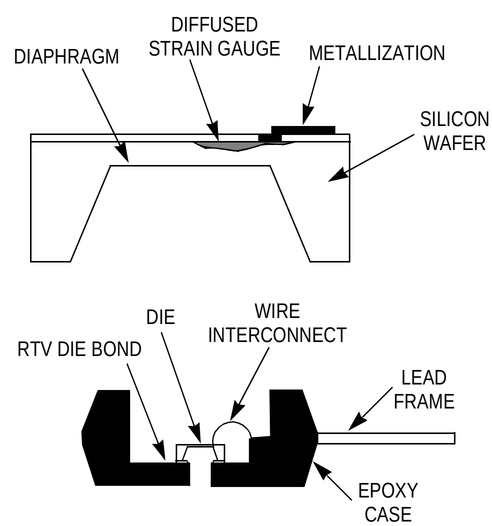

Figure 1. Typical Bulk Micromachined Silicon Piezoresistive Pressure Sensor Device and Package Configuration

1. This paper was presented at Sensors Expo, Anaheim, CA, and is reprinted with permission, Sensors Magazine (174 Concord St., Peterborough, NH 03458) and Expocon Management Associates, Inc. (P.O. Box 915, Fairfield, CT 06430).

The failure mechanisms that may affect a sensor or actuator will be discussed along with the contributors and acceleration means. Failure mechanisms of interest during media testing of semiconductor MEMS devices are shown in Table 1. MEMS applications may involve disposable applications such as a blood pressure monitor whose lifetime is several days. General attributes to consider during testing include: lifetime expectations, cost target, quality level, size, form, and functionality.

Table 1. Typical Failure Mechanisms for Sensors and Actuators [6-10]

Uniform Corrosion
Localized Corrosion
Galvanic Corrosion
Silicon Etching
Polymer Swelling or Dissolution
Interfacial Permeability
Adhesive Strength
Fatigue Crack Initiation
Fatigue Crack Propagation
Environment Assisted Cracking
Creep

Methods for performing media compatibility testing to determine the potential for the various failure mechanisms will be presented. Attributes of the testing need to be well understood so that proper assessment of failure and lifetime approximation can be made. The lifetime modeling is key for determination of the ability of a sensor device to perform its intended function. Reliability modeling and determination of activation energies for the models will provide the customer with an understanding of the device performance. The definition of an electrical failure can range from catastrophic, to exceeding a predetermined limit, to just a small shift. The traditional pre to post electrical characterization (before and after the test interval) can be enhanced by *in situ* monitoring. *In situ* monitoring may expose a problem with a MEMS device during testing that might have gone undetected once the media or another environmental factor is removed. This is a common occurrence for a failure mechanism, such as swelling, that may result in a shift in the output voltage of the sensor. Response variables during environmental testing can include: electrical, visual, analytical, or physical characteristics such as swelling or weight change.

DEFINITIONS AND UNDERLYING CAUSES

The definition of a media compatible pressure sensor is as follows: the ability of a pressure sensor to perform its specified electromechanical function over an intended lifetime in the chemical, electrical, mechanical, and thermal environments encountered in a customer's application.

The key elements of the definition are perform, function, lifetime, environment, and application. All of these elements are critical to meet the media compatibility needs. The underlying causes of poor media compatibility is the hostile environment and permeability of the environment. The environment may consist of media or moisture with ionics, organics, and/or aqueous solutions, extreme temperatures, voltage, and stress.

Permeability is the product of diffusivity and solubility. Contributors to permeability include materials (e.g. polymeric structures), geometry, processing, and whether or not the penetration is in the bulk or at an interface. The environment can also accelerate permeation if a concentration gradient, elevated temperature and/or pressure exist. An example of material dependence of permeation is shown in Figure 2. Organic materials such as silicone can permeate 50% of the relative moisture from the exterior within minutes where inorganic materials such as glass takes years for the same process to occur.

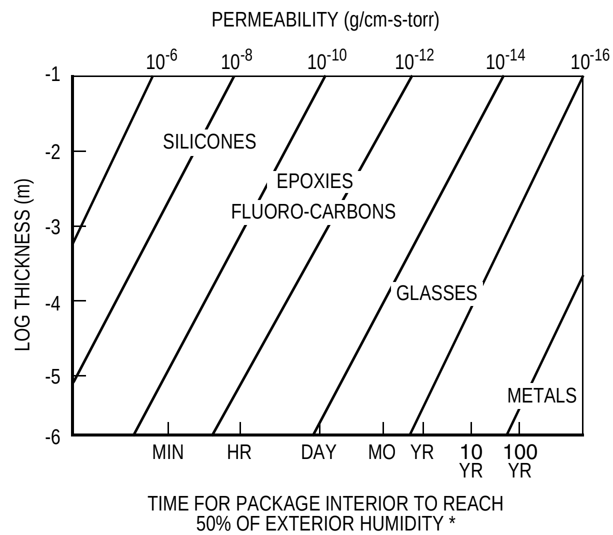

Figure 2. Permeation relationship for various materials.

* *Richard K. Traeger, "Nonhermiticity of Polymeric Lid Sealants, IEEE Transactions on Parts, Hybrids, and Packaging, Vol. PHP-13, No. 2, June 1977.*

Gasoline and aqueous alkaline solutions represent two relatively diverse applications that are intended for use with a micromachined pressure sensor. The typical automotive temperature range is from -40° to 150°C. This not only makes material selection more difficult but also complicates the associated hardware to perform the media related testing [11]. A typical aqueous alkaline solution application would be found in the appliance industry. This industry typically has a narrower temperature extreme then the automotive market, but the solutions and the level of ions provide a particular challenge to MEMS device reliability.

Gasoline contains additives such as: antiknock, anti-preignition agents, dyes, antioxidants, metal deactivators, corrosion inhibitors, anti-icers, injector or carburetor detergents, and intake valve deposit control additives [12]. To develop a common test scheme for the liquid, a mixture table was developed for material testing in gasoline/methanol mixtures. The gasoline/methanol mixtures developed were intended for accelerated material testing with a gasoline surrogate of ASTM Fuel Reference "C" (50% toluene and 50% iso-octane) [13]. Material testing is performed with samples either immersed in the liquid or exposed to the vapor over the liquid. The highly aromatic Fuel “C” is intended to swell polymeric materials. Contaminants in actual gasoline can result in corrosion or material degradation, so chloride ions or formic acid with distilled water are added to create an aggressive fuel media. Gasoline can decompose by a process called auto-oxidation that will form aggressive substances that can dissolve polymers or corrode metal. Copper is added as a trace metal to accelerate the formation of free radicals from the hydroperoxides. Table 2 details the various gasoline/methanol mixtures with additives recommended by the task force from Chrysler, Ford, and General Motors.

Table 2. Fuel Testing Methods

	Elastomer	Polymer	Metal
Alcohol/Fuel Blends	CMO	CMO	
	CM15	CM15	CM15
	CM30	CM30	
	CM50	CM50	
	CM85	CM85	CM85
Aggressive Fuel, Add		Chloride ion	Distilled water
		Formic Acid	Chloride ion
		Sodium Chloride	Formic Acid
Auto Oxidized Fuels, Add		t-Butyl Hydroperoxide	t-Butyl Hydroperoxide
		Cu^+	

Recommended gasoline/methanol mixtures for material testing. The recommended testing for metals should include immersion in the liquid as well as exposure to the vapor. The coding for the alcohol/fuel blends, CMxx is: C for Fuel C; M for methanol; and xx indicating the percentage of methanol in the mixture.

The general question for the appliance industry compatibility issues is not whether the media will contain ions (as it most assuredly will) but at what concentration. Tap water with no alkali additives contains ions capable of contributing to a corrosive reaction [14]. A typical application of a pressure sensor in the appliance industry is sensing the water level in a washing machine. The primary ingredients of detergent used in a washing machine are: surfactants, builders, whitening agents and enzymes [15]. The surfactants dissolve dirt and emulsify oil, grease and dirt. They can be anionic or cationic. Cationic surfactants are present in detergent-softener combinations. Builders or alkaline water conditioning agents are added to the detergent to soften the water, thus increasing the efficiency of the surfactant. These builders maintain alkalinity that results in improved cleaning. Alkaline solutions at temperatures indicated by the appliance industry range can etch bare silicon similar to the bulk micromachining process. Thus bare silicon could be adversely affected by exposure to these liquids [16].

FAILURE MECHANISMS

The failure mechanisms that can affect sensors and actuators are similar to that for electronic devices. These failure mechanisms provide a means of categorizing the varIous effects caused by chemical, mechanical, electrical, and thermal environments encountered. An understanding of the potential failure mechanisms should be determined before media testing begins. The typical industry scenario has been to follow a set boiler plate of tests and then determine reliability. This may have been acceptable for typical electronic devices, but the applications for sensors are more demanding of a thorough understanding before testing begins. The sensitivity of the device to its physical environment is heightened for a pressure sensor. Any change in the material properties results in a change of the sensor performance. Failure mechanisms for pressure sensors in harsh media application are listed below. The pressure sensor allows a format for discussion, though the mechanisms discussed are applicable in some degree to all sensor and actuator devices.

Corrosion

Corrosion has been defined as any destructive result of a chemical reaction between a metal or metal alloy and its environment [17]. Several metal surfaces exist within a pressure sensor package: metallic lines on the die, trimmable resistors, bonding pads, wires, leadframes, etc. Much of the die-level metal is protected by an overlying inorganic passivation material (e.g., PECVD silicon nitride); however, unless some package-level encapsulant is used, bondpads, wires, and leadframes are exposed to the harsh media and are potential corrosion sites. Furthermore, an energized pressure sensor has a voltage difference between these exposed metallic surfaces, which compounds the corrosion problem. Generally, corrosion problems are organized into the following categories: uniform corrosion; galvanic corrosion, and localized corrosion (including, crevice corrosion, pitting corrosion, etc.) [17]. The factors that contribute to corrosion are: the substrate (metallic) material and its surface structure and composition; the influence of a barrier coating, its processing conditions and/or adhesion promotion; the cleanliness of the surface, adhesion between a coating and the surface, solution concentration, solution components (especially impurities and/or oxidizers); localized geometry and applied potential. In addition, galvanic corrosion is influenced by specific metal-to-metal connections.

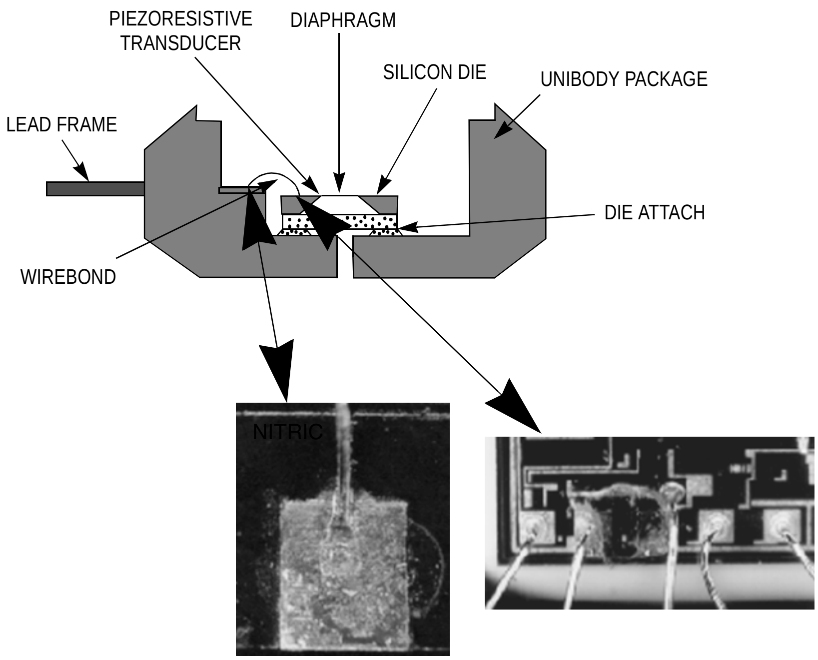

Figure 3. Examples of uniform corrosion of a gold leadframe in nitric acid at 5 Vdc and galvanic corrosion on an unbiased device at the gold wire/aluminum bondpad interface in commercial detergent

Part of Figure 3 shows an example of what we have described as electrolytic corrosion (i.e., corrosion of similar metallic surfaces in an electrolytic solution caused by a sufficient difference in potential between the two surfaces). This appears to be uniform corrosion of the gold leadframe surface. It should be noted that this type of failure is observed even on ‘noble' metals like gold. Applied potential is the driving force for the reaction. All metals can corrode in this fashion depending on the solution concentration (pH) and the applied potential. Pourbaix diagrams describe these thermodynamic relationships [18].

Figure 3 shows an example of galvanic corrosion. The figure illustrates that corrosion can also occur because of dissimilar metals that are connected electrically and are immersed in an electrolytic solutions. A difference in the corrosion potential between the two metals is the driving force for the reaction. Localized corrosion examples are prevalent as well. Often they may be the precursor to what appears on a macro scale to be uniform or galvanic corrosion. *In situ* monitoring of devices in electrolytic media will allow better diagnosis of this failure mechanism. Typical *ex situ* or interval reliability testing may not allow diagnosis of the root cause to the failure, thus limiting the predictive power of any resulting reliability models.

Silicon Etching

Figure 4 shows the result of an accelerated test of a pressure sensor die to a high temperature detergent solution. The detergent used was a major consumer brand and resulted in dramatic etching of the silicon. Alkaline solutions that undergo a hydrolysis reaction may result in etching of the silicon similar to a bulk micromaching operation. This failure mechanism can cause a permanent change in the sensitivity of the device because the sensitivity is proportional to the inverse square of the silicon thickness. Moreover, it can lead to loss in bond integrity between wafers (Fig. 4). Silicon etching [19-20], like corrosion reactions, is a chemical reaction, so the contributing factors include the silicon material, its crystal orientation and its doping level, the solution type, concentration and pH, and the applied potential. Temperature, concentration (i.e., pH), and voltage all act to accelerate this process. Figure 5 shows an example of modeling results that illustrates two of these variables.

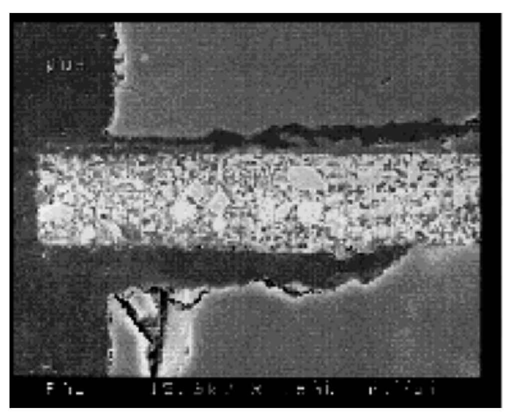

Figure 4. Photograph of silicon etching after exposure to an aqueous detergent solution at elevated temperature for an extended time. A frit layer, horizontally in the middle, adheres to silicon on either side. The amount of etching is evident by referencing the glass frit edge on the far left. These two silicon edges were aligned to the frit edge when the die was sawn.

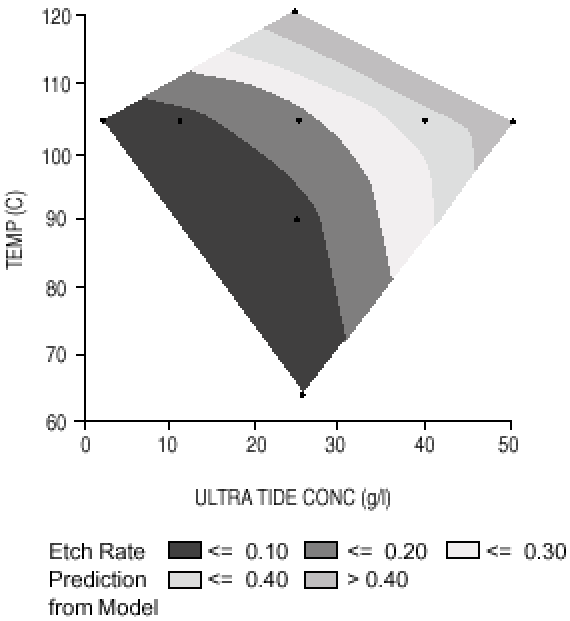

Figure 5. Experimental results for the etching of (100) silicon with approximately 5x10^{-5} cm^{-3} boron doping density in a commercially available detergent as a function of temperature and detergent concentration (which is proportional to pH).

Polymer Swelling or Dissolution

Swelling or dissolution affects those polymers typically employed to package the micromachined structure and depending on the nature of the media, may have a degrading effect on device performance. These two related phenomena are caused by solvent diffusing into the material and occupying free volume within the polymer. The solubility parameter gives a quantitative measure of the potential for swelling [21]: i.e., it provides a quantitative measure of "like dissolves like" (Figure 6). Both the polymer and the solution contribute to this failure mechanism, while the media (specifically, the solubility parameter), the temperature, and the pressure can be used as acceleration factors.

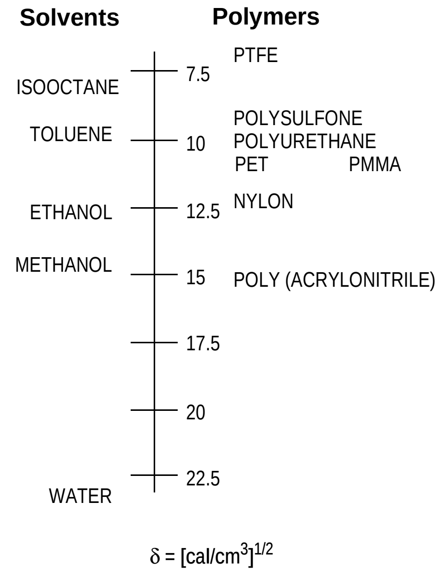

Figure 6. Typical values of solubility parameter (δ [cal/cm^3]$^{1/2}$) for solvents and polymers.

Figure 7 shows a photograph of a device after exposure to a harsh fuel containing corrosive water solution. This corrosion and evidence of swelling of the gel demonstrates the vital importance the package has on the reliability of the pressure sensor device. Also, it has been observed that corrosion occurs more readily following swelling of a polymeric encapsulant.

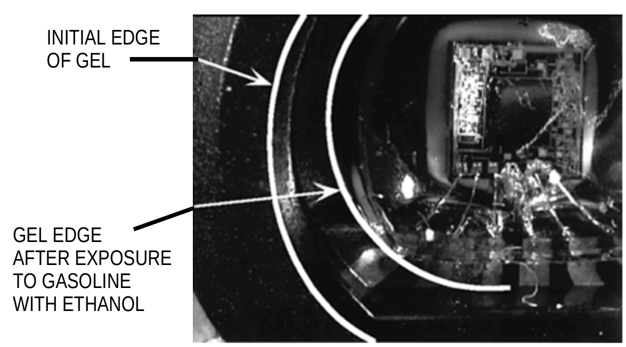

Figure 7. Photograph of a pressure sensor device after extended exposure to harsh fuel containing corrosive water, followed by exposure to a strong acid. Evidence of the gel swelling during the test, and corresponding shrinkage after removal from the test media can be seen by the gel retracting away from the sidewall of the package.

Interfacial Permeability

Lead leakage is a specific example of interfacial permeability. It is pressure leakage through the polymer housing material/metallic leadframe material interface from the inside of the pressure sensor package to the outside of the pressure sensor package or vice versa [22]. In addition, other material interfaces can result in leakage. We describe another specific example of this in the next section. Lead leakage is like polymer swelling in that it may allow another failure mechanism, like corrosion, to occur more readily. It also causes a systematic pressure measurement error. Figure 8 shows the result of lead leakage measurements as a function of temperature cycling. The polymer housing material (and its CTE as a function of temperature), the leadframe material (and its CTE), surface preparation and contamination, the polymer matrix composition, and polymer processing all contribute to this effect. It is accelerated by media, temperature cycling, and applied pressure.

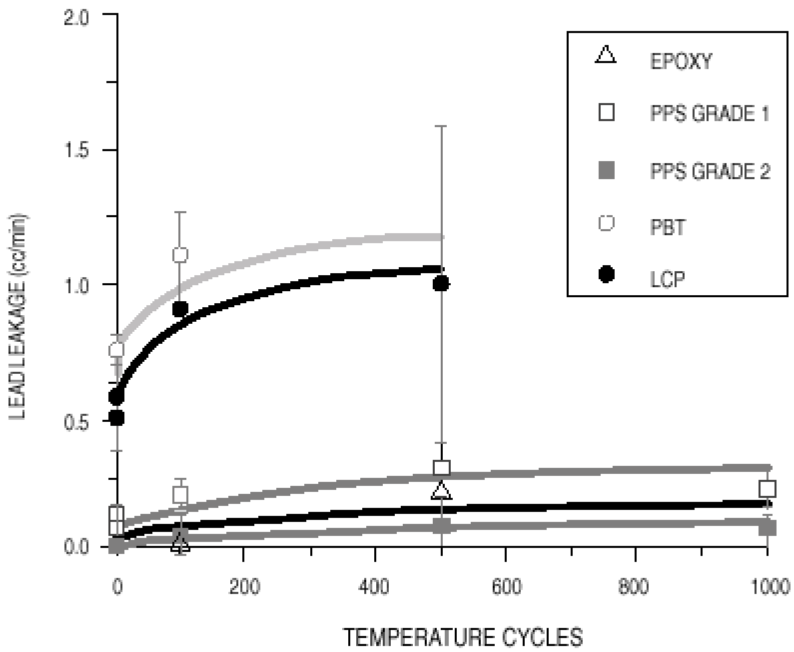

Figure 8. Pressure leakage measurements through the metallic leadframe/polymeric housing material interface on a pressure sensor as a function of temperature cycles between -40 and 125°C.

Adhesive Strength

Packaging of the sensor relies on adhesive material to maintain a seal but not impart stress on the piezoresistive element. Polymeric materials are the primary adhesive materials which can range from low modulus material such as silicone to epoxy with a high modulus. An example of a typical joint is shown in Figure 9. The joint has three possible failure locations with the preferred break being cohesive. Contributors to a break include whether the joint is in tension or compression, residual stresses, the adhesive material, surface preparation, and contamination. An adhesive failure is accelerated by media contact, cyclic or static temperature, and cyclic or static stress (e.g. pressure).

Strength Components

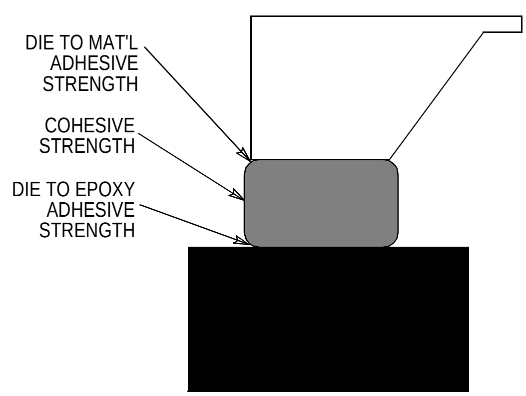

Figure 9. Failure locations for an adhesive bond of dissimilar materials.

Mechanical Failures

The occurrence of mechanical failures include components of fatigue, environment assisted cracking, and creep. Packaging materials, process, and residual stresses are all contributors to mechanical failure. A summary of acceleration stresses is shown in Table 3. Contact with harsh media is an accelerating stress for all of the mechanical failure mechanisms.

Table 3. Mechanical Failure Mechanisms

Failure Mechanism	Acceleration Stresses
Fatigue crack initiation	Mechanical stress/strain range Cyclic temperature range Frequency Media
Fatigue crack propagation	Mechanical stress range Cyclic temperature range Frequency Media
Environment assisted cracking	Mechanical stress Temperature Media
Creep	Mechanical stress Temperature Media

PRESSURE SENSOR SOLUTIONS

The range of solutions for pressure sensors to media compatibility is very diverse. Mechanical pressure sensors still occupy a number of applications due to this media compatibility concern. These devices typically operate on a variable inductance method and are typically not as linear as a piezoresistive element. Figure 10 shows a comparison between a mechanical pressure sensor and a piezoresistive element for a washing machine level sensing application. The graph shows a nonlinear response for the mechanical sensor and a corresponding straight line for the piezoresistive element.

A common method of obtaining media compatibility is to place a barrier coating over the die and wire interconnection. This organic encapsulant provides a physical barrier between the harsh environment and the circuitry. The barrier coating can range from silicone to parylene or other dense films that are typically applied as a very thin layer. This technique offers limited protection to some environments due to swelling and/or dissolution of the encapsulant material when in contact with media with a similar solubility. When a polymeric material has a solubility parameter of the same value as the corresponding media, swelling or dissolution will occur.

Stainless steel diaphragms backfilled with silicone oil provide a rugged barrier to most media environments, but

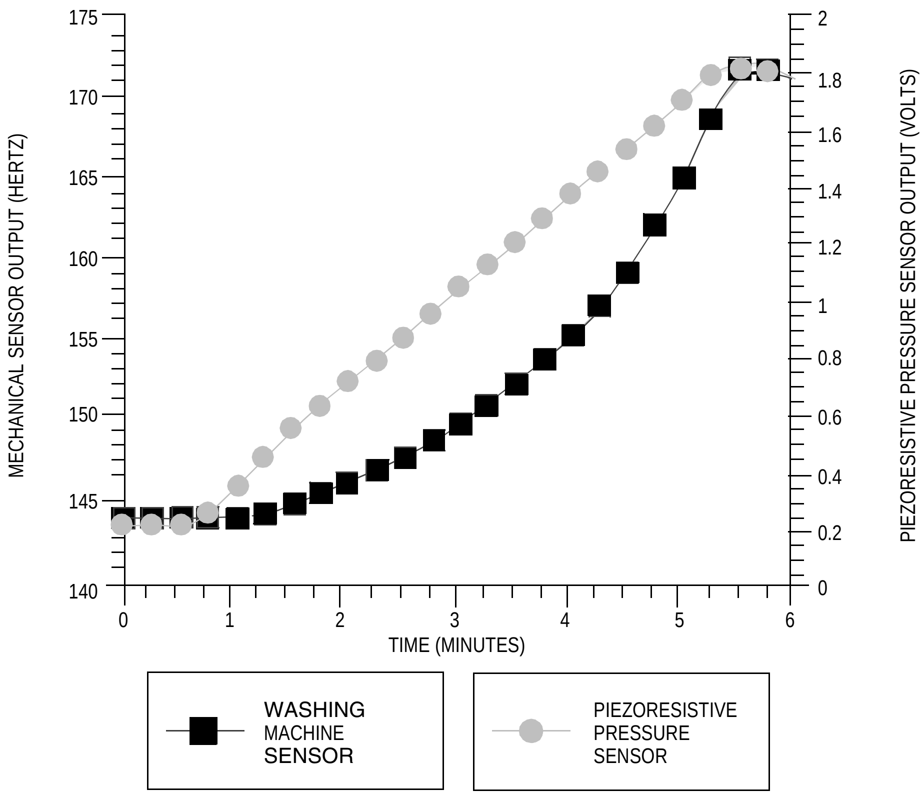

Figure 10. Graphical comparison of the output from a mechanical pressure sensor compared to a piezoresistive sensor during a washing machine fill cycle.

MEDIA TEST METHODS

Figure 11 and Figure 12 show a test apparatus specifically intended for use with solvents and Figure 13 an apparatus for aqueous solutions. This test system has resulted in a realistic test environment that provides electrical bias, *in situ* measurements, consistent stoichiometry, and temperature control all within a safe environment. The safety aspects of the testing were obtained by creating an environment free of oxygen to eliminate the possibility of a fire. Results from the testing have included swelling of silicone materials, corrosion, and adhesive failures.

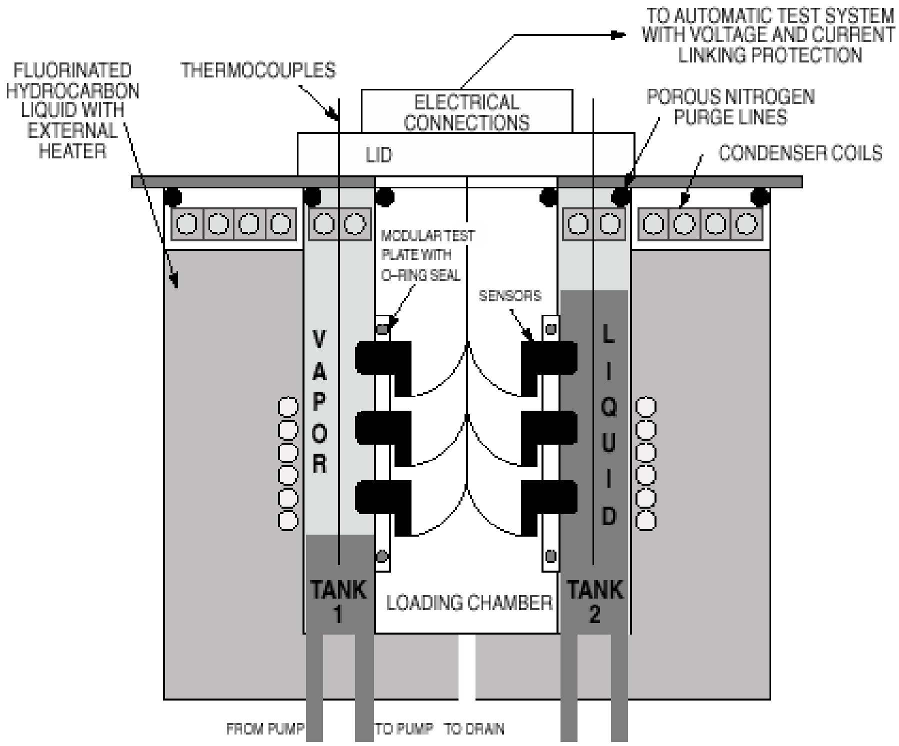

Figure 11. Graphical depiction of the sensor media tester used for liquid or vapor exposure of the device to the harsh media to accelerate the failure mechanisms or demonstrate compatibility.

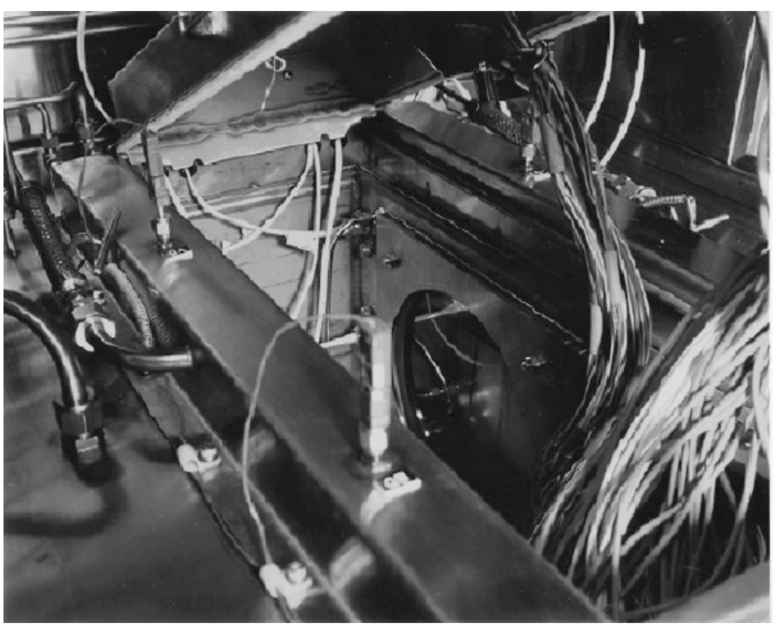

Figure 12. Photograph of the load chamber area of the Media Test System allowing for fuel or solvent testing at temperature with in situ monitoring of the devices under test (DUT's) output.

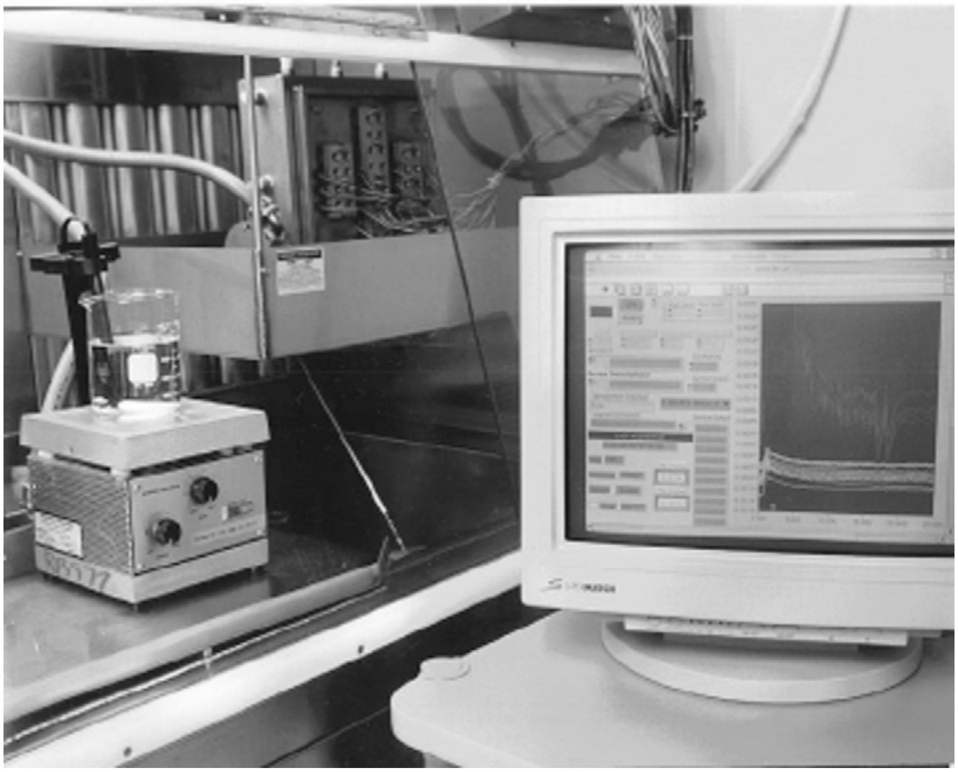

Figure 13. Photograph of the aqueous alkaline solution test system and the data acquisition system for *in situ* monitoring of the MEMS devices.

LIFETIME MODELING

Reliability techniques provide a means to analyze media test results and equate the performance to a lifetime [23-24]. The primary reliability techniques involve an understanding of the failure rate, life distributions, and acceleration modeling. The failure rate for a product's lifetime follows the bathtub curve. This curve, as shown in Figure 14, has an early life period with a decreasing failure rate. Manufacturing defects would be an example of failures during this portion of the curve. The second portion of the curve, often described as the useful life region has a constant failure rate. The last section has an increasing failure rate and is referred to as the wearout region. This wearout region would include failure mechanisms such as corrosion or fatigue.

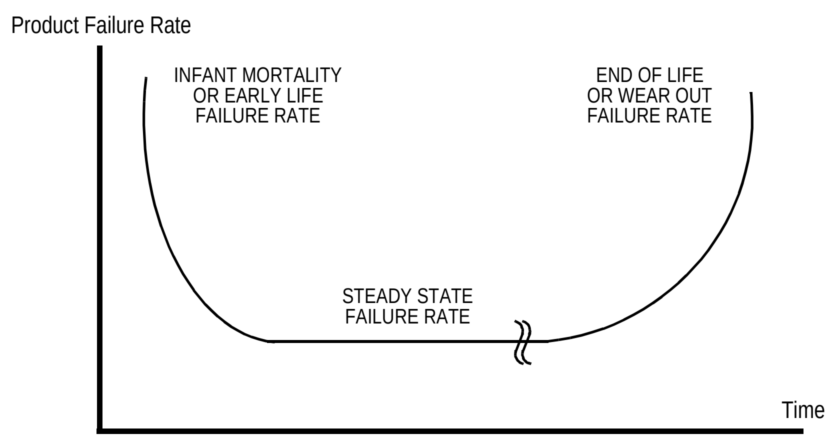

Figure 14. Bathtub curve showing various failure rate regions.

Lifetime distributions provide a theoretical model to describe device lifetimes. Common lifetime distributions include the exponential, Weibull, lognormal, and extreme value. The exponential distribution models a lifetime with a constant failure rate An example of the exponential distribution is a glass which has an equal probability of failing the moment after it is manufactured, or when its ten years old. The Weibull and lognormal distribution are all right, or positively skewed distributions. A right skewed distribution will be a good model for data in a histogram with an extended right tail. The Weibull distribution is sometimes referred to as a distribution of minima. An example of a Weibull distribution is the strength to break a chain where the weakest link describes the strength of the chain. The extreme value distribution is a distribution of maxima. It is the least utilized of the four life distributions.

For means of example, the Weibull distribution will be used. The Weibull lifetime distribution as the form:

$$F(t, \theta, \beta) = 1 - e^{-\left(\frac{t}{\theta}\right)^{\beta}} \qquad (1)$$

The two parameters for the Weibull distribution are q and b. Theta is the scale parameter, or characteristic life. It represents the 63.2 percentile of the life distribution. Beta is the shape parameter. In order to determine the parameters for the Weibull distribution, testing must be performed produce failure on the devices. The failure data can be used to calculate the maximum likelihood estimates or determined graphically. It has not always been customary to perform reliability demonstration testing until failures occur. In regards to media testing, this seems to be the only method to derive lifetime estimates that reflect a true understanding of the device capability.

$$AF = e^{\left[\frac{Ea}{k}\left(\frac{1}{T_{low}} - \frac{1}{T_{high}}\right)\right]} \bullet \left(\frac{RH_{high}}{RH_{low}}\right)^{n} \qquad (2)$$

A media test typically needs to take results received in weeks or months to predict lifetime in years. Acceleration models are used to determine the relationship between the accelerated test and the normal lifetime. Literature has reported numerous models to equate testing to lifetime including the Peck model for temperature and humidity [25]. The acceleration equation based on Peck's model is where Ea is 0.9 eV and n is -3.0. The value K is Boltzmann's constant which is equal to 8.6171×10^{-5} eV/K. The relative humidity is entered as a whole number, i.e. 85 for 85%. Using this sample model, test results from humidity testing can be related to the lifetime. The methods to equate test time to lifetime first involves fitting the failure data to a lifetime distribution. For an example, humidity data at 60°C, 90% relative humidity and bias was tested to failure. The failure data fit a Weibull distribution with a characteristic life of 40,000 hours. By applying the acceleration factor equation shown above, quantification of the lifetime in the use conditions can be calculated. Figure 15 shows the cumulative failure distribution for the test and use conditions for a 15 year lifetime. This technique is key for media testing since the range of use conditions is very broad. The consumer can determine the attributes for the sensor to use for the application. The attributes might include cost, performance, and possibility for replacement.

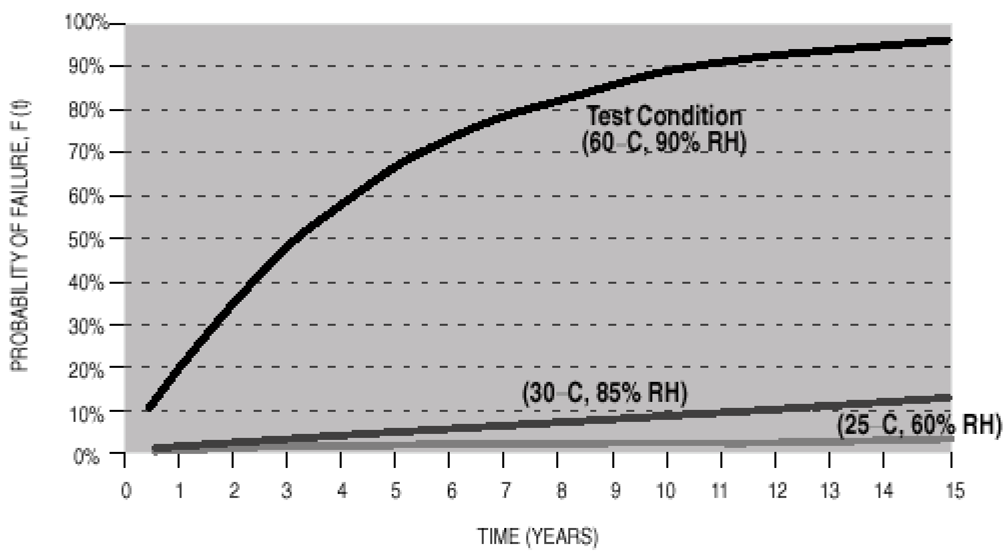

Figure 15. Probability of failure versus time for humidity testing with bias on an integrated sensor device.

The failure distribution example shown typically represents one failure mechanism. The failure mechanism that typifies humidity testing is mobile ions. An elevated test temperature, humidity and bias contributes to the mobility of the ions and the ability to create a surface charge. By lowering the temperature, humidity or switching the bias, an improvement in the lifetime can be obtained. If a device manufacturer would test to failure and report the lifetimes, the customer could select the appropriate product for their application. Following a template of reliability tests that have not been verified and do not coincide with the applicable failure mechanism may put the application at risk for surviving.

Humidity testing was used as an example above, but a similar case could be made of other attributes involved with media testing. Other attributes of the media test may include the bias level and duty cycle, the pH or conductivity of the solution, and any stress such as a pressure differential. By modeling these attributes against the various solutions, models for media compatibility can be developed.

INDUSTRY STANDARDIZATION

Why an industry standard? The increasing use of electronic sensors in everyday life has designers wrestling with the complexity of defining the compatibility of a sensor with the media they are measuring. A designer may decide to solve the question of media compatibility by choosing to isolate the sensor from the media via a stainless steel diaphragm. While this solution provides very good media isolation, it is not without some drawbacks such as cost, size of packaging, decreased sensitivity and long term drift. Without a recognized standard for defining media compatibility, the designer is left to a series of ad hoc test methods and conflicting specifications.

An industry media compatibility standard will provide the designer with a method of evaluating sensor performance. The designer could match an application's requirements, for media compatibility, with the available sensor products thus taking price and performance into account. This will enable the designer to minimize the total cost of an application. A standard will also enable suppliers to provide products warranted to defined criteria. Once a standard is adopted, the suppliers may rationalize their test efforts and pass the savings on to their customers.

A standard should provide a designer with a simple, coherent, complete definition of a media's effects on a sensor. The standard should included an accepted test methodology, test equipment guidelines, life time model, acceleration factors model, and a definition of failures. A proposed list of criteria to include in a model are shown in Table 4.

Table 4. Suggested Criteria for Media Compatibility

Media Contact - Front or Back	Supply Voltage	Solubility Parameter
Pressure Range	Supply Voltage Duty Cycle	Conductivity of Media
Temperature Range	Voltage Potential within Media	pH
Recipe of Media and Contaminants	Frequency Output is Measured	Lifetime Expectancy
Sensor to Media Interconnection	Relative Motion of Media (e.g., Flow)	

These criteria must be included not only for the media, but also for the contaminants in the media. An example is a washing machine level sensor which must be compatible with water vapor (the media) and detergent and chlorine (the contaminant). To create a standard, a series of tests which benchmark the criteria must be designed and performed. The results would form the basis of the life time and acceleration factor models.

There are several ways to create a standard, each of which have their own associated pros and cons. Three possible ways to create a standard are: an industry association committee, a panel of industry representatives, or a de facto standard set by one or more industry suppliers. To define a standard for media compatibility may require more than one of these methods. An industry leader may define a standard form to which they deliver product. This may stimulate the formation of a committee which defines a broader standard for the industry. As this standard becomes more accepted by the industry, the committee may work with an industry association to “legitimize” the de facto standard. No matter how the standard is formulated, receiving broad industry acceptance will require meeting the customers' needs.

CONCLUSION

Investigation of media compatibility for pressure sensors has been presented from a physics-of-failure approach. We have developed a set of internal standard test and reliability lifetime analysis procedures to simulate our customers' requirements. These activities have incorporated information from several fields beyond sensors and/or electronics, including: electrochemistry and corrosion, polymers, safety and environmental, automotive and appliance industry standards, and reliability. The next critical step to elevating the awareness of this problem, in our opinion, is to develop an industry-wide set of standards, driven by customer applications, that include media testing experimental procedures, reliability lifetime analysis, and media compatibility reporting to allow easier customer interpretation of results.

ACKNOWLEDGEMENTS

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NOTES

Section Two

Accelerometer Overview

Freescale's series of acceleration sensors incorporate a surface micromachined structure. The force of acceleration moves the seismic mass, thereby changing the g-cell's capacitance. Coupled with the g-cell is a control chip to provide the accelerometer with signal amplification, signal conditioning, low pass filter, and temperature compensation. With Zero-g offset, sensitivity and filter roll-off that is factory set, the device requires only a few external passives. In fact, this acceleration sensor device offers a calibrated self-test feature that mechanically displaces the seismic mass with the application of a digital self-test signal. The g-cell is hermetically sealed at the die level, creating a particle-free environment with features such as built in damping and over-range stops to protect it from mechanical shock. These acceleration sensors are rugged, highly accurate and feature X, XY, XYZ, and Z axis of sensitivity.

Freescale's acceleration sensors are economical, accurate, and highly reproducible for the ideal sensing solution in automotive, industrial, commercial, and consumer applications.

Acceleration Sensor Products

Mini Selector Guide

Accelerometer Sensor

Device	Acceleration (g)	Sensing Axis	Sensitivity (mV/g)	Rolloff Frequency (Hz)	VDD Supply Voltage (Typ) (V)
MMA7260Q	1.5/2/4/6	XYZ	800/600/300/200	350/150	3.3
MMA6260Q	1.5/1.5	X-Y	800/800	50	3.3
MMA2260D	1.5	X	1200	50	5.0
MMA1260D	1.5	Z	1200	50	5.0
MMA1270D	2.5	Z	750	50	5.0
MMA1250D	5.0	Z	400	50	5.0
MMA1220D	8.0	Z	250	250	5.0
MMA6231Q	10/10	X-Y	120/120	300	3.3
MMA3201D	40/40	X-Y	50/50	400	5.0
MMA2201D	40	X	50	400	5.0
MMA2202D	50	X	40	400	5.0
MMA3202D	100/50	X-Y	50/100	400	5.0
MMA2204D	100	X	20	400	5.0
MMA1213D	50	Z	40	400	5.0
MMA1210D	100	Z	20	400	5.0
MMA1211D	150	Z	13	400	5.0
MMA2301D	200	X	10	400	5.0
MMA1212D	200	Z	10	400	5.0
MMA2300D	250	X	8.0	400	5.0
MMA1200D	250	Z	8.0	400	5.0

Sensor Applications

AUTOMOTIVE APPLICATIONS

- Airbags
- Rollover detection
- Fuel shut-off valve
- Crash detection
- Suspension control
- Vehicle dynamic control
- Braking systems
- Occupant safety

HEALTHCARE / FITNESS APPLICATIONS

- Physical therapy
- Rehabilitation equipment
- Range of body motion measurement
- Pedometers
- Ergonomics tools
- Sports medicine equipment
- Sports diagnostic systems

INDUSTRIAL / CONSUMER APPLICATIONS

- Fall detection
- Fall log
- HDD protection
- MP3 players
- Portable electronics
- Warranty purpose recording
- E-compass
- Ergonomic tools
- Gaming
- Image stability
- Physical therapy
- Text scrolling
- 3-D motion dialing
- Pedometer
- Robotics
- Virtual reality input devices
- Anti-theft devices
- Car/personal navigation
- Dead reckoning for GPS
- Black boxes/event recorders
- Shipping/handling monitor
- Tap to mute
- Acoustics
- Appliance balance/monitoring
- Bearing wear monitoring
- Seismic monitoring
- Smart motor maintenance

Acceleration Sensor FAQ's

We have discovered that many of our customers have similar questions about certain aspects of our accelerometer's technology and operation. Here are the most frequently asked questions and answers that have been explained in relatively non-technical terms.

Q. What is the g-cell?

A. The g-cell is the acceleration transducer within the accelerometer device. It is hermetically sealed at the wafer level to ensure a contaminant free environment, resulting in superior reliability performance.

Q. What does the output typically interface with?

A. The accelerometer device is designed to interface with an analog to digital converter available on most microcontrollers. The output has a 2.5 V DC offset, therefore positive and negative acceleration is measurable. For unique customer applications, the output voltage can be scaled and shifted to meet requirements using external circuitry.

Q. What is the resonant frequency of the g-cell?

A. The resonant frequency of the g-cell is much higher than the cut-off frequency of the internal filter. Therefore, the resonant frequency of the g-cell does not play a role in the accelerometer response.

Q. What is ratiometricity?

A. Ratiometricity simply means that the output offset voltage and sensitivity scales linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter. Ratiometricity allows for system level cancellation of supply induced errors in the analog to digital conversion process. Refer to the Special Features section under the Principle of Operation for more information.

Q. Is the accelerometer device sensitive to electro static discharge (ESD)?

A. Yes. The accelerometer should be handled like other CMOS technology devices.

Q. Can the g-cell part “latch"?

A. No, overrange stops have been designed into the g-cell to prevent latching. (Latching is when the middle plate of the g-cell sticks to the top or bottom plate.)

Freescale Semiconductor
Technical Data

MMA1200D
Rev 3, 05/2005

Surface Mount Micromachined Accelerometer

MMA1200D

MMA1200D: Z AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±250g

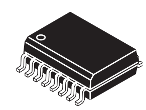
The MMA series of silicon capacitive, micromachined accelerometers features signal conditioning, a 4-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

Features

- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability

Typical Applications

- Vibration Monitoring and Recording
- Impact Monitoring



16-LEAD SOIC CASE 475-01

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Case No.**	**Package**
MMA1200D	– 40 to +125°C	475-01	SOIC-16
MMA1200DR2	– 40 to +125°C	475-01	SOIC-16, Tape & Reel

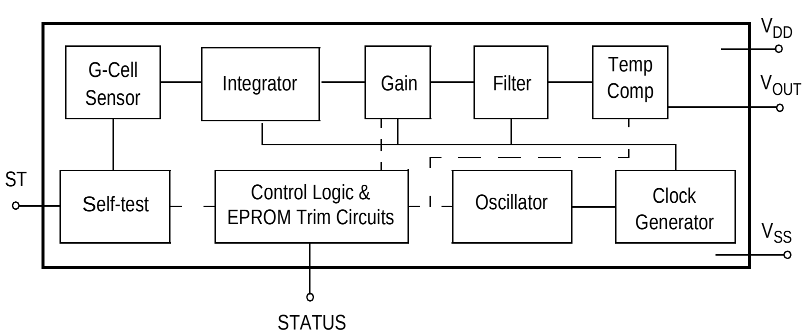


Figure 1. Simplified Accelerometer Functional Block Diagram

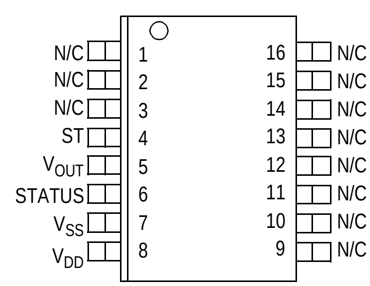


Figure 2. Pin Connections

Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test[1]	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2 kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

Table 2. Operating Characteristics

(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output(1))

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range(2)					
Supply Voltage(3)	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	3.0	—	6.0	mA
Operating Temperature Range	T_A	–40	—	+125	C
Acceleration Range	g_{FS}	—	281	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)(4)	V_{OFF}	2.35	2.5	2.65	V
Zero g	$V_{OFF,V}$	0.47 V_{DD}	0.50 V_{DD}	0.53 V_{DD}	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)(5)	S	7.6	8.0	8.4	mV/g
Sensitivity	S_V	1.49	1.6	1.71	mV/g/V
Bandwidth Response	$f_{–3dB}$	360	400	440	Hz
Nonlinearity	NL_{OUT}	–2.0	—	2.0	% FSO
Noise					
RMS (0.1-1 kHz)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	110	—	μV/(Hz$^{1/2}$)
Clock Noise (without RC load on output)(6)	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	55	75	95	g
Input Low	V_{IL}	V_{SS}	—	0.3 × V_{DD}	V
Input High	V_{IH}	0.7 × V_{DD}	—	V_{DD}	V
Input Loading(7)	I_{IN}	–30	–100	–260	μA
Response Time(8)	t_{ST}	—	2.0	10	ms
Status(9),(10)					
Output Low (I_{load} = 100 μA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 μA)	V_{OH}	V_{DD} –0.8	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{min}	50	—	260	kHz
Output Stage Performance					
Electrical Saturation Recovery Time(11)	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 μA)	V_{FSO}	0.25	—	V_{DD}–0.25	V
Capacitive Load Drive(12)	C_L	—	—	100	pF
Output Impedance	Z_O	—	300	—	Ω
Mechanical Characteristics					
Transverse Sensitivity(13)	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 μF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 volts, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above $V_{DD}/2$ and for negative acceleration the output will decrease below $V_{DD}/2$.
5. The device is calibrated at 35g.
6. At clock frequency ≅ 70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
10. The Status pin output latches high if a Low Voltage Detection or Clock Frequency failure occurs, or the EPROM parity changes to odd. The Status pin can be reset low if the self-test pin is pulsed with a high input for at least 100 μs, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined “cap'' wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as two stationary plates with a moveable plate in-between. The center plate can be deflected from its rest position by subjecting the system to an acceleration (Figure 3).

When the center plate deflects, the distance from it to one fixed plate will increase by the same amount that the distance to the other plate decreases. The change in distance is a measure of acceleration.

The g-cell plates form two back-to-back capacitors (Figure 4). As the center plate moves with acceleration, the distance between the plates changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the plate, ε is the dielectric constant, and D is the distance between the plates.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

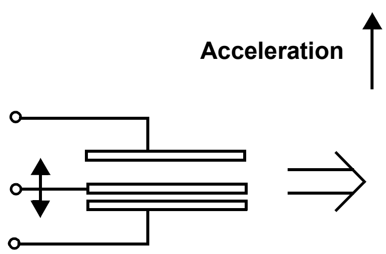


Figure 3. Transducer Physical Model

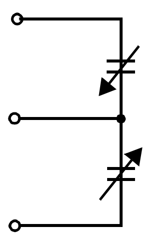


Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an onboard 4-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive airbag systems where system integrity must be ensured over the life of the vehicle. A fourth “plate'' is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^1/_2\ AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a rising edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

BASIC CONNECTIONS

Pinout Description

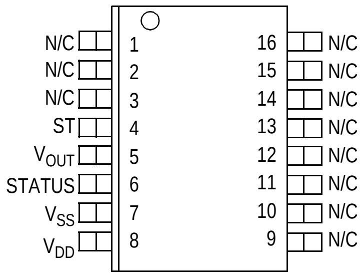


Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	—	Leave unconnected.
4	ST	Logic input pin used to initiate self-test.
5	V_{OUT}	Output voltage of the accelerometer.
6	STATUS	Logic output pin to indicate fault.
7	V_{SS}	The power supply ground.
8	V_{DD}	The power supply input.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

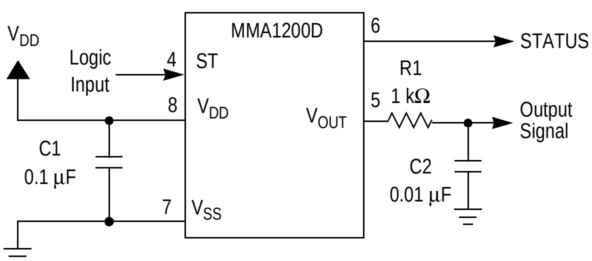


Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

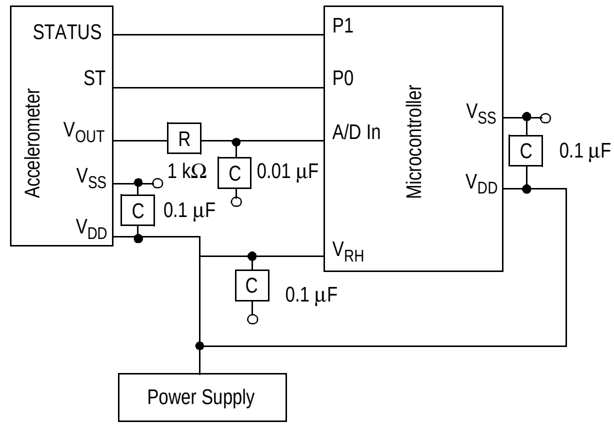
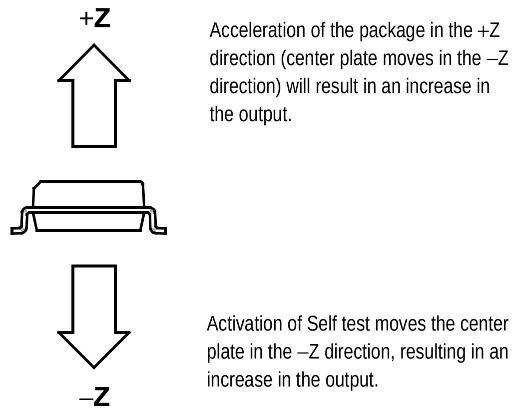


Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

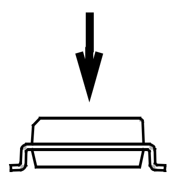
Dynamic Acceleration Sensing Direction



Side View

Static Acceleration Sensing Direction

Direction of Earth's gravity field(1)



Side View

1. When positioned as shown, the Earth's gravity will result in a positive 1g output

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

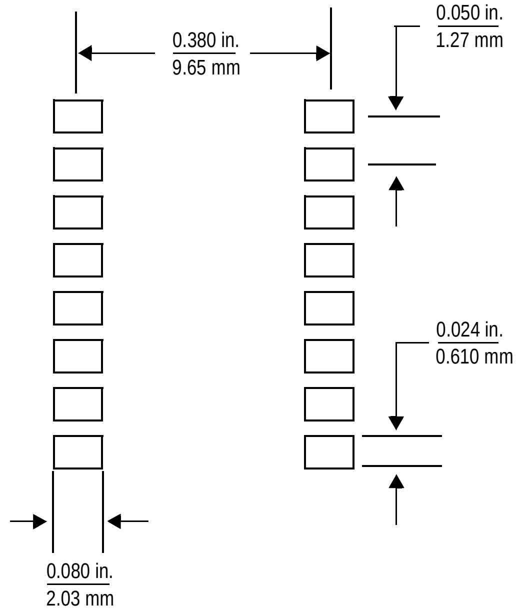


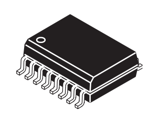
Figure 7. Footprint SOIC-16 (Case 475-01)

MMA1210D

Surface Mount Micromachined Accelerometer

The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 4-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

MMA1210D: Z AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±100g



D SUFFIX
16-LEAD SOIC
CASE 475-01

Features

- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4^{th} Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability

Typical Applications

- Vibration Monitoring and Recording
- Impact Monitoring

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Case No.**	**Package**
MMA1210D	–40° to 125°C	475-01	SOIC-16
MMA1210DR2	–40° to 125°C	475-01	SOIC16, Tape & Reel

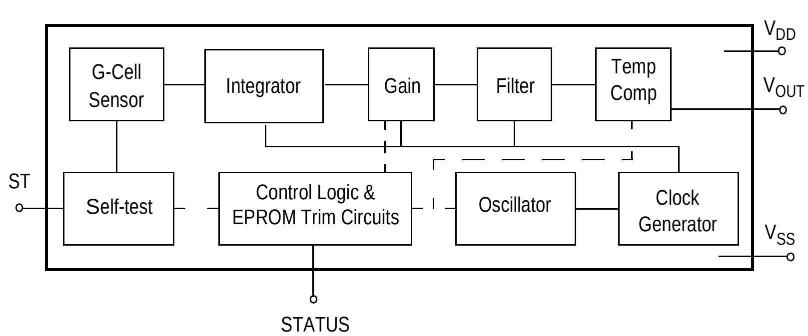


Figure 1. Simplified Accelerometer Functional Block Diagram

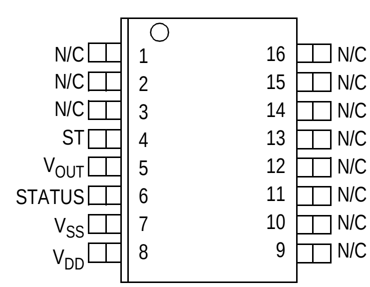


Figure 2. Pin Connections

Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test [1]	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

Table 2. Operating Characteristics
(Unless otherwise noted: $-40°C \leq T_A \leq +105°C$, $4.75 \leq V_{DD} \leq 5.25$, Acceleration = 0g, Loaded output.[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	3.0	—	6.0	mA
Operating Temperature Range	T_A	–40	—	+125	C
Acceleration Range	g_{FS}	—	112.5	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.35	2.5	2.65	V
Zero g	$V_{OFF,V}$	0.46 V_{DD}	0.50 V_{DD}	0.54 V_{DD}	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	19	20.0	21	mV/g
Sensitivity	S_V	3.72	4.0	4.28	mV/g/V
Bandwidth Response	f_{-3dB}	360	400	440	Hz
Nonlinearity	NL_{OUT}	–1.0	—	1.0	% FSO
Noise					
RMS (0.1–1 kHz)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	110	—	$\mu V/(Hz^{1/2})$
Clock Noise (without RC load on output)[6]	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	55	75	95	g
Input Low	V_{IL}	V_{SS}	—	$0.3 \times V_{DD}$	V
Input High	V_{IH}	$0.7 \times V_{DD}$	—	V_{DD}	V
Input Loading[7]	I_{IN}	–30	–100	–260	µA
Response Time[8]	t_{ST}	—	2.0	10	ms
Status[9], [10]					
Output Low (I_{load} = 100 µA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 µA)	V_{OH}	V_{DD} –.8	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{min}	50	—	260	kHz
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 µA)	V_{FSO}	0.25	—	V_{DD}–0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	300	—	W
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 µF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 volts, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above $V_{DD}/2$ and for negative acceleration the output will decrease below $V_{DD}/2$.
5. The device is calibrated at 35g.
6. At clock frequency ≅70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
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11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined "cap'' wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as two stationary plates with a moveable plate in-between. The center plate can be deflected from its rest position by subjecting the system to an acceleration (Figure 3).

When the center plate deflects, the distance from it to one fixed plate will increase by the same amount that the distance to the other plate decreases. The change in distance is a measure of acceleration.

The g-cell plates form two back-to-back capacitors (Figure 4). As the center plate moves with acceleration, the distance between the plates changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the plate, ε is the dielectric constant, and D is the distance between the plates.

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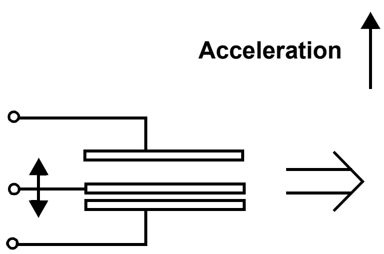


Figure 3. Transducer Physical Model

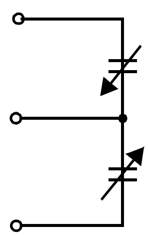


Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an onboard 4-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive airbag systems where system integrity must be ensured over the life of the vehicle. A fourth "plate'' is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^1/_2\ AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a rising edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

BASIC CONNECTIONS

Pinout Description

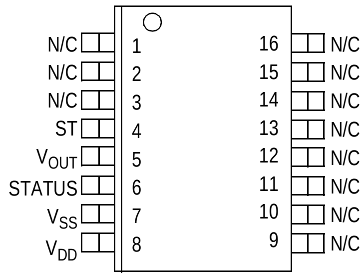


Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	—	Leave unconnected.
4	ST	Logic input pin used to initiate self-test.
5	V_{OUT}	Output voltage of the accelerometer.
6	STATUS	Logic output pin to indicate fault.
7	V_{SS}	The power supply ground.
8	V_{DD}	The power supply input.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

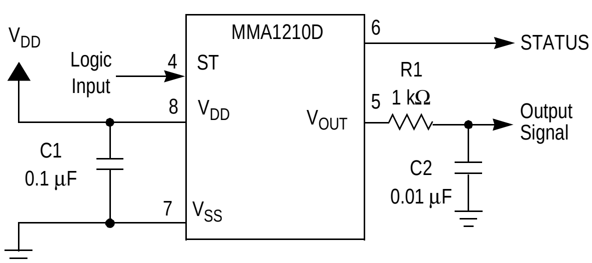


Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

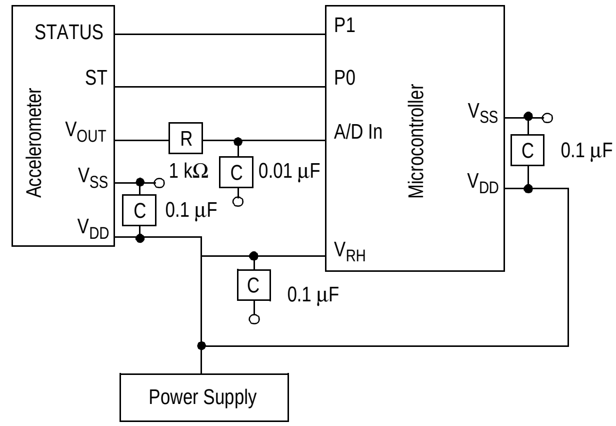
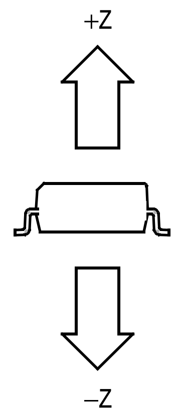


Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

Dynamic Acceleration Sensing Direction



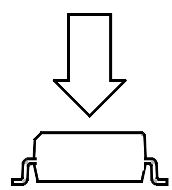
Acceleration of the package in the +Z direction (center plate moves in the –Z direction) will result in an increase in the output.

Activation of Self test moves the center plate in the –Z direction, resulting in an increase in the output.

Side View

Static Acceleration Sensing Direction

Direction of Earth's gravity field[1]



Side View

1. When positioned as shown, the Earth's gravity will result in a positive 1g output.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

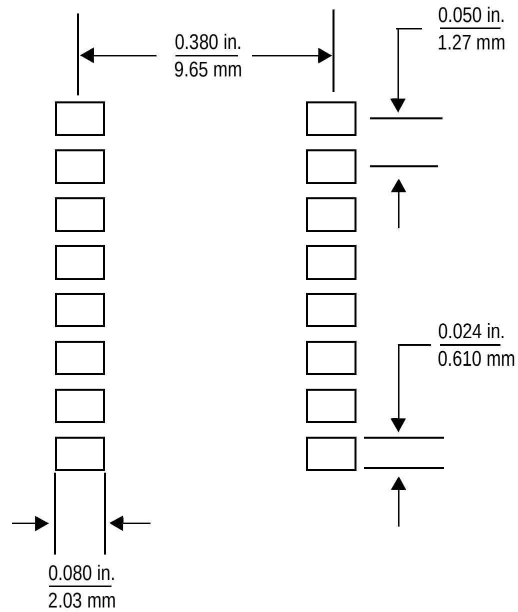


Figure 7. Footprint SOIC-16 (Case 475-01)

Surface Mount Micromachined Accelerometer

The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 4-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

Features

- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability

Typical Applications

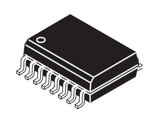
- Vibration Monitoring and Recording
- Impact Monitoring

ORDERING INFORMATION

Device Name	Temperature Range	Case No.	Package
MMA1211D	–40° to 125°C	475-01	SOIC-16
MMA1211DR2	–40° to 125°C	475-01	SOIC16, Tape & Reel

MMA1211D

MMA1211D: Z AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±150g



D SUFFIX
16-LEAD SOIC
CASE 475-01

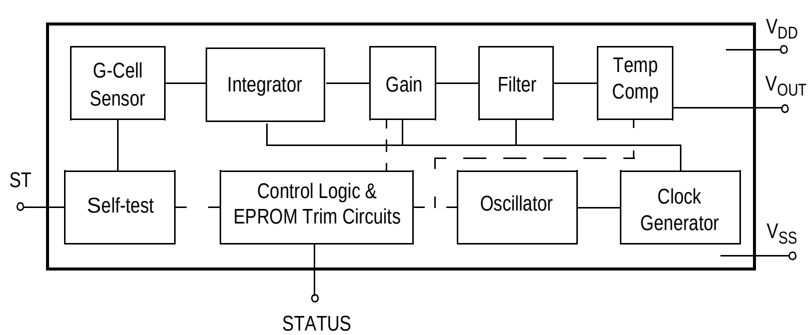


Figure 1. Simplified Accelerometer Functional Block Diagram

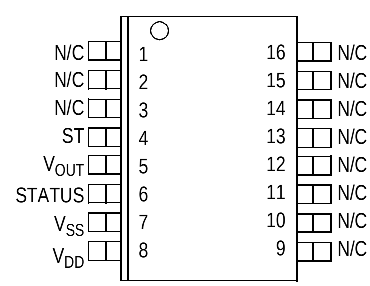


Figure 2. Pin Connections

Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test [1]	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

Table 2. Operating Characteristics
(Unless otherwise noted: $-40°C \le T_A \le +105°C$, $4.75 \le V_{DD} \le 5.25$, Acceleration = 0g, Loaded output.[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range [2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	3.0	—	6.0	mA
Operating Temperature Range	T_A	–40	—	+125	°C
Acceleration Range	g_{FS}	—	169	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.35	2.5	2.65	V
Zero g	$V_{OFF,V}$	0.46 V_{DD}	0.50 V_{DD}	0.54 V_{DD}	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	12.66	13.33	14.00	mV/g
Sensitivity	S_V	2.480	2.667	2.853	mV/g/V
Bandwidth Response	f_{-3dB}	360	400	440	Hz
Nonlinearity	NL_{OUT}	–2.0	—	2.0	% FSO
Noise					
RMS (0.1-1 kHz)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	110	—	$\mu V/(Hz^{1/2})$
Clock Noise (without RC load on output)[6]	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	55	75	95	g
Input Low	V_{IL}	V_{SS}	—	$0.3 \times V_{DD}$	V
Input High	V_{IH}	$0.7 \times V_{DD}$	—	V_{DD}	V
Input Loading[7]	I_{IN}	-30	–100	–260	µA
Response Time[8]	t_{ST}	—	2.0	10	ms
Status[9], [10]					
Output Low (I_{load} = 100 µA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 µA)	V_{OH}	V_{DD} –0.8	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{min}	50	—	260	kHz
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 µA)	V_{FSO}	0.25	—	V_{DD}–0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	300	—	W
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 µF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 V, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at mid supply. For positive acceleration the output will increase above $V_{DD}/2$ and for negative acceleration the output will decrease below $V_{DD}/2$.
5. The device is calibrated at 35g.
6. At clock frequency ≅70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
10. The Status pin output latches high if a Low Voltage Detection or Clock Frequency failure occurs, or the EPROM parity changes to odd. The Status pin can be reset low if the self-test pin is pulsed with a high input for at least 100 µs, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined "cap'' wafer.

The g-cell is a mechanical structure formed from semiconductor materials (poly silicon) using semiconductor processes (masking and etching). It can be modeled as two stationary plates with a moveable plate in-between. The center plate can be deflected from its rest position by subjecting the system to an acceleration (Figure 3).

When the center plate deflects, the distance from it to one fixed plate will increase by the same amount that the distance to the other plate decreases. The change in distance is a measure of acceleration.

The g-cell plates form two back-to-back capacitors (Figure 4). As the center plate moves with acceleration, the distance between the plates changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the plate, ε is the dielectric constant, and D is the distance between the plates.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

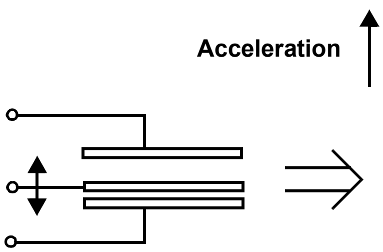


Figure 3. Transducer Physical Model

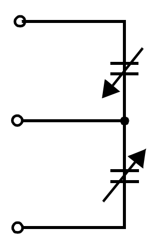


Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an on board 4-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive air bag systems where system integrity must be ensured over the life of the vehicle. A fourth "plate'' is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^1/_2 AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a rising edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

BASIC CONNECTIONS

Pinout Description

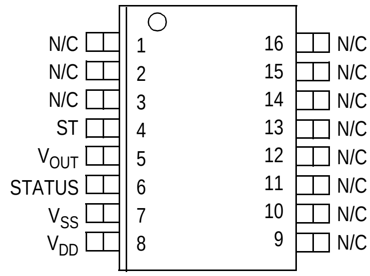


Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	—	Leave unconnected
4	ST	Logic input pin used to initiate self-test
5	V_{OUT}	Output voltage of the accelerometer
6	STATUS	Logic output pin to indicate fault
7	V_{SS}	The power supply ground
8	V_{DD}	The power supply input
9 thru 13	Trim pins	Used for factory trim. Leave unconnected
14 thru 16	—	No internal connection. Leave unconnected

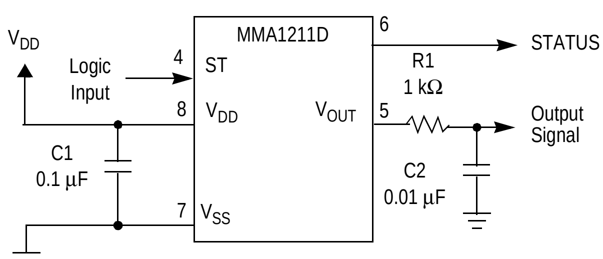


Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

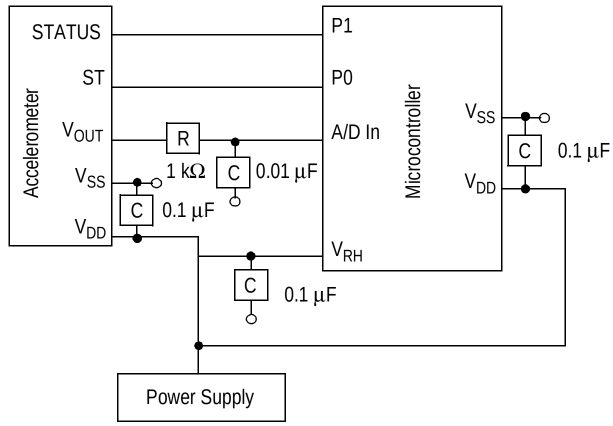
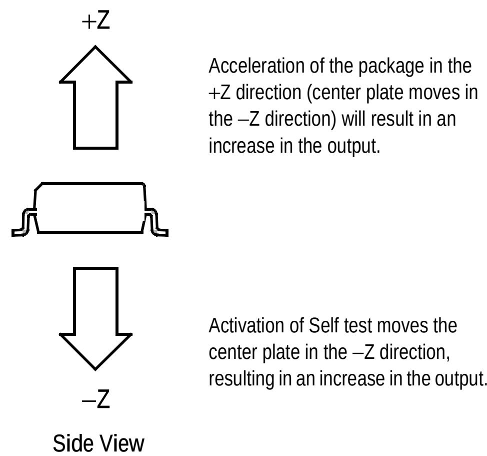


Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

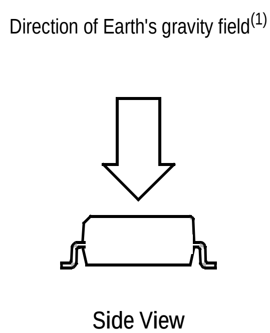
NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

Dynamic Acceleration Sensing Direction



Static Acceleration Sensing Direction



1. When positioned as shown, the Earth's gravity will result in a positive 1g output.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

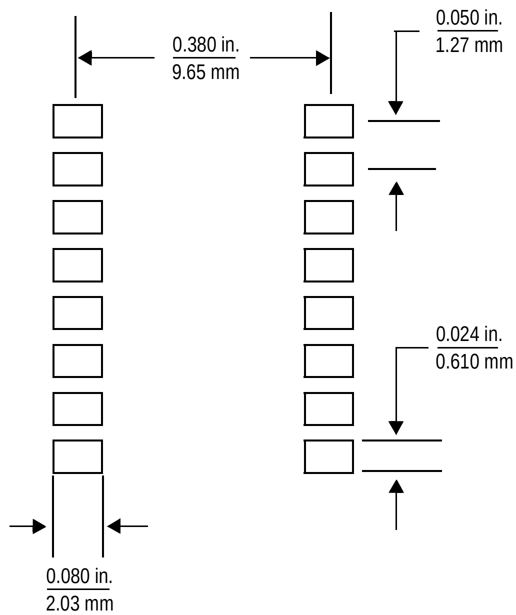


Figure 7. Footprint SOIC-16 (Case 475-01)

Freescale Semiconductor
Technical Data

MMA1212D
Rev 3, 05/2005

MMA1212D

Surface Mount Micromachined Accelerometer

MMA1212D: Z AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±200g

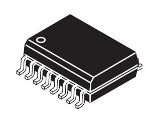
The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 4-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

Features

- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability

Functional Description

- Vibration Monitoring and Recording
- Impact Monitoring



D SUFFIX
16-LEAD SOIC
CASE 475-01

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Case No.**	**Package**
MMA1212D	–40° to 125°C	475-01	SOIC-16
MMA1212DR2	–40° to 125°C	475-01	SOIC16, Tape & Reel

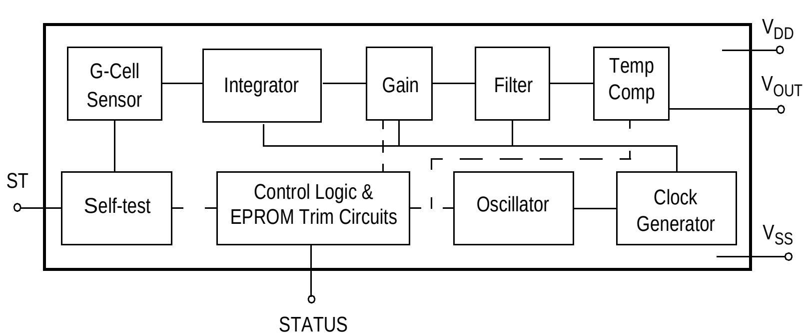


Figure 1. Simplified Accelerometer Functional Block Diagram

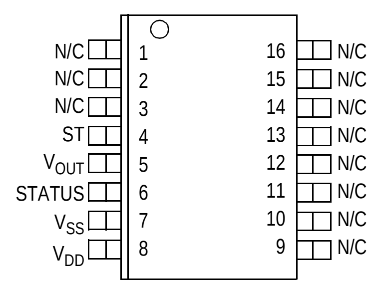


Figure 2. Pin Connections

Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test [(1)]	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

Table 2. Operating Characteristics

(Unless otherwise noted: $-40°C \le T_A \le +105°C$, $4.75 \le V_{DD} \le 5.25$, Acceleration = 0g, Loaded output.[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range [2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	3.0	—	6.0	mA
Operating Temperature Range	T_A	–40	—	+125	C
Acceleration Range	g_{FS}	—	225	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.35	2.5	2.65	V
Zero g	$V_{OFF,V}$	$0.47V_{DD}$	$0.50\ V_{DD}$	$0.53\ V_{DD}$	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	9.5	10	10.5	mV/g
Sensitivity	S_V	1.86	2	2.14	mV/g/V
Bandwidth Response	f_{-3dB}	360	400	440	Hz
Nonlinearity	NL_{OUT}	–2.0	—	2.0	% FSO
Noise					
RMS (0.1-1 kHz)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	110	—	$\mu V/(Hz^{1/2})$
Clock Noise (without RC load on output)[6]	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	55	75	95	g
Input Low	V_{IL}	V_{SS}	—	$0.3 \times V_{DD}$	V
Input High	V_{IH}	$0.7 \times V_{DD}$	—	V_{DD}	V
Input Loading[7]	I_{IN}	–30	–100	–260	µA
Response Time[8]	t_{ST}	—	2.0	10	ms
Status[9], [10]					
Output Low (I_{load} = 100 µA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 µA)	V_{OH}	V_{DD} –.8	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{MIN}	50	—	260	kHz
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 µA)	V_{FSO}	0.25	—	V_{DD}–0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	300	—	W
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 µF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 V, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at mid supply. For positive acceleration the output will increase above $V_{DD}/2$ and for negative acceleration the output will decrease below $V_{DD}/2$.
5. The device is calibrated at 35g.
6. At clock frequency ≅70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
10. The Status pin output latches high if a Low Voltage Detection or Clock Frequency failure occurs, or the EPROM parity changes to odd. The Status pin can be reset low if the self-test pin is pulsed with a high input for at least 100 µs, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined “cap" wafer.

The g-cell is a mechanical structure formed from semiconductor materials (poly silicon) using semiconductor processes (masking and etching). It can be modeled as two stationary plates with a moveable plate in-between. The center plate can be deflected from its rest position by subjecting the system to an acceleration (Figure 3).

When the center plate deflects, the distance from it to one fixed plate will increase by the same amount that the distance to the other plate decreases. The change in distance is a measure of acceleration.

The g-cell plates form two back-to-back capacitors (Figure 4). As the center plate moves with acceleration, the distance between the plates changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the plate, ε is the dielectric constant, and D is the distance between the plates.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

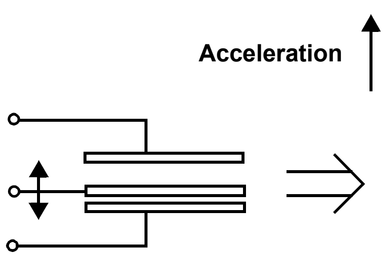


Figure 3. Transducer Physical Model

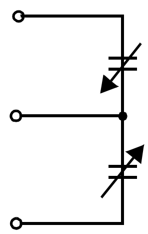


Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an on board 4-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive air bag systems where system integrity must be ensured over the life of the vehicle. A fourth “plate" is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^{1}/_{2}\, AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a falling edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

BASIC CONNECTIONS

Pinout Description

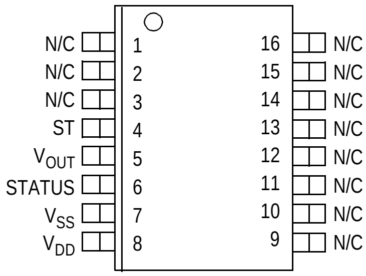


Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	—	Leave unconnected
4	ST	Logic input pin used to initiate self-test
5	V_{OUT}	Output voltage of the accelerometer
6	STATUS	Logic output pin to indicate fault
7	V_{SS}	The power supply ground
8	V_{DD}	The power supply input
9 thru 13	Trim pins	Used for factory trim. Leave unconnected
14 thru 16	—	No internal connection. Leave unconnected

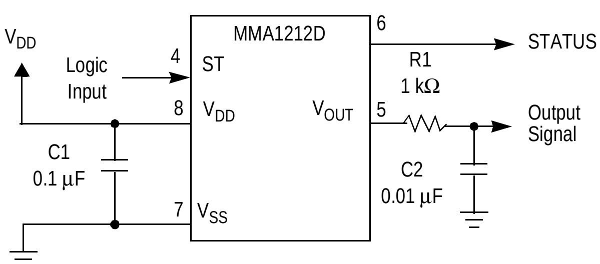


Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

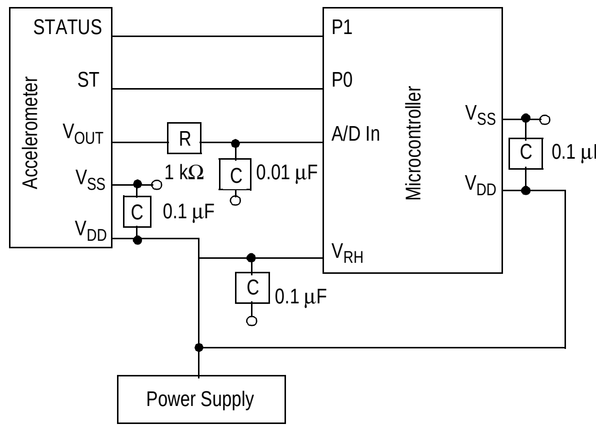
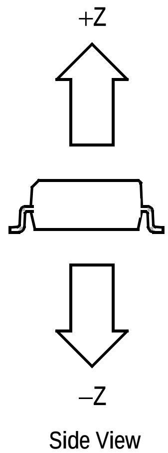


Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

Dynamic Acceleration Sensing Direction

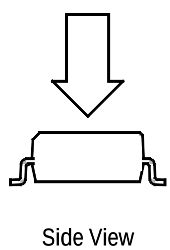


Acceleration of the package in the +Z direction (center plate moves in the –Z direction) will result in an increase in the output.

Activation of Self test moves the center plate in the –Z direction, resulting in an increase in the output.

Static Acceleration Sensing Direction

Direction of Earth's gravity field(1)



1. When positioned as shown, the Earth's gravity will result in a positive 1g output.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

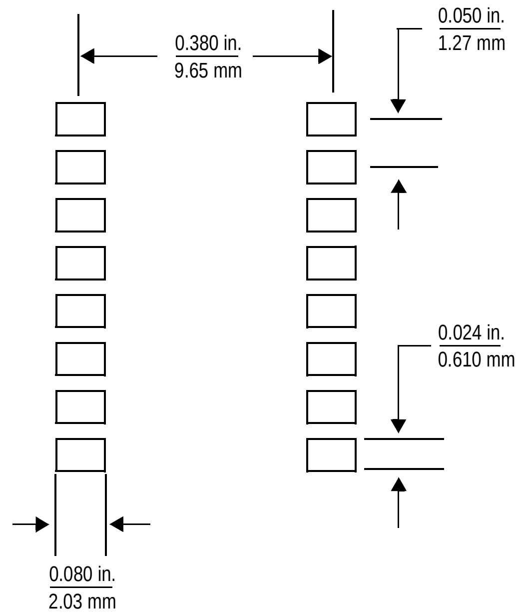


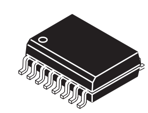
Figure 7. Footprint SOIC-16 (Case 475-01)

MMA1213D

Surface Mount Micromachined Accelerometer

The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 4-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

MMA1213D: Z AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±50g



D SUFFIX
16-LEAD SOIC
CASE 475-01

Features

- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability

Typical Applications

- Vibration Monitoring and Recording
- Impact Monitoring

ORDERING INFORMATION

Device Name	Temperature Range	Case No.	Package
MMA1213D	–40° to 125°C	475-01	SOIC-16
MMA1213DR2	–40° to 125°C	475-01	SOIC16, Tape & Reel

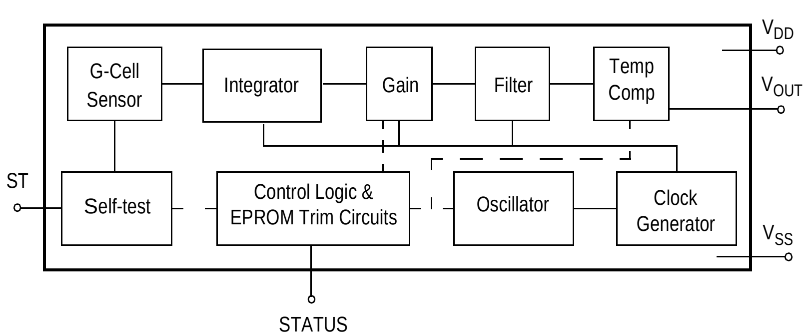


Figure 1. Simplified Accelerometer Functional Block Diagram

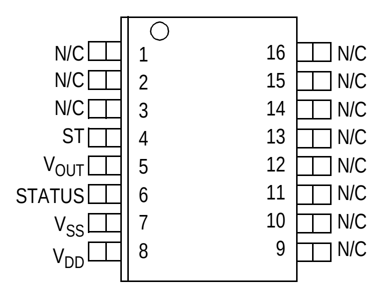


Figure 2. Pin Connections

Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test [(1)]	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

Table 2. Operating Characteristics
(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output.(1))

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range (2)					
Supply Voltage(3)	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	3.0	—	6.0	mA
Operating Temperature Range	T_A	–40	—	+125	C
Acceleration Range	g_{FS}	—	56.3	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)(4)	V_{OFF}	2.35	2.5	2.65	V
Zero g	$V_{OFF,V}$	0.46 V_{DD}	0.50 V_{DD}	0.54 V_{DD}	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)(5)	S	38	40	42	mV/g
Sensitivity	S_V	7.44	8	8.56	mV/g/V
Bandwidth Response	$f_{–3dB}$	360	400	440	Hz
Nonlinearity	NL_{OUT}	–1.0	—	1.0	% FSO
Noise					
RMS (0.1-1 kHz)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	110	—	$\mu V/(Hz^{1/2})$
Clock Noise (without RC load on output)(6)	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	24	30	36	g
Input Low	V_{IL}	V_{SS}	—	0.3 × V_{DD}	V
Input High	V_{IH}	0.7 × V_{DD}	—	V_{DD}	V
Input Loading(7)	I_{IN}	–30	–100	–260	µA
Response Time(8)	t_{ST}	—	2.0	10	ms
Status(9), (10)					
Output Low (I_{load} = 100 µA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 µA)	V_{OH}	V_{DD} –.8	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{MIN}	50	—	260	kHz
Output Stage Performance					
Electrical Saturation Recovery Time(11)	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 µA)	V_{FSO}	–0.25	—	V_{DD} –0.25	V
Capacitive Load Drive(12)	C_L	—	—	100	pF
Output Impedance	Z_O	—	300	—	W
Mechanical Characteristics					
Transverse Sensitivity(13)	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 µF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 V, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at mid supply. For positive acceleration the output will increase above $V_{DD}/2$ and for negative acceleration the output will decrease below $V_{DD}/2$.
5. The device is calibrated at 20g.
6. At clock frequency ≅70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
10. The Status pin output latches high if a Low Voltage Detection or Clock Frequency failure occurs, or the EPROM parity changes to odd. The Status pin can be reset low if the self-test pin is pulsed with a high input for at least 100 µs, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined “cap" wafer.

The g-cell is a mechanical structure formed from semiconductor materials (poly silicon) using semiconductor processes (masking and etching). It can be modeled as two stationary plates with a moveable plate in-between. The center plate can be deflected from its rest position by subjecting the system to an acceleration (Figure 3).

When the center plate deflects, the distance from it to one fixed plate will increase by the same amount that the distance to the other plate decreases. The change in distance is a measure of acceleration.

The g-cell plates form two back-to-back capacitors (Figure 4). As the center plate moves with acceleration, the distance between the plates changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the plate, ε is the dielectric constant, and D is the distance between the plates.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

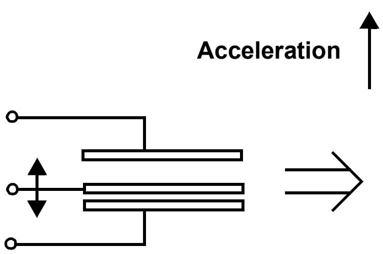


Figure 3. Transducer Physical Model

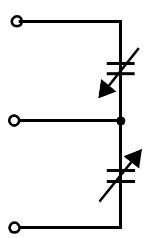


Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an on board 4-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive air bag systems where system integrity must be ensured over the life of the vehicle. A fourth “plate" is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^{1}/_{2}\ AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a rising edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

BASIC CONNECTIONS

Pinout Description

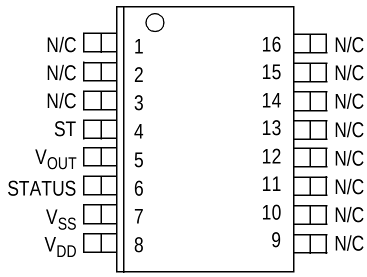


Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	—	Leave unconnected
4	ST	Logic input pin used to initiate self-test
5	V_{OUT}	Output voltage of the accelerometer
6	STATUS	Logic output pin to indicate fault
7	V_{SS}	The power supply ground
8	V_{DD}	The power supply input
9 thru 13	Trim pins	Used for factory trim. Leave unconnected
14 thru 16	—	No internal connection. Leave unconnected

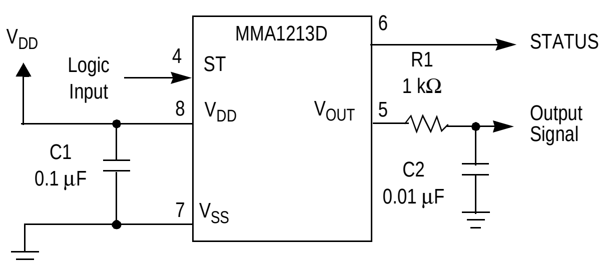


Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

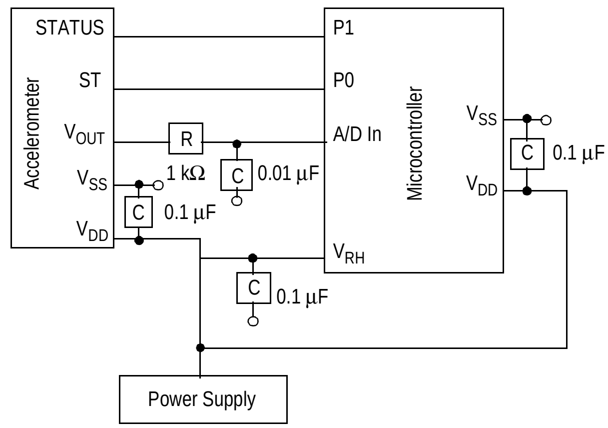
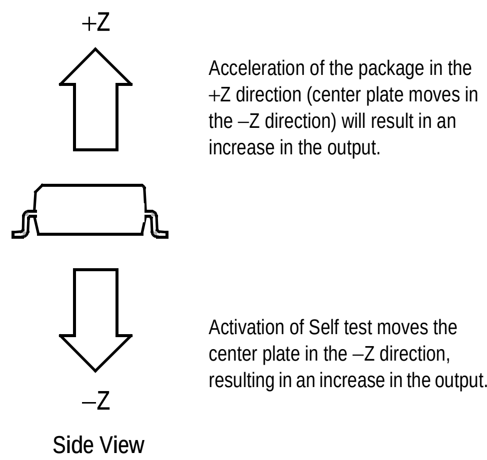


Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

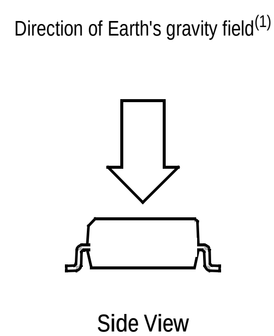
NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

Dynamic Acceleration Sensing Direction



Static Acceleration Sensing Direction



1. When positioned as shown, the Earth's gravity will result in a positive 1g output.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

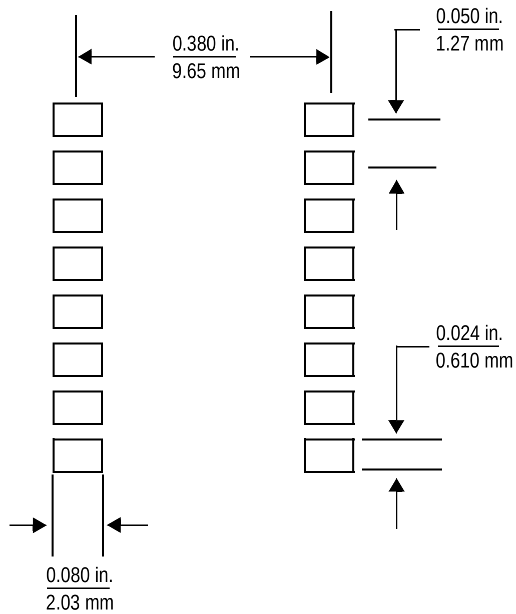


Figure 7. Footprint SOIC-16 (Case 475-01)

Low G
Micromachined Accelerometer

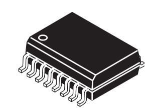
MMA1220D

The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 4-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

MMA1220D: Z AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±8g

Features

- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability



D SUFFIX
16-LEAD SOIC
CASE 475-01

Typical Applications

- Vibration Monitoring and Recording
- Appliance Control
- Mechanical Bearing Monitoring
- Computer Hard Drive Protection
- Computer Mouse and Joysticks
- Virtual Reality Input Devices
- Sport Diagnostic Devices and Systems

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Case No.**	**Package**
MMA1220D	–40° to 125°C	475-01	SOIC-16
MMA1220DR2	–40° to 125°C	475-01	SOIC16, Tape & Reel

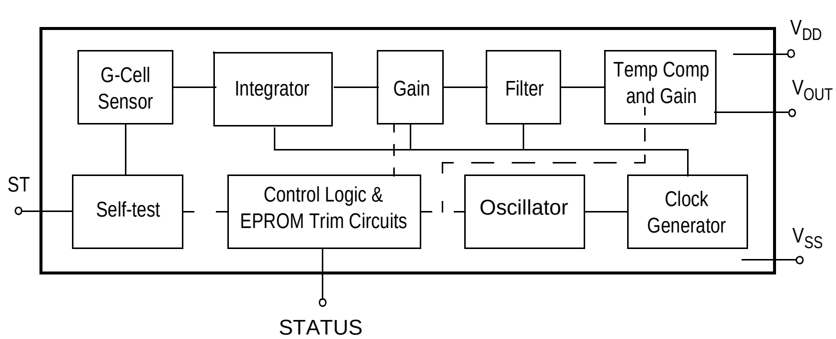


Figure 1. Simplified Accelerometer Functional Block Diagram

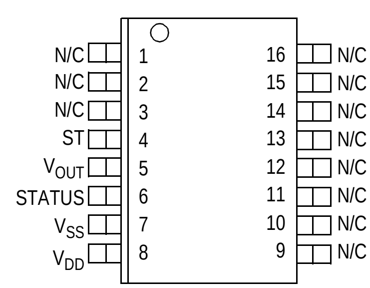


Figure 2. Pin Connections

Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test [(1)]	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

Table 2. Operating Characteristics
(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output.(1))

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range(2)					
Supply Voltage(3)	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	3.0	5.0	6.0	mA
Operating Temperature Range	T_A	–40	—	+125	°C
Acceleration Range	g_{FS}	—	11.0	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)(4)	V_{OFF}	2.25	2.5	2.75	V
Zero g	$V_{OFF,V}$	0.45 V_{DD}	0.50 V_{DD}	0.55 V_{DD}	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)(5)	S	237.5	250	262.5	mV/g
Sensitivity	S_V	46.5	50	53.5	mV/g/V
Bandwidth Response	f_{-3dB}	150	250	350	Hz
Nonlinearity	NL_{OUT}	–1.0	—	+3.0	% FSO
Noise					
RMS (10 Hz – 1 kHz)	n_{RMS}	—	—	6.0	mVrms
Clock Noise (without RC load on output)(6)	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	ΔV_{ST}	0.2 V_{DD}	—	0.3 V_{DD}	V
Input Low	V_{IL}	V_{SS}	—	0.3 V_{DD}	V
Input High	VIH	0.7 V_{DD}	—	V_{DD}	V
Input Loading(7)	I_{IN}	–50	–100	–200	µA
Response Time(8)	t_{ST}	—	2.0	10	ms
Status(9), (10)					
Output Low (I_{load} = 100 µA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 µA)	V_{OH}	V_{DD} – 0.8	—	—	V
Output Stage Performance					
Electrical Saturation Recovery Time(11)	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 µA)	V_{FSO}	V_{SS} + 0.25	—	V_{DD} – 0.25	V
Capacitive Load Drive(12)	C_L	—	—	100	pF
Output Impedance	Z_O	—	300	—	W
Mechanical Characteristics					
Transverse Sensitivity(13)	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 µF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 volts, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above $V_{DD}/2$ and for negative acceleration the output will decrease below $V_{DD}/2$.
5. The device is calibrated at 5g.
6. At clock frequency ≅70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
10. The Status pin output latches high if a Low Voltage Detection or Clock Frequency failure occurs, or the EPROM parity changes to odd. The Status pin can be reset low if the self-test pin is pulsed with a high input for at least 100 µs, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined “cap" wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as two stationary plates with a moveable plate in-between. The center plate can be deflected from its rest position by subjecting the system to an acceleration (Figure 3).

When the center plate deflects, the distance from it to one fixed plate will increase by the same amount that the distance to the other plate decreases. The change in distance is a measure of acceleration.

The g-cell plates form two back-to-back capacitors (Figure 4). As the center plate moves with acceleration, the distance between the plates changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the plate, ε is the dielectric constant, and D is the distance between the plates.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

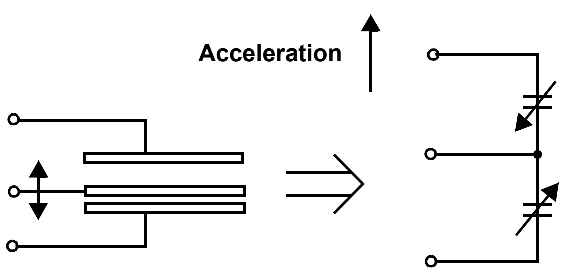


Figure 3. Transducer Physical Model

Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an onboard 4-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive airbag systems where system integrity must be ensured over the life of the vehicle. A fourth “plate" is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^1/_2\ AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a falling edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

BASIC CONNECTIONS

Pinout Description

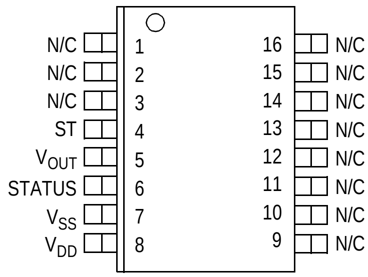


Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	—	Redundant V_{SS}. Leave unconnected.
4	ST	Logic input pin used to initiate self-test.
5	V_{OUT}	Output voltage of the accelerometer.
6	STATUS	Logic output pin to indicate fault.
7	V_{SS}	The power supply ground.
8	V_{DD}	The power supply input.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

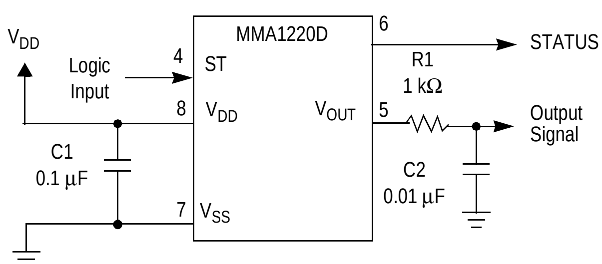


Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

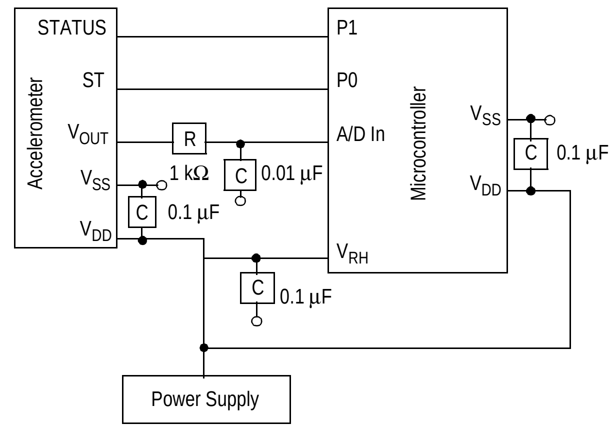
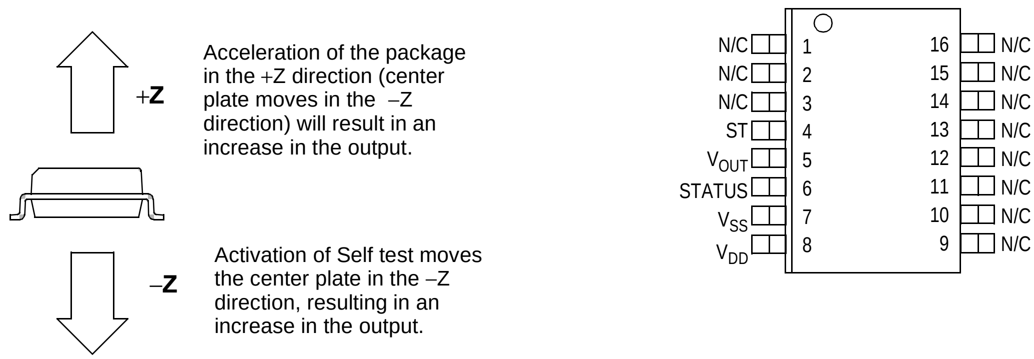


Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

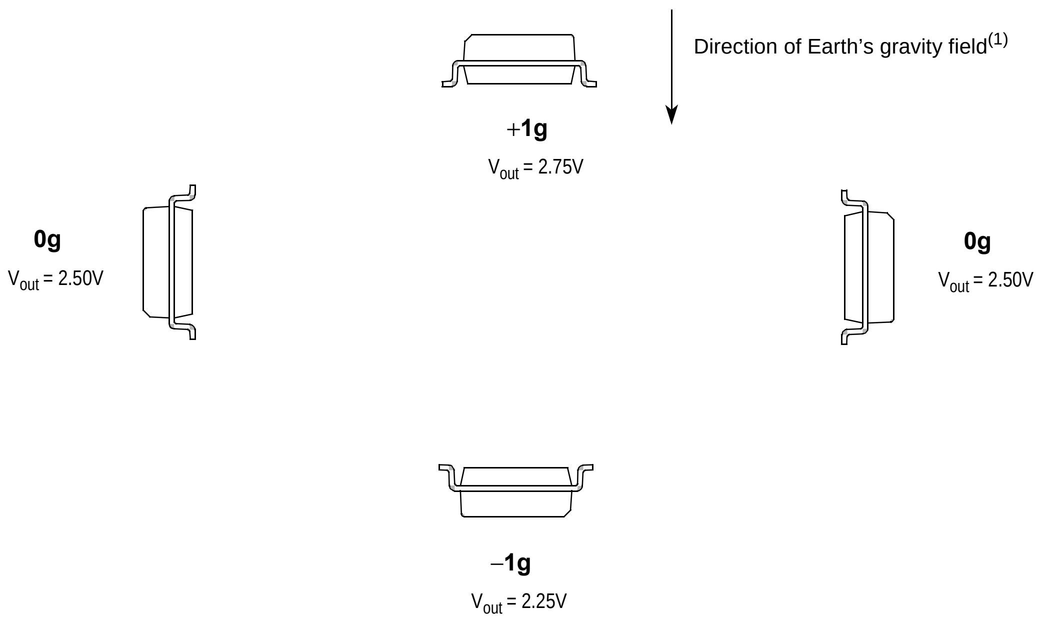
NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

DYNAMIC ACCELERATION SENSING DIRECTION



STATIC ACCELERATION SENSING DIRECTION



1. When positioned as shown, the Earth's gravity will result in a positive 1g output.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

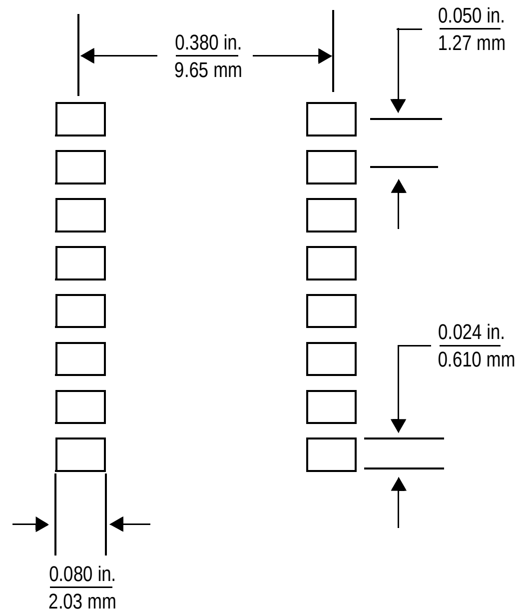


Figure 7. Footprint SOIC-16 (Case 475-01)

Low G Micromachined Accelerometer

MMA1250D

The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 2-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

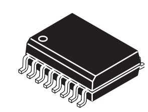
MMA1250D: Z AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±5g

Features

- Integral Signal Conditioning
- Linear Output
- 2nd Order Bessel Filter
- Calibrated Self-test
- EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shock Survivability

Typical Applications

- Vibration Monitoring and Recording
- Appliance Control
- Mechanical Bearing Monitoring
- Computer Hard Drive Protection
- Computer Mouse and Joysticks
- Virtual Reality Input Devices
- Sports Diagnostic Devices and Systems



D SUFFIX
16-LEAD SOIC
CASE 475-01

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Case No.**	**Package**
MMA1250D	–40° to 125°C	475-01	SOIC-16

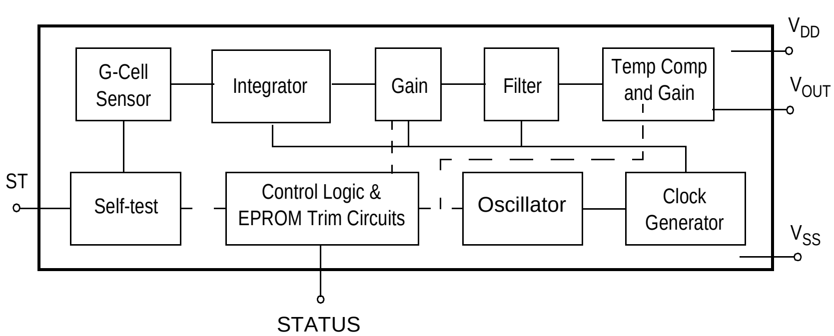


Figure 1. Simplified Accelerometer Functional Block Diagram

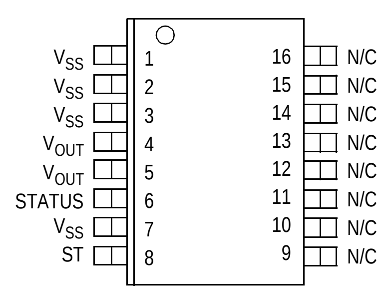


Figure 2. Pin Connections

Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test [(1)]	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

Table 2. Operating Characteristics
(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output.[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	3.0	2.1	3.0	mA
Operating Temperature Range	T_A	–40	—	+105	°C
Acceleration Range	g_{FS}	—	5	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.25	2.5	2.75	V
Zero g (V_{DD} = 5.0 V)	V_{OFF}	2.0	2.5	3.0	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	380	400	420	mV/g
Sensitivity (V_{DD} = 5.0 V)	S	370	400	430.1	mV/g/V
Bandwidth Response	f_{-3dB}	42.5	50	57.5	Hz
Nonlinearity	NL_{OUT}	–1.0	—	+1.0	% FSO
Noise					
RMS (0.1 Hz – 1.0 kHz)	n_{RMS}	—	2.0	4.0	mVrms
Spectral Density (RMS, 0.1 Hz – 1.0 KHz)[6]	n_{SD}	—	700	—	$\mu g/\sqrt{Hz}$
Self-Test					
Output Response (V_{DD} = 5.0 V)	ΔV_{ST}	1.0	1.25	1.5	V
Input Low	V_{IL}	V_{SS}	—	0.3 V_{DD}	V
Input High	V_{IH}	0.7 V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	–50	–125	–300	µA
Response Time[8]	t_{ST}	—	2.0	25	ms
Status[9], [10]					
Output Low (I_{load} = 100 µA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 µA)	V_{OH}	V_{DD} –0.8	—	—	V
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	—	2.0	ms
Full Scale Output Range (I_{OUT} = 200 µA)	V_{FSO}	V_{SS} + 0.25	—	V_{DD} – 0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	50	—	W
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 µF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 volts, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above $V_{DD}/2$ and for negative acceleration the output will decrease below $V_{DD}/2$.
5. The device is calibrated at 5g.
6. At clock frequency ≅70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
10. The Status pin output latches high if a Low Voltage Detection or Clock Frequency failure occurs, or the EPROM parity changes to odd. The Status pin can be reset low if the self-test pin is pulsed with a high input for at least 100 µs, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined "cap" wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as two stationary plates with a moveable plate in-between. The center plate can be deflected from its rest position by subjecting the system to an acceleration (Figure 3).

When the center plate deflects, the distance from it to one fixed plate will increase by the same amount that the distance to the other plate decreases. The change in distance is a measure of acceleration.

The g-cell plates form two back-to-back capacitors (Figure 4). As the center plate moves with acceleration, the distance between the plates changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the plate, ε is the dielectric constant, and D is the distance between the plates.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

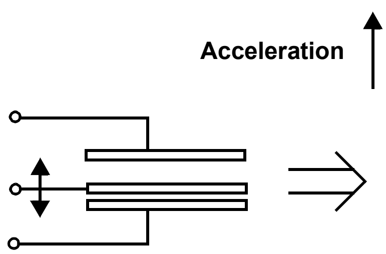


Figure 3. Transducer Physical Model

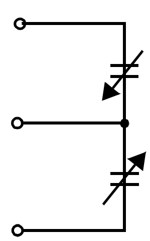


Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an onboard 2-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive airbag systems where system integrity must be ensured over the life of the vehicle. A fourth "plate" is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^{1}/_{2}\, AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever the following event occurs:

- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a rising edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

BASIC CONNECTIONS

Pinout Description

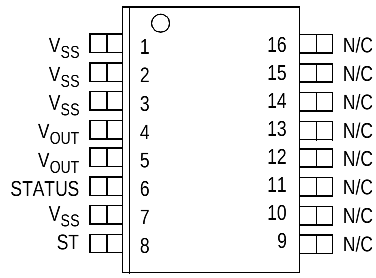


Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	V_{SS}	Redundant connections to the internal V_{SS} and may be left unconnected.
4	V_{OUT}	Output voltage of the accelerometer.
5	STATUS	Logic output pin to indicate fault.
6	V_{DD}	The power supply input.
7	V_{SS}	The power supply ground.
8	ST	Logic input pin used to initiate self-test.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

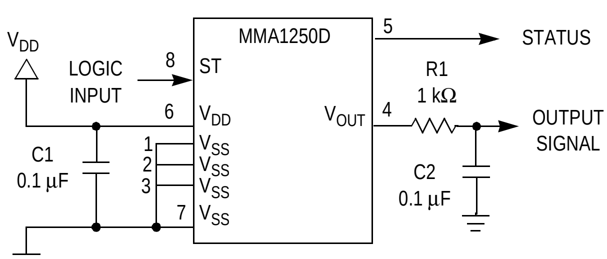


Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

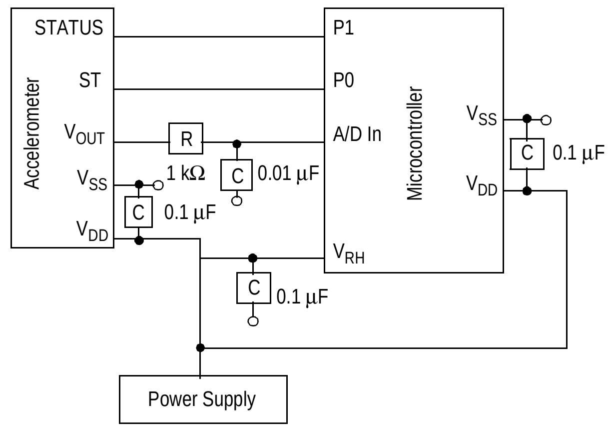


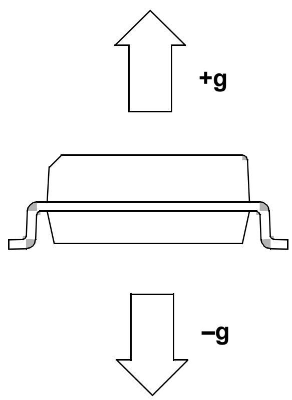
Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

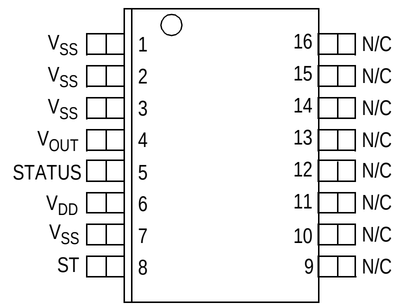
NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

ACCELERATION SENSING DIRECTIONS

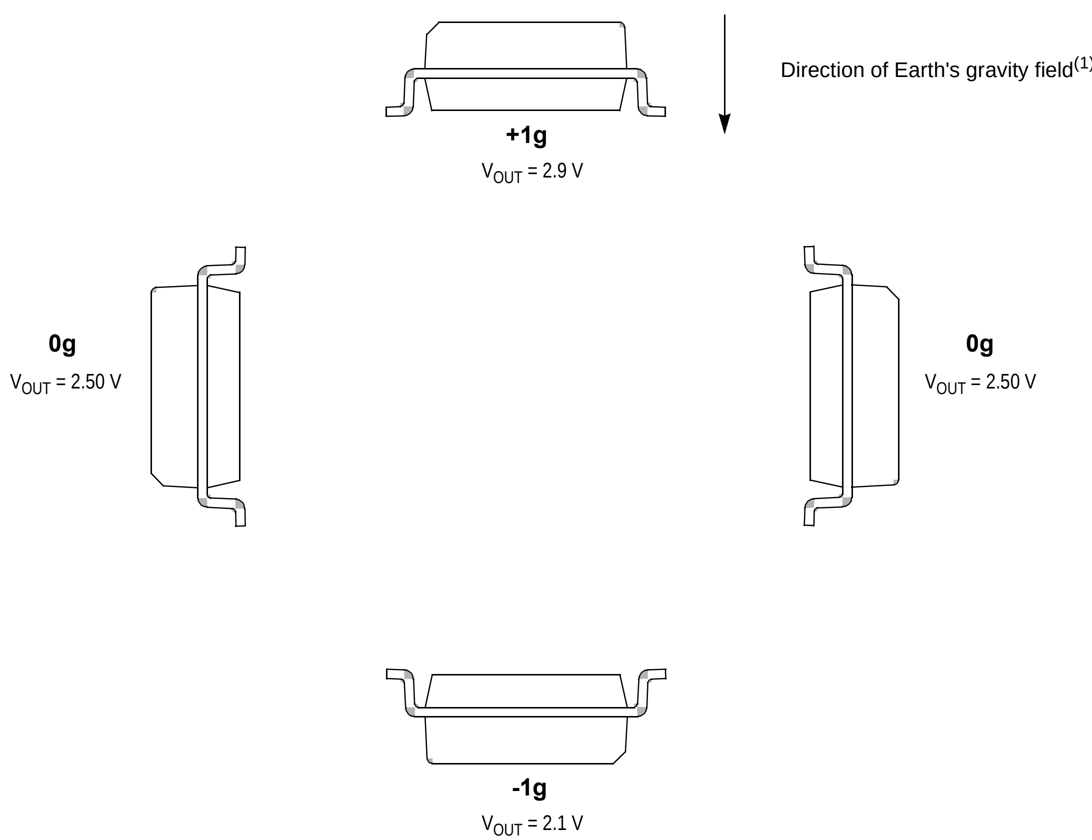
DYNAMIC ACCELERATION





16-Pin SOIC Package
N/C pins are recommended to be left FLOATING

STATIC ACCELERATION



1. When positioned as shown, the Earth's gravity will result in a positive 1g output

Low G
Micromachined Accelerometer

MMA1260D

MMA1260D: Z AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±1.5g

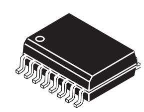
The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 2-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

Features

- Integral Signal Conditioning
- Linear Output
- 2nd Order Bessel Filter
- Calibrated Self-test
- EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shock Survivability

Typical Applications

- Vibration Monitoring and Recording
- Appliance Control
- Mechanical Bearing Monitoring
- Computer Hard Drive Protection
- Computer Mouse and Joysticks
- Virtual Reality Input Devices
- Sports Diagnostic Devices and Systems



D SUFFIX
16-LEAD SOIC
CASE 475-01

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Case No.**	**Package**
MMA1260D	–40° to 105°C	475-01	SOIC-16

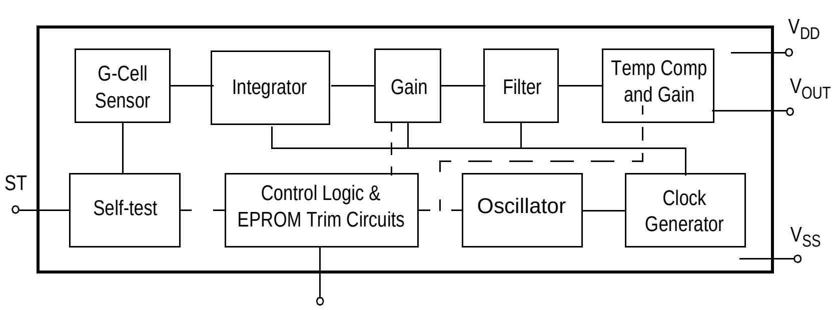


Figure 1. Simplified Accelerometer Functional Block Diagram

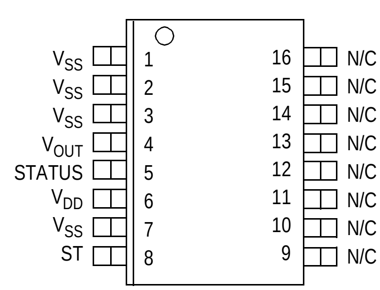


Figure 2. Pin Connections

Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test [(1)]	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

Table 2. Operating Characteristics
(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output.[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	1.1	2.2	3.2	mA
Operating Temperature Range	T_A	–40	—	+105	°C
Acceleration Range	g_{FS}	—	1.55	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.25	2.5	2.75	V
Zero g (V_{DD} = 5.0 V)	V_{OFF}	2.2	2.5	2.8	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	1140	1200	1260	mV/g
Sensitivity (V_{DD} = 5.0 V)	S	1110	1200	1290	mV/g/V
Bandwidth Response	$f_{–3dB}$	40	50	60	Hz
Nonlinearity	NL_{OUT}	–1.0	—	+1.0	% FSO
Noise					
RMS (0.1 Hz – 1.0 kHz)	n_{RMS}	—	5.0	9.0	mVrms
Spectral Density (RMS, 0.1 Hz – 1.0 KHz)[6]	n_{SD}	—	500	—	$\mu g/\sqrt{Hz}$
Self-Test					
Output Response (V_{DD} = 5.0 V)	ΔV_{ST}	0.3	0.6	0.9	V
Input Low	V_{IL}	V_{SS}	—	0.3 V_{DD}	V
Input High	V_{IH}	0.7 V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	–50	–25	–300	µA
Response Time[8]	t_{ST}	—	10	25	ms
Status[9], [10]					
Output Low (I_{load} = 100 µA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 µA)	V_{OH}	V_{DD} – 0.8	—	—	V
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	—	2.0	ms
Full Scale Output Range (I_{OUT} = 200 µA)	V_{FSO}	V_{SS} + 0.25	—	V_{DD} – 0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	50	—	W
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 µF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 volts, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above $V_{DD}/2$ and for negative acceleration the output will decrease below $V_{DD}/2$.
5. The device is calibrated at 5g.
6. At clock frequency ≅70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
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11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
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PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined "cap" wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as two stationary plates with a moveable plate in-between. The center plate can be deflected from its rest position by subjecting the system to an acceleration (Figure 3).

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The g-cell plates form two back-to-back capacitors (Figure 4). As the center plate moves with acceleration, the distance between the plates changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the plate, ε is the dielectric constant, and D is the distance between the plates.

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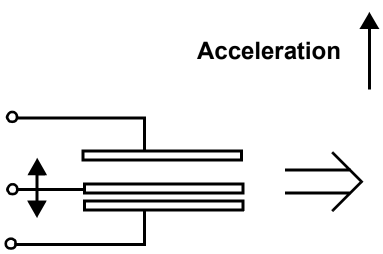

Figure 3. Transducer Physical Model

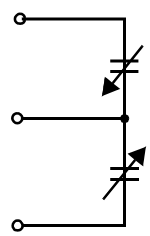

Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an onboard 2-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

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Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever the following event occurs:

- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a rising edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

BASIC CONNECTIONS

Pinout Description

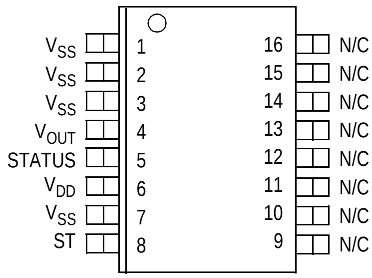


Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	V_{SS}	Redundant connections to the internal V_{SS} and may be left unconnected.
4	V_{OUT}	Output voltage of the accelerometer.
5	STATUS	Logic output pin to indicate fault.
6	V_{DD}	The power supply input.
7	V_{SS}	The power supply ground.
8	ST	Logic input pin used to initiate self-test.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

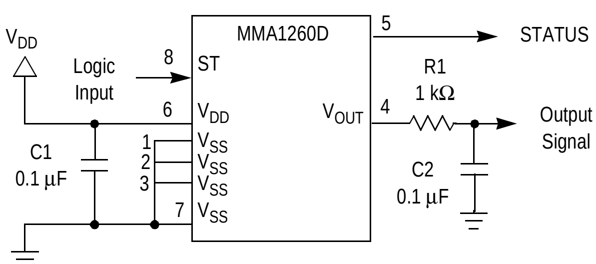


Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

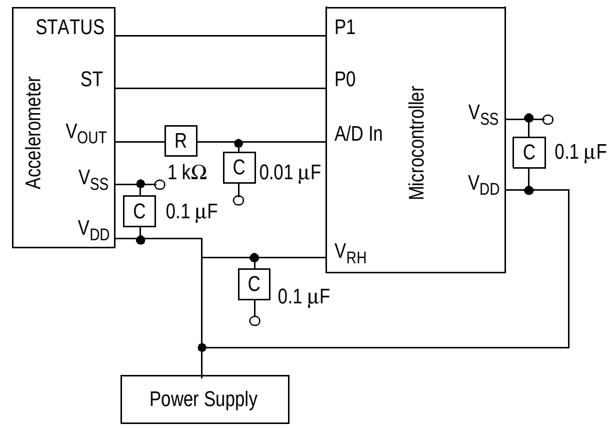


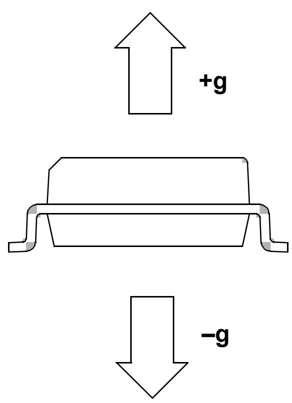
Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

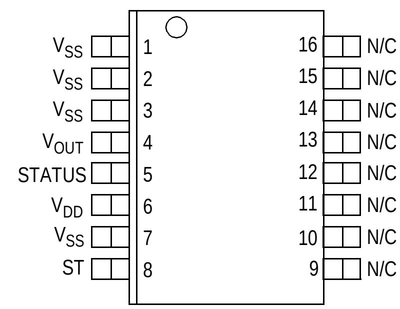
NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

ACCELERATION SENSING DIRECTIONS

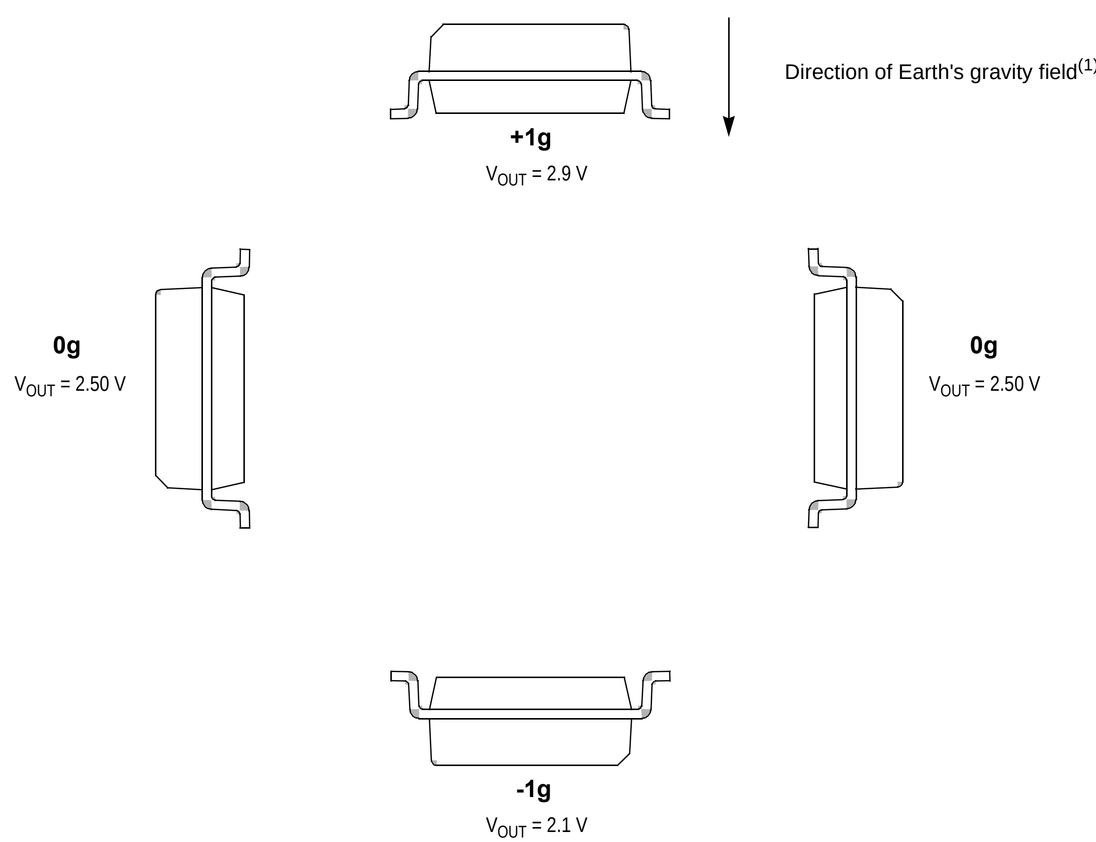
DYNAMIC ACCELERATION





16-Pin SOIC Package
N/C pins are recommended to be left FLOATING

STATIC ACCELERATION



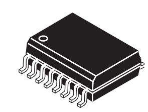
1. When positioned as shown, the Earth's gravity will result in a positive 1g output

Low G
Micromachined Accelerometer

MMA1270D

The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 2-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

MMA1270D: Z AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±2.5g



D SUFFIX
16-LEAD SOIC
CASE 475-01

Features

- Integral Signal Conditioning
- Linear Output
- 2nd Order Bessel Filter
- Calibrated Self-test
- EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shock Survivability

Typical Applications

- Vibration Monitoring and Recording
- Appliance Control
- Mechanical Bearing Monitoring
- Computer Hard Drive Protection
- Computer Mouse and Joysticks
- Virtual Reality Input Devices
- Sports Diagnostic Devices and Systems

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Case No.**	**Package**
MMA1270D	–40° to 105°C	475-01	SOIC-16

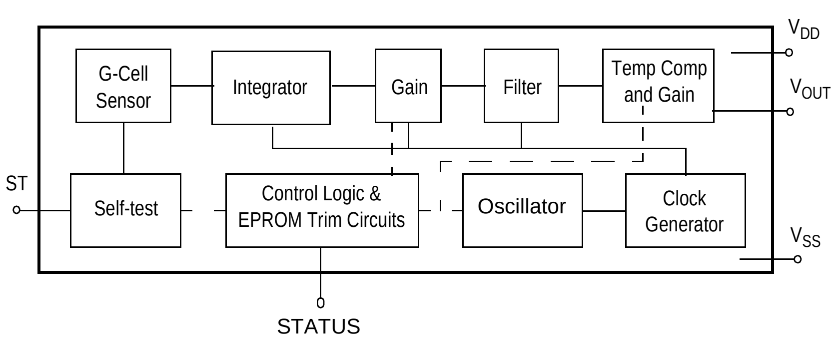


Figure 1. Simplified Accelerometer Functional Block Diagram

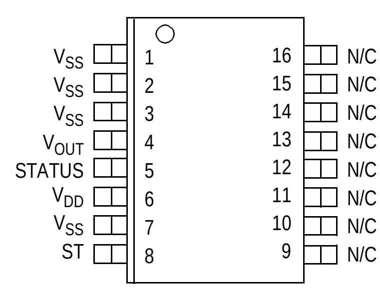


Figure 2. Pin Connections

Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test (1)	H_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

Table 2. Operating Characteristics
(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output.[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	1.1	2.1	3.0	mA
Operating Temperature Range	T_A	– 40	—	+105	°C
Acceleration Range	g_{FS}	—	2.5	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.25	2.5	2.75	V
Zero g (V_{DD} = 5.0 V)	V_{OFF}	2.2	2.5	2.8	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	712.5	750	787.5	mV/g
Sensitivity (V_{DD} = 5.0 V)	S	693.8	750	806.3	mV/g
Bandwidth Response	f_{-3dB}	40	50	60	Hz
Nonlinearity	NL_{OUT}	– 1.0	—	+1.0	% FSO
Noise					
RMS (0.1 Hz – 1.0 kHz)	n_{RMS}	—	3.5	6.5	mVrms
Spectral Density (RMS, 0.1 Hz – 1.0 KHz)[6]	n_{SD}	—	700	—	$\mu g/\sqrt{Hz}$
Self-Test					
Output Response (V_{DD} = 5.0 V)	ΔV_{ST}	0.9	1.25	1.6	V
Input Low	V_{IL}	V_{SS}	—	0.3 V_{DD}	V
Input High	V_{IH}	0.7 V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	– 50	– 125	– 300	µA
Response Time[8]	t_{ST}	—	10	25	ms
Status[9], [10]					
Output Low (I_{load} = 100 µA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 µA)	V_{OH}	V_{DD} – 0.8	—	—	V
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	—	2.0	ms
Full Scale Output Range (I_{OUT} = 200 µA)	V_{FSO}	V_{SS} +0.25	—	V_{DD} – 0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	50	—	Ω
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 µF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 volts, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above $V_{DD}/2$ and for negative acceleration the output will decrease below $V_{DD}/2$.
5. Sensitivity limits apply to 0 Hz acceleration.
6. At clock frequency ≅ 35 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high.
10. The Status pin output latches high if the EPROM parity changes to odd. The Status pin can be reset by rising edge on self-test, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined “cap'' wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as two stationary plates with a moveable plate in-between. The center plate can be deflected from its rest position by subjecting the system to an acceleration (Figure 3).

When the center plate deflects, the distance from it to one fixed plate will increase by the same amount that the distance to the other plate decreases. The change in distance is a measure of acceleration.

The g-cell plates form two back-to-back capacitors (Figure 4). As the center plate moves with acceleration, the distance between the plates changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the plate, ε is the dielectric constant, and D is the distance between the plates.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

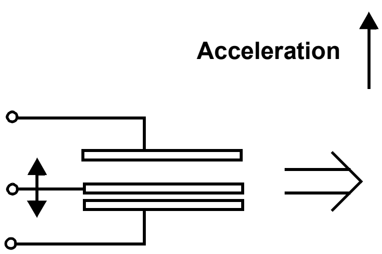


Figure 3. Transducer Physical Model

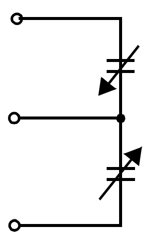


Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an onboard 2-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive airbag systems where system integrity must be ensured over the life of the vehicle. A fourth “plate'' is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^{1}/_{2}\ AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever the following event occurs:

- Parity of the EPROM bits becomes odd in number.
- The fault latch can be reset by a rising edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

BASIC CONNECTIONS

Pinout Description

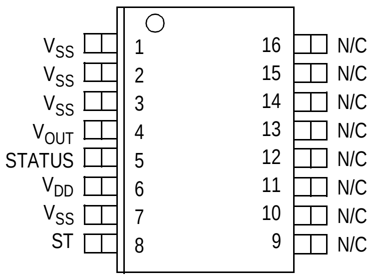


Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	V_{SS}	Redundant connections to the internal V_{SS} and may be left unconnected.
4	V_{OUT}	Output voltage of the accelerometer.
5	STATUS	Logic output pin used to indicate fault.
6	V_{DD}	The power supply input.
7	V_{SS}	The power supply ground.
8	ST	Logic input pin used to initiate self-test.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

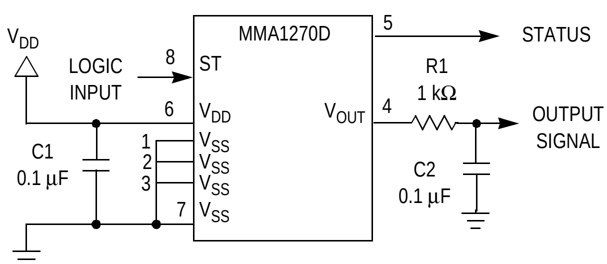


Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

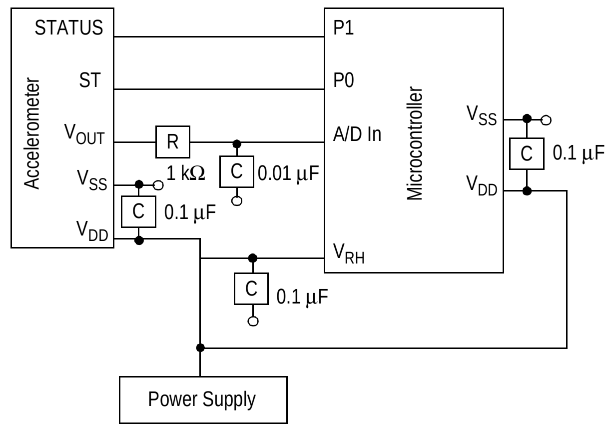


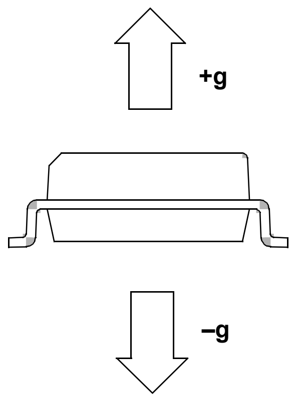
Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

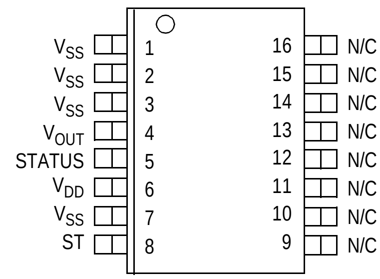
NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

ACCELERATION SENSING DIRECTIONS

DYNAMIC ACCELERATION

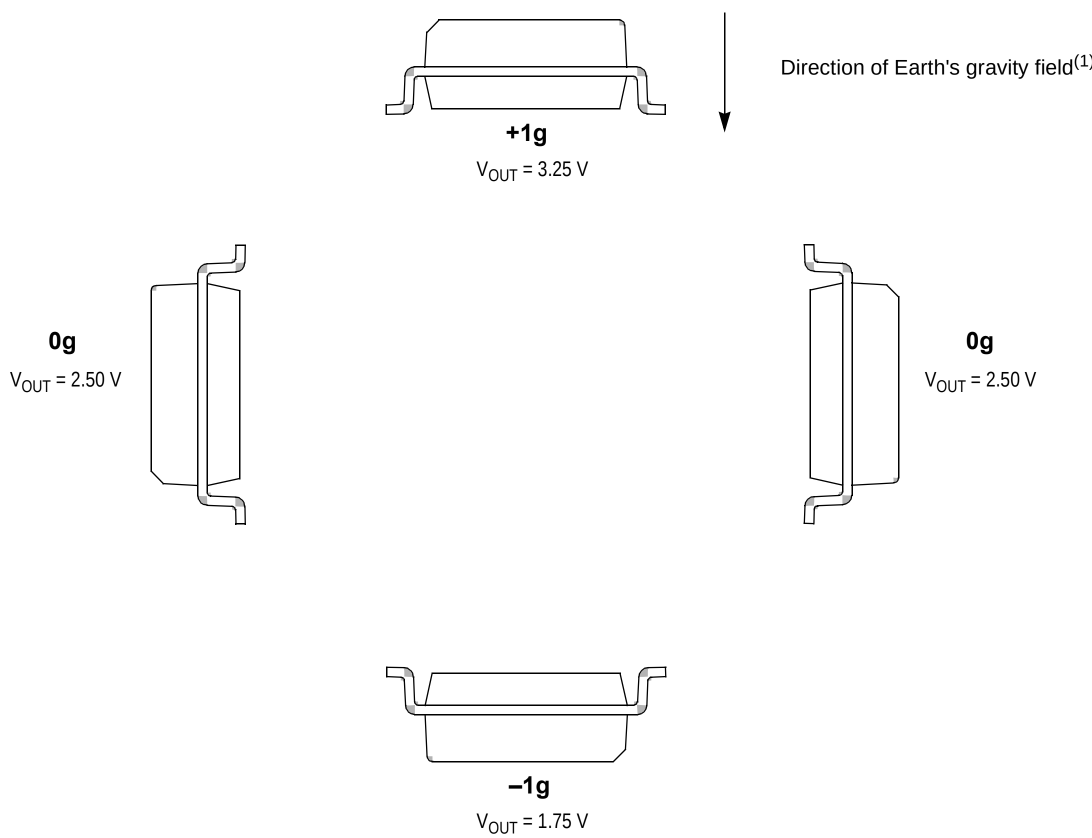




16-Pin SOIC Package

N/C pins are recommended to be left FLOATING

STATIC ACCELERATION



1. When positioned as shown, the Earth's gravity will result in a positive 1g output

Low G
Micromachined Accelerometer

MMA2201D

The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 4-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

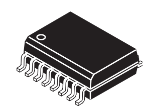
Features

- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability

Typical Applications

- Vibration Monitoring and Recording
- Appliance Control
- Mechanical Bearing Monitoring
- Computer Hard Drive Protection
- Computer Mouse and Joysticks
- Virtual Reality Input Devices
- Sport Diagnostic Devices and Systems

MMA2201D: X AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±40g



**D SUFFIX
16-LEAD SOIC
CASE 475-01**

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Case No.**	**Package**
MMA2201D	–40° to 105°C	475-01	SOIC-16
MMA2201DR2	–40° to 105°C	475-01	SOIC16, Tape & Reel

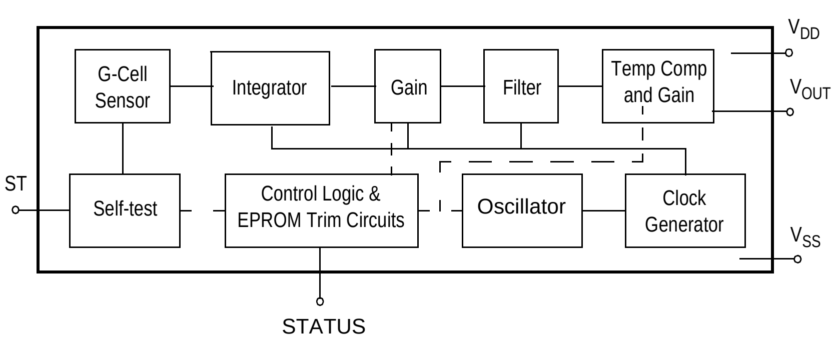


Figure 1. Simplified Accelerometer Functional Block Diagram

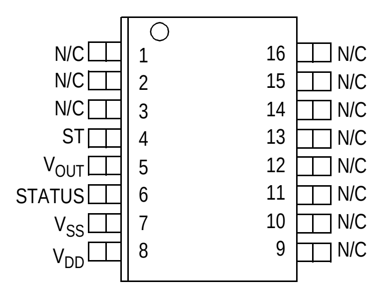


Figure 2. Pin Connections

Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test (1)	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

Table 2. Operating Characteristics
(Unless otherwise noted: $-40°C \le T_A \le +105°C$, $4.75 \le V_{DD} \le 5.25$, Acceleration = 0g, Loaded output.(1))

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range(2)					
Supply Voltage(3)	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	4.0	5.0	6.0	mA
Operating Temperature Range	T_A	–40	—	+125	°C
Acceleration Range	g_{FS}	—	45	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)(4)	V_{OFF}	2.35	2.5	2.65	V
Zero g	$V_{OFF,V}$	0.46 V_{DD}	0.50 V_{DD}	0.54 V_{DD}	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)(5)	S	47.5	50	52.5	mV/g
Sensitivity	S_V	9.3	10	10.7	mV/g/V
Bandwidth Response	f_{-3dB}	360	400	440	Hz
Nonlinearity	NL_{OUT}	–1.0	—	+1.0	% FSO
Noise					
RMS (10 Hz – 1 kHz)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	110	—	$\mu V/(Hz^{1/2})$
Clock Noise (without RC load on output)(6)	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	10	12	14	g
Input Low	V_{IL}	V_{SS}	—	$0.3 \times V_{DD}$	V
Input High	V_{IH}	$0.7 \times V_{DD}$	—	V_{DD}	V
Input Loading(7)	I_{IN}	–30	–100	–300	µA
Response Time(8)	t_{ST}	—	2.0	10	ms
Status(9), (10)					
Output Low (I_{load} = 100 µA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 µA)	V_{OH}	V_{DD} –0.8	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{min}	150	—	400	kHz
Output Stage Performance					
Electrical Saturation Recovery Time(11)	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 µA)	V_{FSO}	0.25	—	V_{DD} –0.25	V
Capacitive Load Drive(12)	C_L	—	—	100	pF
Output Impedance	Z_O	—	300	—	Ω
Mechanical Characteristics					
Transverse Sensitivity(13)	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 µF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 volts, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above $V_{DD}/2$ and for negative acceleration the output will decrease below $V_{DD}/2$.
5. The device is calibrated at 20g.
6. At clock frequency ≅70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
10. The Status pin output latches high if a Low Voltage Detection or Clock Frequency failure occurs, or the EPROM parity changes to odd. The Status pin can be reset low if the self-test pin is pulsed with a high input for at least 100 µs, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined “cap” wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that moves between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration (Figure 3).

When the beams attached to the center mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell beams form two back-to-back capacitors (Figure 4). As the center plate moves with acceleration, the distance between the beams change and each capacitor's value will change, ($C = NA\varepsilon/D$). Where A is the area of the facing side of the beam, ε is the dielectric constant, and D is the distance between the beams, and N is the number of beams.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

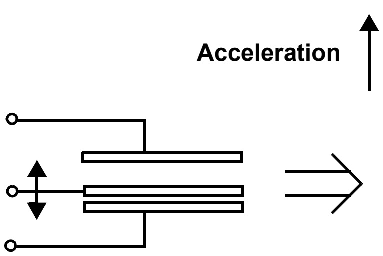


Figure 3. Transducer Physical Model

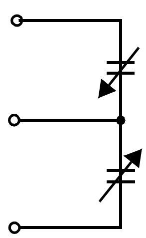


Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an onboard 4-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive airbag systems where system integrity must be ensured over the life of the vehicle. A fourth “plate” is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^1/_2 AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer’s control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a falling edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

BASIC CONNECTIONS

Pinout Description

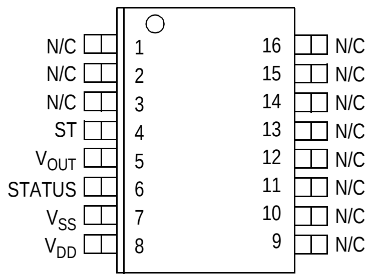


Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	—	Leave unconnected.
4	ST	Logic input pin used to initiate self-test.
5	V_{OUT}	Output voltage of the accelerometer.
6	STATUS	Logic output pin to indicate fault.
7	V_{SS}	The power supply ground.
8	V_{DD}	The power supply input.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

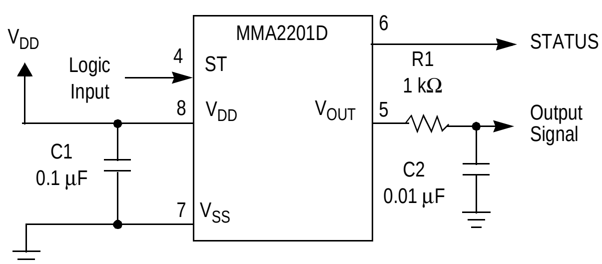


Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

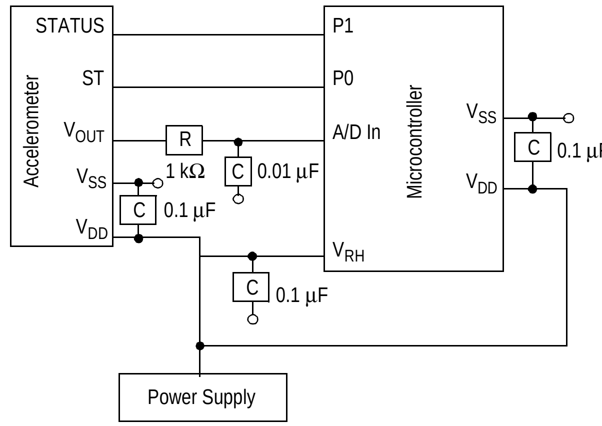


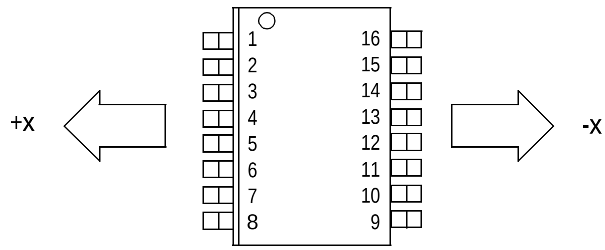
Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

Dynamic Acceleration Sensing Direction

Acceleration of the package in the +X direction (center plate moves in the –X direction) will result in an increase in the output.

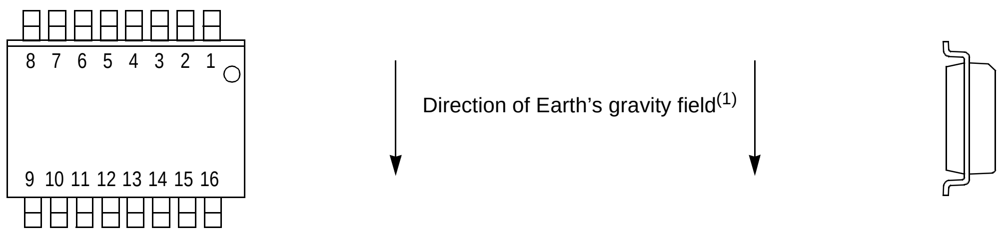


Activation of Self test moves the center plate in the –X direction, resulting in an increase in the output.

Top View

16-Pin SOIC Package
N/C pins are recommended to be left FLOATING

Static Acceleration Sensing Direction



Front View **Side View**

1. When positioned as shown, the Earth's gravity will result in a positive 1g output.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

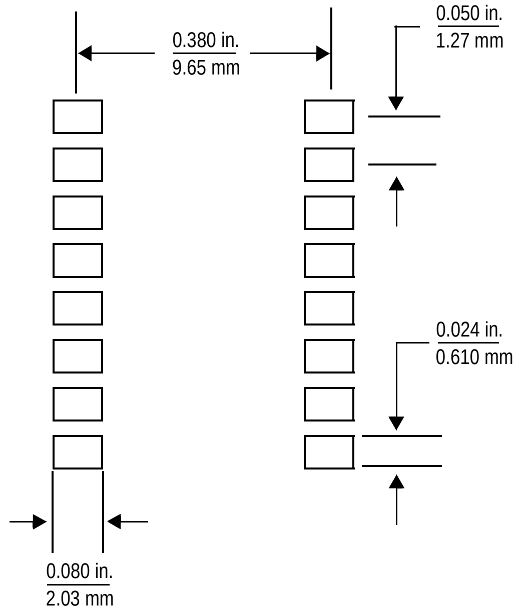


Figure 7. Footprint SOIC-16 (Case 475-01)

Surface Mount Micromachined Accelerometer

The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 4-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

Features

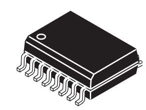
- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability

Typical Applications

- Vibration Monitoring and Recording
- Appliance Control
- Mechanical Bearing Monitoring
- Computer Hard Drive Protection
- Computer Mouse and Joysticks
- Virtual Reality Input Devices
- Sport Diagnostic Devices and Systems

MMA2202D

MMA2202D: X AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±50g



D SUFFIX
16-LEAD SOIC
CASE 475-01

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Case No.**	**Package**
MMA2202D	–40° to 125°C	475-01	SOIC-16
MMA2202DR2	–40° to 125°C	475-01	SOIC16, Tape & Reel

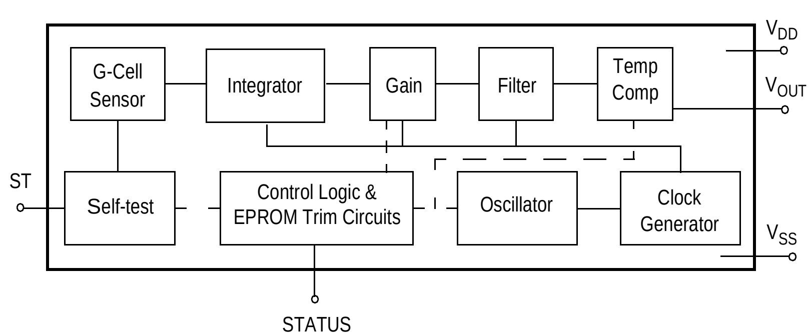


Figure 1. Simplified Accelerometer Functional Block Diagram

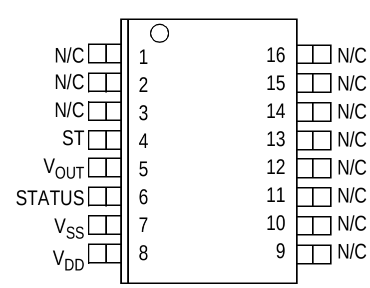


Figure 2. Pin Connections

Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test [1]	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

Table 2. Operating Characteristics
(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output.[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	4.0	5.0	6.0	mA
Operating Temperature Range	T_A	−40	—	+125	C
Acceleration Range	g_{FS}	—	56.3	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.35	2.5	2.65	V
Zero g	$V_{OFF,V}$	$0.46V_D$	0.50 V_{DD}	0.54 V_{DD}	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	38	40	42	mV/g
Sensitivity	S_V	7.44	8	8.56	mV/g/V
Bandwidth Response	f_{-3dB}	360	400	440	Hz
Nonlinearity	NL_{OUT}	–1.0	—	+1.0	% FSO
Noise					
RMS (10 Hz – 1 kHz)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	110	—	$\mu V/(Hz^{1/2})$
Clock Noise (without RC load on output)[6]	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	10	12	14	g
Input Low	V_{IL}	V_{SS}	—	0.3 x V_{DD}	V
Input High	VIH	0.7 x V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	–30	–100	–300	µA
Response Time[8]	t_{ST}	—	2.0	10	ms
Status[9], [10]					
Output Low (I_{load} = 100 µA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 µA)	V_{OH}	V_{DD} –0.8	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{min}	150	—	400	kHz
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 µA)	V_{FSO}	0.25	—	V_{DD} –0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	300	—	W
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 µF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 V and 5.25 V, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above $V_{DD}/2$ and for negative acceleration the output will decrease below $V_{DD}/2$.
5. The device is calibrated at 20g.
6. At clock frequency ≅ 70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
10. The Status pin output latches high if a Low Voltage Detection or Clock Frequency failure occurs, or the EPROM parity changes to odd. The Status pin can be reset low if the self-test pin is pulsed with a high input for at least 100 µs, unless a fault condition continues to exist. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 µF capacitor to ground.
11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined "cap" wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that moves between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration (Figure 3).

When the beams attached to the center mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell beams form two back-to-back capacitors (Figure 4). As the center plate moves with acceleration, the distance between the beams change and each capacitor's value will change, ($C = NA\varepsilon/D$). Where A is the area of the facing side of the beam, ε is the dielectric constant, and D is the distance between the beams, and N is the number of beams.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

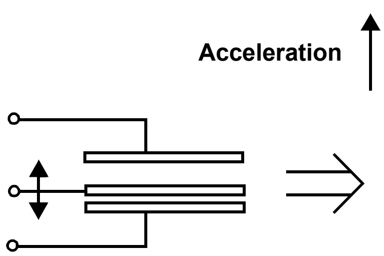


Figure 3. Transducer Physical Model

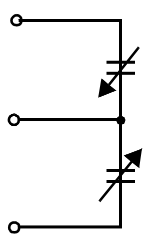


Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an onboard 4-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive airbag systems where system integrity must be ensured over the life of the vehicle. A fourth "plate" is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^{1}/_{2}\, AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a falling edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

BASIC CONNECTIONS

Pinout Description

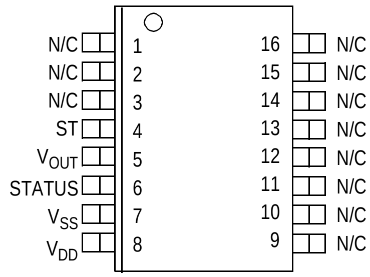


Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	—	No internal connection. Leave unconnected.
4	ST	Logic input pin used to initiate self-test.
5	V_{OUT}	Output voltage of the accelerometer.
6	STATUS	Logic output pin to indicate fault.
7	V_{SS}	The power supply ground.
8	V_{DD}	The power supply input.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

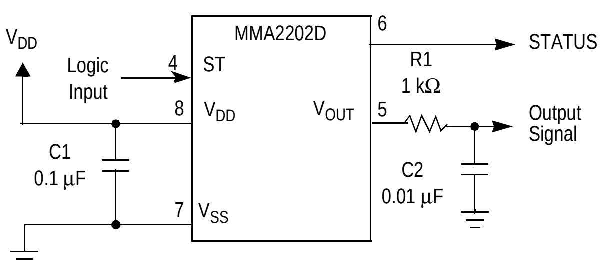


Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

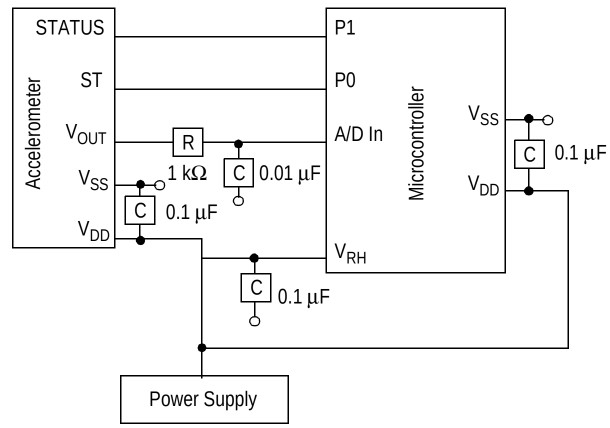


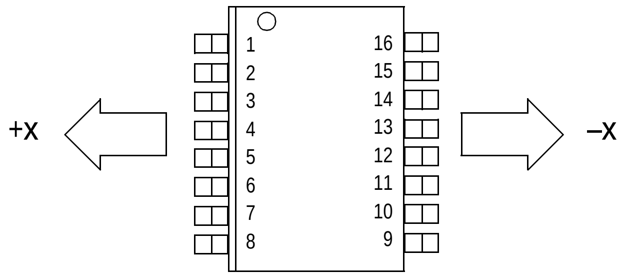
Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

Dynamic Acceleration Sensing Direction

Acceleration of the package in the +X direction (center plate moves in the –X direction) will result in an increase in the output.

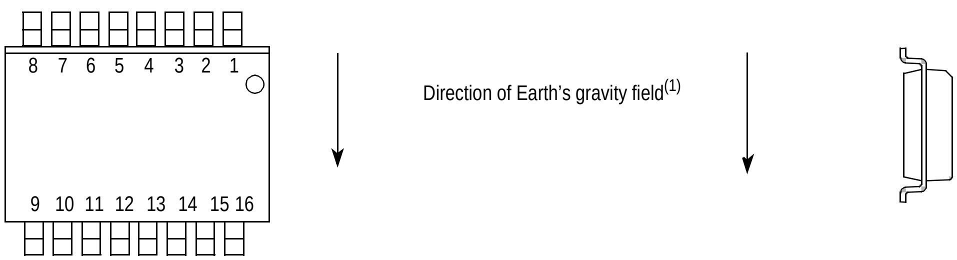


Activation of Self Test moves the center plate in the –X direction, resulting in an increase in the output.

16-Pin SOIC Package
N/C pins are recommended to be left FLOATING

Top View

Static Acceleration Sensing Direction



Front View

Side View

1. When positioned as shown, the Earth's gravity will result in a positive 1g output.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

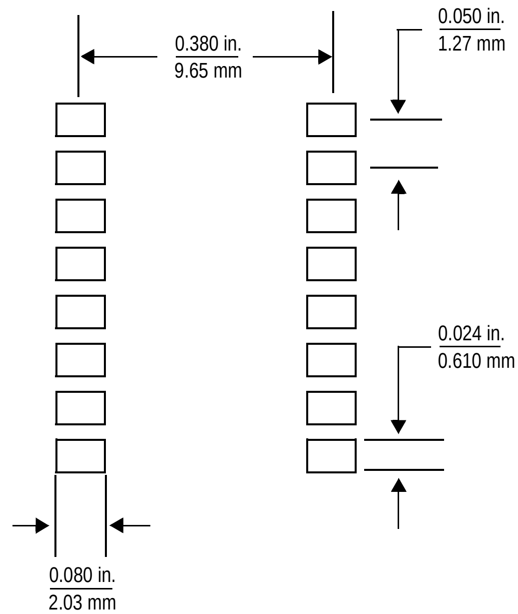


Figure 7. Footprint SOIC-16 (Case 475-01)

Surface Mount Micromachined Accelerometer

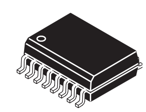
MMA2204D

The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 4-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

MMA2204D: X AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±100g

Features

- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability



D SUFFIX
16-LEAD SOIC
CASE 475-01

Typical Applications

- Vibration Monitoring and Recording
- Appliance Control
- Mechanical Bearing Monitoring
- Computer Hard Drive Protection
- Computer Mouse and Joysticks
- Virtual Reality Input Devices
- Sport Diagnostic Devices and Systems

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Case No.**	**Package**
MMA2204D	–40° to 125°C	475-01	SOIC-16
MMA2204DR2	–40° to 125°C	475-01	SOIC16, Tape & Reel

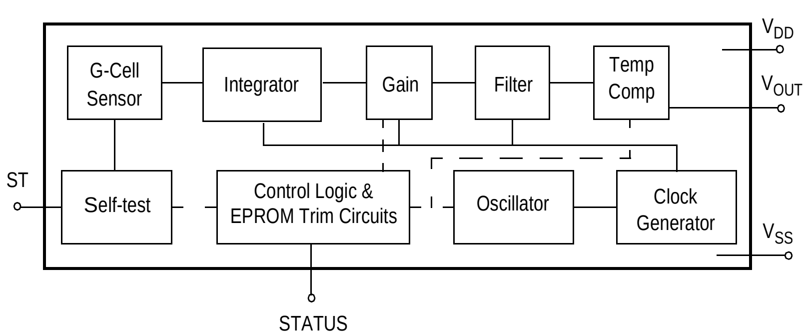


Figure 1. Simplified Accelerometer Functional Block Diagram

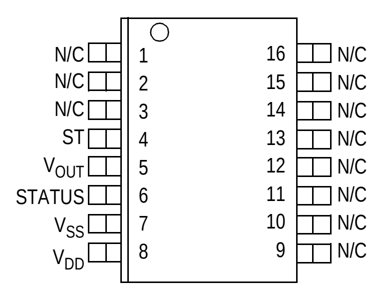


Figure 2. Pin Connections

Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test [1]	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

Table 2. Operating Characteristics
(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output.[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	4.0	5.0	6.0	mA
Operating Temperature Range	T_A	–40	—	+125	°C
Acceleration Range	g_{FS}	—	112.5	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.35	2.5	2.65	V
Zero g	$V_{OFF,V}$	0.46 V_{DD}	0.50 V_{DD}	0.54 V_{DD}	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	19	20	21	mV/g
Sensitivity	S_V	3.72	4	4.28	mV/g/V
Bandwidth Response	$f_{–3dB}$	360	400	440	Hz
Nonlinearity	NL_{OUT}	–1.0	—	+1.0	% FSO
Noise					
RMS (.01 Hz – 1 kHz)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	110	—	μV/($Hz^{1/2}$)
Clock Noise (without RC load on output)[6]	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	10	12	14	g
Input Low	V_{IL}	V_{SS}	—	0.3 × V_{DD}	V
Input High	V_{IH}	0.7 × V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	–30	–110	–300	μA
Response Time[8]	t_{ST}	—	2.0	10	ms
Status[9], [10]					
Output Low (I_{load} = 100 μA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 μA)	V_{OH}	V_{DD} –0.8	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{min}	150	—	400	kHz
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 μA)	V_{FSO}	0.25	—	V_{DD} –0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	300	—	W
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 μF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 V, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above $V_{DD}/2$ and for negative acceleration the output will decrease below $V_{DD}/2$.
5. The device is calibrated at 20g.
6. At clock frequency ≅ 70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
10. The Status pin output latches high if a Low Voltage Detection or Clock Frequency failure occurs, or the EPROM parity changes to odd. The Status pin can be reset low if the self-test pin is pulsed with a high input for at least 100 μs, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined "cap'' wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that moves between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration (Figure 3).

When the beams attached to the center mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell beams form two back-to-back capacitors (Figure 4). As the center plate moves with acceleration, the distance between the beams change and each capacitor's value will change, ($C = NA\varepsilon/D$). Where A is the area of the facing side of the beam, ε is the dielectric constant, and D is the distance between the beams, and N is the number of beams.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

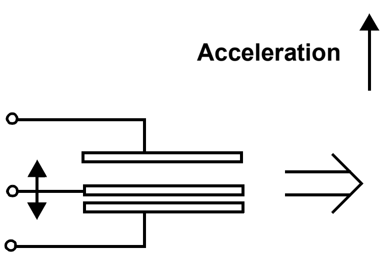


Figure 3. Transducer Physical Model

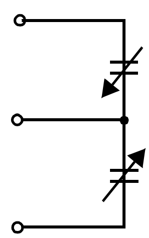


Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an onboard 4-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive airbag systems where system integrity must be ensured over the life of the vehicle. A fourth "plate'' is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^{1}/_{2}\, AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a falling edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

BASIC CONNECTIONS

Pinout Description

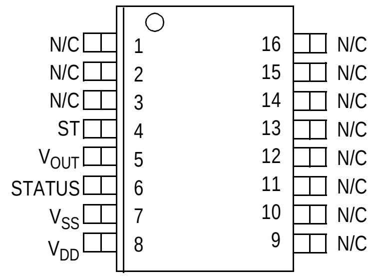


Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	—	No internal connection. Leave unconnected.
4	ST	Logic input pin used to initiate self-test.
5	V_{OUT}	Output voltage of the accelerometer.
6	STATUS	Logic output pin to indicate fault.
7	V_{SS}	The power supply ground.
8	V_{DD}	The power supply input.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

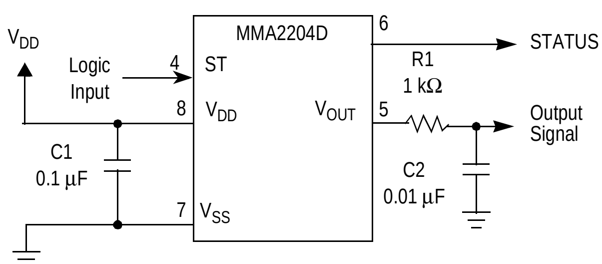


Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

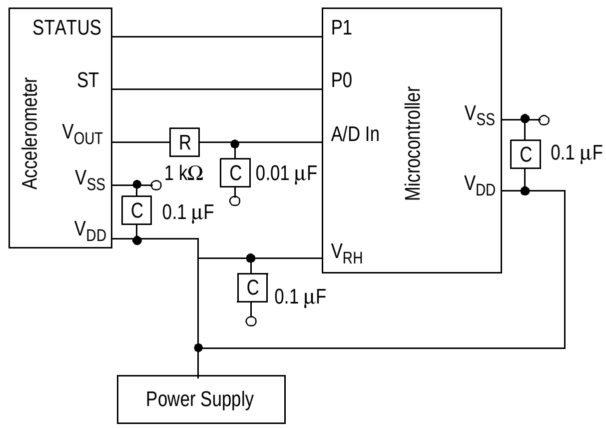


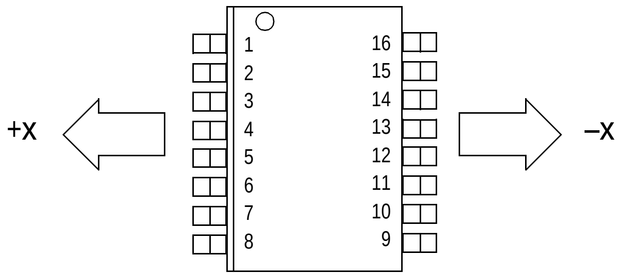
Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

Dynamic Acceleration Sensing Direction

Acceleration of the package in the +X direction (center plate moves in the –X direction) will result in an increase in the output.

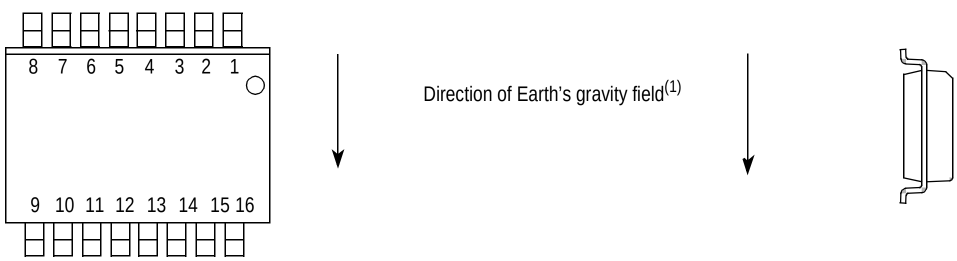


Activation of Self Test moves the center plate in the –X direction, resulting in an increase in the output.

16-Pin SOIC Package
N/C pins are recommended to be left FLOATING

Top View

Static Acceleration Sensing Direction



Front View

Side View

1. When positioned as shown, the Earth's gravity will result in a positive 1g output.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

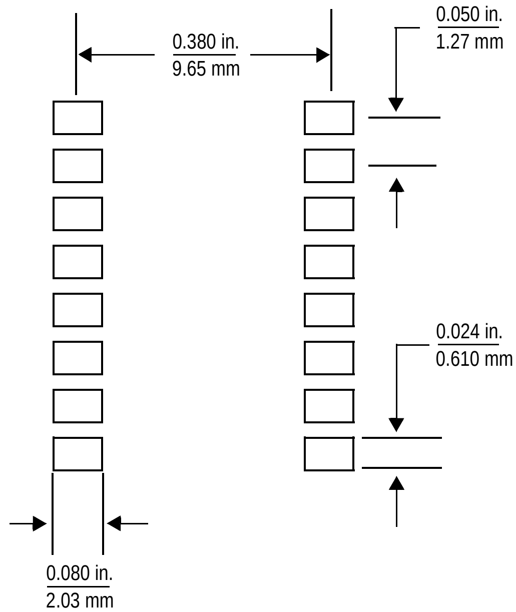


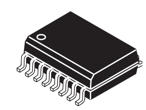
Figure 7. Footprint SOIC-16 (Case 475-01)

±1.5g X-Axis Micromachined Accelerometer

MMA2260D

The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 2-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

MMA2260D: X AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±1.5g



D SUFFIX
16-LEAD SOIC
CASE 475-01

Features

- Integral Signal Conditioning
- High Sensitivity
- Linear Output
- 2nd Order Bessel Filter
- Calibrated Self-test
- EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shock Survivability

Typical Applications

- Tilt Monitoring
- Inclinometers
- Appliance Control
- Mechanical Bearing Monitoring
- Vibration Monitoring and Recording
- Sports Diagnostic Devices and Systems
- Trailer Brake Controls
- Automotive Aftermarket

ORDERING INFORMATION

Device	Temperature Range	Case No.	Package
MMA2260D	–40 to +105°C	475-01	SOIC-16
MMA2260DR2	–40 to +105°C	475-01	SOIC-16, Tape & Reel

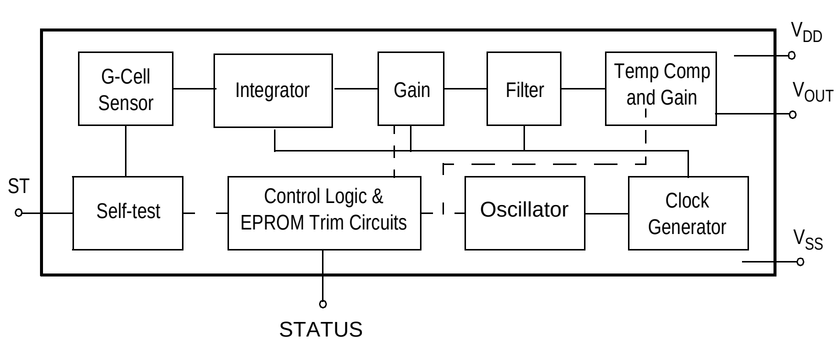


Figure 1. Simplified Accelerometer Functional Block Diagram

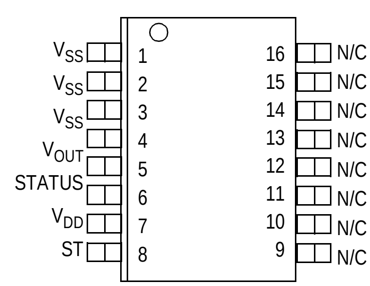


Figure 2. Pin Connections

Table 1. Maximum Ratings[1]
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Unpowered Acceleration (all axes)	g_{upd}	2000	g
Supply Voltage	V_{DD}	-0.3 to +7.0	V
Drop Test[1]	H_{drop}	1.2	m
Storage Temperature Range	T_{stg}	-40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

Table 2. Operating Characteristics

(Unless otherwise noted: $-40°C \le T_A \le +105°C$, $4.75 \le V_{DD} \le 5.25$, Acceleration = 0g, Loaded output(1))

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range(2)					
Supply Voltage(3)	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	1.1	2.2	3.2	mA
Operating Temperature Range	T_A	–40	–	+105	°C
Acceleration Range	g_{FS}	–	1.5	–	g
Output Signal					
Zero g (V_{DD} = 5.0 V)(4)	V_{OFF}	2.3	2.5	2.7	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)(5)	S	1140	1200	1260	mV/g
Sensitivity (V_{DD} = 5.0 V)(5)	S	1110	1200	1290	mV/g
Bandwidth Response	f_{-3dB}	40	50	60	Hz
Nonlinearity	NL_{OUT}	–1.0	–	+1.0	% FSO
Noise					
RMS (0.1 Hz – 1.0 kHz)	n_{RMS}	–	3.5	–	mVrms
Spectral Density (RMS, 0.1 Hz – 1.0 kHz)(6)	n_{SD}	–	350	–	$\mu g/\sqrt{Hz}$
Self-Test					
Output Response (V_{DD} = 5.0 V)	ΔV_{ST}	0.3	0.4	0.5	V
Input Low	V_{IL}	V_{SS}	–	0.3 V_{DD}	V
Input High	V_{IH}	0.7 V_{DD}	–	V_{DD}	V
Input Loading(7)	I_{IN}	–50	–125	–300	µA
Response Time(8)	t_{ST}	–	20	25	ms
Status(9)(10)					
Output Low (I_{load} = 100 µA)	V_{OL}	–	–	0.4	V
Output High (I_{load} = –100 µA)	V_{OH}	V_{DD} –0.8	–	–	V
Output Stage Performance					
Electrical Saturation Recovery Time(11)	t_{DELAY}	–	–	2.0	ms
Full Scale Output Range (I_{OUT} = –200 µA)	V_{FSO}	V_{SS}+0.25	–	V_{DD}–0.25	V
Capacitive Load Drive(12)	C_L	–	–	100	pF
Output Impedance	Z_O	–	50	–	Ω
Mechanical Characteristics					
Transverse Sensitivity(13)	$V_{YX,ZX}$	–	–	5.0	% FSO

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.1 µF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 volts, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above $V_{DD}/2$ and for negative acceleration the output will decrease below $V_{DD}/2$.
5. Sensitivity limits apply to 0 Hz acceleration.
6. At clock frequency ≅ 34 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high.
10. The Status pin output latches high if the EPROM parity changes to odd. The Status pin can be reset by a rising edge on self-test, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined “cap'' wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that moves between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration (Figure 3).

As the beams attached to the central mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell beams form two back-to-back capacitors (). As the central mass moves with acceleration, the distance between the beams change and each capacitor's value will change, ($C = NA\varepsilon/D$). Where A is the area of the facing side of the beam, e is the dielectric constant, D is the distance between the beams, and N is the number of beams.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

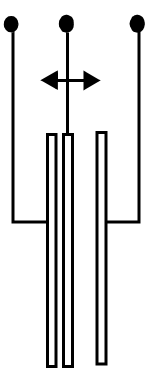


Figure 3. Transducer Physical Model

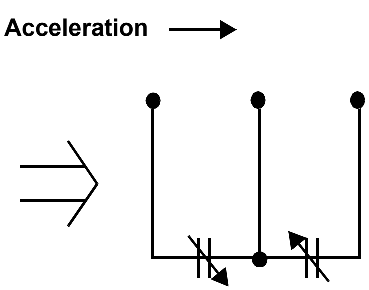


Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

Freescale accelerometers contain an onboard 2-pole switched capacitor filter. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. A fourth “plate'' is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = \frac{1}{2} AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever the following event occurs:

- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a rising edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

BASIC CONNECTIONS

Pinout Description

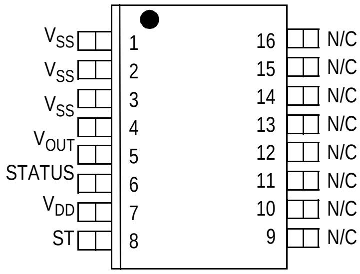


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Table 3. Pin Description

Pin No.	Pin Name	Description
1 thru 3	V_{SS}	Redundant connections to the internal V_{SS} and may be left unconnected.
4	V_{OUT}	Output voltage of the accelerometer.
5	STATUS	Logic output pin to indicate fault.
6	V_{DD}	The power supply ground.
7	V_{SS}	The power supply input.
8	ST	Logic input pin used to initiate self-test.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

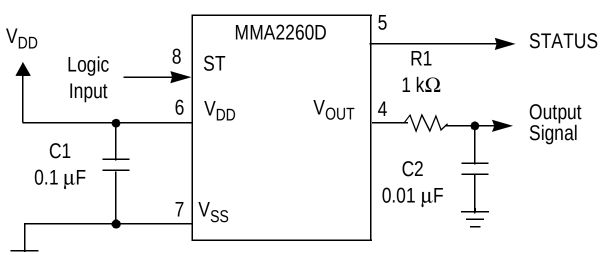


Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

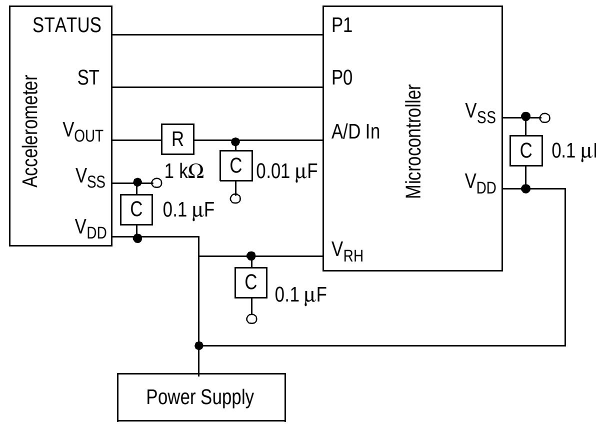
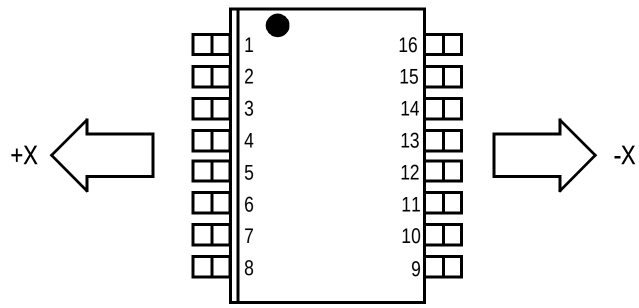


Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

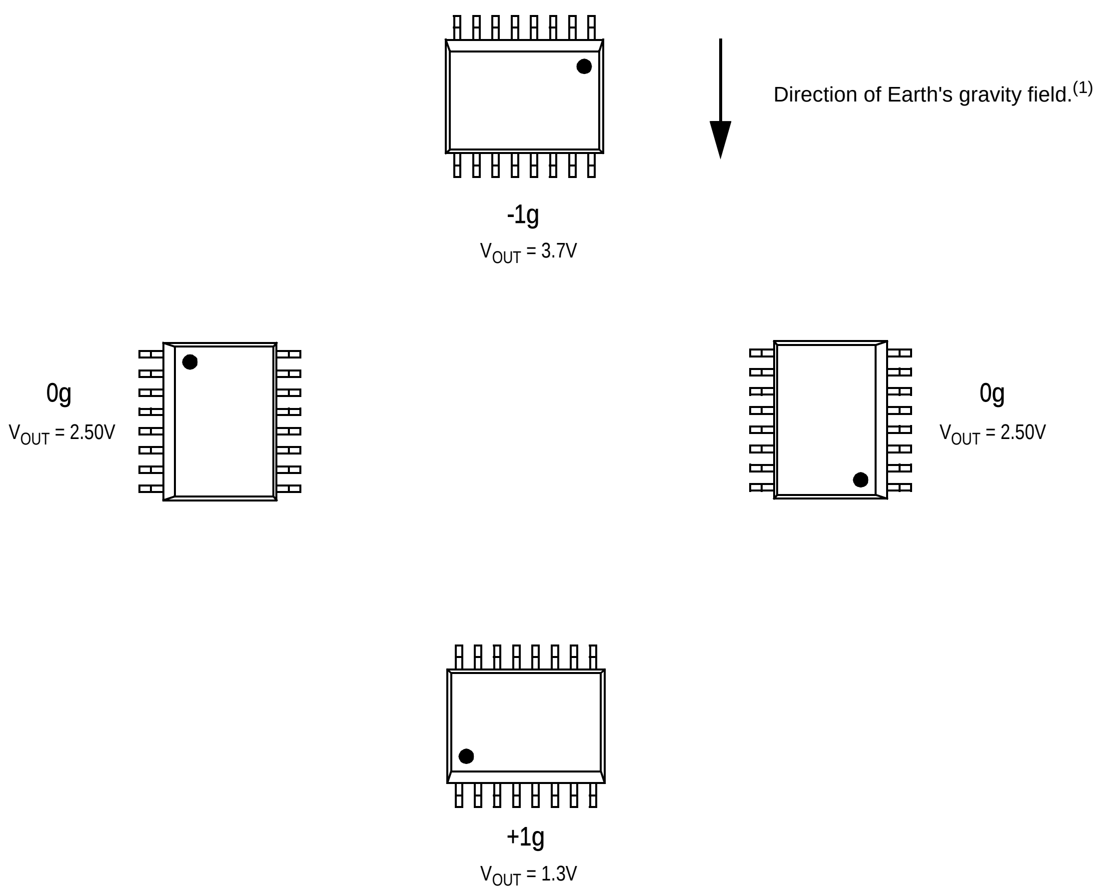
DYNAMIC ACCELERATION



16-Pin SOIC Package

Top View

STATIC ACCELERATION



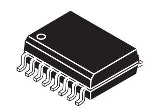
1. When positioned as shown, the Earth's gravity will result in a positive 1g output

Surface Mount Micromachined Accelerometer

MMA2300D

The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 4-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

MMA2300D: X AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±250g



D SUFFIX
16-LEAD SOIC
CASE 475-01

Features

- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability

Typical Applications

- Vibration Monitoring and Recording
- Impact Monitoring

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Case No.**	**Package**
MMA2300D	–40° to 125°C	475-01	SOIC-16
MMA2300DR2	–40° to 125°C	475-01	SOIC16, Tape & Reel

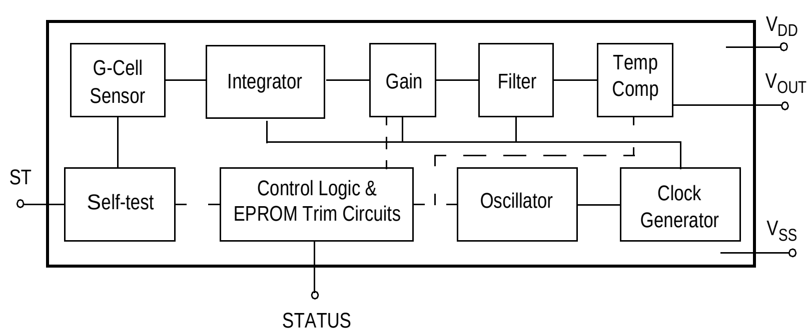


Figure 1. Simplified Accelerometer Functional Block Diagram

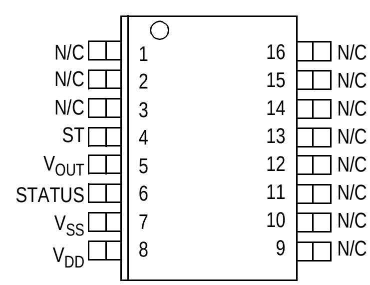


Figure 2. Pin Connections

Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test (1)	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

Table 2. Operating Characteristics
(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output.[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	3.0	—	6.0	mA
Operating Temperature Range	T_A	–40	—	+125	C
Acceleration Range	g_{FS}	—	281	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.4	2.5	2.6	V
Zero g	$V_{OFF,V}$	0.47 V_{DD}	0.50 V_{DD}	0.53 V_{DD}	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	7.6	8.0	8.4	mV/g
Sensitivity	S_V	1.488	1.6	1.712	mV/g/V
Bandwidth Response	f_{-3dB}	360	400	440	Hz
Nonlinearity	NL_{OUT}	–1.0	—	1.0	% FSO
Noise					
RMS (10 Hz – 1 kHz)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	110	—	$\mu V/(Hz^{1/2})$
Clock Noise (without RC load on output)[6]	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	24	30	36	g
Input Low	V_{IL}	V_{SS}	—	0.3 x V_{DD}	V
Input High	VIH	0.7 x V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	–30	–100	–260	µA
Response Time[8]	t_{ST}	—	2.0	10	ms
Status[9], [10]					
Output Low (I_{load} = 100 µA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 µA)	V_{OH}	V_{DD} –0.8	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{min}	50	—	260	kHz
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 µA)	V_{FSO}	0.25	—	V_{DD}–0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	300	—	W
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 µF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 V, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above V_{DD}/2 and for negative acceleration the output will decrease below V_{DD}/2.
5. The device is calibrated at 35g.
6. At clock frequency ≅ 70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
10. The Status pin output latches high if a Low Voltage Detection or Clock Frequency failure occurs, or the EPROM parity changes to odd. The Status pin can be reset low if the self-test pin is pulsed with a high input for at least 100 µs, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined “cap'' wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that moves between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration (Figure 3).

As the beams attached to the central mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell plates form two back-to-back capacitors (Figure 4). As the central mass moves with acceleration, the distance between the beams change and each capacitor's value will change, ($C = NA\varepsilon/D$). Where A is the area of the facing side of the beam, ε is the dielectric constant, D is the distance between the beams, and N is the number of beams.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

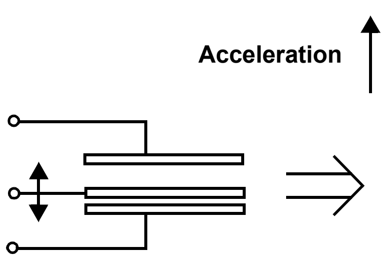


Figure 3. Transducer Physical Model

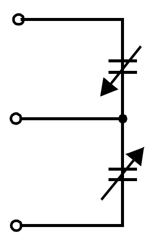


Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an onboard 4-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive airbag systems where system integrity must be ensured over the life of the vehicle. A fourth “plate'' is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^{1}/_{2}\, AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a falling edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

BASIC CONNECTIONS

Pinout Description

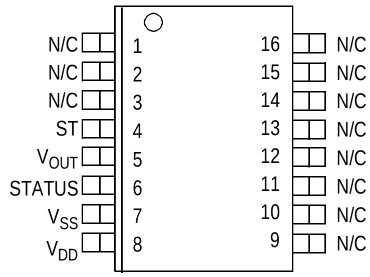


Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	—	Leave unconnected.
4	ST	Logic input pin used to initiate self-test.
5	V_{OUT}	Output voltage of the accelerometer.
6	STATUS	Logic output pin to indicate fault.
7	V_{SS}	The power supply ground.
8	V_{DD}	The power supply input.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

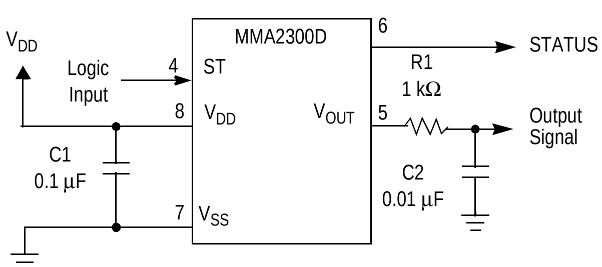


Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

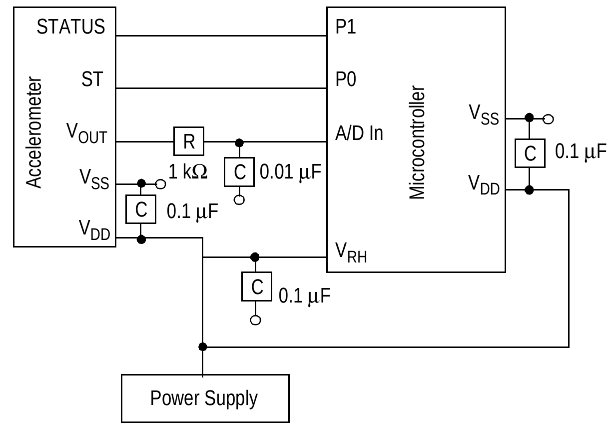


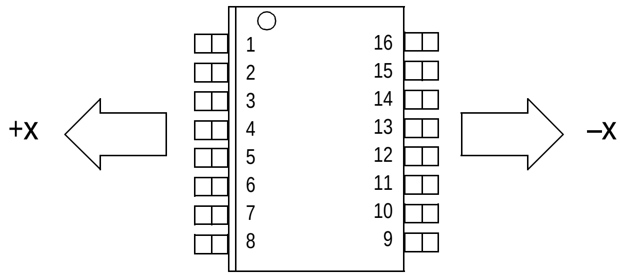
Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

Dynamic Acceleration Sensing Direction

Acceleration of the package in the +X direction (center plate moves in the –X direction) will result in an increase in the output.

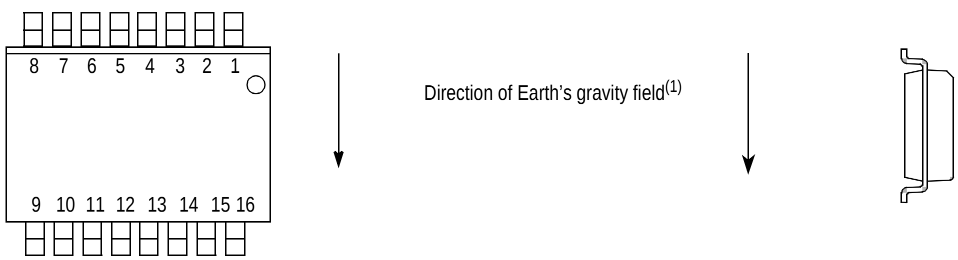


Activation of Self Test moves the center plate in the –X direction, resulting in an increase in the output.

16-Pin SOIC Package
N/C pins are recommended to be left FLOATING

Top View

Static Acceleration Sensing Direction



Front View

Side View

1. When positioned as shown, the Earth's gravity will result in a positive 1g output.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

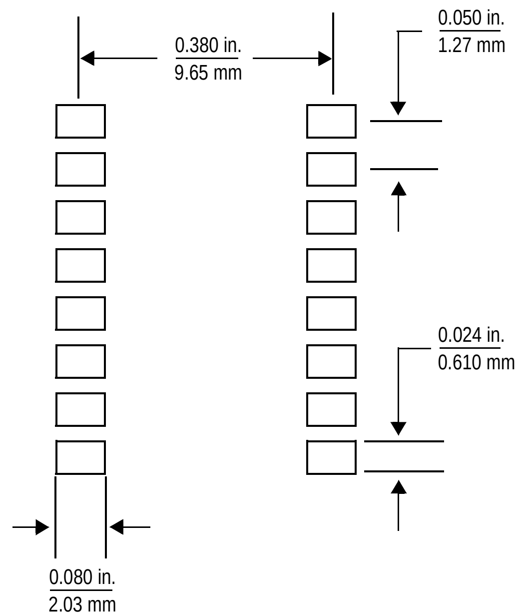


Figure 7. Footprint SOIC-16 (Case 475-01)

Surface Mount Micromachined Accelerometer

MMA2301D

MMA2301D: X-AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±200G

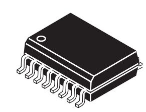
The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 4-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

Features

- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability

Typical Applications

- Vibration Monitoring and Recording
- Impact Monitoring



D SUFFIX
16-LEAD SOIC
CASE 475-01

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Case No.**	**Package**
MMA2301D	–40° to 125°C	475-01	SOIC-16
MMA2301DR2	–40° to 125°C	475-01	SOIC16, Tape & Reel

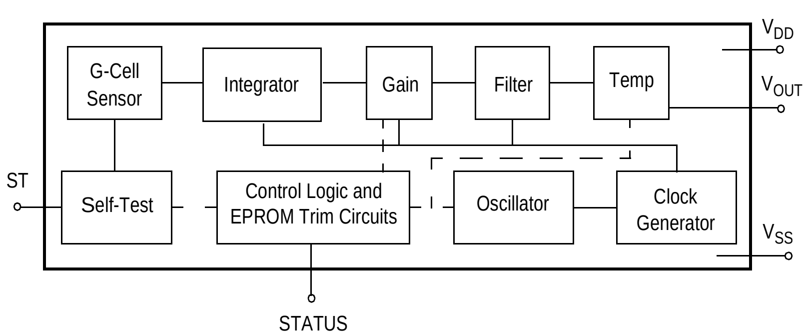


Figure 1. Simplified Accelerometer Functional Block Diagram

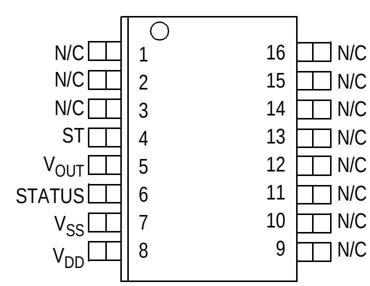


Figure 2. Pin Connections

Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test[1]	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the accelerometers contain internal 2 kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

Table 2. OPERATING CHARACTERISTICS
(Unless otherwise noted: -40°C ≤ T_A ≤ +105°C, 4.75 ≤ VDD ≤ 5.25, Acceleration = 0g, Loaded output)[1]

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.0	5.25	V
Supply Current	I_{DD}	3.0	—	6.0	mA
Operating Temperature Range	T_A	-40	—	+125	°C
Acceleration Range	g_{FS}	—	225	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.4	2.5	2.6	V
Zero g	$V_{OFF,V}$	0.46 V_{DD}	0.50 V_{DD}	0.54 V_{DD}	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	9.5	10.0	10.5	mV/g
Sensitivity	S_V	1.86	2.0	2.14	mV/g/V
Bandwidth Response	f_{-3dB}	360	400	440	Hz
Nonlinearity	NL_{OUT}	-1.0	—	1.0	% FSO
Noise					
RMS (.01-1 kHz)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	110	—	µV/(Hz$^{1/2}$)
Clock Noise (without RC load on output)[6]	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	24	30	36	g
Input Low	V_{IL}	V_{SS}	—	0.3 x V_{DD}	V
Input High	V_{IH}	0.7 x V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	-30	-100	-260	µA
Response Time[8]	t_{ST}	—	2.0	10	ms
Status[9] [10]					
Output Low (I_{load} = 100 µA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 µA)	V_{OH}	V_{DD} -0.8	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{min}	50	—	260	kHz
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 µA)	V_{FSO}	0.25	—	V_{DD} -0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	300	—	Ω
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 µF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 volts, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and - acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above $V_{DD}/2$ and for negative acceleration the output will decrease below $V_{DD}/2$.
5. The device is calibrated at 35g.
6. At clock frequency ≅ 70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
10. The Status pin output latches high if a Low Voltage Detection or Clock Frequency failure occurs, or the EPROM parity changes to odd. The Status pin can be reset low if the self-test pin is pulsed with a high input for at least 100 us, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causing them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

PRINCIPLE OF OPERATION

The Freescale Semiconductor, Inc. accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined *cap* wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that move between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration(Figure 3).

As the beams attached to the central mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell plates form two back-to-back capacitors (Figure 3). As the central mass moves with acceleration, the distance between the beams change and each capacitor's value will change, ($C = NA\varepsilon/D$). Where A is the area of the facing side of the beam, ε is the dielectric constant, D is the distance between the beams, and N is the number of beams.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

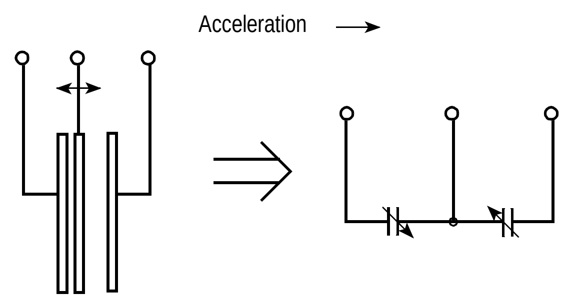


Figure 3. Simplified Transducer Physical Model versus Transducer Physical Model

SPECIAL FEATURES

Filtering

The accelerometers contain an onboard 4-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive airbag systems where system integrity must be ensured over the life of the vehicle. A fourth *plate* is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^{1}/_{2}\ AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

Status

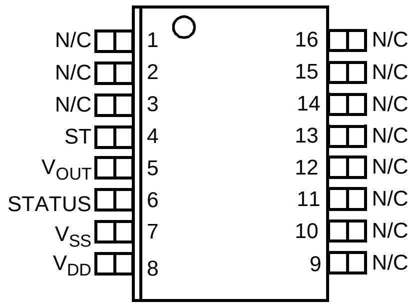
Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a rising edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

BASIC CONNECTIONS

PINOUT DESCRIPTION



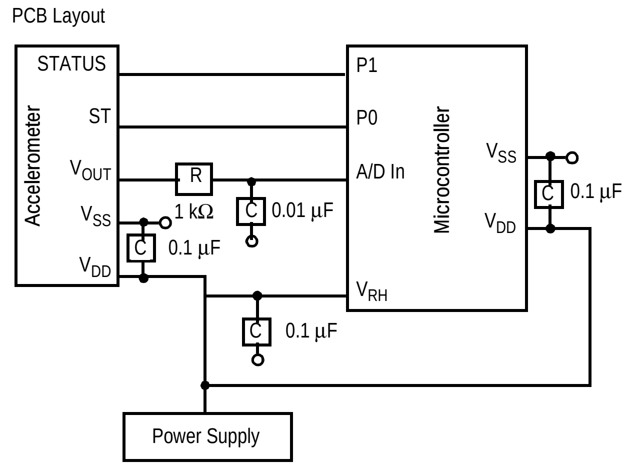


Figure 5. Recommend PCB Layout for Interfacing Accelerometer to Microcontroller

Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	N/C	Leave unconnected.
4	ST	Logic input pin used to initiate self-test.
5	V_{OUT}	Output voltage of the accelerometer.
6	STATUS	Logic output pin to indicate fault.
7	V_{SS}	The power supply ground.
8	V_{DD}	The power supply input.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

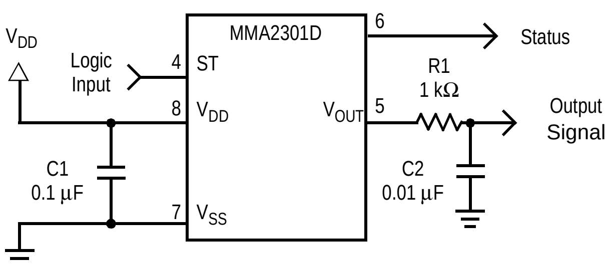


Figure 4. SOIC Accelerometer with Recommended Connection Diagram

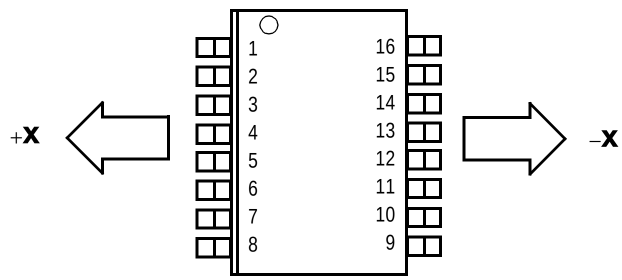
NOTES:

- Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
- Physical coupling distance of the accelerometer to the microcontroller should be minimal.
- Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 5
- Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
- PCB layout of power and ground should not couple power supply noise.
- Accelerometer and microcontroller should not be a high current path.

A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

Dynamic Acceleration Sensing Direction

Acceleration of the package in the +X direction (center plate moves in the -X direction) will result in an increase in the output.

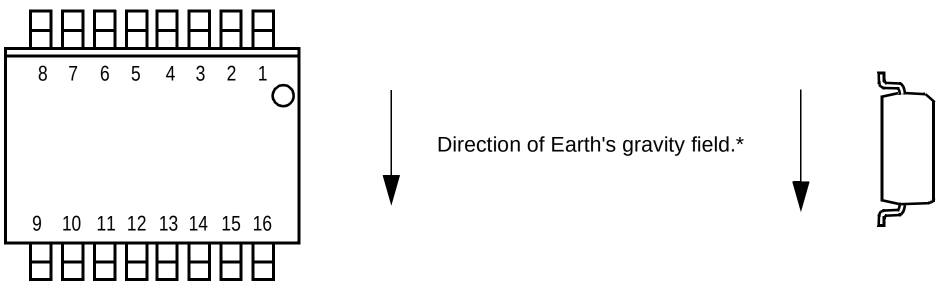


Activation of Self Test moves the center plate in the –X direction, resulting in an increase in the output.

16-Pin SOIC Package
N/C pins are recommended to be left FLOATING

Top View

Static Acceleration Sensing Direction



Front View

Side View

* When positioned as shown, the Earth's gravity will result in a positive 1g output.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

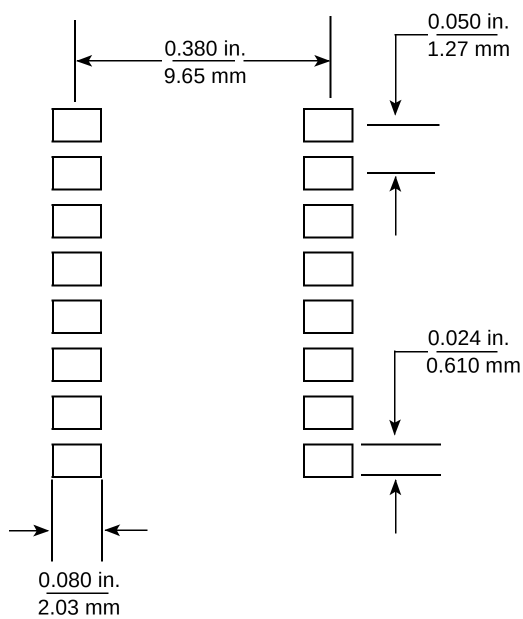


Figure 6. Footprint SOIC-16 (Case 475-01)

Surface Mount Micromachined Accelerometer

MMA3201D

The MMA3200 series of dual axis (X and Y) silicon capacitive, micromachined accelerometers features signal conditioning, a 4-pole low pass filter and temperature compensation, and separate outputs for the two axes. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

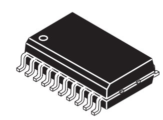
Features

- Sensitivity in two separate axes: 40g X-axis and 40g Y-axis
- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability

Typical Applications

- Vibration Monitoring and Recording
- Impact Monitoring
- Appliance Control
- Mechanical Bearing Monitoring
- Computer Hard Drive Protection
- Computer Mouse and Joysticks
- Virtual Reality Input Devices
- Sports Diagnostic Devices and Systems

MMA3201D: X-Y AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±40g



D SUFFIX
20-LEAD SOIC
CASE 475A-01

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Case No,**	**Package**
MMA3201D	–40 to +125°C	475A-01	SOIC-20
MMA3201DR2	–40 to +125°C	475A-01	SOIC-20, Tape & Reel

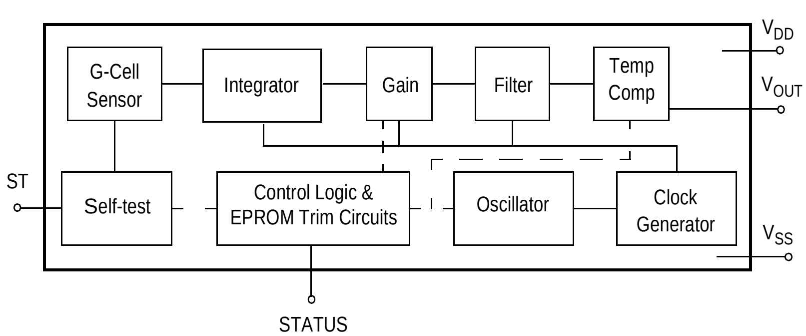


Figure 1. Simplified Accelerometer Functional Block Diagram

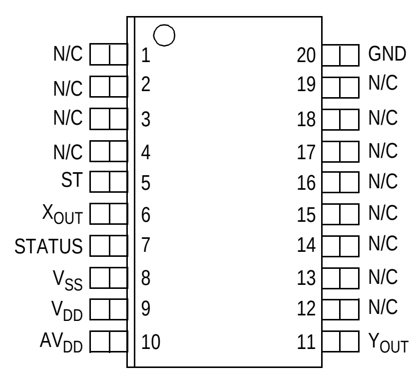


Figure 2. Pin Connections

Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test[1]	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2 kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

Table 2. Operating Characteristics
(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, X and Y Channels, Acceleration = 0g, Loaded output.[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	6	8	10	mA
Operating Temperature Range	T_A	–40	—	+125	°C
Acceleration Range	g_{FS}	—	45	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.35	2.5	2.65	V
Zero g	$V_{OFF,V}$	0.46 V_{DD}	0.50 V_{DD}	0.54 V_{DD}	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	45	50	55	mV/g
Sensitivity	S_V	9.3	10	10.7	mV/g/V
Bandwidth Response	$f_{–3dB}$	360	400	440	Hz
Nonlinearity	NL_{OUT}	–1.0	—	+1.0	% FSO
Noise					
RMS (.01 Hz – 1 kHz)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	110	—	µV/(Hz$^{1/2}$)
Clock Noise (without RC load on output)[6]	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	9.6	12	14.4	g
Input Low	V_{IL}	V_{SS}	—	0.3 × V_{DD}	V
Input High	V_{IH}	0.7 × V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	–30	–110	–300	µA
Response Time[8]	t_{ST}	—	2.0	–	ms
Status[9], [10]					
Output Low (I_{load} = 100 µA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 µA)	V_{OH}	V_{DD} –.8	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{min}	50	—	260	kHz
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 µA)	V_{FSO}	0.25	—	V_{DD}–0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	300	—	W
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 µF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 volts, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above $V_{DD}/2$ and for negative acceleration the output will decrease below $V_{DD}/2$.
5. The device is calibrated at 20g.
6. At clock frequency ≅70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
10. The Status pin output latches high if a Low Voltage Detection or Clock Frequency failure occurs, or the EPROM parity changes to odd. The Status pin can be reset low if the self-test pin is pulsed with a high input for at least 100 µs, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causing them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined “cap'' wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that move between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration (Figure 3).

As the beams attached to the central mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell beams form two back-to-back capacitors (Figure 4). As the central mass moves with acceleration, the distance between the beams change and each capacitor's value will change, ($C = NA\varepsilon/D$). Where A is the area of the facing side of the beam, ε is the dielectric constant, D is the distance between the beams, and N is the number of beams. The X-Y device contains two structures at right angles to each other.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

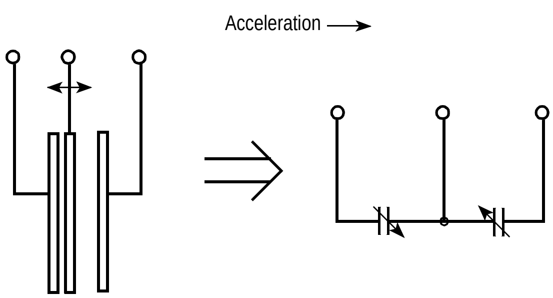


Figure 3. Transducer Physical Model

Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an on board 4-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive airbag systems where system integrity must be ensured over the life of the vehicle. A fourth “plate'' is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^1/_2 AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

Status

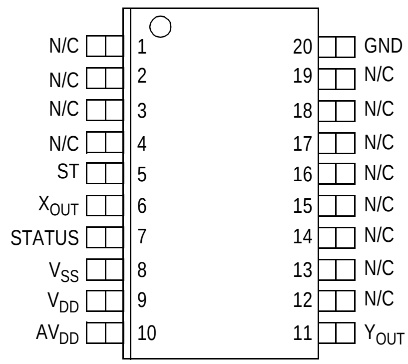
Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a rising edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

BASIC CONNECTIONS

Pinout Description



Pin No.	Pin Name	Description
1 thru 3	—	Leave unconnected.
4	—	No internal connection. Leave unconnected.
5	ST	Logic input pin used to initiate self-test.
6	X_{OUT}	Output voltage of the accelerometer. X Direction.
7	STATUS	Logic output pin to indicate fault.
8	V_{SS}	The power supply ground.
9	V_{DD}	The power supply input.
10	AV_{DD}	Power supply input (Analog).
11	Y_{OUT}	Output voltage of the accelerometer. Y Direction.
12 thru 16	—	Used for factory trim. Leave unconnected.
17 thru 19	—	No internal connection. Leave unconnected.
20	GND	Ground.

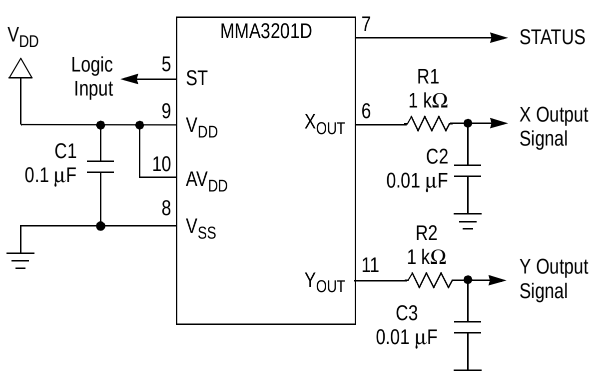


Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

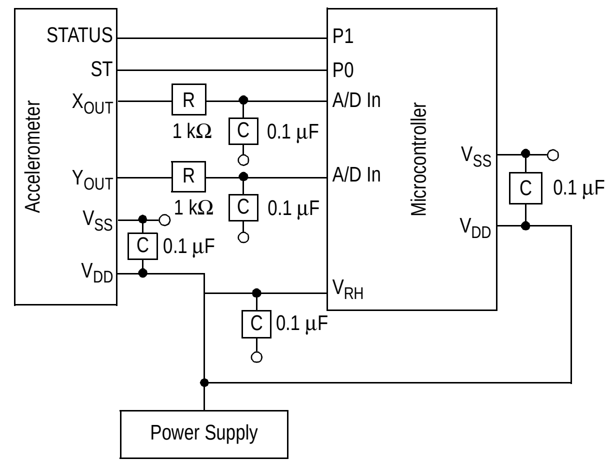


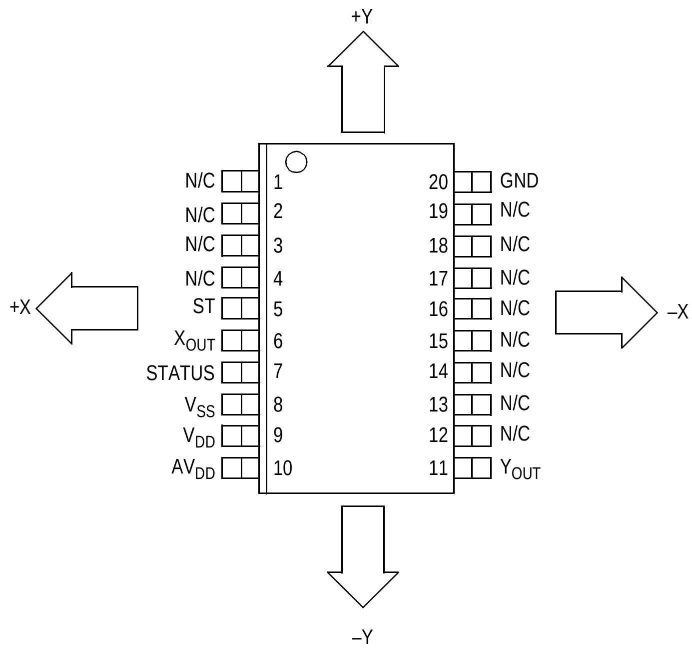
Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

Dynamic Acceleration Sensing Direction

Acceleration of the package in the +X and +Y direction (center plates move in the -X and -Y direction) will result in an increase in the X and Y outputs.

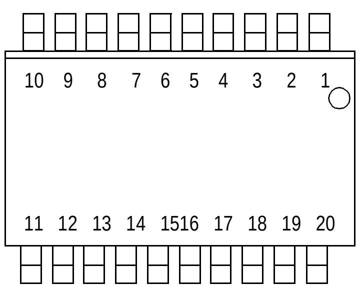


Activation of Self test moves the center plates in the -X and -Y direction, resulting in an increase in the X and Y outputs.

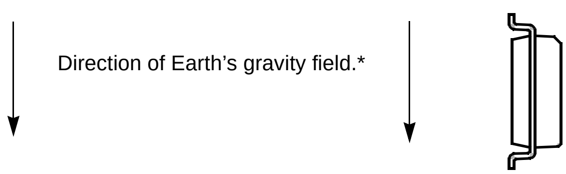
20-Pin SOIC Package
N/C pins are recommended to be left FLOATING

Top View

Static Acceleration Sensing Direction



Front View



Side View

* When positioned as shown, the Earth's gravity will result in a positive 1g output in the X channel.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

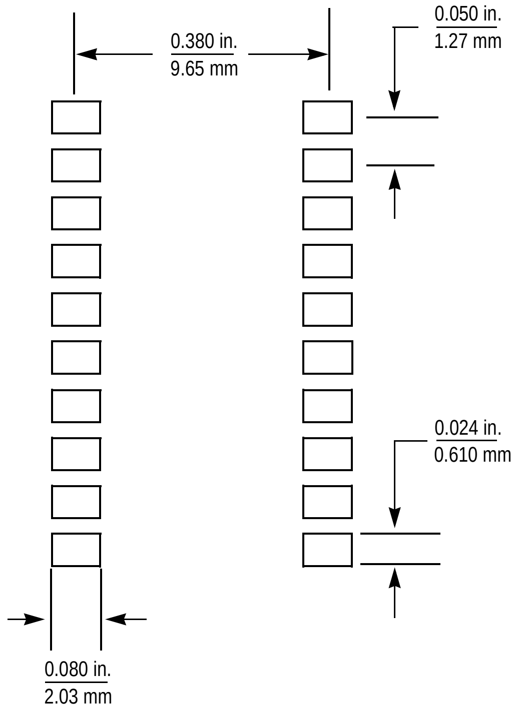


Figure 7. Footprint SOIC-20 (Case 475A-01)

Freescale Semiconductor
Technical Data

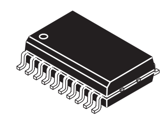
MMA3202D
Rev 3, 05/2005

Surface Mount Micromachined Accelerometer

MMA3202D

MMA3202D: X-Y AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±100/50g

The MMA3202 series of dual axis (X and Y) silicon capacitive, micromachined accelerometers features signal conditioning, a 4-pole low pass filter and temperature compensation and separate outputs for the two axes. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.



D SUFFIX
20-LEAD SOIC
CASE 475A-01

Features

- Sensitivity in two separate axes: 100g X-axis and 50g Y-axis
- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability

Typical Applications

- Vibration Monitoring and Recording
- Impact Monitoring
- Appliance Control
- Mechanical Bearing Monitoring
- Computer Hard Drive Protection
- Computer Mouse and Joysticks
- Virtual Reality Input Devices
- Sports Diagnostic Devices and Systems

ORDERING INFORMATION			
Device	**Temperature Range**	**Case No.**	**Package**
MMA3202D	– 40 to +125°C	475A-01	SOIC-20
MMA3202DR2	– 40 to +125°C	475A-01	SOIC-20, Tape & Reel

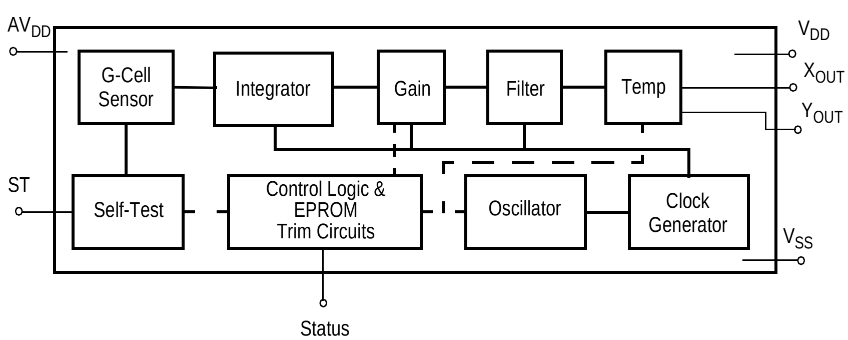


Figure 1. Simplified Accelerometer Functional Block Diagram

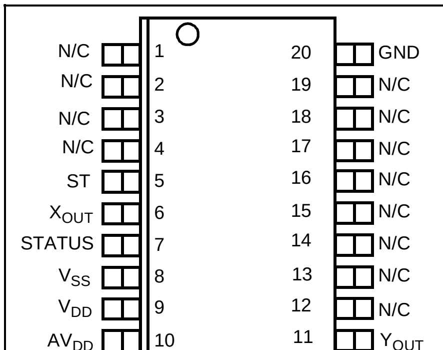


Figure 2. Pin Connections

Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test [(1)]	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the accelerometers contain internal 2 kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

Table 2. Operating Characteristics
(Unless otherwise noted: $-40°C \le T_A \le +105°C$, $4.75 \le V_{DD} \le 5.25$, Acceleration = 0g, Loaded output.)[1]

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	6	8	10	mA
Operating Temperature Range	T_A	–40	—	+125	°C
Acceleration Range X-axis	g_{FS}	—	112.5	—	g
Acceleration Range Y-axis	g_{FS}	—	56.3	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.35	2.5	2.65	V
Zero g	$V_{OFF,V}$	0.46 V_{DD}	0.50 V_{DD}	0.54 V_{DD}	V
Sensitivity X-axis (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	19	20	21	mV/g
Sensitivity Y-axis (T_A = 25°C, V_{DD} = 5.0 V)	S	38	40	42	mV/g
Sensitivity X-axis	S_V	3.72	4	4.28	mV/g/V
Sensitivity Y-axis	S_V	7.44	8	8.56	mV/g/V
Bandwidth Response	f_{-3dB}	360	400	440	Hz
Nonlinearity	NL_{OUT}	–1.0	—	+1.0	% FSO
Noise					
RMS (.01 Hz – 1 kHz)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	110	—	$\mu V/(Hz^{1/2})$
Clock Noise (without RC load on output)[6]	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	9.6	12	14.4	g
Input Low	V_{IL}	V_{SS}	—	$0.3 \times V_{DD}$	V
Input High	V_{IH}	$0.7 \times V_{DD}$	—	V_{DD}	V
Input Loading[7]	I_{IN}	–30	–100	–300	µA
Response Time[8]	t_{ST}	—	2.0	–	ms
Status[9] [10]					
Output Low (I_{load} = 100 µA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 µA)	V_{OH}	$V_{DD} - 0.8$	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{min}	50	—	260	kHz
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 µA)	V_{FSO}	0.25	—	$V_{DD} - 0.25$	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedence	Z_O	—	300	—	W
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 µF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 volts, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above $V_{DD}/2$ and for negative acceleration the output will decrease below $V_{DD}/2$.
5. The device is calibrated at 20g.
6. At clock frequency ≅70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
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12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

PRINCIPLE OF OPERATION

The Freescale Semiconductor, Inc. accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined "cap" wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that move between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration (Figure 3).

As the beams attached to the central mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell beams form two back-to-back capacitors (Figure 3). As the central mass moves with acceleration, the distance between the beams change and each capacitor's value will change, ($C = NA\varepsilon/D$). Where A is the area of the facing side of the beam, ε is the dielectric constant, D is the distance between the beams, and N is the number of beams. The X-Y device contains two structures at right angles to each other.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

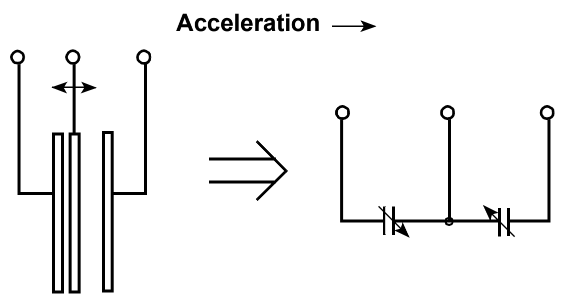


Figure 3. Simplified Transducer Physical Model

SPECIAL FEATURES

Filtering

The Freescale Semiconductor, Inc. accelerometers contain an onboard 4-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive airbag systems where system integrity must be ensured over the life of the vehicle. A fourth "plate" is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^1/_2\, AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a rising edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

BASIC CONNECTIONS

PINOUT DESCRIPTION

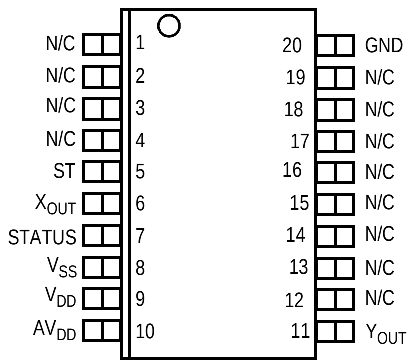


Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	—	Leave unconnected.
4	—	No internal connection. Leave unconnected.
5	ST	Logic input pin used to initiate self-test.
6	X_{OUT}	Output voltage of the accelerometer. X Direction.
7	STATUS	Logic output pin to indicate fault.
8	V_{SS}	The power supply ground.
9	V_{DD}	The power supply input.
10	AV_{DD}	Power supply input (Analog).
11	Y_{OUT}	Output voltage of the accelerometer. Y Direction.
12 thru 16	—	Used for factory trim. Leave unconnected.
17 thru 19	—	No internal connection. Leave unconnected.
20	GND	Ground.

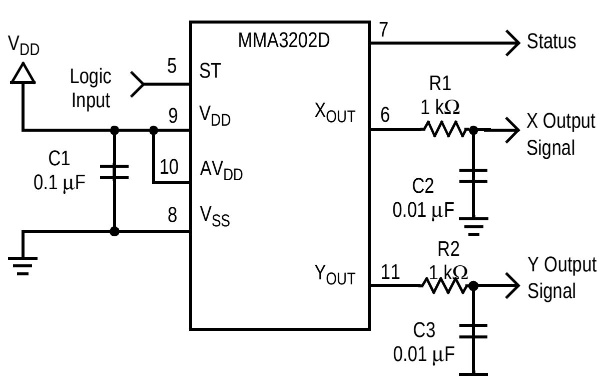


Figure 4. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

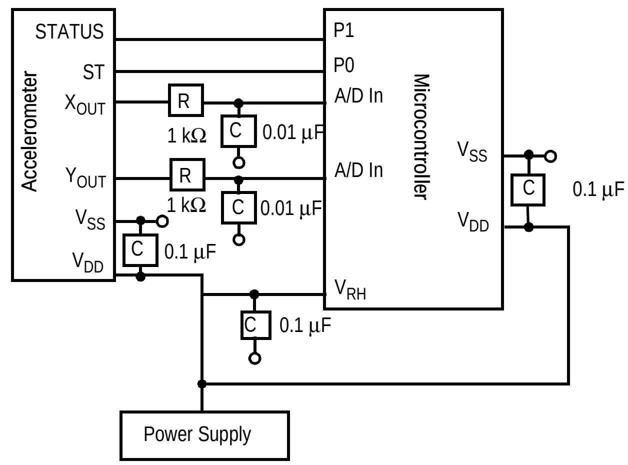


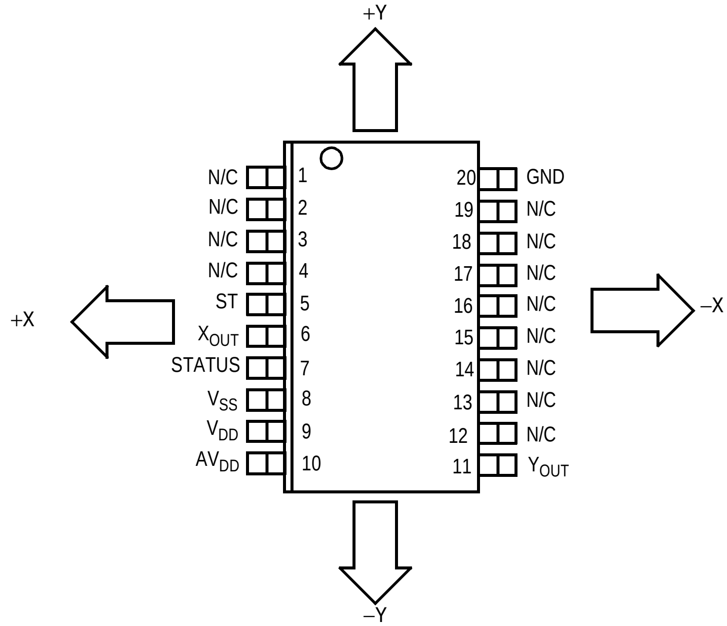
Figure 5. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTE:

- Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
- Physical coupling distance of the accelerometer to the microcontroller should be minimal.
- Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 5.
- Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
- PCB layout of power and ground should not couple power supply noise.
- Accelerometer and microcontroller should not be a high current path.
- A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

Dynamic Acceleration Sensing Direction

Acceleration of the package in the +X and +Y direction (center plates move in the –X and –Y direction) will result in an increase in the X and Y outputs.

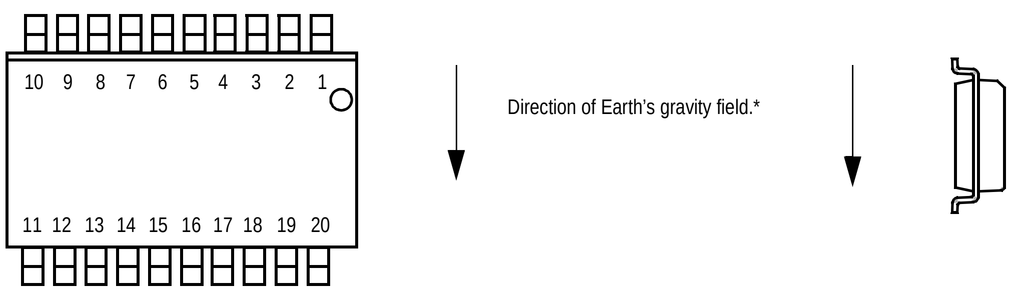


Activation of Self test moves the center plates in the –X and –Y direction, resulting in an increase in the X and Y outputs.

20-Pin SOIC Package
N/C pins are recommended to be left FLOATING

Top View

Static Acceleration Sensing Direction



Front View

Side View

* When positioned as shown, the Earth's gravity will result in a positive 1g output in the X channel.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

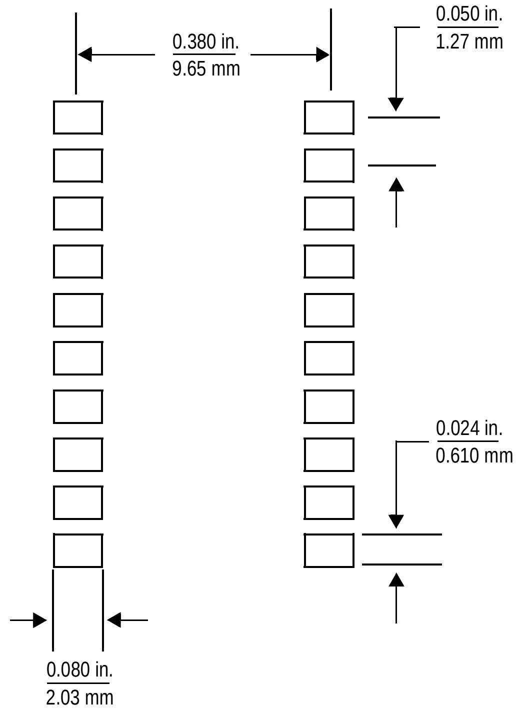


Figure 6. Footprint SOIC-20 (Case 475A-01)

±10g Dual Axis Micromachined Accelerometer

MMA6231Q
MMA6233Q

The MMA6200 series of low cost capacitive micromachined accelerometers feature signal conditioning, a 1-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

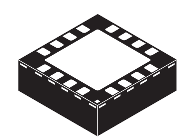
Features

- Low Noise
- Low Cost
- Low Power
- 2.7 V to 3.6 V Operation
- 6mm x 6mm x 1.98 mm QFN
- Integral Signal Conditioning with Low Pass Filter
- Linear Output
- Ratiometric Performance
- Self-Test
- Robust Design, High Shocks Survivability

Typical Applications

- Pedometer
- Appliance Control
- Impact Monitoring
- Vibration Monitoring and Recording
- Position & Motion Sensing
- Freefall Detection
- Smart Portable Electronics

MMA6230Q Series: X-Y AXIS SENSITIVITY MICROMACHINED ACCELEROMETER
±10 g



16-LEAD
QFN
CASE 1477-01

ORDERING INFORMATION				
Device Name	**Bandwidth Response**	**I_{DD}**	**Case No.**	**Package**
MMA6231Q	300 Hz	1.2 mA	1477-01	QFN-16, Tube
MMA6231QR2	300 Hz	1.2 mA	1477-01	QFN-16,Tape & Reel
MMA6233Q	900 Hz	2.2 mA	1477-01	QFN-16, Tube
MMA6233QR2	900 Hz	2.2 mA	1477-01	QFN-16,Tape & Reel

Top View

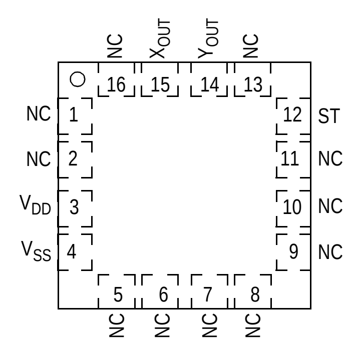


Figure 1. Pin Connections

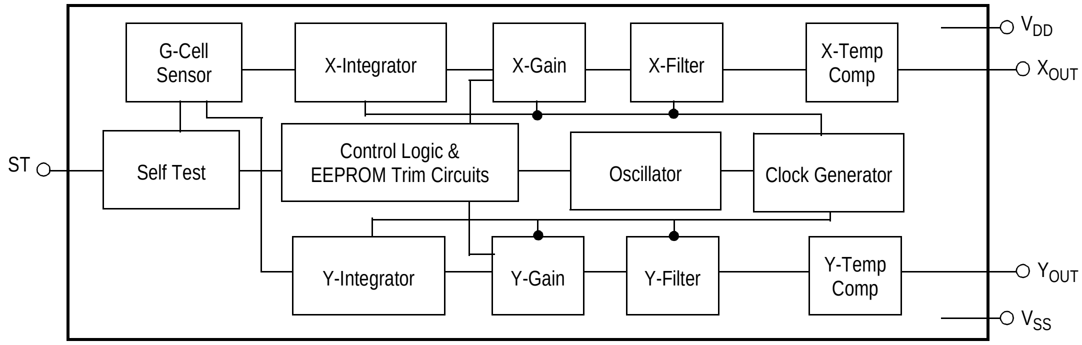


Figure 2. Simplified Accelerometer Functional Block Diagram

Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Maximum Acceleration (all axis)	g_{max}	±2000	g
Supply Voltage	V_{DD}	–0.3 to +3.6	V
Drop Test(1)	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2 kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

Table 2. Operating Characteristics
Unless otherwise noted: -20°C ≤ T_A ≤ 85°C, 3.0 V ≤ V_{DD} ≤ 3.6 V, Acceleration = 0g, Loaded output (1)

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range(2)					
Supply Voltage(3)	V_{DD}	2.7	3.3	3.6	V
Supply Current					
MMA6231Q	I_{DD}	—	1.2	1.5	mA
MMA6233Q	I_{DD}	—	2.2	3.0	mA
Operating Temperature Range	T_A	–20	—	+85	°C
Acceleration Range	g_{FS}	—	10	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 3.3 V)(4)	V_{OFF}	1.485	1.65	1.815	V
Zero g	V_{OFF}, T_A	—	2.0	—	mg/°C
Sensitivity (T_A = 25°C, V_{DD} = 3.3 V)	S	111	120	129	mV/g
Sensitivity	S, T_A	—	0.015	—	%/°C
Bandwidth Response					
MMA6231Q	$f_{\_3dB}$	—	300	—	Hz
MMA6233Q	$f_{\_3dB}$	—	900	—	Hz
Nonlinearity	NL_{OUT}	–1.0	—	+1.0	% FSO
Noise					
MMA6231Q RMS (0.1 Hz – 1 kHz)	n_{RMS}	—	0.7	—	mVrms
MMA6233Q RMS (0.1 Hz – 1 kHz)	n_{RMS}	—	0.6	—	
Power Spectral Density RMS (0.1 Hz – 1 kHz)					
MMA6231Q	n_{PSD}	—	50	—	ug/√Hz
MMA6233Q	n_{PSD}	—	30	—	
Self-Test					
Output Response	g_{ST}	2.0	—	—	g
Input Low	V_{IL}	—	—	0.3 V_{DD}	V
Input High	V_{IH}	0.7 V_{DD}	—	V_{DD}	V
Pull-Down Resistance(5)	R_{PO}	43	57	71	kΩ
Response Time(6)	t_{ST}	—	2.0	—	ms
Output Stage Performance					
Full-Scale Output Range (I_{OUT} = 200 µA)	V_{FSO}	V_{SS} +0.25	—	V_{DD} –0.25	V
Capacitive Load Drive(7)	C_L	—	—	100	pF
Output Impedance	Z_O	—	50	300	Ω
Power-Up Response Time					
MMA6231Q	$t_{RESPONSE}$	—	2.0	—	ms
MMA6233Q	$t_{RESPONSE}$	—	0.7	—	ms
Mechanical Characteristics					
Transverse Sensitivity(8)	$V_{ZX, YX, ZY}$	–5.0	—	+5.0	% FSO

1. For a loaded output, the measurements are observed after an RC filter consisting of a 1.0 kΩ resistor and a 0.1 µF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 2.7 and 3.6 V, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above $V_{DD}/2$. For negative acceleration, the output will decrease below $V_{DD}/2$.
5. The digital input pin has an internal pull-down resistance to prevent inadvertent self-test initiation due to external board level leakages.
6. Time for the output to reach 90% of its final value after a self-test is initiated.
7. Preserves phase margin (60°) to guarantee output amplifier stability.
8. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined *cap* wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that moves between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration (Figure 3).

As the beams attached to the central mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell plates form two back-to-back capacitors (Figure 4). As the center plate moves with acceleration, the distance between the plates changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the plate, ε is the dielectric constant, and D is the distance between the plates.

The ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

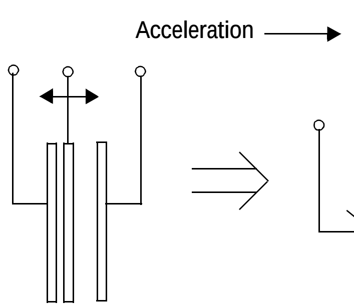


Figure 3. Transducer Physical Model

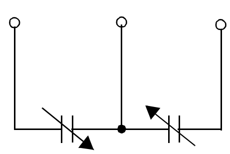


Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

These Freescale accelerometers contain an onboard single-pole switched capacitor filter. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature allowing the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. A fourth *plate* is used in the g-cell as a self-test plate. When a logic high input to the self-test pin is applied, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^1/_2\ AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's ASIC and a proportional output voltage results. This procedure assures both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Freescale accelerometers include fault detection circuitry and a fault latch. Parity of the EEPROM bits becomes odd in number.

Self-test is disabled when EEPROM parity error occurs.

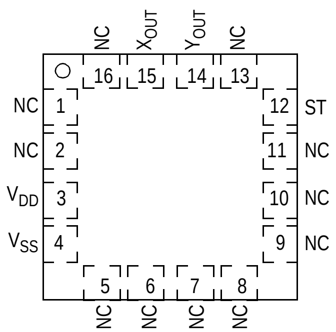
Ratiometricity

Ratiometricity simply means the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as supply voltage is increased, the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

BASIC CONNECTIONS

Pinout Description

Top View



Pin No.	Pin Name	Description
1, 5–7, 13, 16	N/C	No internal connection. Leave unconnected.
14	Y_{OUT}	Output voltage of the accelerometer. Y Direction.
15	X_{OUT}	Output voltage of the accelerometer. X Direction.
3	V_{DD}	Power supply input.
4	V_{SS}	The power supply ground.
2, 8–11	N/C	Used for factory trim. Leave unconnected.
12	ST	Logic input pin used to initiate self-test.

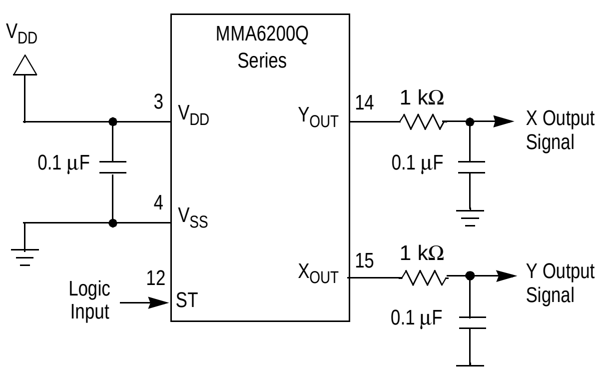


Figure 5. Accelerometer with Recommended Connection Diagram

PCB Layout

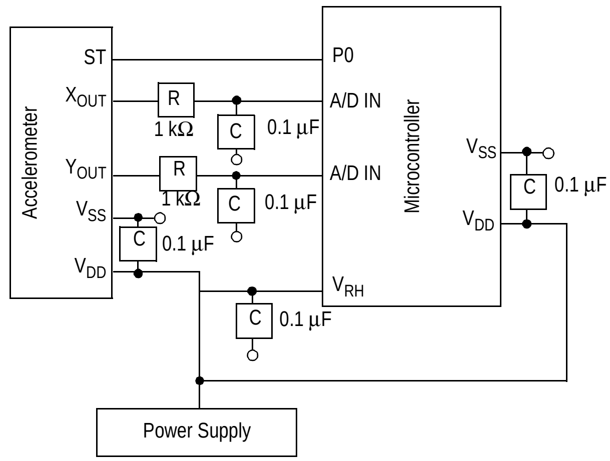
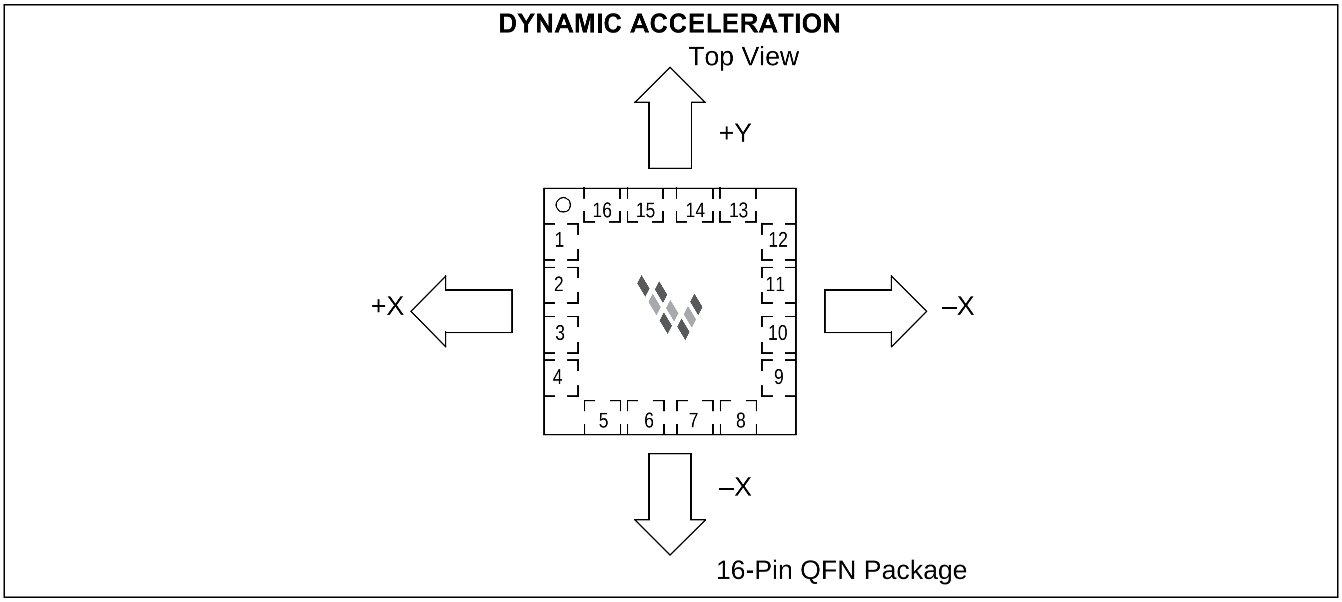
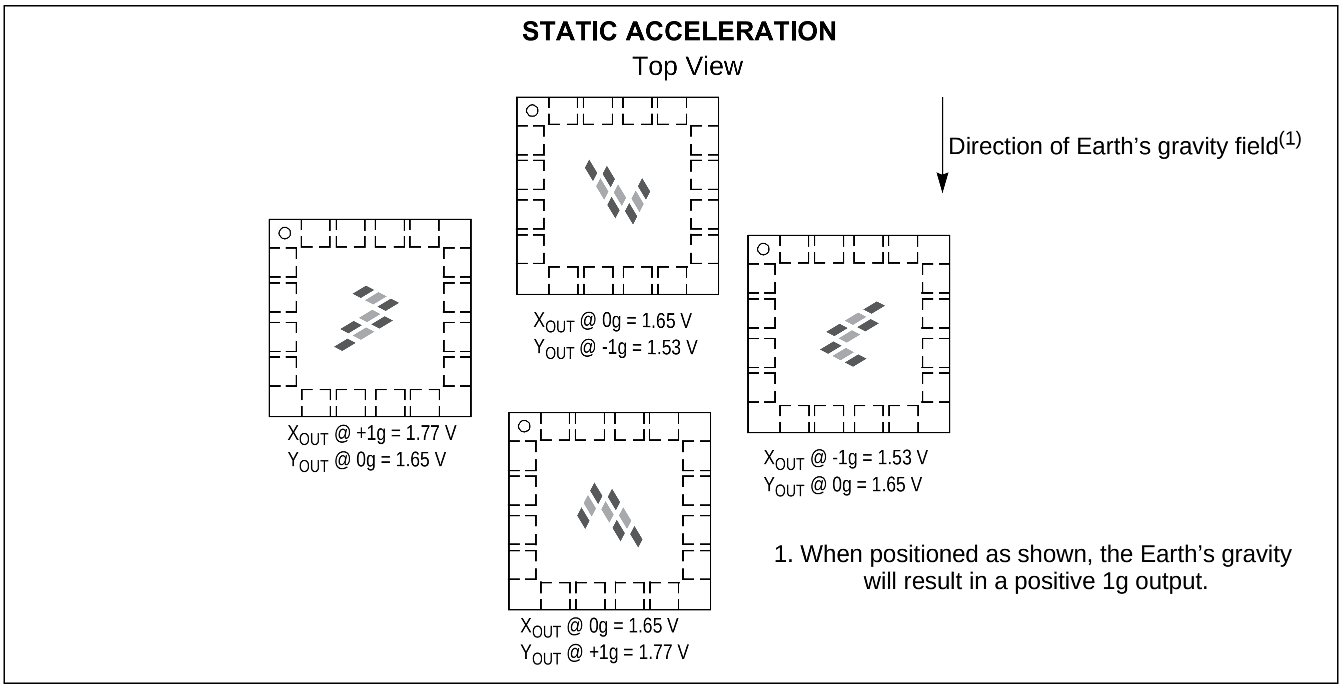


Figure 6. Recommend PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Flag underneath package is connected to ground.
4. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
5. Use an RC filter with 1.0 kΩ and 0.1 µF on the outputs of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
6. PCB layout of power and ground should not couple power supply noise.
7. Accelerometer and microcontroller should not be a high current path.
8. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency (16 kHz for Low I_{DD} and 52 kHz for Standard I_{DD} for the sampling frequency). This will prevent aliasing errors.

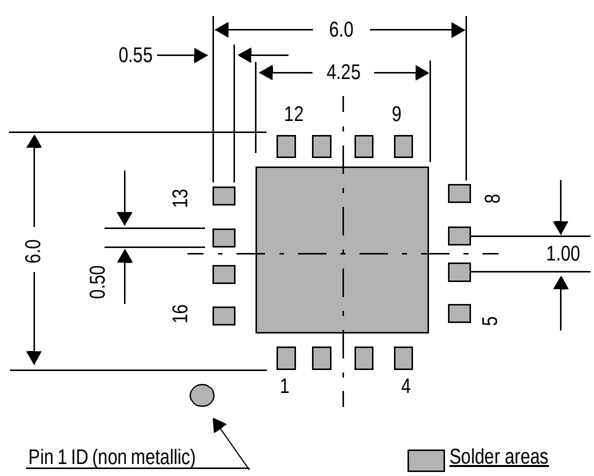




MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package.

With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.



MMA6260Q
MMA6261Q
MMA6262Q
MMA6263Q

±1.5g Dual Axis Micromachined Accelerometer

The MMA6200 series of low cost capacitive micromachined accelerometers feature signal conditioning, a 1-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

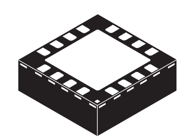
MMA6260Q Series: X-Y AXIS SENSITIVITY MICROMACHINED ACCELEROMETER
±1.5 g

Features

- High Sensitivity
- Low Noise
- Low Power
- 2.7 V to 3.6 V Operation
- 6mm x 6mm x 1.98 mm QFN
- Integral Signal Conditioning with Low Pass Filter
- Linear Output
- Ratiometric Performance
- Self-Test
- Robust Design, High Shocks Survivability

Typical Applications

- Tilt Monitoring
- Position & Motion Sensing
- Freefall Detection
- Impact Monitoring
- Appliance Control
- Vibration Monitoring and Recording
- Smart Portable Electronics



16-LEAD
QFN
CASE 1477-01

ORDERING INFORMATION				
Device Name	**Bandwidth Response**	**I_{DD}**	**Case No.**	**Package**
MMA6260Q	50 Hz	1.2 mA	1477-01	QFN-16, Tube
MMA6260QR2	50 Hz	1.2 mA	1477-01	QFN-16,Tape & Reel
MMA6261Q	300 Hz	1.2 mA	1477-01	QFN-16, Tube
MMA6261QR2	300 Hz	1.2 mA	1477-01	QFN-16,Tape & Reel
MMA6262Q	150 Hz	2.2 mA	1477-01	QFN-16,Tube
MMA6262QR2	150 Hz	2.2 mA	1477-01	QFN-16,Tape & Reel
MMA6263Q	900 Hz	2.2 mA	1477-01	QFN-16, Tube
MMA6263QR2	900 Hz	2.2 mA	1477-01	QFN-16,Tape & Reel

Top View

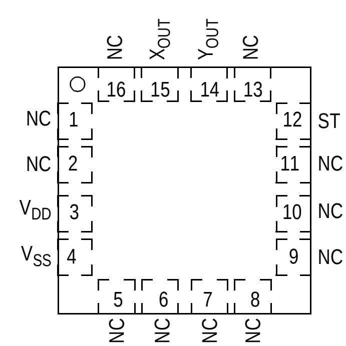


Figure 1. Pin Connections

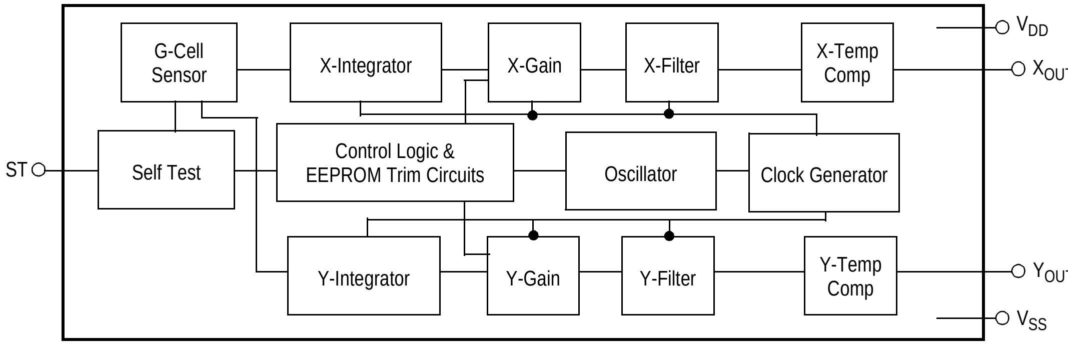


Figure 2. Simplified Accelerometer Functional Block Diagram

Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Maximum Acceleration (all axis)	g_{max}	±2000	g
Supply Voltage	V_{DD}	–0.3 to +3.6	V
Drop Test[1]	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2 kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

Table 2. Operating Characteristics

Unless otherwise noted: –20°C ≤ T_A ≤ 85°C, 3.0 V ≤ V_{DD} ≤ 3.6 V, Acceleration = 0g, Loaded output [(1)]

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[(2)]					
Supply Voltage[(3)]	V_{DD}	2.7	3.3	3.6	V
Supply Current					
MMA6260Q, MMA6261Q	I_{DD}	—	1.2	1.5	mA
MMA6262Q, MMA6263Q	I_{DD}	—	2.2	3.0	mA
Operating Temperature Range	T_A	–20	—	+85	°C
Acceleration Range	g_{FS}	—	1.5	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 3.3 V)[(4)]	V_{OFF}	1.485	1.65	1.815	V
Zero g	V_{OFF}, T_A	—	2.0	—	mg/°C
Sensitivity (T_A = 25°C, V_{DD} = 3.3 V)	S	740	800	860	mV/g
Sensitivity	S, T_A	—	0.015	—	%/°C
Bandwidth Response					
MMA6260Q	$f_{\_3dB}$	—	50	—	Hz
MMA6261Q	$f_{\_3dB}$	—	300	—	Hz
MMA6262Q	$f_{\_3dB}$	—	150	—	Hz
MMA6263Q	$f_{\_3dB}$	—	900	—	Hz
Nonlinearity	NL_{OUT}	–1.0	—	+1.0	% FSO
Noise					
MMA6260Q RMS (0.1 Hz – 1 kHz)	n_{RMS}	—	1.8	—	mVrms
MMA6261Q RMS (0.1 Hz – 1 kHz)	n_{RMS}	—	3.5	—	
MMA6262Q RMS (0.1 Hz – 1 kHz)	n_{RMS}	—	1.3	—	
MMA6263Q RMS (0.1 Hz – 1 kHz)	n_{RMS}	—	2.5	—	
Power Spectral Density RMS (0.1 Hz – 1 kHz)					
MMA6260Q, MMA6261Q	n_{PSD}	—	300	—	ug/√Hz
MMA6262Q, MMA6263Q	n_{PSD}	—	200	—	
Self-Test					
Output Response	V_{ST}	0.9 V_{DD}	—	V_{DD}	V
Input Low	V_{IL}	—	—	0.3 V_{DD}	V
Input High	V_{IH}	0.7 V_{DD}	—	V_{DD}	V
Pull-Down Resistance[(5)]	R_{PO}	43	57	71	kΩ
Response Time[(6)]	t_{ST}	—	2.0	—	ms
Output Stage Performance					
Full-Scale Output Range (I_{OUT} = 200 µA)	V_{FSO}	V_{SS} +0.25	—	V_{DD} –0.25	V
Capacitive Load Drive[(7)]	C_L	—	—	100	pF
Output Impedance	Z_O	—	50	300	W
Power-Up Response Time					
MMA6260Q	$t_{RESPONSE}$	—	14	—	ms
MMA6261Q	$t_{RESPONSE}$	—	2.0	—	ms
MMA6262Q	$t_{RESPONSE}$	—	4.0	—	ms
MMA6263Q	$t_{RESPONSE}$	—	0.7	—	ms
Mechanical Characteristics					
Transverse Sensitivity[(8)]	$V_{ZX, YX, ZY}$	–5.0	—	+5.0	% FSO

1. For a loaded output, the measurements are observed after an RC filter consisting of a 1.0 kΩ resistor and a 0.1 µF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 2.7 and 3.6 V, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above V_{DD}/2. For negative acceleration, the output will decrease below V_{DD}/2.
5. The digital input pin has an internal pull-down resistance to prevent inadvertent self-test initiation due to external board level leakages.
6. Time for the output to reach 90% of its final value after a self-test is initiated.
7. Preserves phase margin (60°) to guarantee output amplifier stability.
8. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined *cap* wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that moves between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration (Figure 3).

As the beams attached to the central mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell plates form two back-to-back capacitors (Figure 4). As the center plate moves with acceleration, the distance between the plates changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the plate, ε is the dielectric constant, and D is the distance between the plates.

The ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

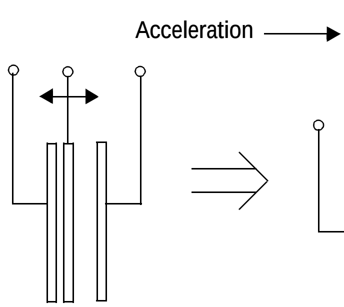


Figure 3. Transducer Physical Model

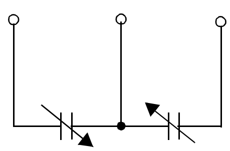


Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

These Freescale accelerometers contain an onboard single-pole switched capacitor filter. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature allowing the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. A fourth *plate* is used in the g-cell as a self-test plate. When a logic high input to the self-test pin is applied, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^1/_2\ AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's ASIC and a proportional output voltage results. This procedure assures both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Freescale accelerometers include fault detection circuitry and a fault latch. Parity of the EEPROM bits becomes odd in number.

Self-test is disabled when EEPROM parity error occurs.

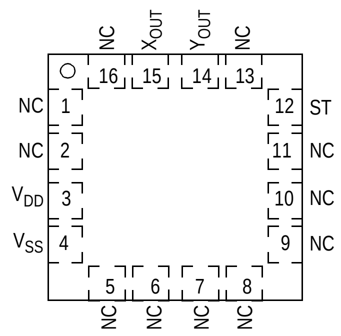
Ratiometricity

Ratiometricity simply means the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as supply voltage is increased, the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

BASIC CONNECTIONS

Pinout Description

Top View



Pin No.	Pin Name	Description
1, 5 – 7, 13, 16	N/C	No internal connection. Leave unconnected.
14	Y_{OUT}	Output voltage of the accelerometer. Y Direction.
15	X_{OUT}	Output voltage of the accelerometer. X Direction.
3	V_{DD}	Power supply input.
4	V_{SS}	The power supply ground.
2, 8 – 11	N/C	Used for factory trim. Leave unconnected.
12	ST	Logic input pin used to initiate self-test.

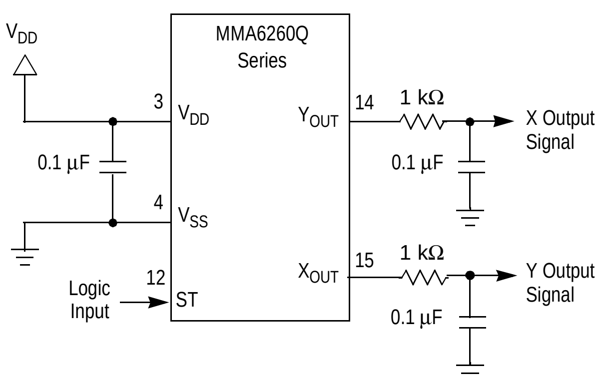


Figure 5. Accelerometer with Recommended Connection Diagram

PCB Layout

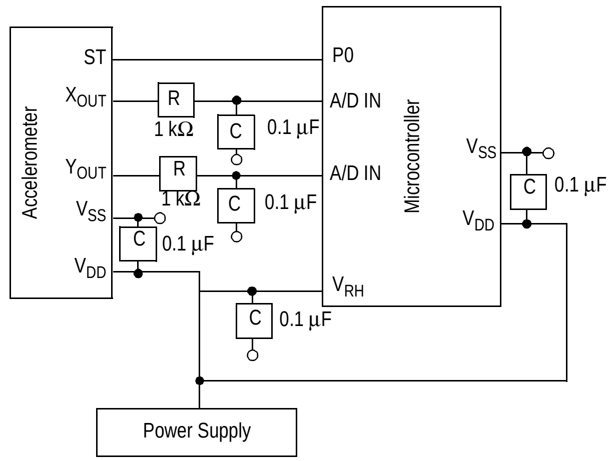


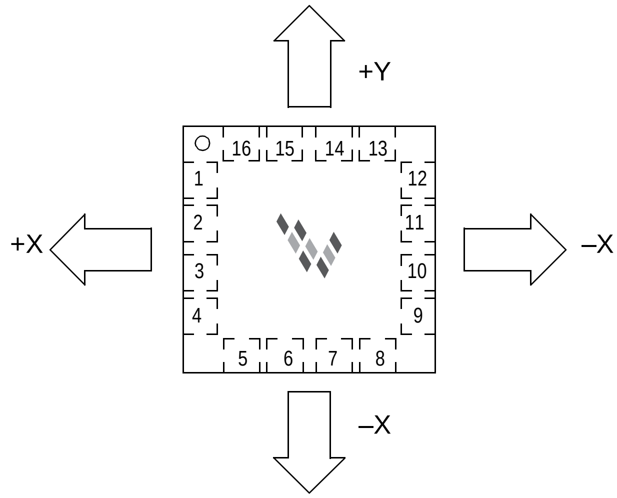
Figure 6. Recommend PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Flag underneath package is connected to ground.
4. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
5. Use an RC filter with 1.0 kΩ and 0.1 µF on the outputs of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
6. PCB layout of power and ground should not couple power supply noise.
7. Accelerometer and microcontroller should not be a high current path.
8. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency (16 kHz for Low I_{DD} and 52 kHz for Standard I_{DD} for the sampling frequency). This will prevent aliasing errors.

DYNAMIC ACCELERATION

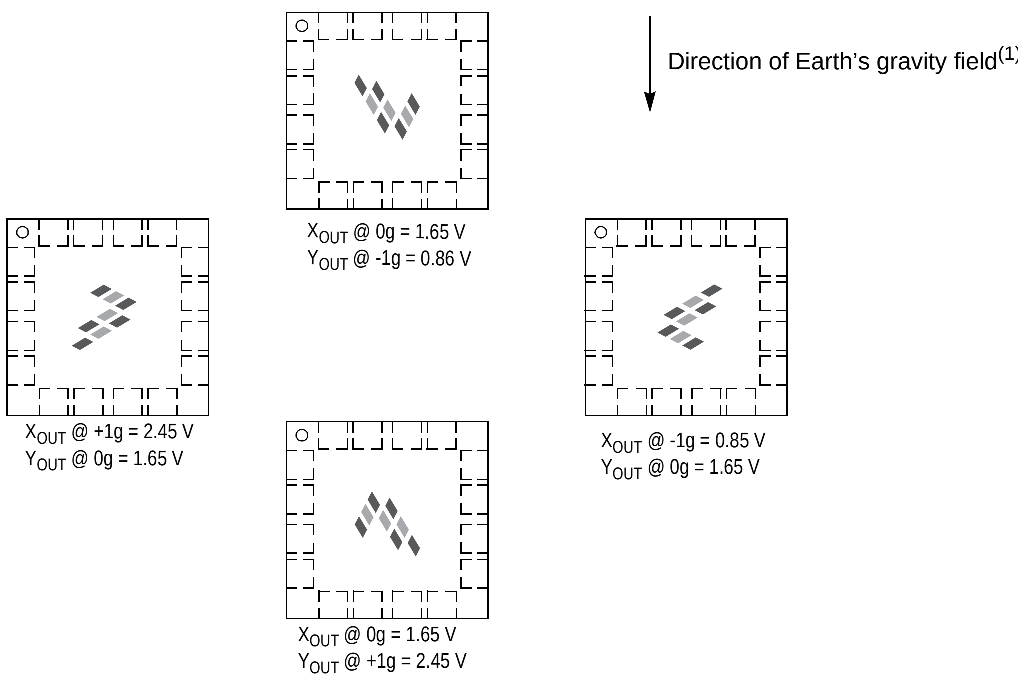
Top View



16-Pin QFN Package

STATIC ACCELERATION

Top View

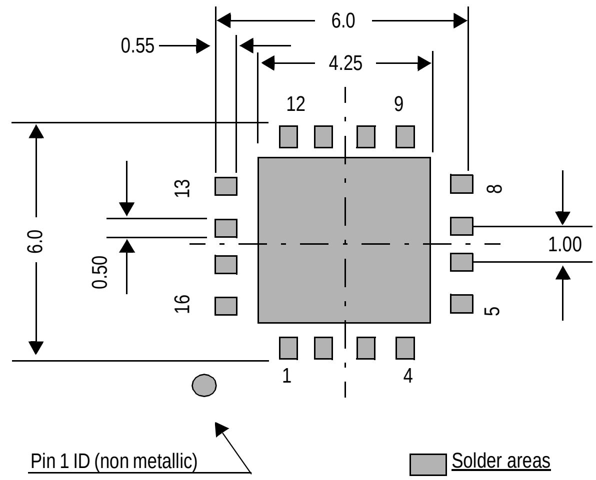


1. When positioned as shown, the Earth's gravity will result in a positive 1g output.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package.

With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.



±1.5g - 6g Three Axis Low-g Micromachined Accelerometer

The MMA7260Q low cost capacitive micromachined accelerometer features signal conditioning, a 1-pole low pass filter, temperature compensation and g-Select which allows for the selection among 4 sensitivities. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. Includes a Sleep Mode that makes it ideal for handheld battery powered electronics.

Features

- Selectable Sensitivity (1.5g/2g/4g/6g)
- Low Current Consumption: 500 µA
- Sleep Mode: 3 µA
- Low Voltage Operation: 2.2 V – 3.6 V
- 6mm x 6mm x 1.45mm QFN
- High Sensitivity (800 mV/g @1.5 g)
- Fast Turn On Time
- High Sensitivity (1.5 g)
- Integral Signal Conditioning with Low Pass Filter
- Robust Design, High Shocks Survivability
- Pb-Free Terminations
- Environmentally Preferred Package
- Low Cost

Typical Applications

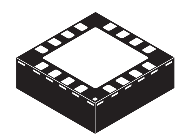
- HDD MP3 Player : Freefall Detection
- Laptop PC : Freefall Detection, Anti-Theft
- Cell Phone : Image Stability, Text Scroll, Motion Dialing, E-Compass
- Pedometer : Motion Sensing
- PDA : Text Scroll
- Navigation and Dead Reckoning : E-Compass Tilt Compensation
- Gaming : Tilt and Motion Sensing, Event Recorder
- Robotics : Motion Sensing

ORDERING INFORMATION			
Device Name	**Temperture Range**	**Case No.**	**Package**
MMA7260Q	– 20 to +85°C	1622-01	QFN-16, Tube
MMA7260QR2	– 20 to +85°C	1622-01	QFN-16,Tape & Reel

MMA7260Q

MMA7260Q: XYZ AXIS ACCELEROMETER ±1.5g/2g/4g/6g

Bottom View



16 LEAD QFN CASE 1622-01

Top View

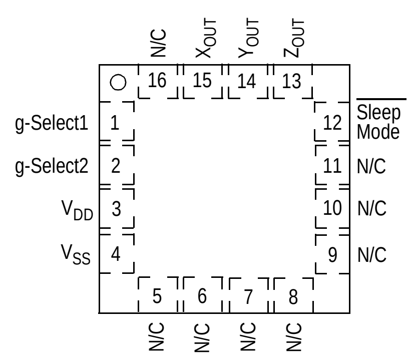


Figure 1. Pin Connections

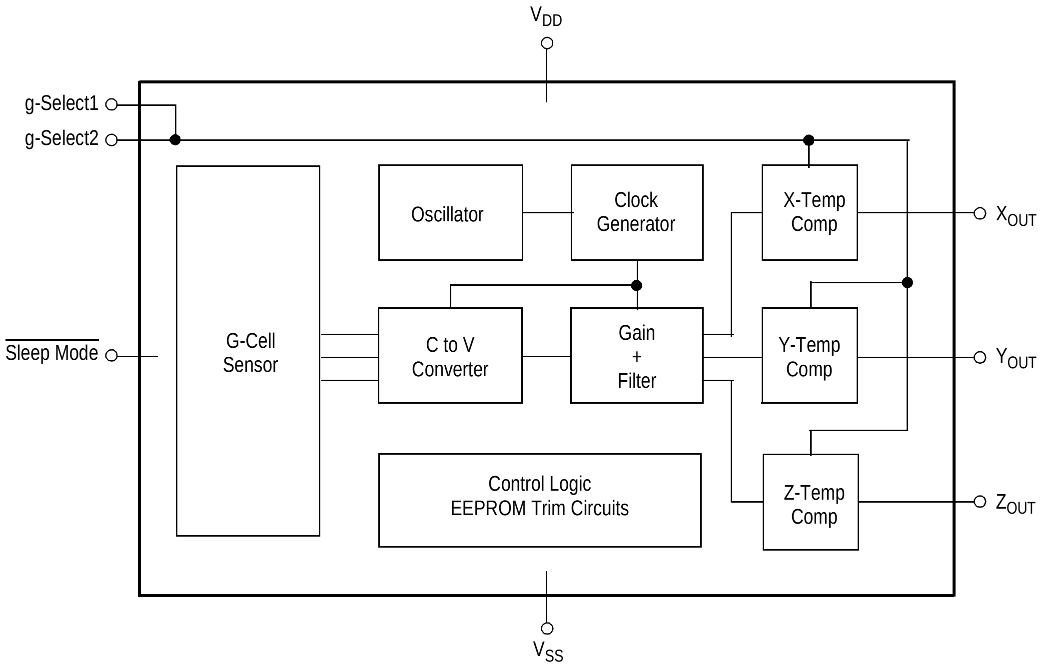


Figure 2. Simplified Accelerometer Functional Block Diagram

Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Maximum Acceleration (all axis)	g_{max}	±2000	g
Supply Voltage	V_{DD}	–0.3 to +3.6	V
Drop Test[1]	D_{drop}	1.8	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometer contains internal 2000 V ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

Table 2. Operating Characteristics
Unless otherwise noted: $-20°C \leq T_A \leq 85°C$, $2.2 V \leq V_{DD} \leq 3.6 V$, Acceleration = 0g, Loaded output[1]

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	2.2	3.3	3.6	V
Supply Current	I_{DD}	—	500	800	µA
Supply Current at Sleep Mode[4]	I_{DD}	—	3	10	µA
Operating Temperature Range	T_A	–20	—	+85	°C
Acceleration Range, X-Axis, Y-Axis, Z-Axis					
g-Select1 & 2: 00	g_{FS}	—	±1.5	—	g
g-Select1 & 2: 10	g_{FS}	—	±2.0	—	g
g-Select1 & 2: 01	g_{FS}	—	±4.0	—	g
g-Select1 & 2: 11	g_{FS}	—	±6.0	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 3.3 V)[5]	V_{OFF}	1.485	1.65	1.815	V
Zero g	V_{OFF}, T_A	—	±2	—	mg/°C
Sensitivity (T_A = 25°C, V_{DD} = 3.3 V)					
1.5g	$S_{1.5g}$	740	800	860	mV/g
2g	S_{2g}	555	600	645	mV/g
4g	S_{4g}	277.5	300	322.5	mV/g
6g	S_{6g}	185	200	215	mV/g
Sensitivity	S,T_A	—	±3	—	%/°C
Bandwidth Response					
XY	f_{-3dB}	—	350	—	Hz
Z	f_{-3dB}	—	150	—	Hz
Noise					
RMS (0.1 Hz – 1 kHz)[4]	n_{RMS}	—	4.7	—	mVrms
Power Spectral Density RMS (0.1 Hz – 1 kHz)[4]	n_{PSD}	—	350	—	$\mu g/\sqrt{Hz}$
Control Timing					
Power-Up Response Time[6]	$t_{RESPONSE}$	—	1.0	2.0	ms
Enable Response Time[7]	t_{ENABLE}	—	0.5	2.0	ms
Sensing Element Resonant Frequency					
XY	f_{GCELL}	—	6.0	—	kHz
Z	f_{GCELL}	—	3.4	—	kHz
Internal Sampling Frequency	f_{CLK}	—	11	—	kHz
Output Stage Performance					
Full-Scale Output Range (I_{OUT} = 30 µA)	V_{FSO}	V_{SS}+0.25	—	V_{DD}–0.25	V
Nonlinearity, X_{OUT}, Y_{OUT}, Z_{OUT}	NL_{OUT}	–1.0	—	+1.0	%FSO
Cross-Axis Sensitivity[8]	$V_{XY, XZ, YZ}$	—	—	5.0	%

1. For a loaded output, the measurements are observed after an RC filter consisting of a 1.0 kΩ resistor and a 0.1 µF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 2.2 and 3.6 V, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. This value is measured with g-Select in 1.5g mode.
5. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above $V_{DD}/2$. For negative acceleration, the output will decrease below $V_{DD}/2$.
6. The response time between 10% of full scale Vdd input voltage and 90% of the final operating output voltage.
7. The response time between 10% of full scale Sleep Mode input voltage and 90% of the final operating output voltage.
8. A measure of the device’s ability to reject an acceleration applied 90° from the true axis of sensitivity.

PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of two surface micromachined capacitive sensing cells (g-cell) and a signal conditioning ASIC contained in a single integrated circuit package. The sensing elements are sealed hermetically at the wafer level using a bulk micromachined cap wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that move between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration (Figure 3) .

As the beams attached to the central mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell beams form two back-to-back capacitors (Figure 3). As the center beam moves with acceleration, the distance between the beams changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the beam, ε is the dielectric constant, and D is the distance between the beams.

The ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

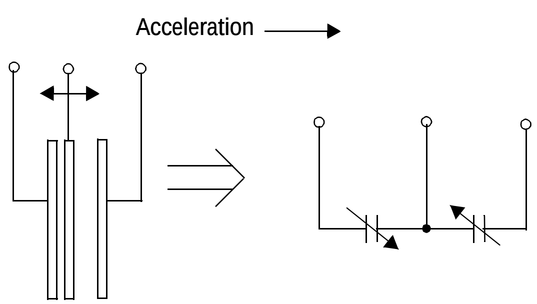


Figure 3. Simplified Transducer Physical Model

SPECIAL FEATURES

g-Select

The g-Select feature allows for the selection among 4 sensitivities present in the device. Depending on the logic input placed on pins 1 and 2, the device internal gain will be changed allowing it to function with a 1.5g, 2g, 4g, or 6g sensitivity (Table 3). This feature is ideal when a product has applications requiring different sensitivities for optimum performance. The sensitivity can be changed at anytime during the operation of the product. The g-Select1 and g-Select2 pins can be left unconnected for applications requiring only a 1.5g sensitivity as the device has an internal pulldown to keep it at that sensitivity (800mV/g).

Table 3. g-Select pin Descriptions

g-Select2	g-Select1	g-Range	Sensitivity
0	0	1.5g	800mV/g
0	1	2g	600mV/g
1	0	4g	300mV/g
1	1	6g	200mV/g

Sleep Mode

The 3 axis accelerometer provides a Sleep Mode that is ideal for battery operated products. When Sleep Mode is active, the device outputs are turned off, providing significant reduction of operating current. A low input signal on pin 12 (Sleep Mode) will place the device in this mode and reduce the current to 3uA typ. For lower power consumption, it is recommended to set g-Select1 and g-Select2 to 1.5g mode. By placing a high input signal on pin 12, the device will resume to normal mode of operation.

Filtering

The 3 axis accelerometer contains onboard single-pole switched capacitor filters. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Ratiometricity

Ratiometricity simply means the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as supply voltage is increased, the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

BASIC CONNECTIONS

Pin Descriptions

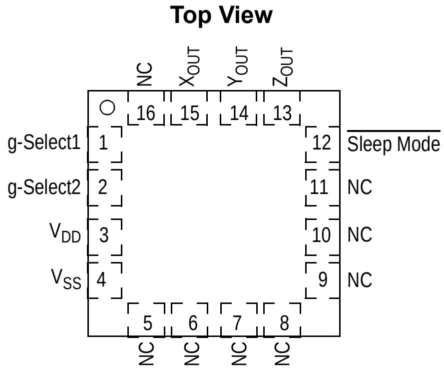


Figure 4. Pinout Description

Table 4. Pin Descriptions

Pin No.	Pin Name	Description
1	g-Select1	Logic input pin to select g level.
2	g-Select2	Logic input pin to select g level.
3	V_{DD}	Power Supply Input
4	V_{SS}	Power Supply Ground
5 - 7	N/C	No internal connection. Leave unconnected.
8 - 11	N/C	Unused for factory trim. Leave unconnected.
12	$\overline{\text{Sleep Mode}}$	Logic input pin to enable product or Sleep Mode.
13	Z_{OUT}	Z direction output voltage.
14	Y_{OUT}	Y direction output voltage.
15	X_{OUT}	X direction output voltage.
16	N/C	No internal connection. Leave unconnected.

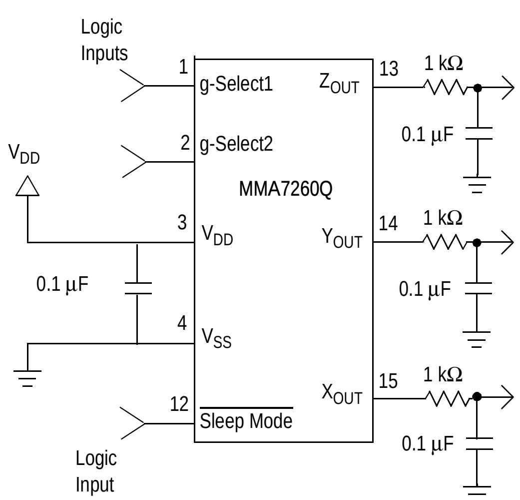


Figure 5. Accelerometer with Recommended Connection Diagram

PCB Layout

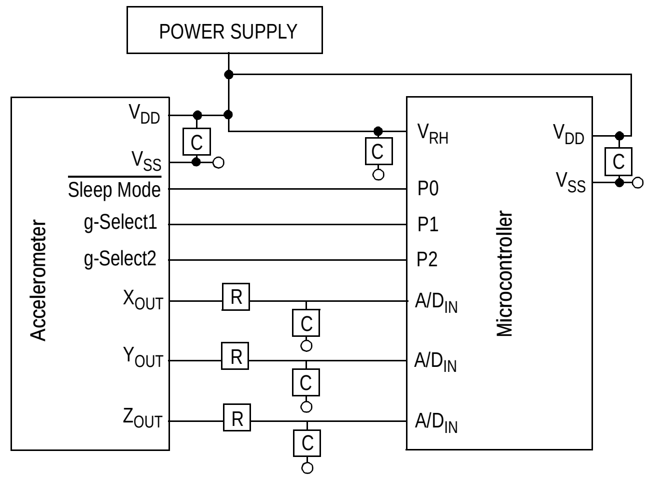
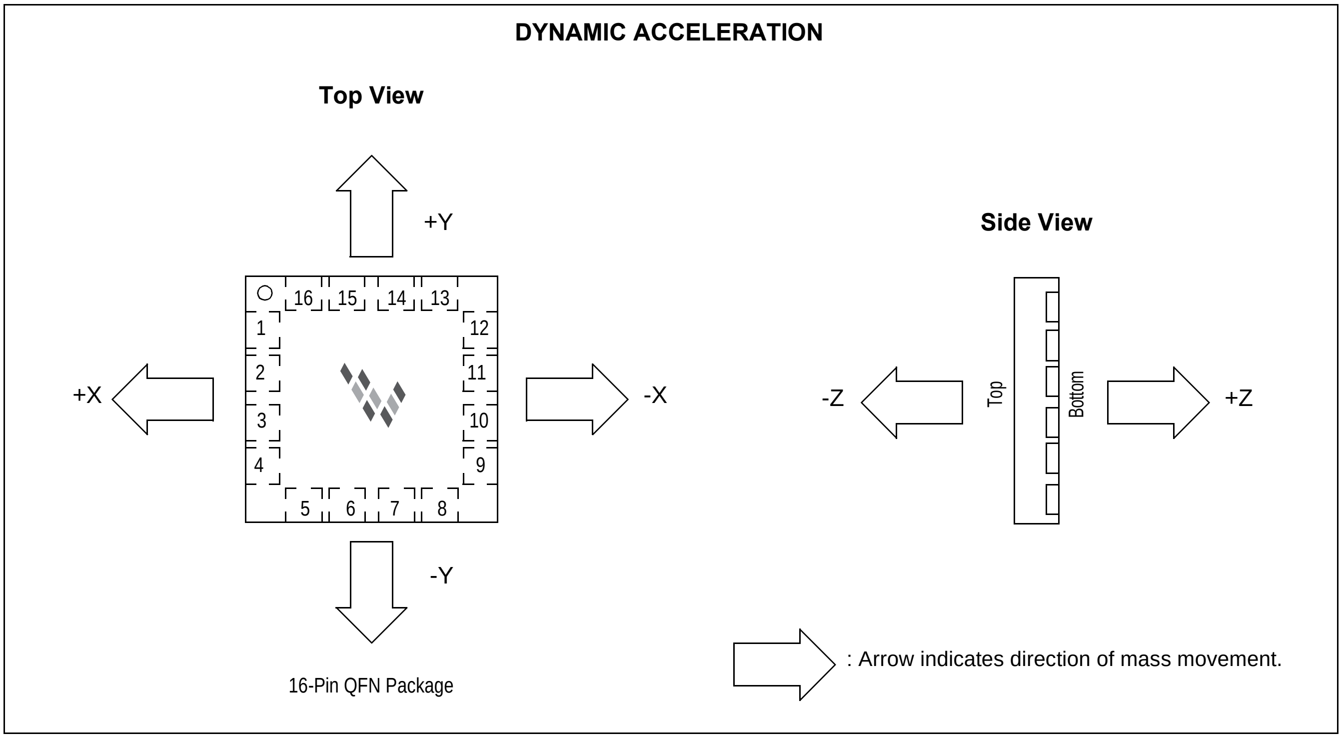
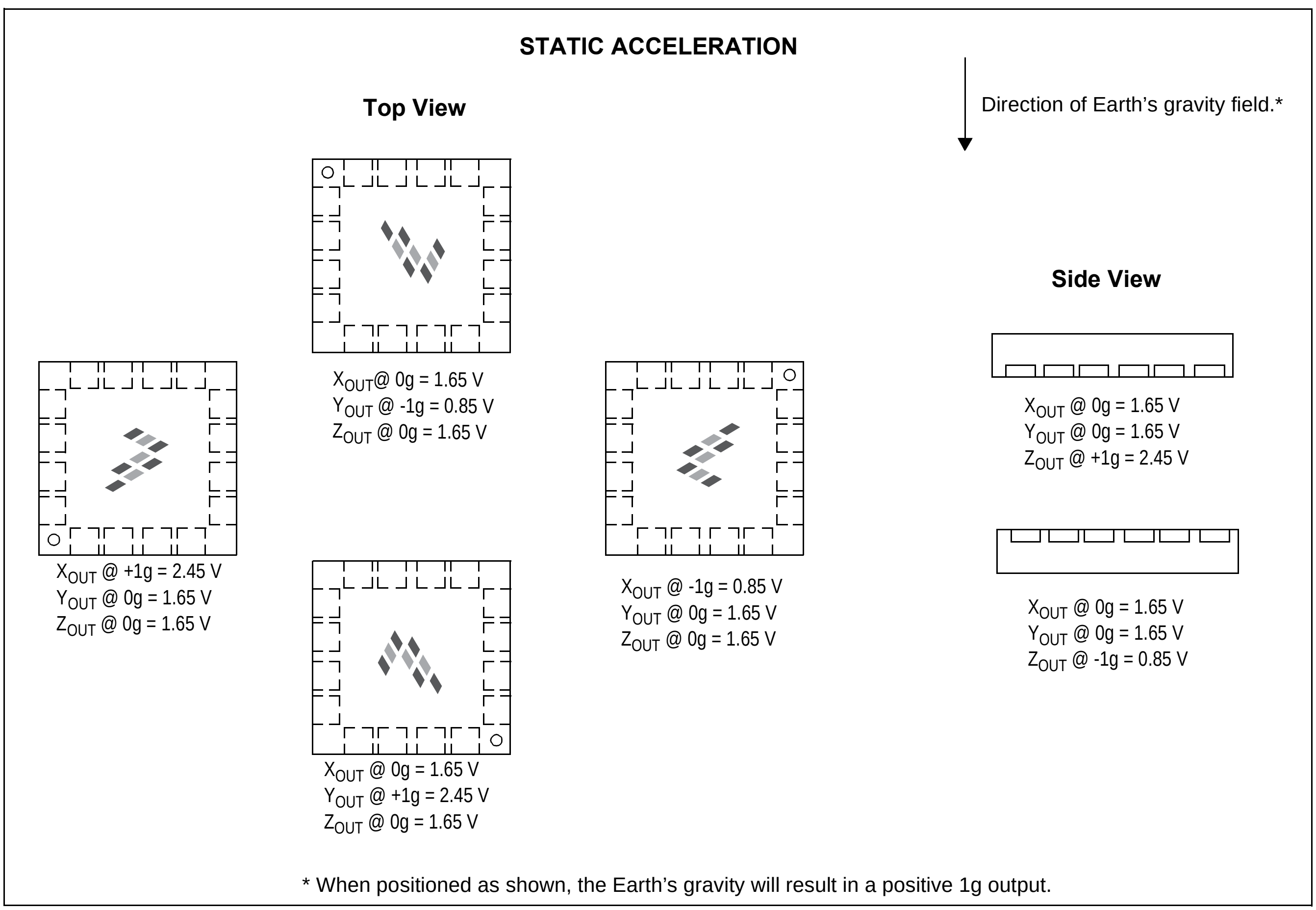


Figure 6Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Flag underneath package is connected to ground.
4. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
5. Use an RC filter with 1.0 kΩ and 0.1 µF on the outputs of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
6. PCB layout of power and ground should not couple power supply noise.
7. Accelerometer and microcontroller should not be a high current path.
8. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency (11 kHz for the sampling frequency). This will prevent aliasing errors.


DYNAMIC ACCELERATION
Top View
+Y
+X
-X
-Y
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
16-Pin QFN Package
Side View
-Z
+Z
Top
Bottom
: Arrow indicates direction of mass movement.


STATIC ACCELERATION
Top View
Direction of Earth's gravity field.*
X_{OUT}@ 0g = 1.65 V
Y_{OUT} @ -1g = 0.85 V
Z_{OUT} @ 0g = 1.65 V
X_{OUT} @ +1g = 2.45 V
Y_{OUT} @ 0g = 1.65 V
Z_{OUT} @ 0g = 1.65 V
X_{OUT} @ -1g = 0.85 V
Y_{OUT} @ 0g = 1.65 V
Z_{OUT} @ 0g = 1.65 V
X_{OUT} @ 0g = 1.65 V
Y_{OUT} @ +1g = 2.45 V
Z_{OUT} @ 0g = 1.65 V
Side View
X_{OUT} @ 0g = 1.65 V
Y_{OUT} @ 0g = 1.65 V
Z_{OUT} @ +1g = 2.45 V
X_{OUT} @ 0g = 1.65 V
Y_{OUT} @ 0g = 1.65 V
Z_{OUT} @ -1g = 0.85 V
* When positioned as shown, the Earth's gravity will result in a positive 1g output.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package.

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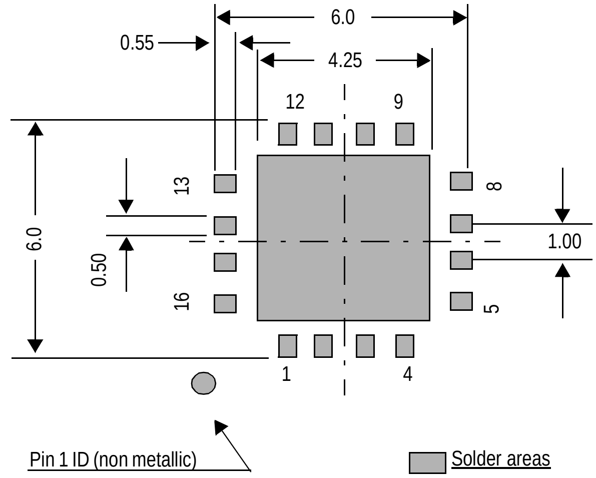

Freescale Semiconductor
Technical Data

AN1559
Rev 2, 05/2005

Application Considerations for a Switched Capacitor Accelerometer

by: Wayne Chavez

INTRODUCTION

Today's low cost accelerometers are highly integrated devices employing features such as signal conditioning, filtering, offset compensation and self test. Combining this feature set with economical plastic packaging requires that the signal conditioning circuitry be as small as possible. One approach is to implement sampled data system and switched capacitor techniques as in the Freescale accelerometer.

As in all sampled data systems, precautions should be taken to avoid signal aliasing errors. This application note describes the accelerometer and how signal aliasing can be introduced and more importantly minimized.

BACKGROUND

What is aliasing? Simply put, aliasing is the effect of sampling a signal at an insufficient rate, thus creating another signal at a frequency that is the difference between the original signal frequency and the sampling rate. A graphical explanation of aliasing is offered in Figure 1. In this figure, the upper trace shows a 50 kHz sinusoidal waveform. Note that when sampled at a 45 kHz rate, denoted by the boxes, a sinusoidal pattern is formed. Lowpass filtering the sampled points, to create a continuous signal, produces the 5 kHz waveform shown in Figure 1 (lower). (The phase shift in the lower figure is due to the low-pass filter).

Aliased signals, like the one in Figure 1 (lower) are often unintentionally produced. Signal processing techniques are well understood and sampling rates are chosen appropriately (i.e. Nyquist criteria). However, the assumption is that the signals of interest are well characterized and have a limited bandwidth. This assumption is not always true, as in the case of wideband noise.

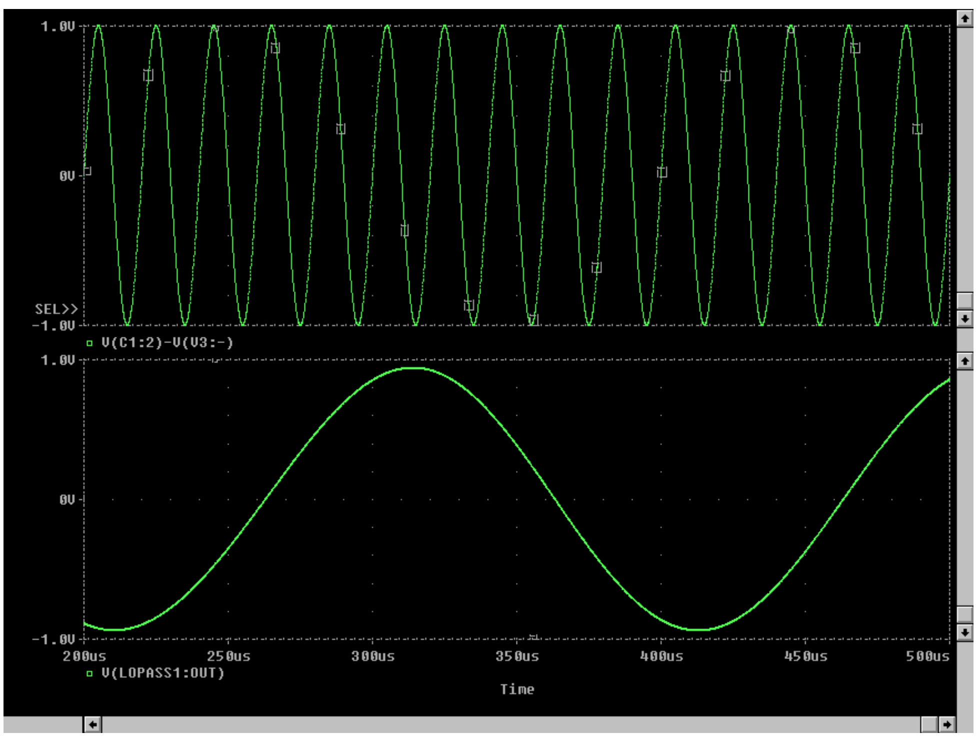

Figure 1. Aliased Signals

Given the brief example on how aliasing can occur, how does the accelerometer relate to aliasing? To answer this question, a brief summary on how the accelerometer works is in order.

The accelerometer is a two chip acceleration sensing solution. The first chip is the acceleration transducer, termed G-Cell, constructed by Micro Electro-Mechanical Systems (MEMS) technology. The G-Cell is a two capacitor element where the capacitors are in series and share a common center plate. The deflection in the center plate changes the capacitance of each capacitor which is measured by the second chip, termed control chip.

The control chip performs the signal conditioning (amplification, filtering, offset level shift) function in the system. This chip measures the G-Cell output using switched capacitor techniques. By the nature of switched cap techniques, the system is a sampled data system operating at sampling frequency f_s. The filter is switched capacitor, 4-pole Bessel implementation with a -3 dB frequency of 400 Hz.

As a sampled data system, the accelerometer is not immune to signal aliasing. However, given the accelerometer's internal filter, aliased signals will only appear in the output passband when input signals are in the range $| n \bullet f_s - f_{signal} | \leq f_{BW}$. Where f_s is the sampling rate, f_{Signal} is the input signal frequency, f_{BW} is the filter bandwidth and n is a positive integer to account for all harmonics. The graphical representation is shown in Figure 2. The bounds can be extended beyond f_{BW} to ensure an alias free output.

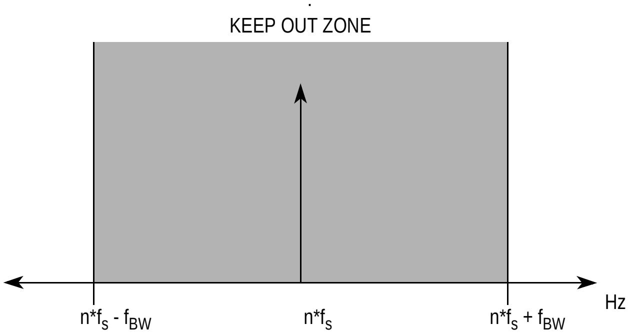

Figure 2. Input Signal Frequency Range Where a Signal Will Be Produced in the Output Passband

ACCELEROMETER INPUT SIGNALS

The accelerometer is a ratiometric electro-mechanical transducer. Therefore, the input signals to the device are the acceleration and the input power source.

The acceleration input is limited in frequency bandwidth by the geometry of the sensing, packaging, and mounting structures that define the resonant frequency and response. This response is in the range of 10 kHz, however, the practical range is less than 600 Hz for most mechanical systems. Therefore, aliasing an acceleration signal is unlikely.

The power input signal is ideally dc. However, depending on the application system architecture, the power supply line can be riddled with high frequency components. For example, dc to dc converters can operate with switching frequencies between 20 kHz and 200 kHz. This range encompasses the sampling rate of the accelerometer and point to the power source as the culprit in producing aliased signal.

DEMONSTRATION OF ALIASING

Under zero acceleration conditions a 100 mV_{rms} signal was injected onto the power supply line of 5.0 Vdc. The frequency of the injected signal was tuned in to produce an alias in the accelerometer's passband. Figure 3 and Figure 4 show the difference in output when a high frequency signal is not and is present on the V_{CC} pin of the accelerometer.

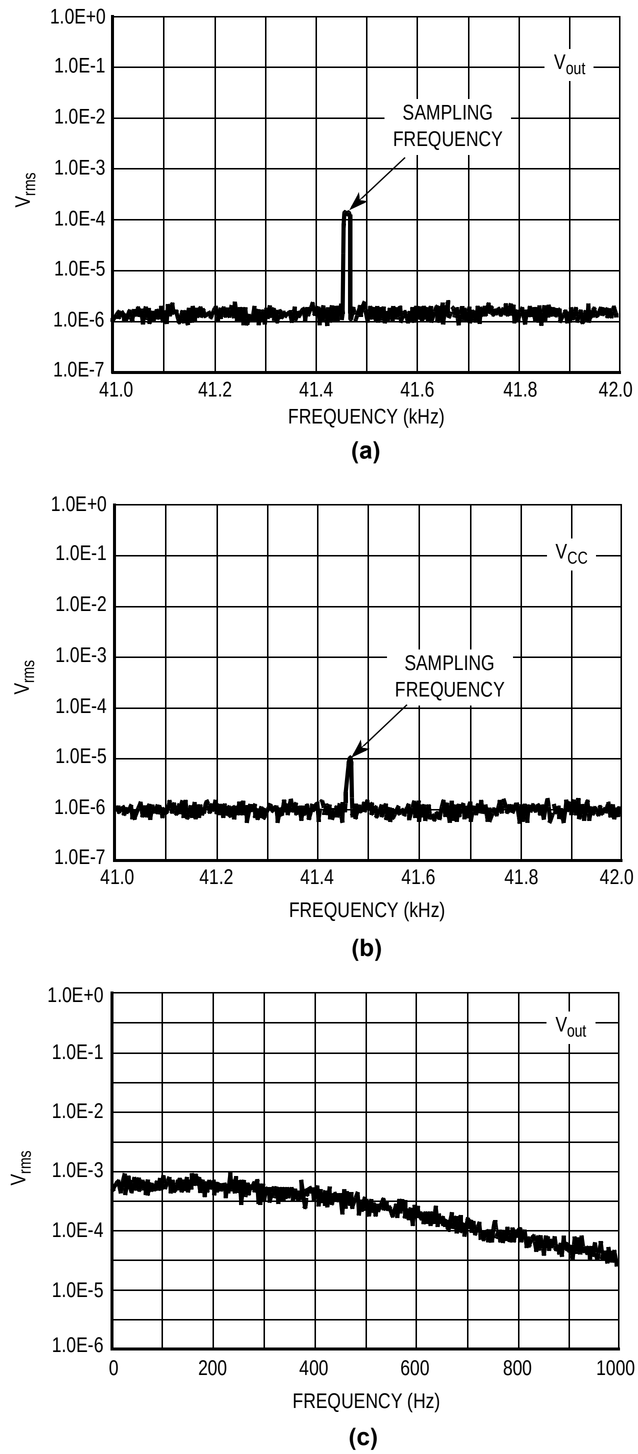

Figure 3. Normal Waveforms

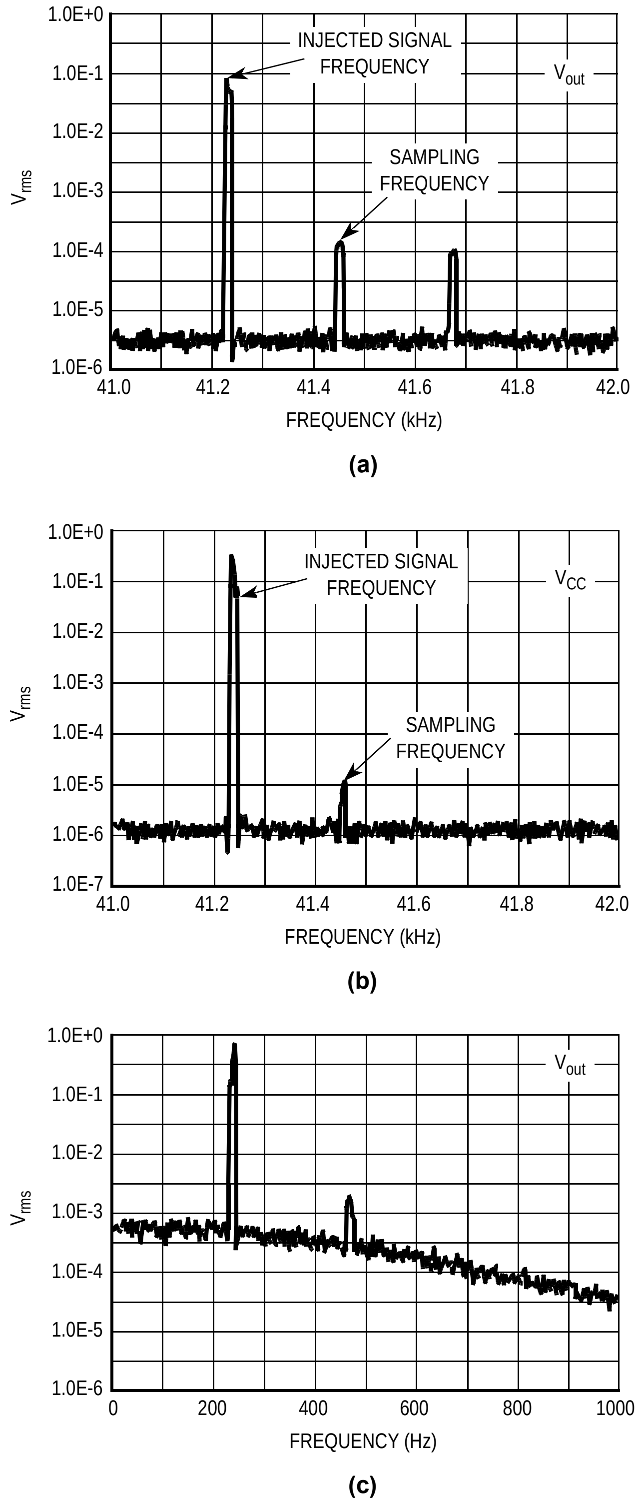

Figure 4. Aliasing Comparison

Points to Note:

- Under clean dc bias, V_{out} and V_{CC}, Figure 3a and Figure 3b have a signal component at the sampling rate. This is due to switched capacitor currents coupling through finite power supply source impedances and PCB paracitics.
- The low frequency output spectrum, Figure 3c, displays the internal lowpass filter characteristics. (The filter and sampling characteristics are sometimes useful in system debugging.)
- When an ac component is superimposed onto V_{CC} near the sampling frequency, as shown in Figure 4b, the output will contain the original signal plus a mirrored signal about the sampling frequency, shown in Figure 4a. Signals on the V_{CC} line will appear at the output due to the ratiometric characteristic of the accelerometer and will be one half the amplitude.
- As a result of sampling, the output waveform of Figure 4c is produced where the injected high frequency signal has now produced a signal in the passband.
- Harmonics of the aliased signal in the pass band are also shown in Figure 4c.
- Aliased signals in the passband will be amplified versions of the injected signals. This is due to the signal conditioning circuitry in the accelerometer that includes gain.

ALIASING AVOIDANCE KEYS

- Use a linear regulated power source when feasible. Linear regulators have excellent power supply rejection offering a stable dc source.
- If using a switching power supply, ensure that the switching frequency is not close to the accelerometer sampling frequency or its harmonics. Noting that the accelerometer will gain the aliasing signal, it is desirable to keep frequencies at least 4 kHz away from the sampling frequency and its harmonics. 4 kHz is one decade from the -3 dB frequency, therefore any signals will be sufficiently attenuated by the internal 4-pole lowpass filter.
- Proper bias decoupling will aid in noise reduction from other sources. With dense surface mount PCB assemblies, it is often difficult to place and route decoupling components. However, the accelerometer is not like a typical logic device. A little extra effort on decoupling goes a long way.
- Good PCB layout practices should always be followed. Proper system grounding is essential. Parasitic capacitance and inductance could prove to be troublesome, particularly during EMC testing. Signal harmonics and sub-harmonics play a significant role in introducing aliased signals. Clean layouts minimize the effects of parasitics and thus signal harmonics and sub-harmonics.

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Technical Data

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Impact Measurement Using Accelerometers

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INTRODUCTION

This application note describes the concept of measuring impact of an object using an accelerometer, microcontroller hardware/software and a liquid crystal display. Due to the wide frequency response of the accelerometer from d.c. to 400 Hz, the device is able to measure both the static acceleration from the Earth's gravity and the shock or vibration from an impact. This design uses a 40g accelerometer and yields a minimum acceleration range of -40g to +40g.

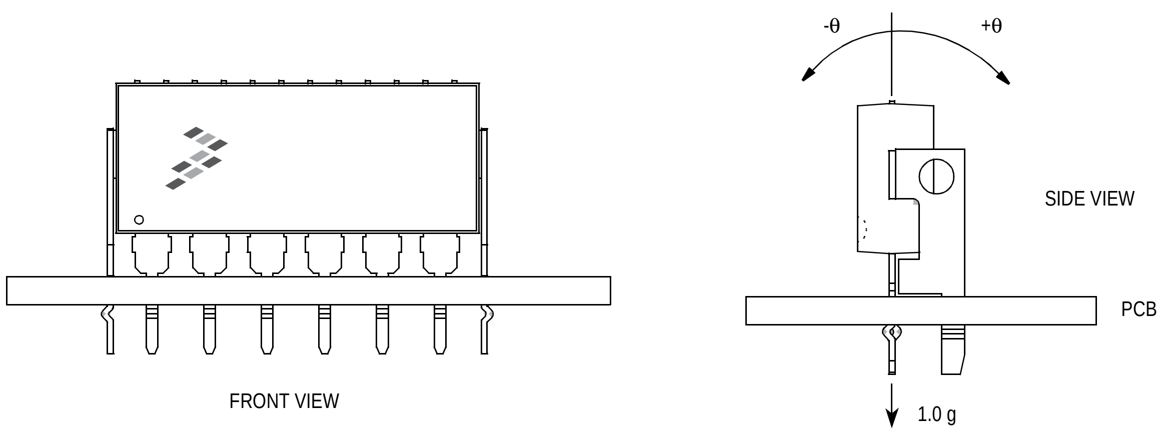

Figure 1. Orientation of Accelerometer

CONCEPT OF IMPACT MEASUREMENT

During an impact, the accelerometer will be oriented as shown in Figure 1 to measure the deceleration experienced by the object from dc to 400 Hz. Normally, the peak impact pulse is in the order of a few milliseconds. Figure 2 shows a typical crash waveform of a toy car having a stiff bumper.

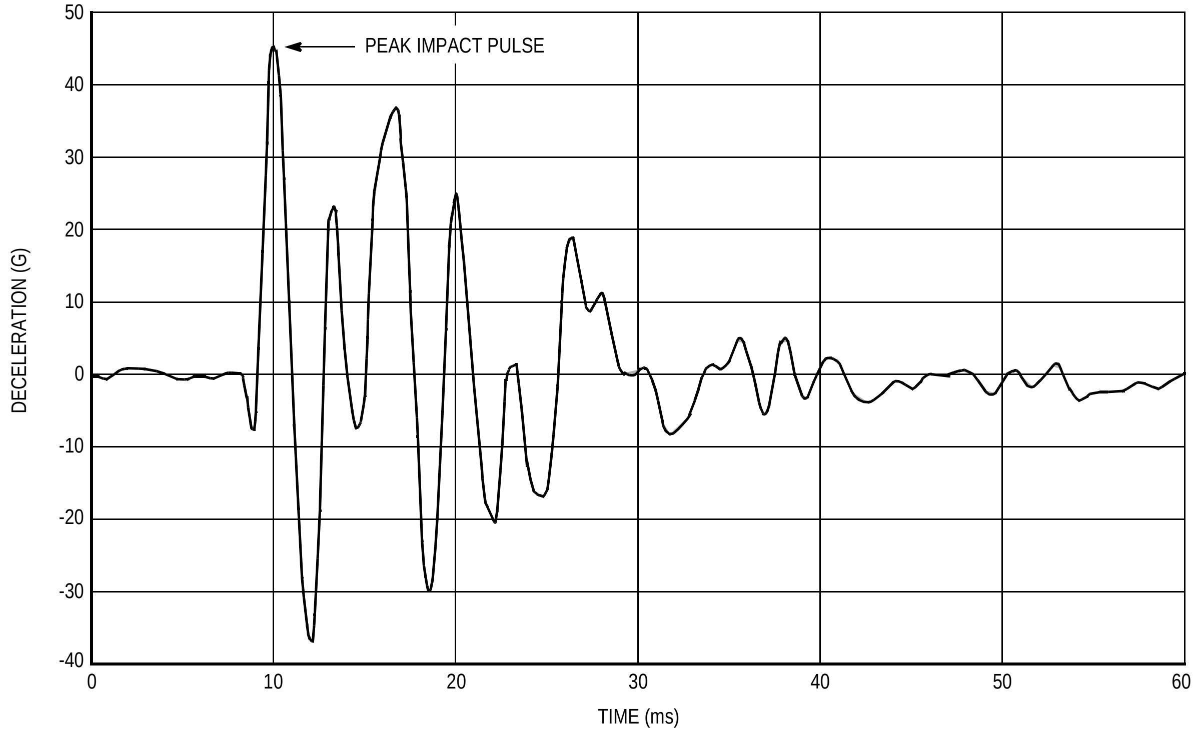

Figure 2. Typical Crash Pattern

HARDWARE DESCRIPTION AND OPERATION

Since the accelerometer is fully signal-conditioned by its internal op-amp and temperature compensation, the output of the accelerometer can be directly interfaced with an analog-to-digital (A/D) converter for digitization. A filter consists of one RC network and should be added if the connection between the output of the accelerometer and the A/D converter is a long track or cable. This stray capacitance may change the position of the internal pole which would drive the output amplifier of the accelerometer into oscillation or unstability. In this design, the cut-off frequency is chosen to be 15.9 kHz which also acts as an anti-alias filter for the A/D converter. The 3 dB frequency can be approximated by the following equation.

$$f_{-3db} = \frac{1}{2\pi RC}$$

Referring to the schematic, Figure 3, the accelerometer is connected to PORT D bit 5 and the output of the amplifier is connected to PORT D bit 6 of the microcontroller. This port is an input to the on-chip 8-bit analog-to-digital (A/D) converter. Typically, the accelerometer provides a signal output to the microprocessor of approximately 0.3 Vdc at -55g to 4.7 Vdc at +55g of acceleration. However, Freescale only guarantees the accuracy within ±40g range. Using the same reference voltage for the A/D converter and accelerometer minimizes the number of additional components, but does sacrifice resolution. The resolution is defined by the following:

$$\text{count} = \frac{V_{out}}{5} \times 255$$

The count at 0g = $[2.5/5] \times 255 \propto 128$

The count at +25g = $[3.5/5] \times 255 \propto 179$

The count at -25g = $[1.5/5] \times 255 \propto 77$

Therefore the resolution 0.5g/count

The output of the accelerometer is ratiometric to the voltage applied to it. The accelerometer and the reference voltages are connected to a common supply; this yields a system that is ratiometric. By nature of this ratiometric system, variations in the voltage of the power supplied to the system will have no effect on the system accuracy.

The liquid crystal display (LCD) is directly driven from I/O ports A, B, and C on the microcontroller. The operation of a LCD requires that the data and backplane (BP) pins must be driven by an alternating signal. This function is provided by a software routine that toggles the data and backplane at approximately a 30 Hz rate. Other than the LCD, one light emitting diode (LED) are connected to the pulse length converter (PLM) of the microcontroller. This LED will light up for 3 seconds when an impact greater or equal to 7g is detected.

The microcontroller section of the system requires certain support hardware to allow it to function. The MC34064P-5 provides an undervoltage sense function which is used to reset the microprocessor at system power-up. The 4 MHz crystal provides the external portion of the oscillator function for clocking the microcontroller and provides a stable base for time bases functions, for instance calculation of pulse rate.

SOFTWARE DESCRIPTION

Upon power-up of the system, the LCD will display CAL for approximately four seconds. During this period, the output of the accelerometer are sampled and averaged to obtain the zero offset voltage or zero acceleration. This value will be saved in the RAM which is used by the equation below to calculate the impact in term of g-force. One point to note is that the accelerometer should remain stationary during the zero calibration.

$$\text{Impact} = [\text{count} - \text{count}_{\text{offset}}] \times \text{resolution}$$

In this software program, the output of the accelerometer is calculated every 650 µs. During an impact, the peak deceleration is measured and displayed on the LCD for three seconds before resetting it to zero. In the mean time, if a higher impact is detected, the value on the LCD will be updated accordingly.

However, when a low g is detected (e.g. 1.0g), the value will not be displayed. Instead, more samples will be taken for further averaging to eliminate the random noise and high frequency component. Due to the fact that tilting is a low g and low frequency signal, large number of sampling is preferred to avoid unstable display. Moreover, the display value will not hold for three seconds as in the case of an impact.

Figure 4 is a flowchart for the program that controls the system.

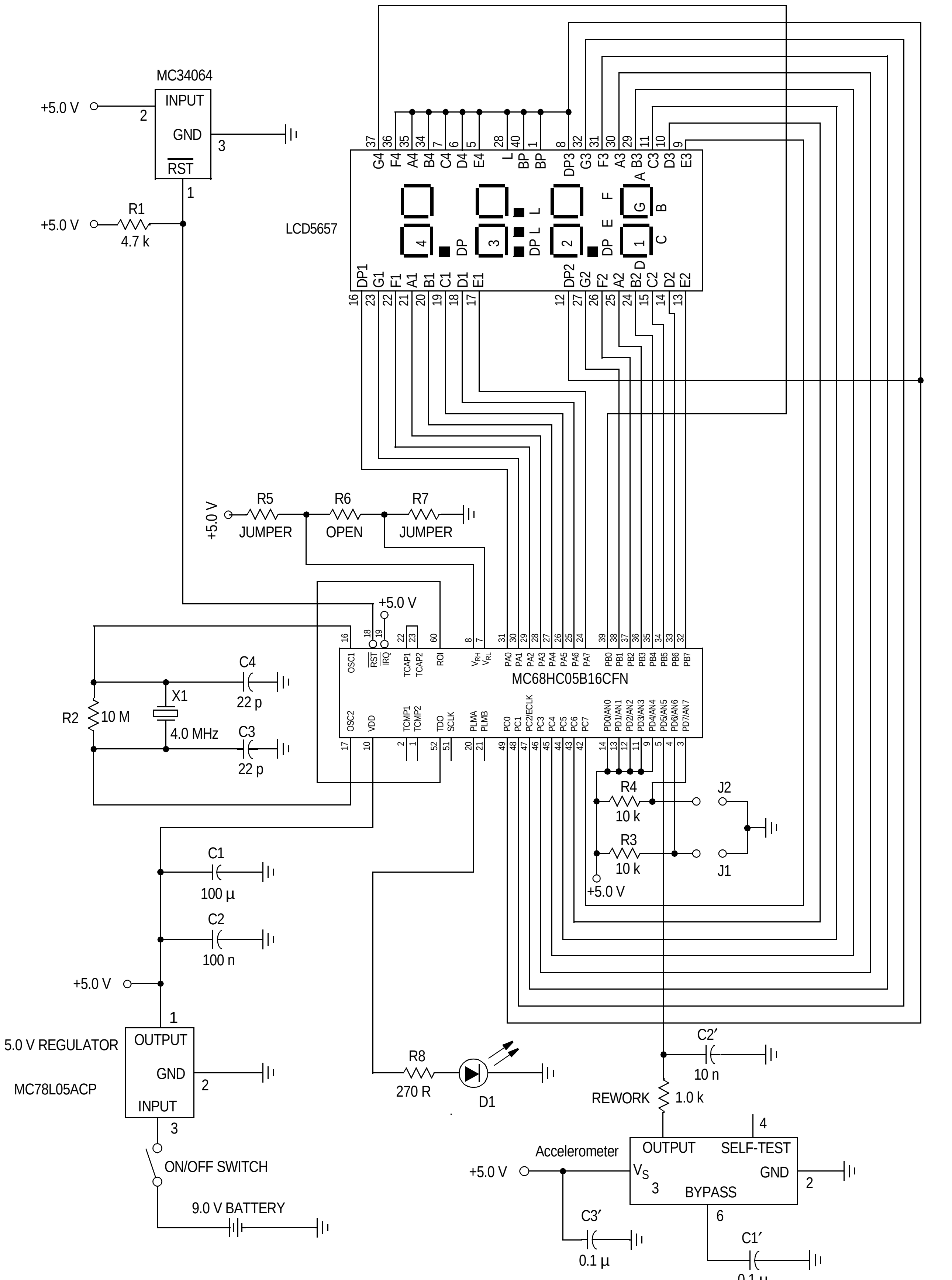

Figure 3. Impact Measurement Schematic Drawing

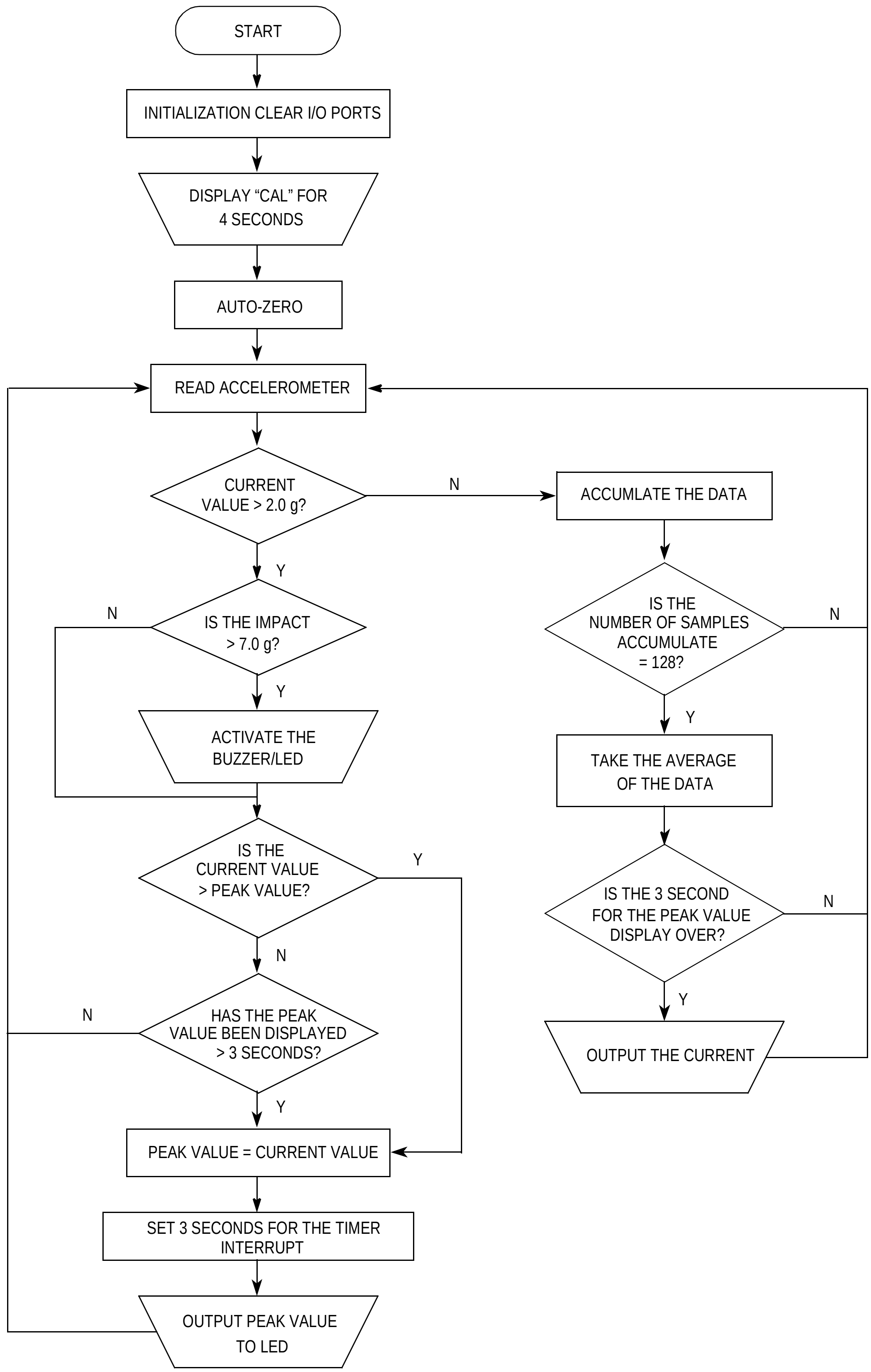

Figure 4. Main Program Flowchart

SOFTWARE SOURCE/ASSEMBLY PROGRAM CODE

```
******************************************************************************
*                                                                            *
*                    Accelerometer Demo Car Version 2.0                      *
*                                                                            *
*   The following code is written for MC68HC705B16 using MMDS05 software     *
*   Version 1.01                                                             *
*   CASM05 - Command line assembler Version 3.04                             *
*   P & E Microcomputer Systems, Inc.                                        *
*                                                                            *
*                        Written by : C.S. Chua                              *
*                            29 August 1996                                  *
*                                                                            *
*                                                                            *
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*                                                                            *
******************************************************************************
******************************************************************************
*                                                                            *
*                           Software Description                             *
*                                                                            *
*   This software is used to read the output of the accelerometer MMA2200W   *
*   and display it to a LCD as gravity force. It ranges from -55g to +55g    *
*   with 0g as zero acceleration or constant velocity. The resolution is     *
*   0.5g.                                                                    *
*                                                                            *
*   The program will read from the accelerometer and hold the maximum        *
*   deceleration value for about 3.0 seconds before resetting. At the same   *
*   time, the buzzer/LED is activated if the impact is more than 7.0g.       *
*   However, if the maximum deceleration changes before 3.0 seconds, it      *
*   will update the display using the new value. Note that positive value    *
*   implies deceleration whereas negative value implies acceleration         *
*                                                                            *
******************************************************************************
******************************************
*                                        *
*             Initialisation             *
*                                        *
******************************************
PORTA        EQU     $00           ; Last digit

PORTB        EQU     $01           ; Second digit (and negative sign)
PORTC        EQU     $02           ; First digit (and decimal point)
ADDATA       EQU     $08           ; ADC Data
ADSTAT       EQU     $09           ; ADC Status
PLMA         EQU     $0A           ; Pulse Length Modulator (Output to Buzzer)
MISC         EQU     $0C           ; Miscellaneous Register (slow/fast mode)
TCONTROL     EQU     $12           ; Timer control register
TSTATUS      EQU     $13           ; Timer Status Register
OCMPHI1      EQU     $16           ; Output Compare Register 1 High Byte
```

```
OCMPLO1      EQU     $17           ; Output Compare Register 1 Low Byte
TCNTHI       EQU     $18           ; Timer Count Register High Byte
TCNTLO       EQU     $19           ; Timer Count Register Low Byte
OCMPHI2      EQU     $1E           ; Output Compare Register 2 High Byte
OCMPLO2      EQU     $1F           ; Output Compare Register 2 Low Byte
*****************************************
*                                       *
*           User-defined RAM            *
*                                       *
*****************************************
SIGN         EQU     $54           ; Acceleration (-) or deceleration (+)
PRESHI2      EQU     $55           ; MSB of accumulated acceleration
PRESHI       EQU     $56
PRESLO       EQU     $57           ; LSB of accumulated acceleration
PTEMPHI      EQU     $58           ; Acceleration High Byte (Temp storage)
PTEMPLO      EQU     $59           ; Acceleration Low Byte (Temp storage)
ACCHI        EQU     $5A           ; Temp storage of acc value (High byte)
ACCLO        EQU     $5B           ;                           (Low byte)
ADCOUNTER    EQU     $5C           ; Sampling Counter
AVERAGE_H    EQU     $5D           ; MSB of the accumulated data of low g
AVERAGE_M    EQU     $5E
AVERAGE_L    EQU     $5F           ; LSB of the accumulated data of low g
SHIFT_CNT    EQU     $60           ; Counter for shifting the accumulated data
AVE_CNT1     EQU     $61           ; Number of samples in the accumulated data
AVE_CNT2     EQU     $75
TEMPTCNTHI   EQU     $62           ; Temp storage for Timer count register
TEMPTCNTLO   EQU     $63           ; Temp storage for Timer count register
DECHI        EQU     $64           ; Decimal digit high byte
DECLO        EQU     $65           ; Decimal digit low byte
DCOFFSETHI   EQU     $66           ; DC offset of the output (high byte)
DCOFFSETLO   EQU     $67           ; DC offset of the output (low byte)
MAXACC       EQU     $68           ; Maximum acceleration
TEMPHI       EQU     $69
TEMPLO       EQU     $6A
TEMP1        EQU     $6B           ; Temporary location for ACC during delay
TEMP2        EQU     $6C           ; Temporary location for ACC during ISR
DIV_LO       EQU     $6D           ; No of sampling (low byte)
DIV_HI       EQU     $6E           ; No of sampling (high byte)
NO_SHIFT     EQU     $6F           ; No of right shift to get average value
ZERO_ACC     EQU     $70           ; Zero acceleration in no of ADC steps
HOLD_CNT     EQU     $71           ; Hold time counter
HOLD_DONE    EQU     $72           ; Hold time up flag
START_TIME   EQU     $73           ; Start of count down flag
RSHIFT       EQU     $74           ; No of shifting required for division
             ORG     $300          ; ROM space 0300 to 3DFE (15,104 bytes)
             DB      $FC           ; Display "0"
             DB      $30           ; Display "1"
             DB      $DA           ; Display "2"
             DB      $7A           ; Display "3"
             DB      $36           ; Display "4"
             DB      $6E           ; Display "5"
             DB      $EE           ; Display "6"
             DB      $38           ; Display "7"
             DB      $FE           ; Display "8"
             DB      $7E           ; Display "9"
HUNDREDHI    DB      $00           ; High byte of hundreds
HUNDREDLO    DB      $64           ; Low byte of hundreds
TENHI        DB      $00           ; High byte of tens
TENLO        DB      $0A           ; Low byte of tens
*****************************************
*                                       *
*   Program starts here upon hard reset *
*                                       *
*****************************************
RESET        CLR     PORTC         ; Port C = 0
             CLR     PORTB         ; Port B = 0
             CLR     PORTA         ; Port A = 0
             LDA     #$FF
             STA     $06           ; Port C as output
             STA     $05           ; Port B as output
             STA     $04           ; Port A as output
             LDA     TSTATUS       ; Dummy read the timer status register
             CLR     OCMPHI2       ; so as to clear the OCF
             CLR     OCMPHI1
             LDA     OCMPLO2
             JSR     COMPRGT
             CLR     START_TIME
```

```
            LDA     #$40          ; Enable the output compare interrupt
            STA     TCONTROL
            CLI                   ; Interrupt begins here
            LDA     #$CC          ; Port C = 1100 1100   Letter "C"
            STA     PORTC
            LDA     #$BE          ; Port B = 1011 1110   Letter "A"
            STA     PORTB
            LDA     #$C4          ; Port A = 1100 0100   Letter "L"
            STA     PORTA
            LDA     #16
IDLE        JSR     DLY20         ; Idling for a while (16*0.125 = 2 sec)
            DECA                  ; for the zero offset to stabilize
            BNE     IDLE          ; before perform auto-zero
            LDA     #$00          ; Sample the data 32,768 times and take
            STA     DIV_LO        ; the average 8000 H = 32,768
            LDA     #$80          ; Right shift of 15 equivalent to divide
            STA     DIV_HI        ; by 32,768
            LDA     #!15          ; Overall sampling time = 1.033 s)
            STA     NO_SHIFT
            JSR     READAD        ; Zero acceleration calibration
            LDX     #5            ; Calculate the zero offset
            LDA     PTEMPLO       ; DC offset = PTEMPLO * 5
            STA     ZERO_ACC
            MUL
            STA     DCOFFSETLO    ; Save the zero offset in the RAM
            TXA
            STA     DCOFFSETHI
            CLR     HOLD_CNT
            LDA     #$10         ; Sample the data 16 times and take
            STA     DIV_LO       ; the average 0100 H = 16
            LDA     #$00         ; Right shift of 4 equivalent to divide
            STA     DIV_HI       ; by 16
            LDA     #$4          ; Overall sampling time = 650 us
            STA     NO_SHIFT
            LDA     ZERO_ACC     ; Display 0.0g at the start
            STA     MAXACC
            JSR     ADTOLCD
            CLR     START_TIME
            CLR     AVE_CNT1
            CLR     AVE_CNT2
            CLR     SHIFT_CNT
            CLR     AVERAGE_L
            CLR     AVERAGE_M
            CLR     AVERAGE_H
REPEAT      JSR     READAD        ; Read acceleration from ADC
            LDA     ZERO_ACC
            ADD     #$04
            CMP     PTEMPLO
            BLO     CRASH         ; If the acceleration < 2.0g
            LDA     PTEMPLO       ; Accumulate the averaged results
            ADD     AVERAGE_L     ; for 128 times and take the averaging
            STA     AVERAGE_L     ; again to achieve more stable
            CLRA                  ; reading at low g
            ADC     AVERAGE_M
            STA     AVERAGE_M
            CLRA
            ADC     AVERAGE_H
            STA     AVERAGE_H
            LDA     #$01
            ADD     AVE_CNT1
            STA     AVE_CNT1
            CLRA
            ADC     AVE_CNT2
            STA     AVE_CNT2
            CMP     #$04
            BNE     REPEAT
            LDA     AVE_CNT1
            CMP     #$00
            BNE     REPEAT
SHIFTING    INC     SHIFT_CNT     ; Take the average of the 128 samples
            LSR     AVERAGE_H
            ROR     AVERAGE_M
            ROR     AVERAGE_L
            LDA     SHIFT_CNT
            CMP     #$0A
            BLO     SHIFTING
            LDA     AVERAGE_L
```

```
            STA     PTEMPLO
            LDA     HOLD_CNT      ; Check if the hold time of crash data
            CMP     #$00          ; is up
            BNE     NON-CRASH
            LDA     PTEMPLO       ; If yes, display the current acceleration
            STA     MAXACC        ; value
            JSR     ADTOLCD
            BRA     NON-CRASH
CRASH       LDA     ZERO_ACC
            ADD     #$0E          ; If the crash is more than 7g
            CMP     PTEMPLO       ; 7g = 0E H * 0.5
            BHS     NO_INFLATE
            LDA     #$FF          ; activate the LED
            STA     PLMA
NO_INFLATE  JSR     MAXVALUE      ; Display the peak acceleration
            JSR     ADTOLCD
NON-CRASH   CLR     SHIFT_CNT
            CLR     AVE_CNT1
            CLR     AVE_CNT2
            CLR     AVERAGE_L
            CLR     AVERAGE_M
            CLR     AVERAGE_H
            BRA     REPEAT        ; Repeat the whole process
******************************************
*                                        *
*           Delay Subroutine             *
*     (162 * 0.7725 ms = 0.125 sec)      *
*                                        *
******************************************
DLY20       STA     TEMP1
            LDA     #!162             ; 1 unit = 0.7725 ms
OUTLP       CLRX
INNRLP      DECX
            BNE     INNRLP
            DECA
            BNE     OUTLP
            LDA     TEMP1
            RTS
******************************************
*                                        *
*     Reading the ADC data X times       *
*        and take the average            *
*   X is defined by DIV_HI and DIV_LO    *
*                                        *
******************************************
READAD      LDA     #$25
            STA     ADSTAT           ; AD status = 25H
            CLR     PRESHI2
            CLR     PRESHI           ; Clear the memory
            CLR     PRESLO
            CLRX
            CLR     ADCOUNTER
LOOP128     TXA
            CMP     #$FF
            BEQ     INC_COUNT
            BRA     CONT
INC_COUNT   INC     ADCOUNTER
CONT        LDA     ADCOUNTER        ; If ADCOUNTER = X
            CMP     DIV_HI           ; Clear bit = 0
            BEQ     CHECK_X          ; Branch to END100
            BRA     ENDREAD
CHECK_X     TXA
            CMP     DIV_LO
            BEQ     END128
ENDREAD     BRCLR   7,ADSTAT,ENDREAD ; Halt here till AD read is finished
            LDA     ADDATA           ; Read the AD register
            ADD     PRESLO           ; PRES = PRES + ADDATA
            STA     PRESLO
            CLRA
            ADC     PRESHI
            STA     PRESHI
            CLRA
            ADC     PRESHI2
            STA     PRESHI2
            INCX                     ; Increase the AD counter by 1
            BRA     LOOP128          ; Branch to Loop128
END128      CLR     RSHIFT           ; Reset the right shift counter
```

```
DIVIDE       INC     RSHIFT          ; Increase the right counter
             LSR     PRESHI2
             ROR     PRESHI          ; Right shift the high byte
             ROR     PRESLO          ; Right shift the low byte
             LDA     RSHIFT
             CMP     NO_SHIFT        ; If the right shift counter >= NO_SHIFT
             BHS     ENDDIVIDE       ; End the shifting
             JMP     DIVIDE          ; otherwise continue the shifting
ENDDIVIDE    LDA     PRESLO
             STA     PTEMPLO
             RTS
******************************************
*                                        *
*       Timer service interrupt          *
*     Alternates the Port data and       *
*          backplane of LCD              *
*                                        *
******************************************
TIMERCMP     STA     TEMP2           ; Push Accumulator
             COM     PORTC           ; Port C = - (Port C)
             COM     PORTB           ; Port B = - (Port B)
             COM     PORTA           ; Port A = - (Port A)
             LDA     START_TIME      ; Start to count down the hold time
             CMP     #$FF            ; if START_TIME = FF
             BNE     SKIP_TIME
             JSR     CHECK_HOLD
SKIP_TIME    BSR     COMPRGT         ; Branch to subroutine compare register
             LDA     TEMP2           ; Pop Accumulator
             RTI
******************************************
*                                        *
*      Check whether the hold time       *
*        of crash impact is due          *
*                                        *
******************************************
CHECK_HOLD   DEC     HOLD_CNT
             LDA     HOLD_CNT
             CMP     #$00            ; Is the hold time up?
             BNE     NOT_YET
             LDA     #$00            ; If yes,
             STA     PLMA            ; stop buzzer
             LDA     #$FF            ; Set HOLD_DONE to FF indicate that the
             STA     HOLD_DONE       ; hold time is up
             CLR     START_TIME      ; Stop the counting down of hold time
NOT_YET      RTS
******************************************
*                                        *
*           Subroutine reset             *
*      the timer compare register        *
*                                        *
******************************************
COMPRGT      LDA     TCNTHI          ; Read Timer count register
             STA     TEMPTCNTHI      ; and store it in the RAM
             LDA     TCNTLO
             STA     TEMPTCNTLO
             ADD     #$4C            ; Add 1D4C H = 7500 periods
             STA     TEMPTCNTLO      ; with the current timer count
             LDA     TEMPTCNTHI      ; 1 period = 2 us
             ADC     #$1D
             STA     TEMPTCNTHI      ; Save the next count to the register
             STA     OCMPHI1
             LDA     TSTATUS         ; Clear the output compare flag
             LDA     TEMPTCNTLO      ; by access the timer status register
             STA     OCMPLO1         ; and then access the output compare
             RTS                     ; register
******************************************
*                                        *
*      Determine which is the next       *
*    acceleration value to be display    *
*                                        *
******************************************
MAXVALUE     LDA     PTEMPLO
             CMP     MAXACC          ; Compare the current acceleration with
             BLS     OLDMAX          ; the memory, branch if it is <= maxacc
             BRA     NEWMAX1
OLDMAX       LDA     HOLD_DONE       ; Decrease the Holdtime when
             CMP     #$FF            ; the maximum value remain unchanged
```

```
            BEQ     NEWMAX1          ; Branch if the Holdtime is due
            LDA     MAXACC           ; otherwise use the current value
            BRA     NEWMAX2
NEWMAX1     LDA     #$C8             ; Hold time = 200 * 15 ms = 3 sec
            STA     HOLD_CNT         ; Reload the hold time for the next
            CLR     HOLD_DONE        ; maximum value
            LDA     #$FF
            STA     START_TIME       ; Start to count down the hold time
            LDA     PTEMPLO          ; Take the current value as maximum
NEWMAX2     STA     MAXACC
            RTS
******************************************
*                                        *
*     This subroutine is to convert      *
*        the AD data to the LCD          *
*    Save the data to be diaplayed       *
*             in MAXACC                  *
*                                        *
******************************************
ADTOLCD     SEI                      ; Disable the Timer Interrupt !!
            LDA     #$00             ; Load 0000 into the memory
            STA     DECHI
            LDA     #$00
            STA     DECLO
            LDA     MAXACC
            LDX     #5
            MUL                      ; Acceleration = AD x 5
            ADD     DECLO            ; Acceleration is stored as DECHI
            STA     DECLO            ; and DECLO
            STA     ACCLO            ; Temporary storage
            LDA     #$00             ; Assume positive deceleration
            STA     SIGN             ; "00" positive ; "01" negative
            CLRA
            TXA
            ADC     DECHI
            STA     DECHI
            STA     ACCHI            ; Temporary storage
            LDA     DECLO
            SUB     DCOFFSETLO       ; Deceleration = Dec - DC offset
            STA     DECLO
            LDA     DECHI
            SBC     DCOFFSETHI
            STA     DECHI
            BCS     NEGATIVE         ; Branch if the result is negative
            BRA     SEARCH
NEGATIVE    LDA     DCOFFSETLO       ; Acceleration = DC offset - Dec
            SUB     ACCLO
            STA     DECLO
            LDA     DCOFFSETHI
            SBC     ACCHI
            STA     DECHI
            LDA     #$01             ; Assign a negative sign
            STA     SIGN
SEARCH      CLRX                     ; Start the search for hundred digit
LOOP100     LDA     DECLO            ; Acceleration = Acceleration - 100
            SUB     HUNDREDLO
            STA     DECLO
            LDA     DECHI
            SBC     HUNDREDHI
            STA     DECHI
            INCX                     ; X = X + 1
            BCC     LOOP100          ; if acceleration >= 100, continue the
            DECX                     ; loop100, otherwise X = X - 1
            LDA     DECLO            ; Acceleration = Acceleration + 100
            ADD     HUNDREDLO
            STA     DECLO
            LDA     DECHI
            ADC     HUNDREDHI
            STA     DECHI
            TXA                      ; Check if the MSD is zero
            AND     #$FF
            BEQ     NOZERO           ; If MSD is zero, branch to NOZERO
            LDA     $0300,X          ; Output the first second digit
            STA     PORTC
            BRA     STARTTEN
NOZERO      LDA     #$00             ; Display blank if MSD is zero
            STA     PORTC
```

```
STARTTEN     CLRX                        ; Start to search for ten digit
LOOP10       LDA     DECLO               ; acceleration = acceleration - 10
             SUB     TENLO
             STA     DECLO
             LDA     DECHI
             SBC     TENHI
             STA     DECHI
             INCX
             BCC     LOOP10              ; if acceleration >= 10 continue the
             DECX                        ; loop, otherwise end
             LDA     DECLO               ; acceleration = acceleration + 10
             ADD     TENLO
             STA     DECLO
             LDA     DECHI
             ADC     TENHI
             STA     DECHI
             LDA     $0300,X             ; Output the last second digit
             EOR     SIGN                ; Display the sign
             STA     PORTB
             CLRX                        ; Start to search for the last digit
             LDA     DECLO               ; declo = declo - 1
             TAX
             LDA     $0300,X             ; Output the last digit
             EOR     #$01                ; Add a decimal point in the display
             STA     PORTA
             CLI                         ; Enable Interrupt again !
             RTS
******************************************
*                                        *
*   This subroutine provides services    *
*    for those unintended interrupts     *
*                                        *
******************************************
SWI          RTI                         ; Software interrupt return
IRQ          RTI                         ; Hardware interrupt
TIMERCAP     RTI                         ; Timer input capture
TIMERROV     RTI                         ; Timer overflow
SCI          RTI                         ; Serial communication Interface
                                         ; Interrupt
             ORG     $3FF2               ; For 68HC05B16, the vector location
             FDB     SCI                 ; starts at 3FF2
             FDB     TIMERROV            ; For 68HC05B5, the address starts
             FDB     TIMERCMP            ; 1FF2
             FDB     TIMERCAP
             FDB     IRQ
             FDB     SWI
             FDB     RESET
```

Shock and Mute Pager Applications Using Accelerometer

by: **C.S. Chua**
Sensor Application Engineering, Singapore, A/P

INTRODUCTION

In the current design, whenever there is an incoming page, the buzzer will “beep” until any of the buttons is depressed. It can be quite annoying or embarrassing sometime when the button is not within your reach. This application note describes the concept of muting the “beeping” sound by tapping the pager lightly, which could be located in your pocket or handbag. This demo board uses an accelerometer, microcontroller hardware/software and a piezo audio transducer. Due to the wide frequency response of the accelerometer from d.c. to 400 Hz, the device is able to measure both the static acceleration from the Earth's gravity and the shock or vibration from an impact. This design uses a 40G accelerometer (P/N: MMA1201P) which yields a minimum acceleration range of -40G to +40G.

CONCEPT OF TAP DETECTION

To measure the tapping of a pager, the accelerometer must be able to respond in the range of hundreds of hertz. During the tapping of a pager at the top surface, illustrated in Figure 1, the accelerometer will detect a negative shock level between -15g to -50g of force depending on the intensity. Similarly, if the tapping action comes from the bottom of the accelerometer, the output will be a positive value. Normally, the peak impact pulse is in the order of a few milliseconds. Figure 2 shows a typical waveform of the accelerometer under shock.

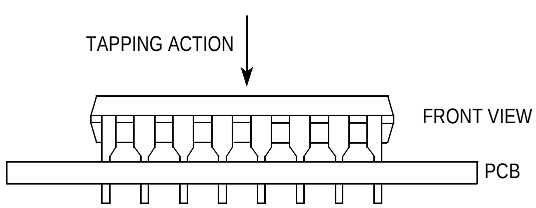


Figure 1. Tapping Action of Accelerometer

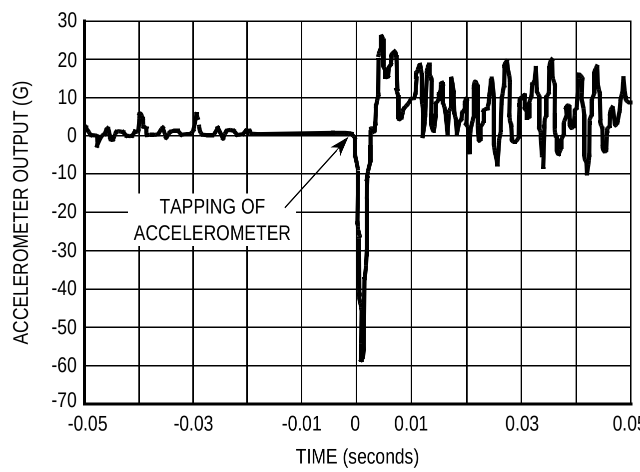


Figure 2. Typical Waveform of Accelerometer Under Tapping Action

Therefore, we could set a threshold level, either by hardware circuitry or software algorithm, to determine the tapping action and mute the “beeping.” In this design, a hardware solution is used because there will be minimal code added to the existing pager software. However, if a software solution is used, the user will be able to program the desire shock level.

HARDWARE DESCRIPTION AND OPERATION

Since MMA1201P is fully signal-conditioned by its internal op-amp and temperature compensation, the output of the accelerometer can be directly interfaced with a comparator. To simplify the hardware, only one direction (tapping on top of the sensor) is monitored. The comparator is configured in such a way that when the output voltage of the accelerometer is less than the threshold voltage or Vref (refer to Figure 3), the output of the comparator will give a logic 1, illustrated in Figure 4. To decrease the V_{REF} voltage or increase the threshold impact in magnitude, turn the trimmer R2 anti-clockwise.

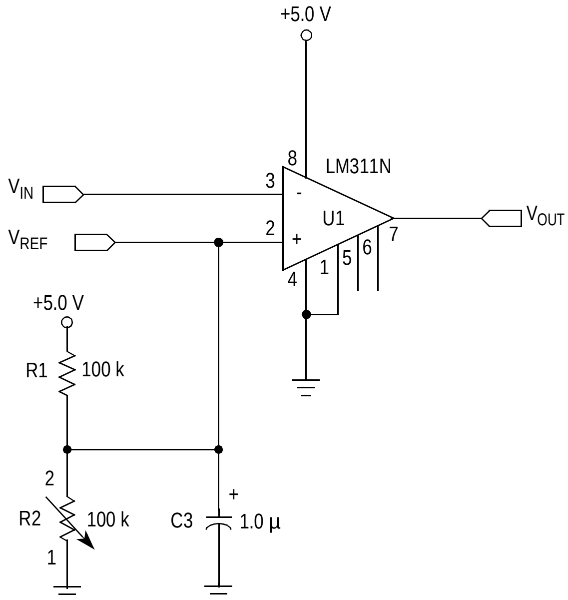


Figure 3. Comparator Circuitry

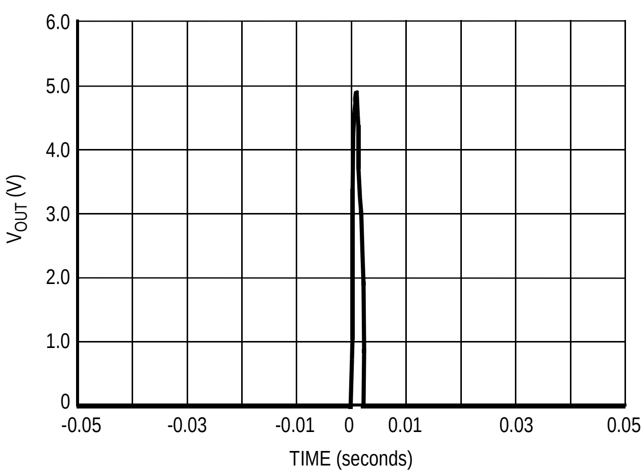


Figure 4. Comparator Output Waveform

For instance, if the threshold level is to be set to -20g, this will correspond to a Vref voltage of 1.7 V.

$$V_{REF} = V_{OFFSET} + \left(\frac{\Delta V}{\Delta G} \times G_{THRESHOLD}\right)$$
$$= 2.5 + (0.04 \times [-20])$$
$$= 1.7\text{ V}$$

Under normal condition, V_{IN} (which is the output of the accelerometer) is at about 2.5 V. Since V_{IN} is higher than Vref, the output of the comparator is at logic 0. During any shock or impact which is greater than -20g in magnitude, the output voltage of the accelerometer will go below V_{REF}. In this case, the output logic of the comparator changes from 0 to 1.

When the pager is in silence mode, the vibrator produces an output of about ±2g. This will not trigger the comparator. Therefore, even in silence mode, the user can also tap the pager to stop the alert. Refer to Figure 5 for the vibrator waveform.

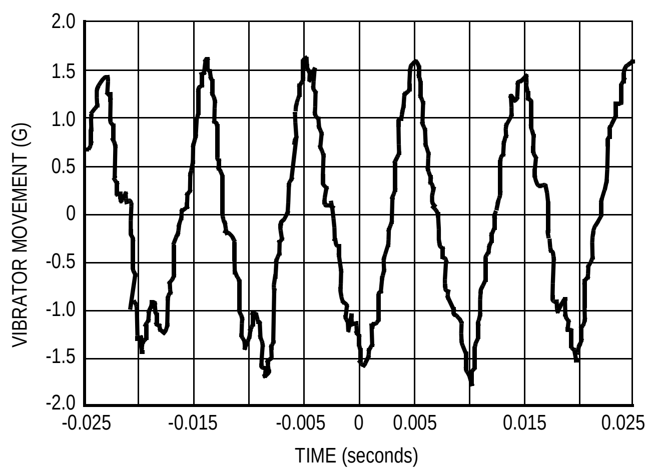


Figure 5. Vibrator Waveform

Figure 6 is a schematic drawing of the whole demo and Figure 7, Figure 8, and Figure 9 show the printed circuit board and component layout for the shock and mute pager. Table 1 is the corresponding part list.

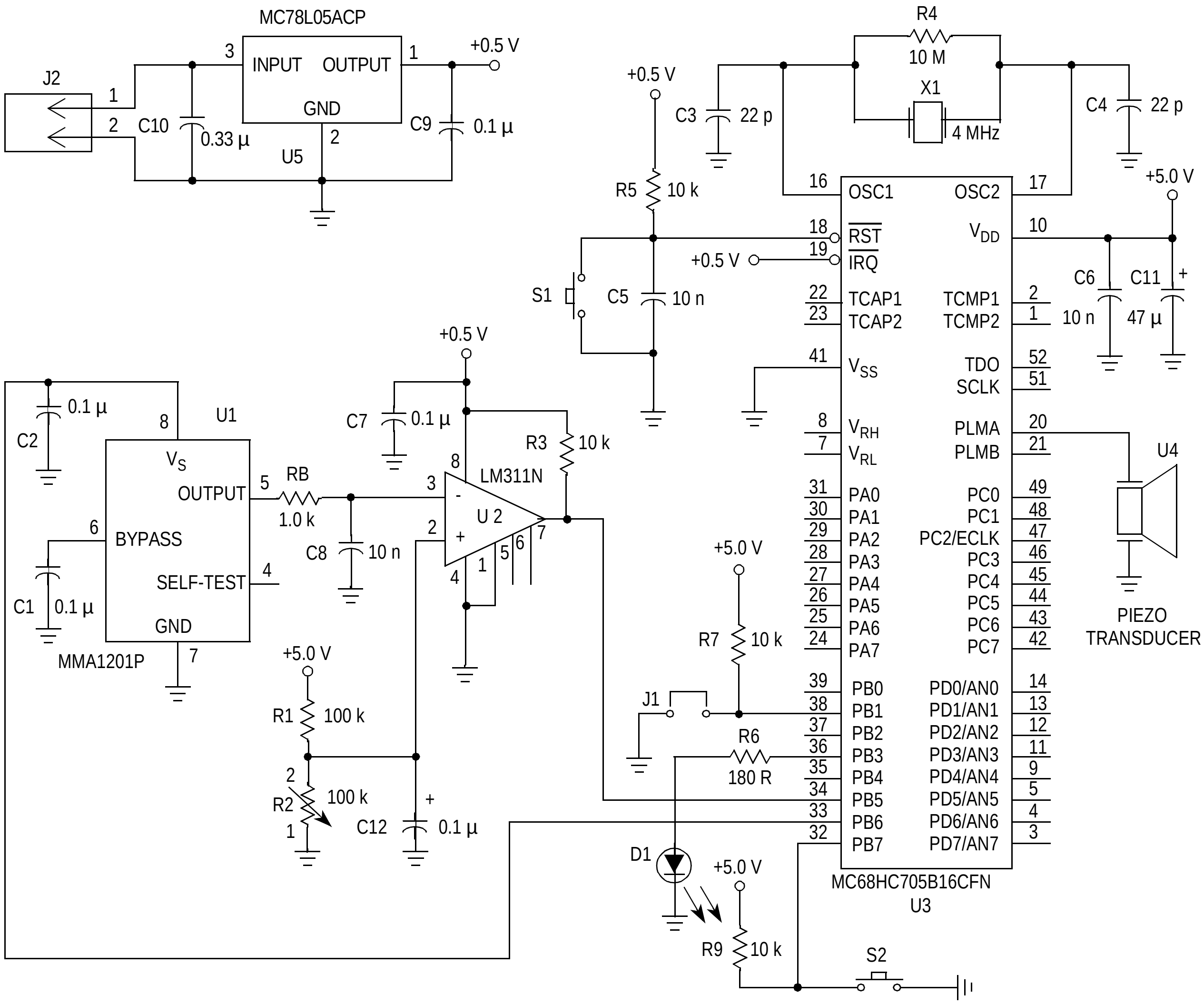


Figure 6. Overall Schematic Diagram of the Demo

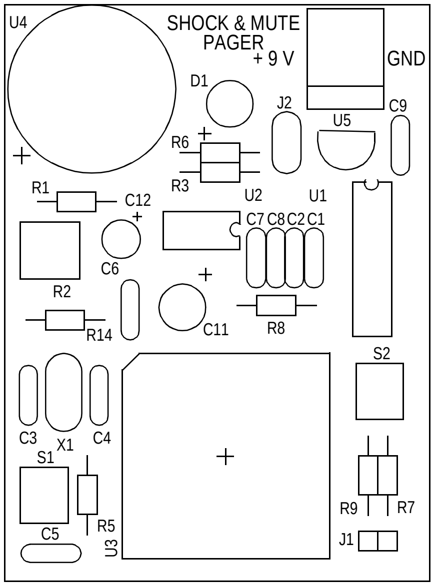


Figure 7. Silk Screen of the PCB

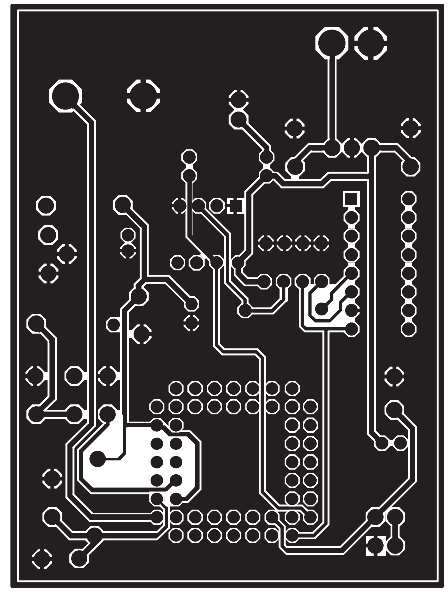


Figure 8. Solder Side of the PCB

Table 1. Bill of Material for the Shock and Mute Pager

Device Type	Qty.	Value	References
Ceramic Capacitor	4	0.1µ	C1, C2, C7, C9
Ceramic Capacitor	2	22p	C3, C4
Ceramic Capacitor	3	10n	C5, C6, C8
Solid Tantalum	1	0.33µ	C10
Electrolytic Capacitor	1	47µ	C11
Electrolytic Capacitor	1	1µ	C12
LED	1	5mm	D1
Header	1	2 way	J1
PCB Terminal Block	1	2 way	J2
Resistor ±5% 0.25W	1	100k	R1
Single Turn Trimmer	1	100k	R2
Resistor ±5% 0.25W	4	10k	R3, R5, R7, R9
Resistor ±5% 0.25W	1	10M	R4
Resistor ±5% 0.25W	1	180R	R6
Resistor ±5% 0.25W	1	1k	R8
Push Button	2	6mm	S1, S2
MMA1201P	1	—	U1
LM311N	1	—	U2
MC68HC705B16CFN	1	—	U3
Piezo Transducer	1	—	U4
MC78L05ACP	1	—	U5
Crystal	1	4MHz	X1

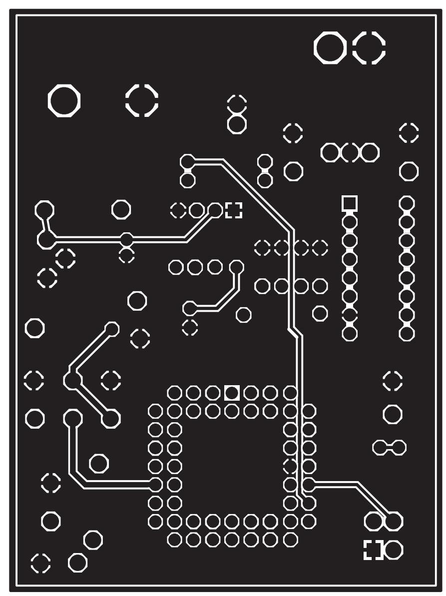


Figure 9. Component Side of the PCB

SOFTWARE DESCRIPTION

Upon powering up the system, the piezo audio transducer is activated simulating an incoming page, if the pager is in sound mode (jumper J1 in ON). Then, the accelerometer is powered up and the output of the comparator is sampled to obtain the logic level. The “beeping” will continue until the accelerometer senses an impact greater than the threshold level. Only then the alert is muted. However, when the pager is in silence mode (jumper J1 is OFF), indicated by the blinking red LED, the accelerometer is not activated. To stop the alert, press the push-button S2.

To repeat the whole process, simply push the reset switch S1.

Figure 10 is a flowchart for the program that controls the system.

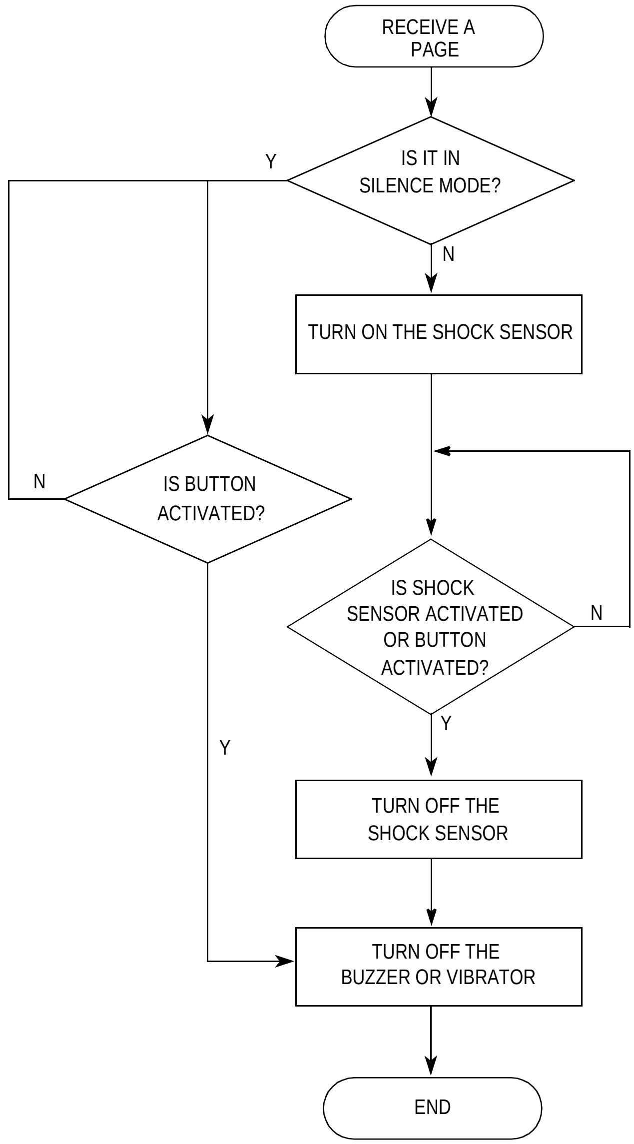


Figure 10. Main Program Flowchart

CONCLUSION

The shock and mute pager design uses a comparator to create a logic level output by comparing the accelerometer output voltage and a user-defined reference voltage. The flexibility of this minimal component, high performance design makes it compatible with many different applications, e.g. hard disk drive knock sensing, etc. The design presented here uses a comparator which yields excellent logic-level outputs and output transition speeds for many applications.

SOFTWARE SOURCE/ASSEMBLY PROGRAM CODE

```
******************************************************************************
*                                                                            *
******************************************************************************
*                                                                            *
*                  Pager Shock & Mute Detection Version 1.0                  *
*                                                                            *
*   The following code is written for MC68HC705B16 using MMDS05 software    *
*   Version 1.01                                                             *
*   CASM05 - Command line assembler Version 3.04                             *
*   P & E Microcomputer Systems, Inc.                                        *
*                                                                            *
*                          Written by : C.S. Chua                            *
*                              9th January 1997                              *
*                                                                            *
*                            Software Description                            *
*                                                                            *
*   J1 ON - Sound mode                                                       *
*   Buzzer will turn off if the accelerometer is tapped or switch S2 is      *
*   depressed.                                                               *
*                                                                            *
*   J1 OFF - Silence mode                                                    *
*   LED will turn off if and only if S2 is depressed                         *
*                                                                            *
******************************************************************************
******************************************
*                                        *
*            I/O Declaration             *
*                                        *
******************************************
PORTB        EQU     $01           ; Port B
PLMA         EQU     $0A           ; D/A to control buzzer
TCONTROL     EQU     $12           ; Timer control register
TSTATUS      EQU     $13           ; Timer Status Register
OCMPHI1      EQU     $16           ; Output Compare Register 1 High Byte
OCMPLO1      EQU     $17           ; Output Compare Register 1 Low Byte
TCNTHI       EQU     $18           ; Timer Count Register High Byte
TCNTLO       EQU     $19           ; Timer Count Register Low Byte
OCMPHI2      EQU     $1E           ; Output Compare Register 2 High Byte
OCMPLO2      EQU     $1F           ; Output Compare Register 2 Low Byte
******************************************
*                                        *
*        RAM Area ($0050 - $0100)        *
*                                        *
******************************************
             ORG     $50
STACK        RMB     4             ; Stack segment
TEMPTCNTLO   RMB     1             ; Temp. storage of timer result (LSB)
TEMPTCNTHI   RMB     1             ; Temp. storage of timer result (MSB)
******************************************
*                                        *
*        ROM Area ($0300 - $3DFD)        *
*                                        *
******************************************
             ORG     $300
******************************************
*                                        *
*   Program starts here upon hard reset  *
*                                        *
******************************************
RESET         CLR      PORTB              ; Initialise Ports
              LDA      #%01001000         ; Configure Port B
              STA      $05
              LDA      TSTATUS            ; Dummy read the timer status register so as to clear the OCF
              CLR      OCMPHI2
              CLR      OCMPHI1
              LDA      OCMPLO2
              JSR      COMPRGT
              LDA      #$40               ; Enable the output compare interrupt
              STA      TCONTROL
              LDA      #10                ; Idle for a while before "beeping"
IDLE          JSR      DLY20
              DECA
              BNE      IDLE
              CLI                         ; Interrupt begins here
              BRSET    1,PORTB,SILENCE    ; Branch if J1 is off
              BSET     6,PORTB            ; Turn on accelerometer
              JSR      DLY20              ; Wait till the supply is stable
TEST          BRSET    5,PORTB,MUTE       ; Sample shock sensor for tapping
              BRCLR    7,PORTB,MUTE       ; Sample switch S2 for muting
              JMP      TEST
MUTE          BCLR     6,PORTB            ; Turn off accelerometer
              SEI
              CLR      PLMA               ; Turn off buzzer
```

```
DONE          JMP      DONE              ; End
SILENCE       BRSET    7,PORTB,SILENCE   ; Sample switch S2 for stopping LED
              SEI
              BCLR     3,PORTB           ; Turn off LED
              JMP      DONE              ; End
******************************************
*                                        *
*       Timer service interrupt          *
*       Alternates the PLMA data         *
*       and bit 3 of Port B              *
*                                        *
******************************************
TIMERCMP     BSR     COMPRGT             ; Branch to subroutine compare register
             BRSET   1,PORTB,SKIPBUZZER  ; Branch if J1 is OFF
             LDA     PLMA
             EOR     #$80                ; Alternate the buzzer
             STA     PLMA
             RTI
SKIPBUZZER   BRSET   3,PORTB,OFF_LED     ; Alternate LED supply
             BSET    3,PORTB
             RTI
OFF_LED      BCLR    3,PORTB
             RTI
******************************************
*                                        *
*           Subroutine reset             *
*      the timer compare register        *
*                                        *
******************************************
COMPRGT      LDA     TCNTHI           ; Read Timer count register
             STA     TEMPTCNTHI       ; and store it in the RAM
             LDA     TCNTLO
             STA     TEMPTCNTLO
             ADD     #$50             ; Add C350 H = 50,000 periods
             STA     TEMPTCNTLO       ; with the current timer count
             LDA     TEMPTCNTHI       ; 1 period = 2 us
             ADC     #$C3
             STA     TEMPTCNTHI       ; Save the next count to the register
             STA     OCMPHI1
             LDA     TSTATUS          ; Clear the output compare flag
             LDA     TEMPTCNTLO       ; by access the timer status register
             STA     OCMPLO1          ; and then access the output compare register
             RTS
******************************************
*                                        *
*       Delay Subroutine for 0.20 sec    *
*                                        *
*   Input: None                          *
*   Output: None                         *
*                                        *
******************************************
DLY20        STA     STACK+2
             STX     STACK+3
             LDA     #!40           ; 1 unit = 0.7725 mS
OUTLP        CLRX
INNRLP       DECX
             BNE     INNRLP
             DECA
             BNE     OUTLP
             LDX     STACK+3
             LDA     STACK+2
             RTS
******************************************
*                                        *
*   This subroutine provides services    *
*    for those unintended interrupts     *
*                                        *
******************************************
SWI          RTI                      ; Software interrupt return
IRQ          RTI                      ; Hardware interrupt
TIMERCAP     RTI                      ; Timer input capture
TIMERROV     RTI                      ; Timer overflow interrupt
SCI          RTI                      ; Serial communication Interface Interrupt
             ORG     $3FF2            ; For 68HC05B16, the vector location
             FDB     SCI              ; starts at 3FF2
             FDB     TIMERROV         ; For 68HC05B5, the address starts at 1FF2
             FDB     TIMERCMP
             FDB     TIMERCAP
             FDB     IRQ
             FDB     SWI
             FDB     RESET
```

Freescale Semiconductor
Technical Data

AN1635
Rev 2, 05/2005

Baseball Pitch Speedometer

by: Carlos Miranda, Systems and Applications Engineer and
David Heeley, Systems and Applications Mechanical Engineer

INTRODUCTION

The Baseball Pitch Speedometer, in its simplest form, consists of a target with acceleration sensors mounted on it, an MCU to process the sensors' outputs and calculate the ball speed, and a display to show the result. The actual implementation, shown in Figure 1, resembles a miniature pitching cage, that can be used for training and/or entertainment. The cage is approximately 6 ft. tall by 3 ft. wide by 6 ft. deep. The upper portion is wrapped in a nylon net to retain the baseballs as they rebound off the target. A natural rubber mat, backed by a shock resistant acrylic plate, serve as the target. Accelerometers, used to sense the ball impact, and buffers, used to drive the signal down the transmission line, are mounted on the back side of the target. The remainder of the electronics is contained in a display box on the top front side of the cage.

Accelerometers are sensors that measure the acceleration exerted on an object. They convert a physical quantity into an electrical output signal. Because acceleration is a vector quantity, defined by both magnitude and direction, an accelerometer's output signal typically has an offset voltage and can swing positive and negative relative to the offset, to account for both positive and negative acceleration. An example acceleration profile is shown in Figure 2. Because acceleration is defined as the rate of change of velocity with respect to time, the integration of acceleration as a function of time will yield a net change in velocity. By digitizing and numerically integrating the output signal of an accelerometer through the use of a microcontroller, *the area under the curve* could be computed. The result corresponds to the net change in velocity of the object under observation. This is the basic principle behind the Baseball Pitch Speedometer.

Figure 1. David Heeley, mechanical designer of the Baseball Pitch Speedometer Demo, tests his skills at Sensors Expo Boston '97.

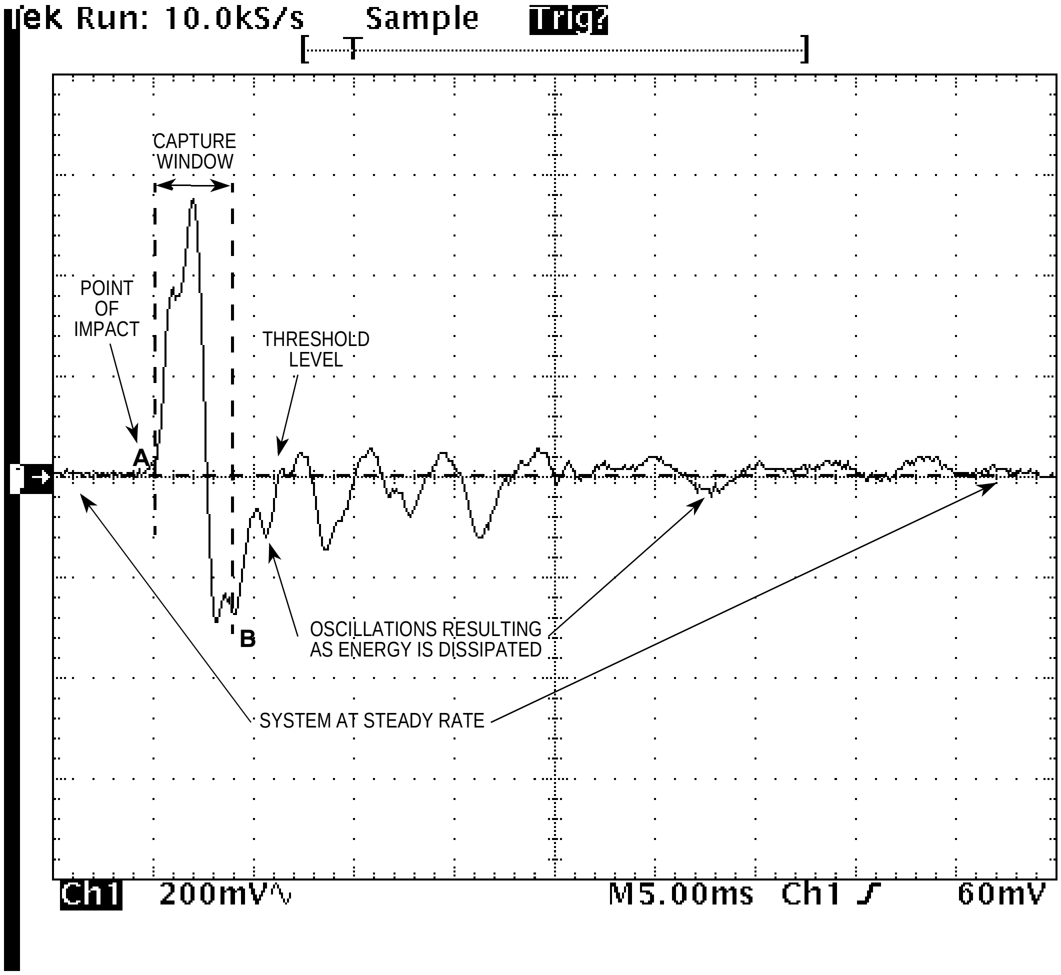


Figure 2. Typical Crash Pattern for the Baseball Pitch Speedometer Demo

THEORY OF OPERATION

When a ball is thrown against the target, the accelerometer senses the impact and produces an analog output signal, proportional to the acceleration measured, resulting in a crash signature. The amplitude and duration of the crash signature is a function of the velocity of the ball. How can this crash signature be correlated to the velocity of the baseball? By making use of the principle of conservation of momentum (see Equation 1). The principle of conservation of momentum states that the total momentum within a closed system remains constant. In our case, the system consists of the thrown ball and the target.

$$m_{ball} * V_{ball,initial} + m_{target} * V_{target,initial} = m_{ball} * V_{ball,final} + m_{target} * V_{target,final} \quad (1)$$

When the ball is thrown, it has a momentum equivalent to $m_{ball} * V_{ball,initial}$. The target initially has zero momentum since it is stationary. When the ball collides with the target, part of the momentum of the ball is transferred to the target, and the target will momentarily experience acceleration, velocity, and some finite, though small, displacement before dissipating the momentum and returning to a rest state. The other portion of momentum is retained by the ball as it bounces off the target, due to the elastic nature of the collision. By measuring the acceleration imparted on the target, its velocity is computed through integration. Ideally, if the mass of the ball, the mass of the target, and the final velocity of the ball are known, then the problem could be solved analytically and the initial velocity of the baseball determined.

The analysis of the crash phenomenon is, however, actually quite complex. Some factors that must be taken into account and that complicate the analysis greatly, are the spring constant and damping coefficient of the target. The target will be displaced during impact because it is anchored to the frame by a thick rubber mat. This action effectively causes the system to have a certain amount of spring. Also, though the mat is very dense, it will deform somewhat during impact and will act as shock absorber. In addition, the ball itself also has a spring constant and damping coefficient associated with it, since it bounces off the target and, though not noticeable by the naked eye, will deform during the impact. Finally, and of even greater significance, the mass of the ball, the mass of the target, and the final velocity of the ball are neither known nor measured. So how can the system work?

The Baseball Pitch Speedometer works by exploiting the fact that the final velocity of the target will be, according to Eq. 1, linearly proportional to the initial velocity of the thrown ball. Therefore, by measuring the acceleration response of the system to various ball velocities, which can be measured by independent means such as a radar gun, the system could be calibrated and a linear model developed. To facilitate the characterization and calibration of the system, a pitching machine was used to ensure that the incident ball speed would be repeatable. It also eliminated potential error caused by the variability of location of impact on the target that would inevitably result from several manual throws. Figure 3shows a linear regression plot of the response of the system as a function of incident velocity. As is indicated by the plot, just a simple constant of proportionality could be used to correlate the measured acceleration response to the incident velocity of the ball, with fairly accurate results.

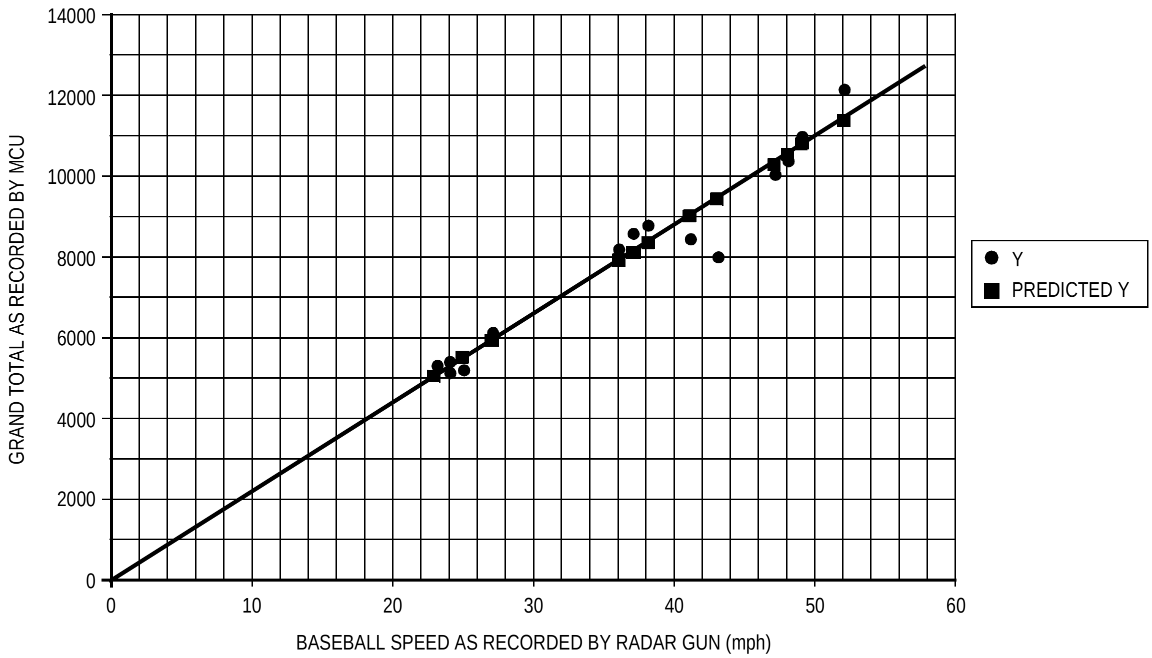


Figure 3. Baseball Pitch Speedometer Characterization Data

IMPLEMENTATION — HARDWARE

The target mat of the Baseball Pitch Speedometer has an area of approximately 9 ft^2 (3 by 3). Even though the rubber material used to construct the target is quite dense and heavy, the transmission of an impact is very poor if the ball strikes the target too far from the sensor. Therefore, to cover such a relatively large area it is necessary to use at least four devices; one centered in each quadrant of the square target. In addition, a shock resistant plate about a quarter inch thick is mounted behind the rubber mat. These features help make the response of the system more uniform and reduce errors that result from the variability of where the ball strikes the target.

The bulk of the circuit hardware is contained in a display box mounted on the top front side of the cage. Since the accelerometers are physically located far away from the mother board (about 10 feet of wiring), op-amps were used to buffer the accelerometers' output and drive the transmission line. The four accelerometer signals are then simultaneously fed into a comparator network and four of the ADC inputs on an MC68HC11 microcontroller. The MC68HC11 was selected because it has the capability of converting four A/D channels in one conversion sequence and operates at a higher clock speed. These two features reduce the overall time interval between digitizations of the analog signal (that result from the minimum required time for proper A/D conversion and from software latency) thus allowing a more accurate representation of the acceleration waveform to be captured. The comparator network serves a similar purpose by eliminating the additional software algorithm and execution time that would be required to continually monitor the outputs of all four accelerometers and determine whether impact has occurred or not. By minimizing this delay (some is still present since the output signal must exceed a threshold, and a finite amount of time is required for this) more of the initial and more significant part of the signal is captured.

The comparator network employs four LM311's configured to provide an OR function, and a single output is fed into an input capture pin on the MCU. A potentiometer and filter capacitor are used to provide a stable reference threshold voltage to the comparator network. The threshold voltage is set as close as possible to the accelerometers' offset voltage to minimize the delay between ball impact and the triggering of the conversion sequence, but enough clearance must be provided to prevent false triggering due to noise. Because the comparator network is wired such that any one of the accelerometer outputs can trigger it, the threshold voltage must be higher than the highest accelerometer offset voltage. Hysteresis is not necessary for the comparator network, because once the MCU goes into the conversion sequence it ignores the input capture pin.

The system is powered using a commercially available 9 V supply. A Freescale MC7805 voltage regulator is used to provide a steady 5 Volt supply for the operation of the MCU, the accelerometers, the comparator network, and the op-amp buffers. The 9 V supply is directly connected to the common anode 8-segment LED displays. Each segment can draw as much as 30 mA of current. Therefore, to ensure proper operation, the power supply selected to build this circuit should be capable of supplying at least 600 mA. Ports B and C on the MCU are used to drive the LED displays. Each port output pin is connected via a resistor to the base of a BJT, which has the emitter tied to ground. A current limiting resistor is connected between the collector of each BJT and the cathode of the corresponding segment on the display. To minimize the amount of board space consumed by the output driving circuitry, MPQ3904s (quad packaged 2N3904s) were selected instead of the standard discrete 2N3904s. The zero bit on Port C is connected to a combination BJT and MOSFET circuit that drives the “Your Speed” and “Best Speed” LED's. The circuit is wired so that the LED's toggle, and only one can be ON at a time.

Figure 4 shows a schematic of the circuit used. Part (a) shows the accelerometers, the op-amps used to buffer the outputs and drive the transmission lines, the comparator network and the potentiometer used to set the detection threshold. Part (b) shows the MCU, with its minimal required supporting circuitry. Part (c) shows the voltage regulator, a mapping of the cathodes to the corresponding segments on the LED displays, the BJT switch circuitry used to drive the seven segment display LEDs (although not shown on the schematic, this circuit block is actually repeated 15 times), and finally, the circuitry used to drive the “Your Speed”/“Best Speed” LEDs.

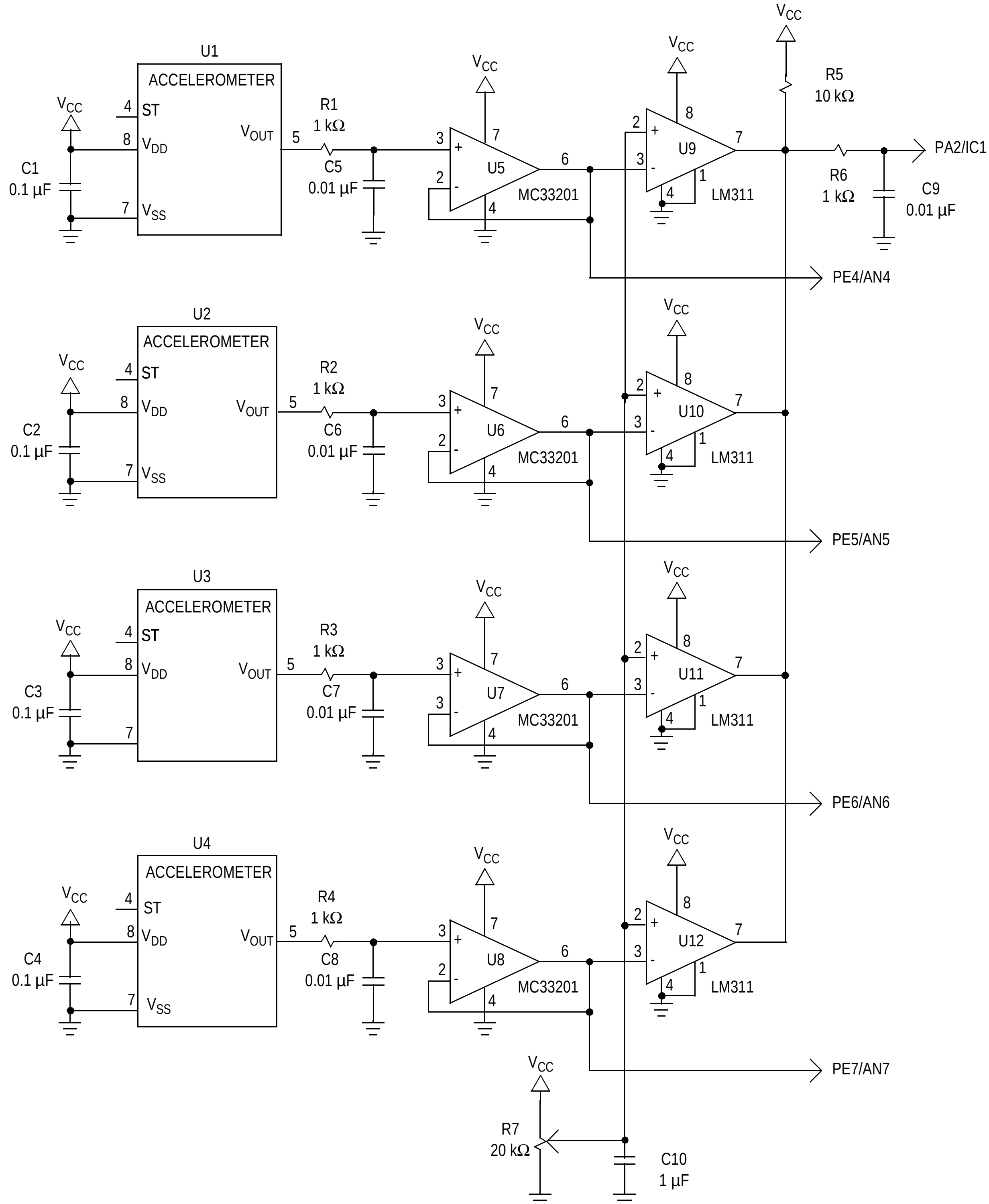


Figure 4a. Accelerometers, Buffer Op-Amps, and Comparator Network

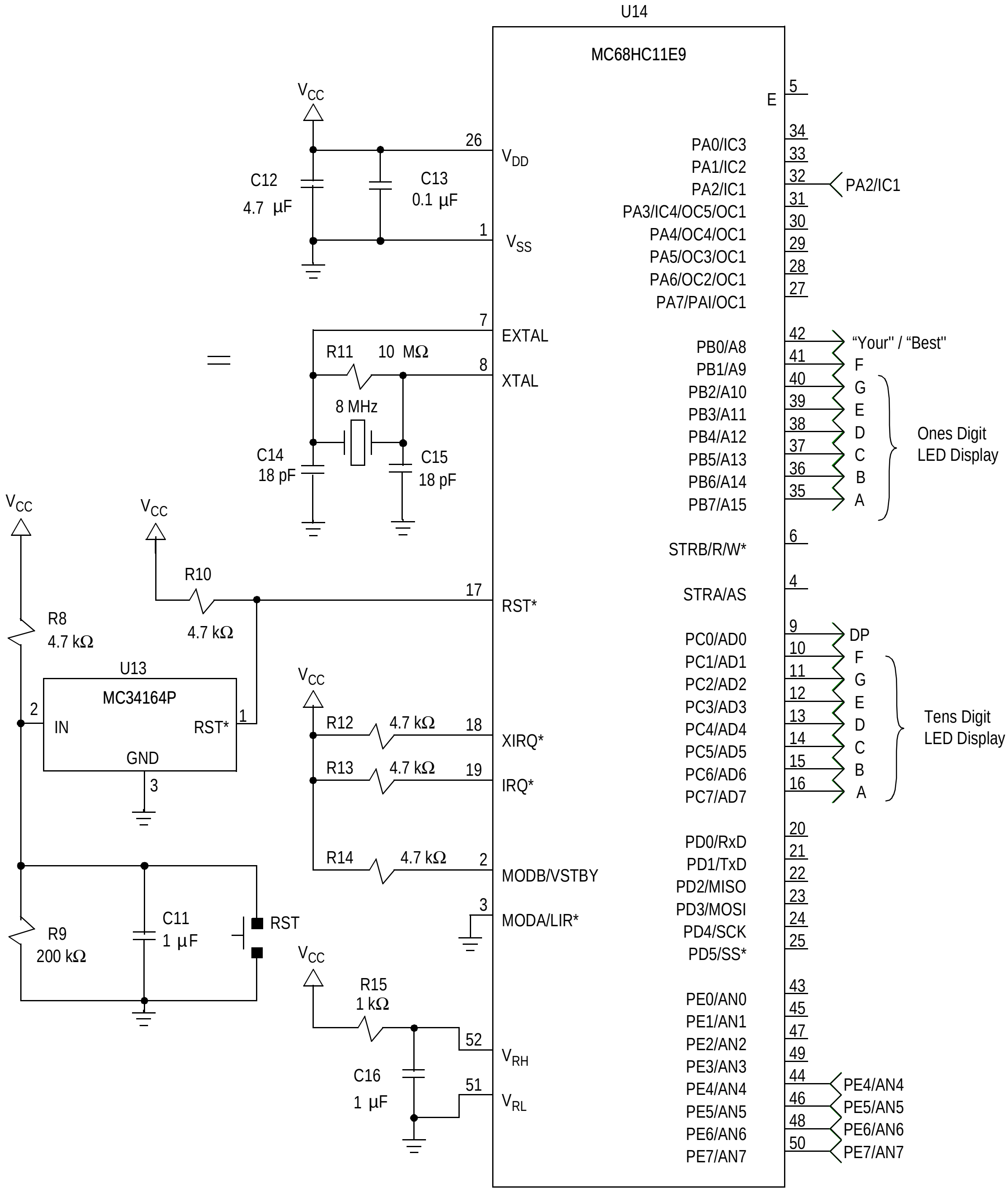


Figure 4b. MC68HC11E9 MCU with Supporting Circuitry

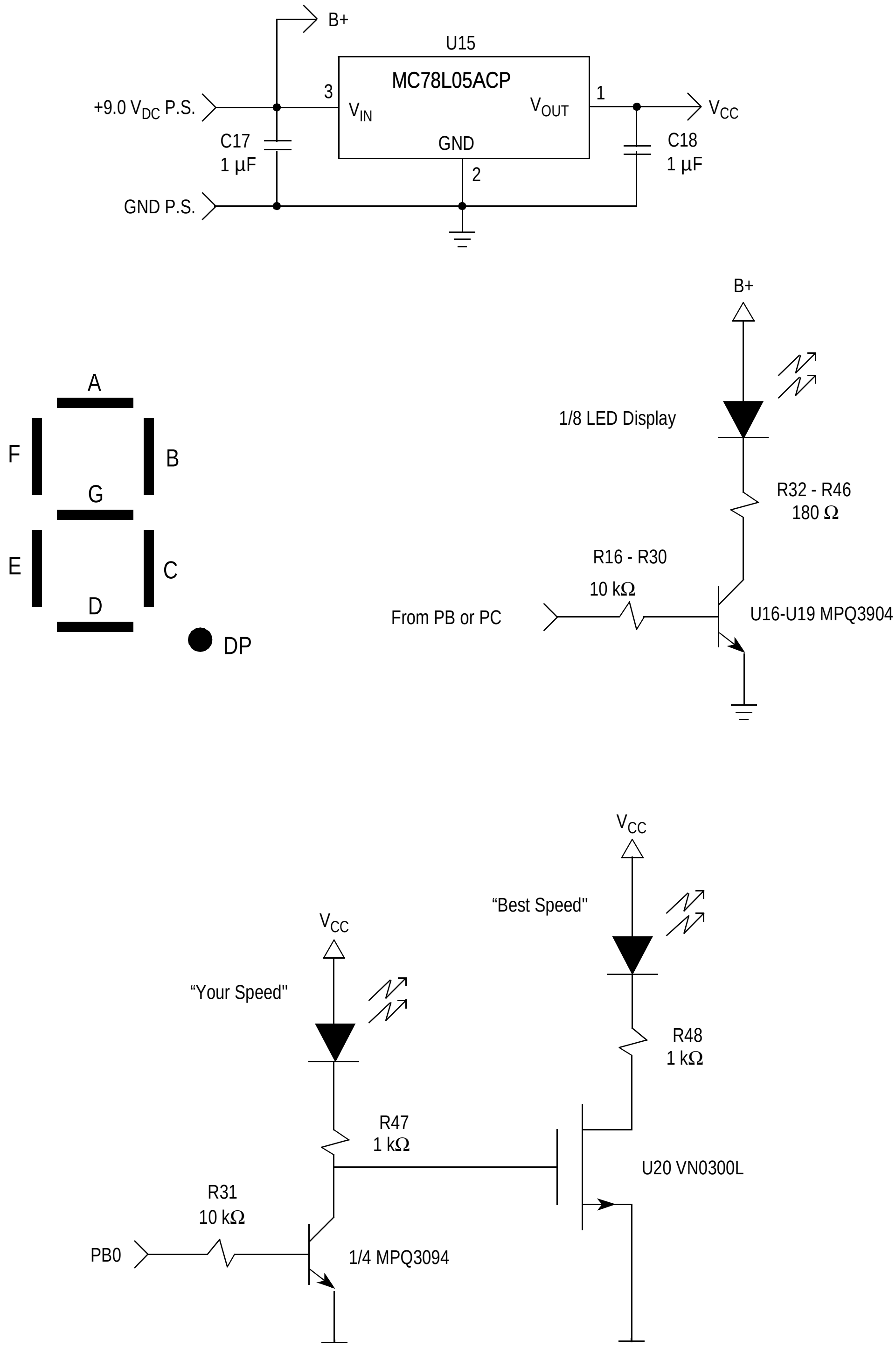


Figure 4c. Voltage Regulator, LED Segment Mapping, and LED Driving Circuitry

IMPLEMENTATION — SOFTWARE

The operation of the Baseball Pitch Speedometer is very simple. Upon power on reset, the output LEDs are initialized to display 00 and “Best Speed.” The analog to digital converter is turned on and the offset voltages of the accelerometers are measured and stored. Finally, all the variables are initialized and the MCU goes into a dormant state, where it will wait for a negative edge input capture pulse to trigger it to begin processing the crash signal.

Once the input capture flag is set, the MCU will immediately begin the analog to digital conversion sequence. As it digitizes the crash signature, it will calculate the absolute difference between the current value and the stored offset voltage value. It will integrate by summing up all the differences. Figure 2 shows a typical crash signature of the Baseball Pitch Speedometer. As illustrated, starting at the point of impact (A), the acceleration will initially ramp up, reaching a maximum, then decrease as the target is displaced. Because the target is constrained to the frame structure, the acceleration will continue to decrease until it reaches a minimum (point B), which correspond to the travel stop of the target. It is difficult to determine exactly when point B will occur, because the amplitude and duration of the initial acceleration pulse will vary with ball speed. Therefore, the capture window duration is set so that it will encompass most typical crash signatures, while rejecting most of the secondary ripples that result as the energy is dissipated by the system.

After integrating the four signals, the results are added together to produce an overall sum. This procedure averages out the individual responses and reduces measurement error due to the variability of where the ball lands on the target. The MCU then divides the grand sum by an empirically predetermined constant of proportionality. The result will then go through a binary to BCD conversion algorithm. A look-up table is used to match the BCD numbers to their corresponding 7-segment display codes. The calculated speed is displayed on the two digit 8-segment displays (one segment corresponds to the decimal point), and the “Your Speed” LED is turned on while the “Best Speed” LED is turned off. After a duration of approximately five seconds, the LEDs are toggled and stored best speed is redisplayed. The five second delay is used to provide enough time for the user to check his/her speed and also to allow the target to return to a rest state. The system is now ready for another pitch. A complete listing of the software is presented in the Appendix.

CONCLUSION

The Baseball Pitch Speedometer works fairly well, with an accuracy of ±5 mph. The dynamic range of the system is also worthy of note, measuring speeds from less than 10 mph up to well above the 70 mph range. One key point to emphasize, is that the system is empirically calibrated, and so to maintain good accuracy the system should only be used with balls of mass equal to those used during calibration.

Although intended mainly for training and recreational purposes, the Baseball Pitch Speedometer demonstrates a very important concept concerning the use of accelerometers. Accelerometers can be used not only to detect that an event such as impact or motion has occurred, but more importantly they measure the intensity of such events. They can be used to discern between different crash levels and durations. This is very useful in applications where it is desired to have the system respond in accord with the magnitude of the input being monitored. An example application would be a smart air bag system, where the speed at which the bag inflates is proportional to the severity of the crash. The deployment rate of the airbag would be controlled so that it does not throw the occupant back against the seat, thus minimizing the possibility of injury to the occupant. Another application where this concept may be utilized is in car alarms, where the response may range from an increased state of readiness and monitoring, to a full alarm sequence depending on the intensity of the shock sensed by the accelerometer. This could be used to prevent unnecessary firing of the alarm in the event that an animal or person were to inadvertently bump or brush against the automobile.

APPENDIX — ASSEMBLY CODE LISTING FOR BASEBALL PITCH SPEEDOMETER

```
* Baseball Pitch Speedometer - Rev. 1.0
*
* Program waits for detection of impact via the input capture pin and then reads four A/D channels.
* The area under the Acceleration vs. Time curve is found by subtracting the steady state offsets
* from the digitized readings and summing the results.  The sum is then divided by an empirically
* determined constant of proportionality, and the speed of the ball is displayed.
*
* Written by Carlos Miranda
* Systems and Applications
* Sensor Products Division
* Freescale Semiconductor Products Sector
* May 6, 1997
*
*
*****************************************************************************************************
*        Although the information contained herein, as well as any information provided relative      *
*        thereto, has been carefully reviewed and is believed accurate, Freescale assumes no          *
*        liability arising out of its application or use, neither does it convey any license under    *
*        its patent rights nor the rights of others.                                                   *
*****************************************************************************************************
* These equates assign memory addresses to variables.
EEPROM          EQU             $B600
CODEBGN         EQU             $B60D
REGOFF          EQU             $1000   ;Offset to access registers beyond direct addressing range.
PORTC           EQU             $03
PORTB           EQU             $04
DDRC            EQU             $07
TCTL2           EQU             $21
TFLG1           EQU             $23
ADCTL           EQU             $30
ADR1            EQU             $31
ADR2            EQU             $32
ADR3            EQU             $33
ADR4            EQU             $34
OPTION          EQU             $39
STACK           EQU             $01FF   ;Starting address for the Stack Pointer.
RAM             EQU             $0000
* These equates assign specific masks to variables to facilitate bit setting, clearing, etc.
ADPU            EQU             $80     ;Power up the analog to digital converter circuitry.
CSEL            EQU             $40     ;Select the internal system clock.
CCF             EQU             $80     ;Conversion complete flag.
IC1F            EQU             $04     ;Input Capture 1 flag.
IC1FLE          EQU             $20     ;Configure Input Capture 1 to detect falling edges only.
IC1FCLR         EQU             $FB     ;Clear the Input Capture 1 flag.
CHNLS47         EQU             $14     ;Select channels 4 through 7 with MULT option ON.
SAMPLES         EQU             $0200   ;Number of A/D samples taken.
OC1F            EQU             $80     ;Output Compare 1 flag.
OC1FCLR         EQU             $7F     ;Clear the Output Compare flag.
CURDLY          EQU             $0098   ;Timer cycles to create delay for displaying "Your Speed."
RAMBYTS         EQU             $19     ;Number of RAM variables to clear during initialization.
ALLONES         EQU             $FF
YOURSPD         EQU             $01
PRPFCTR         EQU             $00AD   ;This constant of proportionality was empirically determined.
* Variables used for computation.
                ORG             RAM
OFFSET1         RMB             1       ;One for each accelerometer.
OFFSET2         RMB             1
OFFSET3         RMB             1
OFFSET4         RMB             1
SUM1            RMB             2       ;Area under the acceleration vs. time curve.
SUM2            RMB             2
SUM3            RMB             2
SUM4            RMB             2
GRNDSUM         RMB             2
COUNT           RMB             2
CURBIN          RMB             1
TEMPBIN         RMB             1
BCD             RMB             2
CURDSPL         RMB             2
MAXBIN          RMB             1
MAXDSPL         RMB             2
* LED seven segment display patterns table.
                ORG             EEPROM
```

```
               JMP            START
SEVSEG         FCB            %11111010
               FCB            %01100000
               FCB            %11011100
               FCB            %11110100
               FCB            %01100110
               FCB            %10110110
               FCB            %10111110
               FCB            %11100000
               FCB            %11111110
               FCB            %11100110
* This is the main program loop.
               ORG            CODEBGN
START          LDS            #STACK
               LDX            #REGOFF
               JSR            LEDINIT
               JSR            ADCINIT
               JSR            VARINIT
MAIN           JSR            CAPTURE
               JSR            COMPUTE
               JSR            BINTBCD
               JSR            OUTPUT
               BRA            MAIN
* This subroutine initializes ports B & C, and the LED display.
LEDINIT        PSHX
               PSHA
               LDX            #REGOFF
               BSET           DDRC,X,ALLONES        ;Configure port C as an output.
               LDAA           SEVSEG
               STAA           PORTB,X
               STAA           PORTC,X
               PULA
               PULX
               RTS
* This subroutine initializes the analog to digital converter.
ADCINIT        PSHX
               PSHA
               LDX            #REGOFF
               BSET           OPTION,X,ADPU         ;Turn on A/D converter via ADPU bit.
               BCLR           OPTION,X,CSEL         ;Select system e clock via CSEL bit.
               CLRA
DELAY          INCA
               BNE            DELAY
               PULA
               PULX
               RTS
* This subroutine clears all the memory variables.
VARINIT        PSHX
               LDX            #$0000
CLRVAR         CLR            OFFSET1,X
               INX
               CPX            #RAMBYTS              ;Number of RMB bytes.
               BLO            CLRVAR
DONECLR        LDX            #REGOFF
               LDAA           #CHNLS47              ;Measure the offset.
               STAA           ADCTL,X
OFSWAIT        BRCLR          ADCTL,X,CCF,OFSWAIT
               LDD            ADR1,X
               STD            OFFSET1
               LDD            ADR3,X
               STD            OFFSET3
               PULX
               RTS
* This subroutine waits for impact and computes the area under the curve.
CAPTURE        PSHX
               PSHA
               PSHB
               LDX            #REGOFF
               BSET           TCTL2,X,IC1FLE        ;Set IC1 to detect falling edge only.
               BCLR           TFLG1,X,IC1FCLR
MONITOR        BRCLR          TFLG1,X,IC1F,MONITOR
ADCREAD        LDAA           #CHNLS47              ;Select channels 4 - 7 for conversion.
               STAA           ADCTL,X
ADCWAIT        BRCLR          ADCTL,X,CCF,ADCWAIT
CALDLT1        LDAB           ADR1,X
```

```
            SUBB            OFFSET1
            BPL             ADDSUM1
            COMB
            INCB
ADDSUM1     CLRA
            ADDD            SUM1
            STD             SUM1
CALDLT2     LDAB            ADR2,X
            SUBB            OFFSET2
            BPL             ADDSUM2
            COMB
            INCB
ADDSUM2     CLRA
            ADDD            SUM2
            STD             SUM2
CALDLT3     LDAB            ADR3,X
            SUBB            OFFSET3
            BPL             ADDSUM3
            COMB
            INCB
ADDSUM3     CLRA
            ADDD            SUM3
            STD             SUM3
CALDLT4     LDAB            ADR4,X
            SUBB            OFFSET4
            BPL             ADDSUM4
            COMB
            INCB
ADDSUM4     CLRA
            ADDD            SUM4
            STD             SUM4
            LDD             COUNT
            ADDD            #$0001
            STD             COUNT
            CPD             #SAMPLES
            BLO             ADCREAD
            PULB
            PULA
            PULX
            RTS
* This subroutine computes the ball speed by dividing the overall sum by a constant.
COMPUTE     PSHX
            PSHA
            PSHB
            LDD             SUM1
            ADDD            SUM2
            ADDD            SUM3
            ADDD            SUM4
            STD             GRNDSUM
            LDX             #PRPFCTR
            IDIV
            XGDX
            STAB            CURBIN
            PULB
            PULA
            PULX
            RTS
* This subroutine converts from binary to BCD. (Limited to number up to 99 decimal.)
BINTBCD     PSHX
            PSHA
            PSHB
            LDX             #$0000
            LDAA            CURBIN
            STAA            TEMPBIN
            CLRA
            CLRB
BINSHFT     LSL             TEMPBIN
            ROLB
            LSLA
            CMPB            #$10
            BLO             CHKDONE
            INCA
            ANDB            #$0F
CHKDONE     INX
            CPX             #$0008
```

```
                BEQ                    RAILAT9
CHKFIVE         CMPB                   #$05
                BLO                    BINSHFT
                ADDB                   #$03
                BRA                    BINSHFT
RAILAT9         CMPA                   #$09            ;Force the display to "99" if speed > 100 mph.
                BLS                    DONE
                LDD                    #$0909
DONE            STD                    BCD
                LDX                    #SEVSEG         ;This part finds the seven segment display codes.
                XGDX
                ADDB                   BCD
                XGDX
                LDAA                   $00,X
                STAA                   CURDSPL
                LDX                    #SEVSEG
                XGDX
                ADDB                   BCD+1
                XGDX
                LDAA                   $00,X
                STAA                   CURDSPL+1
                PULB
                PULA
                PULX
                RTS
* This subroutine displays the current speed for 5 seconds & then displays the maximum.
OUTPUT          PSHX
                PSHA
                PSHB
LDX             #REGOFF
                LDAA                   CURBIN
                CMPA                   MAXBIN
                BLS                    OLDMAX
                STAA                   MAXBIN
                LDD                    CURDSPL
                STD                    MAXDSPL
OLDMAX          LDD                    CURDSPL
                STD                    PORTC,X
                BSET                   PORTB,X,YOURSPD             ;Toggle the "YOUR"/"BEST" LEDs.
                LDD                    #$0000
LEDWAIT         BCLR                   TFLG1,X,OC1FCLR             ;Clear output compare 1 flag.
DSPLDLY         BRCLR                  TFLG1,X,OC1F,DSPLDLY
                ADDD                   #$0001
                CPD                    #CURDLY                     ;Decimal 152. (152 * 33ms = 5.0 sec)
                BLO                    LEDWAIT
                LDX                    #$0000
RECLEAR         CLR                    SUM1,X          ;Clear 12 RAM bytes beginning at address "SUM1".
                INX                                    ;Clears SUM1 thru SUM4, GRNDSUM, and COUNT.
                CPX                    #$000C
                BLO                    RECLEAR
                LDX                    #REGOFF
                LDD                    MAXDSPL
                STD                    PORTC,X         ;The "YOUR"/"BEST" LEDS are automatically toggled.
                PULB
                PULA
                PULX
                RTS
```

AN1640
Rev 3, 05/2005

Reducing Accelerometer Susceptibility to BCI

by: Brandon Loggins

INTRODUCTION

Automobile manufacturers require all system electronics to pass stringent electromagnetic compatibility (EMC) tests. Airbag systems are one of the systems that must perform adequately under EMC tests. There are different types of tests for EMC, one of which is testing the tolerance of the system to high frequency conducted emissions. One of the most stringent methods for EMC evaluation is the Bulk Current Injection (BCI) test. The entire airbag system must continue to function normally throughout the BCI test. This application note will discuss how to reduce susceptibility to BCI for the Freescale accelerometer but the information presented here can be applied to other electronic components in the system.

BCI TEST SETUP

The BCI test procedure follows a published SAE engineering standard, "Immunity to Radiated Electric Fields ~ Bulk Current Injection (BCI)", or SAE J 1113/401. For an airbag module, this involves injecting the desired current into the wiring harness by controlling current in the injection probe. The test frequency can vary from one to several hundred MHz. There are at least 20 frequency steps per octave required for the test, but as many as 50 steps per octave can be used. The injection probe is placed on the harness in one of three distances from the airbag module connector: 120, 450 and 750 mm. There is a monitor pickup probe present to measure the amount of current being injected. It is placed 50 mm from the airbag module. This feeds back to the system to ensure that the desired test current is being injected on to the wiring harness. Figure 1 shows the setup for the BCI test. (For more details, see the SAE J 1113/401 Test Procedure).

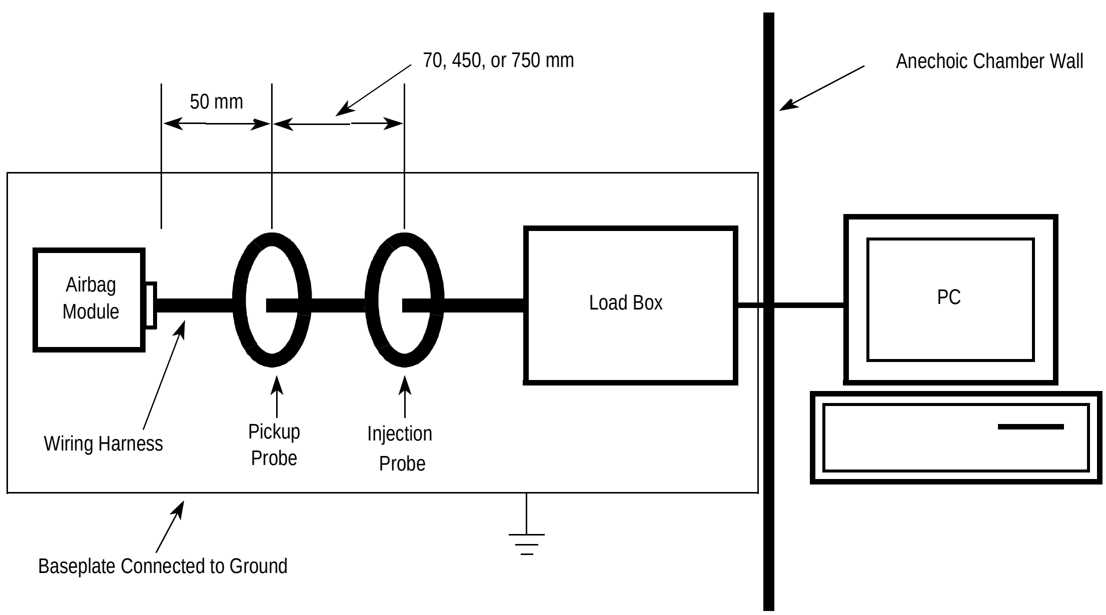


Figure 1. BCI Test Setup

The harness connects the airbag module to a load box. This load box provides simulated loads for terminating the remainder of the airbag system (firing ignitors, etc.). The data coming back is translated from J1850 to RS232 to be communicated to a dummy terminal on a PC. For safety reasons, this test is typically performed inside an anechoic chamber to shield high frequency emissions from equipment and humans.

BCI TEST PROCEDURE FOR THE MMA2202D ACCELEROMETER

The accelerometer is evaluated in the following manner. In an airbag system, the microcontroller's A/D converter digitizes the accelerometer output. The microcontroller sends this value to the communication ASIC which translates the logic from board level logic to RS232, then sends the value back along the wiring harness. Once through the chamber wall, the data is translated to RS232 and fed to a dummy terminal. On the terminal screen, the A/D codes for the accelerometer can be monitored for unexpected performance.

Ideally, when the accelerometer is at rest (no acceleration applied), the output should be at 0*g*, regardless of what EMC testing the system may be subjected to. Depending on the crash algorithm of the airbag module software, there is some allowable offset shift that can be tolerated. Higher shift in output could create errors in the crash analysis software, perhaps causing the airbags to unnecessarily deploy when there is not a crash or not deploy when there is a crash.

The accelerometer must be able to meet the airbag system requirements throughout BCI exposure. It has a sensitivity of 40 mV/g and an offset (0*g* output) of 2.50 V. During the BCI test, the accelerometer output should be 2.50 V at 0*g* with as little drift as possible. A typical airbag system may have software that can tolerate from as little as 0.5 *g* up to 2.0 *g*. of deviation from the offset. The system would then expect the accelerometer output to be within 40 mV of the offset during the entire BCI test. Therefore, at any given frequency of the BCI test, if the output deviates outside this expected window of drift, it fails the test.

MMA2202D ACCELEROMETER BCI TEST RESULTS

If a system has not been well designed for electromagnetic compatibility, the accelerometer, as well as other devices, can have performance problems. What has been found for the accelerometer is that in some system applications, it suffers from an offset shift when certain frequencies of BCI are applied. For example, in one airbag system being tested at a certain frequency, with the desired BCI current applied, the offset is found to shift down by 60 mV. This would equate to an error of 1.5 *g*. See Figure 2. At other frequencies, this shift is even higher. This DC shift plot was taken with an oscilloscope using a 20 MHz filter to remove the high frequency component of the signal. Probes are placed at the accelerometer in the system application. The plot shows the accelerometer output before and after BCI was applied (before and after the RF generator creating the high frequency signal was turned on).

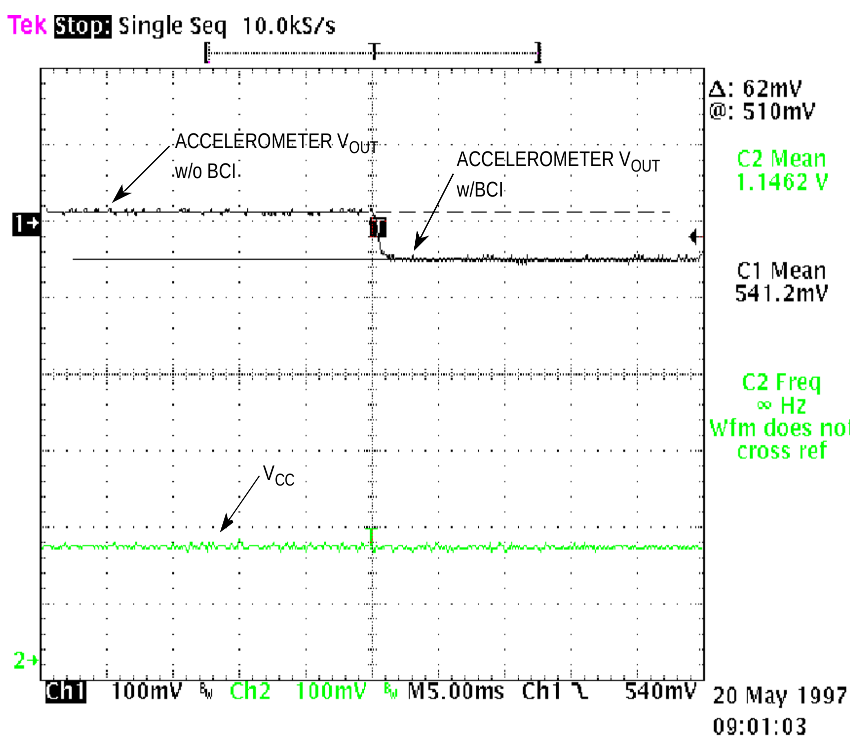


Figure 2. Accelerometer Tested Under High Frequency BCI

This phenomenon has been determined to be system level related. PCB layout and grounding for the accelerometer will affect its performance. This was found by testing the accelerometer outside of the airbag module. The device was put on a test board by itself with only the supply decoupling capacitor of 0.1 μF connected to it. To simulate the effect of BCI on V_{CC}, a frequency generator was used to inject a known high frequency sinusoid that caused BCI failure on to the 5.0 V supply voltage. The device was first tested in small test board with ground provided by one wire back to the supply. This grounding reproduced the failure due to BCI seen at the module level. The test board was then mounted down to a ground plane provided by a copper plate and the accelerometer ground was soldered to the plate (providing a low impedance path to ground). With this setup, the offset shift did not occur.

If a system does not incorporate a good PCB layout providing a low impedance to ground, the accelerometer output may shift at certain high frequencies. This output offset shift was caused by a shift in the 0-5.0 V supply window. Because the accelerometer has a ratiometric output, its offset is dependent on the supply voltage. Any change in the supply voltage will result in the same proportional change in the output. For example, if the 5.0 V supply were to change by 10%, from 5.0 V to 5.5 V, the accelerometer offset will change by 10% also, from 2.5 V to 2.75 V. This phenomena would also occur if the ground were to shift. A 100 mV change in ground would result in a 50 mV change in the output. If the accelerometer does not have low impedance path to ground and parasitics from a poor ground are present as a result, the ground seen by the accelerometer may change over frequency. So, during a BCI test, if the 5.0 V supply does not shift but the output of the accelerometer does, the ground to the accelerometer may be moving.

It was found with some experimentation that the offset shift can be eliminated with proper board layout techniques as described below.

PROPER LAYOUT TECHNIQUES

Since the accelerometer is a sensitive analog device that relies on a clean supply to function within established parameters, there are some techniques that can be employed to minimize the effects of BCI on the accelerometer performance. PCB layout is paramount to reducing susceptibility to BCI.

- A low impedance path to ground will provide shunting of the high frequency interference and minimize its effect on the accelerometer. The best way to provide a good path is by putting a solid, unbroken ground plane in the PCB. This ground plane should be shunted to chassis ground at the module connector. This will ensure that the high frequency BCI will be shunted before interfering with accelerometer performance.
- All accelerometer pins that require ground connection should be tied together to a common ground.
- Traces attached directly to the connector pins can receive high RF noise, which can couple to nearby traces and components. Increasing series impedance of the traces helps reduce the couple or conducted noise. High frequency filters on the supply line and other susceptible lines may be required to filter out high frequency interference introduced by the BCI test. Signal lines that carry low current can tolerate series resistances of 100-200 Ω.
- Decoupling capacitors on every input line to the common ground plane will help shunt the high frequency away from the system. These should be placed near the connector.
- Signal trace lengths to and from the accelerometer should be kept at a minimum. The shorter the trace, the less chance it has of picking up high frequency BCI signals as it crosses the board. Trace lengths can be reduced by placing the accelerometer and the microcontroller as close together as possible. Signal and ground traces looping should be minimized.
- A decoupling capacitor on the accelerometer Vcc pin will also help minimize BCI effects. The recommended value is 0.1 μF. This capacitor should be placed as close as possible to the accelerometer to achieve the best results.
- To maximize ratiometricity, the accelerometer Vcc and the microcontroller A/D reference pin should be on the same trace. The accelerometer ground and the microcontroller ground should also share the same ground point. Therefore, when there is signal interference due to BCI, the A/D converter and the accelerometer will see the interference at the same level. This will result in the same digital code representation of acceleration without signal interference.
- A clean power supply to both the accelerometer and the microcontroller should be provided. Supply traces should avoid high current traces that might carry high RF currents during the BCI test. The traces should be as short as possible.
- The accelerometer should be placed on the opposite end of the PCB away from the connector. The farther the distance, the lower the chance high frequency RF from BCI will interfere with the accelerometer.
- The accelerometer should be placed away from high current paths that may carry high RF currents during the BCI test.

Automotive customers will continue to require airbag systems to have high standards for EMC. One way to test for EMC is perform the Bulk Current Injection test. Because of the high current involved, BCI is one of the most difficult EMC tests to pass. Being part of the airbag system, the accelerometer must continue to function normally under application of high frequency BCI. The accelerometer is highly sensitive to placement on the board and its connection to ground. Poor design will caused the device to fail the BCI test. The practice of good PCB layout, device placement and good grounding will allow the accelerometer to function within specification and pass the BCI test.

Using an Accelerometer Evaluation Board

by: Leticia Gomez and Raul Figueroa
Sensor Products, Systems and Applications Engineering

INTRODUCTION

This application note describes the Accelerometer Evaluation Board. The accelerometer evaluation boards are small circuit boards intended to serve as aids in system designs with the capability for mounting and quickly evaluating the low g devices. It also provides a means for understanding the best mounting position and location of an accelerometer in your product.

CIRCUIT DESCRIPTION

Figure 2 and Figure 3 are circuit schematics of the single and dual-axis evaluation boards respectively. The recommended decoupling capacitor at the power source and recommended RC filter at the output, are included on the evaluation board. This RC filter at the output of the accelerometer minimizes clock noise that may be present from the switched capacitor filter circuit. No additional components are necessary to use the evaluation board.

Refer to the respective datasheet of the device being used for specifications and technical operation of a specific accelerometer.

POWER HEADER ON LOW G SINGLE AXIS EVALUATION BOARDS

The power header provides a means for connecting to the accelerometer analog output through a wire to another breadboard or system. Four through-hole sockets are included to allow access to the following signals: VDD, GND, ST and STATUS. These sockets can be used as test points or as means for connecting to other hardware.

The ON/OFF switch (S1) provides power to the accelerometer and helps preserve battery life if a battery is being used as the power source. S1 must be set towards the ON position for the accelerometer to function. The green LED (D1) is lit when power is supplied to the accelerometer.

A self-test pushbutton (S2) on the evaluation board is a self-test feature that provides verification of the mechanical and electrical integrity of the accelerometer. The STATUS pin is an output from the fault latch and is set high if one of the fault conditions exists. A second pressing of the pushbutton (S2) resets the fault latch, unless of course one or more fault conditions continue to exist.

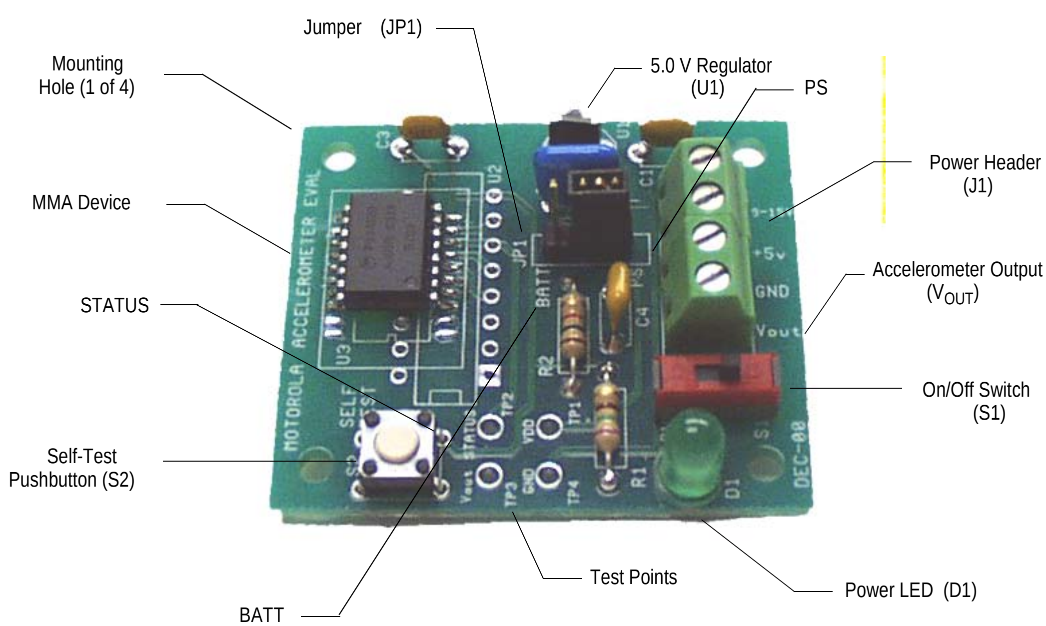


Figure 1. MMA1250D, MMA1260D, MMA1270D and MMA2260D Accelerometer Evaluation Board

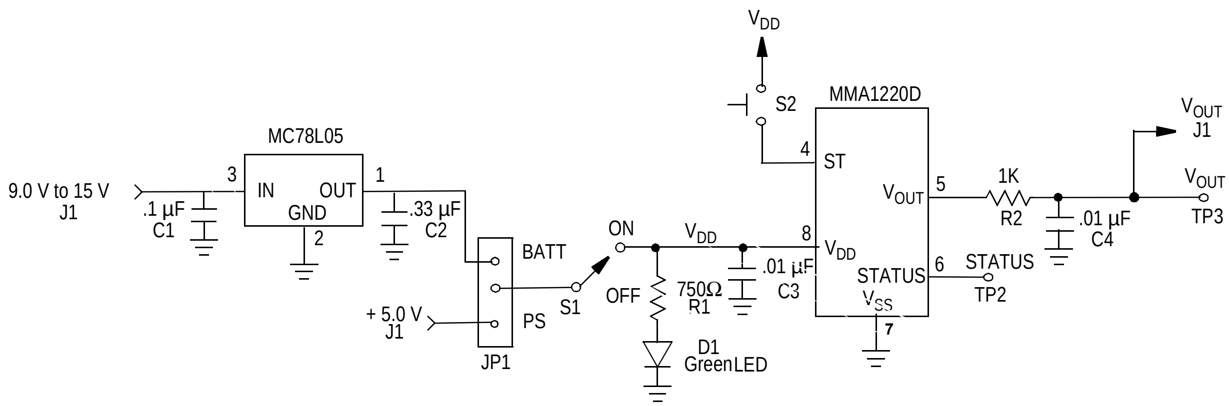


Figure 2. MMA1250D, MMA1260D, MMA1270D and MMA2260D Evaluation Board Circuit Schematics

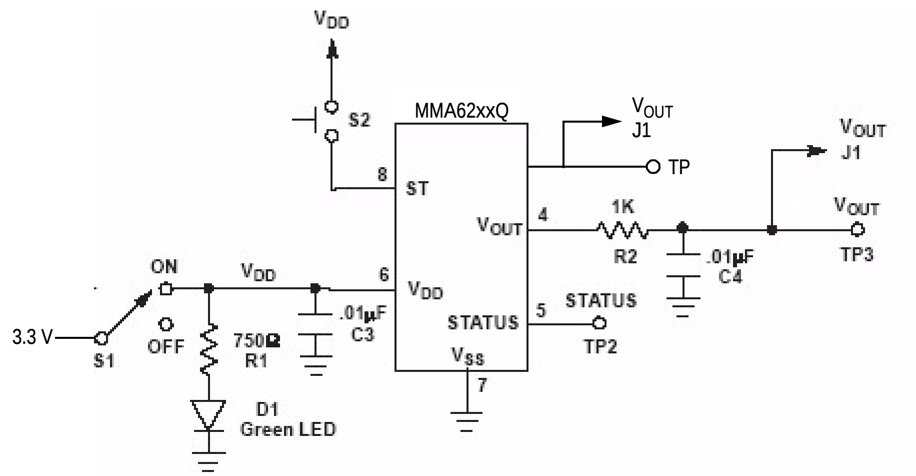


Figure 3. MMA6200Q Series Evaluation Board Circuit Schematic

OPTIONAL SOCKET MOUNTING

The board allows for direct mounting of a 16-pin DIP or SOIC package. For the SOIC device, a 20-pin test socket is used to allow for evaluation of more than one device without soldering directly to the board and potentially damaging the PCB. Care must be taken in placing the device correctly in the socket as four pins of the socket will not be used. With the board oriented as shown in Figure 3, Pin 1 should face downward and the device should be positioned toward the top of the test socket, thereby exposing the bottom four pins of the test socket. The socket is marked to help identify the four unused socket pins. Lids to secure the device in the socket are included with the board and delicately snap into place. The lids can be removed by applying pressure to the sides of the lid or by lifting the top and bottom snaps of the lid.

The evaluation board has a 4-pin header (J1 in Figure 1) for interfacing to a 5 volt power source or a 9 to 15 volt power source (for example, 9 V battery). Jumper JP1 (see Figure 1) must have the following placement: on PS if a 5 V supply is being used or on BATT if a 9 V to 15 V supply is used. A 5 V regulator (U1 in Figure 1) supplies the necessary power for the accelerometer in the BATT option.

Table 1. Pin Out Description

Pin	Name	Description
4	ST	Logic input pin to initiate self-test
5	V_{OUT}	Output voltage of the accelerometer
6	STATUS	Logic output pin to indicate fault
7	V_{SS}	Power supply ground
8	V_{DD}	Power supply input

Board Layout and Content

Figure 4 and Figure 5 show the layout used on the evaluation board. Through-hole mounting components have been selected to facilitate component replacement.

Mounting Considerations

System design and sensor mounting can affect the response of a sensor system. The placement of the sensor itself is critical to obtaining the desired measurements. It is important that the sensor be mounted as rigidly as possible to obtain accurate results. Since the thickness and mounting of the board varies, parasitic resonance may distort the sensor measurement. Hence, it is vital to fasten and secure to the largest mass structure of the system, i.e. the largest truss, the largest mass, the point closest to source of vibration. On the other hand, dampening of the sensor device can absorb much of the vibration and give false readings as well. The evaluation board has holes on the four corners of the board for mounting. It is important to maintain a secure mounting scheme to capture the true motion.

Orientation of the sensor is also crucial. For best results, align the sensitive axis of the accelerometer to the axis of vibration. In the case of the MMA1220D, the sensitive axis is perpendicular to the plane of the evaluation board.

SUMMARY

The Accelerometer Evaluation Board is a design-in tool for customers seeking to quickly evaluate an accelerometer in terms of output signal, device orientation, and mounting considerations. Both through-hole and surface mount packages can be evaluated. With the battery supply option and corner perforations, the board can easily be mounted on the end product; such as a motor or a piece of equipment. Easy access to the main pins allows for effortless interfacing to a microcontroller or other system electronics. The simplicity of this evaluation board provides reduced development time and assists in selecting the best accelerometer for the application.

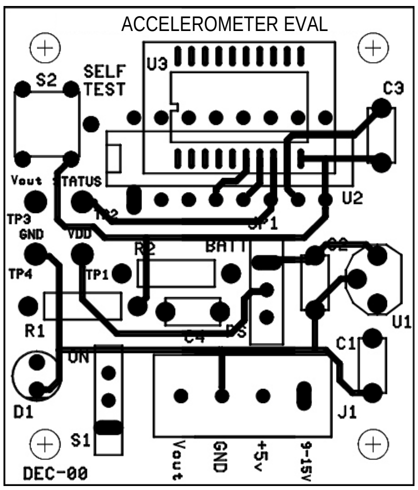


Figure 4. Board Layout (Component Side)

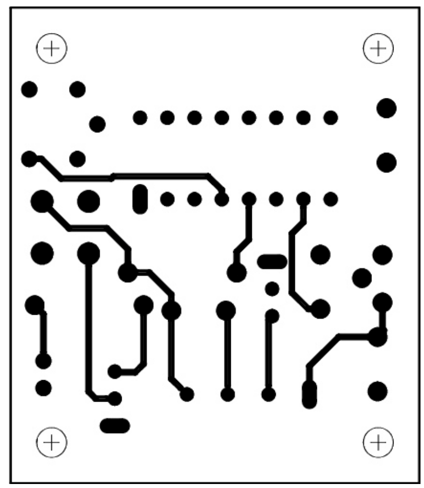


Figure 5. Board Layout (Back Side)

ORDERING INFORMATION

The Accelerometer Evaluation Boards are available to order as Evaluation Kits. Each kit includes an Evaluation Board with the accelerometer in an anti–static bag, a sensor repository CD that contains sensor brochures, data sheets, and the revised data book, and instructions for using the Evaluation Board.

Table 2 shows the kits that are available, or will be available soon. Check our website for availability.

Table 2. Evaluation Kits Order Information

Part Number	G Range	Axis
Kit1925MMA1250D	5.0g	Z
Kit1925MMA1260D	1.5g	Z
Kit1925MMA1270D	2.5g	Z
Kit1925MMA2260D	1.5g	X
Kit1925MMA6260Q	1.5g	XY, 50 Hz
Kit1925MMA6261Q	1.5g	XY, 300 Hz
Kit1925MMA6262Q	1.5g	XY, 150 Hz
Kit1925MMA6263Q	1.5g	XY, 900 Hz
Kit1925MMA6231Q	1.5g	XY, 300 Hz
Kit1925MMA6233Q	1.5g	XY, 900 Hz

Using the TRIAX Evaluation Board

by: Michelle Clifford
Sensor Products Division, Tempe, AZ

INTRODUCTION

Using micro machining and integrated circuit technology, Freescale produces highly reliable, capacitive, acceleration sensors. Freescale's accelerometers were initially designed for front- and side-impact airbags in the automotive arena, but now there are extensive applications in medical, appliance, consumer, and industrial areas such as high-end washing machines, gaming devices, LCD projectors, robotics, and fitness equipment.

TRIAX Board Overview

The TRIAX demo was built to combine many of the demos that we have available for accelerometers. These modules enable you to see how accelerometers can add additional functionality to many applications in different industries. By thinking of accelerometer applications in terms of the measurements performed, they can be grouped into five categories — **Tilt, Position, Movement, Vibration, and Shock**. This document describes the different demos available for each of the five categories of accelerometer measurement and how they can be demonstrated using the TRIAX board.

The TRIAX board is designed for three-axis sensing. Freescale offers three-axis sensing in several different ways. A three accelerometer solution can be achieved using two X-axis accelerometers in a 16-pin SOIC package, with one device rotated 90 degrees from the other to achieve X and Y axis sensing, and a Z-axis accelerometer in a 16-pin SOIC package. A two accelerometer solution is achieved using the MMA6260D, which is an X and Y-axis device and a Z-axis accelerometer, both in 6x6x2mm QFN packages. Sensor Products is in development with three-axis sensing in a single package.

Tilt

Tilt Applications refer to Inclinometers, Anti-Theft Devices, Game pads for Video Games or Joysticks, Sports Diagnostics and Physical Therapy Applications, PDAs, LCD Projection, and Camcorder Stability.

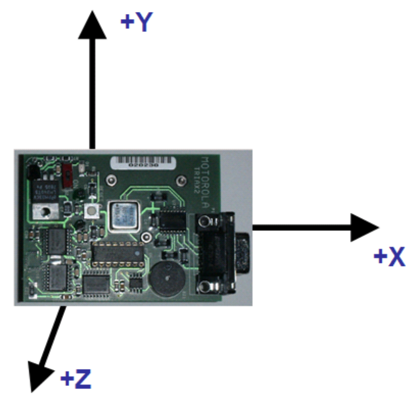


Figure 1. TRIAX Board and Corresponding Axis

Medical Applications for tilt range from Physical Therapy devices to Medical Equipment monitoring, where the accelerometers are used to ensure that the equipment is being used properly. For example, wrist mounted heartbeat monitors obtain the most accurate measurement if the blood pressure sensing device is at the same elevation as your heart. By using an accelerometer to measure the angle of your arm, the monitor can guide the user to the correct arm position before taking the measurement. The accuracy and the repeatability of the blood pressure measurement is greatly increased by using that tilt information to tell users exactly where to position their arms. In addition, the accelerometer is also able to stop a measurement if a user's wrist shifts out of the proper position by constantly sensing motion and position. Through software the monitor can tell not only at what angle it is mounted, but also if it is moving significantly or if the angle has changed.

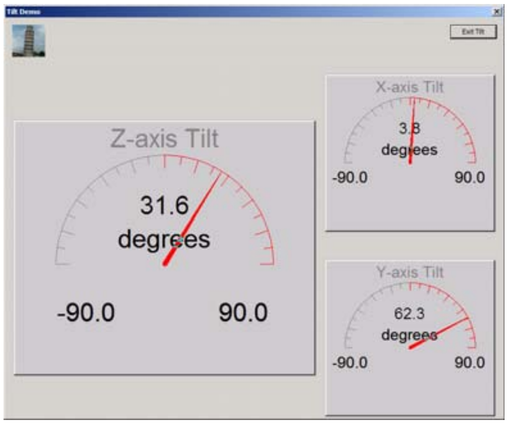


Figure 2. Tilt Demo Interface

Another large consumer application for Tilt is represented in the PDA Module. New cell phones and PDAs will be designed with fewer buttons, leaving room for a larger screen. Accelerometers can be used for many new functions—one being menu navigation. The user would simply navigate through a list of items simply by tilting the phone. The PDA Module uses the Z-axis accelerometer output data to extract the degree of tilt and moves the cursor on the list displayed on the PC up or down.

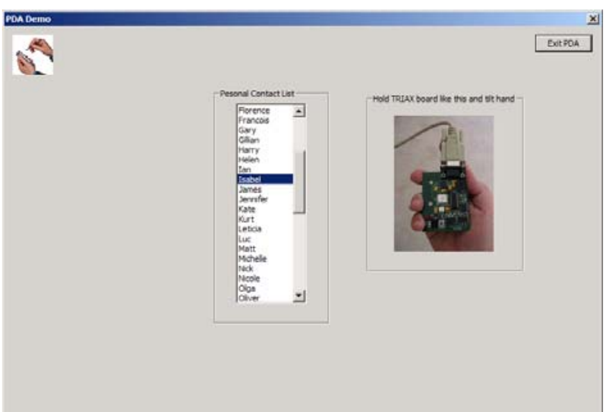


Figure 3. PDA Demo Interface

The Digitally Filtered Tilt Module will measure tilt in lawnmowers, forklifts, and other industrial equipment where there is vibration that can distort the accelerometer output. Using software filtering algorithms, the tilt information can be more accurately determined. In addition, the accelerometer can also be used to extract information on whether the motor is running or if the blades are engaged.

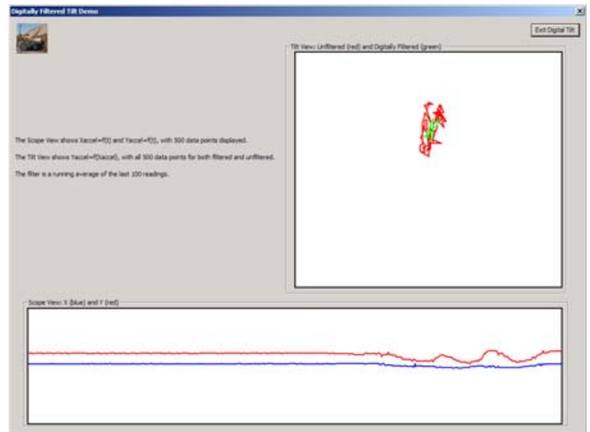


Figure 4. Digitally Filtered Tilt Demo Interface

The Anti-Theft Alarm Module is a stand-alone demo that can be used in laptops or other electronic equipment for added security features. The accelerometer is used to detect when the laptop is lifted. When the Anti-Theft Alarm Module is selected, the serial cable can be removed. The microcontroller constantly samples the accelerometer for static tilt information. If the TRIAX board is tilted 15 degrees, then the piezohorn will sound.

Position

Personal navigation applications are Car navigation, Back-up GPS, and Map Tracking.

An accelerometer can be used to measure position values by using software algorithms to integrate the accelerometer signal. Since integration introduces errors over time, the accuracy of the derived velocity and position values decrease as the integration interval increases.

To obtain postion data, first velocity data is obtained through integration. Then position is obtained through a second integration. The accelerometer accuracy is approximated based on the integration interval and the desired velocity accuracy by either of the following equations:

$a = v / (9.807 * t)$, where $v = m/sec$, $t = sec$, $a = G's$

Similarly, for position measurements, the required accelerometer accuracy can be approximated based on the integration interval and the desired position accuracy by:

$a = x / (9.807 * t * t)$, where $x = m$, $t = sec$, $a = G's$

Motion

Some MOTION Applications are Braking Systems (trailer brakes), Pedometers, Accidental Drop Protection, Battery Conservation, Robotics and Motion Control, and Virtual Reality.

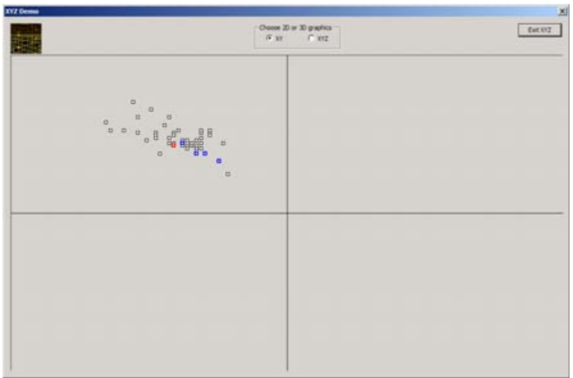


Figure 5. Positioning Demo Interface

Translation of accelerometer motion can be used for further calculation of position or speed. The Positioning Demo uses the TRIAX Board to show the first step for determining position.

Another application of movement measurement is pedometers. Mechanical pedometers simply count the number of steps taken. The pedometer displays either the number of steps taken or the distance traveled by using simple multiplication based on the average length of the user's stride. For this reason, they are not exceptionally accurate; if stride length varies, these mechanical pedometers may have a margin of error greater than 10 percent.

Using accelerometers, a pedometer can be designed with two-axis sensing for determining not only distance, but speed as well. One axis, measuring in the Z-axis, would determine the number of steps taken. A second accelerometer, sensing movement in the X-axis direction, parallel to the ground can be used with the Z-axis device to determine the length, the speed, and the impact of each stride. With all this information, pedometers can be more accurate and provide more functionality as well.

Movement can be detected using the accelerometer, but with that, also lack of movement can be detected as well. This is demonstrated in the Battery Saver Module. The X, Y, and Z-axis accelerometers are sampled by the microcontroller. When there is movement detected, the piezohorn is turned on signaling the movement detected. When there is no movement detected, the horn is silent. This module is used to demonstrate how the accelerometer can be effectively used in applications with full power and low power mode options, such as cell phones or GPS equipment. The cell phone or GPS device will detect motion and run in full power mode or continually receive satellite updates for positioning information. When there is no movement detected, they will run in low power mode and will not receive Satellite updates as often.

Rotational Acceleration

Rotational Acceleration is another measurement of movement that is obtained from accelerometers. Applications that can be enhanced by rotational acceleration data are Washing Machines for load imbalance and rotational compensation for Video Camera Stability.

Washing Machine load imbalance can be determined with an accelerometer after the fact by measuring the vibration. However, the accelerometer is used more effectively to predict the imbalance before it occurs. The accelerometer monitors the rotational orbit of the tub, extracting the RPM and elliptic geometric figures of merit to predict a load imbalance condition. The Load Imbalance Module (see Figure 6) monitors the rotational orbit of the TRIAX board, displaying the RPMs and a graphical elliptical display to demonstrate the application.

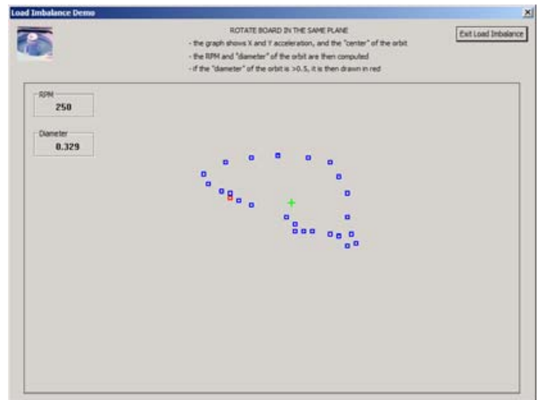


Figure 6. Load Imbalance Demo Interface

Vibration Measurement

Applications measuring vibration are Seismic Activity for earthquake detection, Smart Motor Preventive Maintenance, Hard Disk Drive Vibration Correction, and Acoustics Measurement and Control.

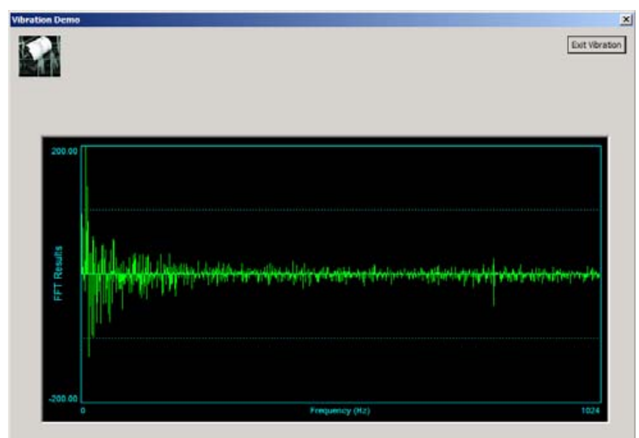


Figure 7. Vibration Demo Interface

Smart Motor Preventive Maintenance can be demonstrated using the Vibration Analysis Module (see Figure 7). Structural resonance in rotating machinery often increases noise and vibration levels leading to premature failure. An accelerometer can be used to not only detect when a rotating machine is failing from increased vibration, but an accelerometer can predict the failure by recognizing the vibration signature. Every motion has a vibration signature that is comprised of various levels of harmonics of vibration. The accelerometer is able to determine the harmonics of the motor and monitor when the values have changed, predicting a problem with the machinery before a failure occurs. The Music Pitch Analysis Demo uses an accelerometer to detect the harmonics from a vibration. This can be quickly demonstrated using tuning forks with the TRIAX board. For example, striking an “A” tuning fork and placing it next to the TRIAX board, the highest amplitude frequency recognized by the accelerometer would be 440 Hz and the check box corresponding to an “A” would be selected. See Figure 8.

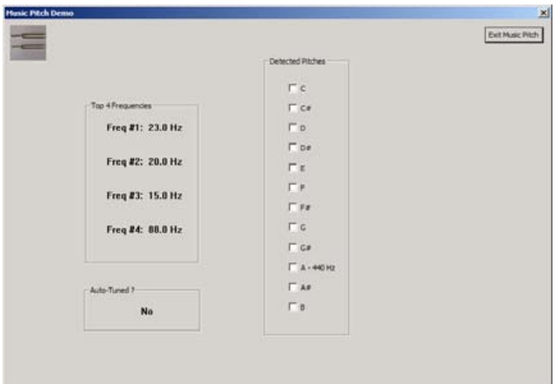


Figure 8. Music Pitch Analysis Demo

Accelerometers can also be used to detect the rotational vibration (RV) of hard disk drives (HDDs). When the RV characteristics of an operational HDD becomes too large or contains certain spectral content, the drive’s performance is often compromised. Poor seek times, read/write errors, and lost data can be the result of excessive RV. The accelerometer detects the RV and enables the HDD to adjust the drive for better operation.

Shock Measurement

Shock Applications range from Black Boxes and Event Data Recorders, Hard Disk Drive Protection, and Shipping & Handling Monitors to record shock levels experienced during transportation of fragile products.

The Shock Detection Module provides a simple demonstration of using the accelerometer to not only detect shock, but also to detect which axis the shock occurred. This is a stand-alone module. Therefore, once the Shock Detection Module is selected, the serial cable can be disconnected for the demonstration. The TRIAX board beeps once when the impact occurs in the X-axis, twice when it occurs in the Y-axis and three times when the impact occurs in the Z-axis.

This demonstration can be further enhanced by adding software to sample the signal for shock recognition features that would determine different actions for different types of shock. The accelerometers available on the TRIAX board are ±1.5g, therefore the shock conditions are anything above 1g. For many applications, a higher g-range is necessary. Freescale offers accelerometers from ±1.5g all the way up to ±250g. For applications requiring a higher g range, there are devices available.

Circuit Description

The TRIAX board is used to demonstrate many different applications; therefore it was not optimally designed for one specific application. The basic components are three low g accelerometers, a microcontroller, serial communication circuitry, EEPROM for data collection, and a piezohorn. This TRIAX board displays the three-axis solution with three accelerometers in the 16-pin SOIC. The microcontroller selected was the MC68908KX8. It was selected because it has an SCI required for the serial communication, four 8-bit ADC channels, three of which are required for the three accelerometer voltage outputs, and 8 Kb of on-chip, in-circuit programmable FLASH memory that is used for calibration data and remembering which software module was last run using the PC.

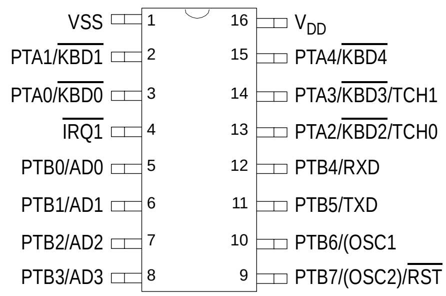


Figure 9. MC68HC908KX8 PDIP and SOIC Pin Assignments

Calibration

The zero g offset for the MMA1260D and the MMA2260D accelerometers are specified with a typical value of 2.5 V ±.

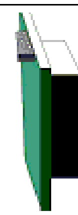
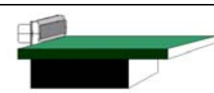
Follow these steps to determine the calibration values. Write down the A/D values for the X, Y, and Z outputs at 0g and 1g:

1. Start the RAW data software module.
2. Enter the A/D values for X, Y, and Z when experiencing 0g and 1g of static acceleration. Refer to Table 1 to see how to position the TRIAX boards to achieve the correct values.
3. Write the value in a similar table as show in Figure 10.
4. Close the RAW data module.
5. Start the CALIBRATE software module.
6. Fill in the A/D values that were determined. See Figure 11 for typical values.
7. Press the Calibration button.
8. Close the CALIBRATE software module.

	X AXIS	Y AXIS	Z AXIS
0g			
1g			

Figure 10. Calibration Data Table

Table 1. TRIAX Board Calibration Positions

	0g	
X at 0g	Place the TRIAX board on a flat surface so the components are face up and the battery is resting on the table.	
Y at 0g	Place the TRIAX board on a flat surface so the components are face up and the battery is resting on the table.	
Z at 0g	Hold the TRIAX board on its side so that the serial cable is at the top. The TRIAX board is perfectly horizontal when X has a maximum voltage without being shaken.	
	1g	
X at 1g	Hold the TRIAX board perpendicular so that the serial cable is at the top. The TRIAX board is perfectly horizontal when Y has a maximum voltage without being shaken.	
Y at 1g	Hold the TRIAX board on its side so that the serial cable is at the top. The TRIAX board is perfectly horizontal when X has a maximum voltage without being shaken.	
Z at 1g	Place the TRIAX board on a flat surface so the components are face up and the battery is resting on the table.	

The table in Figure 11 provides *typical values*. These typical values enable the TRIAX board to work with the PC software; however, accurately calibrating the accelerometers is necessary to find the exact values for the board. Use these values as a reference to enure the values that were obtained using the RAW DATA module were gathered by holding the board correctly.

	X AXIS	Y AXIS	Z AXIS
0g	128	128	128
1g	189	189	189

Figure 11. Typical A/D Values for Calibrating the TRIAX Board

Serial Connection and PC Operation

The TRIAX boards have serial circuitry and a DB9 connector for serial communication with the PC. The microcontroller is programmed with different modules that transmit data to the PC at different speeds and with different accelerometer data, depending on the current module selected with the PC interface.

To set up the system for PC operation, follow these steps:

1. Connect the TRIAX board to the PC using a DB9 male/female serial cable.
2. Launch the PC Software Executable program TRIAX3.2.exe.
3. Slide the TRIAX board switch in the On position.
4. Confirm that a data handshake occurs when the piezohorn beeps.

Before any module is started, a handshake occurs with the PC and the TRIAX board. If S2 is pressed after Reset and before the Handshake, then the system goes into Sample Mode (X&Y 100x/s 40.96s).

A Handshake occurs by the microcontroller waiting for the character *R*. When recognized, it responds with a character that represents the version of the microcontroller software available. For Version 2 (TRIAX07.asm), the microcontroller returns an *N*. (i.e., *M* for TRIAX06.asm) and it beeps once. When the connection between the TRIAX board and the PC is established, the microcontroller waits for a character from the PC. Each character received tells the microcontroller which firmware module should be run. Then the selected firmware module will continue to run until the microcontroller is restarted.

Stand Alone Operation

There is a feature on the TRIAX board that does not require the PC. It allows two demonstrations to run. The first demonstration that is always available in stand-alone operation is the free-fall demonstration. The second demonstration is the most recently used stand-alone application that was selected using the PC software.

To run the free-fall demonstration without the PC connected, turn the TRIAX board on while holding the pushbutton. Continue holding the pushbutton for 10 seconds. When the piezohorn sounds, the Free-fall Module is activated. To allow the user to drop and catch the TRIAX board, it sounds the piezohorn when the free-fall conditions are met. The Free-fall Module continues to run until the board is restarted.

To run the most recently used stand-alone operation, hold down the pushbutton while turning on the TRIAX board. For example, if the battery saver demo was the last module run, then you will be able to run the battery saver module or the Free-fall Module. To run the battery saver module, hold the pushbutton while turning on the TRIAX board and then quickly release the pushbutton. The piezohorn automatically starts beeping to signal that movement is detected. The battery saver module continues to run until the board is restarted.

SUMMARY

There are many new applications being designed using accelerometers. The TRIAX board is designed to demonstrate some of the general accelerometer applications. This application note describes these applications using the software programs available for the TRIAX board. After reading this application note, the user will be able to use the TRIAX board to demonstrate the existing accelerometer applications and be able to demonstrate their own design ideas.

±1.5g Dual Axis Micromachined Accelerometer Power Supply Rejection Ratio (PSRR) Suggestions

by: Peter Schultz
Product Engineer

COMPONENT DESCRIPTION

The MMA6200Q series is a two axis (X and Y) accelerometer family with sensitivity parallel to the device's mounting plane. The device utilizes variable capacitance sensing elements and a two-channel interface IC all in a 16-pin QFN package.

This section provides a general description of the device power supply rejection ratio (PSRR), how it affects device performance, and suggestions for improvement.

INTRODUCTION TO POWER SUPPLY

Rejection Ratio

The power supply rejection ratio is a measure of how well the device rejects the noise on the power supply line. The MMA6200Q series is capable of being used in several different applications. In some cases it may be possible for supply line noise to adversely affect the output signal. This phenomenon can create large output signals when the supply line noise frequencies are roughly equal to the device's oscillator frequency and/or harmonics. The oscillator drives the g-cell sampling as well as the internal low pass filter. When the difference between the frequency of the noise on the supply and the oscillator frequency is less than the low pass filter cutoff frequency the aliased signal passes through the filter. This aliased signal is then amplified internally by the device creating an even more adverse effect. This noise at the output can be as much as ten times the amplitude of the input noise at the oscillator frequency or its harmonics.

IMPROVING THE POWER SUPPLY

Rejection Ratio

If the power supply contains noise approaching the oscillator frequency, large amounts of noise may be observed at the output of the device. This does not become an issue until the noise frequency is a little larger than the oscillator frequency; a little larger here meaning still within the internal low pass filter's bandwidth. In application a simple low pass filter at the input helped to resolve this issue by attenuating much of the offending noise before it enters the device.

A simple two element low pass filter at the input of the device, made up of a resistor in series with a capacitor in shunt with V_{dd}, works rather well (see Figure 1).

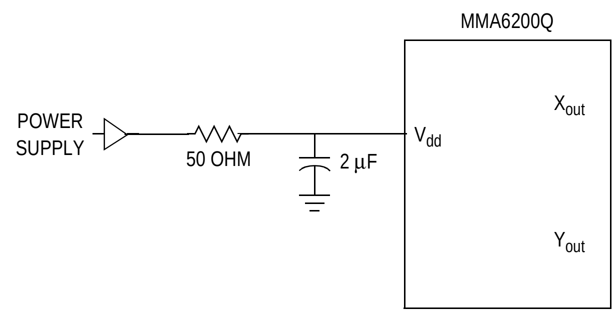


Figure 1. RC Input Loading for PSRR at V_{dd}

With this combination of a 50 ohm resistor and a 2 µF capacitor there is a large reduction in the PSRR, roughly 10X. This is now well below unity gain; meaning at the output of the device there is noticeably less noise than was supplied to the device, at the oscillator frequency and/or its harmonics. The first harmonic is at the oscillator frequency of roughly 15 KHz. The following illustration shows the effect on the PSRR when placing different values of capacitance at the input and retaining the 50 ohm resistor. There is six harmonics represented in the illustration the first of which is at about 15 KHz. These data points at the different harmonics represent the ratio of the output noise to the input noise. Depending on the application needs one can use this illustration to help determine the capacitive needs for the filter (see Figure 2). The plot is given in Log scale.

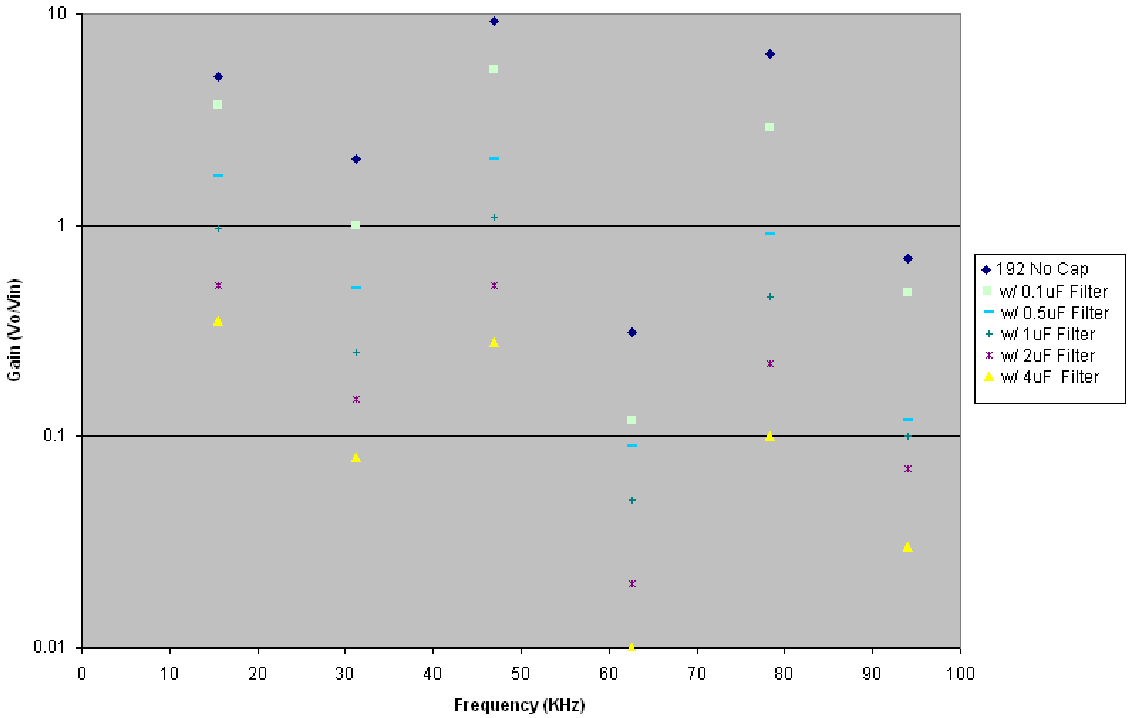


Figure 2. PSRR with 50 Ohm and Varying Input Capacitance

One can see the PSRR has improved by roughly a factor of 10 with a 2 µF capacitor at the input. Not only can the plot be used as a guide in the design of an input filter, it can also help put in perspective the possible amplitudes of the signal and about what frequencies they may occur. From looking at the plot one can see that for a capacitance of 1uF the gains at the two most predominate noise frequencies is unity. This means the aliased signals will not be larger in amplitude than the input noise that created it; giving the recommended smaller capacitance filter in the following illustration (see Figure 3).

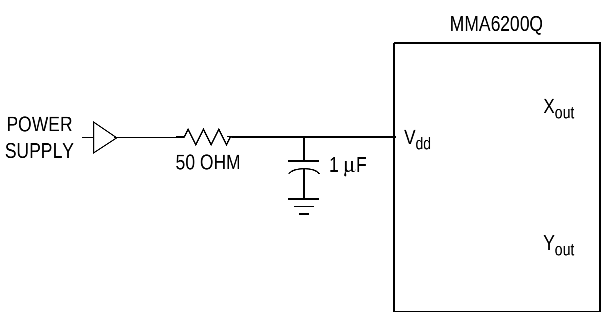


Figure 3. Recommended RC Input Loading for PSRR at V_{dd}

With cost as one of the deciding factors, this is a recommended filter design for reducing the PSRR. One should note however that variations in the individual devices and the different axes of the device produce plots that may look significantly different. The intent here is only to give an idea of the effects of different capacitances on the oscillator induced frequency gains. One must also remember to absorb any impedance the source may have into the RC filter as the source will also add its own impedance to the network.

If the series resistance and/or reactance is increased the amount of noise at the output will be decreased. The series reactance can be increased with the use of an inductor in series with the resistor (see Figure 4). This is more advantageous then adding more resistance due to the fact that it does not produce a large DC voltage drop.

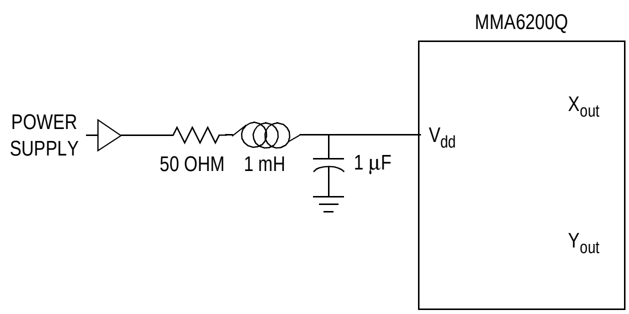


Figure 4. Recommended RCL Input Loading for PSRR at V_{dd}

The device was designed to operate with 3.3 Vdc at V_{dd}. If this input voltage is allowed to drop by more than half a volt the device may not operate correctly; hence the use of an inductor. With the use of an application board there was found to be greater than a factor of two drop in the output noise at the first harmonic with the use of the 1 mH inductor. The later harmonics incur a larger improvement due to the higher reactance of the inductor at the higher frequencies. As a result there was greater than a factor of eight improvement with the third and fifth harmonics. This RC and RLC circuit produced the following PSRR plot (see Figure 5).

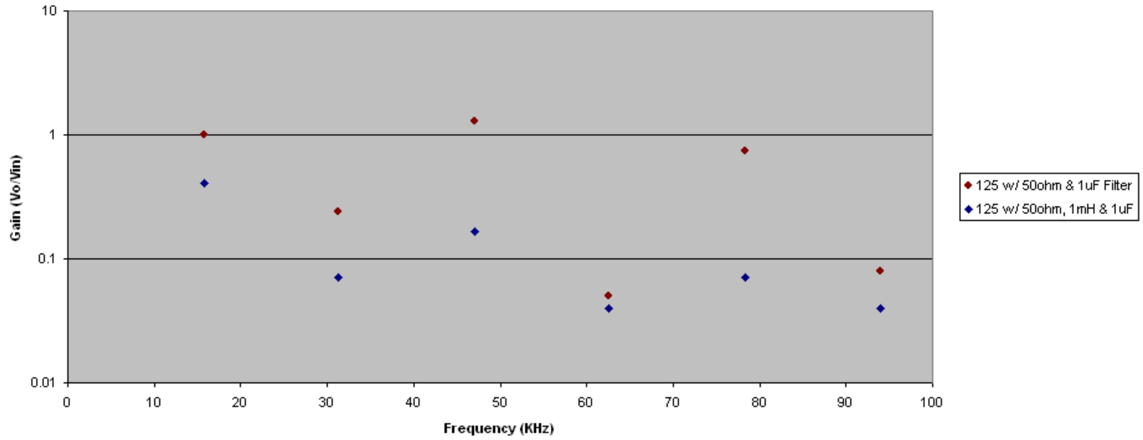


Figure 5. PSRR with RC and RLC Input Filter

If a smaller capacitance is desired in application with no inductor one can increase the value of just the series resistor. However one must take into consideration the tradeoffs involved. In order to get roughly the same improvement in the PSRR with a 0.5 µF capacitor as there was with the 50 ohm and 2 µF RC combination one must increase the series impedence to 150 ohms (see Figure 6).

This alternate RC circuit produces the following effect on the PSRR (see Figure 7). Notice the similarity in the gain when compared with the 50 ohm 2 µF filter. It is still well below unity for this configuration.

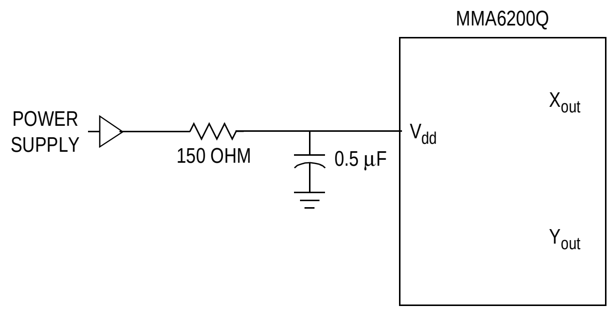


Figure 6. Alternate RC Input Loading for PSRR at V_{dd}

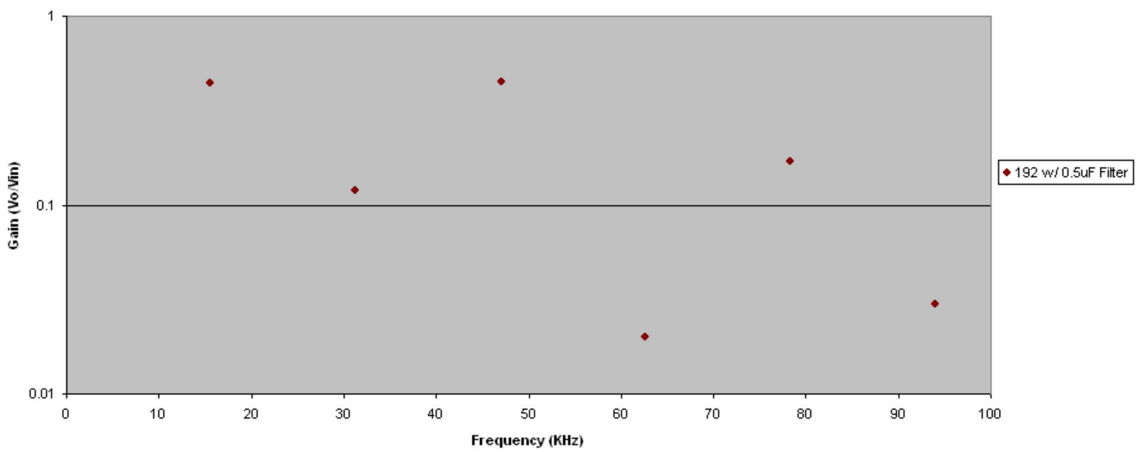


Figure 7. PSRR with 150 Ohm and 0.5 µF Input Capacitance

As stated before this large value of resistance creates a DC voltage drop at the input of the device. However, it could be reduced some and still achieve less than unity gain. With the same voltage at the input of the filter the output voltage of the device is lowered. In this case it drops by roughly 5 percent. In turn, this loss in DC voltage also lowers the ratio-metric error. However if the voltage at Vdd is allowed to drop much lower than 2.7 volts the device may not operate at all. If cost and space permits, one should consider, as stated previously, the substitution of a series inductor in place of at least part of this series resistance. This can greatly decrease the DC voltage drop problem.

To get a 150 ohm impedance at the frequency of the first harmonic we have X = 2*pie*(15 KHz)*L = 150 ohm. Solving for L gives the somewhat large value of 1.6 mH for the inductor. A 1 mH inductor at 15 KHz has an impedance of about 95 ohms and these devices can be had in quantity (1000 or more) for less then twenty cents each.

CONCLUSION

The MMA6200Q series family of devices require external RC and possibly L components to correct power supply rejection ratio issues caused by noisy power supply lines. This may not be of concern in many applications; however, it may be in some. The preceding gives an introduction to power supply rejection ratio as well as some information to better understand this potential problem. Also included are some example filters, the effects on PSRR, as well as suggested choices.

Freescale Semiconductor
Technical Data

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Rev 0, 05/2005

Measuring Tilt with Low-g Accelerometers

by: Michelle Clifford and Leticia Gomez
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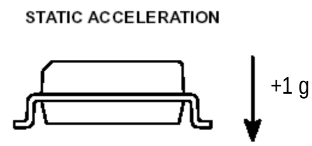
INTRODUCTION

This application note describes how accelerometers are used to measure the tilt of an object. Accelerometers can be used for measuring both dynamic and static measurements of acceleration. Tilt is a static measurement where gravity is the acceleration being measured. Therefore, to achieve the highest degree resolution of a tilt measurement, a low-g, high-sensitivity accelerometer is required. The Freescale MMA6200Q and MMA7260Q series accelerometers are good solutions for XY and XYZ tilt sensing. These devices provide a sensitivity of 800 mV/g in 3.3 V applications. The MMA2260D and MMA1260D are also good solutions for 5 V applications providing a sensitivity of 1200mV/g for X and Z, respectively. All of these accelerometers will experience acceleration in the range of +1g to -1g as the device is tilted from -90 degrees to +90 degrees.

1g = 9.8 m/s



MODULE

A simple tilt application can be implemented using an 8 or 10-bit microcontroller that has 1 or 2 ADC channels to input the analog output voltage of the accelerometers and general purpose I/O pins for displaying the degrees either on a PC through a communication protocol or on an LCD. See Figure 1 for a typical block diagram. Some applications may not require a display at all. These applications may only require an I/O channel to send a signal for turning on or off a device at a determined angle range.

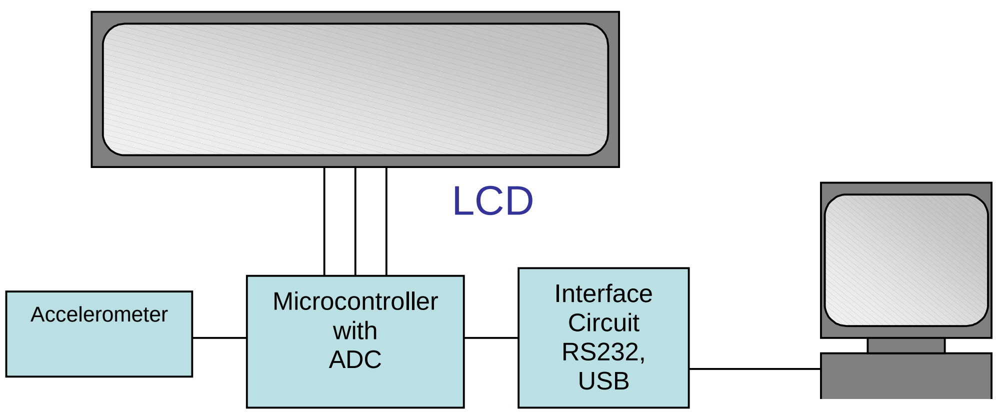


Figure 1. Typical Tilt Application Block Diagram

MOUNTING CONSIDERATIONS

Device selection depends on the angle of reference and how the device will be mounted in the end application. This will allow you to achieve the highest degree resolution for a given solution due to the nonlinearity of the technology. First, you need to know what the sensing axis is for the accelerometer. See Figure 2 to see where the sensing axes are for the MMA7260Q. To obtain the most resolution per degree of change, the IC should be mounted with the sensitive axis parallel to the plane of movement where the most sensitivity is desired. For example, if the degree range that an application will be measuring is only 0° to 45° and the PCB will be mounted perpendicular to gravity, then an X-Axis device would be the best solution. If the degree range was 0° to 45° and the PCB will be mounted perpendicular to gravity, then a Z-Axis device would be the best solution. This is understood more when thinking about the output response signal of the device and the nonlinearity.

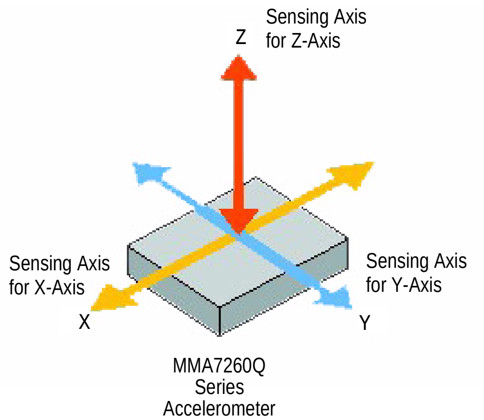


Figure 2. Sensing Axis for the MMA7260Q Accelerometer With X, Y, and Z-Axis for Sensing Acceleration

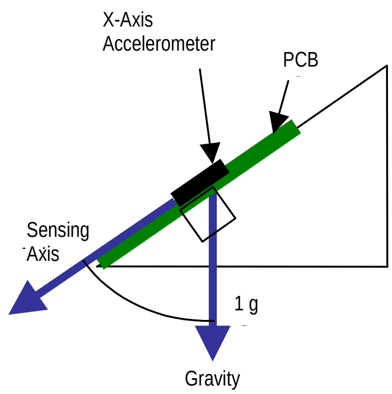


Figure 3. Gravity Component of a Tilted X-Axis Accelerometer

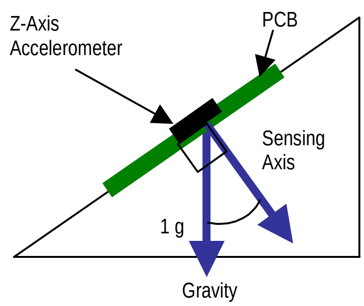


Figure 4. Gravity Component of a Tilted Z-Axis Accelerometer

NONLINEARITY

As seen in Figure 5, the typical output of capacitive, micro-machined accelerometers is more like a sine function. The figure shows the analog output voltage from the accelerometer for degrees of tilt from -90° to +90°. The change in degrees of tilt directly corresponds to a change in the acceleration due to a changing component of gravity acted on the accelerometer. The slope of the curve is actually the sensitivity of the device.

As the device is tilted from 0°, the sensitivity decreases. You see this in the graph as the slope of output voltage decreases for an increasing tilt towards 90°. Because of this nonlinearity, the degree resolution of the application must be determined at 0° and 90° to ensure the lowest resolution is still within the required application resolution. This will be explained more in the following section.

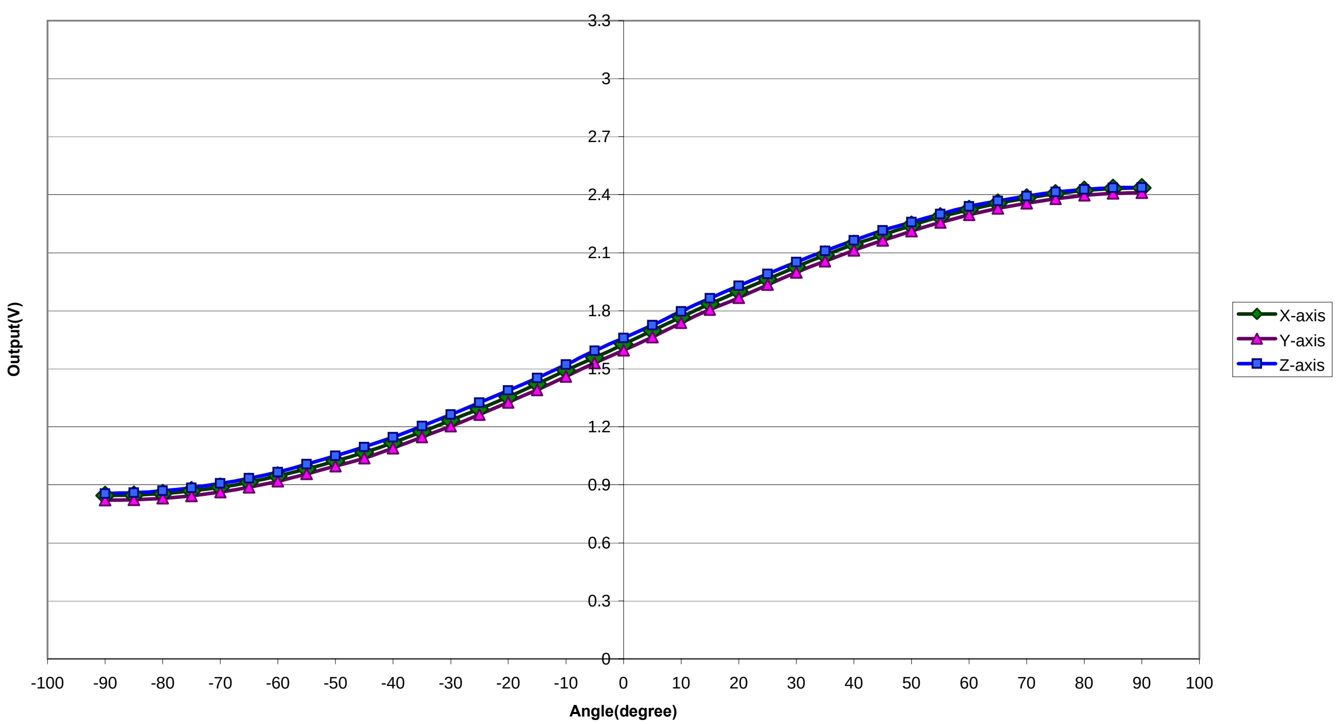


Figure 5. Typical Nonlinear Output of X, Y, and Z-Axis Accelerometers

CALCULATING DEGREE OF TILT

In order to determine the angle of tilt, θ, the A/D values from the accelerometer are sampled by the ADC channel on the microcontroller. The acceleration is compared to the zero g offset to determine if it is a positive or negative acceleration, e.g., if value is greater than the offset then the acceleration is seeing a positive acceleration, so the offset is subtracted from the value and the resulting value is then used with a lookup table to determine the corresponding degree of tilt (See Table1 for a typical 8-bit lookup table), or the value is passed to a tilt algorithm. If the acceleration is negative, then the value is subtracted from the offset to determine the amount of negative acceleration and then passed to the lookup table or algorithm. One solution can measure 0° to 90° of tilt with a single axis accelerometer, or another solution can measure 360° of tilt with two axis configuration (XY, X and Z), or a single axis configuration (e.g. X or Z), where values in two directions are converted to degrees and compared to determine the quadrant that they are in. A tilt solution can be solved by either implementing an arccosine function, an arcsine function, or a look-up table depending on the power of the microcontroller and the accuracy required by the application. For simplicity, we will use the equation: θ = arcsin(x). The arcsin(y) can determine the range from 0° to 180°, but it cannot discriminate the angles in range from 0° to 360°, e.g. arcsin(45º) = arcsin(135º). However, the sign of x and y can be used to determine which quadrant the angle is in. By this means, we can calculate the angle β in one quadrant (0-90º) using arcsin(y) and then determine θ in the determined quadrant.

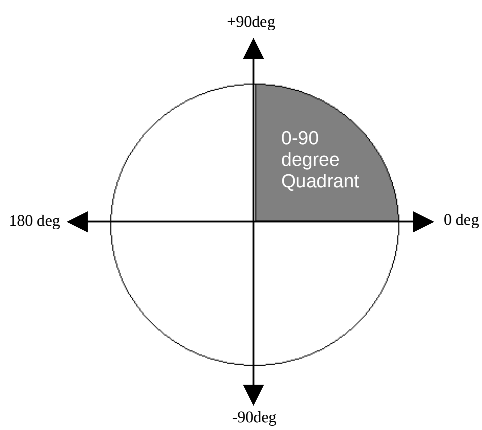


Figure 6. The Quadrants of a 360 Degree Rotation

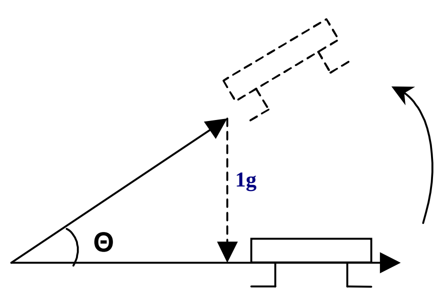


Figure 7. An Example of Tilt in the First Quadrant

[1] $$V_{OUT} = V_{OFFSET} + \left(\frac{\Delta V}{\Delta g} \times 1.0g \times \sin\theta\right)$$

where:
V_{OUT} = Accelerometer Output in Volts
V_{OFF} = Accelerometer 0g Offset
$\Delta V/\Delta g$ = Sensitivity
1g = Earth's Gravity
θ = Angle of Tilt

Solving for the angle:

[2] $$\theta = \arcsin\left(\frac{V_{OUT} - V_{OFFSET}}{\frac{\Delta V}{\Delta g}}\right)$$

This equation can be used with the MMA6260Q as an example:

$$V_{OUT} = 1650mV + 800mV \times \sin\theta$$

Where the angle can be solved by

$$\theta = \arcsin\left(\frac{V_{OUT} - 1650mV}{800mV/g}\right)$$

From this equation, you can see that at 0° the accelerometer output voltage would be 1650mV and at 90° the accelerometer output would be 2450mV.

INTERFACING TO ADC

An 8-Bit ADC

An 8-bit ADC cuts 3.3V supply into 255 steps of 12.9mV for each step. Therefore, by taking one ADC reading of the MMA6260Q at 0g (0°of tilt for an x-axis device) and 1g (90° of tilt for an x-axis device), would result in the following:

0°: 1650mV + 12.9mV = 1662.9mV,
which is 0.92° resolution

90°: 2450mV+ 12.9mV = 2462.9mV,
which is 6.51° resolution

Due to the nonlinearity discussed earlier, you will see that the accelerometer is most sensitive when the sensing axis is closer to 0°, and less sensitive when closer to 90°. Therefore, the system provides a 0.92 degree resolution at the highest sensitivity point (0 degrees), and a 6.51 degree resolution at the lowest sensitivity point (90°).

A 10-Bit ADC

A 10-bit ADC cuts 3.3V supply into 1023 steps of 3.2mV for each step. Therefore, by taking one ADC reading of the MMA6260Q again at 0g (0° of tilt for an x-axis device), would now result in the following:

0°: 1650mV + 3.2mV = 1653.2mV

90° 2450mV + 3.2mV = 2453.2mV

This results in a 0.229 degree resolution at the highest sensitivity point (0°) and a 3.26 degree resolution at the lowest sensitivity point (90°).

A 12-Bit ADC

A 12-bit ADC cuts 3.3V supply into 4095 steps of 0.8mV for each step. Therefore, by taking one ADC reading of the MMA6260Q again at 0g (0° of tilt for an x-axis device), would now result in the following:

0°: 1650mV + 0.8mV = 1650.8mV

90°: 2450mV + 0.8mV = 2450.8mV

This results in a 0.057 degree resolution at the highest sensitivity point (0°) and 1.63 degree resolution at the lowest sensitivity point (90°). However, for 0.8mV changes, the noise factor becomes the factor to consider during design. How much noise the system has will depend on how much resolution you can get with a higher bit count.

TILT APPLICATIONS

There are many applications where tilt measurements are required or will enhance its functionality. In the cell phone market and handheld electronics market, tilt applications can be used for controlling menu options, e-compass compensation, image rotation, or function selection in response to different tilt measurements. In the medical markets, tilt is used for making blood pressure monitors more accurate. They can also be used for feedback for tilting hospital beds or chairs. A tilt controller can also be used for an easier way to control this type of equipment. Accelerometers for tilt measurements can also be designed into a multitude of products, such as game controllers, virtual reality input devices, HDD portable products, computer mouse, cameras, projectors, washing machines, and personal navigation systems.

Table 1. 8-Bit Lookup Table for Determining Degree of Tilt

ADC Bits	Calculated Voltage	g	arcsine	arccos
66	-0.80	-1.00	-87.47	177.47
67	-0.79	-0.98	-79.39	169.39
68	-0.77	-0.97	-75.19	165.19
69	-0.76	-0.95	-71.93	161.93
70	-0.75	-0.93	-69.16	159.16
71	-0.73	-0.92	-66.70	156.70
72	-0.72	-0.90	-64.47	154.47
73	-0.71	-0.89	-62.40	152.40
74	-0.70	-0.87	-60.47	150.47
75	-0.68	-0.85	-58.65	148.65
76	-0.67	-0.84	-56.92	146.92
77	-0.66	-0.82	-55.26	145.26
78	-0.64	-0.81	-53.67	143.67
79	-0.63	-0.79	-52.14	142.14
80	-0.62	-0.77	-50.66	140.66
81	-0.61	-0.76	-49.23	139.23
82	-0.59	-0.74	-47.83	137.83
83	-0.58	-0.73	-46.48	136.48
84	-0.57	-0.71	-45.15	135.15
85	-0.55	-0.69	-43.86	133.86
86	-0.54	-0.68	-42.59	132.59
87	-0.53	-0.66	-41.35	131.35
88	-0.52	-0.64	-40.13	130.13
89	-0.50	-0.63	-38.93	128.93
90	-0.49	-0.61	-37.76	127.76
91	-0.48	-0.60	-36.60	126.60
92	-0.46	-0.58	-35.46	125.46
93	-0.45	-0.56	-34.33	124.33
94	-0.44	-0.55	-33.22	123.22
95	-0.43	-0.53	-32.12	122.12
96	-0.41	-0.52	-31.04	121.04
97	-0.40	-0.50	-29.97	119.97
98	-0.39	-0.48	-28.91	118.91
99	-0.37	-0.47	-27.86	117.86
100	-0.36	-0.45	-26.82	116.82
101	-0.35	-0.44	-25.79	115.79
102	-0.34	-0.42	-24.77	114.77
103	-0.32	-0.40	-23.76	113.76
104	-0.31	-0.39	-22.75	112.75
105	-0.30	-0.37	-21.75	111.75
106	-0.28	-0.35	-20.76	110.76
107	-0.27	-0.34	-19.78	109.78
108	-0.26	-0.32	-18.80	108.80
109	-0.24	-0.31	-17.83	107.83
110	-0.23	-0.29	-16.86	106.86
111	-0.22	-0.27	-15.90	105.90
112	-0.21	-0.26	-14.94	104.94
113	-0.19	-0.24	-13.99	103.99
114	-0.18	-0.23	-13.04	103.04
115	-0.17	-0.21	-12.09	102.09
116	-0.15	-0.19	-11.15	101.15
117	-0.14	-0.18	-10.21	100.21
118	-0.13	-0.16	-9.27	99.27
119	-0.12	-0.15	-8.34	98.34
120	-0.10	-0.13	-7.41	97.41
121	-0.09	-0.11	-6.48	96.48
122	-0.08	-0.10	-5.55	95.55
123	-0.06	-0.08	-4.62	94.62
124	-0.05	-0.06	-3.70	93.70
125	-0.04	-0.05	-2.77	92.77
126	-0.03	-0.03	-1.85	91.85
127	-0.01	-0.02	-0.92	90.92
128	0.00	0.00	0.00	90.00

ADC Bits	Calculated Voltage	g	arcsine	arccos
129	0.01	0.02	0.92	89.08
130	0.03	0.03	1.85	88.15
131	0.04	0.05	2.77	87.23
132	0.05	0.06	3.70	86.30
133	0.06	0.08	4.62	85.38
134	0.08	0.10	5.55	84.45
135	0.09	0.11	6.48	83.52
136	0.10	0.13	7.41	82.59
137	0.12	0.15	8.34	81.66
138	0.13	0.16	9.27	80.73
139	0.14	0.18	10.21	79.79
140	0.15	0.19	11.15	78.85
141	0.17	0.21	12.09	77.91
142	0.18	0.23	13.04	76.96
143	0.19	0.24	13.99	76.01
144	0.21	0.26	14.94	75.06
145	0.22	0.27	15.90	74.10
146	0.23	0.29	16.86	73.14
147	0.24	0.31	17.83	72.17
148	0.26	0.32	18.80	71.20
149	0.27	0.34	19.78	70.22
150	0.28	0.35	20.76	69.24
151	0.30	0.37	21.75	68.25
152	0.31	0.39	22.75	67.25
153	0.32	0.40	23.76	66.24
154	0.34	0.42	24.77	65.23
155	0.35	0.44	25.79	64.21
156	0.36	0.45	26.82	63.18
157	0.37	0.47	27.86	62.14
158	0.39	0.48	28.91	61.09
159	0.40	0.50	29.97	60.03
160	0.41	0.52	31.04	58.96
161	0.43	0.53	32.12	57.88
162	0.44	0.55	33.22	56.78
163	0.45	0.56	34.33	55.67
164	0.46	0.58	35.46	54.54
165	0.48	0.60	36.60	53.40
166	0.49	0.61	37.76	52.24
167	0.50	0.63	38.93	51.07
168	0.52	0.64	40.13	49.87
169	0.53	0.66	41.35	48.65
170	0.54	0.68	42.59	47.41
171	0.55	0.69	43.86	46.14
172	0.57	0.71	45.15	44.85
173	0.58	0.73	46.48	43.52
174	0.59	0.74	47.83	42.17
175	0.61	0.76	49.23	40.77
176	0.62	0.77	50.66	39.34
177	0.63	0.79	52.14	37.86
178	0.64	0.81	53.67	36.33
179	0.66	0.82	55.26	34.74
180	0.67	0.84	56.92	33.08
181	0.68	0.85	58.65	31.35
182	0.70	0.87	60.47	29.53
183	0.71	0.89	62.40	27.60
184	0.72	0.90	64.47	25.53
185	0.73	0.92	66.70	23.30
186	0.75	0.93	69.16	20.84
187	0.76	0.95	71.93	18.07
188	0.77	0.97	75.19	14.81
189	0.79	0.98	79.39	10.61
190	0.80	1.00	87.47	2.53

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Using the MMA7260Q Evaluation Board

by: Michelle Clifford and John Young
Applications Engineers
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INTRODUCTION

This application note describes the Accelerometer Evaluation Board (Figure 2) for the MMA7260Q 3-axis low-g accelerometer. The Accelerometer Evaluation Board is a small circuit board intended to be used for evaluating the MMA7260Q and developing prototypes quickly without requiring a PCB to be designed to accommodate for the small profile QFN package. It also provides a means for understanding the best mounting position and location of an accelerometer in your product with provided board mounting points.

CIRCUIT DESCRIPTION

Figure 3 is a circuit schematic of the evaluation board. The recommended decoupling capacitor at the power source and recommended RC filter at the output, are included on the evaluation board. For a complete description of the operation of the accelerometer, refer to the MMA7260Q datasheet. There is an RC filter at each of the three accelerometer outputs in order to minimize clock noise that may be present from the switched capacitor filter circuit. No additional components are necessary to use the evaluation board.

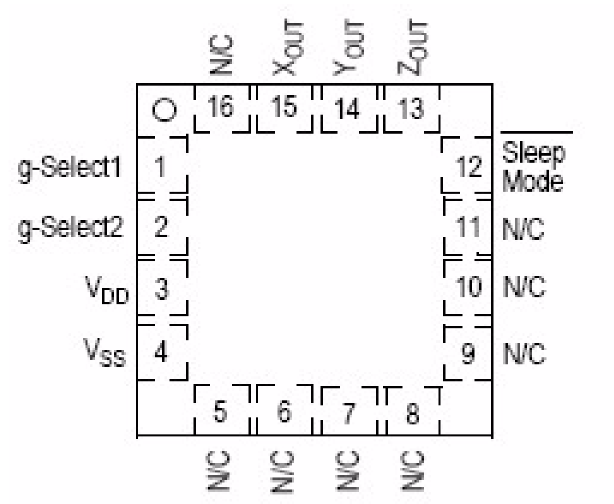

Figure 1. Pin Connections

Figure 2. Evaluation Board for MMA7260Q

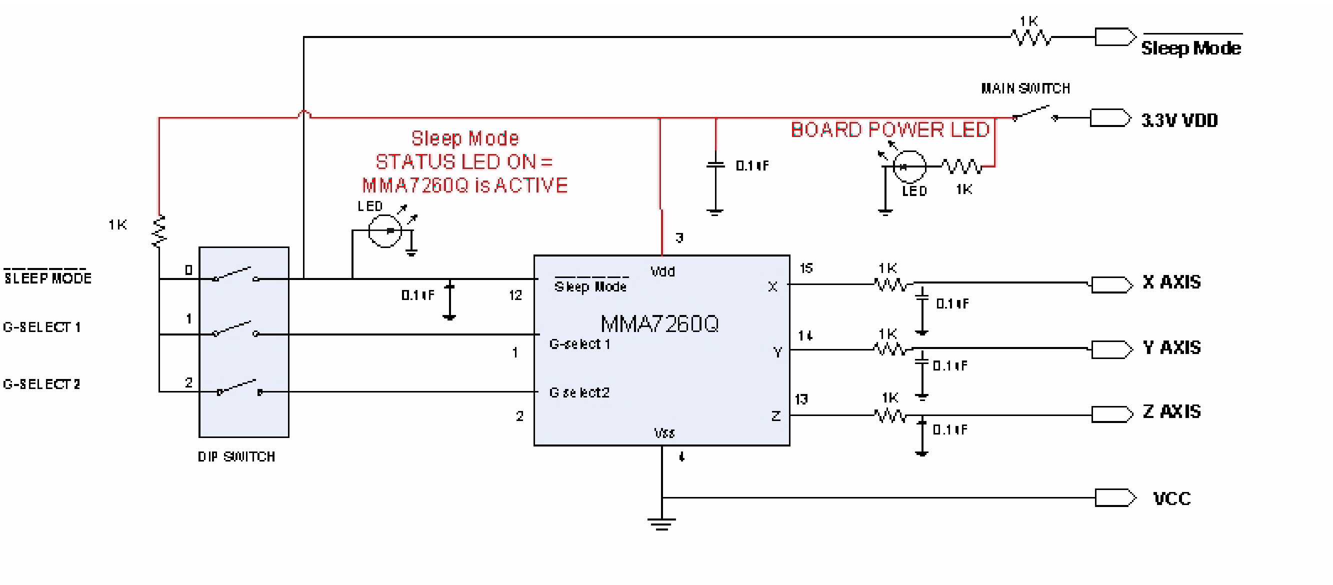

Figure 3. Circuit Schematic of the MMA7260Q Evaluation Board

Table 1. Description of Output/Input Pads

Output/Input Pads	Description
Sleep Mode	Used for an external source to enable/disable sleep mode
3.3V VDD	Input Voltage
X axis	Analog Voltage output of X axis
Y axis	Analog Voltage output of Y axis
Z axis	Analog Voltage output of Z axis

The evaluation board has pads for interfacing to a 3.3 volt power source or battery. The pads on the side of the board also provide a means for connecting to the accelerometer analog output by soldering a wire from the evaluation board to another breadboard or system. The ON/OFF switch provides power to the accelerometer and helps preserve battery life if a battery is being used as the power source. S1 must be set towards the ON position for the accelerometer to function. The green LED labeled PWR is lit when power is supplied to the accelerometer.

G-SELECT DIPSWITCH SETTINGS

The g-Select is a powerful features on the MMA7260Q allowing one device to measure 4 different ranges of acceleration. See Table 2. The g-Select allows one device to provide two different applications in one package. By adjusting the dip-switches on the evaluation board, the accelerometer can toggle between the different g-Ranges with the same accelerometer part. The following table outlines the g-Ranges that the toggle selections correspond to. The dip-switches on the evaluation board allow users to make selections without having to create the PCB board and define settings as in the finished product. A microcontroller in a finished product could also use this g-Select functionality of the MMA7260Q to adjust the g-Ranges of the device as needed by the end customer.

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Table 2. g-Select pin Descriptions

g-Select2	g-Select1	g-Range	Sensitivity
0	0	1.5g	800mV/g
0	1	2g	600mV/g
1	0	4g	300mV/g
1	1	6g	200mV/g

SLEEP MODE FUNCTION

The MMA7260Q device features a sleep mode function, activated by a sleep mode option on the device's pinout. The sleep mode pin on the MMA7260Q is an active high pin, enabling the device 'on' when Vdd is applied to that particular Pin 12.

This is selectable on the evaluation board using either the INPUT/OUTPUT sleep mode Pad or the dip switch that is provided. When the dip switch is activated, the device is enabled. The same occurs with the Sleep Mode Pad. When the user attaches a 3.3 V or VDD voltage to this, the device will be enabled. A VCC connection to this pin will place the device in standby mode. If the device is enabled, the LED labeled sleep mode will be lit.

The sleep mode allows the MMA7260Q device to operate on standby at 5 µA supply current. Regular operation uses 500 µA of supply current.

MOUNTING CONSIDERATIONS

In Figure 4 there is a diagram of the evaluation board and the corresponding axes due to the orientation of the device. System design and sensor mounting can affect the response of a sensor system. The placement of the sensor itself is critical to obtaining the desired measurements. It is important that the sensor be mounted as rigidly as possible to obtain accurate results. Since the thickness and mounting of the board varies, parasitic resonance may distort the sensor measurement. Hence it is vital to fasten and secure to the largest mass structure of the system, i.e. the largest truss, the largest mass, the point closest to the source of vibration. On the other hand, dampening of the sensor device can absorb much of the vibration and give false readings as well. The evaluation board has holes in each of the four corners of the board for mounting. It is important to maintain a secure mounting scheme to capture the true motion.

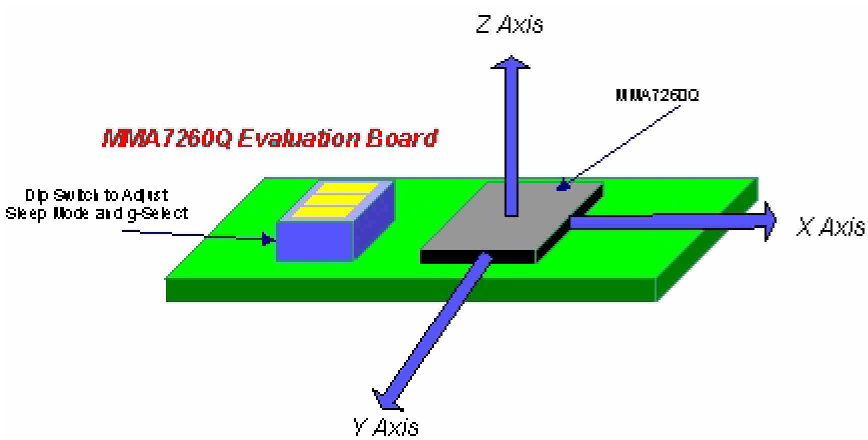

Figure 4. Board Orientation Corresponding to the Three Axes

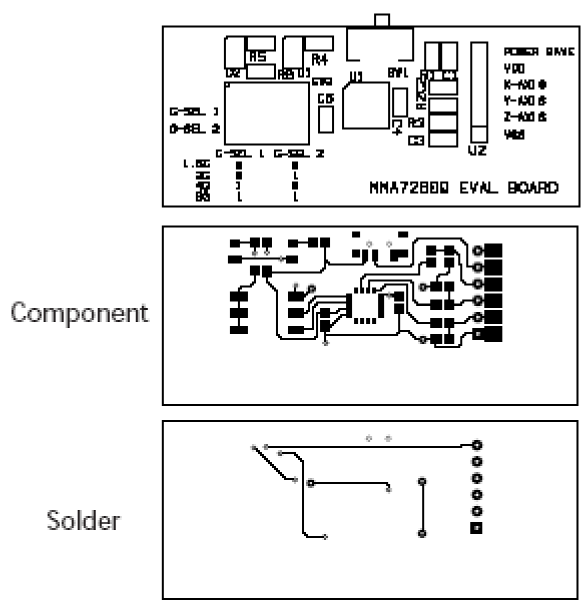

Figure 5. Board Layout for Component, Top Layer, and Bottom Layer

Freescale Semiconductor
Technical Data

AN3111
Rev 0, 05/2005

Soldering the QFN Stacked Die Sensors to the PC Board

by: **Dave Mahadevan**
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INTRODUCTION

The third generation of inertial sensors (accelerometers) uses the Quad Flat No-Lead (QFN) platform with stacked die configuration to minimize the footprint. The QFN sensors are the first product of its kind. This application note describes suggested methods of soldering these devices to the PC board. Figure 1 shows the top and bottom view of QFN 16 lead, 6 x 6 mm individual sensor devices and the device soldered to the board.

Overview of Soldering Considerations

The information provided here is based on experiments executed on QFN devices. They do not represent exact conditions present at a customer site. Hence, information herein should be used as guidance. Any necessary adjustments required should be done by the customers.

The stacked die QFN is designed for both consumer and automotive applications. Solder Joint Reliability (SJR) varies for both applications. Table 1 lists the applications and requirements with their respective results.

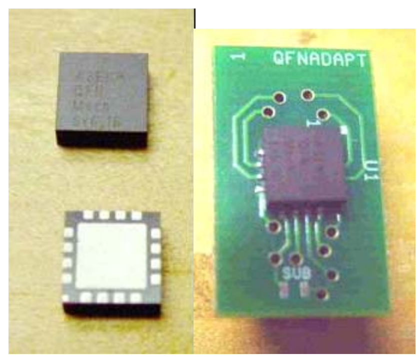


Figure 1. QFN 16-Lead, 6x6 mm Stacked Die Sensor

Table 1. Applications and SJR Requirements

Application	Temperature Cycle Range	No. of Cycles Required	Specification	Preconditions	Remarks	Results
Consumer	-25 to +85°C	500	Freescale spec 12MWS00024B	None	Temperature cycled at -40 to +125°C	Passed more than 2000 cycles
Automotive	-40 to +125°C	1000	AEC-Q100	None		
Special Consumer	-25 to +85°C	500	Special Customer Specification	8 hours of steam aging before soldering		Passed more than 1000 cycles

NOTE: The above specifications are for component life only. Hence, it is assumed that the devices have to meet at least the life cycle of the components for SJR.

The above results show SJR with exposed pads solder down. To meet automotive applications, as well as severe reflow conditions like that of special consumer applications, the exposed pad (die pad or flag) should also to be soldered to the PC board. However, it is always recommended to solder the exposed flag to the PC board, thereby increasing the SJR.

Freescale QFN sensors are compliant with Restrictions on Hazardous Substances (RoHS), having halide free molding compound (green) and lead-free terminations. These terminations are compatible with tin-lead (Sn-Pb) as well as tin-silver-copper (Sn-Ag-Cu) solder paste soldering processes. Reflow profiles applicable to those processes can be used successfully for soldering the devices. This document provides a suggested reflow profile for the JEDEC compliant lead-free soldering process (per JEDEC Standard 20, Revision C) as well as the footprint information for the QFN device (see Figure 3.

Test Procedure

The test board panel design for QFN stacked die package incorporates input from customers as to thickness, trace material, and layers of construction. This was accomplished to simulate as nearly as possible, the same conditions the package will be subjected to by the customers. Solder paste printing at the board level is a critical factor in SJR for QFN and all leadless devices. The final stencil used had a thickness of 6 mils (150 microns). The I/O pad openings (for the so-called *leads*) were 1:1 with the PCB pad size. The exposed flag region for the stencil was pulled away from the I/O to reduce the likelihood for solder bridging or scavenging. Because the evaluation was only done to determine SJR, good electrical dies were not required.

Only mechanical dies to simulate the actual thermal cycling conditions were used in assembly. To check for solder failure, an electrical open was viewed as an indication. Hence, all the leads were shorted in a daisy chain fashion (see Figure 2). For redundancy, two wire bonds were provided for each joint. The temperature range for the experimental cycling was from -40°C to +125°C with 15 minute dwells at extremes and 15 minute ramps between extremes. The chamber was temperature profiled for stability for various packages and test boards.

Resistance measurements through the daisy chain nets were carried out on a continuous basis. Event detectors measured the resistance with a setup point of 300 ohms being the failure criterion [IPC-SM-785]. For the QFN packages, the start resistance through the daisy chain was on the order of 1 ohm. When the event detectors recorded a failure, the net failing was identified and documented. Results indicated that the first failure (with exposed flags soldered down) was more than 2000 temperature cycles. For special customer requirement conditions, the first failure occurred beyond 1000 cycles with exposed flag soldered down. Freescale specification 12MWS00049B, Revision F, was used for the soldering process.

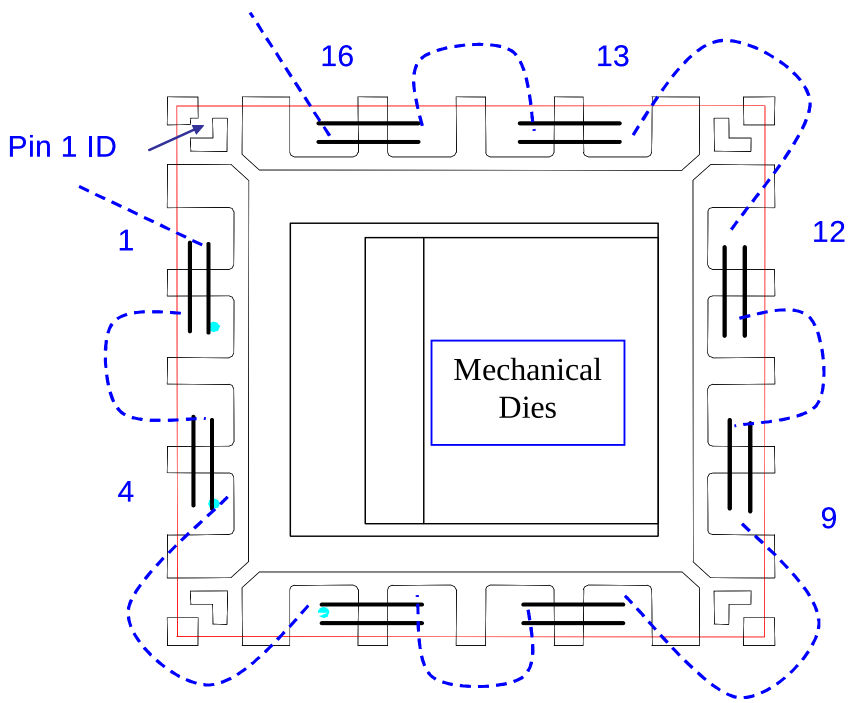
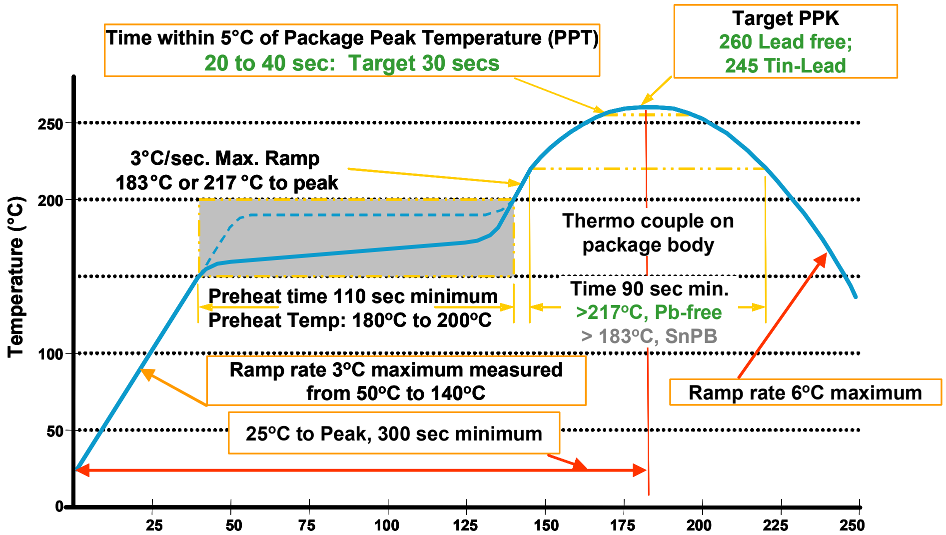


Figure 2. Daisy Chain Wire Bonding of QFN devices

Footprint and Reflow Profiles

Figure 3 provides the JEDEC compliant reflow conditions.

Figure 4 illustrates the footprint of the QFN 16 lead 6 x 6 mm package for solder paste printing purposes. Because the small pads located in the corners of the 6 x 6, 16 lead QFN package do not need to be soldered, they are not represented on the footprint (see Figure 3).



Notes:
1. Time and temperatures are defined from JEDEC Std. 20, Rev C, and averages of 30 customer inputs.
2. Reflow conditions for Sn-PB and Sn-AG-Cu solder paste soldering processes should be less than the profile given above.

Figure 3. Profile (Pattern) for Package Peak Temperature (PPT)

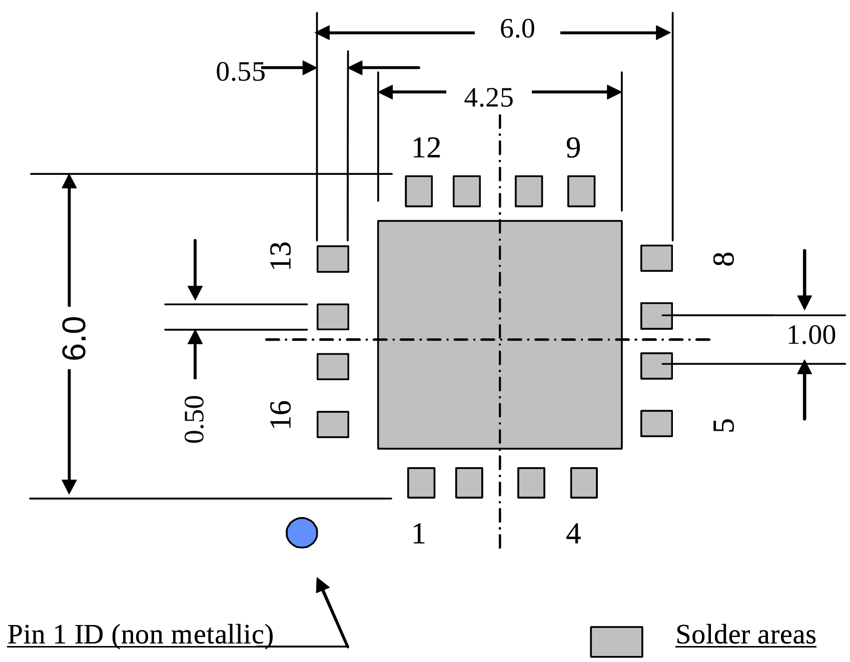


Figure 4. Footprint for 16-Lead OFN, 6 x 6 mm

NOTE: For automotive use, the die-pad (Flag) should be soldered down. All dimensions are in mm.

Summary

There are many new applications being designed using QFN stacked die accelerometers. This application note provides a description of the positive reliability results obtained while following the conditions described in this document.

AN3112
Rev 0, 05/2005

Using the Sensing Triple Axis Reference Board (STAR)

by: John Young and Michelle Clifford
Sensor and Analog Products
Tempe, AZ

INTRODUCTION

The Sensing Triple Axis Reference Board (STAR) is a Freescale demonstration tool that is designed to allow visualization of key accelerometer applications in the consumer industry. In the past few years, accelerometers have changed dramatically during this entrance to the consumer market with increased sensitivity, reduced power consumption, and reduced package size. In addition, there has been development of accelerometer applications in many new markets. The MMA7260Q leaps forward in these requirements in addition to new functionality such as a g-Select feature and low power supply to allow system developer's more opportunities for integration of the five measurements of Freescale accelerometers (See AN1986).

MMA7260Q

The STAR board is a demonstration tool for the MMA7260Q, a 3-Axis Low-g accelerometer. The MMA7260Q has many unique features that make it an ideal solution for many consumer applications such as freefall protection for laptops and MP3 players, tilt detection for e-compass compensation and cell phone scrolling, motion detection for handheld games and game controllers, position sensing for g-mice, shock detection for warranty monitors, and vibration for out of balance detection.

Features such as low power, low current, and sleep mode with a quick turn on time allow the battery life to be extended in end applications. The 3-axis sensing in a small QFN package requires only 6 mm x 6 mm board space, with a profile of 1.45 mm, allowing for easy integration into many small handheld electronics.

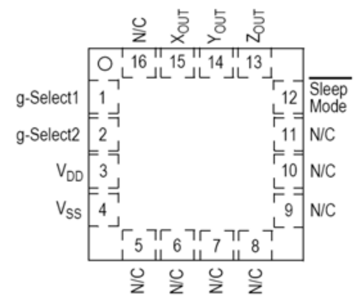


Figure 1. Pin Connections for the MMA7260Q

g-SELECT

The MMA7260Q has a unique feature that allows the range of g-force to be determined by changing inputs to the Quad Flat No-Lead (QFN). Table 1 below shows the configurable settings for the accelerometer, allowing multiple g-ranges.

Table 1. Configurable Setting for Accelerometer

g-Select2	g-Select1	g-Range	Sensitivity
0	0	1.5g	800 mV/g
0	1	2g	600 mV/g
1	0	4g	300 mV/g
1	1	6g	200 mV/g

The dipswitches located on the (STAR) Board allow for the manual setting of the g-range. The ON position indicates a logic "1" which is equal to Vdd of the MMA7260Q. The OFF position is a logic "0" or Vss of the MMA7260Q. For a final design, the g-Select is best configured to additional I/O of a chosen microcontroller. Therefore, the sensitivity of the device could be easily changed with a quick change in the software. In addition, the software can be configured so that different sensitivities can be used for several applications, where the MCU drives the g-Select during different modes of operation.

MICROCONTROLLER

The MC68HC908KX8, an 8-bit MCU with 8-bit ADCs, was selected to sample the MMA7260Q 3-axis signals. An SCI for the serial communication, four 8-bit ADC channels to process the 3 analog signals, and 8 Kbytes of FLASH memory to save calibration data and other software configuration data also make it a suitable solution.

The MCU sends data via RS232 port to a CPU for further processing and graphical display of the acceleration data. In stand alone operation, the MCU can store acceleration, motion, or position data to a set of external EEPROMs which can later be downloaded to an excel file through the serial connection using the demo software provided. During stand alone operation, there are Status LEDs and a Piezo-electric buzzer allowing the MCU to display program modes.

More information regarding the MCU can be found in the MC68HC908KX8, MC68HC908KX2 Technical Datasheet (Freescale document number MC68HC908KX8/D).

REFERENCE BOARD

The goal of the Mini-TRIAX was to provide a small board with the capability to demonstrate and evaluate many accelerometer applications. Many design considerations were taken in effect to have a small and versatile tool (board size is 1.850" x 1.50").

Table 2 provides a brief description of the components on the STAR board and Figure 2 showing the location on the board.

Table 2. Components on the Mini-TRIAX Board

Component	Component Function
MMA7260Q	3 axis Accelerometer part to give vibration and inertial readings to the board
MC68HC908KX8	8-Bit processor used on the board. It is featured in a dip socket rather than SMT so it can be removed by a user for reprogramming for final solution designing.
LM317-L	Adjustable Voltage regulator. This part allows for the regulation of power to all the components on the board. 3.6 V
LM2765M6	Charge pump. This allows the use of a small 3 V battery to provide power at a higher voltage to the necessary level for the other components. With this, a standard 3V, 2/3A battery can easily be purchased. It keeps the size small rather than using a large 9V battery & holder.
2/3A battery Holder	The power of the board is supplied by a 3 V 2/3 A or 123 battery. It is commercially available at any consumer battery stand. This is the holder.
DB9 Serial Connector	The Mini-TRIAX communicates using a RS232 port, and this is the connector used for the cable.
MAX3316CAE	RS232 Chipset. This part allows the interface between the MCU and the standard RS232 communications port.
CTX690CT-ND	This is the external canned clock oscillator that allows the MCU to communicate with the RS232 port. This clock is set for 14.7456 MHz
25LC640	This is one of two EEPROMs. They are used via SCI to store accelerometer values at 200 times a second to memory.
Dip Switch	The STAR contains a set of 2 dip switches that allow the user to use the function defined as ‘g-select’ on the MMA7260Q accelerometer. This enables the user to define the g-force range, from a 1.5 g device to a 2 g, 4 g, and 6 g device with two simple buttons.
Momentary switch	This enables the MCU to detect inputs to the STAR from the user during standalone mode, when the board is not connected via RS232.
Buzzer & LEDs	These provide status/outputs for the STAR. It notifies the user if the board is on, if a certain condition is satisfied, etc.

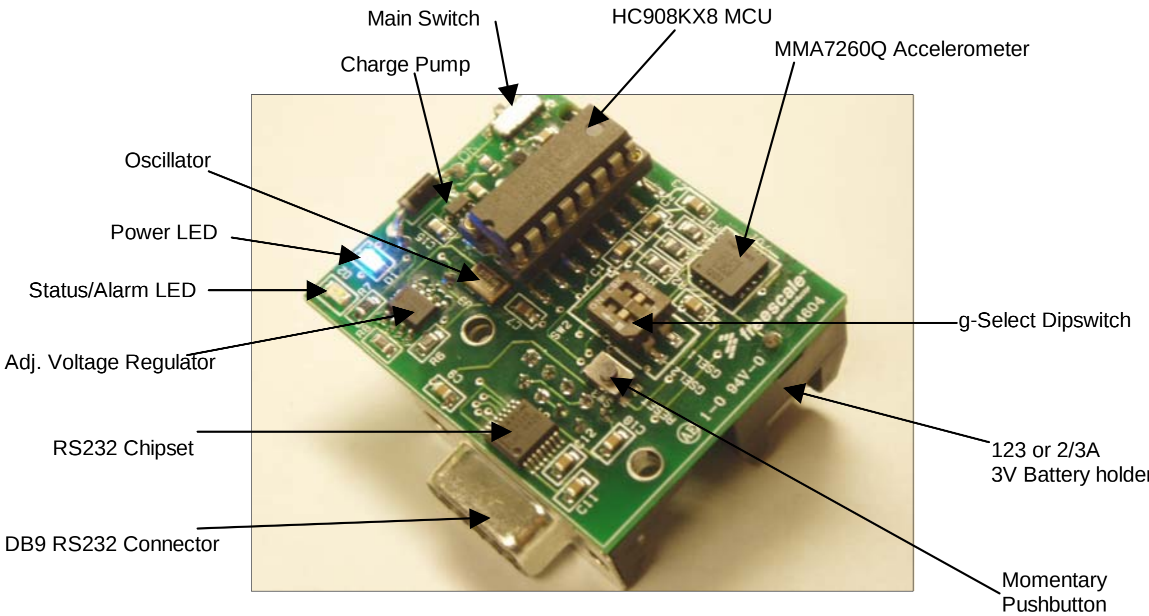


Figure 2. Location of Components on Board

VOLTAGE/POWER

A 2/3 A battery was chosen as a power supply with its ability to supply 1400 mAH for the STAR. It was also a design consideration to reduce the size of the demonstration board. The 2/3 A battery is available at any commercial battery stand. The other options were two AA batteries or a 9 V battery, significantly larger in size when coupled with battery holders. As can be seen in Figure 2, a number of the components are driven at a 3.6 V supply. The MMA7260Q is optimal at 3.3 V so a slightly higher voltage was used to compensate for any small drop in voltage. The RS232 chipset was driven directly from the 3 V source due to the logic level thresholds of that particular device.

The 3.6 V supply is obtained from the 3 V battery by the use of a charge pump, the LM2765M6. This allows the doubling of voltage to 6 V. This is regulated back down to 3.6 V via the adjustable regulator LM317-L and supplied to the other ICs.

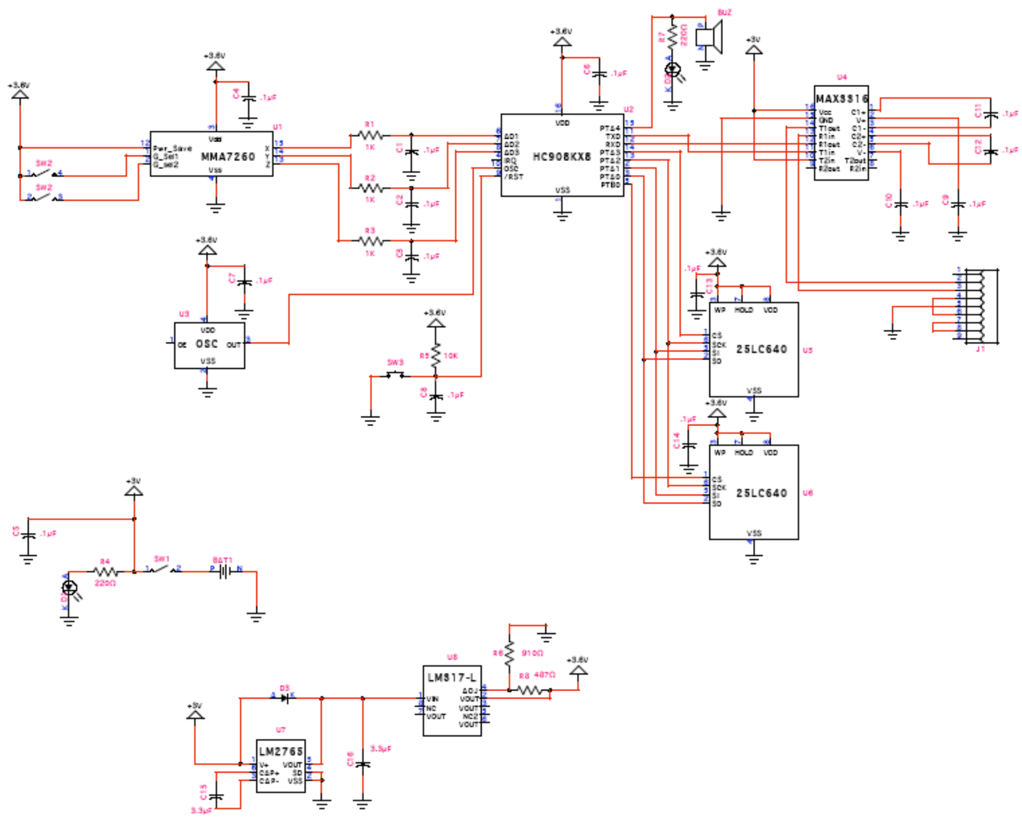


Figure 3. Schematic of Board

SOFTWARE

A software program was developed to provide an interface as well as a development system. The software can be used for displaying the 8-bit ADC values sent through the RS232 connection, or utilized for analyzing accelerometer data to demonstrate end applications. The software is sorted by various modules that showcase these possible end-applications for the MMA7260Q. This allows for developmental ideas for the MMA7260Q as a user can sample possible final products with a single reference/development tool. Some software modules such as free fall and battery saver can be initiated without the use of the PC connection, activated by a push button. The software available for the STAR board can be found on the Freescale Web site.

MODES OF OPERATION

The STAR board has three modes of operation - sending data to the PC for analysis or display, saving data to external memory (2 EEPROMs), or running a stand alone module. The stand alone modules contain demonstration tools such as freefall, battery saver, or shock alarm. The operation mode can be selected via the STAR's push button or by selecting a stand alone module on the PC software. In the push button operation mode, a user can push the STAR's tactile switch to select the most recent stand alone module. If the user depresses the same button for 20 seconds, it will cause the STAR to run the freefall stand alone module.

SUMMARY

The MMA7260Q has many unique features such as low power, low current, a quick turn on time, and 3-axis sensing with g-select all in a small QFN package. The STAR enables the user to quickly see many capabilities of the device along with application ideas to pursue. In addition, with data download capability, the STAR provides a quick way to prototype a software solution to gain a better understanding for the capability of the device.

APPENDIX A

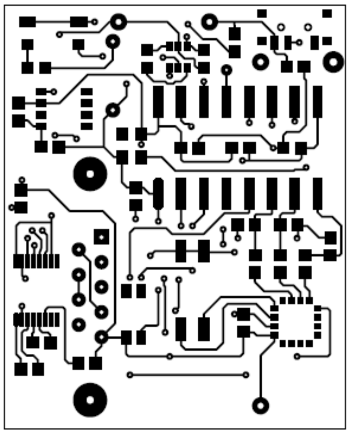


Figure 4. Component Layer of STAR Board

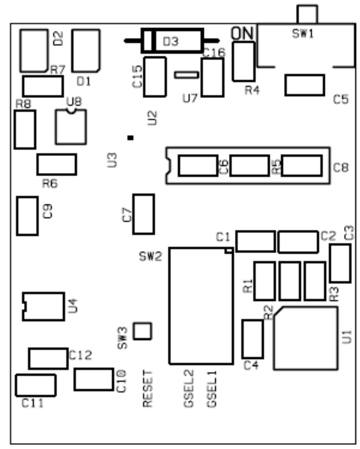


Figure 5. Component Silkscreen

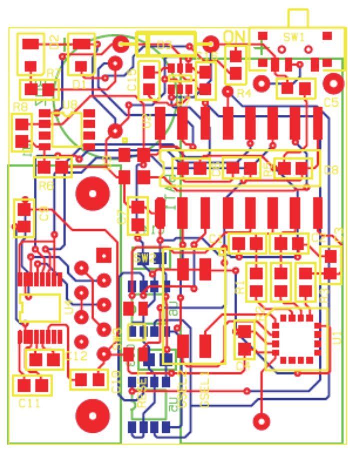
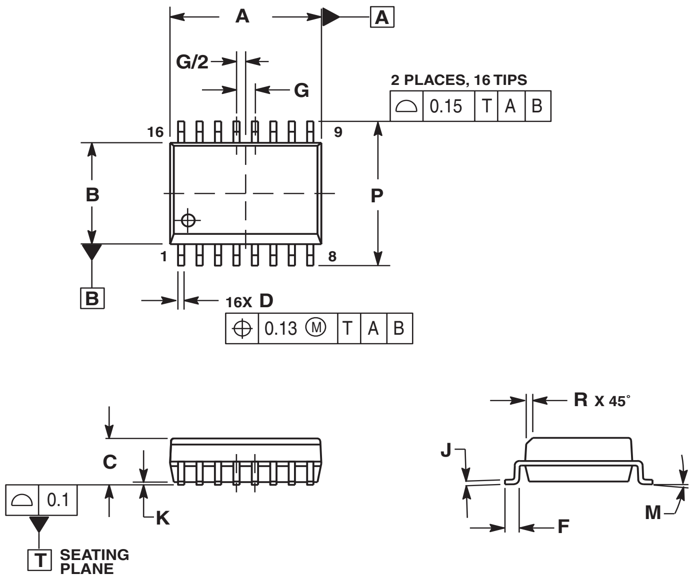


Figure 6. All Layers

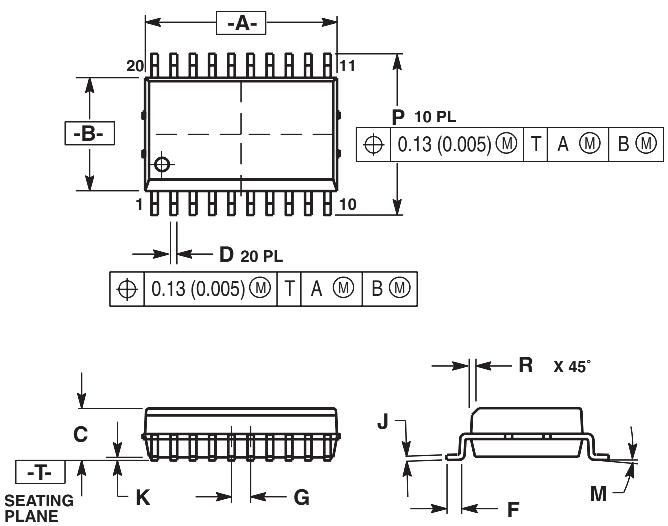
Package Dimensions



NOTES:
1. ALL DIMENSIONS ARE IN MILLIMETERS.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M, 1994.
3. DIMENSIONS "A" AND "B" DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS. MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.15 PER SIDE.
4. DIMENSION "D" DOES NOT INCLUDE DAMBAR PROTRUSION. PROTRUSIONS SHALL NOT CAUSE THE LEAD WIDTH TO EXCEED 0.75.

	MILLIMETERS	
DIM	MIN	MAX
A	10.15	10.45
B	7.40	7.60
C	3.30	3.55
D	0.35	0.49
F	0.76	1.14
G	1.27 BSC	
J	0.25	0.32
K	0.10	0.25
M	0°	7°
P	10.16	10.67
R	0.25	0.75

CASE 475-01
ISSUE B
16 LEAD SOIC

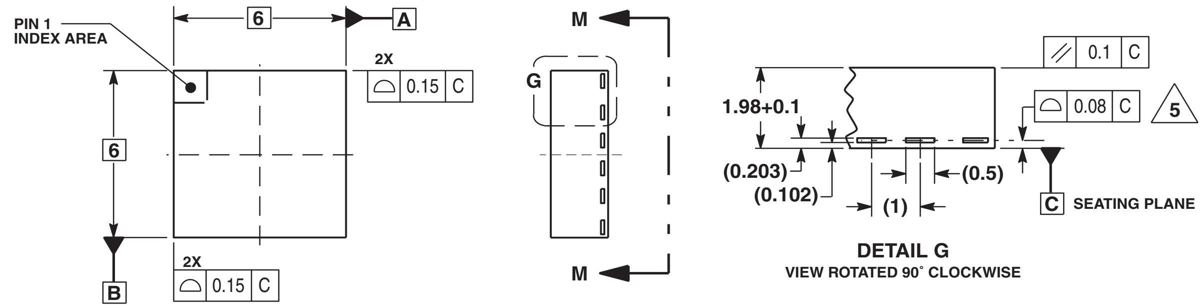


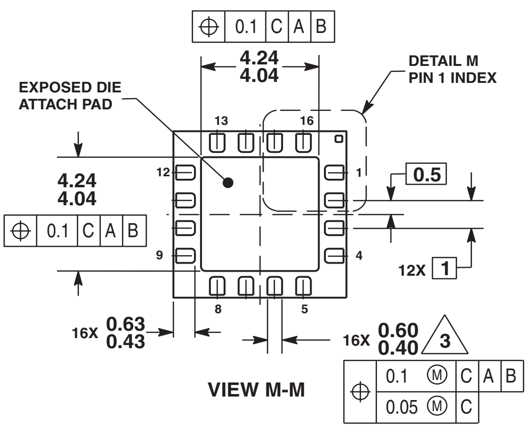
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
5. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.13 (0.005) TOTAL IN EXCESS OF D DIMENSION AT MAXIMUM MATERIAL CONDITION.

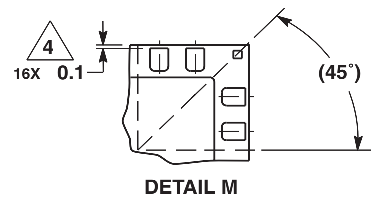
	MILLIMETERS	
DIM	MIN	MAX
A	12.67	12.96
B	7.40	7.60
C	3.30	3.55
D	0.35	0.49
F	0.76	1.14
G	1.27 BSC	
J	0.25	0.32
K	0.10	0.25
M	0°	7°
P	10.16	10.67
R	0.25	0.75

CASE 475A-01
ISSUE A
20 LEAD SOIC

PACKAGE DIMENSIONS (CONTINUED)







NOTES:

1. ALL DIMENSIONS ARE IN MILLIMETERS.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M, 1994.
3. THIS DIMENSION APPLIES TO METALLIZED TERMINAL AND IS MEASURED BETWEEN 0.25MM AND 0.30MM FROM TERMINAL TIP.
4. THIS DIMENSION REPRESENTS TERMINAL FULL BACK FROM PACKAGE EDGE UP TO 0.1MM IS ACCEPTABLE.
5. COPLANARITY APPLIES TO THE EXPOSED HEAT SLUG AS WELL AS THE TERMINAL.
6. RADIUS ON TERMINAL IS OPTIONAL.

CASE 1477-01
ISSUE O
16-LEAD QFN

Accelerometer Glossary of Terms

Acceleration	Change in velocity per unit time.
Acceleration Vector	Vector describing the net acceleration acting upon the device.
Frequency Bandwidth	The accelerometer output frequency range.
g	A unit of acceleration equal to the average force of gravity occurring at the earth's surface. A g is approximately equal to 32.17 ft/s^2 or 9.807 m/s^2.
Nonlinearity	The maximum deviation of the accelerometer output from a point-to-point straight line fitted to a plot of acceleration vs. output voltage. This is determined as the percentage of the full-scale output (FSO) voltage at full-scale acceleration (40g).
Ratiometric	The variation of the accelerometer's output offset and sensitivity linearly proportional to the variation of the power supply voltage.
Sensitivity	The change in output voltage per unit g of acceleration applied. This is specified in mV/g.
Sensitive Axis	The most sensitive axis of the accelerometer. On the DIP package, acceleration is in the direction perpendicular to the top of the package (positive acceleration going into the device). On the SIP package, acceleration is in the direction perpendicular to the pins.
Transverse Acceleration	Any acceleration applied 90° to the axis of sensitivity.
Transverse Sensitivity Error	The percentage of a transverse acceleration that appears at the output. For example, if the transverse sensitivity is 1%, then a +40 g transverse acceleration will cause a 0.4 g signal to appear on the output. Transverse sensitivity can result from sensitivity of the g-cell to transverse forces.

Section Three

Pressure Sensor Overview

Freescale's pressure sensors are silicon micromachined, electromechanical devices featuring device uniformity and consistency, high reliability, accuracy, and repeatability at competitively low costs. With more than 25 years in pressure sensor engineering, technology development, and manufacturing, these pressure sensors have been designed into automotive, industrial, healthcare, commercial, and consumer products worldwide.

Pressure sensors operate in pressures up to 150 psi (1,000 kPa). For maximum versatility, Freescale pressure sensors are single silicon, piezoresistive devices with three levels of device sophistication. The basic sensor device provides uncompensated sensing, the next level adds device compensation, and the third and most value added pressure sensors, are the integrated devices. Compensated sensors are available in temperature compensated and calibrated configurations; integrated devices are available in temperature compensated, calibrated, and signal conditioned (or amplified) configurations. Each sensor family is available in gauge, absolute, and differential pressure references in a variety of packaging and porting options.

Pressure Sensor Products

Mini Selector Guide

PRESSURE SENSORS

Integrated Pressure Sensors

Product Family	Pressure Rating Maximum (PSI)	Pressure Rating Maximum (kPa)	Pressure Rating Maximum (in H_2O)	Pressure Rating Maximum (cm H_2O)	Pressure Rating Maximum (mm Hg)	Full Scale Span (Typ) (Vdc)	Sensitivity (mV/kPa)	Accuracy 0°C–85°C (% of VFSS)	Pressure Type[1]		
									A	D	G
MPX4080	11.6	80	321	815	600	4.3	54	±3.0		•	
MPX4100	15.2	105	422	1070	788	4.6	54	±1.8	•		
MPX4101	14.8	102	410	1040	765	4.6	54	±1.8	•		
MPXH6101	14.8	102	410	1040	765	4.6	54	±1.8	•		
MPX4105	15.2	105	422	1070	788	4.6	51	±1.8	•		
MPX4115	16.7	115	462	1174	863	4.6	46	±1.5	•		
MPX6115	16.7	115	462	1174	863	4.6	46	±1.5	•		
MPX4200	29	200	803	2040	1500	4.6	26	±1.5	•		
MPX4250	36	250	1000	2550	1880	4.7	20	±1.5	•		
	36	250	1000	2550	1880	4.7	19	±1.4		•	•
MPXH6250	36	250	1000	2550	1880	4.7	19	±1.5	•		
MPXV4006	0.87	6	24	61	45	4.6	766	±5.0		•	V
MPXV5004	0.57	4	16	40	29	3.9	1000	±2.5		•	V
MPX5010	1.45	10	40	102	75	4.5	450	±5.0		•	V
MPX5050	7.25	50	201	510	375	4.5	90	±2.5		•	•
MPX5100	14.5	100	401	1020	750	4.5	45	±2.5		•	•
	16.7	115	462	1174	863	4.5	45	±2.5	•		
MPX5500	72.5	500	2000	5100	3750	4.5	9	±2.5		•	•
MPX5700	102	700	2810	7140	5250	4.5	6	±2.5	•	•	•
MPX5999	150	1000	4150	10546	7757	4.5	5	±2.5		•	
MPXH6300	44	300	1200	3060	2250	4.7	16	±1.8	•		
MPXH6400	60	400	1600	4000	3000	4.7	12	±1.5	•		
MPXV7007	±1.0	±7	±28	±70	±53	4.0	286	±5.0		•	•
MPXV7025	±3.5	±25	±100	±254	±190	4.5	90	±5.0		•	•

NOTES:
1. A = Absolute, D = Differential, G = Gauge, V = Vacuum

PRESSURE SENSORS (continued)

Compensated Pressure Sensors

Product Family	Pressure Rating Maximum (PSI)	Pressure Rating Maximum (kPa)	Pressure Rating Maximum (in H_2O)	Pressure Rating Maximum (cm H_2O)	Pressure Rating Maximum (mm Hg)	Offset (mV)	Full Scale Span (Typ) (mV)	Sensitivity (mV/kPa)	Pressure Type(1) A	D	G
MPX2010	1.45	10	40	102	75	±1.0	25	2.5		•	•
MPX2053	7	50	201	510	375	±1.0	40	0.8		•	V
MPX2102	14.5 14.5	100 100	400 400	1020	750 750	±2.0 ±1.0	40 40	0.4 0.4	•	•	V V
MPX2202	29 29	200 200	800 800	2040	1500 1500	±1.0 ±1.0	40 40	0.2 0.2	•	•	V
MPX2050	7	50	201	510	375	±1.0	40	0.8		•	•
MPX2100	14.5 14.5	100 100	400 400	1020	750 750	±2.0 ±1.0	40 40	0.4 0.4	•	•	
MPX2200	29 29	200 200	800 800	2040	1500 1500	±1.0 ±1.0	40 40	0.2 0.2	•	•	V

NOTES:
1. A = Absolute, D = Differential, G = Gauge, V = Vacuum

Compensated Medical Grade Pressure Sensors

Product Family	Pressure Rating Maximum (PSI)	Pressure Rating Maximum (kPa)	Pressure Rating Maximum (in H_2O)	Pressure Rating Maximum (cm H_2O)	Pressure Rating Maximum (mm Hg)	Supply Voltage (Typ) (Vdc)	Offset Maximum (mV)	Sensitivity (mV/kPa)	Pressure Type(1) A	D	G
MPXC2011	1.45	10	40	102	75	10.0	1.0	n/a			•
MPX2300	5.8	40	161	408	300	6.0	0.75	5.0			•

NOTES:
1. A = Absolute, D = Differential, G = Gauge, V = Vacuum

Tire Pressure Monitoring Sensors

Product	Maximum Pressure Rating (PSI)	Maximum Operating Pressure (kPa)	Maximum Pressure Rating (BAR)	Full Scale Span Output (Digital)	Best Pressure Accuracy (-20°C)	Best Pressure Accuracy (+25°C to +70°C)	Best Temperature Accuracy (+25°C)	Supply Voltage (V)	Sensitivity (kPa/count)	Pressure Type(1) A	D	G
MPXY8020A	92.4	637.5	6.4	8-bit	±15 kPa	±7.5 kPa	±4°C	2.1 to 3.6	2.5	•		
MPXY8021A	92.4	637.5	6.4	8-bit	±20 kPa	±7.5 kPa	±4°C	2.1 to 3.6	2.5	•		
MPXY8040A	130.5	900	9.0	8-bit	±25 kPa	±20 kPa	±4°C	2.1 to 3.6	5.0	•		

NOTES:
1. A = Absolute, D = Differential, G = Gauge, V = Vacuum

Uncompensated Pressure Sensors

Product Family	Pressure Rating Maximum (PSI)	Pressure Rating Maximum (kPa)	Pressure Rating Maximum (in H_2O)	Pressure Rating Maximum (cm H_2O)	Pressure Rating Maximum (mm Hg)	Offset (Typ) (mV)	Full Scale Span (Typ) (mV)	Sensitivity (mV/kPa)	Pressure Type(1) A	D	G
MPX10	1.45	10	40	102	75	20	35	3.5		•	•
MPX12	1.45	10	40	102	75	20	55	3.5		•	•
MPX53	7	50	200	510	375	20	60	1.2		•	•

NOTES:
1. A = Absolute, D = Differential, G = Gauge, V = Vacuum

Device Numbering System for Pressure Sensors

M PX A 2 XXX A P X T1

PRESSURE SENSORS

CATEGORY

M	Qualified standard
S	Custom device
P,X	Prototype device

PACKAGE TYPE

None	Unibody
A/V	Small outline package (SOP)
AZ	Small outline media resistant package
C	Chip pak
H	Super small outline package (SSOP)
M	M-Pak
Y	Super small outline package (TPMP)

FEATURES*

None	Uncompensated
2	Temperature compensated/ calibrated
3	Open
4	Temperature compensated/ calibrated/signal conditioned Automotive accuracy
5	Temperature compensated/ calibrated/signal conditioned
6	High temperature
7	Positive/negative pressure
8	CMOS

Rated pressure in kPa, except for MPX2300, expressed in mmHg.

TYPE OF DEVICE

A	Absolute
G	Gauge
D	Differential
V	Vacuum/Gauge

PORTING STYLE

C	Axial port (small outline package)
P	Ported Single port (AP, GP, GVP) Dual port (DP)
S	Stovepipe port (unibody)
SX	Axial port (unibody)

LEADFORM OPTIONS

NONE	No leadform
0	Open
1 thru 2	(Consult factory)
3 thru 5	Open
6 thru 7	SOP only

(6 = Gull wing/Surface mount)
(7 = 87 degrees/DIP)

SHIPPING METHOD

None	Trays
T1	Tape and reel 1 indicates part orientation in tape
U	Rail

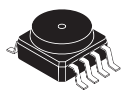
Note: Actual product marking may be abbreviated due to space constraints but packaging label will reflect full part number.
*Only applies to qualified and prototype devices. This does not apply to custom devices.

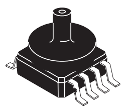
Examples:		
	MPX10DP	10 kPa uncompensated, differential device in minibody package, ported, no leadform, shipped in trays.
	MPXA4115A6T1	115 kPa automotive temperature compensated and calibrated device with signal conditioning, SOP surface mount with gull wing leadform, shipped in tape and reel.

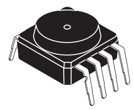
What Are the Pressure Packaging Options?

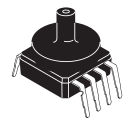
(Sizes not to scale)

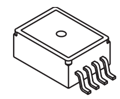
Preferred Pressure Sensor Packaging Options

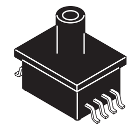

SOP
CASE 482
SUFFIX AG/G6

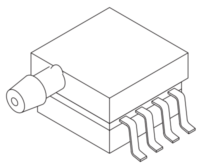

SOP AXIAL PORT
CASE 482A
SUFFIX AC6/GC6

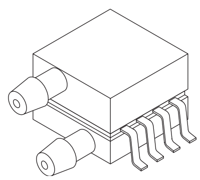

SOP
CASE 482B
SUFFIX G7U

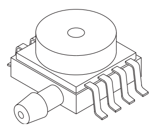

SOP AXIAL PORT
CASE 482C
SUFFIX GC7U

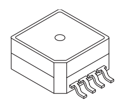

MPAK
CASE 1320
SUFFIX A/D

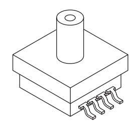

MPAK AXIAL PORT
CASE 1320A
SUFFIX AS/GS

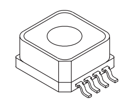

SOP SIDE PORT
CASE 1369
SUFFIX AP/GP


SOP DUAL PORT
CASE 1351
SUFFIX DP

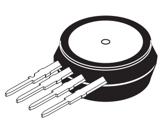

SOP VACUUM PORT
CASE 1368
SUFFIX GVP

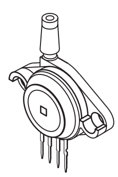

SSOP
CASE 1317
SUFFIX A6

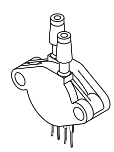

SSOP AXIAL PORT
CASE 1317A
SUFFIX AC6

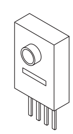

SSOP TIRE PRESSURE MONITOR
CASE 1352
SUFFIX A6

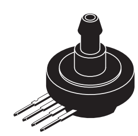
Pressure Sensor Packaging

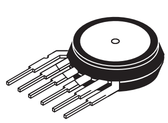

UNIBODY
BASIC ELEMENT
CASE 344
SUFFIX A/D

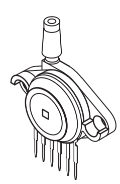

UNIBODY
SINGLE PORT
CASE 344B
SUFFIX AP/GP

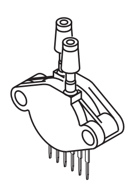

UNIBODY
DUAL PORT
CASE 344C
SUFFIX DP

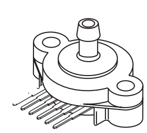

MEDICAL
CHIP PAK
CASE 423A
SUFFIX DT1

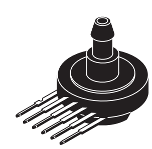

UNIBODY
STOVEPIPE PORT
CASE 344E
SUFFIX AS/GS


UNIBODY
BASIC ELEMENT
CASE 867
SUFFIX A/D


UNIBODY
SINGLE PORT
CASE 867B
SUFFIX AP/GP


UNIBODY
DUAL PORT
CASE 867C
SUFFIX DP


UNIBODY
AXIAL PORT
CASE 867F
SUFFIX ASX/GSX


UNIBODY
STOVEPIPE PORT
CASE 867E
SUFFIX AS/GS

Orderable Part Numbers

PRESSURE SENSOR ORDERABLE PART NUMBERS

Uncompensated	MPX2102D	**Integrated**	MPX5100A	MPXV6115VC6U
MPX10D	MPX2102GP	MPXV5004GC6T1	MPX5100AP	MPX4200A
MPX10DP	MPX2102DP	MPXV5004GC6U	MPX5100D	MPX4250D
MPX10GP	MPX2102GVP	MPXV5004GC7U	MPX5100DP	MPX4250DP
MPX10GS	MPXM2102D	MPXV5004G6U	MPX5100GP	MPX4250GP
MPXV10GC6U	MPXM2102DT1	MPXV5004G7U	MPX5100GSX	MPX4250A
MPXV10GC7U	MPXM2102GS	MPXV5004GP	MPXV5100DP	MPX4250AP
MPX12D	MPXM2102GST1	MPXV5004GP1	MPXV5100GC6U	MPXA4250AC6T1
MPX12DP	MPXV2102GP	MPXV5004DP	MPXV5100GC7U	MPXA4250AC6U
MPX12GP	MPXV2102DP	MPXV5004GVP	MPX4080D	MPXA4250A6T1
MPX53D	MPX2102A	MPXV4006GC6T1	MPX4100A	MPXA4250A6U
MPX53DP	MPX2102AP	MPXV4006GC6U	MPX4100AP	MPXH6250A6U
MPX53GP	MPX2102ASX	MPXV4006GC7U	MPX4100AS	MPXH6250A6T1
MPXM53GS	MPXM2102A	MPXV4006G6U	MPXA4100AC6U	MPXH6300ACGU
MPXM53GST1	MPXM2102AT1	MPXV4006G7U	MPXA4100A6T1	MPXH6300AC6T1
MPXV53GC6U	MPXM2102AS	MPXV4006GP	MPXA4100A6U	MPXH6300A6U
MPXV53GC7U	MPXM2102AST1	MPXV4006DP	MPXAZ4100AC6U	MPXH6300A6T1
Compensated	MPX2100D	MPXV7007DP	MPXAZ4100A6U	MPXH6400A6U
MPX2300DT1	MPX2100GP	MPXV7007GP	MPX4101A	MPXH6400A6T1
MPX2301DT1	MPX2100DP	MPXV7007GC6U	MPXA4101AC6U	MPXH6400AC6U
MPX2010D	MPX2100GVP	MPXV7007GC6T1	MPXH6101A6T1	MPXH6400AC6T1
MPX2010GP	MPX2100A	MPX5010D	MPXH6101A6U	MPX5700A
MPX2010DP	MPX2100AP	MPX5010DP	MPX4105A	MPX5700AP
MPX2010GS	MPX2100ASX	MPX5010DP1	MPXV4115VC6U	MPX5700AS
MPX2010GSX	MPX2202D	MPX5010GP	MPXV4115V6T1	MPX5700ASX
MPXM2010D	MPX2202GP	MPX5010GS	MPXV4115V6U	MPX5700D
MPXM2010DT1	MPX2202DP	MPX5010GSX	MPX5999D	MPX5700DP
MPXM2010GS	MPXM2202D	MPXV5010GC6T1	MPX4115A	MPX5700GP
MPXM2010GST1	MPXM2202DT1	MPXV5010GC6U	MPX4115AP	MPX5700GP1
MPXC2011DT1	MPXM2202GS	MPXV5010GC7U	MPX4115AS	MPX5700GS
MPXC2012DT1	MPXM2202GST1	MPXV5010G6U	MPXA4115AC6U	MPXY8020A6U
MPXV2010GP	MPXV2202GP	MPXV5010G7U	MPXA4115A6T1	MPXY8020A6T1
MPXV2010DP	MPXV2202DP	MPXV5010GP	MPXA4115A6U	MPXY8021A6U
MPX2053D	MPXV2202GC6T1	MPXV5010DP	MPXA4115AP	MPXY8021A6T1
MPX2053GP	MPXV2202GC6U	MPXV7025DP	MPXAZ4115AC6U	MPXY8040A6U
MPX2053DP	MPX2202A	MPXV7025GP	MPXAZ4115A6T1	MPXY8040A6T1
MPX2053GVP	MPX2202AP	MPXV7025GC6U	MPXAZ4115A6U	
MPXM2053D	MPXM2202A	MPXV7025GC6T1	MPXAZ6115A6U	
MPXM2053DT1	MPXM2202AT1	MPX5500D	MPXAZ6115AP	
MPXM2053GS	MPXM2202AS	MPX5500DP	MPXAZ6115APT1	
MPXM2053GST1	MPXM2202AST1	MPX5050D	MP3H6115A6T1	
MPXV2053GP	MPX2200D	MPX5050DP	MP3H6115A6U	
MPXV2053DP	MPX2200GP	MPX5050GP1	MP3H6115AC6T1	
MPX2050D	MPX2200DP	MPX5050GP	MP3H6115AC6U	
MPX2050GP	MPX2200GSX	MPXV5050GP	MPXAZ6115AC6U	
MPX2050DP	MPX2200A	MPXV5050DP	MPXA6115AC6U	
MPX2050GSX	MPX2200AP	MPXV5050VC6T1	MPXA6115A6U	
			MPXH6115A6T1	
			MPXH6115A6U	
			MPXH6115AC6T1	
			MPXH6115AC6U	
			MPXHZ6115A6T1	
			MPXHZ6115A6U	

General Product Information

Performance, competitive price and application versatility are just a few of the Freescale Semiconductor pressure sensor advantages.

PRESSURE SENSOR APPLICATIONS VERSATILITY

For Freescale Semiconductor's pressure sensors, new applications emerge every day as engineers and designers realize that they can convert their expensive mechanical pressure sensors to Freescale Semiconductor's lower-cost, semiconductor-based devices. Applications include automotive and aviation, industrial, healthcare and medical products and systems.

PERFORMANCE

The performance of Freescale Semiconductor pressure sensors is based on its patented strain gauge design. Unlike the more conventional pressure sensors which utilize four closely matched resistors in a distributed Wheatstone bridge configuration, the device uses only a single piezoresistive element ion implanted on an etched silicon diaphragm to sense the stress induced on the diaphragm by an external pressure. The extremely linear output is an analog voltage that is proportional to pressure input and ratiometric with supply voltage. High sensitivity and excellent long-term repeatability make these sensors suitable for the most demanding applications.

ACCURACY

Computer controlled laser trimming of on-chip calibration and compensation resistors provide the most accurate pressure measurement over a wide temperature range. Temperature effect on span is typically ±0.5% of full scale over a temperature range from 0 to 85°C, while the effect on offset voltage over a similar temperature range is a maximum of only ±1 mV.

UNLIMITED VERSATILITY

Choice of Specifications

Freescale Semiconductor's pressure sensors are available in pressure ranges to fit a wide variety of automotive, healthcare, consumer and industrial applications.

Choice of Measurement

Devices are available for differential, absolute, or gauge pressure measurements.

Choice of Chip Complexity

Freescale Semiconductor's pressure sensors are available as the basic sensing element, with temperature compensation and calibration, or with full signal conditioning circuitry included on the chip. Uncompensated devices permit external compensation to any degree desired.

Choice of Packaging

Available as a basic element for custom mounting, or in conjunction with Freescale Semiconductor's designed ports, printed circuit board mounting is easy. Our Small Outline and Super Small Outline packaging options provide surface mount, low profile, and top piston fit package selections. Alternate packaging material, which has been designed to meet biocompatibility requirements, is also available.

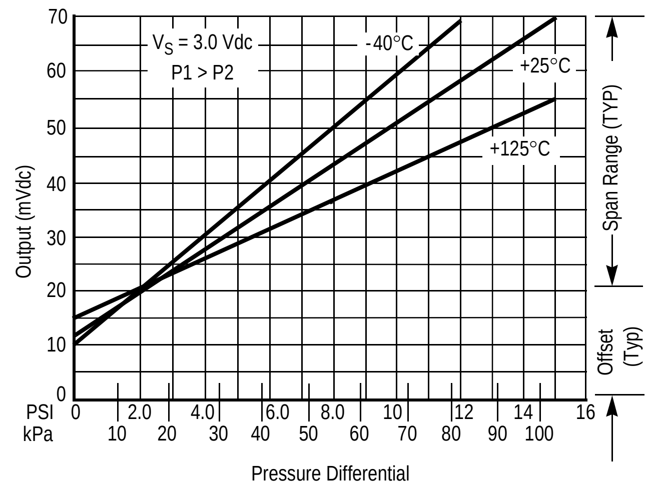
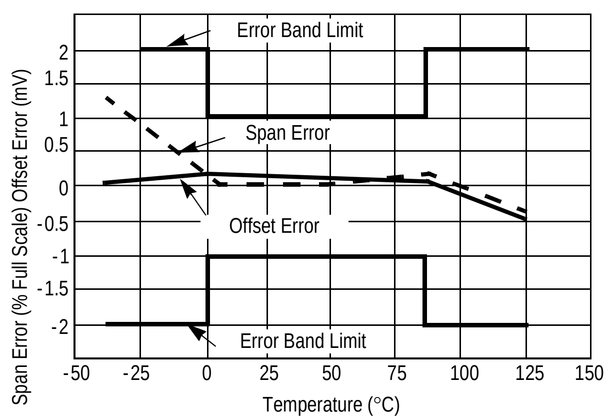


Figure 1. Typical Output versus Pressure Differential



Curves of span and offset errors indicate the accuracy resulting from on-chip compensation and laser trimming.

Figure 2. Temperature Error Band Limit and Typical Span and Offset Errors

Freescale Semiconductor Pressure Sensors

INTRODUCTION

Freescale Semiconductor pressure sensors combine advanced piezoresistive sensor architecture with integrated circuit technology to offer a wide range of pressure sensing devices for automotive, medical, consumer and industrial applications. Selection versatility includes choice of:

Pressure Ranges in PSI

0 to 1.45, 0 to 6, 0 to 7.3, 0 to 14.5, 0 to 29, 0 to 75, 0 to 100, 0 to 150 psi.

Sensing Options

Uncompensated, Temperature Compensated/Calibrated, and Signal Conditioned (with on-chip amplifiers)

Application Measurements

Absolute, Differential, Gauge

Package Options

- Basic Element, Ported Elements for specific measurements
- Surface Mount and Through Hole, Low Profile packages

THE BASIC STRUCTURE

The Freescale Semiconductor pressure sensor is designed utilizing a monolithic silicon piezoresistor, which generates a changing output voltage with variations in applied pressure. The resistive element, which constitutes a strain gauge, is ion implanted on a thin silicon diaphragm.

Applying pressure to the diaphragm results in a resistance change in the strain gauge, which in turn causes a change in the output voltage in direct proportion to the applied pressure. The strain gauge is an integral part of the silicon diaphragm, hence there are no temperature effects due to differences in thermal expansion of the strain gauge and the diaphragm. The output parameters of the strain gauge itself are temperature dependent, however, requiring that the device be compensated if used over an extensive temperature range. Simple resistor networks can be used for narrow temperature ranges, i.e., 0°C to 85°C. For temperature ranges from -40°C to +125°C, more extensive compensation networks are necessary.

FREESCALE SEMICONDUCTOR'S LOCALIZED SENSING ELEMENTS

Excitation current is passed longitudinally through the resistor (taps 1 and 3), and the pressure that stresses the diaphragm is applied at a right angle to the current flow. The stress establishes a transverse electric field in the resistor that is sensed as voltage at taps 2 and 4, which are located at the midpoint of the resistor (Figure 3b).

The transducer (Figure 3a) uses a single element eliminating the need to closely match the four stress and temperature sensitive resistors that form a distributed Wheatstone bridge design. At the same time, it greatly simplifies the additional circuitry necessary to accomplish calibration and temperature compensation. The offset does not depend on matched resistors but instead on how well the transverse voltage taps are aligned. This alignment is accomplished in a single photolithographic step, making it easy to control, and is only a positive voltage, simplifying schemes to zero the offset.

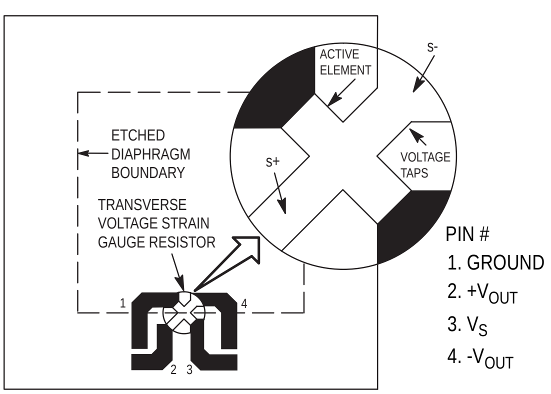


Figure 3a. X-ducer™ Sensor Element — Top View

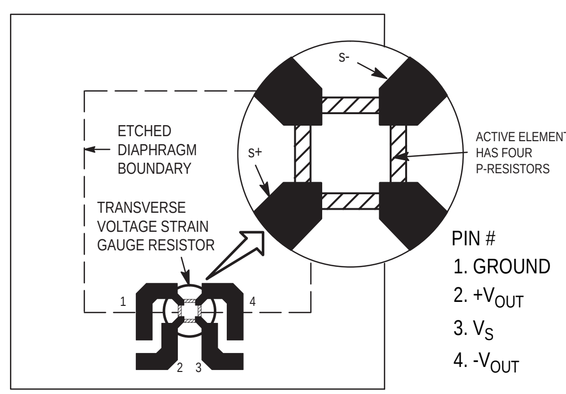


Figure 3b. Localized Sensing Element

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 4) or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Freescale Semiconductor's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

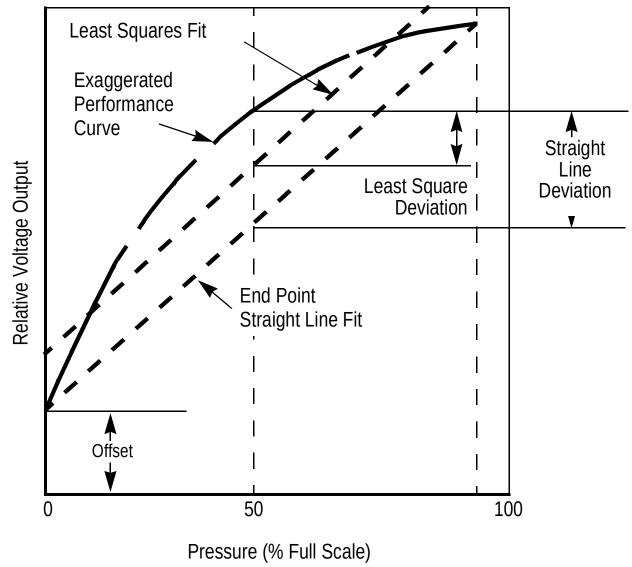


Figure 4. Linearity Specification Comparison

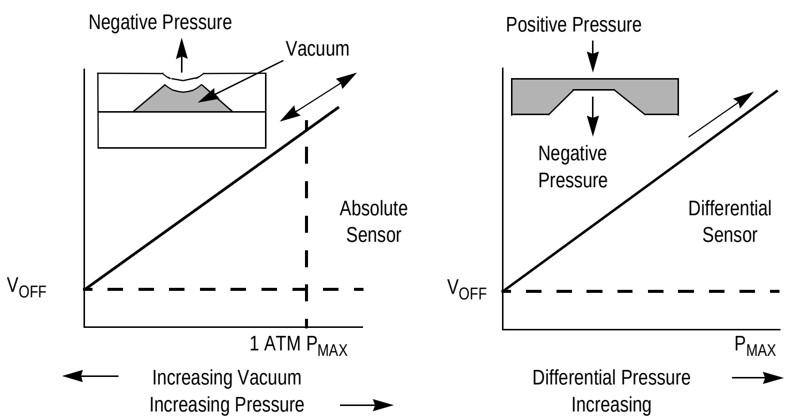
OPERATION

Freescale Semiconductor pressure sensors provide three types of pressure measurement: Absolute Pressure, Differential Pressure and Gauge Pressure.

Absolute Pressure Sensors measure an external pressure relative to a zero-pressure reference (vacuum) sealed inside the reference chamber of the die during manufacture. This corresponds to a deflection of the diaphragm equal to approximately 14.5 psi (one atmosphere), generating a quiescent full-scale output for the MPXH6101A6T1 (14.5 psi) sensor, and a half-scale output for the MPX4200A (29 psi) device. Measurement of external pressure is accomplished by applying a relative negative pressure to the "Pressure" side of the sensor.

Differential Pressure Sensors measure the difference between pressures applied simultaneously to opposite sides of the diaphragm. A positive pressure applied to the "Pressure" side generates the same (positive) output as an equal negative pressure applied to the "Vacuum" side.

Gauge Pressure readings are a special case of differential measurements in which the pressure applied to the "Pressure" side is measured against the ambient atmospheric pressure applied to the "Vacuum" side through the vent hole in the chip of the differential pressure sensor elements.



Freescale Semiconductor sensing elements can withstand pressure inputs as high as four times their rated capacity, although accuracy at pressures exceeding the rated pressure will be reduced. When excessive pressure is reduced, the previous linearity is immediately restored.

Figure 5. Pressure Measurements

TYPICAL ELECTRICAL CHARACTERISTIC CURVES

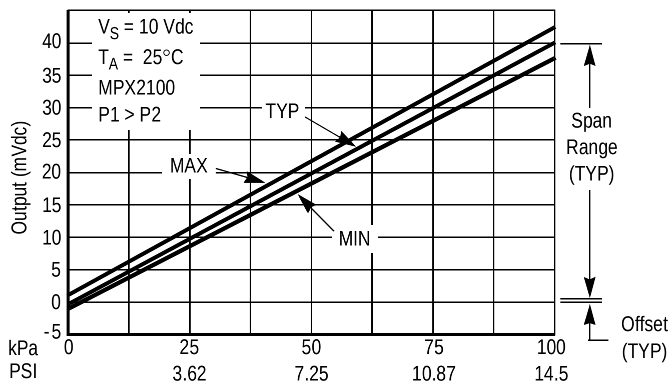


Figure 6. Output versus Pressure Differential

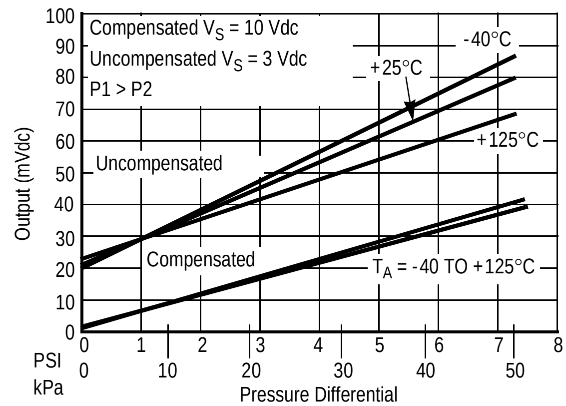


Figure 7. Typical-Output Voltage versus Pressure and Temperature for Compensated and Uncompensated Devices

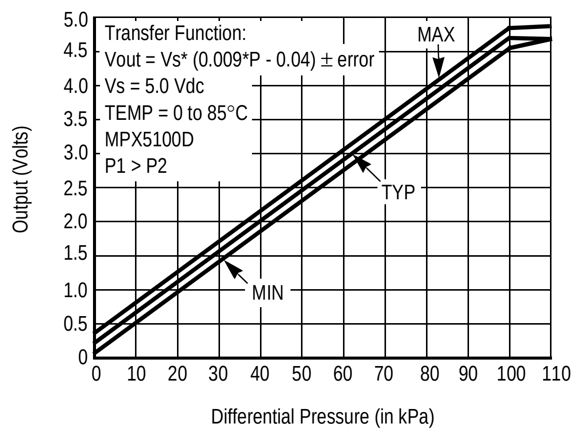


Figure 8. Signal Conditioned MPX5100

UNIBODY CROSS-SECTIONAL DRAWINGS

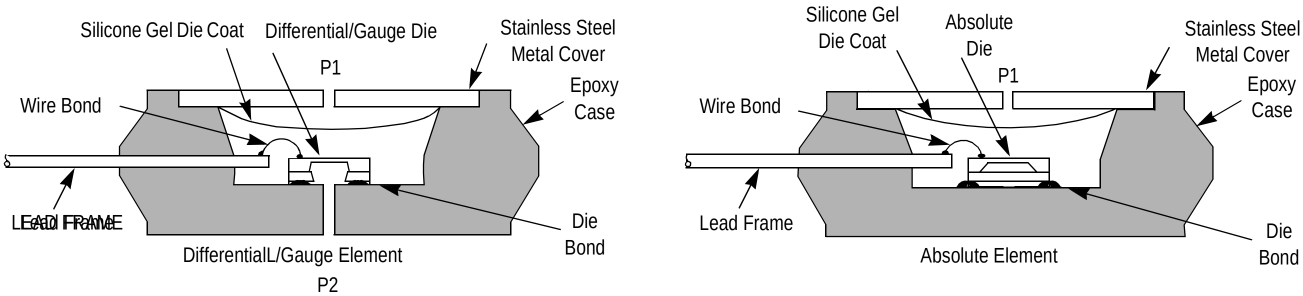


Figure 9. Cross-Sectional Diagrams (not to scale)

Figure 9 illustrates the absolute sensing configuration (right) and the differential or gauge configuration in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from harsh environments, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term stability. Contact the factory for information regarding media compatibility in your application.

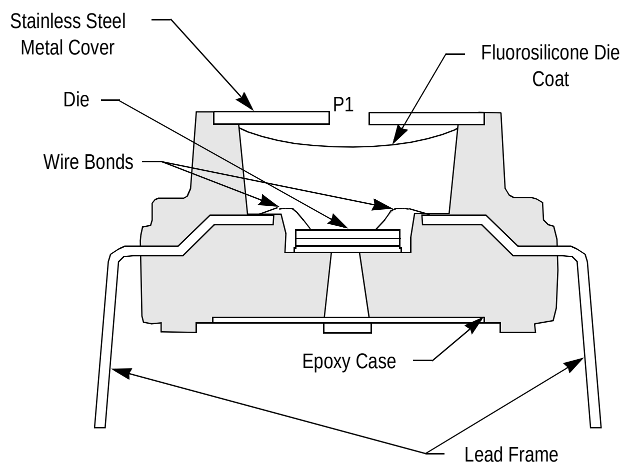


Figure 10. Cross-Sectional Diagram (not to scale)

Figure 10 illustrates the differential/gauge die in the basic chip carrier (Case 473). A silicone gel isolates the die surface and wirebonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

Integration

ON-CHIP SIGNAL CONDITIONING

To make the designer's job even easier, Freescale Semiconductor's integrated devices carry sensor technology one step further. In addition to the on-chip temperature compensation and calibration offered currently on the 2000 series, amplifier signal conditioning has been integrated *on-chip* in the 4000, 5000 and 6000 series to allow interface directly to any microcomputer with an on-board A/D converter.

The signal conditioning is accomplished by means of a four-stage amplification network, incorporating linear bipolar processing, thin-film metallization techniques, and interactive laser trimming to provide the state-of-the-art in sensor technology.

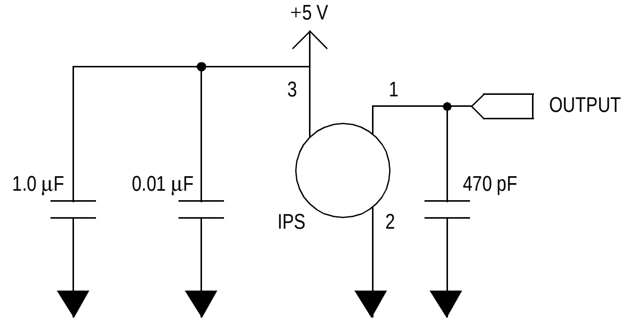


Figure 11. Recommended Power Supply Decoupling. For Output Filtering Recommendations (Refer to Application Note AN1646

DESIGN CONSIDERATIONS FOR DIFFERENT LEVELS OF SENSOR INTEGRATION

	DESIGN ADVANTAGES	DESIGN CONSIDERATIONS
Uncompensated Sensors	High Sensitivity	Device-to-Device Variation in Offset and Span
	Lowest Device Cost	Temperature Compensation Circuitry Required
	Low-Level Output Allows Flexibility of Signal Conditioning	Requires Signal Conditioning/ Amplification of Output Signal
		Relatively Low Input Impedance (400 Ω Typical)
Temperature Compensated & Calibrated (2000 Series)	Reduced Device-to-Device Variations in Offset and Span	Lower Sensitivity Due to Span Compensation (Compared to Uncompensated)
	Reduced Temperature Drift in Offset and Span	Priced Higher than Uncompensated Device
	Reasonable Input Impedance (2K Ω Typical)	Requires Signal Conditioning/ Amplification of Output Signal
	Low Level Output Allows Flexibility in Signal Conditioning	
Integrated Pressure Sensors (4000, 5000 and 6000 Series)	No Amplification Needed Direct Interface to MPU	Priced Higher than Compensated/ Uncompensated Device
	Signal Conditioning, Calibration of Span and Offset, Temperature Compensation Included On-Chip	

Sensor Applications

AUTOMOTIVE/AVIATION APPLICATIONS

- Fuel Level Indicator
- Altimeters
- Air Speed Indicator
- Ejection Seat Control
- Turbo Boost Control
- Manifold Vacuum Control
- Fuel Flow Metering
- Oil Filter Flow Indicator
- Oil Pressure Sensor
- Air Flow Measurement
- Anti-Start
- Breathalizer Systems
- Smart Suspension Systems
- Variometer-Hang glider & Sailplanes
- Automotive Speed Control

HEALTHCARE APPLICATIONS

- Blood Pressure
- Esophagus Pressure
- Heart Monitor
- Interoccular Pressure
- Saline Pumps
- Kidney Dialysis
- Blood Gas Analysis
- Blood Serum Analysis
- Seating Pressure (Paraplegic)
- Respiratory Control
- Intravenous Infusion Pump Control
- Hospital Beds
- Drug Delivery
- IUPC
- Patient Monitors

INDUSTRIAL/COMMERCIAL APPLICATIONS

- Electronic Fire Fighting Control
- Flow Control
- Barometer
- HVAC Systems
- Tire Pressure Monitoring
- Water Filtered Systems (Flow Rate Indicator)
- Air Filtered Systems (Flow Rate Indicator)
- Tactile Sensing for Robotic Systems
- Boiler Pressure Indicators
- End of Tape Readers
- Disc Drive Control/Protection Systems
- Ocean Wave Measurement
- Diving Regulators
- Oil Well Logging
- Building Automation (Balancing, Load Control, Windows)
- Fluid Dispensers
- Explosion Sensing - Shock Wave Monitors
- Load Cells
- Autoclave Release Control
- Soil Compaction Monitor - Construction
- Water Depth Finders (Industrial, Sport Fishing/Diving)
- Pneumatic Controls - Robotics
- Pinch Roller Pressure - Paper Feed
- Blower Failure Safety Switch - Computer
- Vacuum Cleaner Control
- Electronic Drum
- Pressure Controls Systems - Building, Domes
- Engine Dynamometer
- Water Level Monitoring
- Altimeters

Freescale Semiconductor has tested media tolerant sensor devices in selected solutions or environments and test results are based on particular conditions and procedures selected by Freescale Semiconductor. Customers are advised that the results may vary for actual services conditions. Customers are cautioned that they are responsible to determine the media compatibility of sensor devices in their applications and the foreseeable use and misuses of their applications.

Pressure Sensor FAQ's

We have discovered that many of our customers have similar questions about certain aspects of our pressure sensor technology and operation. Here are the most frequently asked questions and answers that have been explained in relatively non-technical terms.

Q. How do I calculate total pressure error for my applications?

A. You can calculate total error in two fashions, worst case error and most probable error. Worst case error is taking all the individual errors and adding them up, while most probable error sums the squares of the individual errors and then take the square root of the total. In summary, Error (Worst Case) = E1 + E2 + E3 + ... + En, while Error (Most Probable) = SQRT[(E1)2 + (E2)2 + (E3)2 + ... (En)2]; Please note that not all errors may apply in your individual application.

Q. What is the media tolerance of our pressure sensors?

A. Most Freescale Semiconductor pressure sensors are specifically designed for dry air applications. However, Freescale Semiconductor now offers an MPXAZ series specifically designed for improved media resistance. This series incorporates a durable barrier that allows the sensor to operate reliably in high humidity conditions as well as environments containing common automotive media. NOTE: Applications exposing the sensor to media other than what has been specified could potentially limit the lifetime of the sensor. Please consult the Freescale Semiconductor factory for more information regarding media compatibility in your specific application.

Q. Can I pull a vacuum on P1?

A. Freescale Semiconductor pressure sensors are designed to measure pressure in one direction and are not bi-directional. It is possible to measure either a positive pressure OR a negative pressure, but not both. For example, the sensor can be designed to accept a "positive" pressure on the P1 port, providing that P1 is greater or equal to P2 while staying with in the sensors specified pressure range. Or, the sensor can measure "negative" pressure (a vacuum)by applying the pressure to the P2 port, again while P1 is greater or equal to P2 and staying within the sensors specified range.

Our pressure sensors are based on a silicon diaphragm and can not tolerate a pressure that alternates from positive to negative without resulting damage. The devices are rated for over pressure and burst but should not be intentionally designed to operate in a bi-directional manner.

If you need to measure both a positive and negative pressure within the same system, we suggest designing with two separate sensors, one for each pressure type. Or, a mechanical pressure transducer should be utilized.

Q. What will happen if I run the pressure sensor beyond the rated operating pressure?

A. For bare elements (uncompensated and compensated series devices), when you take the sensor higher than the rated pressure, the part will still provide an output increasing linearly with pressure. When you go below the minimum rated pressure, the output of the sensor will eventually go negative. Freescale Semiconductor, however, does not guarantee electrical specifications beyond the rated operating pressure range specified in the data sheet of each device. The integrated series devices will not function at all beyond the rated pressure of the part. These series of parts will saturate at near 4.8 V and 0.2 V and thus no further change in output will occur.

High Temperature Accuracy Integrated Silicon Pressure Sensor for Measuring Absolute Pressure, On-Chip Signal Conditioned, Temperature Compensated and Calibrated

Freescale's MP3H6115A series sensor integrates on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The small form factor and high reliability of on-chip integration make the Freescale pressure sensor a logical and economical choice for the system designer.

The MP3H6115A series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

Features

- Improved Accuracy at High Temperature
- Available in Super Small Outline Package
- 1.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated from -40° to +125°C
- Durable Thermoplastic (PPS) Surface Mount Package

Application Examples

- Aviation Altimeters
- Industrial Controls
- Engine Control/Manifold Absolute Pressure (MAP)
- Weather Station and Weather Reporting Device Barometers

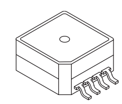
ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Marking
Basic Element	Absolute, Element Only	1317	MP3H6115A6U	Rails	MP3H6115A
	Absolute, Element Only	1317	MP3H6115A6T1	Tape and Reel	MP3H6115A
Ported Element	Absolute, Axial Port	1317A	MP3H6115AC6U	Rails	MP3H6115A
	Absolute, Axial Port	1317A	MP3H6115AC6T1	Tape and Reel	MP3H6115A

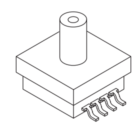
MP3H6115A SERIES

INTEGRATED PRESSURE SENSOR
15 TO 115 KPA (2.2 TO 16.7 PSI)
0.12 TO 2.9 VOLTS OUTPUT

SUPER SMALL OUTLINE PACKAGE



MP3H6115A6U/T1
CASE 1317-04



MP3H6115AC6U/T1
CASE 1317A-01

PIN NUMBER			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

NOTE: Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is denoted by the chamfered corner of the package.

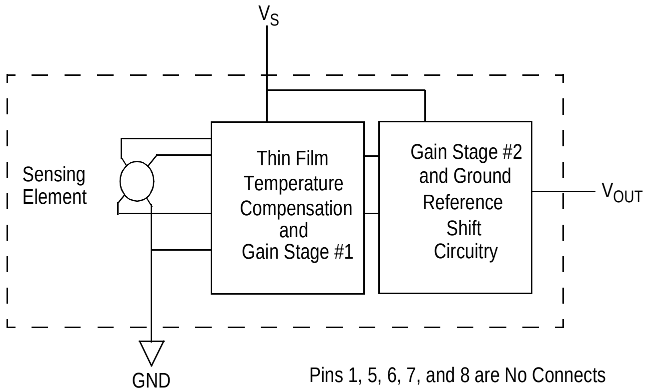


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Parametrics	Symbol	Value	Units
Maximum Pressure (P1 > P2)	P_{max}	400	kPa
Storage Temperature	T_{stg}	-40° to +125°	°C
Operating Temperature	T_A	-40° to +125°	°C
Output Source Current @ Full Scale Output(2)	I_o+	0.5	mAdc
Output Sink Current @ Minimum Pressure Offset(2)	I_o-	-0.5	mAdc

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.
2. Maximum Output Current is controlled by effective impedance from V_{out} to Gnd or V_{out} to V_S in the application circuit.

Table 2. Operating Characteristics
(V_S = 3.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	15	—	115	kPa
Supply Voltage[1]		V_S	2.7	3.0	3.3	Vdc
Supply Current		I_o	—	4.0	8.0	mAdc
Minimum Pressure Offset[2] @ V_S = 3.0 Volts	(0 to 85°C)	V_{off}	0.079	0.12	0.161	Vdc
Full Scale Output[3] @ V_S = 3.0 Volts	(0 to 85°C)	V_{FSO}	2.780	2.82	2.861	Vdc
Full Scale Span[4] @ V_S = 3.0 Volts	(0 to 85°C)	V_{FSS}	2.660	2.70	2.741	Vdc
Accuracy[5]	(0 to 85°C)	—	—	—	±1.5	$\%V_{FSS}$
Sensitivity		V/P	—	27	—	mV/kPa
Response Time[6]		t_R	—	1.0	—	ms
Warm-Up Time[7]		—	—	20	—	ms
Offset Stability[8]		—	—	±0.25	—	$\%V_{FSS}$

1. Device is ratiometric within this specified excitation range.
2. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
3. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
4. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
5. Accuracy is the deviation in actual output from nominal output over the entire pressure range and temperature range as a percent of span at 25°C due to all sources of error including the following:
   - Linearity:Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis:Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis:Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
   - TcSpan:Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset:Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the pressure has been stabilized.
8. Offset Stability is the product's output deviation when subjected to 1000 cycles of Pulsed Pressure, Temperature Cycling with Bias Test.

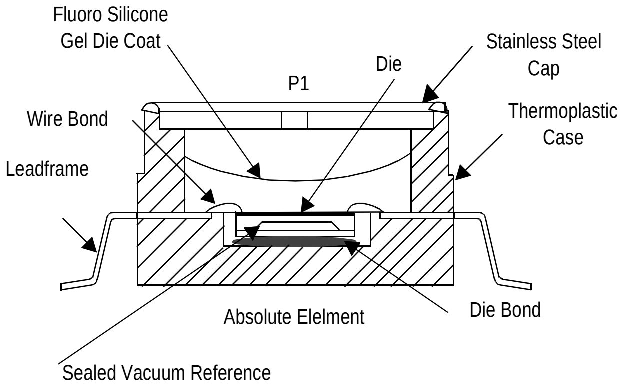


Figure 2. Cross Sectional Diagram SSOP (not to scale)

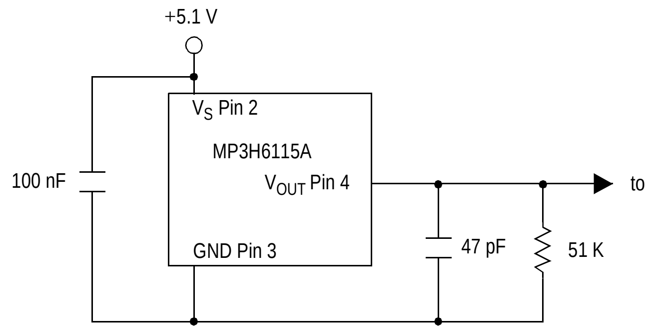


Figure 3. Typical Application Circuit (Output Source Current Operation)

Figure 2 illustrates the absolute sensing chip in the basic Super Small Outline chip carrier (Case 1317).

Figure 3 shows a typical application circuit (output source current operation).

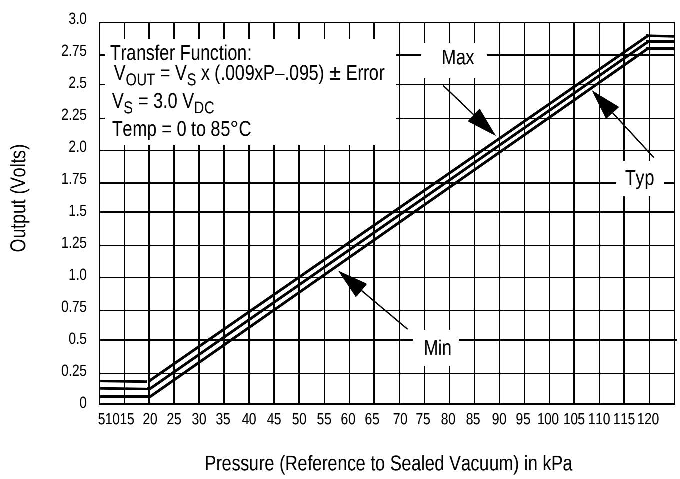


Figure 4. Output versus Pressure Differential

Figure 4 shows the sensor output signal relative to pressure input. Typical minimum and maximum output curves are shown for operation over 0 to 85°C temperature range. The output will saturate outside of the rated pressure range.

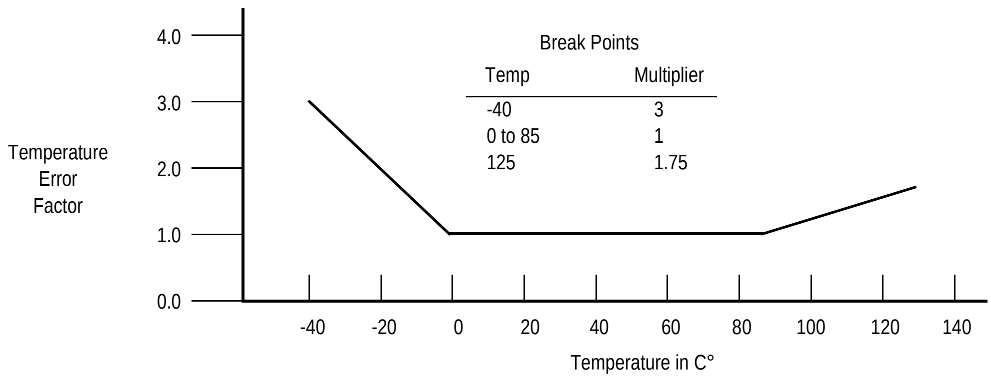
A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm. The MP3H6115A series pressure sensor operating characteristics, internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Transfer Function (MP3H6115A)

Normal Transfer Value: $V_{OUT} = V_S \times (0.009 \times P - 0.095)$
$\pm$ (Pressure Error x Temp. Factor x 0.009 x V_S)
$V_S = 3.0 \pm 0.3\ V_{DC}$

Temperature Error Band

MP3H6115A Series



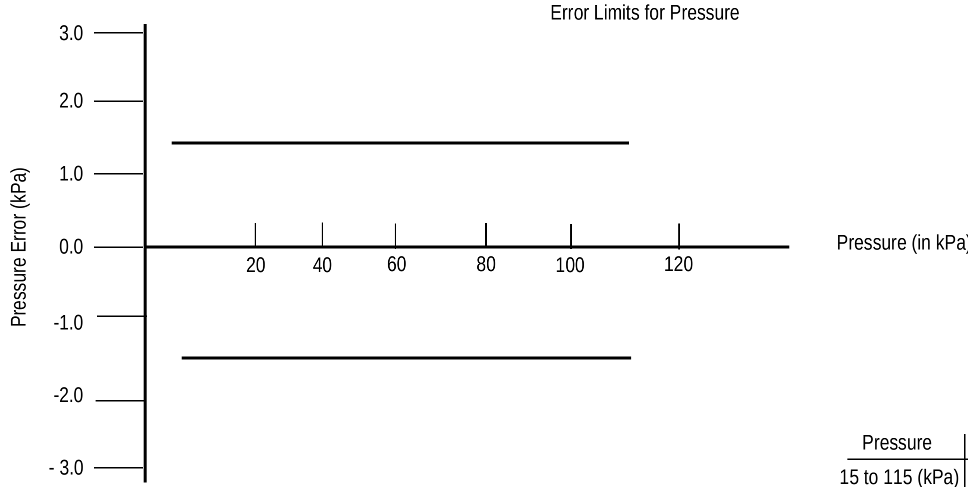
Break Points

Temp	Multiplier
-40	3
0 to 85	1
125	1.75

NOTE: The Temperature Multiplier is a linear response from 0°C to -40°C and from 85°C to 125°C

Pressure Error Band

Error Limits for Pressure



Pressure	Error (Max)
15 to 115 (kPa)	±1.5 (kPa)

MINIMUM RECOMMENDED FOOTPRINT FOR SUPER SMALL OUTLINE PACKAGES

Surface mount board layout is a critical portion of the total design. The footprint for the semiconductor package must be the correct size to ensure proper solder connection interface between the board and the package. With the correct pad geometry, the packages will self-align when subjected to a solder reflow process. It is always recommended to fabricate boards with a solder mask layer to avoid bridging and/or shorting between solder pads, especially on tight tolerances and/or tight layouts.

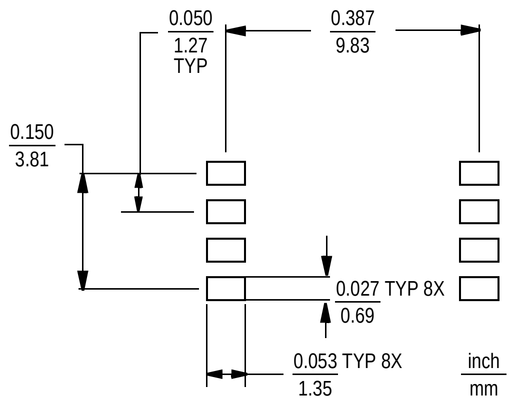


Figure 5. SSOP Footprint (Case 1317 and 1317A)

10 kPa Uncompensated Silicon Pressure Sensors

MPX10
MPXV10GC
SERIES

UNCOMPENSATED PRESSURE SENSOR
0 TO 10 kPA (0–1.45 psi)
35 mV FULL SCALE SPAN (TYPICAL)

The MPX10 and MPXV10GC series devices are silicon piezoresistive pressure sensors providing a very accurate and linear voltage output — directly proportional to the applied pressure. These standard, low cost, uncompensated sensors permit manufacturers to design and add their own external temperature compensation and signal conditioning networks. Compensation techniques are simplified because of the predictability of Freescale's single element strain gauge design. Figure 1 shows a schematic of the internal circuitry on the stand-alone pressure sensor chip.

Features

- Low Cost
- Patented Silicon Shear Stress Strain Gauge Design
- Ratiometric to Supply Voltage
- Easy to Use Chip Carrier Package Options
- Differential and Gauge Options
- Durable Epoxy Unibody Element or Thermoplastic (PPS) Surface Mount Package

Functional Description

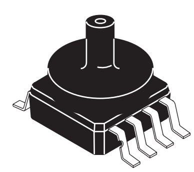
- Air Movement Control
- Environmental Control Systems
- Level Indicators
- Leak Detection
- Medical Instrumentation
- Industrial Controls
- Pneumatic Control Systems
- Robotics

ORDERING INFORMATION[1]

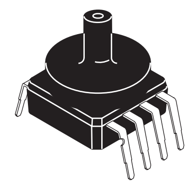
Device Type	Options	Case No.	Order Number	Device Marking
SMALL OUTLINE PACKAGE (MPXV10G SERIES)				
Ported Elements	Rails	482A	MPXV10GC6U	MPXV10G
	Tape and Reel	482A	MPXV10GC6T1	MPXV10G
	Rails	482C	MPXV10GC7U	MPXV10G
UNIBODY PACKAGE (MPX10 SERIES)				
Basic Element	Differential	344	MPX10D	MPX10D
Ported Elements	Differential	344C	MPX10DP	MPX10DP
	Gauge	344B	MPX10GP	MPX10GP
	Gauge	344E	MPX10GS	MPX10D

1. MPX10 series pressure sensors are available in differential and gauge configurations. Devices are available in the basic element package or with pressure port fittings which provide printed circuit board mounting ease and barbed hose pressure connections.

SMALL OUTLINE PACKAGES



MPXV10GC6U
CASE 482A-01



MPXV10GC7U
CASE 482C-03

SMALL OUTLINE PACKAGE PIN NUMBERS

1	GND	5	N/C
2	$+V_{out}$	6	N/C
3	V_S	7	N/C
4	$-V_{out}$	8	N/C

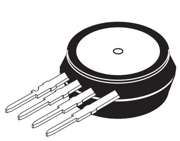
NOTE: Pin 1 is noted by the notch in the lead.

UNIBODY PACKAGE PIN NUMBERS

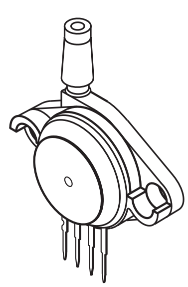
1	GND	3	V_S
2	$+V_{out}$	4	$-V_{out}$

NOTE: Pin 1 is noted by the notch in the lead.

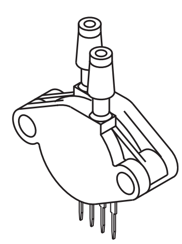
UNIBODY PACKAGES



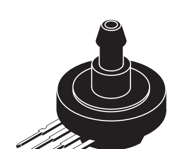
MPX10D
CASE 344-15



MPX10GP
CASE 344B-01



MPX10DP
CASE 344C-01



MPX10GS
CASE 344E-01

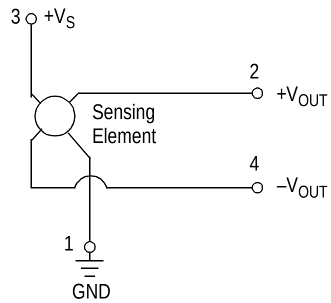


Figure 1. Uncompensated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side (P1) relative to the vacuum side (P2). Similarly, output voltage increases as increasing vacuum is applied to the vacuum side (P2) relative to the pressure side (P1).

Table 1. Maximum Ratings[1]

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	75	kPa
Burst Pressure (P > P2)	P_{BURST}	100	kPa
Storage Temperature	T_{STG}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 3.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Units
Differential Pressure Range(1)	P_{OP}	0	—	10	kPa
Supply Voltage(2)	V_S	—	3.0	60	V_{DC}
Supply Current	I_O	—	6.0	—	mAdc
Full Scale Span(3)	V_{FSS}	20	35	50	mV
Offset(4)	V_{OFF}	0	20	35	mV
Sensitivity	$\Delta V/\Delta P$	—	3.5	—	mV/kPa
Linearity(5)	—	–1.0	—	1.0	$\%V_{FSS}$
Pressure Hysteresis(5) (0 to 10 kPa)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis(5) (–40°C to +125°C)	—	—	±0.5	—	$\%V_{FSS}$
Temperature Coefficient of Full Scale Span(5)	TCV_{FSS}	–0.22	—	–0.16	$\%V_{FSS}$/°C
Temperature Coefficient of Offset(5)	TCV_{OFF}	—	±15	—	µV/°C
Temperature Coefficient of Resistance(5)	TCR	0.28	—	0.34	$\%/Z_{IN}$/°C
Input Impedance	Z_{IN}	400	—	550	Ω
Output Impedance	Z_{OUT}	750	—	1250	Ω
Response Time(6) (10% to 90%)	t_R	—	1.0	—	ms
Warm-Up Time(7)	—	—	20	—	ms
Offset Stability(8)	—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum related pressure.
4. Offset (VOFF) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure with the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - TCR: Z_{IN} deviation with minimum rated pressure applied, over the temperature range of -40°C to ±125°C, relative to 25°C.
6. Response Time is defined as the time form the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the pressure is stabilized.
8. Offset stability is the product’s output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

TEMPERATURE COMPENSATION

Figure 2 shows the typical output characteristics of the MPX10 and MPXV10GC series over temperature.

Because this strain gauge is an integral part of the silicon diaphragm, there are no temperature effects due to differences in the thermal expansion of the strain gauge and the diaphragm, as are often encountered in bonded strain gauge pressure sensors. However, the properties of the strain gauge itself are temperature dependent, requiring that the device be temperature compensated if it is to be used over an extensive temperature range.

Temperature compensation and offset calibration can be achieved rather simply with additional resistive components, or by designing your system using the MPX2010D series sensor.

Several approaches to external temperature compensation over both –40 to +125°C and 0 to +80°C ranges are presented in Application Note AN840.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range (Figure 3). There are two basic methods for calculating nonlinearity: 1) end point straight line fit or 2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Freescale's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

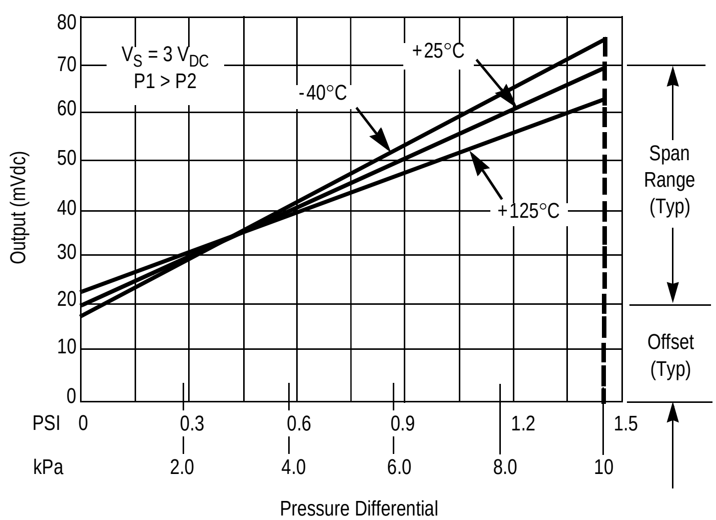


Figure 2. Output versus Pressure Differential

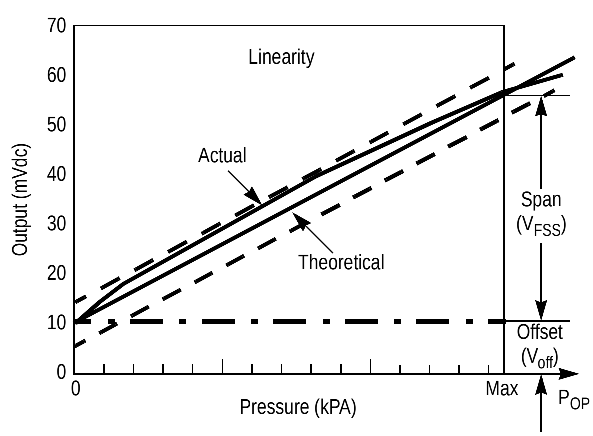


Figure 3. Linearity Specification Comparison

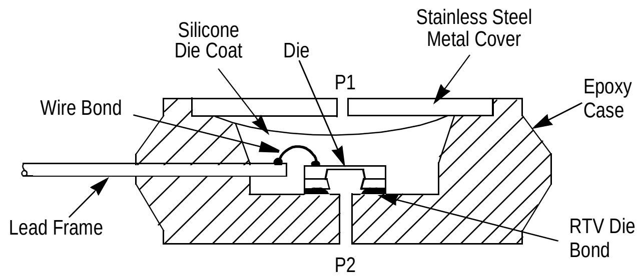


Figure 4. Unibody Package — Cross-Sectional Diagram (Not to Scale)

Figure 4 illustrates the differential or gauge configuration in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX10 and MPXV10GC series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term reliability. Contact the factory for information regarding media compatibility in your application.

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing silicone gel which isolates the die from the environment. The Freescale pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the following table.

Part Number	Case Type	Pressure (P1) Side Identifier
MPX10D	344	Stainless Steep Cap
MPX10DP	344C	Side with Part Marking
MPX10GP	344B	Side with Port Attached
MPX10GS	344E	Side with Port Attached
MPX10GC6U	482A	Side with Part Marking
MPXV10C7U	482C	Side with Part Marking

10 kPa Uncompensated Silicon Pressure Sensors

MPX12 SERIES

UNCOMPENSATED PRESSURE SENSOR
0 TO 10 kPA (0–1.45 psi)
55 mV FULL SCALE SPAN
(TYPICAL)

The MPX12 series device is a silicon piezoresistive pressure sensor providing a very accurate and linear voltage output — directly proportional to the applied pressure. This standard, low cost, uncompensated sensor permits manufacturers to design and add their own external temperature compensating and signal conditioning networks. Compensation techniques are simplified because of the predictability of Freescale's single element strain gauge design.

Features

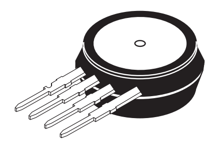
- Low Cost
- Patented Silicon Shear Stress Strain Gauge Design
- Ratiometric to Supply Voltage
- Easy to Use Chip Carrier Package Options
- Differential and Gauge Options
- Durable Epoxy Package

Application Examples

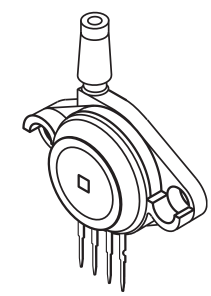
- Air Movement Control
- Environmental Control Systems
- Level Indicators
- Leak Detection
- Medical Instrumentation
- Industrial Controls
- Pneumatic Control Systems
- Robotics

ORDERING INFORMATION[1]				
Device Type	**Options**	**Case No.**	**Order Number**	**Device Marking**
Basic Element	Differential	344	MPX12D	MPX12D
Ported Elements	Differential	344C	MPX12DP	MPX12DP
	Gauge	344B	MPX12GP	MPX12GP

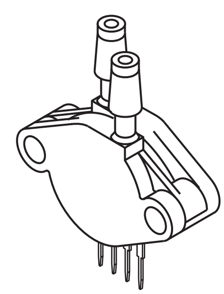
1. MPX12 series pressure sensors are available in differential and gauge configurations. Devices are available in the basic element package or with pressure port fittings which provide printed circuit board mounting ease and barbed hose pressure connections.



MPX12D
CASE 344-15



MPX12GP
CASE 344B-01



MPX12DP
CASE 344C-01

PIN NUMBERS			
1	GND	3	V_{SS}
2	$+V_{out}$	4	$–V_{out}$

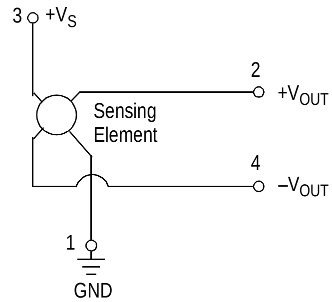


Figure 1. Uncompensated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side (P1) relative to the vacuum side (P2). Similarly, output voltage increases as increasing vacuum is applied to the vacuum side (P2) relative to the pressure side (P1).

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	75	kPa
Burst Pressure (P1 > P2)	P_{BURST}	100	kPa
Storage Temperature	T_{STG}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (VS = 3.0 Vdc, TA = 25×C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Unit
Differential Pressure Range(1)	P_{OP}	0	—	10	kPa
Supply Voltage(2)	V_S	—	3.0	6.0	Vdc
Supply Current	I_o	—	6.0	—	mAdc
Full Scale Span(3)	V_{FSS}	45	55	70	mV
Offset(4)	V_{off}	0	20	35	mV
Sensitivity	ΔV/ΔP	—	5.5	—	mV/kPa
Linearity(5)	—	–0.5	—	5.0	$\%V_{FSS}$
Pressure Hysteresis6 (0 to 10 kPa)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis(5) (–40°C to +125°C)	—	—	±0.5	—	$\%V_{FSS}$
Temperature Coefficient of Full Scale Span(5)	TCV_{FSS}	–0.22	—	–0.16	$\%V_{FSS}$/°C
Temperature Coefficient of Offset(5)	TCV_{off}	—	±15	—	μV/°C
Temperature Coefficient of Resistance(5)	TCR	0.28	—	0.34	$\%Z_{in}$/°C
Input Impedance	Z_{in}	400	—	550	W
Output Impedance	Z_{out}	750	—	1250	W
Response Time(6) (10% to 90%)	t_R	—	1.0	—	ms
Warm-Up Time(7)	—	—	20	—	ms
Offset Stability(8)	—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum related pressure.
4. Offset (V_{OFF}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure with the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - TCR: Z_{IN} deviation with minimum rated pressure applied, over the temperature range of -40°C to ±125°C, relative to 25°C.
6. Response Time is defined as the time form the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the pressure is stabilized.
8. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

TEMPERATURE COMPENSATION

Figure 2 shows the typical output characteristics of the MPX12 series over temperature.

Because this strain gauge is an integral part of the silicon diaphragm, there are no temperature effects due to differences in the thermal expansion of the strain gauge and the diaphragm, as are often encountered in bonded strain gauge pressure sensors. However, the properties of the strain gauge itself are temperature dependent, requiring that the device be temperature compensated if it is to be used over an extensive temperature range.

Temperature compensation and offset calibration can be achieved rather simply with additional resistive components, or by designing your system using the MPX2010D series sensor.

Several approaches to external temperature compensation over both –40 to +125°C and 0 to +80°C ranges are presented in Applications Note AN840.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range (Figure 3). There are two basic methods for calculating nonlinearity: (1) end point straight line fit or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Freescale's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

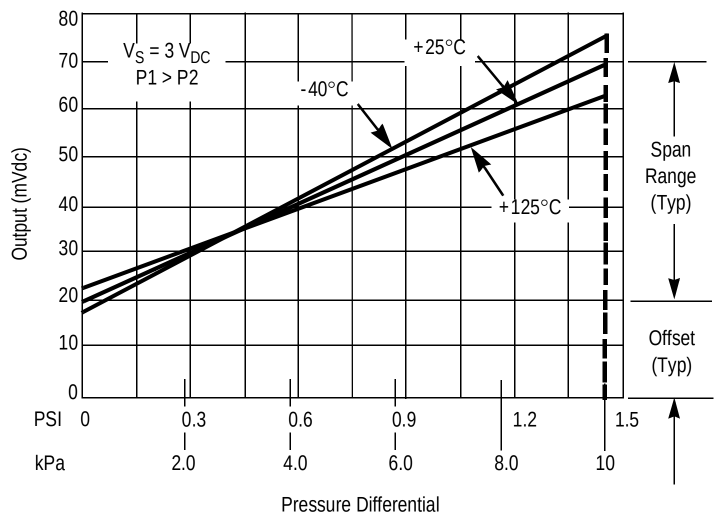


Figure 2. Output versus Pressure Differential

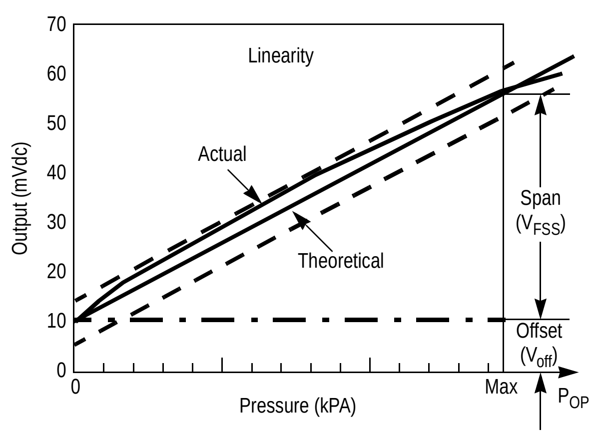


Figure 3. Linearity Specification Comparison

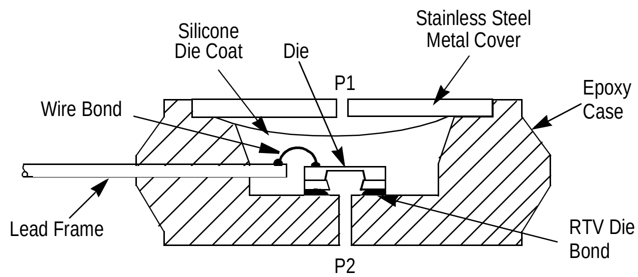


Figure 4. Unibody Package — Cross-Sectional Diagram (not to scale)

Figure 4 illustrates the differential or gauge configuration in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX12 series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term reliability. Contact the factory for information regarding media compatibility in your application/

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing silicone gel which isolates the die from the environment. The Freescale MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the following table

Part Number	Case Type	Pressure (P1) Side Identifier
MPX12D	344	Stainless Steel Cap
MPX12DP	344C	Side with Part Marking
MPX12GP	344B	Side with Port Attached

50 kPa Uncompensated Silicon Pressure Sensors

MPX53 MPXV53GC SERIES

The MPX53/MPXV53GC series silicon piezoresistive pressure sensors provide a very accurate and linear voltage output — directly proportional to the applied pressure. These standard, low cost, uncompensated sensors permit manufacturers to design and add their own external temperature compensating and signal conditioning networks. Compensation techniques are simplified because of the predictability of Freescale's single element strain gauge design.

Features

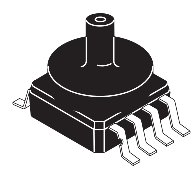
- Low Cost
- Patented Silicon Shear Stress Strain Gauge Design
- Ratiometric to Supply Voltage
- Easy to Use Chip Carrier Package Options
- 60 mV Span (Typ)
- Differential and Gauge Options

Typical Applications

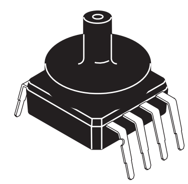
- Air Movement Control
- Environmental Control Systems
- Level Indicators
- Leak Detection
- Medical Instrumentation
- Industrial Controls
- Pneumatic Control Systems
- Robotics

UNCOMPENSATED PRESSURE SENSOR
0 TO 50 kPA (0 – 7.25 psi)
60 mV FULL SCALE SPAN (TYPICAL)

SMALL OUTLINE PACKAGES



MPXV53GC6U
CASE 482A-01



MPXV53GC7U
CASE 482C-03

ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
SMALL OUTLINE PACKAGE[1] (MPXV2010G SERIES)					
Ported Elements	Gauge, Side Port, SMT	482A	MPXV53DC6T1	Tape & Rail	MPXV53G
	Differential, Dual Port, SMT	482A	MPXV53GC6U	Rails	MPXV53G
		482C	MPXV53G7U	Rails	MPXV53G
UNIBODY PACKAGE[2] (MPX2010 SERIES)					
Basic Element	Differential	344	MPX53D	—	MPX2010D
Ported Elements	Differential	344C	MPX53DP	—	MPX2010DP
	Gauge	344B	MPX53GP	—	MPX2010GP

1. The MPXV53GC series pressure sensors are available with a pressure port, surface mount, or DIP leadforms and two packing options.
2. MPX53 series pressure sensors are available in differential and gauge configurations. Devices are available with basic element package or with pressure port fittings, providing printed circuit board mounting ease and barbed hose pressure.

SMALL OUTLINE PACKAGE PIN NUMBERS

1	GND[1]	5	N/C
2	$+V_{OUT}$	6	N/C
3	V_S	7	N/C
4	$-V_{OUT}$	8	N/C

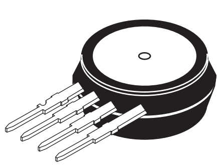
1. Pin 1 in noted by the notch in the lead.

UNIBODY PACKAGE PIN NUMBERS

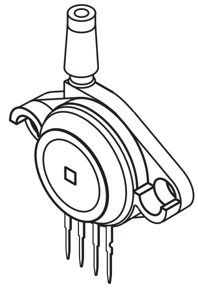
1	GND[1]	3	V_S
2	$+V_{OUT}$	4	$-V_{OUT}$

1. Pin 1 in noted by the notch in the lead.

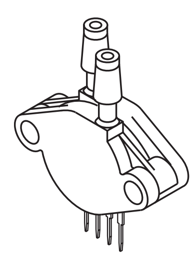
UNIBODY PACKAGES



MPX53D
CASE 344-15



MPX53GP
CASE 344B-01



MPX53DP
CASE 344C-01

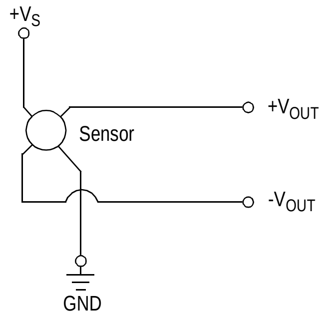


Figure 1. Uncompensated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the sensor is directly proportional to the differential the pressure side (P1) relative to the vacuum side (P2). Similarly, output voltage increases as increasing vacuum is applied to the vacuum side (P2) relative to the pressure side (P1).

Figure 1 shows a schematic of the internal circuitry on the stand-alone pressure sensor chip.

Table 1. Maximum Ratings[1]

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	200	kPa
Storage Temperature	T_{STG}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 3.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Units
Pressure Range(1)	P_{OP}	0	—	50	kPa
Supply Voltage(2)	V_S	—	3.0	60	V_{DC}
Supply Current	I_O	—	6.0	—	mAdc
Full Scale Span(3)	V_{FSS}	45	60	90	mV
Offset(4)	V_{OFF}	0	20	35	mV
Sensitivity	$\Delta V/\Delta P$	—	1.2	—	mV/kPa
Linearity(5)	—	–0.6	—	0.4	$\%V_{FSS}$
Pressure Hysteresis(5) (0 to 50 kPa)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis(5) (–40°C to +125°C)	—	—	±0.5	—	$\%V_{FSS}$
Temperature Coefficient of Full Scale Span(5)	TCV_{FSS}	–0.22	—	-0.16	$\%V_{FSS}$/°C
Temperature Coefficient of Offset(5)	TCV_{OFF}	—	±15	—	µV/°C
Temperature Coefficient of Resistance(5)	TCR	0.31	—	0.37	$\%Z_{IN}$/°C
Input Impedance	Z_{IN}	355	—	505	Ω
Output Impedance	Z_{OUT}	750	—	1875	Ω
Response Time(6) (10% to 90%)	t_R	—	1.0	—	ms
Warm-Up Time	—	—	2.0	—	ms
Offset Stability(7)	—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum related pressure.
4. Offset (V_{OFF}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
6. Response Time is defined as the time form the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product’s output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

TEMPERATURE COMPENSATION

Figure 2 shows the typical output characteristics of the MPX53/MPXV53GC series over temperature.

The piezoresistive pressure sensor element is a semiconductor device which gives an electrical output signal proportional to the pressure applied to the device. This device uses a unique transverse voltage diffused semiconductor strain gauge which is sensitive to stresses produced in a thin silicon diaphragm by the applied pressure.

Because this strain gauge is an integral part of the silicon diaphragm, there are no temperature effects due to differences in the thermal expansion of the strain gauge and the diaphragm, as are often encountered in bonded strain gauge pressure sensors. However, the properties of the strain gauge itself are temperature dependent, requiring that the device be temperature compensated if it is to be used over an extensive temperature range.

Temperature compensation and offset calibration can be achieved rather simply with additional resistive components, or by designing your system using the MPX2053 series sensors.

Several approaches to external temperature compensation over both –40 to +125°C and 0 to +80°C ranges are presented in Freescale Application Note AN840.

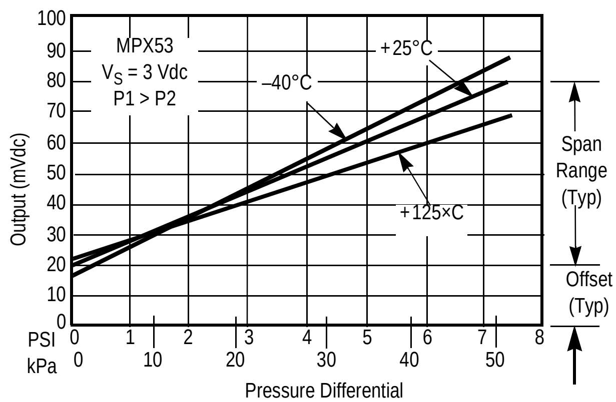


Figure 2. Output vs. Pressure Differential

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range (see Figure 3). There are two basic methods for calculating nonlinearity: (1) end point straight line fit or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Freescale's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

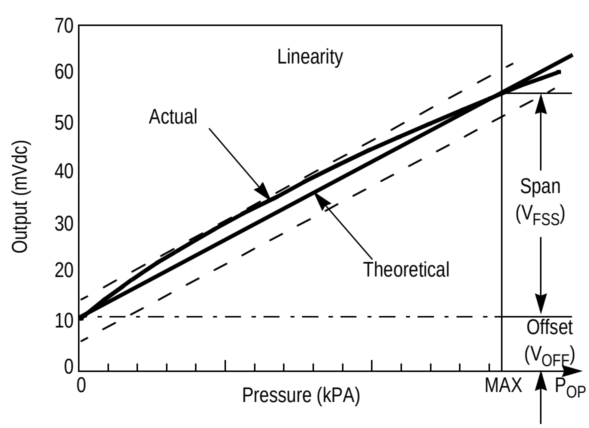


Figure 3. Linearity Specification Comparison

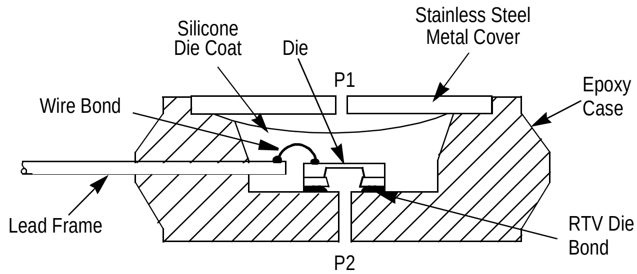


Figure 4. Unibody Package: Cross Sectional Diagram (Not to Scale)

Figure 4 illustrates the differential or gauge configuration in the unibody chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX53/MPXV53GC series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term reliability. Contact the factory for information regarding media compatibility in your application.

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing silicone gel which isolates the die from the environment. The Freescale MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the following table.

Part Number	Case Type	Pressure (P1) Side Identifier
MPX53D	344	Stainless Steep Cap
MPX53DP	344C	Side with Port Marking
MPX53GP	344B	Side with Port Attached
MPX53GC Series	482A, 482C	Side with Port Attached

10 kPa On-Chip Temperature Compensated & Calibrated Silicon Pressure Sensors

The MPX2010/MPXV2010G series silicon piezoresistive pressure sensors provide a very accurate and linear voltage output directly proportional to the applied pressure. These sensors house a single monolithic silicon die with the strain gauge and thin film resistor network integrated on each chip. The sensor is laser trimmed for precise span, offset calibration and temperature compensation.

Features

- Temperature Compensated over 0°C to +85°C
- Ratiometric to Supply Voltage
- Differential and Gauge Options

Typical Applications

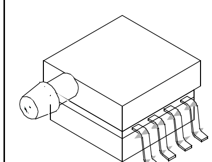
- Respiratory Diagnostics
- Air Movement Control
- Controllers
- Pressure Switching

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
SMALL OUTLINE PACKAGE (MPXV2010G SERIES)					
Ported Elements	Gauge, Side Port, SMT	1369	MPXV2010GP	Trays	MPXV2010G
	Differential, Dual Port, SMT	1351	MPXV2010DP	Trays	MPXV2010G
UNIBODY PACKAGE (MPX2010 SERIES)					
Basic Element	Differential	344	MPX2010D	—	MPX2010D
Ported Elements	Differential, Dual Port	344C	MPX2010DP	—	MPX2010DP
	Gauge	344B	MPX2010GP	—	MPX2010GP
	Gauge, Axial	344E	MPX2010GS	—	MPX2010D
	Gauge, Axial PC Mount	344F	MPX2010GSX	—	MPX2010D

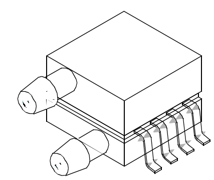
MPX2010 MPXV2010G SERIES

COMPENSATED PRESSURE SENSOR
0 to 10 kPa (0 to 1.45 psi)
FULL SCALE SPAN: 25 mV

SMALL OUTLINE PACKAGES



MPXV2010GP
CASE 1369-01



MPXV2010DP
CASE 1351-01

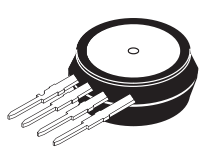
SMALL OUTLINE PACKAGE PIN NUMBERS			
1	GND(1)	5	N/C
2	$+V_{OUT}$	6	N/C
3	V_S	7	N/C
4	$-V_{OUT}$	8	N/C

1. Pin 1 in noted by the notch in the lead.

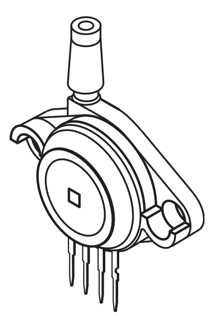
UNIBODY PACKAGE PIN NUMBERS			
1	GND(1)	3	V_S
2	$+V_{OUT}$	4	$-V_{OUT}$

1. Pin 1 in noted by the notch in the lead.

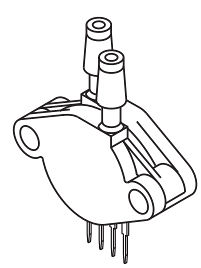
UNIBODY PACKAGES



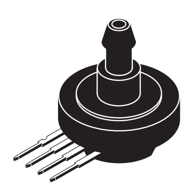
MPX2010GP
CASE 344-15



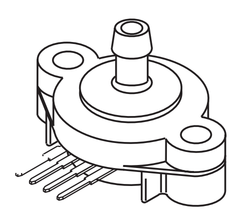
MPX2010GP
CASE 344B-01



MPX2010DP
CASE 344C-01



MPX2010GS
CASE 344E-01



MPX2010GSX
CASE 344F-01

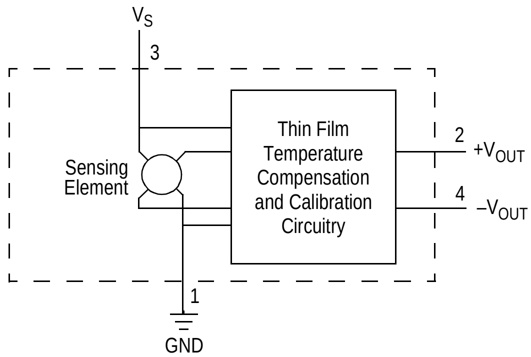


Figure 1. Temperature Compensated and Calibrated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side (P1) relative to the vacuum side (P2). Similarly, output voltage increases as increasing vacuum is applied to the vacuum side (P2) relative to the pressure side (P1).

Figure 1 shows a block diagram of the internal circuitry on the stand-alone pressure sensor chip.

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	75	kPa
Storage Temperature	T_{STG}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 10 V_{DC}, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Units
Pressure Range(1)	P_{OP}	0	—	10	kPa
Supply Voltage(2)	V_S	—	10	16	V_{DC}
Supply Current	I_O	—	6.0	—	mAdc
Full Scale Span(3)	V_{FSS}	24	25	26	mV
Offset(4)	V_{OFF}	–1.0	—	1.0	mV
Sensitivity	$\Delta V/\Delta P$	—	2.5	—	mV/kPa
Linearity(5)	—	–1.0	—	1.0	$\%V_{FSS}$
Pressure Hysteresis(5) (0 to 50 kPa)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis(5) (–40°C to +125°C)	—	—	±0.5	—	$\%V_{FSS}$
Temperature Effect on Full Scale Span(5)	TCV_{FSS}	–1.0	—	1.0	$\%V_{FSS}$
Temperature Effect on Offset(5)	TCV_{OFF}	–1.0	—	1.0	mV
Input Impedance	Z_{IN}	1000	—	2550	W
Output Impedance	Z_{OUT}	1400	—	3000	W
Response Time(6) (10% to 90%)	t_R	—	1.0	—	ms
Warm-Up Time	—	—	2.0	—	ms
Offset Stability(7)	—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum related pressure.
4. Offset (V_{OFF}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
6. Response Time is defined as the time form the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

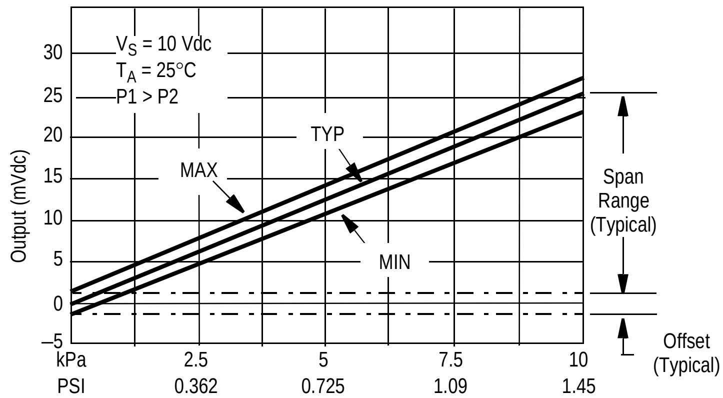


Figure 2. Output vs. Pressure Differential

Figure 2 shows the output characteristics of the MPX2010/MPXV2010G series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

The effects of temperature on full scale span and offset are very small and are shown under Operating Characteristics.

This performance over temperature is achieved by having both the shear stress strain gauge and the thin-film resistor circuitry on the same silicon diaphragm. Each chip is dynamically laser trimmed for precise span and offset calibration and temperature compensation.

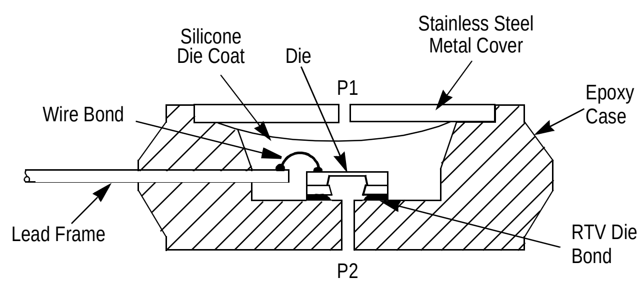


Figure 3. Unibody Package: Cross Sectional Diagram (Not to Scale)

Figure 3 illustrates the differential/gauge die in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX2010/MPXV2010G series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term reliability. Contact the factory for information regarding media compatibility in your application.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 4) or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Freescale's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

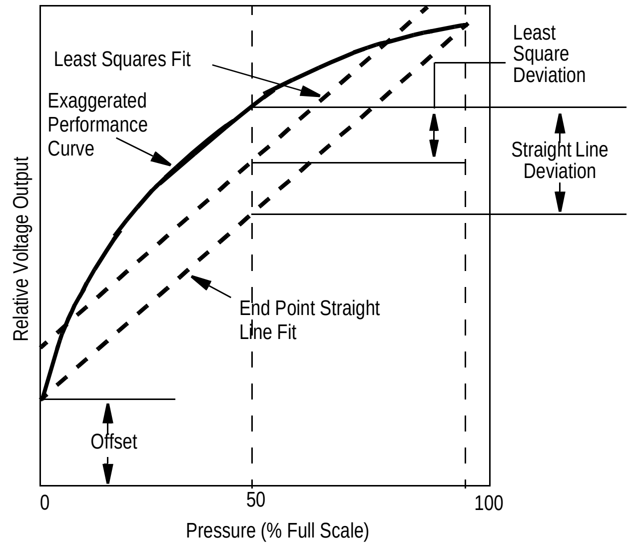


Figure 4. Linearity Specification Comparison

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing silicone gel which isolates the die from the environment. The Freescale MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the following table.

Table 3. Pressure (P1) Side Delineation

Part Number	Case Type	Pressure (P1) Side Identifier
MPX2010D	344	Stainless Steep Cap
MPX2010DP	344C	Side with Part Marking
MPX2010GP	344B	Side with Port Attached
MPX2010GS	344E	Side with Port Attached
MPX2010GSX	344F	Side with Port Attached
MPXV2010GP	1369	Side with Port Attached
MPXV2010DP	1351	Side with Part Marking

50 kPa On-Chip Temperature Compensated & Calibrated Silicon Pressure Sensors

MPX2053
MPXV2053G
SERIES

0 TO 50 kPA (0 TO 7.25 psi)
40 mV FULL SCALE SPAN
(TYPICAL)

The MPX2053/MPXV2053G device is a silicon piezoresistive pressure sensor providing a highly accurate and linear voltage output - directly proportional to the applied pressure. The sensor is a single, monolithic silicon diaphragm with the strain gauge and a thin-film resistor network integrated on-chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation.

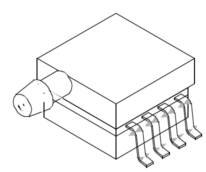
Features

- Temperature Compensated Over 0°C to +85°C
- Easy-to-Use Chip Carrier Package Options
- Ratiometric to Supply Voltage
- Differential and Gauge Options

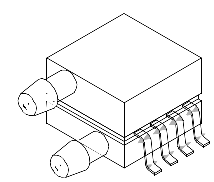
Application Examples

- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Non-Invasive Blood Pressure Measurement

SMALL OUTLINE PACKAGES



MPXV2053GP
CASE 1369-01



MPXV2053DP
CASE 1351-01

ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
SMALL OUTLINE PACKAGE (**MPXV2053G** SERIES)					
Ported Elements	Gauge, Side Port, SMT	1369	MPXV2053GP	Trays	MPXV2053G
	Differential Dual Port, SMT	1351	MPXV2053DP	Trays	MPXV2053G
UNIBODY PACKAGE (**MPX2053** SERIES)					
Basic Element	Differential	344	MPX2053D	—	MPX2053D
Ported Elements	Differential, Dual Port	344C	MPX2053DP	—	MPX20153DP
	Gauge	344B	MPX2053GP	—	MPX2053GP
	Gauge, Axial PC Mount	344F	MPX2053GSX	—	MPX2053D
	Gauge, Vacuum	344D	MPX2053GVP	—	MPX2053GVP

SMALL OUTLINE PACKAGE PIN NUMBERS

1	GND[1]	5	N/C
2	$+V_{OUT}$	6	N/C
3	V_S	7	N/C
4	$-V_{OUT}$	8	N/C

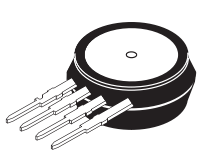
1. Pin 1 in noted by the notch in the lead.

UNIBODY PACKAGE PIN NUMBERS

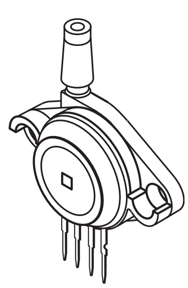
1	GND[1]	3	V_S
2	$+V_{OUT}$	4	$-V_{OUT}$

1. Pin 1 in noted by the notch in the lead.

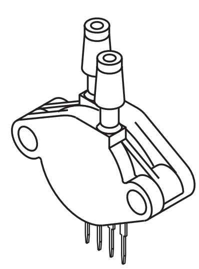
UNIBODY PACKAGES



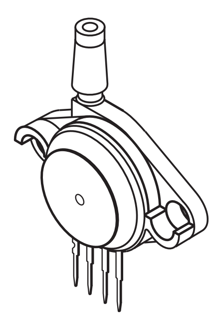
MPX2053GP
CASE 344-15



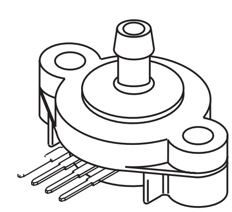
MPX2053GP
CASE 344B-01



MPX2053DP
CASE 344C-01



MPX2053GVP
CASE 344D-01



MPX2053GSX
CASE 344F-01

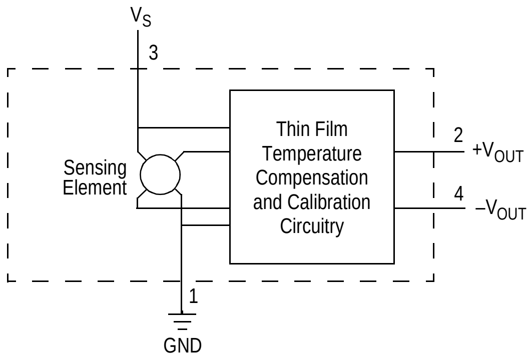


Figure 1. Temperature Compensated and Calibrated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side (P1) relative to the vacuum side (P2). Similarly, output voltage increases as increasing vacuum is applied to the vacuum side (P2) relative to the pressure side (P1).

Figure 1 shows a block diagram of the internal circuitry on the stand-alone pressure sensor chip.

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	20	kPa
Storage Temperature	T_{STG}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 10 V_{DC}, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Units
Pressure Range(1)	P_{OP}	0	—	50	kPa
Supply Voltage(2)	V_S	—	10	16	V_{DC}
Supply Current	I_O	—	6.0	—	mAdc
Full Scale Span(3)	V_{FSS}	38.5	40	41.5	mV
Offset(4)	V_{OFF}	–1.0	—	1.0	mV
Sensitivity	$\Delta V/\Delta P$	—	0.8	—	mV/kPa
Linearity(5)	—	-0.6	—	0.4	$\%V_{FSS}$
Pressure Hysteresis(5) (0 to 50 kPa)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis(5) (–40°C to +125°C)	—	—	±0.5	—	$\%V_{FSS}$
Temperature Effect on Full Scale Span(5)	TCV_{FSS}	–2.0	—	2.0	$\%V_{FSS}$
Temperature Effect on Offset(5)	TCV_{OFF}	–1.0	—	1.0	mV
Input Impedance	Z_{IN}	1000	—	2550	W
Output Impedance	Z_{OUT}	1400	—	3000	W
Response Time(6) (10% to 90%)	t_R	—	1.0	—	ms
Warm-Up Time	—	—	2.0	—	ms
Offset Stability(7)	—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum related pressure.
4. Offset (V_{OFF}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
6. Response Time is defined as the time form the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product’s output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

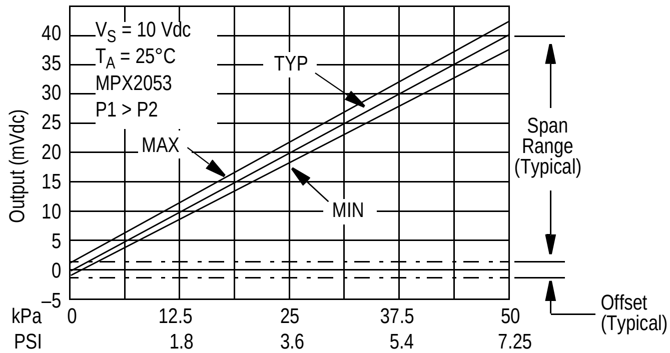


Figure 2. Output vs. Pressure Differential

Figure 2 shows the output characteristics of the MPX2053/MPXV2053G series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

The effects of temperature on full scale span and offset are very small and are shown under Operating Characteristics.

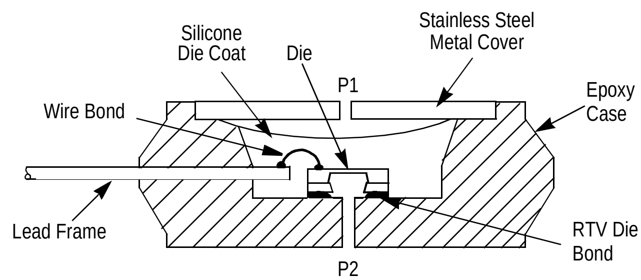


Figure 3. Unibody Package: Cross Sectional Diagram (Not to Scale)

Figure 3 illustrates the differential/gauge die in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX2053/MPXV2053G series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term reliability. Contact the factory for information regarding media compatibility in your application.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 4) or (2) a least squares best line fit. While a least squares fit gives the “best case” linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the “worst case” error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Freescale's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

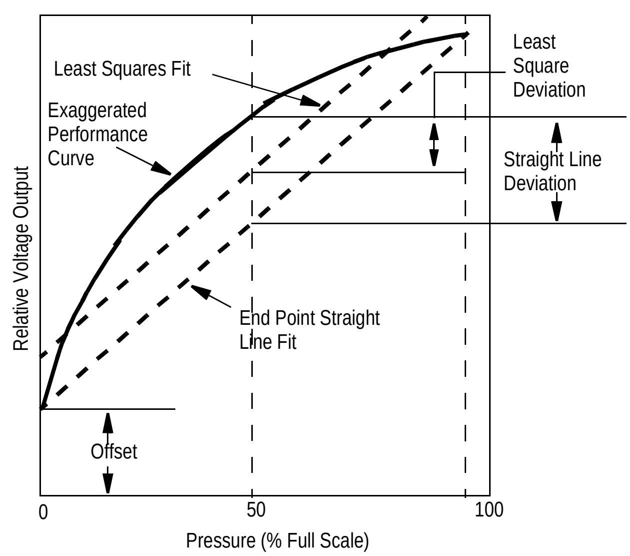


Figure 4. Linearity Specification Comparison

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing silicone gel which isolates the die from the environment. The Freescale MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the following table.

Table 3. Pressure (P1) Side Delineation

Part Number	Case Type	Pressure (P1) Side Identifier
MPX2053D	344	Stainless Steep Cap
MPX2053DP	344C	Side with Part Marking
MPX2053GP	344B	Side with Port Attached
MPX2053GSX	344F	Side with Port Attached
MPXV2053GVP	344D	Stainless Steep Cap
MPXV2053GP	1369	Side with Port Attached
MPXV2053DP	1351	Side with Part Marking

100 kPa On-Chip Temperature Compensated & Calibrated Silicon Pressure Sensors

MPX2102
MPXV2102G
SERIES

0 TO 100 kPA (0 TO 14.5 psi)
40 mV FULL SCALE SPAN
(TYPICAL)

The MPX2102/MPXV2102G series device is a silicon piezoresistive pressure sensor providing a highly accurate and linear voltage output directly proportional to the applied pressure. The sensor is a single, monolithic silicon diaphragm with the strain gauge and a thin-film resistor network integrated on-chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation.

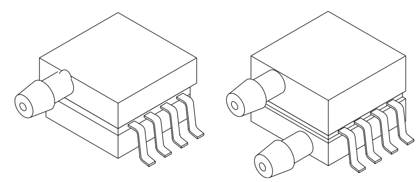
Features

- Temperature Compensated Over 0°C to +85°C
- Easy-to-Use Chip Carrier Package Options
- Available in Absolute, Differential and Gauge Configurations
- Ratiometric to Supply Voltage

Application Examples

- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Barometers
- Altimeters

SMALL OUTLINE PACKAGES



MPX2102GP
CASE 1369-01

MPXV2102DP
CASE 1351-01

ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
SMALL OUTLINE PACKAGE (MPXV2102G SERIES)					
Ported Elements	Gauge, Side Port, SMT	1369	MPXV2102GP	Trays	MPXV2102G
	Differential, Dual Port, SMT	1351	MPXV2102DP	Trays	MPXV2102G
UNIBODY PACKAGE (MPX2102 SERIES)					
Basic Element	Absolute, Differential	344	MPX2102A MPX2102D	—	MPX2102A MPX2102D
Ported Elements	Differential, Dual Port	344C	MPX2102DP	—	MPX2102DP
	Absolute, Gauge	344B	MPX2102AP MPX2102GP	—	MPX2102AP MPX2102GP
	Absolute, Gauge Axial	344F	MPX2102ASX MPX2102GSX	—	MPX2102A MPX2102D
	Gauge, Vacuum	344D	MPX2102GVP	—	MPX2102GVP

SMALL OUTLINE PACKAGE PIN NUMBERS

1	GND(1)	5	N/C
2	$+V_{OUT}$	6	N/C
3	V_S	7	N/C
4	$-V_{OUT}$	8	N/C

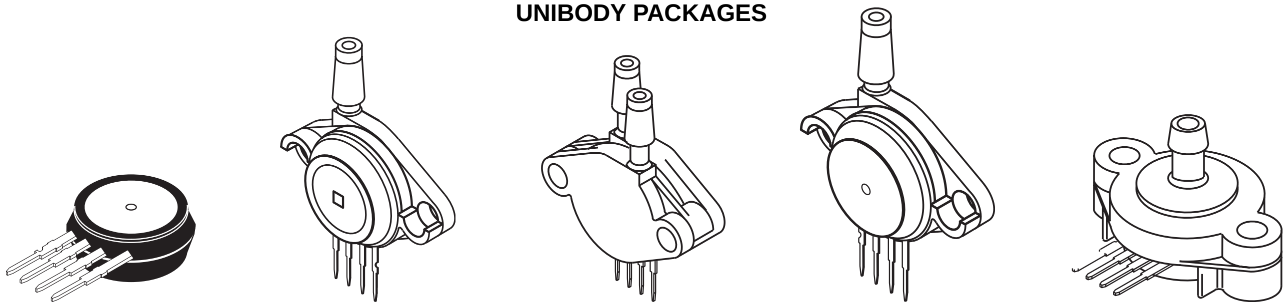
1. Pin 1 in noted by the notch in the lead.

UNIBODY PACKAGE PIN NUMBERS

1	GND(1)	3	V_S
2	$+V_{OUT}$	4	$-V_{OUT}$

1. Pin 1 in noted by the notch in the lead.

UNIBODY PACKAGES



MPX2102A/D
CASE 344-15

MPX2102AP/GP
CASE 344B-01

MPX2102DP
CASE 344C-01

MPX2102GVP
CASE 344D-01

MPX2102ASX/GSX
CASE 344F-01

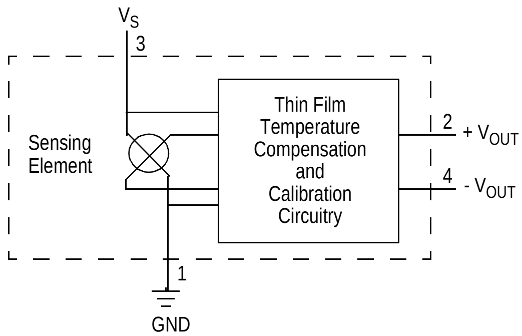


Figure 1. Temperature Compensated Pressure Sensor Schematic

VOLTAGE OUTPUT VS. APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the sensor is directly proportional to the differential pressure applied.

The absolute sensor has a built-in reference vacuum. The output voltage will decrease as vacuum, relative to ambient, is drawn on the pressure (P1) side.

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure (P1) side relative to the vacuum (P2) side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum (P2) side relative to the pressure (P1) side.

Figure 1 illustrates a block diagram of the internal circuitry on the stand-alone pressure sensor chip.

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	400	kPa
Storage Temperature	T_{STG}	-40 to +125	°C
Operating Temperature	T_A	-40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 10 V_{DC}, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Units
Differential Pressure Range(1)		P_{OP}	0	—	100	kPa
Supply Voltage(2)		V_S	—	10	16	V_{DC}
Supply Current		I_O	—	6.0	—	mAdc
Full Scale Span(3)		V_{FSS}	38.5	40	41.5	mV
Offset(4)	MPX2102D Series MPX2102A Series	V_{OFF}	-1.0 -2.0	— —	1.0 2.0	mV
Sensitivity		$\Delta V/\Delta P$	—	0.4	—	mV/kPa
Linearity(5)	MPX2102D Series MPX2102A Series	— —	-0.6 -1.0	— —	0.4 1.0	$\%V_{FSS}$
Pressure Hysteresis(5) (0 to 100 kPa)		—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis(5)(- 40°C to +125°C)		—	—	±0.5	—	$\%V_{FSS}$
Temperature Coefficient of Full Scale Span(5)		TCV_{FSS}	-2.0	—	2.0	$\%V_{FSS}$
Temperature Coefficient of Offset(5)		TCV_{OFF}	-1.0	—	1.0	mV
Input Impedance		Z_{IN}	1000	—	2500	W
Output Impedance		Z_{OUT}	1400	—	3000	W
Response Time(6) (10% to 90%)		t_R	—	1.0	—	ms
Warm-Up Time		—	—	20	—	ms
Offset Stability(7)		—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum related pressure.
4. Offset (V_{OFF}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure with the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
6. Response Time is defined as the time form the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product’s output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{OUT} = V_{OFF}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Freescale's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

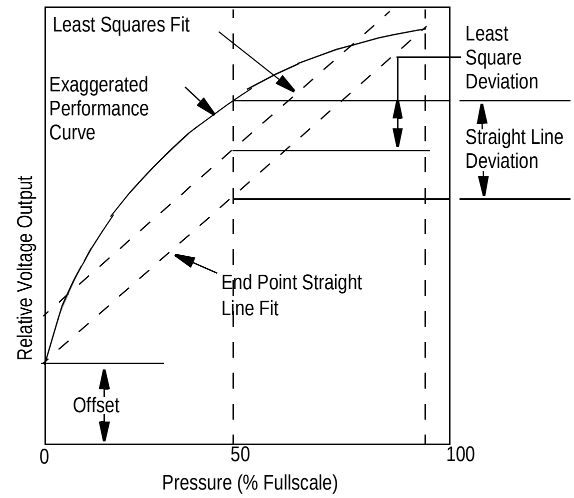


Figure 2. Linearity Specification Comparison

ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

Figure 3 shows the output characteristics of the MPX2102/MPXV2102G series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

The effects of temperature on Full Scale Span and Offset are very small and are shown under Operating Characteristics.

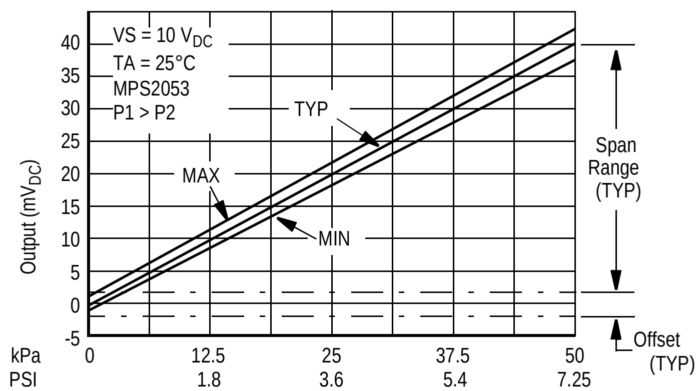


Figure 3. Output vs. Pressure Differential

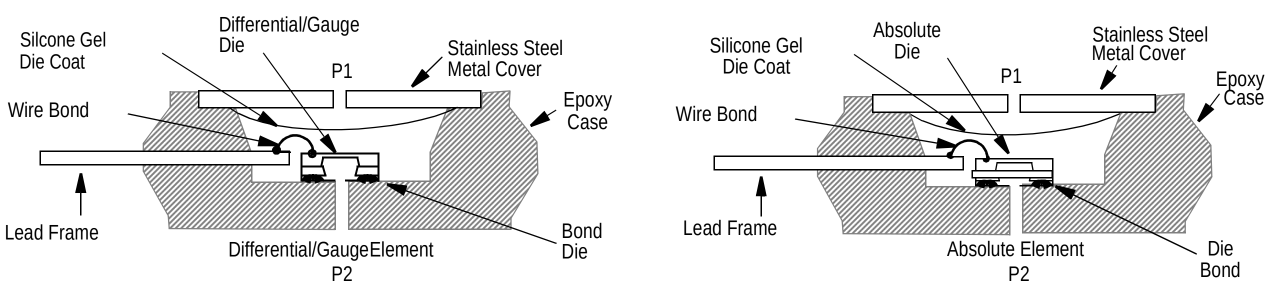


Figure 4. Cross Sectional Diagrams (Not to Scale)

Figure 4 illustrates the absolute sensing configuration (right) and the differential or gauge configuration in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX2102/MPXV2102G series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term reliability. Contact the factory for information regarding media compatibility in your application.

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing the silicone gel which isolates the die. The differential or gauge sensor is designed to operate with positive differential pressure applied, P1 > P2. The absolute sensor is designed for vacuum applied to P1 side.

The Pressure (P1) side may be identified by using Table 3.

Table 3. Pressure (P1) Side Delineation

Part Number		Case Type	Pressure (P1) Side Identifier
MPX2102A	MPX2102D	344	Stainless Steep Cap
MPX2102DP		344C	Side with Part Marking
MPX2102AP	MPX2102GP	344B	Side with Port Attached
MPX2102GVP		344D	Stainless Steep Cap
MPX2102ASX	MPX2102GSX	344F	Side with Port Marking
MPX2102GP		1369	Side with Port Attached
MPX2102DP		1351	Side with Part Marking

200 kPa On-Chip Temperature Compensated & Calibrated Pressure Sensors

MPX2200 SERIES

0 TO 200 kPA (0 TO 29 psi)
40 mV FULL SCALE SPAN
(TYPICAL)

The MPX2200 series device is a silicon piezoresistive pressure sensor providing a highly accurate and linear voltage output - directly proportional to the applied pressure. The sensor is a single monolithic silicon diaphragm with the strain gauge and a thin-film resistor network integrated on-chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation. They are designed for use in applications such as pump/motor controllers, robotics, level indicators, medical diagnostics, pressure switching, barometers, altimeters, etc.

Features

- Temperature Compensated Over 0°C to +85°C
- ±0.25% Linearity (MPX2200D)
- Easy-to-Use Chip Carrier Package Options
- Available in Absolute, Differential and Gauge Configurations

Typical Applications

- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Barometers
- Altimeters

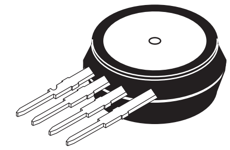
ORDERING INFORMATION(1)

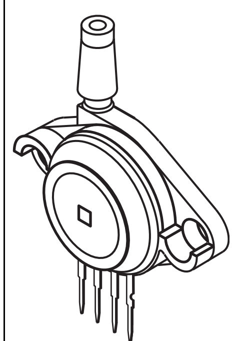
Device Type	Options	Case No.	MPX Series Order Number	Device Marking
Basic Element	Absolute, Differential	344	MPX2200A MPX2200D	MPX2200A MPX2200D
Ported Elements	Differential	344C	MPX2200DP	MPX2200DP
	Absolute, Gauge	344B	MPX2200AP MPX2200GP	MPX2200AP MPX2200GP
	Gauge, Vacuum	344D	MPX2200GVP	MPX2200GVP

1. MPX2200 series pressure sensors are available in absolute, differential and gauge configurations. Devicesare available in the basic element package or with pressure port fittings which provide printed circuit board mounting ease and barbed hose pressure connections.

UNIBODY PACKAGES

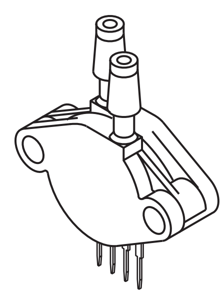
MPX2200A/D
CASE 344-15

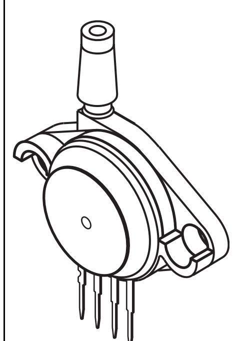




MPX2200AP/GP
CASE 344B-01

MPX2200DP
CASE 344C-01





MPX2200GVP
CASE 344D-01

PIN NUMBER

1	GND[1]	3	V_S
2	$+V_{OUT}$	4	$-V_{OUT}$

1. Pin 1 in noted by the notch in the lead.

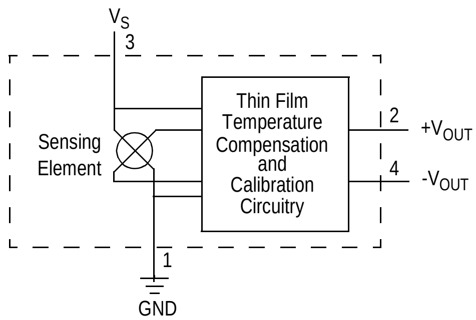


Figure 1. Temperature Compensation Pressure Sensor Schematic

VOLTAGE OUTPUT VS. APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the sensor is directly proportional to the differential pressure applied.

The absolute sensor has a built-in reference vacuum. The output voltage will decrease as vacuum, relative to ambient, is drawn on the pressure (P1) side.

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure (P1) side relative to the vacuum (P2) side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum (P2) side relative to the pressure (P1) side.

Figure 1 illustrates a block diagram of the internal circuitry on the stand-alone pressure sensor chip.

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	800	kPa
Storage Temperature	T_{STG}	-40 to +125	°C
Operating Temperature	T_A	-40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 10 V_{DC}, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Units
Differential Pressure Range(1)		P_{OP}	0	—	200	kPa
Supply Voltage(2)		V_S	—	10	16	V_{DC}
Supply Current		I_O	—	6.0	—	mAdc
Full Scale Span(3)		V_{FSS}	38.5	40	41.5	mV
Offset(4)		V_{OFF}	-1.0	—	1.0	mV
Sensitivity		$\Delta V/\Delta P$	—	0.2	—	mV/kPa
Linearity(5)	MPX2200D Series MPX2200A Series	—	-0.25 -1.0	— —	0.25 1.0	$\%V_{FSSI}$
Pressure Hysteresis(5)(0 to 200 kPa)		—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis(5)(- 40°C to +125°C)		—	—	±0.5	—	$\%V_{FSS}$
Temperature Coefficient of Full Scale Span(5)		TCV_{FSS}	-1.0	—	1.0	$\%V_{FSS}$
Temperature Coefficient of Offset(5)		TCV_{OFF}	-1.0	—	1.0	mV
Input Impedance		Z_{IN}	1300	—	2500	W
Output Impedance		Z_{OUT}	1400	—	3000	W
Response Time(6) (10% to 90%)		t_R	—	1.0	—	ms
Warm-Up Time		—	—	20	—	ms
Offset Stability(7)		—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum related pressure.
4. Offset (V_{OFF}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure with the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
6. Response Time is defined as the time form the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{OUT} = V_{OFF}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Freescale's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

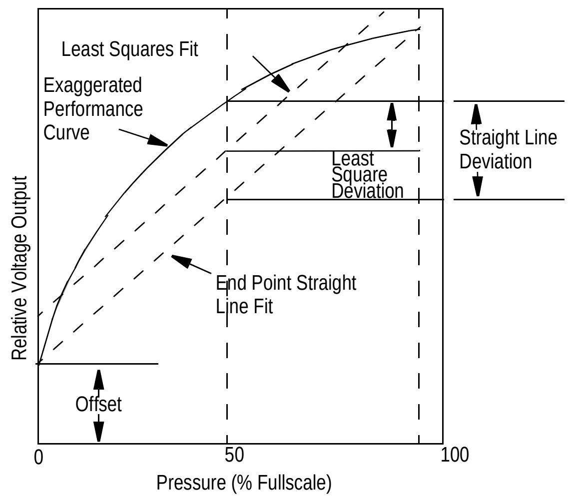


Figure 2. Linearity Specification Comparison

ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

Figure 3 shows the output characteristics of the MPX2102/MPXV2102G series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

The effects of temperature on Full Scale Span and Offset are very small and are shown under Operating Characteristics.

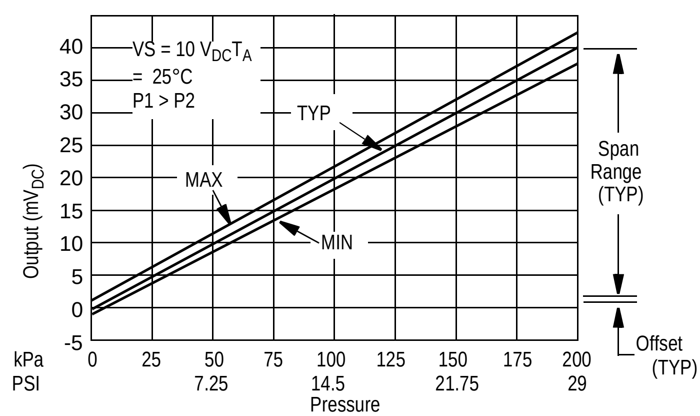


Figure 3. Output vs. Pressure Differential

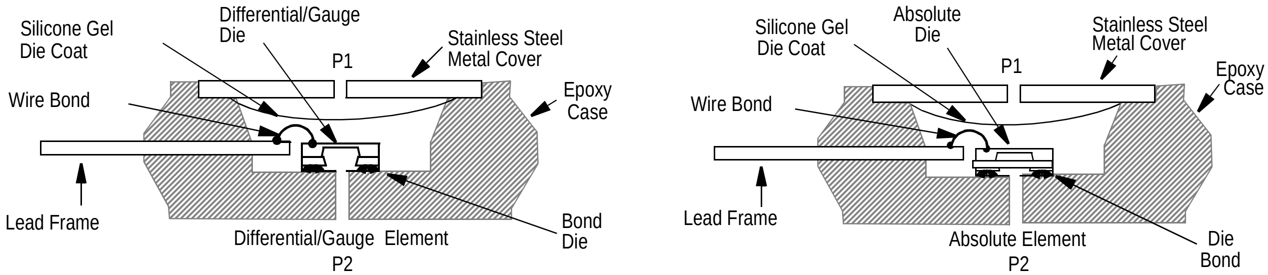


Figure 4. Cross Sectional Diagrams (Not to Scale)

Figure 4 illustrates an absolute sensing die (right) and the differential or gauge die in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX2200 series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term reliability. Contact the factory for information regarding media compatibility in your application.

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing the silicone gel which isolates the die from the environment. The differential or gauge sensor is designed to operate with positive differential pressure applied, P1 > P2. The absolute sensor is designed for vacuum applied to P1 side.

The Pressure (P1) side may be identified by using Figure 3.

Table 3. Pressure (P1) Side Delineation

Part Number	Case Type	Pressure (P1) Side Identifier
MPX2200A/D	344	Stainless Steep Cap
MPX2200DP	344C	Side with Part Marking
MPX2200AP/GP	344B	Side with Port Attached
MPX2200GVP	344D	Stainless Steep Cap

200 kPa On-Chip Temperature Compensated & Calibrated Pressure Sensors

MPX2202 SERIES

0 TO 200 kPA (0 TO 29 psi)
40 mV FULL SCALE SPAN
(TYPICAL)

The MPX2202/MPXV2202G device series is a silicon piezoresistive pressure sensor providing a highly accurate and linear voltage output - directly proportional to the applied pressure. The sensor is a single monolithic silicon diaphragm with the strain gauge and a thin-film resistor network integrated on-chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation. They are designed for use in applications such as pump/motor controllers, robotics, level indicators, medical diagnostics, pressure switching, barometers, altimeters, etc.

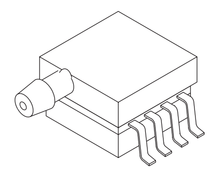
Features

- Temperature Compensated Over 0°C to +85°C
- Easy-to-Use Chip Carrier Package Options
- Available in Absolute, Differential and Gauge Configurations

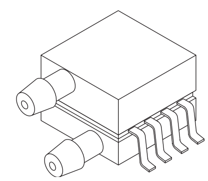
Typical Applications

- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Barometers
- Altimeters

SMALL OUTLINE PACKAGE SURFACE MOUNT



MPXV2202GP
CASE 1369-01



MPXV2202DP
CASE 1351-01

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
SMALL OUTLINE PACKAGE (MPX2202G SERIES)					
Ported Elements	Gauge, Side Port, SMT	1369	MPXV2202GP	Trays	MPXV2202G
	Differential, Dual Port, SMT	1351	MPXV2202DP	Trays	MPXV2202G
UNIBODY PACKAGE (MPX2202 SERIES)					
Basic Element	Absolute, Differential	344	MPX2202A MPX2202D	—	MPX2202A MPX2202D
Ported Elements	Differential, Dual Port	344C	MPX2202DP	—	MPX2202DP
	Absolute, Gauge	344B	MPX2202AP MPX2202GP	—	MPX2202AP MPX2202GP
	Absolute, Gauge Axial	344F	MPX2202ASX MPX2202GSX	—	MPX2202A MPX2202D
	Gauge, Vacuum	344D	MPX2202GVP	—	MPX2202GVP

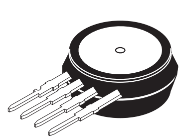
SMALL OUTLINE PACKAGE PIN NUMBERS			
1	GND(1)	5	N/C
2	$+V_{OUT}$	6	N/C
3	V_S	7	N/C
4	V_S	8	N/C

1. Pin 1 is noted by the notch in the lead.

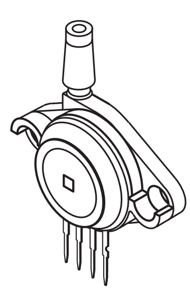
UNIBODY PACKAGE PIN NUMBERS			
1	GND(1)	3	V_S
2	$+V_{OUT}$	4	V_S

1. Pin 1 is noted by the notch in the lead.

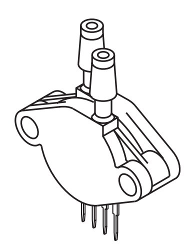
UNIBODY PACKAGES



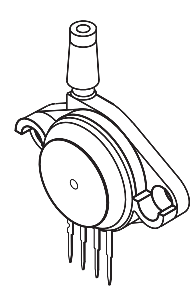
MPXV2202A/D
CASE 344-15



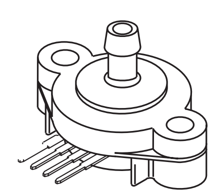
MPXV2202AP/GP
CASE 344B-01



MPXV2202DP
CASE 344C-01



MPXV2202GVP
CASE 344D-01



MPXV2202ASX/GSX
CASE 344F-01

Figure 1 illustrates a block diagram of the internal circuitry on the stand-alone pressure sensor chip.

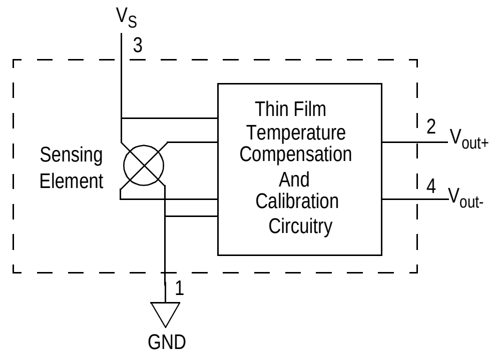


Figure 1. Temperature Compensated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the sensor is directly proportional to the differential pressure applied.

The absolute sensor has a built-in reference vacuum. The output voltage will decrease as vacuum, relative to ambient, is drawn on the pressure (P1) side.

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure (P1) side relative to the vacuum (P2) side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum (P2) side relative to the pressure (P1) side.

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{max}	800	kPa
Storage Temperature	T_{stg}	-40 to +125	°C
Operating Temperature	T_A	-40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics
(V_S = 10 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristics	Symbol	Min	Typ	Max	Unit
Pressure Range(1)	P_{OP}	0	-	200	kPa
Supply Voltage(2)	V_S	—	10	16	Vdc
Supply Current	I_o	—	6.0	-	mAdc
Full Scale Span(3)	V_{FSS}	38.5	40	41.5	mV
Offset(4)	V_{off}	-1.0	—	1.0	mV
Sensitivity	ΔV/ΔP	—	0.2	—	mV/kPa
Linearity(5) MPX2202D Series MPX2202A Series	—	-0.6 -1.0	— —	0.4 1.0	$\%V_{FSS}$
Pressure Hysteresis(5) (0 to 200 kPa)	—	—	±0.1	-	$\%V_{FSS}$
Temperature Hysteresis(5) (-40°C to +125°C)	—	—	±0.5	-	$\%V_{FSS}$
Temperature Effect on Full Scale Span(5)	TCV_{FSS}	-2.0	—	2.0	$\%V_{FSS}$
Temperature Effect on Offset(5)	TCV_{off}	-1.0	—	1.0	mV
Input Impedance	Z_{in}	1000	—	2500	W
Output Impedance	Z_{out}	1400	—	3000	W
Response Time(6) (10% to 90%)	t_R	—	1.0	—	ms
Warm-Up	—	—	20	—	ms
Offset Stability(7)	—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Freescale's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

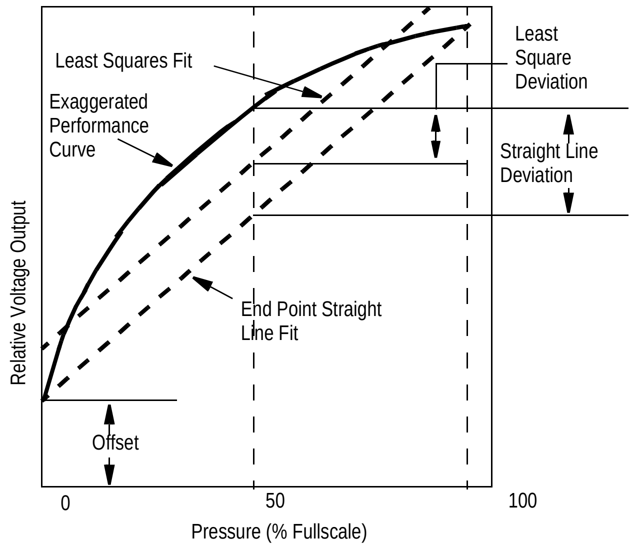


Figure 2. Linearity Specification Comparison

ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

Figure 3 shows the output characteristics of the MPX2202/ MPXV2202G series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

The effects of temperature on Full Scale Span and Offset are very small and are shown under Operating Characteristics.

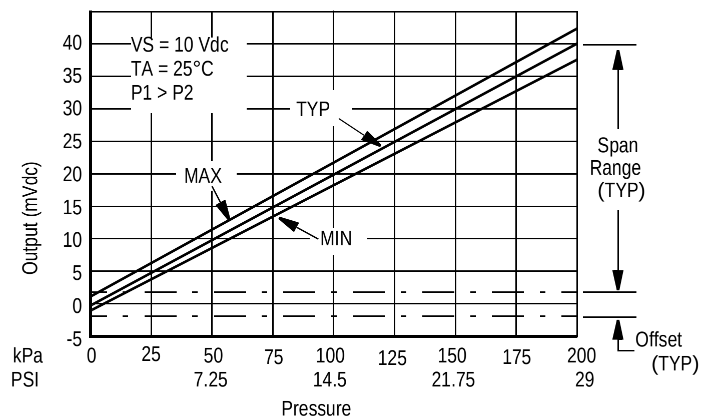


Figure 3. Output versus Pressure Differential

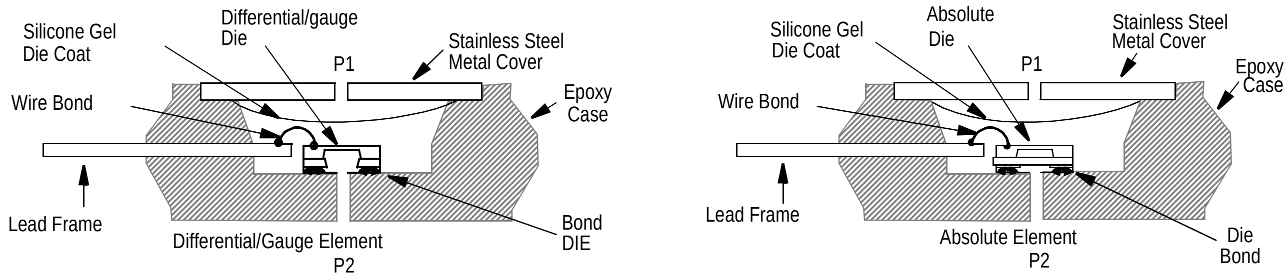


Figure 4. . Cross-Sectional Diagrams (Not to Scale)

Figure 4 illustrates an absolute sensing die (right) and the differential or gauge die in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX2202/MPXV2202G series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term reliability. Contact the factory for information regarding media compatibility in your application.

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing the silicone gel which isolates the die from the environment. The differential or gauge sensor is designed to operate with positive differential pressure applied, P1 > P2. The absolute sensor is designed for vacuum applied to P1 side.

The Pressure (P1) side may be identified by using the table below:

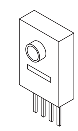
Table 3. Pressure (P1)/Vacuum (P2) Side Identification Table

Part Number	Case Type	Pressure (P1) Side Identifier
MPX2202A/D	344	Stainless Steel Cap
MPX2202DP	344C	Side with Part Marking
MPX2202AP/GP	344B	Side with Port Attached
MPX2202GVP	344D	Stainless Steel Cap
MPX2202ASX/GSX	344F	Side with Port Attached
MPXV2202GP	1369	Side with Port Attached
MPXV2202DP	1351	Side with Part Marking

High Volume Pressure Sensor For Disposable Applications

MPX2300DT1
MPX2301DT1

PRESSURE SENSORS
0 TO 300 MM HG (0 TO 40 kPA)



MPX2300DT1/MPX2301DT1
CASE 423A-03

PIN NUMBER			
1	V_S	3	S-
2	S+	4	GND

Freescale Semiconductor, Inc. has developed a low-cost, high volume miniature pressure sensor package which is ideal as a sub-module component or a disposable unit. The unique concept of the Chip Pak allows great flexibility in system design while allowing an economic solution for the designer. This new chip carrier package uses Freescale's unique sensor die with its piezoresistive technology, along with the added feature of on-chip, thin-film temperature compensation and calibration.

NOTE: Freescale is also offering the Chip Pak package in application-specific configurations, which will have an "SPX" prefix, followed by a four-digit number, unique to the specific customer.

Features

- Low Cost
- Integrated Temperature Compensation and Calibration
- Ratiometric to Supply Voltage
- Polysulfone Case Material (Medical, Class V Approved)
- Provided in Easy-to-Use Tape and Reel

Typical Applications

- Medical Diagnostics
- Infusion Pumps
- Blood Pressure Monitors
- Pressure Catheter Applications
- Patient Monitoring

The MPX2300DT1/MPX2301DT1 silicon pressure sensors are available in tape and reel packaging

ORDERING INFORMATION

Device Type	Case No.	Device Description	Marking
MPX2300DT1	423A	Chip Pak, Full Gel	Date Code, Lot ID
MPX2301DT1	423A	Chip Pak, 1/3 Gel	Date Code, Lot ID

Packaging Information	Reel Size	Tape Width	Quantity
Tape and Reel	330 mm	24 mm	1000 pc/reel

NOTE: The die and wire bonds are exposed on the front side of the Chip Pak (pressure is applied to the backside of the device). Front side die and wire protection must be provided in the customer's housing. Use caution when handling the devices during all processes.

The MPX2300DT1/MPX2301DT1 Pressure Sensors have been designed for medical usage by combining the performance of Freescale's shear stress pressure sensor design and the use of biomedically approved materials. Materials with a proven history in medical situations have been chosen to provide a sensor that can be used with confidence in applications, such as invasive blood pressure monitoring. It can be sterilized using ethylene oxide. The portions of the pressure sensor that are required to be biomedically approved are the rigid housing and the gel coating.

The rigid housing is molded from a white, medical grade polysulfone that has passed extensive biological testing including: tissue culture test, rabbit implant, hemolysis, intracutaneous test in rabbits, and system toxicity, USP.

A silicone dielectric gel covers the silicon piezoresistive sensing element. The gel is a nontoxic, nonallergenic elastomer system which meets all USP XX Biological Testing Class V requirements. The properties of the gel allow it to transmit pressure uniformly to the diaphragm surface, while isolating the internal electrical connections from the corrosive effects of fluids, such as saline solution. The gel provides electrical isolation sufficient to withstand defibrillation testing, as specified in the proposed Association for the Advancement of Medical Instrumentation (AAMI) Standard for blood pressure transducers. A biomedically approved opaque filler in the gel prevents bright operating room lights from affecting the performance of the sensor. The MPX2301DT1 is a reduced gel option.

Table 1. Maximum Ratings[1]

Rating	Symbol	Value	Unit
Maximum Pressure (Backside)	P_{max}	125	PSI
Storage Temperature	T_{stg}	-25 to +85	°C
Operating Temperature	T_A	+15 to +40	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (VS = 6 Vdc, TA = 25×C unless otherwise noted)

Characteristics	Symbol	Min	Typ	Max	Unit
Pressure Range	P_{OP}	0	—	300	mm Hg
Supply Voltage(1)	V_S	—	6.0	10	Vdc
Supply Current	I_o	—	1.0	—	mAdc
Zero Pressure Offset	V_{off}	-0.75	—	0.75	mV
Sensitivity	—	4.95	5.0	5.05	µV/V/mmHg
Full Scale Span(2)	V_{FSS}	2.976	3.006	3.036	mV
Linearity + Hysteresis(3)	—	-1.5	—	1.5	$\%V_{FSS}$
Accuracy(9) V_S = 6 V, P = 101 to 200 mmHg	—	-1.5	—	1.5	%
Accuracy(9) V_S = 6 V, P = 201 to 300 mmHg	—	-3.0	—	3.0	%
Temperature Effect on Sensitivity	TCS	-0.1	—	+0.1	%/°C
Temperature Effect on Full Scale Span(4)	TCV_{FSS}	-0.1	—	+0.1	%/°C
Temperature Effect on Offset(5)	TCV_{off}	-9.0	—	+9.0	µV/°C
Input Impedance	Z_{in}	1800	—	4500	W
Output Impedance	Z_{out}	270	—	330	W
R_{CAL} (150 kΩ)(6)	R_{CAL}	97	100	103	mm Hg
Response Time(7) (10% to 90%)	t_R	—	1.0	—	ms
Temperature Error Band	—	0	—	85	°C
Stability(8)	—	—	±0.5	—	$\%V_{FSS}$

1. Recommended voltage supply: 6 V ± 0.2 V, regulated. Sensor output is ratiometric to the voltage supply. Supply voltages above +10 V may induce additional error due to device self-heating.
2. Measured at 6.0 Vdc excitation for 100 mmHg pressure differential. V_{FSS} and FSS are like terms representing the algebraic difference between full scale output and zero pressure offset.
3. Maximum deviation from end-point straight line fit at 0 and 200 mmHg.
4. Slope of end-point straight line fit to full scale span at 15°C and +40°C relative to +25°C.
5. Slope of end-point straight line fit to zero pressure offset at 15°C and +40°C relative to +25°C.
6. Offset measurement with respect to the measured sensitivity when a 150k ohm resistor is connected to V_S and S+ output.
7. For a 0 to 300 mm Hg pressure step change.
8. Stability is defined as the maximum difference in output at any pressure within P_{OP} and temperature within +10°C to +85°C after:
   - 1000 temperature cycles, -40°C to +125°C.
   - 1.5 million pressure cycles, 0 to 300 mm Hg.

Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

The MPX4080D series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This patented, single element transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

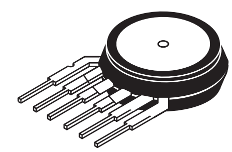
Features

- 3.0% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated from -40° to 105°C
- Easy-to-Use, Durable Epoxy Unibody Package

ORDERING INFORMATION			
Device	**Device Type**	**Case No.**	**Device Marking**
MPX4080D	Differential	867	MPX4080D

MPX4080D

INTEGRATED PRESSURE SENSOR
0 TO 80 kPA (0 TO 11.6 psi)
0.58 TO 4.9 V OUTPUT



MPX4080D
CASE 867-08

PIN NUMBERS			
1	V_{out}	4	NC
2	GND	5	NC
3	V_S	6	NC

Note: Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

Figure 1 shows a block diagram of the internal circuitry integrated on the pressure sensor chip.

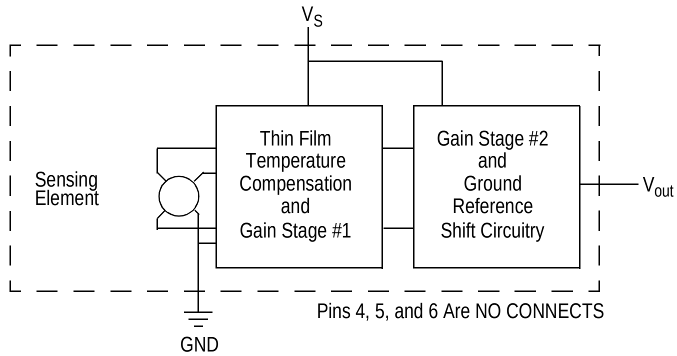


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings (1)

Rating		Symbol	Value	Unit
Maximum Pressure	(P1 > P2) (P2 > P1)	P_{max}	400 400	kPa
Storage Temperature		T_{stg}	-40° to +125°	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (VS = 5.1 Vdc, TA = 25×C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 4 required to meet electrical specifications.)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range(1)	P_{OP}	0	—	80	kPa
Supply Voltage(2)	V_S	4.85	5.1	5.35	Vdc
Supply Current	I_o	—	7.0	10	mAdc
Minimum Pressure Offset(3)(0 to 85°C) @ V_S = 5.1 V	V_{off}	0.478	0.575	0.672	Vdc
Full Scale Output(4)(0 to 85°C) @ V_S = 5.1 V	V_{FSO}	4.772	4.900	5.020	Vdc
Full Scale Span(5)(0 to 85°C) @ V_S = 5.1 V	V_{FSS}	—	4.325	—	Vdc
Accuracy(6)	—	—	—	3.0	$\%V_{FSS}$
Sensitivity	V/P	—	54	—	mV/kPa

1. 0kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS} at 25°C.

ON-CHIP TEMPERATURE COMPENSATION, CALIBRATION AND SIGNAL CONDITIONING

Figure 2 shows the sensor output signal relative to differential pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit shown in Figure 4. The output will saturate outside of the specified pressure range.

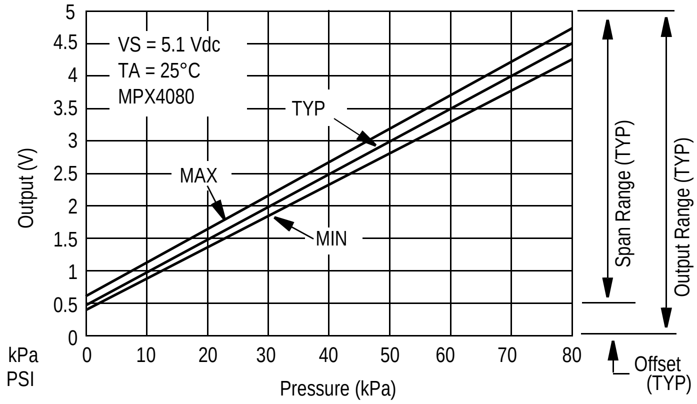


Figure 2. Output versus Pressure Differential

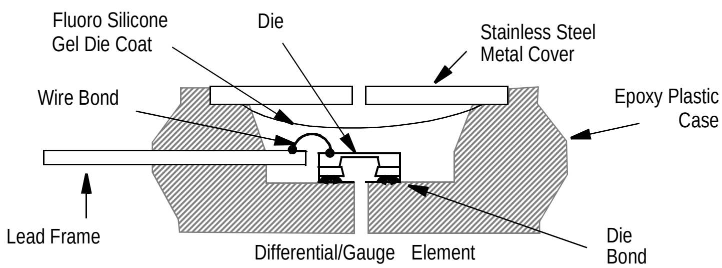


Figure 3. Cross-Sectional Diagrams (Not to Scale)

Figure 3 illustrates the differential sensing chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm.

The MPX4080D pressure sensor operating characteristics, internal reliability, and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 4 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

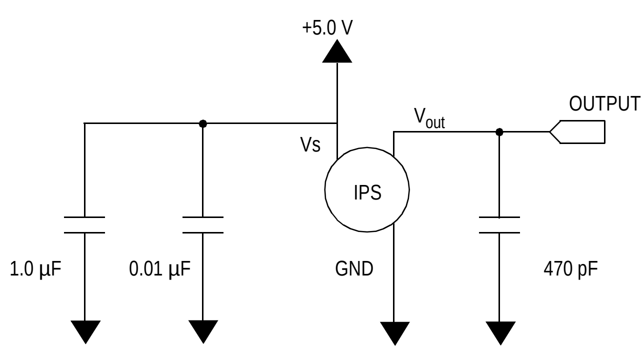


Figure 4. Recommended Power Supply Decoupling and Output Filter

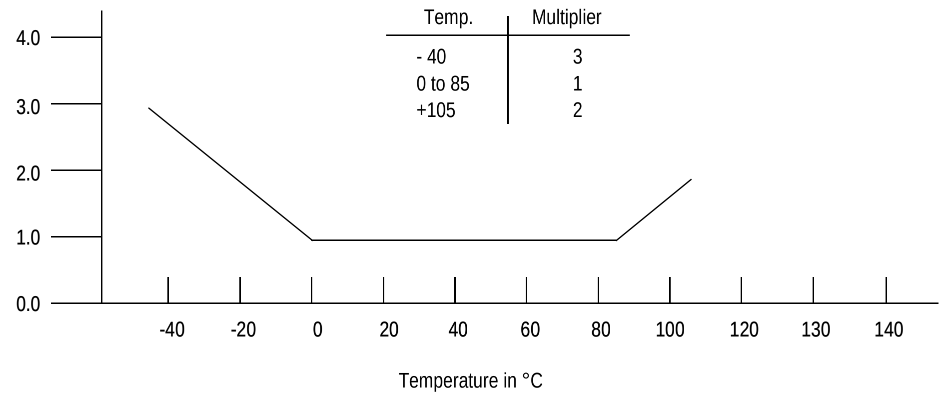
(For additional output filtering information, refer to Application Note AN1646.)

Transfer Function (MPX4080D)

Nominal Transfer Value: $V_{out} = V_S (P \times 0.01059 + 0.11280)$
$\pm$ (Pressure Error x Temp. Mult. x $0.01059 \times V_S$)
$V_S = 5.1\ V \pm 0.25\ V$ P kPa

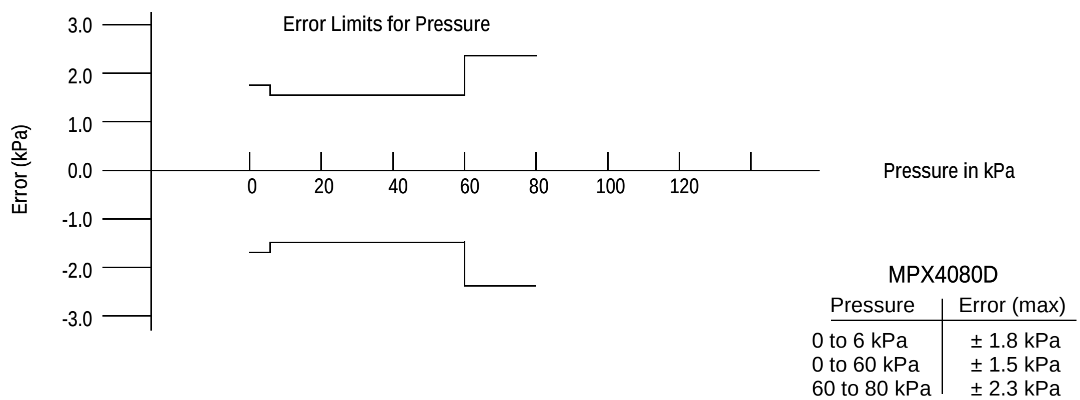
Temperature Error Multiplier

MPX4080D



NOTE: The Temperature Multiplier is a linear response from 0° to -40°C and from 85° to 105°C.

Pressure Error Band



PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

The two sides of the pressure sensor are designated as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluorosilicone gel which protects the die from harsh media. The pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side is identified by the stainless steel cap.

Integrated Silicon Pressure Sensor Manifold Absolute Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

The MPX4100 series Manifold Absolute Pressure (MAP) sensor for engine control is designed to sense absolute air pressure within the intake manifold. This measurement can be used to compute the amount of fuel required for each cylinder. The small form factor and high reliability of on-chip integration makes the MAP sensor a logical and economical choice for automotive system designers.

FeaturesFeatures

- 1.8% Maximum Error Over 0° to 85°C
- Specifically Designed for Intake Manifold Absolute Pressure Sensing in Engine Control Systems
- Ideally Suited for Microprocessor Interfacing
- Temperature Compensated Over -40°C to +125°C
- Durable Epoxy Unibody Element
- Ideal for Non-Automotive Applications

Typical Applications

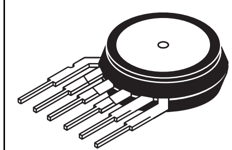
- Manifold Sensing for Automotive Systems

ORDERING INFORMATION[1]				
Device Type	**Options**	**Case No.**	**MPX Series Order Number**	**Device Marking**
Basic Element	Absolute, Element Only	867-08	MPX4100A	MPX4100A
Ported Elements	Absolute, Ported	867B-04	MPX4100AP	MPX4100AP
	Absolute, Stove Pipe Port	867E-03	MPX4100AS	MPX4100A
	Absolute, Axial Port	867F-03	MPX4100ASX	MPX4100A

1. The MPX4100A series MAP silicon pressure sensors are available in the Basic Element, or with pressure port fittings that provide mounting ease and barbed hose connections.

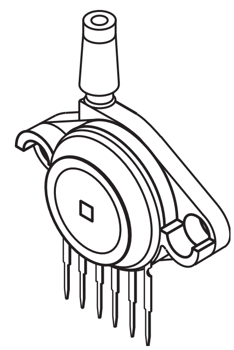
MPX4100 SERIES

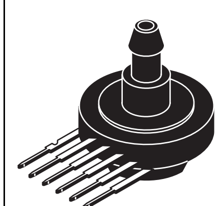
INTEGRATED PRESSURE SENSOR
20 TO 105 kPA (2.9 TO 15.2 psi)
0.3 TO 4.9 V OUTPUT



MPX4100A
CASE 867-08

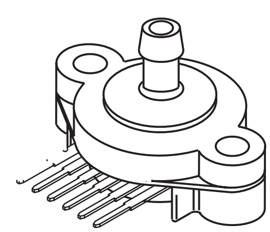
MPX4100AP
CASE 867B-04





MPX4100AS
CASE 867E-03

MPX4100ASX
CASE 867F-03



PIN NUMBERS			
1	V_{OUT}	4	NC
2	GND	5	NC
3	V_S	6	NC

The MPX4100 series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

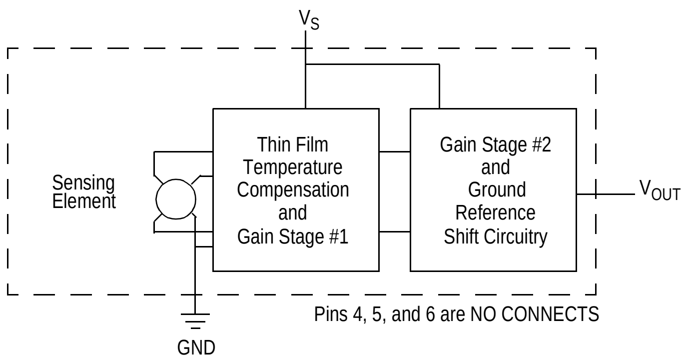


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. MAXIMUM RATINGS(1)

Rating	Symbol	Value	Unit
Overpressure(2) (P1 > P2)	P_{max}	400	kPa
Burst Pressure(2) (P1 > P2)	P_{burst}	1000	kPa
Storage Temperature	T_{stg}	-40 to +125	°C
Operating Temperature	T_A	-40 to +125	°C

1. T_C = 25°C unless otherwise noted.
2. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. OPERATING CHARACTERISTICS (VS = 5.1 Vdc, TA = 25×C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range(2)		P_{OP}	20	—	105	kPa
Supply Voltage(2)		V_S	4.85	5.1	5.35	Vdc
Supply Current		I_O	—	7.0	10	mAdc
Minimum Pressure Offset(3) @ V_S = 5.1 V	(0 to 85°C)	V_{off}	0.225	0.306	0.388	Vdc
Full Scale Output(4) @ V_S = 5.1 V	(0 to 85°C)	V_{FSO}	4.815	4.897	4.978	Vdc
Full Scale Span(5) @ V_S = 5.1 V	(0 to 85°C)	V_{FSS}	—	4.59	—	Vdc
Accuracy(6)	(0 to 85°C)	—	—	—	±1.8	$\%V_{FSS}$
Sensitivity		V/P	—	54	—	mV/kPa
Response Time(7)		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{O+}	—	0.1	—	mAdc
Warm-Up Time(8)		—	—	20	—	ms
Offset Stability(9)		—	—	±0.5	—	$\%V_{FSS}$

1. Decoupling circuit shown in Figure 3 required to meet electrical specifications.
2. 1.0 kPa (kiloPascal) equals 0.145 psi.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.
10. Device is ratiometric within this specified excitation range.

Table 3. MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight, Basic Element (Case 867)	—	—	4.0	—	Grams
Common Mode Line Pressure(1)	—	—	—	690	kPa

1. Common mode pressures beyond specified may result in leakage at the case-to-lead interface.

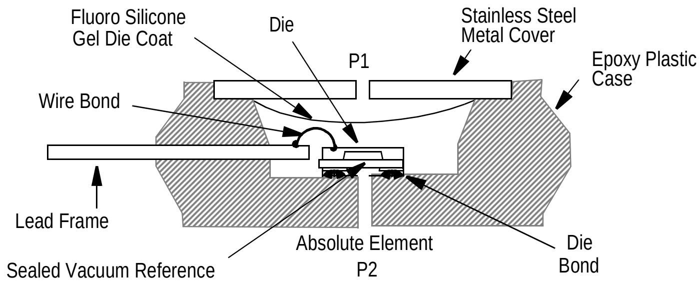


Figure 2. Cross-Sectional Diagram (Not to Scale)

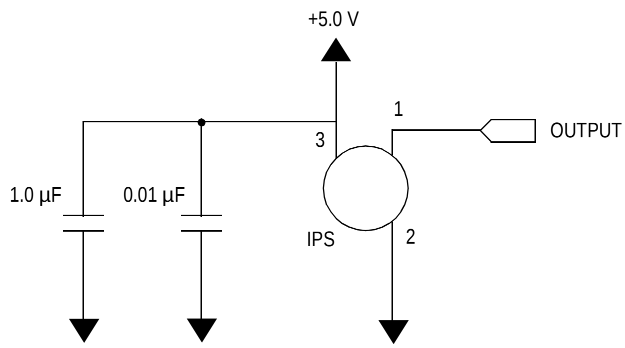


Figure 3. Recommended Power Supply Decoupling
(For output filtering recommendations, refer to Application Note AN1646.)

Figure 2 illustrates an absolute sensing chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. The MPX4100A series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C. (The output will saturate outside of the specified pressure range.)

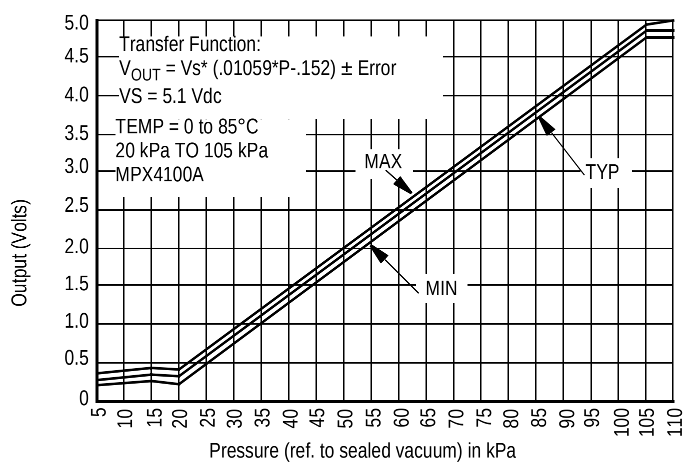


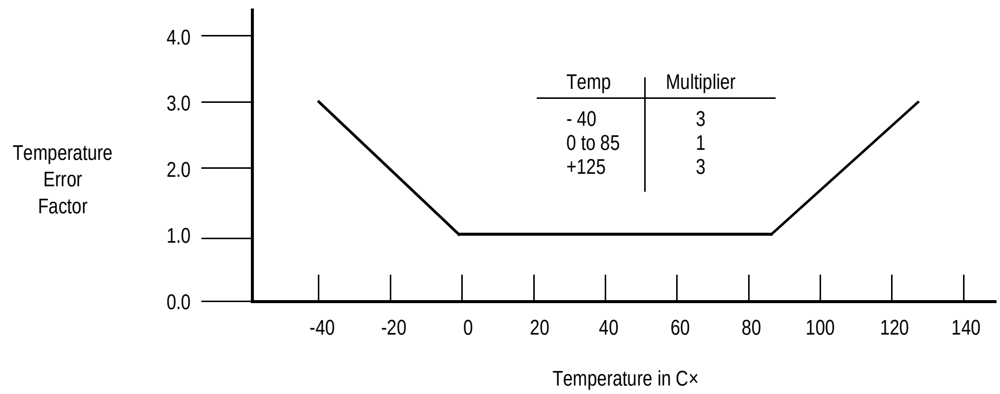
Figure 4. Output versus Absolute Pressure

Transfer Function (MPX4100A)

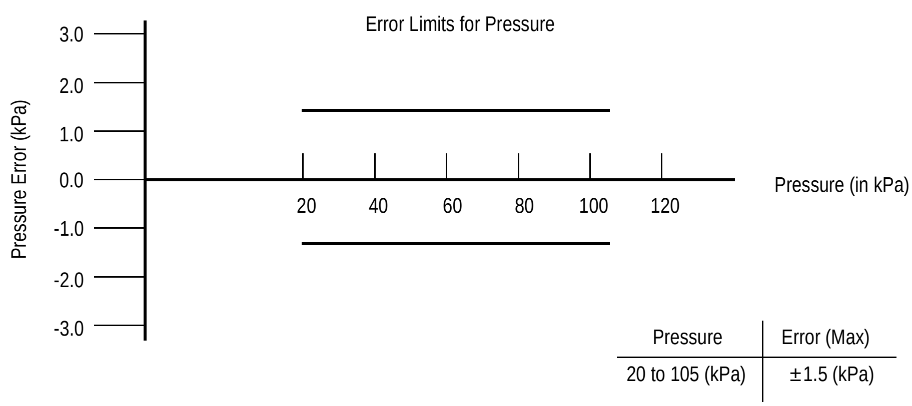
Nominal Transfer Value: $V_{out} = V_S$ (P x 0.01059 - 0.1518)
± (Pressure Error x Temp. Factor x 0.01059 x V_S)
V_S = 5.1 V ± 0.25 Vdc

Temperature Error Band

MPX4100A Series



Pressure Error Band



PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

The two sides of the pressure sensor are designated as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluorosilicone gel, which protects the die from harsh media. The MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX4100A	867	Stainless Steel Cap
MPX4100AP	867B	Side with Port Marking
MPX4100AS	867E	Side with Port Attached
MPX4100ASX	867F	Side with Port Attached

Integrated Silicon Pressure Sensor for Manifold Absolute Pressure Applications On-Chip Signal Conditioned, Temperature Compensated and Calibrated

The Freescale MPX4100A/MPXA4100A series Manifold Absolute Pressure (MAP) sensor for engine control is designed to sense absolute air pressure within the intake manifold. This measurement can be used to compute the amount of fuel required for each cylinder. The small form factor and high reliability of on-chip integration makes the Freescale MAP sensor a logical and economical choice for automotive system designers.

The MPX4100A/MPXA4100A series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Features

- 1.8% Maximum Error Over 0° to 85°C
- Specifically Designed for Intake Manifold Absolute Pressure Sensing in Engine Control Systems
- Temperature Compensated Over –40°C to +125°C
- Durable Epoxy Unibody Element or Thermoplastic (PPS) Surface Mount Package

Typical ApplicationsApplication Examples

- Manifold Sensing for Automotive Systems
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Also Ideal for Non-Automotive Applications

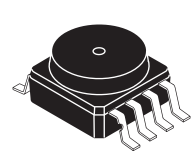
ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
SMALL OUTLINE PACKAGE (MPXA4100A SERIES)					
Basic Element	Absolute, Element Only	482	MPXA4100A6U	Rails	MPXA4100A
		482	MPXA4100A6T1	Tape & Reel	MPXA4100A
Ported Element	Absolute, Axial Port	482A	MPXA4100AC6U	Rails	MPXA4100A
UNIBODY PACKAGE (MPX4100A SERIES)					
Basic Element	Absolute, Element Only	867	MPX4100A	—	MPX4100A
Ported Element	Absolute, Ported	867B	MPX4100AP	—	MPX4100AP
	Absolute, Stove Pipe Port	867E	MPX4100AS	—	MPX4100A

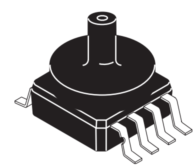
MPX4100A MPXA4100A SERIES

INTEGRATED PRESSURE SENSOR
15 TO 115 KPA (2.2 TO 16.7 PSI)
0.2 TO 4.8 V OUTPUT

SMALL OUTLINE PACKAGES



MPXA4100A6U
CASE 482-01



MPXA4100AC6U
CASE 482A-01

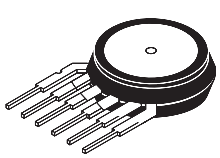
SMALL OUTLINE PACKAGE PIN NUMBERS(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

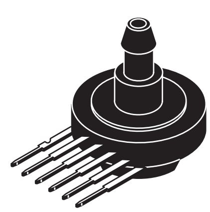
UNIBODY PACKAGE PIN NUMBERS(1)			
1	V_{OUT}	4	N/C
2	GND	5	N/C
3	V_S	6	N/C

1. Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

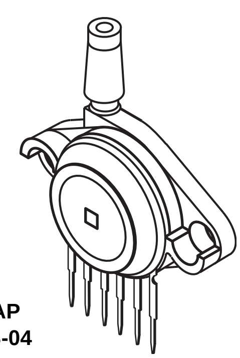
UNIBODY PACKAGES



MPX4100A
CASE 867-08



MPX4100AS
CASE 867E-03



MPX4100AP
CASE 867B-04

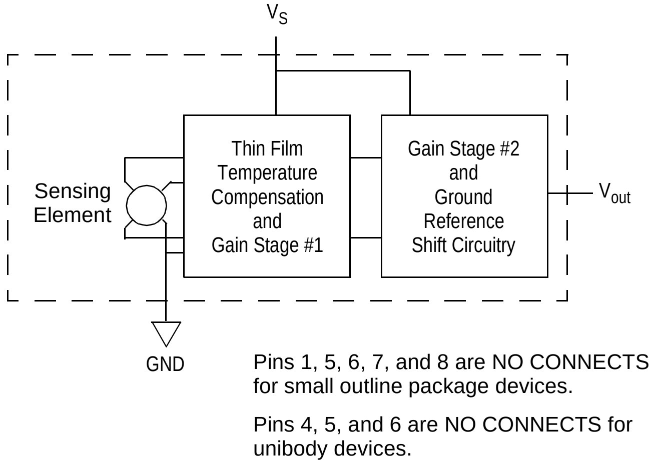


Figure 1. Temperature Compensated and Calibrated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side (P1) relative to the vacuum side (P2). Similarly, output voltage increases as increasing vacuum is applied to the vacuum side (P2) relative to the pressure side (P1).

Figure 1 shows a block diagram of the internal circuitry on the stand-alone pressure sensor chip.

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	20	kPa
Storage Temperature	T_{STG}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 10 V_{DC}, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Units
Pressure Range(1)	P_{OP}	0	—	50	kPa
Supply Voltage(2)	V_S	—	10	16	V_{DC}
Supply Current	I_O	—	6.0	—	mAdc
Full Scale Span(3)	V_{FSS}	38.5	40	41.5	mV
Offset(4)	V_{OFF}	–1.0	—	1.0	mV
Sensitivity	$\Delta V/\Delta P$	—	0.8	—	mV/kPa
Linearity(5)	—	-0.6	—	0.4	$\%V_{FSS}$
Pressure Hysteresis(5) (0 to 50 kPa)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis(5) (–40°C to +125°C)	—	—	±0.5	—	$\%V_{FSS}$
Temperature Effect on Full Scale Span(5)	TCV_{FSS}	–2.0	—	2.0	$\%V_{FSS}$
Temperature Effect on Offset(5)	TCV_{OFF}	–1.0	—	1.0	mV
Input Impedance	Z_{IN}	1000	—	2550	W
Output Impedance	Z_{OUT}	1400	—	3000	W
Response Time(6) (10% to 90%)	t_R	—	1.0	—	ms
Warm-Up Time	—	—	2.0	—	ms
Offset Stability(7)	—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum related pressure.
4. Offset (V_{OFF}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
6. Response Time is defined as the time form the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product’s output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

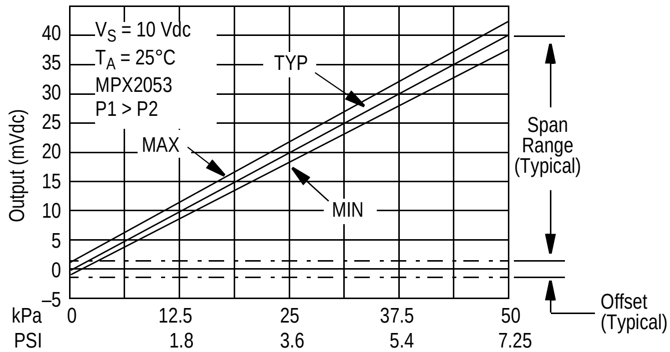


Figure 2. Output vs. Pressure Differential

Figure 2 shows the output characteristics of the MPX2053/MPXV2053G series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

The effects of temperature on full scale span and offset are very small and are shown under Operating Characteristics.

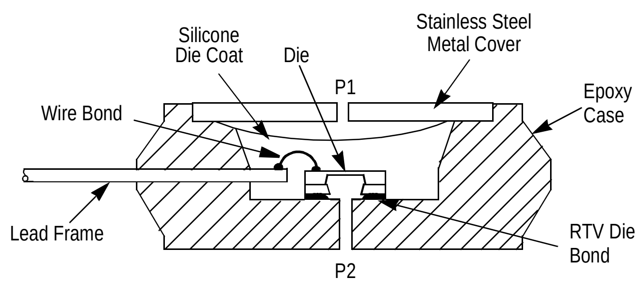


Figure 3. Unibody Package: Cross Sectional Diagram (Not to Scale)

Figure 3 illustrates the differential/gauge die in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX2053/MPXV2053G series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term reliability. Contact the factory for information regarding media compatibility in your application.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 4) or (2) a least squares best line fit. While a least squares fit gives the “best case” linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the “worst case” error (often more desirable in error budget calculations) and the calculations are more straightforward for the user.

Freescale’s specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

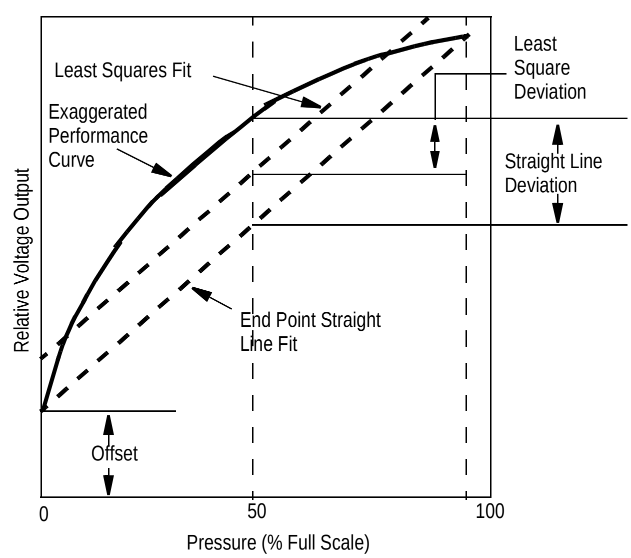


Figure 4. Linearity Specification Comparison

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing silicone gel which isolates the die from the environment. The Freescale MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the following table.

Table 3. Pressure (P1) Side Delineation

Part Number	Case Type	Pressure (P1) Side Identifier
MPX2053D	344	Stainless Steep Cap
MPX2053DP	344C	Side with Part Marking
MPX2053GP	344B	Side with Port Attached
MPX2053GSX	344F	Side with Port Attached
MPXV2053GVP	344D	Stainless Steep Cap
MPXV2053GP	1369	Side with Port Attached
MPXV2053DP	1351	Side with Part Marking

Integrated Silicon Pressure Sensor for Manifold Absolute Pressure Applications On-Chip Signal Conditioned, Temperature Compensated and Calibrated

The Freescale MPX4101A/MPXA4101A/MPXH6101A series Manifold Absolute Pressure (MAP) sensor for engine control is designed to sense absolute air pressure within the intake manifold. This measurement can be used to compute the amount of fuel required for each cylinder. The small form factor and high reliability of on-chip integration makes the Freescale MAP sensor a logical and economical choice for automotive system designers.

The MPX4101A/MPXA4101A/MPXH6101A series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Features

- 1.72% Maximum Error Over 0° to 85°C
- Specifically Designed for Intake Manifold Absolute Pressure Sensing in Engine Control Systems
- Temperature Compensated Over –40°C to +125°C
- Durable Epoxy Unibody Element or Thermoplastic (PPS) Surface Mount Package

Typical Applications

- Manifold Sensing for Automotive Systems
- Ideally Suited for Microprocessor or Microcontroller-Based Systems
- Also Ideal for Non-Automotive Applications

UNIBODY PACKAGE PIN NUMBERS(1)			
1	V_{OUT}	4	N/C
2	GND	5	N/C
3	V_S	6	N/C

1. Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

SMALL OUTLINE PACKAGE PIN NUMBERS(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

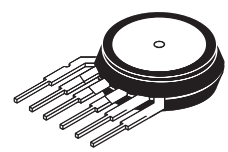
SUPER SMALL OUTLINE PACKAGE PIN NUMBERS(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

MPX4101A
MPXA4101A
MPXH6101A
SERIES

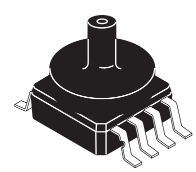
INTEGRATED PRESSURE SENSOR
15 TO 102 kPA
(2.18 TO 14.8 psi)
0.25 TO 4.95 V OUTPUT

UNIBODY PACKAGE



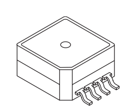
MPX4101A
CASE 867-O8

SMALL OUTLINE PACKAGE



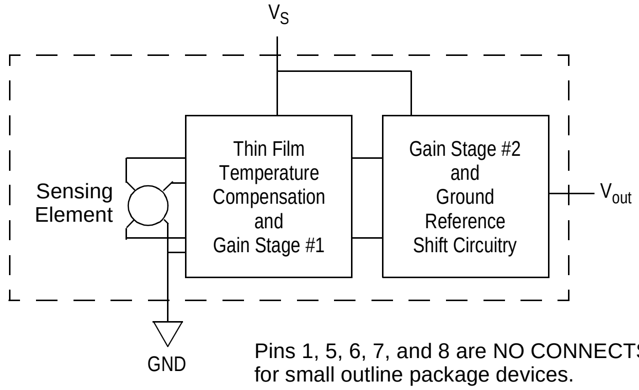
MPXA4101AC6U
CASE 482A-01

SUPER SMALL OUTLINE PACKAGE



MPXH6101A6U/6T1
CASE 1317-04

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
UNIBODY PACKAGE (MPX4101A SERIES)					
Basic Element	Absolute, Element Only	867	MPX4101A	—	MPX4101A
SMALL OUTLINE PACKAGE (MPXA4101A SERIES)					
Ported Element	Absolute, Axial Port	482A	MPXA4101AC6U	Rails	MPXA4101A
SUPER SMALL OUTLINE PACKAGE (MPXA6101A SERIES)					
Basic Element	Absolute, Element Only	1317	MPXH6101A6U	Rails	MPXH6101A
	Absolute, Element Only	1317	MPXH6101A6T1	Tape and Reel	MPXH6101A



Pins 1, 5, 6, 7, and 8 are NO CONNECTS for small outline package devices.

Pins 4, 5, and 6 are NO CONNECTS for unibody devices.

Figure 1. Temperature Compensated and Calibrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	400	kPa
Storage Temperature	T_{STG}	-40 to +125	°C
Operating Temperature	T_A	-40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 3 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]		P_{OP}	15	—	102	kPa
Supply Voltage[2]		V_S	4.85	5.1	5.35	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset @ V_S = 5.1 Volts[3]	(0 to 85°C)	V_{off}	0.171	0.252	0.333	Vdc
Full Scale Output @ V_S = 5.1 Volts[4]	(0 to 85°C)	V_{FSO}	4.870	4.951	5.032	Vdc
Full Scale Span @ V_S = 5.1 Volts[5]	(0 to 85°C)	V_{FSS}	—	4.7	—	Vdc
Accuracy[6]	(0 to 85°C)	—	—	—	±1.72	$\%V_{FSS}$
Sensitivity		V/P	—	54	—-	mV/kPa
Response Time[7]		t_R	—	15	—-	ms
Output Source Current at Full Scale Output		I_{o+}	—	0.1	—-	mAdc
Warm-Up Time[8]		—	—	20	—-	ms
Offset Stability[9]		—	—	±0.5	—-	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
    - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
    - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
    - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
    - TcSpan: Output deviation over the temperature range of 0 to 85°C, relative to 25°C.
    - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
    - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

Figure 2 illustrates an absolute sensing chip in the super small outline package (Case 1317).

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C. The output will saturate outside of the specified pressure range.

A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. The MPX4101A/MPXA4101A/MPXH6101A series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 3 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

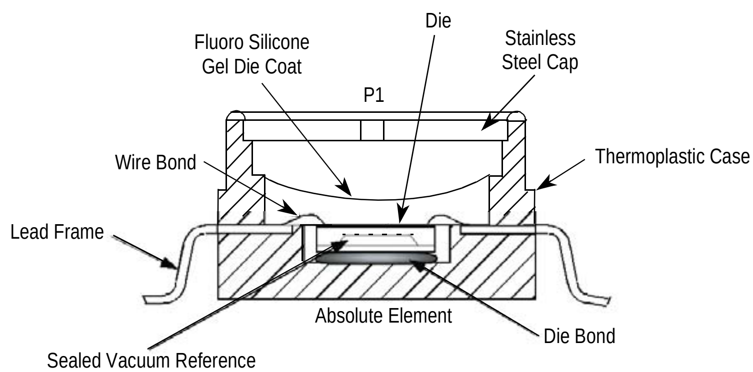


Figure 2. Cross Sectional Diagram SSOP (not to scale)

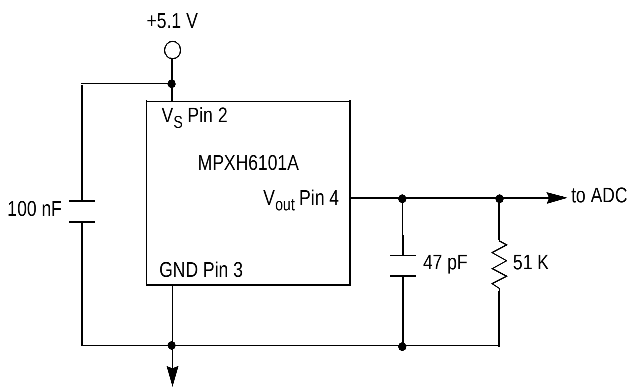


Figure 3. Recommended Power Supply Decoupling and Output Filtering

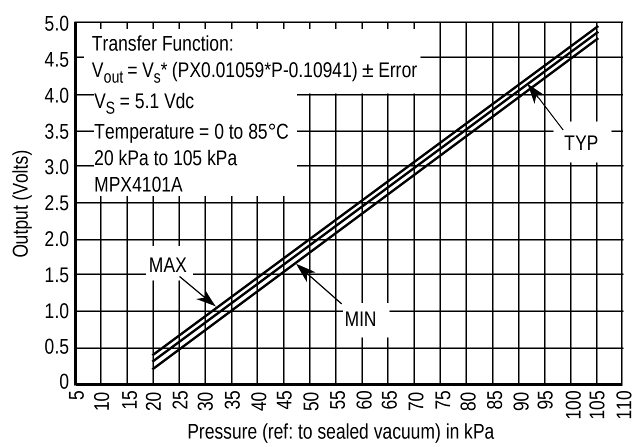


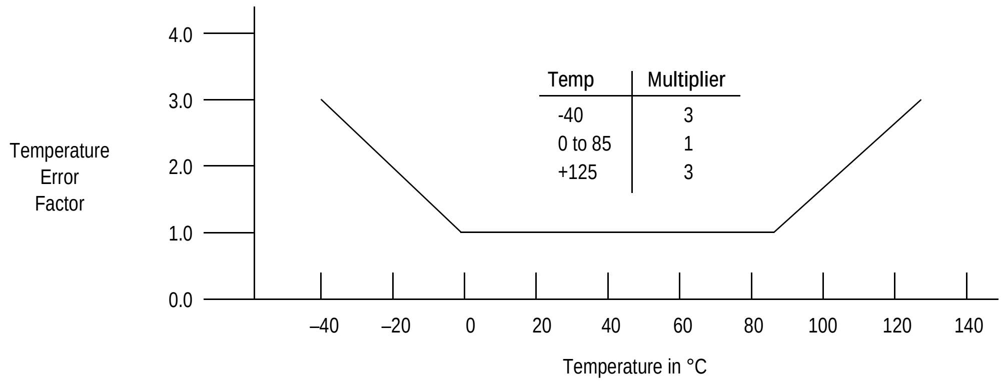
Figure 4. Output versus Absolute Pressure

Transfer Function (MPX4101A, MPXA4101A, MPXH6101A)

Nominal Transfer Value: $V_{out} = V_S (P \times 0.01059 - 0.10941)$
$\pm$ (Pressure Error x Temp. Factor x 0.01059 x V_S)
$V_S = 5.1\ V \pm 0.25\ Vdc$

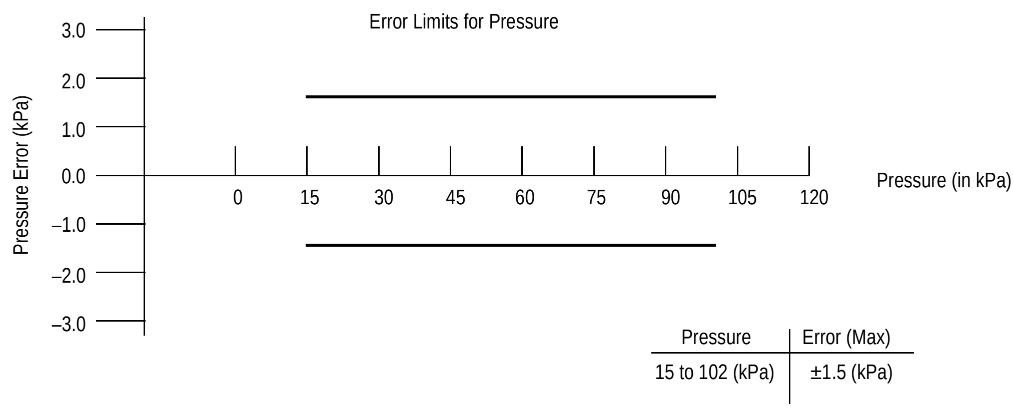
Temperature Error Band

MPX4101A, MPXA4101A MPXH6101A SERIES



NOTE: The Temperature Multiplier is a linear response from 0°C to –40°C and from 85°C to 125°C.

Pressure Error Band



PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluorosilicone gel which protects the die from harsh media. The Freescale pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX4101A	867	Stainless Steel Cap
MPXA4101AC6U	482A	Side with Port Attached
MPXH6101A6U	1317	Stainless Steel Cap
MPXH6101A6T1	1317	Stainless Steel Cap

INFORMATION FOR USING THE SMALL OUTLINE PACKAGES

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

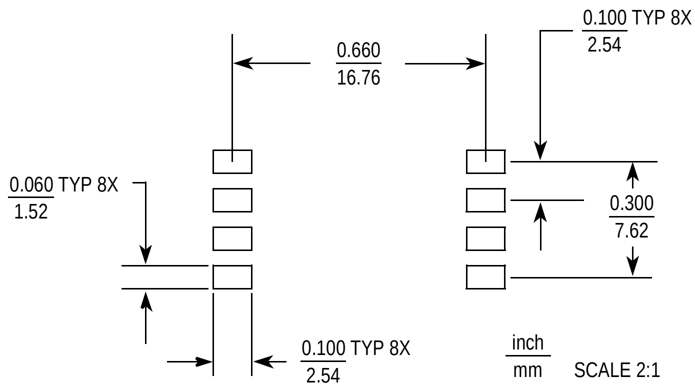


Figure 5. SOP Footprint (Case 482)

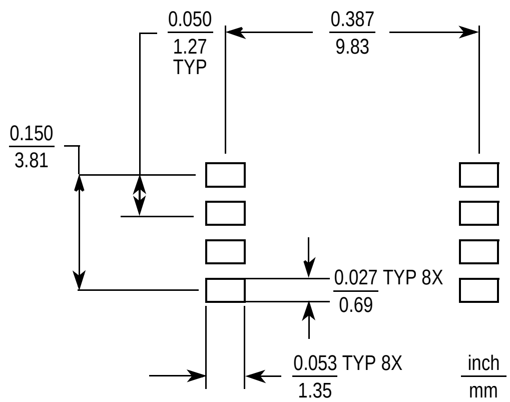


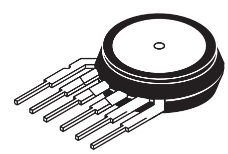
Figure 6. SSOP Footprint (Case 1317)

Integrated Silicon Pressure Sensor for Manifold Absolute Pressure Applications On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPX4105A SERIES

INTEGRATED PRESSURE SENSOR
15 TO 105 kPA (2.2 TO 15.2 psi)
0.3 TO 4.9 V OUTPUT

UNIBODY PACKAGE



MPX4105A
CASE 867-08

PIN NUMBERS(1)			
1	V_{out}	4	N/C
2	GND	5	N/C
3	V_S	6	N/C

1. Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

The Freescale MPX4105A series Manifold Absolute Pressure (MAP) sensor for engine control is designed to sense absolute air pressure within the intake manifold. This measurement can be used to compute the amount of fuel required for each cylinder.

Freescale's MAP sensor integrates on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The small form factor and high reliability of on-chip integration make the Freescale MAP sensor a logical and economical choice for the automotive system designer.

The MPX4105A series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

Features

- 1.8% Maximum Error Over 0° to 85°C
- Specifically Designed for Intake Manifold Absolute Pressure Sensing in Engine Control Systems
- Temperature Compensated Over –40 to +125°C
- Durable Epoxy Unibody Element

Typical Applications

- Manifold Sensing for Automotive Systems
- Ideally Suited for Microprocessor or Microcontroller-Based Systems
- Also Ideal for Non-Automotive Applications

ORDERING INFORMATION				
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Device Marking**
UNIBODY PACKAGE (MPX4105A SERIES)				
Basic Element	Absolute, Element	867	MPX4105A	MPX4105A

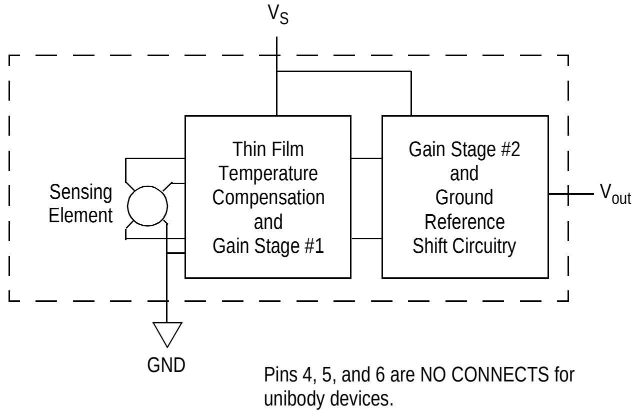


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings[1]

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	400	kPa
Storage Temperature	T_{STG}	-40 to +125	°C
Operating Temperature	T_A	-40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 3 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]		P_{OP}	15	—	105	kPa
Supply Voltage[2]		V_S	4.85	5.1	5.35	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset[3]	(0 to 85°C)	V_{off}	0.184	0.306	0.428	Vdc
Full Scale Output[4]	(0 to 85°C)	V_{FSO}	4.804	4.896	4.988	Vdc
Full Scale Span[5]	(0 to 85°C)	V_{FSS}	—	4.590	—	Vdc
Accuracy[6]	(0 to 85°C)	—	—	—	±1.8	$\%V_{FSS}$
Sensitivity		ΔV/ΔP	—	51	—-	mV/kPa
Response Time[7]		t_R	—	1.0	—-	ms
Output Source Current at Full Scale Output		I_{o+}	—	0.1	—-	mAdc
Warm-Up Time[8]		—	—	15	—-	ms
Offset Stability[9]		—	—	±0.65	—-	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

Table 3. Mechanical Characteristics

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	grams

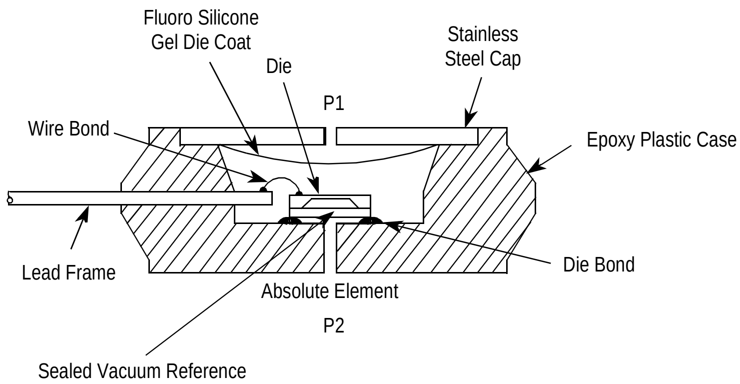


Figure 2. Cross Sectional Diagram (not to scale)

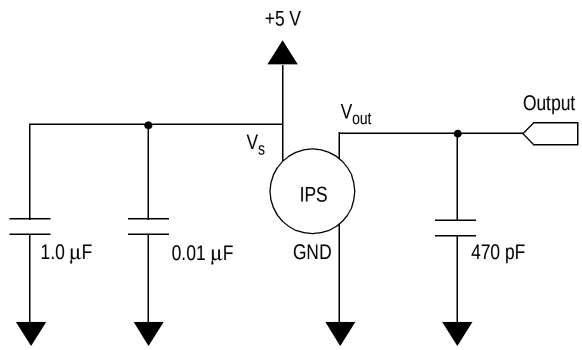


Figure 3. Recommended Power Supply Decoupling and Output Filtering

(For additional output filtering, please refer to Application Note AN1535)

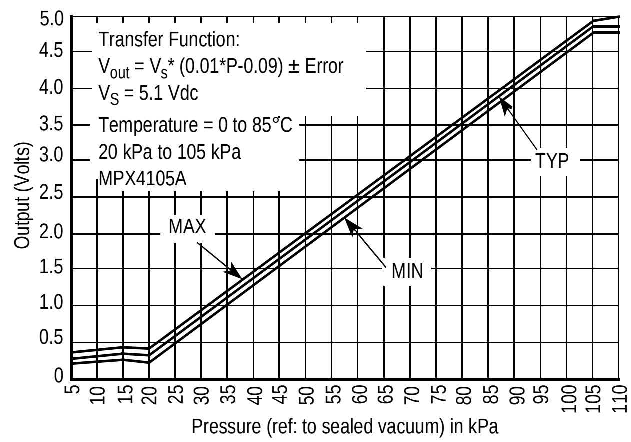


Figure 4. Output versus Absolute Pressure

Figure 2 illustrates an absolute sensing chip in the basic chip carrier (Case 867).

A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. The MPX4105A series pressure sensor operating characteristics, internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 3 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

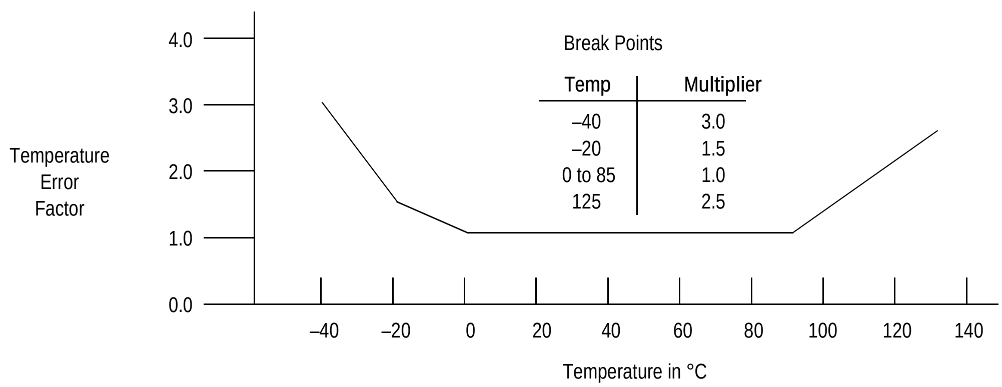
Figure 4 shows the sensor output signal relative to pressure input. Typical minimum and maximum output curves are shown for operation over a temperature range of 0° to 85°C. The output will saturate outside of the specified pressure range.

Transfer Function (MPX4105A)

Nominal Transfer Value: $V_{out} = V_S$ (P x 0.01 - 0.09)
± (Pressure Error x Temp. Factor x 0.01 x V_S)
V_S = 5.1 V ± 0.25 Vdc

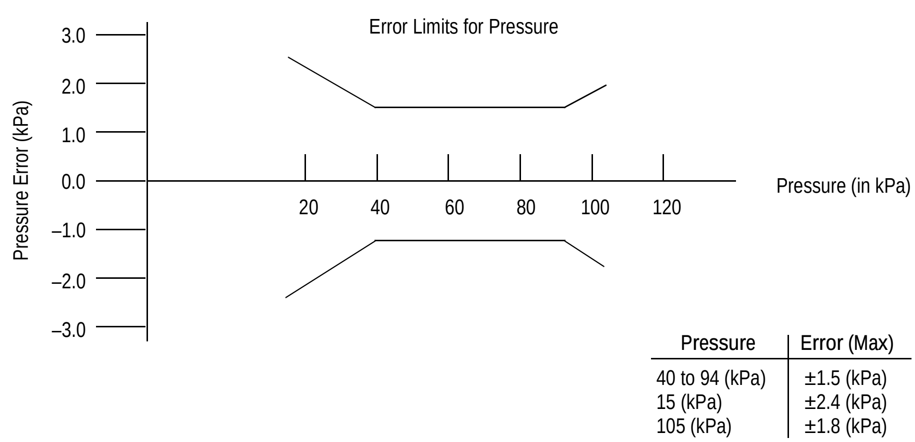
Temperature Error Band

MPX4105A Series



NOTE: The Temperature Multiplier is a linear response from –40°C to –20°C, –20°C to 0°C, and from 85°C to 125°C.

Pressure Error Band

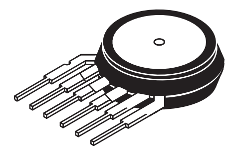


Integrated Silicon Pressure Sensor for Manifold Absolute Pressure Applications On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPX4200A SERIES

INTEGRATED PRESSURE SENSOR
20 to 200 kPa (2.9 to 29 psi)
0.3 to 4.9 V OUTPUT

UNIBODY PACKAGE



MPX4200A
CASE 867-08

PIN NUMBERS[(1)]			
1	V_{out}	4	N/C
2	GND	5	N/C
3	V_S	6	N/C

1. Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

The Freescale MPX4200A series Manifold Absolute Pressure (MAP) sensor for turbo boost engine control is designed to sense absolute air pressure within the intake manifold. This measurement can be used to compute the amount of fuel required for each cylinder.

The MPX4200A series sensor integrates on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high level analog output signal and temperature compensation. The small form factor and reliability of on-chip integration make the Freescale MAP sensor a logical and economical choice for automotive system designers.

Features

- Specifically Designed for Intake Manifold Absolute Pressure Sensing in Engine Control Systems
- Patented Silicon Shear Stress Strain Gauge
- Temperature Compensated Over –40° to +125°C
- Offers Reduction in Weight and Volume Compared to Existing Hybrid Modules
- Durable Epoxy Unibody Element

Typical Applications

- Manifold Sensing for Automotive Systems
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Also ideal for Non-Automotive Applications

ORDERING INFORMATION				
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Device Marking**
UNIBODY PACKAGE (MPX4200A SERIES)				
Basic Element	Absolute, Element	867	MPX4200A	MPX4200A

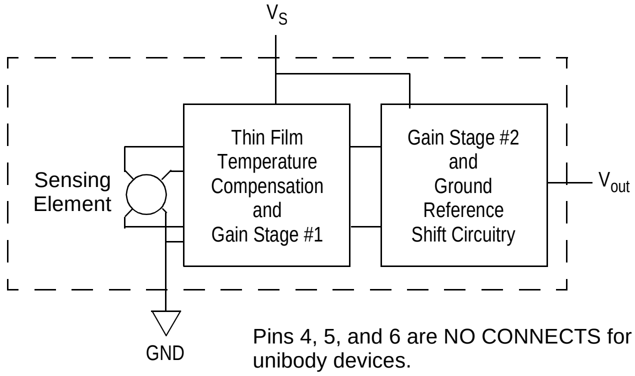


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	800	kPa
Storage Temperature	T_{STG}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 3 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]		P_{OP}	20	—	200	kPa
Supply Voltage[2]		V_S	4.85	5.1	5.35	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset @ V_S = 5.1 Volts[3]	(0 to 85°C)	V_{off}	0.199	0.306	0.413	Vdc
Full Scale Output @ V_S = 5.1 Volts[4]	(0 to 85°C)	V_{FSO}	4.725	4.896	4.978	Vdc
Full Scale Span @ V_S = 5.1 Volts[5]	(0 to 85°C)	V_{FSS}	—	4.590	—	Vdc
Accuracy[6]	(0 to 85°C)	—	—	—	±1.5	$\%V_{FSS}$
Sensitivity		V/P	—	25.5	—-	mV/kPa
Response Time[7]		t_R	—	1.0	—-	ms
Output Source Current at Full Scale Output		I_{o+}	—	0.1	—-	mAdc
Warm-Up Time[8]		—	—	20	—-	ms
Offset Stability[9]		—	—	±0.5	—-	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

Table 3. Mechanical Characteristics

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	grams

ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

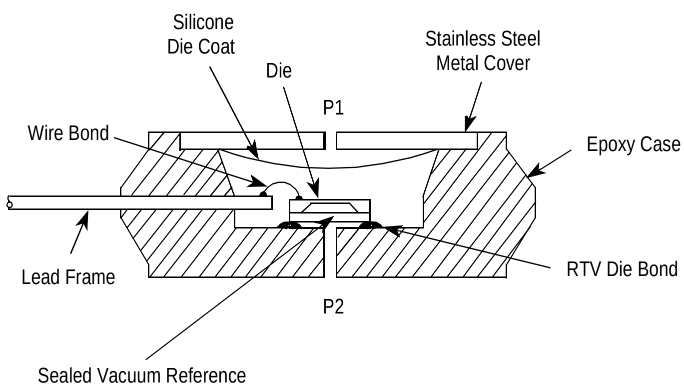


Figure 2. Cross Sectional Diagram (not to scale)

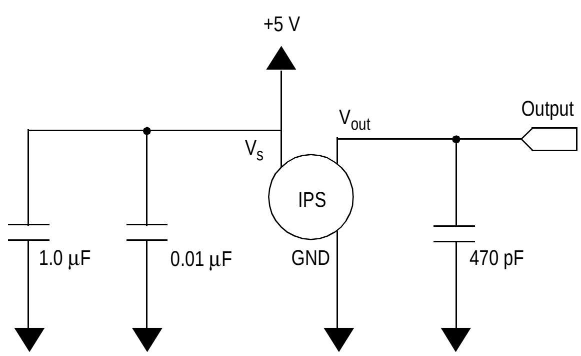


Figure 3. Recommended Power Supply Decoupling and Output Filtering

(For additional output filtering, please refer to Application Note AN1535)

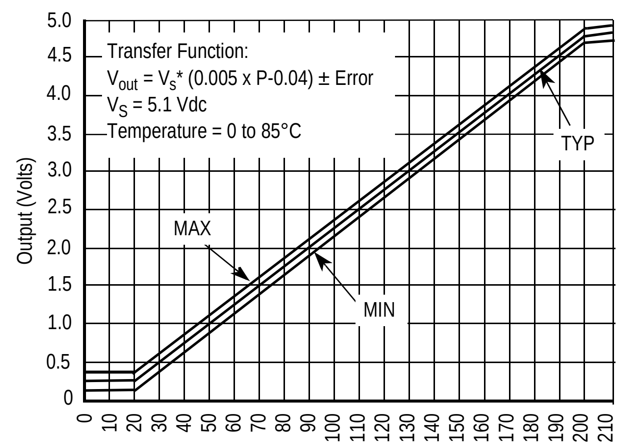


Figure 4. Output versus Absolute Pressure

Figure 2 illustrates the absolute sensing chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. The MPX4200A series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 3 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

Figure 4 shows the sensor output signal relative to pressure input. Typical minimum and maximum output curves are shown for operation over temperature range of 0° to 85°C. The output will saturate outside of the specified pressure range.

Freescale Semiconductor
Technical Data

MPX4250A
Rev 5, 05/2005

Integrated Silicon Pressure Sensor Manifold Absolute Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

The MPX4250A/MPXA4250A series Manifold Absolute Pressure (MAP) sensor for engine control is designed to sense absolute air pressure within the intake manifold. This measurement can be used to compute the amount of fuel required for each cylinder.

The MPX4250A/MPXA4250A series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, particularly those employing a microcontroller or microprocessor with A/D inputs. This transducer combines advanced micromachining techniques, thin-film metallization and bipolar processing to provide an accurate, high-level analog output signal that is proportional to the applied pressure. The small form factor and high reliability of on-chip integration make the Freescale sensor a logical and economical choice for the automotive system engineer.

Features

- 1.5% Maximum Error Over 0° to 85°C
- Specifically Designed for Intake Manifold Absolute Pressure Sensing in Engine Control Systems
- Patented Silicon Shear Stress Strain Gauge
- Temperature Compensated Over -40° to +125°C
- Offers Reduction in Weight and Volume Compared to Existing Hybrid Modules
- Durable Epoxy Unibody Element or Thermoplastic Small Outline, Surface Mount Package
- Ideal for Non-Automotive Applications

Typical Applications

- Turbo Boost Engine Control
- Ideally Suited for Microprocessor or Microcontroller-Based Systems

ORDERING INFORMATION

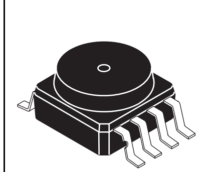
Device Type	Options	Case No.	MPX Series Order Number	Packing Options	Device Marking
SMALL OUTLINE PACKAGE[1] (MPXA4250A SERIES)					
Basic Elements	Absolute, Element Only	482	MPXA4250A6U	Rails	MPXA4250A
		482	MPXA4250A6T1	Tape & Reel	MPXA4250A
Ported Elements	Absolute, Axial Port	482A	MPXA4250AC6U	Rails	MPXA4250A
		482A	MPXA4250AC6T1	Tape & Reel	MPXA4250A
UNIBODY PACKAGE[2] (MPX4250A SERIES)					
Basic Element	Absolute, Element Only	867	MPX4250A	—	MPX4250A
Ported Elements	Absolute, Ported	867B	MPX4250AP	—	MPX4250AP

1. The MPXA4250A series pressure sensors are available in the basic element package or with pressure port fitting. Two packing options are offered for each type.
2. The MPX4250A series pressure sensors are available in the basic element package or with pressure port fittings providing mounting ease and barbed hose connections.

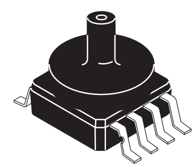
MPX4250A
MPXA4250A
SERIES

INTEGRATED PRESSURE SENSOR
20 TO 250 kPA (2.9 TO 36.3 psi)
0.2 TO 4.9 V OUTPUT

SMALL OUTLINE PACKAGES



MPXA4250A6U/6T1
CASE 482-01



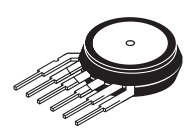
MPXA4250AC6U/C6T1
CASE 482A-01

SMALL OUTLINE PACKAGE PIN NUMBERS

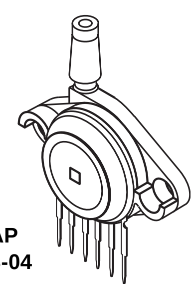
1	N/C[1], [2]	5[2]	N/C
2	V_S	6[2]	N/C
3	GND	7[2]	N/C
4	V_{OUT}	8	N/C

1. Pin 1 in noted by the notch in the lead.
2. Pins 1, 5, 6, and 7 are internal device connections. Do not connect to external circuitry or ground.

UNIBODY PACKAGES



MPX4250A
CASE 867-08



MPX4250AP
CASE 867B-04

UNIBODY PACKAGE PIN NUMBERS

1	V_{OUT}[1]	4	N/C[2]
2	GND	5	N/C[2]
3	V_S	6	N/C[2]

1. Pin 1 in noted by the notch in the lead.
2. Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground.

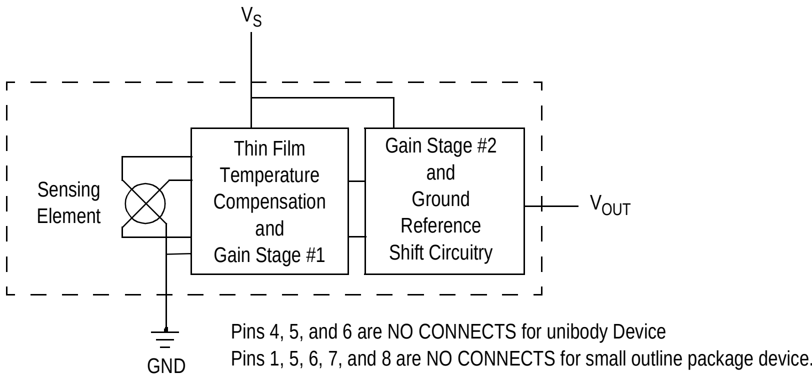


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure(2) (P1 > P2)	P_{MAX}	1000	kPa
Storage Temperature	T_{STG}	-40 to +125	°C
Operating Temperature	T_A	-40 to +125	°C

1. TC = 25°C unless otherwise noted.
2. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 5.1 V_{DC}, T_A = 25°C unless otherwise noted, P1 > P2, Decoupling circuit shown in Figure 3 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Units
Differential Pressure Range(1)		P_{OP}	20	—	250	kPa
Supply Voltage(2)		V_S	4.85	5.1	5.35	V_{DC}
Supply Current		I_O	—	7.0	10	mAdc
Minimum Pressure Offset(3) @ V_S = 5.1 Volts	(0 to 85°C)	V_{OFF}	0.133	0.204	0.264	V_{DC}
Full Scale Output(4) @ V_S = 5.1 Volts	(0 to 85°C)	V_{FSO}	4.826	4.896	4.966	V_{DC}
Full Scale Span(5) @ V_S = 5.1 Volts	(0 to 85°C)	V_{FSS}	—	4.692	—	V_{DC}
Accuracy(6)	(0 to 85°C)	—	—	—	±1.5	$\%V_{FSS}$
Sensitivity		$\Delta V/\Delta P$	—	20	—	mV/kPa
Response Time(7)		t_R	—	1.0	—	msec
Output Source Current at Full Scale Output		I_O+	—	0.1	—	mAdc
Warm-Up Time(8)		—	—	20	—	msec
Offset Stability(9)		—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{OFF}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation at any temperature from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of VFSS, at 25°C.
7. Response Time is defined as the time form the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the pressure is stabilized.
9. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

Table 3. Mechanical Characteristics

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	Grams
Weight, Small Outline Package (Case 482)	1.5	Grams

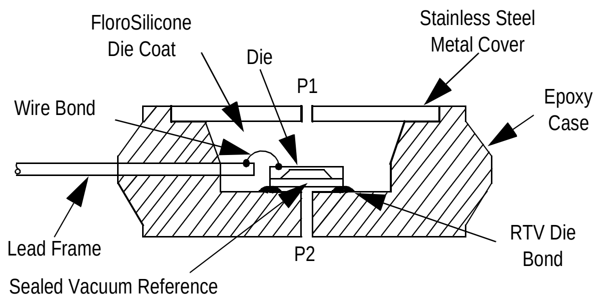


Figure 2. Cross Sectional Diagram (Not to Scale)

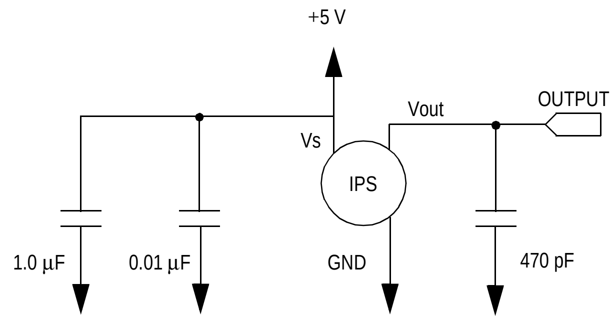


Figure 3. Recommended Power Supply Decoupling and Output Filtering

(For additional output filtering, please refer to Application Note AN1646.

Figure 2 illustrates the absolute pressure sensing chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm.

The MPX4250A/MPXA4250A series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability.

Contact the factory for information regarding media compatibility in your application.

Figure 3 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller.

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over temperature range of 0° to 85°C using the decoupling circuit shown in Figure 3. The output will saturate outside of the specified pressure range.

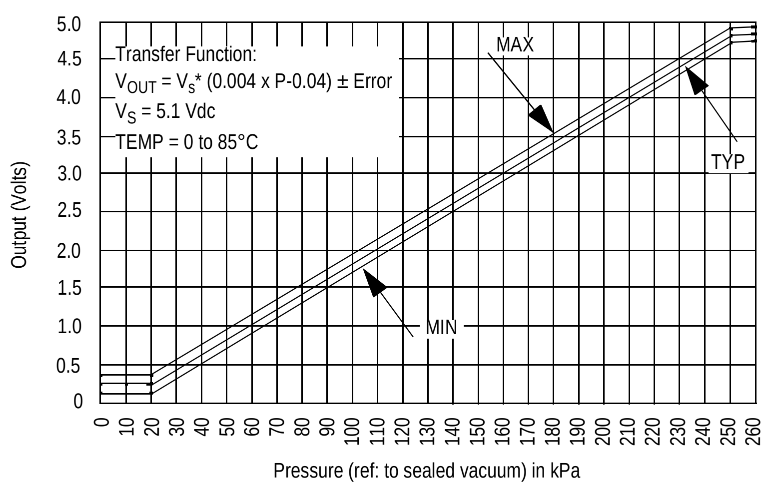
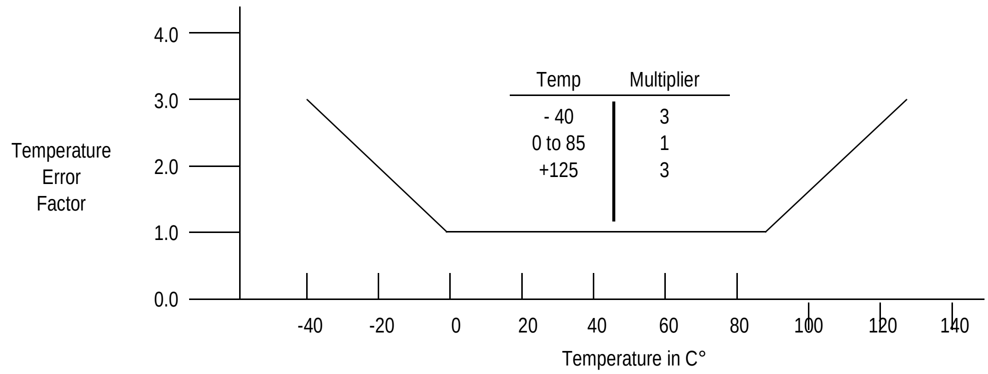


Figure 4. Output vs. Absolute Pressure

Transfer Function

Nominal Transfer Value: $V_{OUT} = V_S (P \times 0.004 - 0.04)$
$\pm$ (Pressure Error $\times$ Temp. Factor $\times$ $0.004 \times V_S$)
$V_S = 5.1\text{ V} \pm 0.25\ V_{DC}$

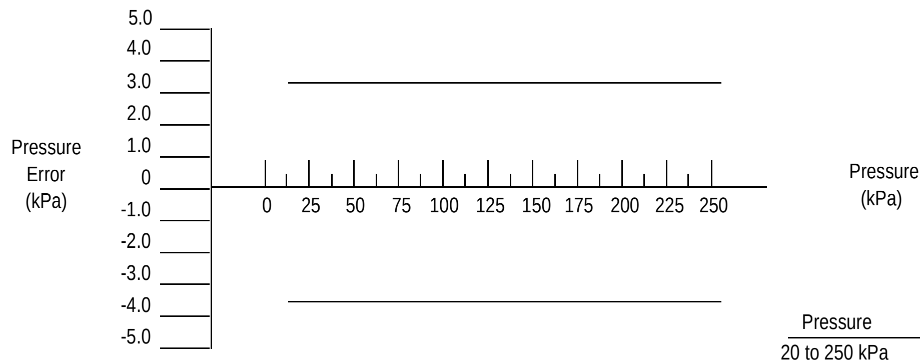
Temperature Error Band



Temp	Multiplier
- 40	3
0 to 85	1
+125	3

NOTE: The Temperature Multiplier is a linear response from 0× to -40°C and from 85° to 125°C.

Pressure Error Band



Pressure	Error (Max)
20 to 250 kPa	±3.45 (kPa)

INFORMATION FOR USING THE SMALL OUTLINE PACKAGE (CASE 482)

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct Footprint, the packages will self align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

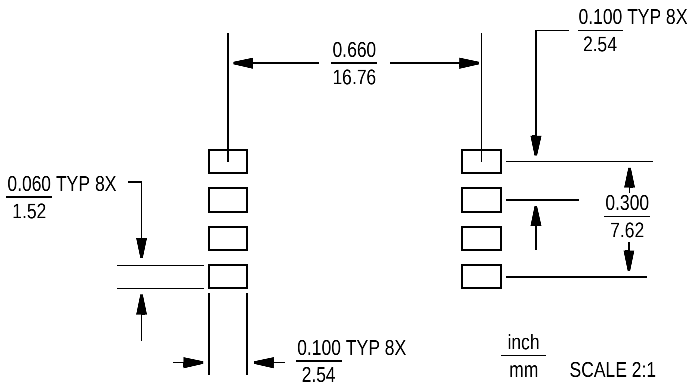


Figure 5. SOP Footprint (Case 482)

Freescale Semiconductor
Technical Data

MPX4250D
Rev 4, 05/2005

Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

The MPX4250D series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, particularly those employing a microcontroller or microprocessor with A/D inputs. This transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high-level analog output signal that is proportional to the applied pressure. The small form factor and high reliability of on-chip integration make the Freescale sensor a logical and economical choice for the automotive system engineer.

Features

- Differential and Gauge Applications Available
- 1.4% Maximum Error Over 0° to 85°C
- Patented Silicon Shear Stress Strain Gauge
- Temperature Compensated Over –40° to +125°C
- Offers Reduction in Weight and Volume Compared to Existing Hybrid Modules
- Durable Epoxy Unibody Element

Typical Applications

- Ideally Suited for Microprocessor or Microcontroller-Based Systems

ORDERING INFORMATION(1)

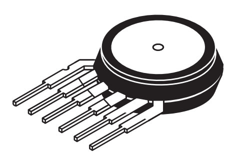
Device Type	Case No.	MPX Series Order No.	Device Marking
UNIBODY PACKAGE (MPX4250D SERIES)			
Basic Element	867	MPX4250D	MPX4250D
Gauge Ported Element	867B	MPX4250GP	MPX4250GP
Dual Ported Element	867C	MPX4250DP	MPX4250DP

1. The MPX4250D series silicon pressure sensors are available in the basic element package or with pressure port fittings that provide mounting ease and barbed hose connections.

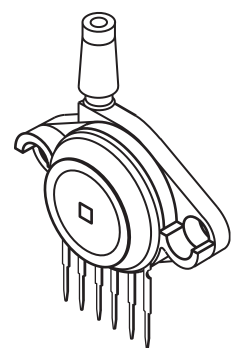
MPX4250D SERIES

INTEGRATED PRESSURE SENSOR
0 TO 250 kPA (0 TO 36.3 psi)
0.2 TO 4.9 V OUTPUT

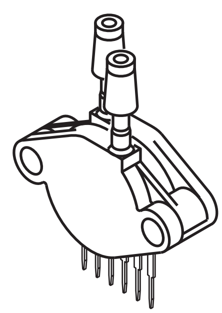
UNIBODY PACKAGES



BASIC CHIP CARRIER ELEMENT CASE 867-08 STYLE 1



GAUGE PORT OPTION CASE 867B-04 STYLE 1



DUAL PORT OPTION CASE 867C-05 STYLE 1

PIN NUMBERS(1)

1	V_{out}	4	N/C
2	GND	5	N/C
3	V_S	6	N/C

1. Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

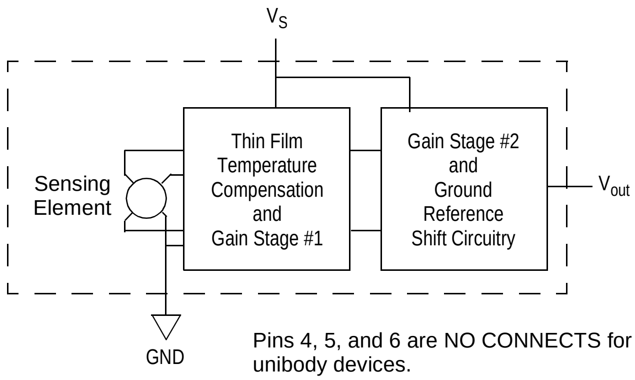


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings[1]

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	1000	kPa
Storage Temperature	T_{STG}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 3 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]		P_{OP}	0	—	250	kPa
Supply Voltage[2]		V_S	4.85	5.1	5.35	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset @ V_S = 5.1 Volts[3]	(0 to 85°C)	V_{off}	0.139	0.204	0.269	Vdc
Full Scale Output @ V_S = 5.1 Volts[4]	(0 to 85°C)	V_{FSO}	4.844	4.909	4.974	Vdc
Full Scale Span @ V_S = 5.1 Volts[5]	(0 to 85°C)	V_{FSS}	—	4.705	—	Vdc
Accuracy[6]	(0 to 85°C)	—	—	—	±1.4	$\%V_{FSS}$
Sensitivity		$\Delta V/\Delta P$	—	18.8	—-	mV/kPa
Response Time[7]		t_R	—	1.0	—-	ms
Output Source Current at Full Scale Output		I_{o+}	—	0.1	—-	mAdc
Warm-Up Time[8]		—	—	20	—-	ms
Offset Stability[9]		—	—	±0.5	—-	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

Table 3. Mechanical Characteristics

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	grams

ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

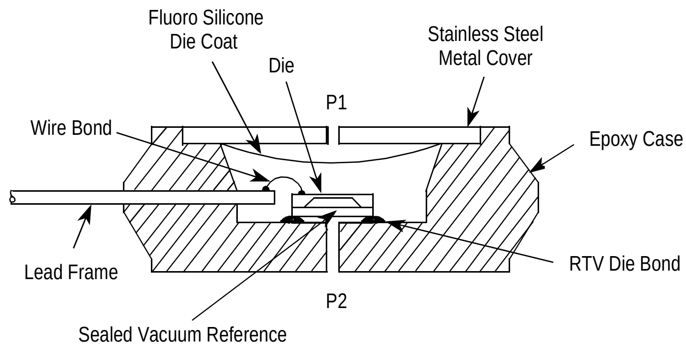


Figure 2. Cross Sectional Diagram (not to scale)

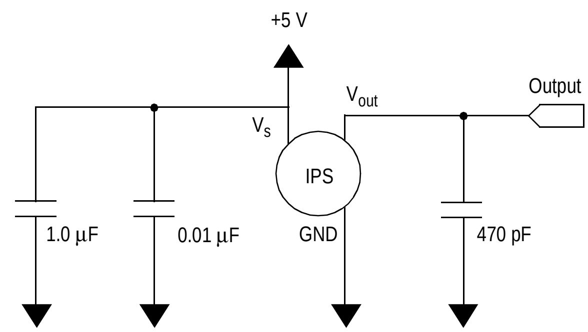


Figure 3. Recommended Power Supply Decoupling and Output Filtering
(For additional output filtering, please refer to Application Note AN1535)

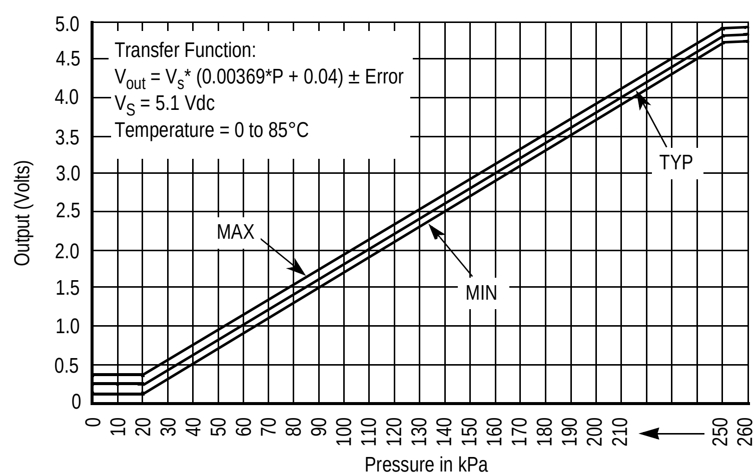


Figure 4. Output versus Absolute Pressure

Figure 2 illustrates the differential/gauge pressure sensing chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm.

The MPX4250D series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

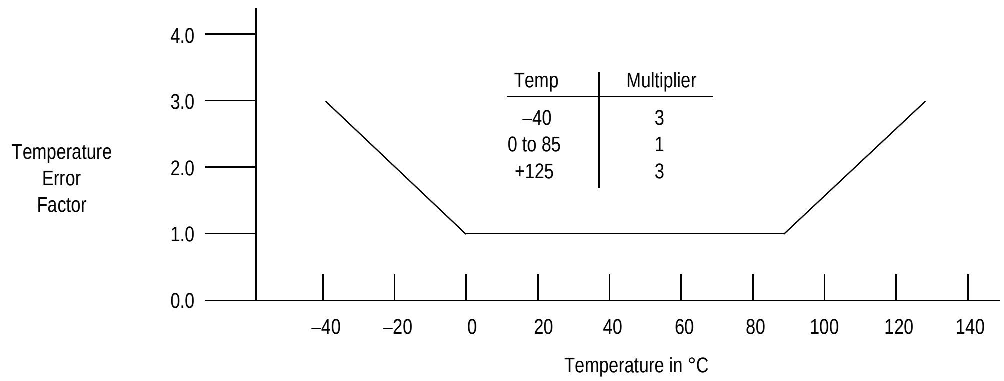
Figure 3 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller.

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit shown in Figure 3. The output will saturate outside of the specified pressure range.

Transfer Function (MPX4250D)

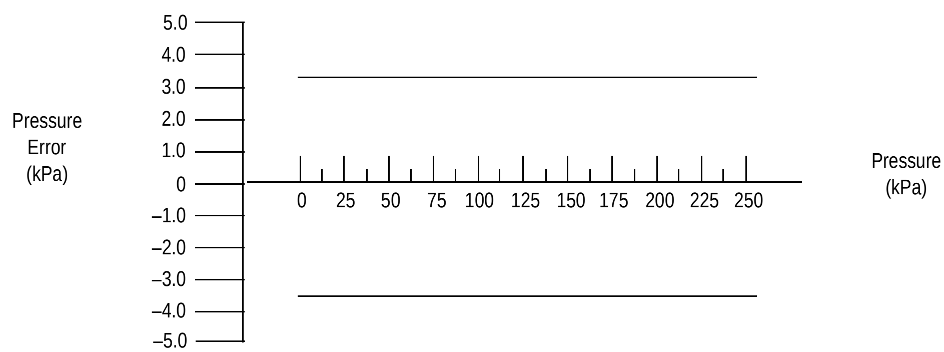
Nominal Transfer Value: $V_{out} = V_S \times (0.00369 \times P + 0.04)$
$\pm$ (Pressure Error x Temp. Factor x $0.00369 \times V_S$)
$V_S = 5.1 \pm 0.25$ Vdc

Temperature Error Band



NOTE: The Temperature Multiplier is a linear response from 0°C to –40°C and from 85°C to 125°C.

Pressure Error Band



Pressure	Error (Max)
0 to 250 kPa	±3.45 kPa

Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPX5010
MPXV5010G
SERIES

INTEGRATED PRESSURE SENSOR
0 to 10 kPa (0 to 1.45 psi)
0.2 to 4.7 V OUTPUT

The MPX5010/MPXV5010G series piezoresistive transducers are state-of-the-art monolithic silicon pressure sensors designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

Features

- 5.0% Maximum Error over 0° to 85°C
- Ideally Suited for Microprocessor or Microcontroller-Based Systems
- Durable Epoxy Unibody and Thermoplastic (PPS) Surface Mount Package
- Temperature Compensated over –40° to +125°C
- Patented Silicon Shear Stress Strain Gauge
- Available in Differential and Gauge Configurations
- Available in Surface Mount (SMT) or Through-hole (DIP) Configurations

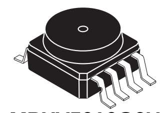
Application Examples

- Hospital Beds
- HVAC
- Respiratory Systems
- Process Control

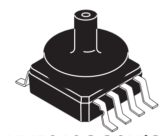
ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
SMALL OUTLINE PACKAGE (MPXV5010G SERIES)					
Basic Elements	Gauge, Element Only, SMT	482	MPXV5010G6U	Rails	MPXV5010G
	Gauge, Element Only, DIP	482B	MPXV5010G7U	Rails	MPXV5010G
Ported Elements	Gauge, Axial Port, SMT	482A	MPXV5010GC6U	Rails	MPXV5010G
	Gauge, Axial Port, DIP	482C	MPXV5010GC7U	Rails	MPXV5010G
	Gauge, Axial Port, SMT	482A	MPXV5010GC6T1	Tape & Reel	MPXV5010G
	Gauge, Side Port, SMT	1369	MPXV5010GP	Trays	MPXV5010G
	Gauge, Dual Port, SMT	1351	MPXV5010DP	Trays	MPXV5010G
UNIBODY PACKAGE (MPX2202 SERIES)					
Basic Element	Differential	867	MPX5010D	—	MPXV5010D
Ported Elements	Differential, Gauge	867C	MPX5010DP	—	MPXV5010DP
	Gauge	867B	MPX5010GP	—	MPXV5010GP
	Gauge, Axial	867E	MPX5010GS	—	MPXV5010D
	Gauge, Axial PC Mount	867F	MPX5010GSX	—	MPXV5010D

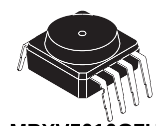
SMALL OUTLINE PACKAGE



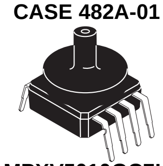
MPXV5010G6U
CASE 482-01



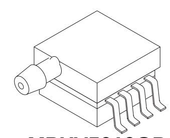
MPXV5010GC6U/C6T1
CASE 482A-01



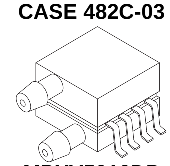
MPXV5010G7U
CASE 482B-03



MPXV5010GC7U
CASE 482C-03



MPXV5010GP
CASE 1369-01



MPXV5010DP
CASE 1351-01

UNIBODY PACKAGE PIN NUMBERS(1)

1	V_{out}	4	N/C
2	Gnd	5	N/C
3	V_S	6	N/C

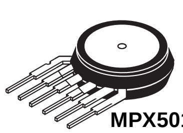
1. Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

SMALL OUTLINE PACKAGE PIN NUMBERS(1)

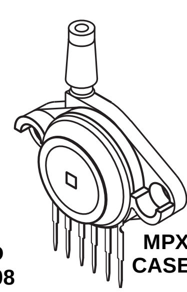
1	N/C	5	N/C
2	V_S	6	N/C
3	Gnd	7	N/C
4	V_{out}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

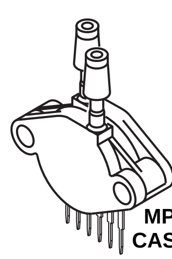
UNIBODY PACKAGES



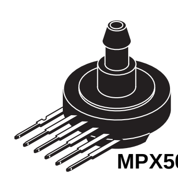
MPX5010D
CASE 867-08



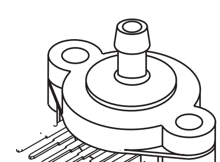
MPX5010GP
CASE 867B-04



MPX5010DP
CASE 867C-05



MPX5010GS
CASE 867E-03



MPX5010GSX
CASE 867F-03

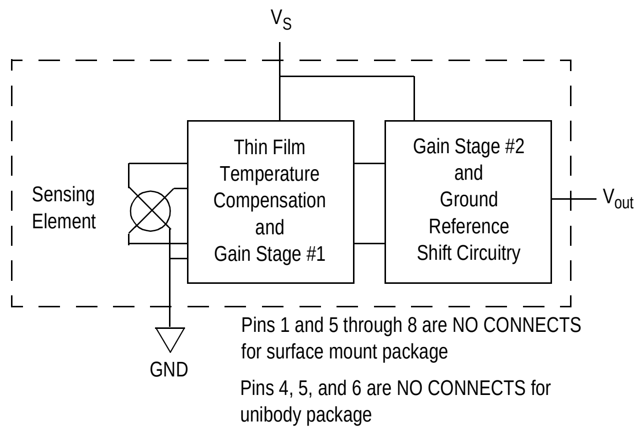


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings[1]

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{max}	75	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 3 required to meet specification.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]		P_{OP}	0	—	10	kPa
Supply Voltage[2]		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	—	5.0	10	mAdc
Minimum Pressure Offset[3] @ V_S = 5.0 Volts	(0 to 85°C)	V_{off}	0	0.2	0.425	Vdc
Full Scale Output[4] @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSO}	4.475	4.7	4.925	Vdc
Full Scale Span[5] @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSS}	4.275	4.5	4.725	Vdc
Accuracy[6]	(0 to 85°C)	—	—	—	±5.0	$\%V_{FSS}$
Sensitivity		V/P	—	450	—-	mV/kPa
Response Time[7]		t_R	—	1.0	—-	ms
Output Source Current at Full Scale Output		I_{O+}	—	0.1	—-	mAdc
Warm-Up Time[8]		—	—	20	—-	ms
Offset Stability[9]		—	—	±0.5	—-	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

Table 3. Mechanical Characteristics

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	grams
Weight, Basic Element (Case 482)	1.5	grams

ON-CHIP TEMPERATURE COMPENSATION, CALIBRATION AND SIGNAL CONDITIONING

The performance over temperature is achieved by integrating the shear-stress strain gauge, temperature compensation, calibration and signal conditioning circuitry onto a single monolithic chip.

Figure 2 illustrates the Differential or Gauge configuration in the basic chip carrier (Case 482). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm.

The MPX5010 and MPXV5010G series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 3 shows the recommended decoupling circuit for interfacing the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit shown in Figure 3. The output will saturate outside of the specified pressure range.

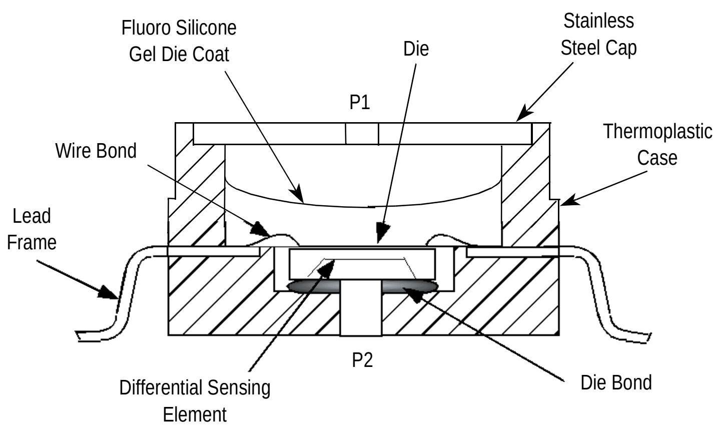


Figure 2. Cross-Sectional Diagram SOP (not to scale)

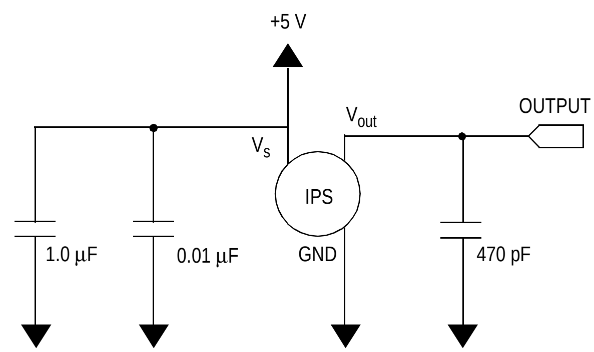


Figure 3. Recommended Power Supply Decoupling and Output Filtering

(For additional output filtering, please refer to Application Note AN1646.)

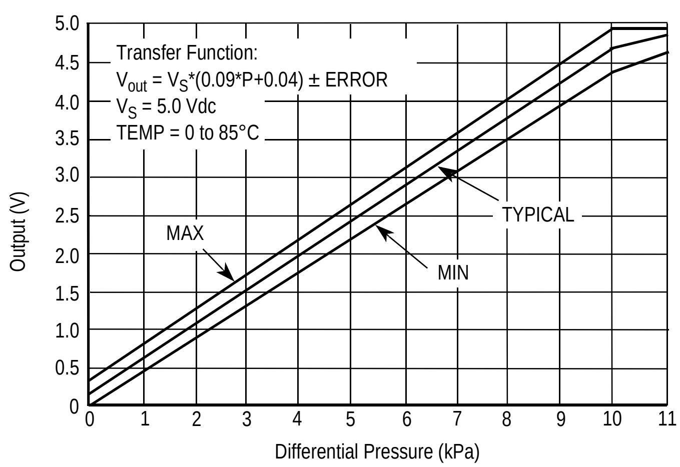


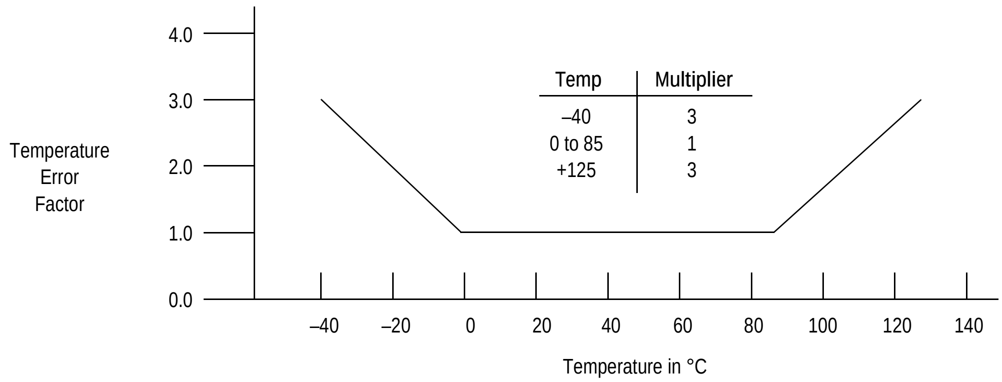
Figure 4. Output versus Pressure Differential

Transfer Function (MPX5010, MPXV5010G)

Nominal Transfer Value: $V_{out} = V_S \times (0.09 \times P + 0.04)$
$\pm$ (Pressure Error x Temp. Factor x 0.09 x V_S)
$V_S = 5.0\ V \pm 0.25\ Vdc$

Temperature Error Band

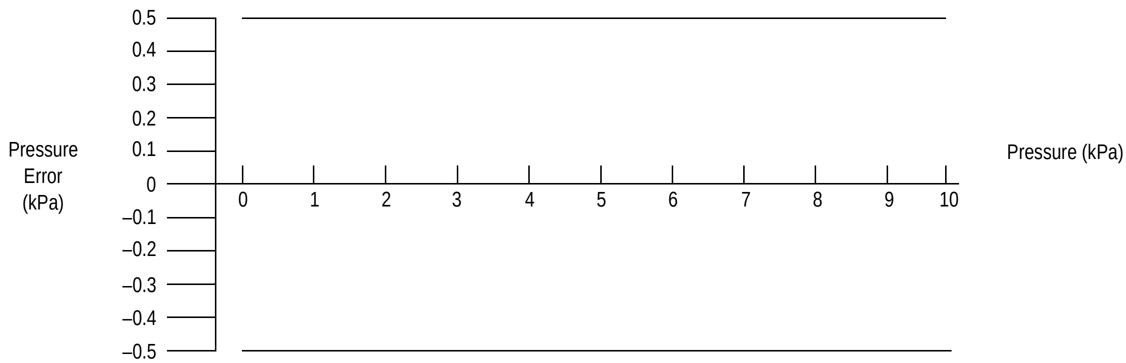
MPX5010, MPXV5010G SERIES



Temp	Multiplier
–40	3
0 to 85	1
+125	3

NOTE: The Temperature Multiplier is a linear response from 0° to –40°C and from 85° to 125°C.

Pressure Error Band



Pressure	Error (Max)
0 to 10 (kPa)	±0.5 (kPa)

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluorosilicone gel which protects the die from harsh media. The MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX5010D	867	Stainless Steel Cap
MPX5010DP	867C	Side with Part Marking
MPX5010GP	867B	Side with Port Attached
MPX5010GS	867E	Side with Port Attached
MPX5010GSX	867F	Side with Port Attached
MPXV5010G6U	482	Stainless Steel Cap
MPXV5010G7U	482B	Stainless Steel Cap
MPXV5010GC6U/T1	482A	Side with Port Attached
MPXV5010GC7U	482C	Side with Port Attached
MPXV5010GP	1369	Side with Port Attached
MPXV5010DP	1351	Side with Part Marking

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

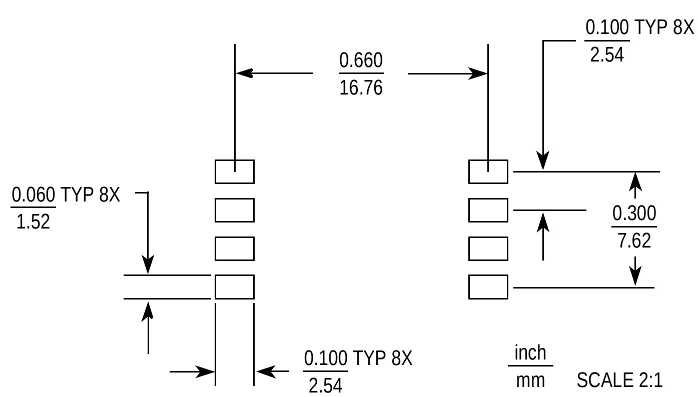


Figure 5. SOP Footprint (Case 482)

Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPX5050
MPXV5050G
SERIES

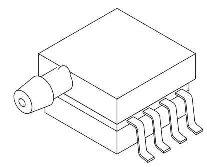
INTEGRATED
PRESSURE SENSOR
0 to 50 kPa (0 to 7.25 psi)
0.2 to 4.7 V Output

The MPX5050/MPXV5050G series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This patented, single element transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

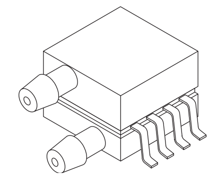
Features

- 2.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated Over –40° to +125°C
- Patented Silicon Shear Stress Strain Gauge
- Durable Epoxy Unibody Element
- Easy-to-Use Chip Carrier Option

SMALL OUTLINE PACKAGE SURFACE MOUNT



MPXV5050GP
CASE 1369-01



MPXV5050DP
CASE 1351-01

SMALL OUTLINE PACKAGE PIN NUMBERS[1]			
1	N/C	5	N/C
2	V_S	6	N/C
3	Gnd	7	N/C
4	V_{out}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

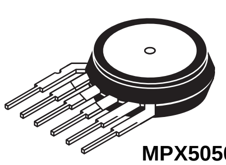
UNIBODY PACKAGE PIN NUMBERS[1]			
1	V_{out}	4	N/C
2	Gnd	5	N/C
3	V_S	6	N/C

1. Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

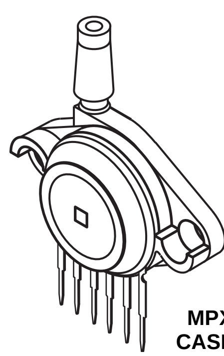
ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
SMALL OUTLINE PACKAGE (MPXV5050G SERIES)					
Ported Elements	Side Port	1369	MPXV5050GP	Trays	MPXV5050G
	Dual Port	1351	MPXV5050DP	Trays	MPXV5050G
UNIBODY PACKAGE (MPX5050 SERIES)					
Basic Element	Differential	867	MPX5050D	—	MPX5050D
Ported Element	Differential Dual Ports	867C	MPX5050DP	—	MPX5050DP
	Gauge	867B	MPX5050GP	—	MPX5050GP

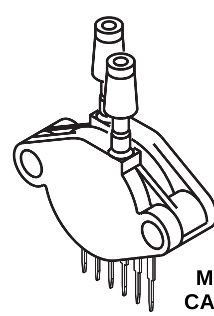
UNIBODY PACKAGES



MPX5050D
CASE 867-08



MPX5050GP
CASE 867B-04



MPX5050DP
CASE 857C-05

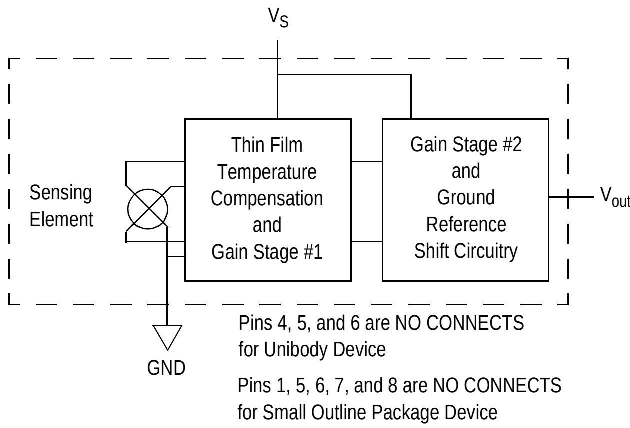


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings[1]

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{max}	200	kPa
Storage Temperature	T_{stg}	–40° to +125°	°C
Operating Temperature	T_A	–40° to +125°	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. . Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 4 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	0	—	50	kPa
Supply Voltage(2)		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset(3) @ V_S = 5.0 Volts	(0 to 85°C)	V_{off}	0.088	0.2	0.313	Vdc
Full Scale Output(4) @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSO}	4.587	4.7	4.813	Vdc
Full Scale Span(5) @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSS}	—	4.5	—	Vdc
Accuracy(6)	(0 to 85°C)	—	—	—	±2.5	$\%V_{FSS}$
Sensitivity		V/P	—	90	—-	mV/kPa
Response Time(7)		t_R	—	1.0	—-	ms
Output Source Current at Full Scale Output		I_{o+}	—	0.1	—-	mAdc
Warm-Up Time(8)		—	—	20	—-	ms
Offset Stability(9)		—	—	±0.5	—-	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS} at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

Table 3. Mechanical Characteristics

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	grams
Weight, Basic Element (Case 1369)	1.5	grams

Figure 3 illustrates the Differential/Gauge Sensing Chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm.

The MPX5050/MPXV5050G series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 2 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0× to 85×C using the decoupling circuit shown in Figure 4. The output will saturate outside of the specified pressure range.

Figure 4 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

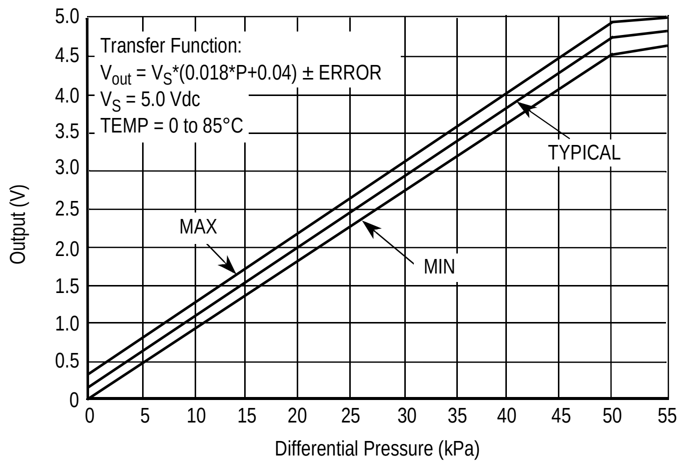


Figure 2. Output versus Pressure Differential

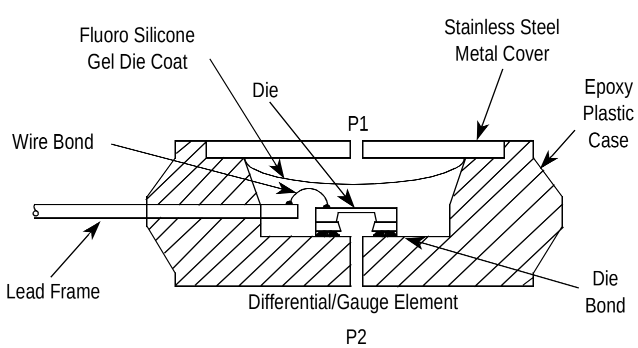


Figure 3. Cross-Sectional Diagram (not to scale)

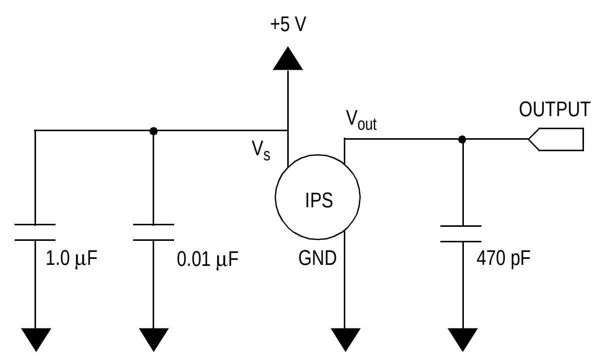


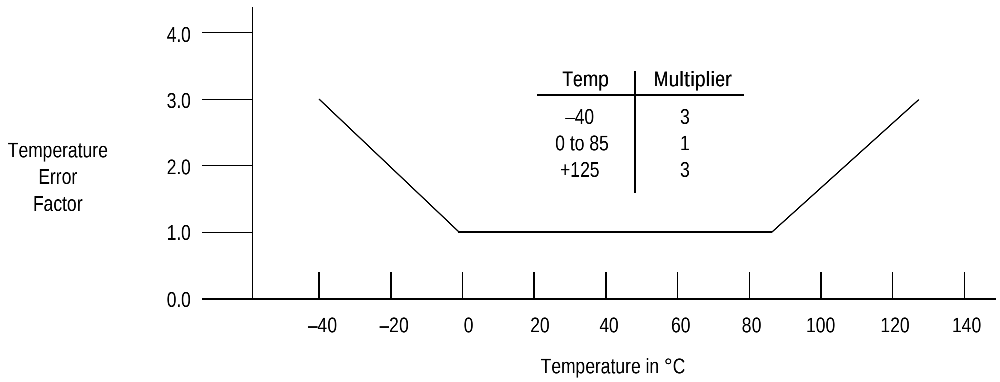
Figure 4. Recommended Power Supply Decoupling and Output Filtering
(For additional output filtering, please refer to Application Note AN1646.)

Transfer Function

Nominal Transfer Value: $V_{out} = V_S (P \times 0.018 + 0.04)$
$\pm$ (Pressure Error x Temp. Factor x 0.018 x V_S)
$V_S = 5.0 V \pm 0.25$ Vdc

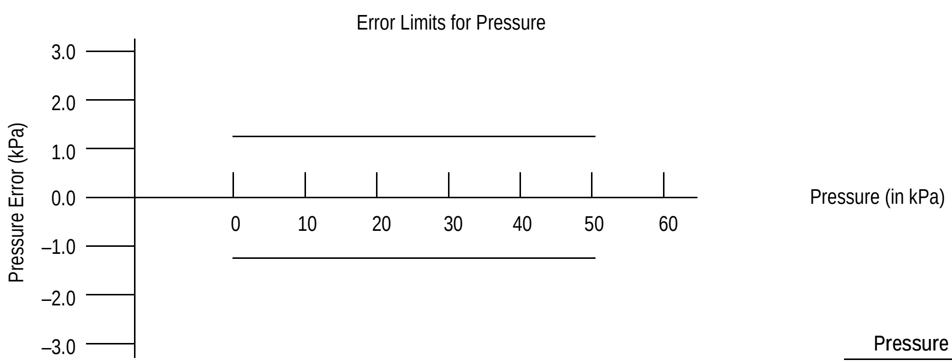
Temperature Error Band

MPX5050/MPXV5050G SERIES



NOTE: The Temperature Multiplier is a linear response from 0° to –40°C and from 85° to 125°C.

Pressure Error Band



Pressure	Error (Max)
0 to 50 (kPa)	±1.25 (kPa)

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluorosilicone gel which protects the die from harsh media. The MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX5050D	867	Stainless Steel Cap
MPX5050DP	867C	Side with Part Marking
MPX5050GP	867B	Side with Port Attached
MPXV5050GP	1369	Side with Port Attached
MPXV5050DP	1351	Side with Part Marking

Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated, and Calibrated

The MPX5100 series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This patented, single element transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

Features

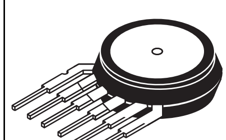
- 2.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Patented Silicon Shear Stress Strain Gauge
- Available in Absolute, Differential and Gauge Configurations
- Durable Epoxy Unibody Element
- Easy-to-Use Chip Carrier Option

ORDERING INFORMATION				
Device Type	**Options**	**Case No.**	**MPX Series Order Number**	**Device Marking**
UNIBODY PACKAGE (MPX5100 SERIES)				
Basic Elements	Absolute	867	MPX5100A	MPX5100A
	Differential	867	MPX5100D	MPX5100D
Ported Elements	Differential Dual Ports	867C	MPX5100DP	MPX5100DP
	Absolute, Single Port	867B	MPX5100AP	MPX5100AP
	Gauge, Single Port	867B	MPX5100GP	MPX5100GP
	Gauge, Axial PC Mount	867F	MPX5100GSX	MPX5100GSX

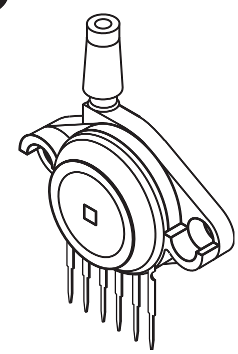
MPX5100 SERIES

INTEGRATED PRESSURE SENSOR
0 to 100 kpa (0 to 14.5 psi)
15 to 115 kPa
(2.18 to 16.68 psi)
0.2 to 4.7 V Output

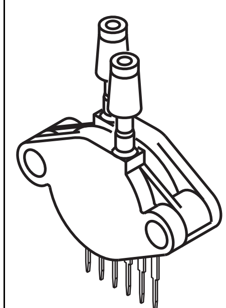
UNIBODY PACKAGES



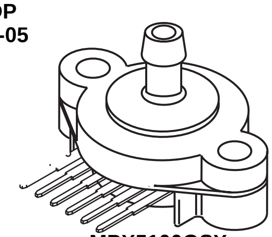
MPX5100A/D
CASE 867-08



MPX5100AP/GP
CASE 867B-04



MPX5100DP
CASE 867C-05



MPX5100GSX
CASE 867F-03

PIN NUMBER[1]			
1	V_{OUT}	4	N/C
2	GND	5	N/C
3	V_S	6	N/C

1. Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

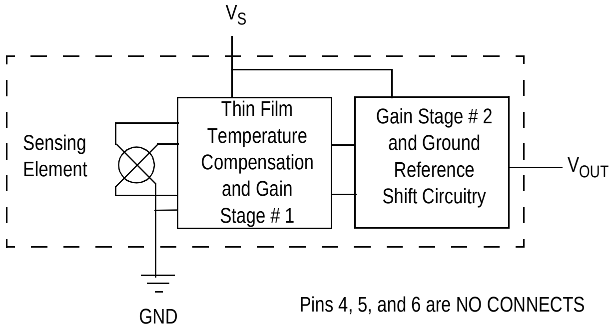


Figure 1. Fully Integrated Pressure Sensor Schematic

TABLE 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	400	kPa
Storage Temperature	T_{STG}	-40° to +125°C	°C
Operating Temperature	T_A	-40° to +125°C	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

TABLE 2. Operating Characteristics (V_S = 5.0 V_{DC}, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 4 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1] Gauge, Differential: MPX5100D Absolute: MPX5100A		P_{OP}	 0 15	 — —	 100 115	kPa
Supply Voltage[2]		V_S	4.75	5.0	5.25	V_{DC}
Supply Current		I_O	—	7.0	10	mAdc
Minimum Pressure Offset[3] @ V_S = 5.0 V	(0 to 85°C)	V_{OFF}	0.088	0.20	0.313	V_{DC}
Full Scale Output[4] @ V_S = 5.0 V	Differential and Absolute (0 to 85°C) Vacuum	V_{FSO}	4.587 3.688	4.700 3.800	4.813 3.913	V_{DC}
Full Scale Span[5] @ V_S = 5.0 V	Differential and Absolute (0 to 85°C) Vacuum	V_{FSS}	— —	4.500 3.600	— —	V_{DC}
Accuracy[6]		—	—	—	±2.5	$\%V_{FSS}$
Sensitivity		V/P	—	45	—	mV/kPa
Response Time[7]		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{O+}	—	0.1	—	mAdc
Warm-Up Time[8]		—	—	20	—	ms
Offset Stability[9]		—	—	±0.5	—	$\%V_{FSS}$

1. 0.1 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{OFF}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS} at 25°C.
7. Response Time is defined as the time for the incremental changed in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-Up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

TABLE 3. MECHANICAL CHARACTERISTICS

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	grams

Figure 2 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0× to 85×C using the decoupling circuit shown in Figure 4. The output will saturate outside of the specified pressure range.

Figure 3 illustrates both the Differential/Gauge and the Absolute Sensing Chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm.

The MPX5100 series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

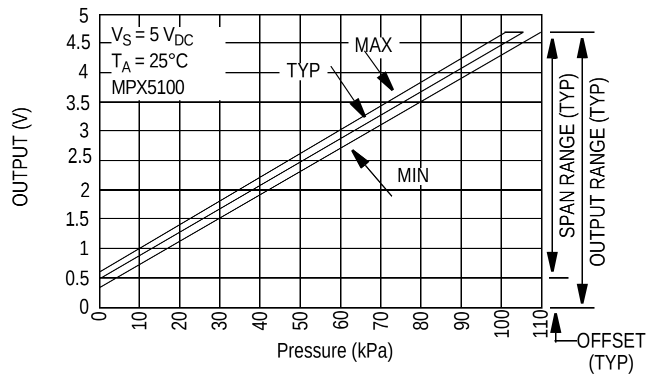


Figure 2. Output Vs. Pressure Differential

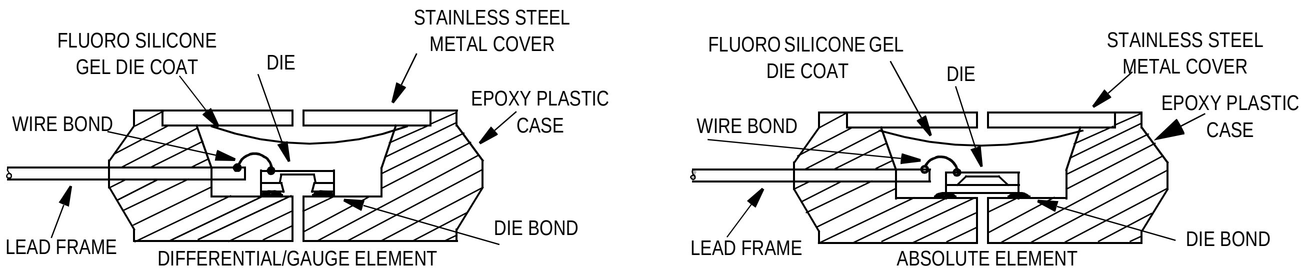


Figure 3. Cross Sectional Diagrams (Not to Scale)

Figure 4 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

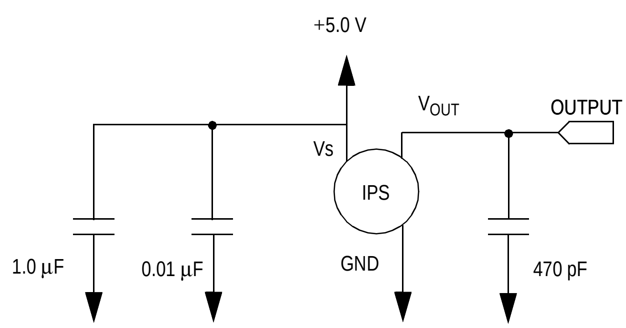


Figure 4. Recommended Power Supply Decoupling and Output Filtering
(For additional output filtering, please refer to Application Note AN1646.)

Transfer Function (MPX5100D, MPX5100G

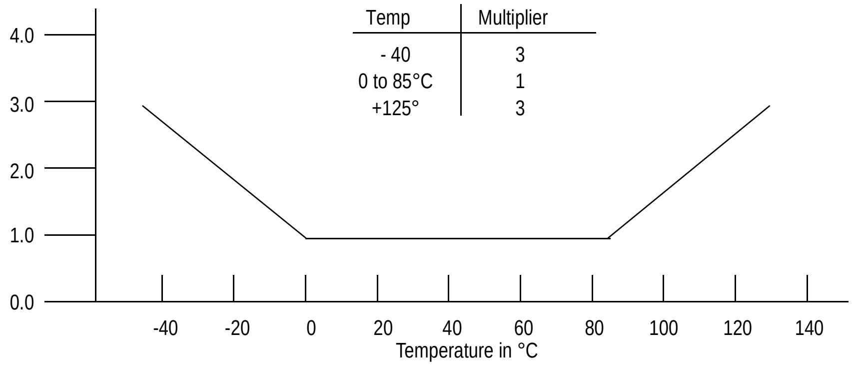
Nominal Transfer Value: VOUT = VS (P x 0.009 + 0.04)
± (Pressure Error x Temp. Mult. x 0.009 x VS)
VS = 5.0 V ±5% P kPa

Temperature Error Multiplier

MPX5100D Series

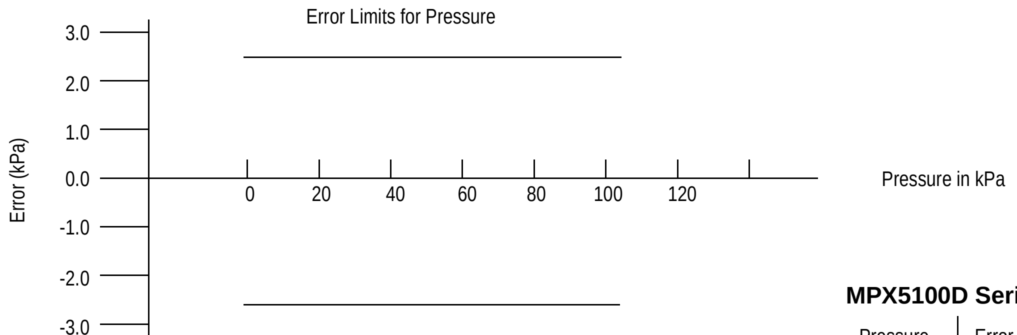
Break Points

Temp	Multiplier
- 40	3
0 to 85°C	1
+125°	3



Note: The Temperature Multiplier is a linear response from 0° to -40°C and from 85° to 125°C.

Pressure Error Band



MPX5100D Series

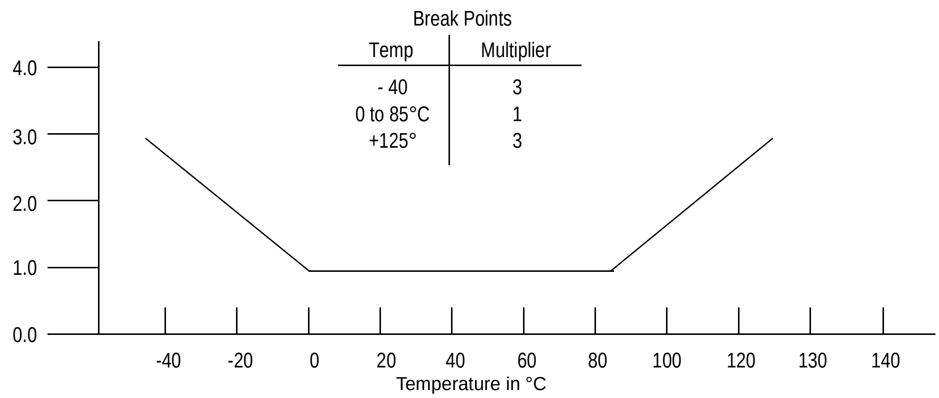
Pressure	Error (max)
0 to 100 kPa	± 2.5 kPa

Transfer Function (MPX5100A

Nominal Transfer Value: $V_{OUT} = V_S$ (P x 0.009 + 0.095)
± (Pressure Error x Temp. Mult. x 0.009 x V_S)
V_S = 5.0 V ±5% P kPa

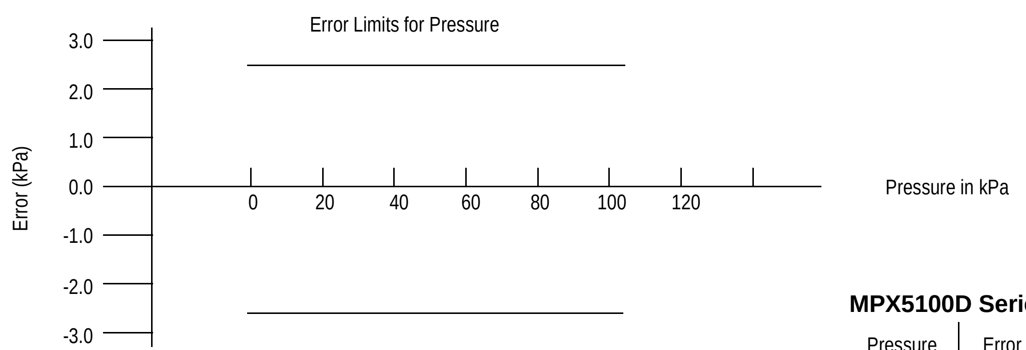
Temperature Error Multiplier

MPX5100A Series



Note: The Temperature Multiplier is a linear response from 0° to -40°C and from 85° to 125°C.

Pressure Error Band



MPX5100D Series

Pressure	Error (max)
0 to 100 kPa	± 2.5 kPa

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluorosilicone gel which protects the die from harsh media. The MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using Table 4 below:

TABLE 4. PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

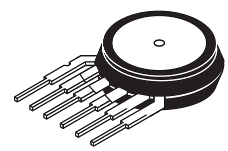
Part Number	Case Type	Pressure (P1) Side Identifier
MPX5100A, MPX5100D	867	Stainless Steel Cap
MPX5100DP	867C	Side with Part Marking
MPX5100AP, MPX5100GP	867B	Side with Port Attached
MPX5100GSX	867F	Side with Port Attached

Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

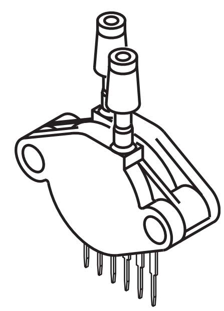
MPX5500 SERIES

INTEGRATED PRESSURE SENSOR
0 to 500 kPa (0 to 72.5 psi)
0.2 to 4.7 V Output

The MPX5500 series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This patented, single element transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.



MPX5500D
CASE 867-08



MPX5500DP
CASE 867C-05

Features

- 2.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Patented Silicon Shear Stress Strain Gauge
- Durable Epoxy Unibody Element
- Available in Differential and Gauge Configurations

ORDERING INFORMATION

Device Type	Options	Case Type	MPX Series	
			Order Number	Device Marking
Basic Element	Differential	867	MPX5500D	MPX5500D
Ported Elements	Differential Dual Ports	867C	MPX5500DP	MPX5500DP

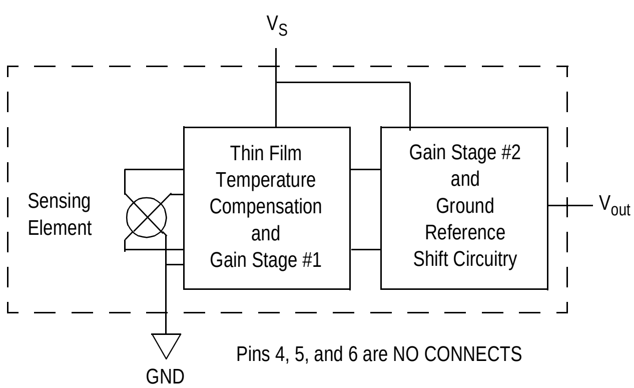


Figure 1. Fully Integrated Pressure Sensor Schematic

PIN NUMBERS(1)

1	V_{out}	4	N/C
2	GND	5	N/C
3	V_S	6	N/C

1. Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

Table 1. Maximum Ratings[1]

Rating	Symbol	Value	Unit
Maximum Pressure[2] (P2 ≤ 1 Atmosphere)	$P1_{max}$	2000	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Maximum Ratings apply to Case 867 only. Extended exposure at the specified limits may cause permanent damage or degradation to the device.
2. This sensor is designed for applications where P1 is always greater than, or equal to P2. P2 maximum is 500 kPa.

Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 4. required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]		P_{OP}	0	—	500	kPa
Supply Voltage[2]		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_O	—	7.0	10	mAdc
Zero Pressure Offset[3]	(0 to 85°C)	V_{off}	0.088	0.20	0.313	Vdc
Full Scale Output[4]	(0 to 85°C)	V_{FSO}	4.587	4.70	4.813	Vdc
Full Scale Span[5]	(0 to 85°C)	V_{FSS}	—	4.50	—	Vdc
Accuracy[6]	(0 to 85°C)	—	—	—	±2.5	$\%V_{FSS}$
Sensitivity		V/P	—	9.0	—-	mV/kPa
Response Time[7]		t_R	—	1.0	—-	ms
Output Source Current at Full Scale Output		I_{O+}	—	0.1	—-	mAdc
Warm-Up Time[8]		—	—	20	—-	ms

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the device to meet the specified output voltage after the pressure has been stabilized.

Table 3. Mechanical Characteristics

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	grams

Figure 3 illustrates the Differential/Gauge basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. (For use of the MPX5500D in a high pressure, cyclic application, consult the factory.)

The MPX5500 series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 2 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit shown in Figure 4. The output will saturate outside of the specified pressure range.

Figure 4 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

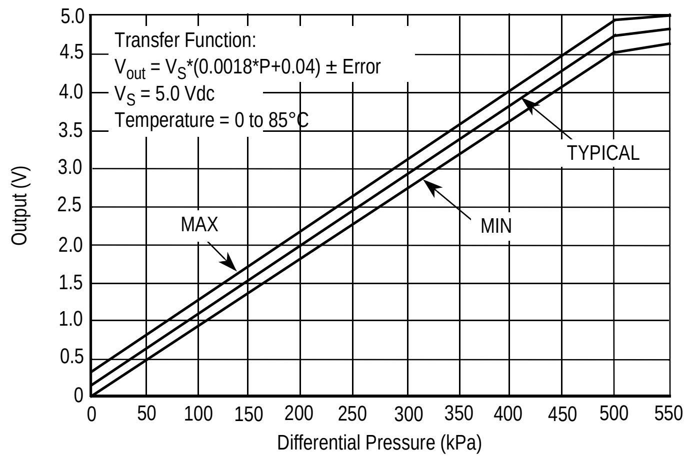


Figure 2. Output versus Pressure Differential

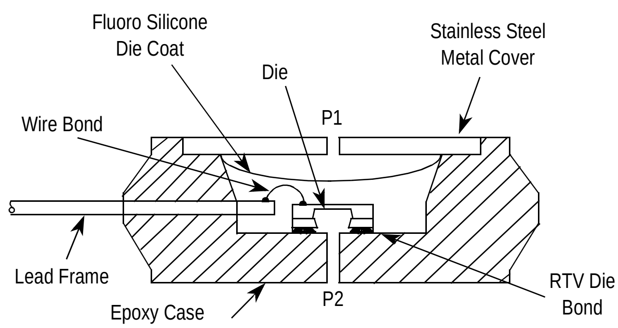


Figure 3. Cross-Sectional Diagrams (not to scale)

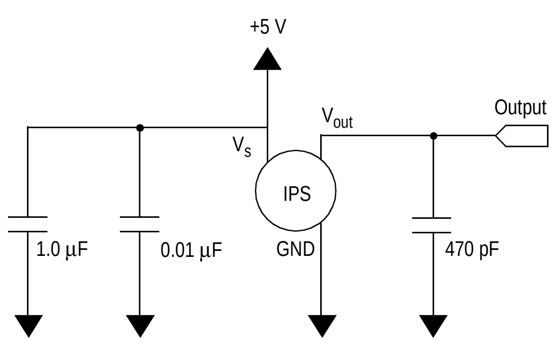


Figure 4. Recommended Power Supply Decoupling and Output Filtering

(For additional output filtering, please refer to Application Note AN1646)

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluoro silicone gel which protects the die from harsh media. The Freescale MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX5500D	867	Stainless Steel Cap
MPX5500DP	867C	Side with Part Marking

Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPX5700 SERIES

INTEGRATED PRESSURE SENSOR
0 to 700 kPa (0 to 101.5 psi)
15 to 700 kPa (2.18 to 101.5 psi)
0.2 to 4.7 V OUTPUT

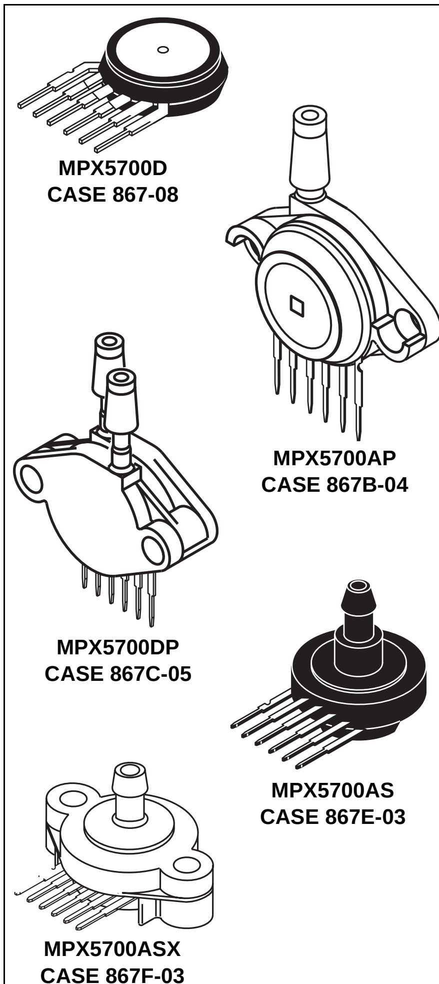
The MPX5700 series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This patented, single element transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

Features

- 2.5% Maximum Error over 0° to 85°C
- Ideally Suited for Microprocessor or Microcontroller-Based Systems
- Available in Absolute, Differential and Gauge Configurations
- Patented Silicon Shear Stress Strain Gauge
- Durable Epoxy Unibody Element

ORDERING INFORMATION

Device Type	Options	Case Type	MPX Series	
			Order Number	Device Marking
Basic Element	Differential	867	MPX5700D	MPX5700D
	Absolute	867	MPX5700A	MPX5700A
Ported Elements	Differential Dual Ports	867C	MPX5700DP	MPX5700DP
	Gauge	867B	MPX5700GP	MPX5700GP
	Gauge, Axial	867E	MPX5700GS	MPX5700D
	Absolute	867B	MPX5700AP	MPX5700AP
	Absolute, Axial	867E	MPX5700AS	MPX5700A
	Absolute, Axial PC Mount	867F	MPX5700ASX	MPX5700A



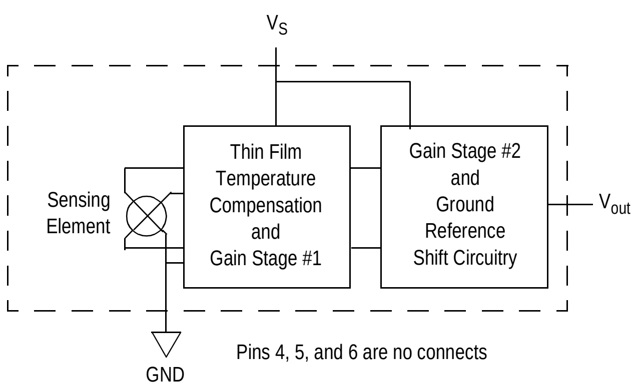


Figure 1. Fully Integrated Pressure Sensor Schematic

PIN NUMBERS

1	V_{out}	4	N/C
2	GND	5	N/C
3	V_S	6	N/C

NOTE: Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

Table 1. Maximum Ratings[1]

Parametrics	Symbol	Value	Unit
Maximum Pressure[2] ($P2 \leq 1$ Atmosphere)	$P1_{max}$	2800	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Maximum Ratings apply to Case 867 only. Extended exposure at the specified limits may cause permanent damage or degradation to the device.
2. This sensor is designed for applications where P1 is always greater than, or equal to P2. P2 maximum is 500 kPa.

Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 4 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]	Gauge, Differential: MPX5700D Absolute: MPX5700A	P_{OP}	0 15	— —	700 700	kPa
Supply Voltage[2]		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_O	—	7.0	10	mAdc
Zero Pressure Offset[3]	Gauge, Differential (0 to 85°C) Absolute (0 to 85°C)	V_{off}	0.088 0.184	0.2 —	0.313 0.409	Vdc
Full Scale Output[4]	(0 to 85°C)	V_{FSO}	4.587	4.7	4.813	Vdc
Full Scale Span[5]	(0 to 85°C)	V_{FSS}	—	4.5	—	Vdc
Accuracy[6]	(0 to 85°C)	—	—	—	±2.5	$\%V_{FSS}$
Sensitivity		V/P	—	6.4	—-	mV/kPa
Response Time[7]		t_R	—	1.0	—-	ms
Output Source Current at Full Scale Output		I_{O+}	—	0.1	—-	mAdc
Warm-Up Time[8]		—	—	20	—-	ms

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the device to meet the specified output voltage after the pressure has been stabilized.

Table 3. Mechanical Characteristics

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	grams

ON-CHIP TEMPERATURE COMPENSATION, CALIBRATION AND SIGNAL CONDITIONING

Figure 3 illustrates both the Differential/Gauge and the Absolute Sensing Chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. (For use of the MPX5700D in a high-pressure cyclic application, consult the factory.)

The MPX5700 series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 2 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit shown in Figure 4. The output will saturate outside of the specified pressure range.

Figure 4 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

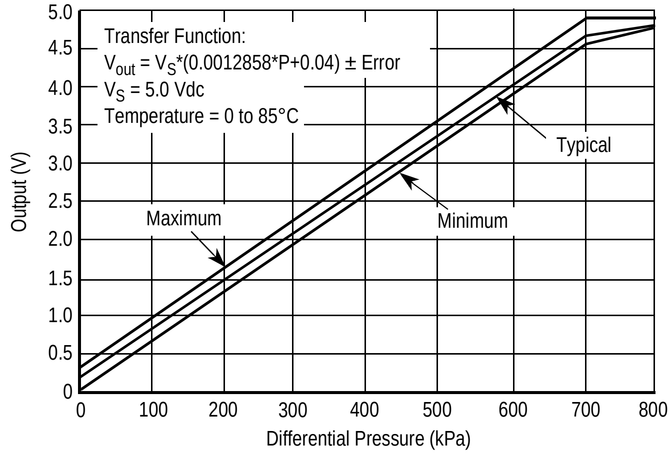


Figure 2. Output versus Pressure Differential

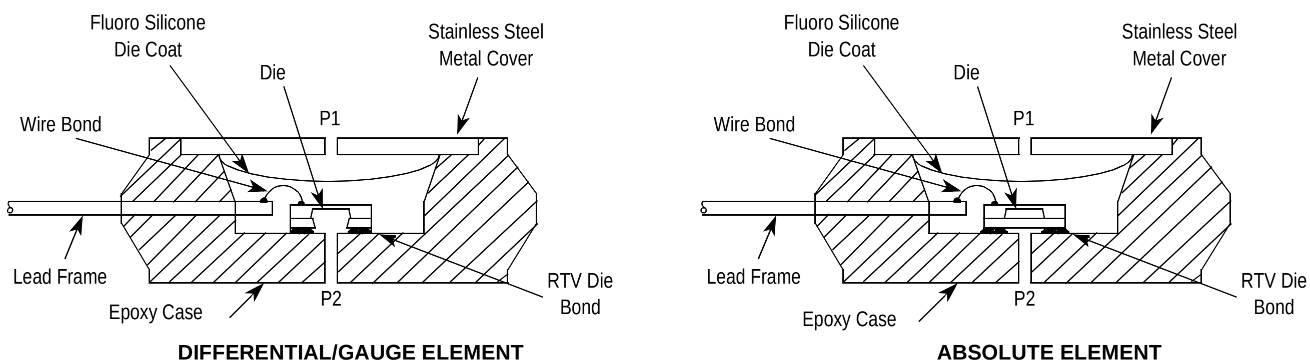


Figure 3. Cross-Sectional Diagrams (not to scale)

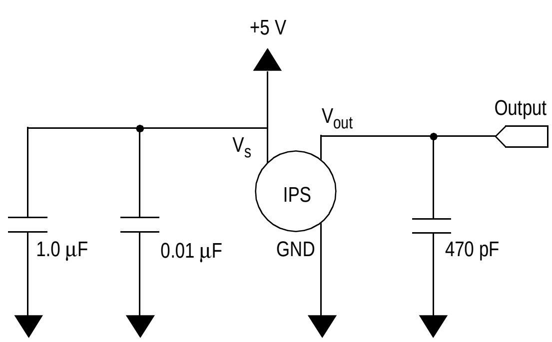


Figure 4. Recommended Power Supply Decoupling and Output Filtering
(For additional output filtering, please refer to Application Note AN1646)

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluoro silicone gel which protects the die from harsh media. The Freescale MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

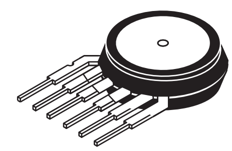
The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX5700D, MPX5700A	867	Stainless Steel Cap
MPX5700DP	867C	Side with Part Marking
MPX5700GP, MPX5700AP	867B	Side with Port Attached
MPX5700GS, MPX5700AS	867E	Side with Port Attached
MPX5700ASX	867F	Side with Port Attached

Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPX5999D SERIES

INTEGRATED PRESSURE SENSOR
0 to 1000 kPa (0 to 150 psi)
0.2 to 4.7 V OUTPUT



MPX5999D
CASE 867-08

The MPX5999D piezoresistive transducer is a state-of-the-art pressure sensor designed for a wide range of applications, but particularly for those employing a microcontroller or microprocessor with A/D inputs. This patented, single element transducer combines advanced micromachining techniques, thin-film metallization and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on the stand-alone sensing chip.

Features

- Temperature Compensated Over 0 to 85°C
- Ideally Suited for Microprocessor or Microcontroller-Based Systems
- Patented Silicon Shear Stress Strain Gauge
- Durable Epoxy Unibody Element

ORDERING INFORMATION[1]

Device Type	Options	Case Type	MPX Series	
			Order Number	Device Marking
Basic Element	Differential	867	MPX5999D	MPX5999D

1. The MPX5999D pressure sensor is available as an element only.

PIN NUMBERS

1	V_{out}	4	N/C
2	GND	5	N/C
3	V_S	6	N/C

NOTE: Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

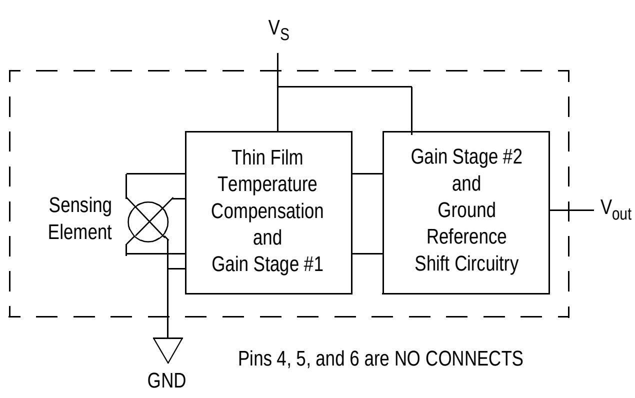


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings[1]

Rating	Symbol	Value	Unit
Maximum Pressure[2] (P2 ≤ 1 Atmosphere)	$P1_{max}$	4000	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Extended exposure at the specified limits may cause permanent damage or degradation to the device.
2. This sensor is designed for applications where P1 is always greater than, or equal to P2. P2 maximum is 500 kPa.

Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 4 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]		P_{OP}	0	—	1000	kPa
Supply Voltage[2]		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_O	—	7.0	10	mAdc
Zero Pressure Offset[3]	(0 to 85°C)	V_{off}	0.088	0.2	0.313	Vdc
Full Scale Output[4]	(0 to 85°C)	V_{FSO}	4.587	4.7	4.813	Vdc
Full Scale Span[5]	(0 to 85°C)	V_{FSS}	—	4.5	—	Vdc
Sensitivity		V/P	—	4.5	—	mV/kPa
Accuracy[6]	(0 to 85°C)	—	—	—	±2.5	$\%V_{FSS}$
Response Time[7]		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{O+}	—	0.1	—	mAdc
Warm-Up Time[8]		—	—	20	—	ms

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the device to meet the specified output voltage after the pressure has been stabilized.

Table 3. Mechanical Characteristics

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	grams

ON-CHIP TEMPERATURE COMPENSATION, CALIBRATION AND SIGNAL CONDITIONING

Figure 2 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit shown in Figure 4. The output will saturate outside of the specified pressure range.

The performance over temperature is achieved by integrating the shear-stress strain gauge, temperature compensation, calibration and signal conditioning circuitry onto a single monolithic chip.

Figure 3 illustrates the differential or gauge configuration in the basic chip carrier (Case 867). A fluoro silicone gel isolates the die surface and wire bonds from harsh environments, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX5999D pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 4 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

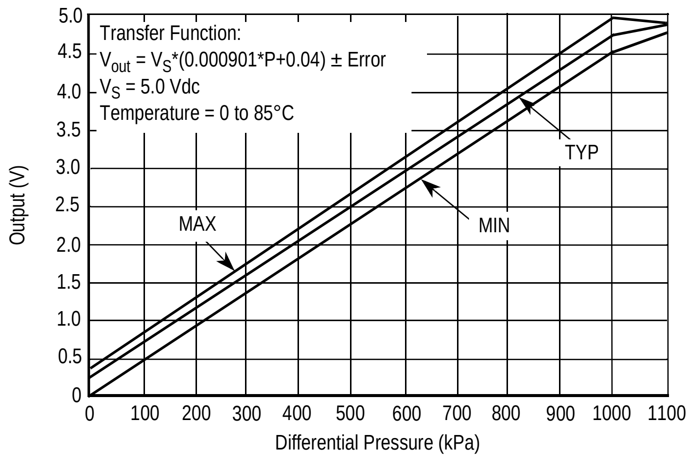


Figure 2. Output versus Pressure Differential

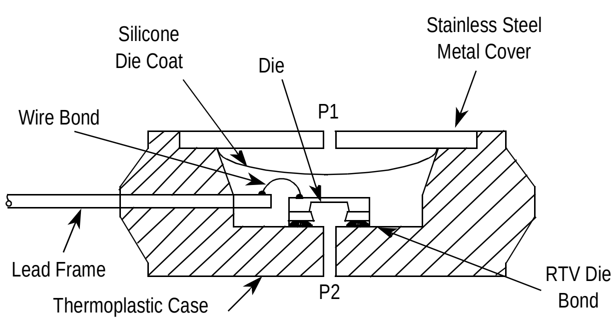


Figure 3. Cross-Sectional Diagrams (not to scale)

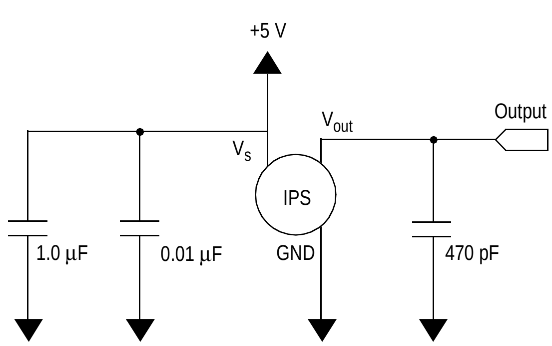


Figure 4. Recommended Power Supply Decoupling and Output Filtering
(For additional output filtering, please refer to Application Note AN1646)

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluoro silicone gel which protects the die from harsh media. The Freescale MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX5999D	867	Stainless Steel Cap

MPXA6115A
Rev 2, 05/2005

High Temperature Accuracy Integrated Silicon Pressure Sensor for Measuring Absolute Pressure, On-Chip Signal Conditioned, Temperature Compensated and Calibrated

The MPXA6115A/MPXH6115A series sensor integrates on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The small form factor and high reliability of on-chip integration make the pressure sensor a logical and economical choice for the system designer.

The MPXA6115A/MPXH6115A series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

Features

- Improved Accuracy at High Temperature
- Available in Small and Super Small Outline Packages
- 1.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated from -40° to +125°C
- Durable Thermoplastic (PPS) Surface Mount Package

Typical Applicationss

- Aviation Altimeters
- Industrial Controls
- Engine Control/Manifold Absolute Pressure (MAP)
- Weather Station and Weather Reporting Device Barometers

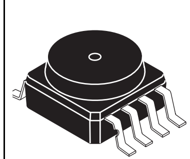
ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
SMALL OUTLINE PACKAGE					
Basic Element	Absolute, Element Only	482	MPXA6115A6U	Rails	MPXA6115A
	Absolute, Element Only	482	MPXA6115A6T1	Tape & Reel	MPXA6115A
Ported Element	Absolute, Axial Port	482A	MPXA6115AC6U	Rails	MPXA6115A
	Absolute, Axial Port	482A	MPXA6115AC6T1	Tape & Reel	MPXA6115A
SUPER SMALL OUTLINE PACKAGE					
Basic Element	Absolute, Element Only	1317	MPXH6115A6U	Rails	MPXH6115A
	Absolute, Element Only	1317	MPXH6115A6T1	Tape & Reel	MPXH6115A
Ported Element	Absolute, Axial Port	1317A	MPXH6115AC6U	Rails	MPXH6115A
	Absolute, Axial Port	1317A	MPXH6115AC6T1	Tape & Reel	MPXH6115A

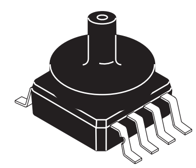
MPXA6115A MPXH6115A SERIES

INTEGRATED PRESSURE SENSOR
15 TO 115 kPA (2.2 TO 16.7 psi)
0.2 TO 4.8 V OUTPUT

SMALL OUTLINE PACKAGE



MPXA6115A6U/6T1
CASE 482-01

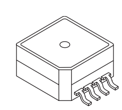


MPXA6115C6U/C6T1
CASE 482A-01

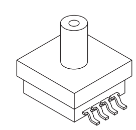
SMALL OUTLINE PACKAGE PIN NUMBERS(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is denoted by the notch in the lead.

SUPER SMALL OUTLINE PACKAGE



MPXH6115A6U/6T1
CASE 1317-04



MPXH6115AC6U/C6T1
CASE 1317A-01

SUPER SMALL OUTLINE PACKAGE PIN NUMBERS(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is denoted by the notch in the lead

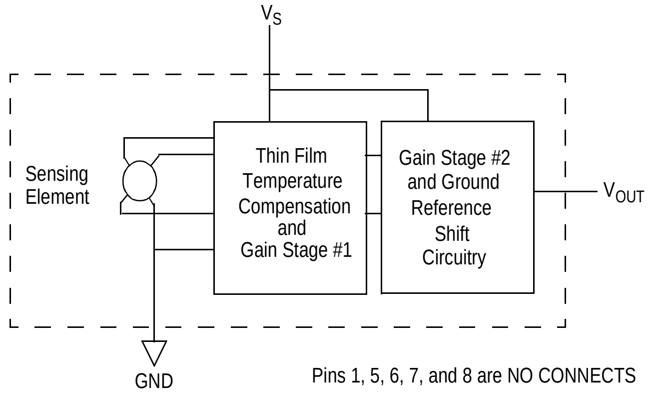


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings[1]

Rating	Symbol	Value	Units
Maximum Pressure (P1 > P2)	P_{max}	400	kPa
Storage Temperature	T_{stg}	-40° to +125°	°C
Operating Temperature	T_A	-40° to +125°	°C
Output Source Current @ Full Scale Output[2]	I_o+	0.5	mAdc
Output Sink Current @ Minimum Pressure Offset[2]	I_o-	-0.5	mAdc

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.
2. Maximum Output Current is controlled by effective impedance from V_{out} to Gnd or V_{out} to V_S in the application circuit.

Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	15	—	115	kPa
Supply Voltage[1]		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	-	6.0	10	mAdc
Minimum Pressure Offset[2] @ V_S = 5.0 Volts	(0 to 85°C)	V_{off}	0.133	0.200	0.268	Vdc
Full Scale Output[3] @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSO}	4.633	4.700	4.768	Vdc
Full Scale Span[4] @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSS}	4.433	4.500	4.568	Vdc
Accuracy[5]	(0 to 85°C)	—	—	—	±1.5	$\%V_{FSS}$
Sensitivity		V/P	—	45.9	—	mV/kPa
Response Time[6]		t_R	—	1.0	—	ms
Warm-Up Time[7]		—	—	20	—	ms
Offset Stability[8]		—	—	±0.25	—	$\%V_{FSS}$

1. Device is ratiometric within this specified excitation range.
2. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
3. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
4. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
5. Accuracy is the deviation in actual output from nominal output over the entire pressure range and temperature range as a percent of span at 25°C due to all sources of error including the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the pressure has been stabilized.
8. Offset Stability is the product's output deviation when subjected to 1000 cycles of Pulsed Pressure, Temperature Cycling with Bias Test.

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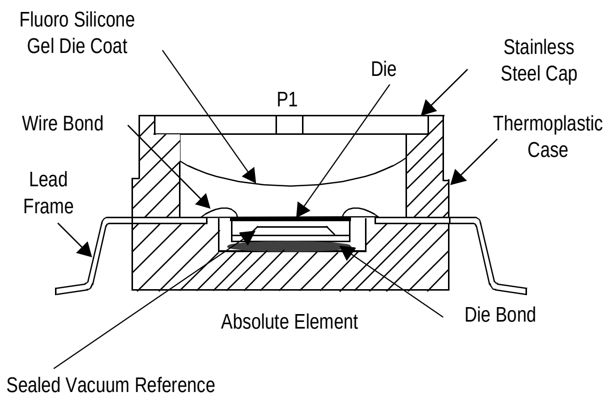


Figure 2. Cross Sectional Diagram SSOP (Not to Scale)

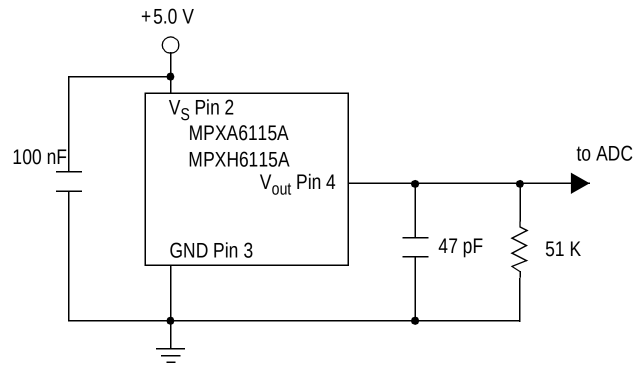


Figure 3. Typical Application Circuit (Output Source Current Operation)

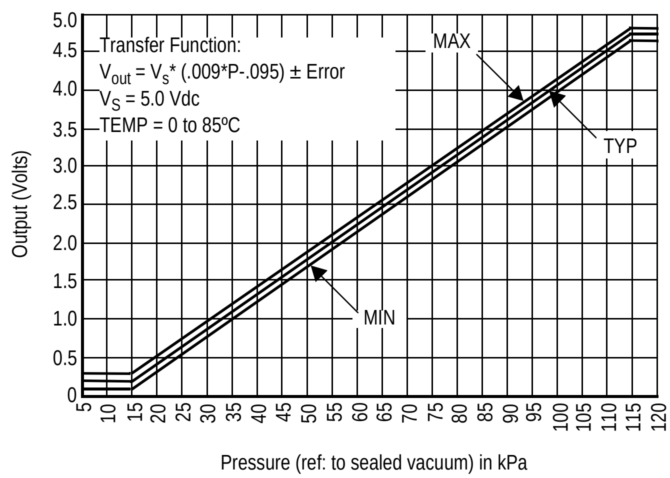


Figure 4. Output versus Absolute Pressure

Figure 2 illustrates the absolute sensing chip in the basic Super Small Outline chip carrier (Case 1317).

Figure 3 shows a typical application circuit (output source current operation).

Figure 4 shows the sensor output signal relative to pressure input. Typical minimum and maximum output curves are shown for operation over 0 to 85×C temperature range. The output will saturate outside of the rated pressure range.

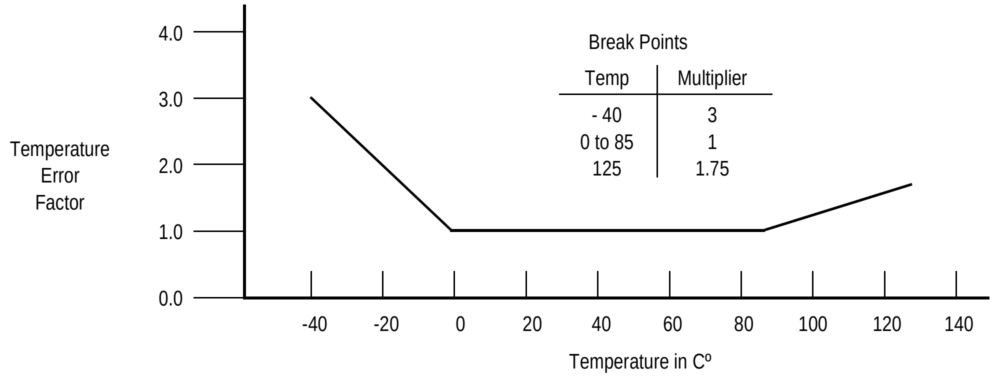
A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm. The MPXA6115A/ MPXH6115A series pressure sensor operating characteristics, internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Transfer Function (MPXA6115A/MPXH6115A)

Nominal Transfer Value: Vout = VS x (0.009 x P - 0.095)
± (Pressure Error x Temp. Factor x 0.009 x VS)
VS = 5.0 ± 0.25 Vdc

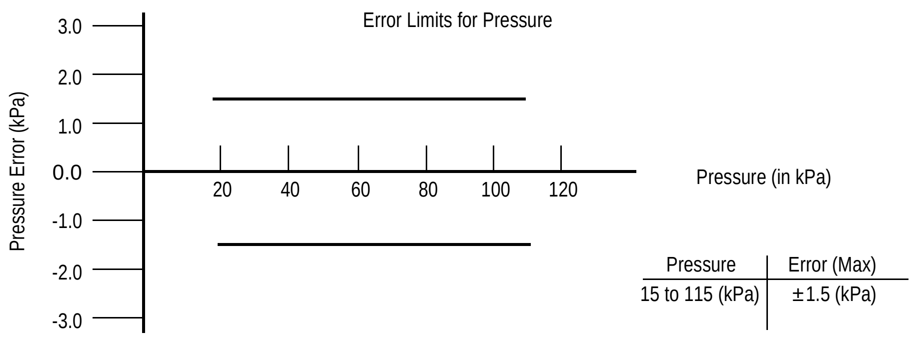
Temperature Error Band

MPXA6115A/MPXH6115A SERIES



NOTE: The Temperature Multiplier is a linear response from 0ºC to -40ºC and from 85ºC to 125ºC

Pressure Error Band



MINIMUM RECOMMENDED FOOTPRINT FOR SMALL AND SUPER SMALL PACKAGES

Surface mount board layout is a critical portion of the total design. The footprint for the semiconductor package must be the correct size to ensure proper solder connection interface between the board and the package. With the correct pad geometry, the packages will self-align when subjected to a solder reflow process. It is always recommended to fabricate boards with a solder mask layer to avoid bridging and/or shorting between solder pads, especially on tight tolerances and/or tight layouts.

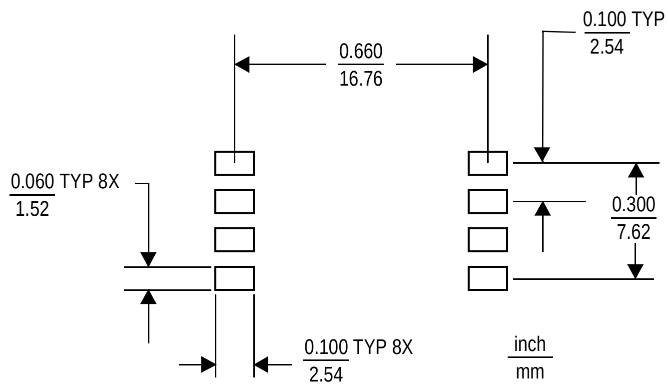


Figure 5. SOP Footprint (Case 482)

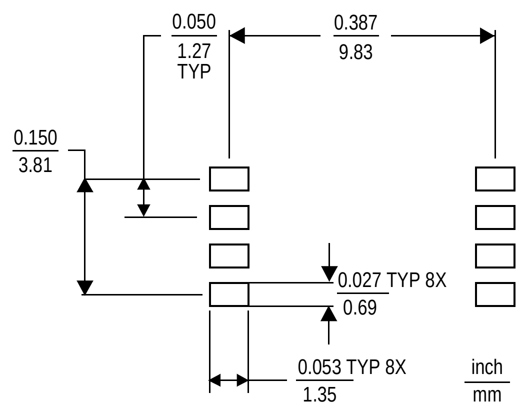


Figure 6. SSOP Footprint (Case 1317 and 1317A)

Integrated Silicon Pressure Sensor for Manifold Absolute Pressure Applications On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPXAZ4100A SERIES

INTEGRATED PRESSURE SENSOR
20 TO 105 kPA (2.9 TO 15.2 psi)
0.3 TO 4.9 V OUTPUT

The Freescale MPXAZ4100A series Manifold Absolute Pressure (MAP) sensor for engine control is designed to sense absolute air pressure within the intake manifold. This measurement can be used to compute the amount of fuel required for each cylinder. The small form factor and high reliability of on-chip integration makes the Freescale MAP sensor a logical and economical choice for automotive system designers.

The MPXAZ4100A series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

Features

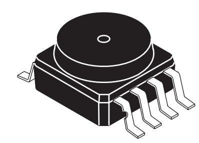
- Resistant to high humidity and common automotive media
- 1.8% Maximum Error Over 0° to 85°C
- Specifically Designed for Intake Manifold Absolute Pressure Sensing in Engine Control Systems
- Ideally Suited for Microprocessor or Microcontroller Based Systems
- Temperature Compensated Over –40°C to +125°C
- Durable Thermoplastic (PPS) Surface Mount Package

Typical Applications

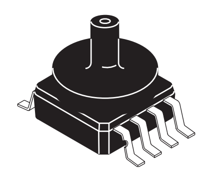
- Manifold Sensing for Automotive Systems
- Also Ideal for Non-Automotive Applications

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
SMALL OUTLINE PACKAGE (MPXAZ4100A SERIES)					
Basic Elements	Absolute, Element Only	482	MPXAZ4100A6U	Rails	MPXAZ4100A
	Absolute, Element Only	482	MPXAZ4100A6T1	Tape & Reel	MPXAZ4100A
Ported Elements	Absolute, Axial Port	482A	MPXAZ4100AC6U	Rails	MPXAZ4100A
	Absolute, Axial Port	482A	MPXAZ4100AC6T1	Tape & Reel	MPXAZ4100A

SMALL OUTLINE PACKAGES



MPXA4100A6U/6T1
CASE 482-01



MPXA4100AC6U/AC6T1
CASE 482A-01

PIN NUMBER(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

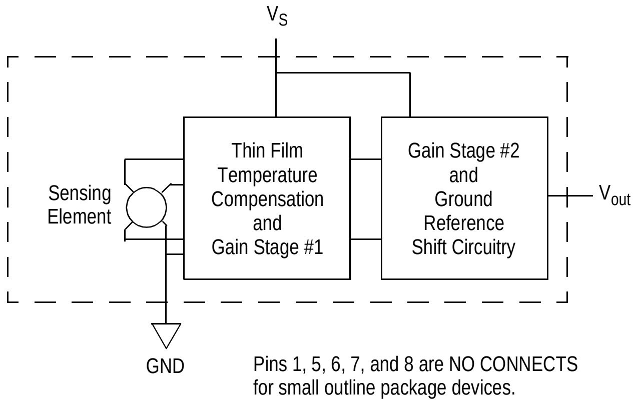


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	400	kPa
Storage Temperature	T_{STG}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 3 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]		P_{OP}	20	—	105	kPa
Supply Voltage[2]		V_S	4.85	5.1	5.35	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset @ V_S = 5.1 Volts[3]	(0 to 85°C)	V_{off}	0.225	0.306	0.388	Vdc
Full Scale Output @ V_S = 5.1 Volts[4]	(0 to 85°C)	V_{FSO}	4.870	4.951	5.032	Vdc
Full Scale Span @ V_S = 5.1 Volts[5]	(0 to 85°C)	V_{FSS}	—	4.59	—	Vdc
Accuracy[6]	(0 to 85°C)	—	—	—	±1.8	$\%V_{FSS}$
Sensitivity		V/P	—	54	—	mV/kPa
Response Time[7]		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{o+}	—	0.1	—	mAdc
Warm-Up Time[8]		—	—	20	—	ms
Offset Stability[9]		—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

[Figure 2](#) illustrates an absolute sensing chip in the basic chip carrier (Case 482).

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit shown in Figure 3. The output will saturate outside of the specified pressure range.

A gel die coat isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. The gel die coat and durable polymer package provide a media resistant barrier that allows the sensor to operate reliably in high humidity conditions as well as environments containing common automotive media. Contact the factory for more information regarding media compatibility in your specific application.

Figure 3 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

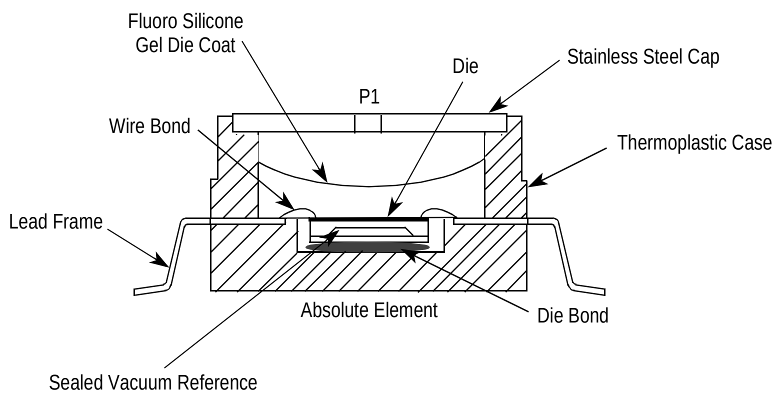


Figure 2. Cross Sectional Diagram SOP (not to scale)

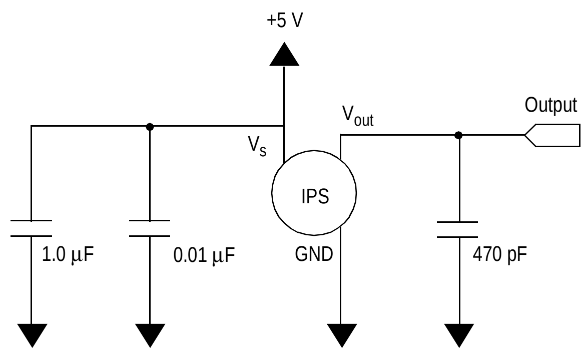


Figure 3. Recommended Power Supply Decoupling and Output Filtering
(For additional output filtering, please refer to Application Note AN1646.)

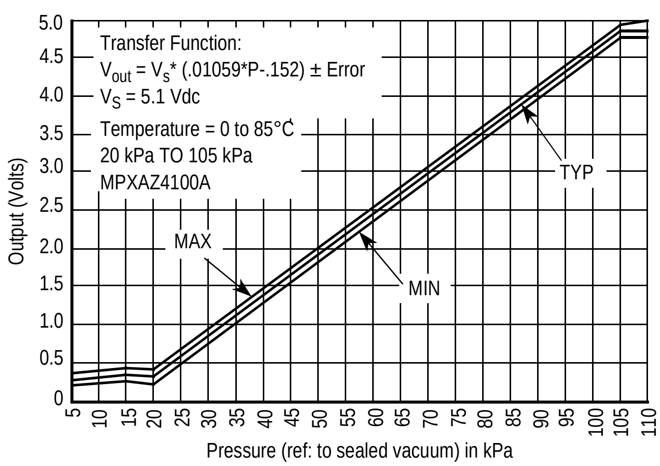


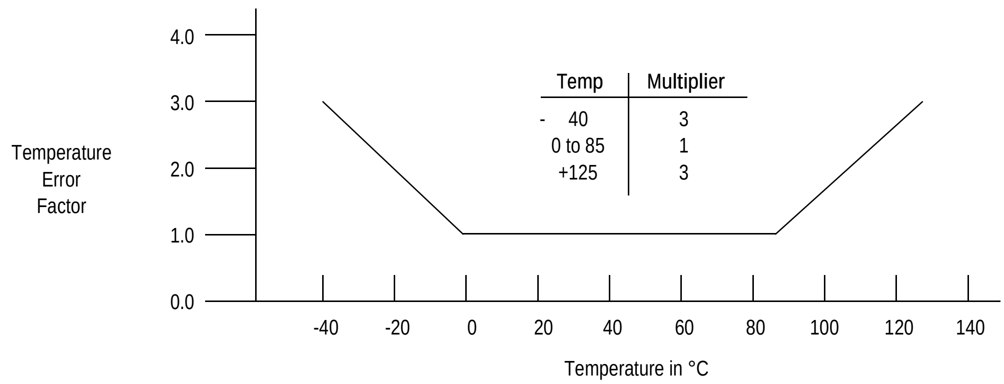
Figure 4. Output versus Absolute Pressure

Transfer Function (MPXAZ4100A)

Nominal Transfer Value: $V_{out} = V_S$ (P x 0.01059 - 0.1518)
± (Pressure Error x Temp. Factor x 0.01059 x V_S)
V_S = 5.1 V ± 0.25 Vdc

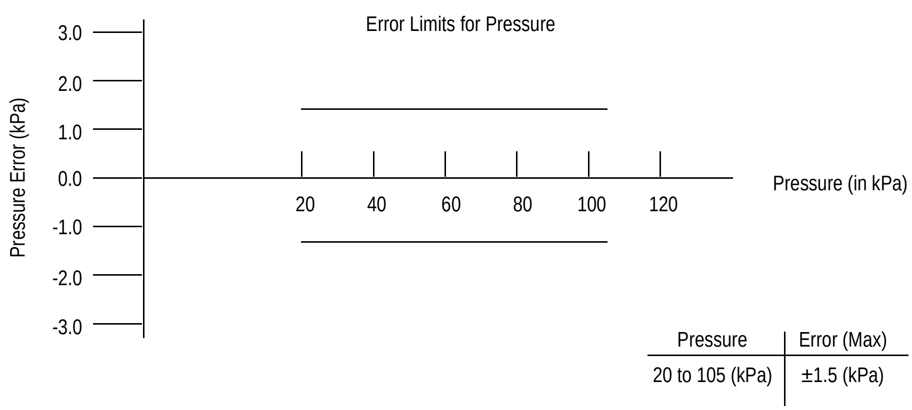
Temperature Error Band

MPXAZ4100A Series



NOTE: The Temperature Multiplier is a linear response from 0°C to-40°C and from 85°C to 125°C.

Pressure Error Band



INFORMATION FOR USING THE SMALL OUTLINE PACKAGE (CASE 482)

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

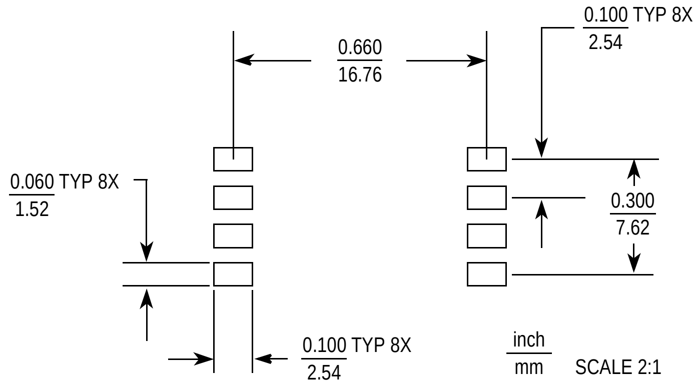


Figure 5. SOP Footprint (Case 482)

Media Resistant and High Temperature Accuracy Integrated Silicon Pressure Sensor for Measuring Absolute Pressure, On-Chip Signal Conditioned, Temperature Compensated and Calibrated

The MPXAZ6115A series sensor integrates on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The sensor's packaging has been designed to provide resistance to high humidity conditions as well as common automotive media. The small form factor and high reliability of on-chip integration make the Freescale Semiconductor, Inc. pressure sensor a logical and economical choice for the system designer.

The MPXAZ6115A series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

Features

- Resistant to High Humidity and Common Automotive Media
- Improved Accuracy at High Temperature
- 1.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated from -40° to +125°C
- Durable Thermoplastic (PPS) Surface Mount Package

Features

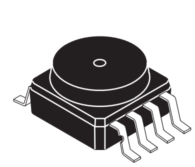
- Aviation Altimeters
- Industrial Controls
- Engine Control/Manifold Absolute Pressure (MAP)
- Weather Station and Weather Reporting Devices

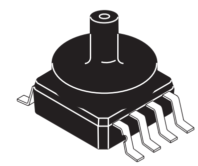
ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
SMALL OUTLINE PACKAGE					
Basic Element	Absolute, Element Only	482	MPXAZ6115A6U	Rails	MPXAZ6115A
	Absolute, Element Only	482	MPXAZ6115A6T1	Tape & Reel	MPXAZ6115A
Ported Element	Absolute, Axial Port	482A	MPXAZ6115AC6U	Rails	MPXAZ6115A
	Absolute, Axial Port	482A	MPXAZ6115AC6T1	Tape & Reel	MPXAZ6115A
SUPER SMALL OUTLINE PACKAGE					
Basic Element	Absolute, Element Only	1317	MPXHZ6115A6U	Rails	MPXHZ6115A
	Absolute, Element Only	1317	MPXHZ6115A6T1	Tape & Reel	MPXHZ6115A
Ported Element	Absolute, Axial Port	1317A	MPXHZ6115AC6U	Rails	MPXHZ6115A
	Absolute, Axial Port	1317A	MPXHZ6115AC6T1	Tape & Reel	MPXHZ6115A

MPXAZ6115A
MPXHZ6115A
SERIES

INTEGRATED
PRESSURE SENSOR
15 TO 115 kPA (2.2 TO 16.7 psi)
0.2 TO 4.8 V OUTPUT

SMALL OUTLINE PACKAGE

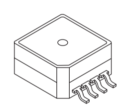

MPXAZ6115A6U
CASE 482-01

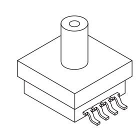

MPXAZ6115AC6U
CASE 482A-01

SMALL OUTLINE PACKAGE PIN NUMBERS(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is denoted by the notch in the lead.

SUPER SMALL OUTLINE PACKAGE


MPXHZ6115A6U
CASE 1317-04


MPXHZ6115AC6U
CASE 1317A-01

SMALL OUTLINE PACKAGE PIN NUMBERS(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is denoted by the notch in the lead.

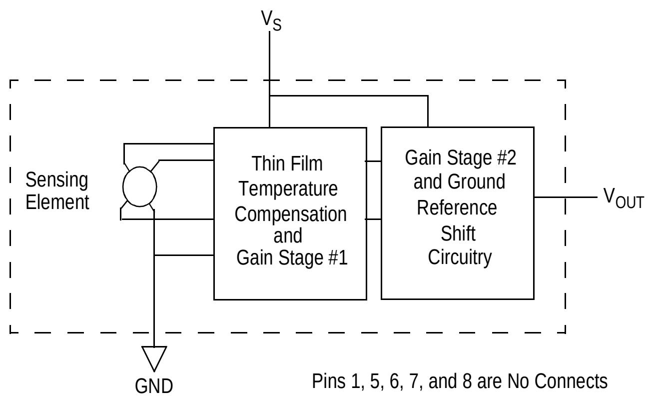


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Units
Maximum Pressure (P1 > P2)	P_{max}	400	kPa
Storage Temperature	T_{stg}	-40° to +125°	°C
Operating Temperature	T_A	-40° to +125°	°C
Output Source Current @ Full Scale Output(2)	I_o+	0.5	mAdc
Output Sink Current @ Minimum Pressure Offset(2)	I_o-	-0.5	mAdc

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.
2. Maximum Output Current is controlled by effective impedance from V_{out} to Gnd or V_{out} to V_S in the application circuit.

Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	15	—	115	kPa
Supply Voltage[1]		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	—	6.0	10	mAdc
Minimum Pressure Offset[2] @ V_S = 5.0 Volts	(0 to 85°C)	V_{off}	0.133	0.200	0.268	Vdc
Full Scale Output[3] @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSO}	4.633	4.700	4.768	Vdc
Full Scale Span[4] @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSS}	4.433	4.500	4.568	Vdc
Accuracy[5]	(0 to 85°C)	—	—	—	±1.5	$\%V_{FSS}$
Sensitivity		V/P	—	45.9	—	mV/kPa
Response Time[6]		t_R	—	1.0	—	ms
Warm-Up Time[7]		—	—	20	—	ms
Offset Stability[8]		—	—	±0.25	—	$\%V_{FSS}$

1. Device is ratiometric within this specified excitation range.
2. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
3. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
4. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
5. Accuracy is the deviation in actual output from nominal output over the entire pressure range and temperature range as a percent of span at 25°C due to all sources of error including the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the pressure has been stabilized.
8. Offset Stability is the product's output deviation when subjected to 1000 cycles of Pulsed Pressure, Temperature Cycling with Bias Test.

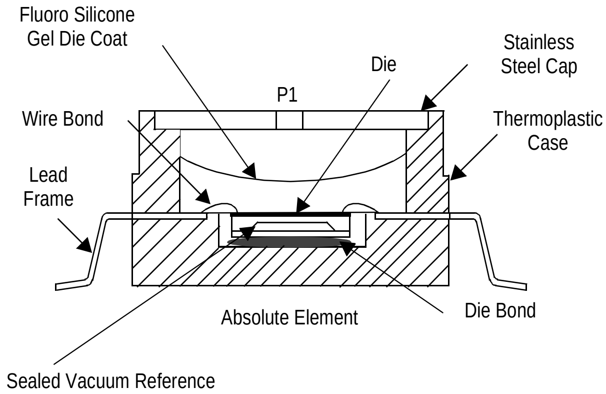


Figure 2. Cross Sectional Diagram SOP (Not to Scale)

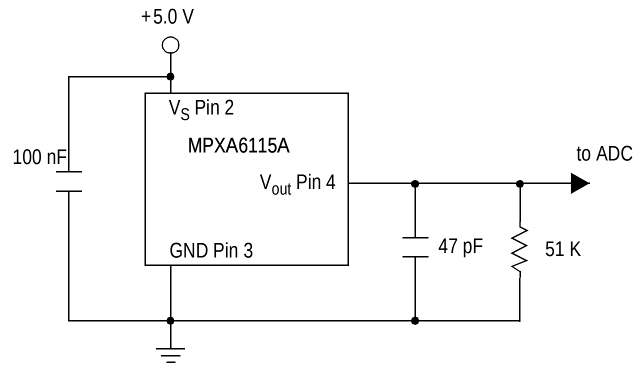


Figure 3. Typical Application Circuit (Output Source Current Operation)

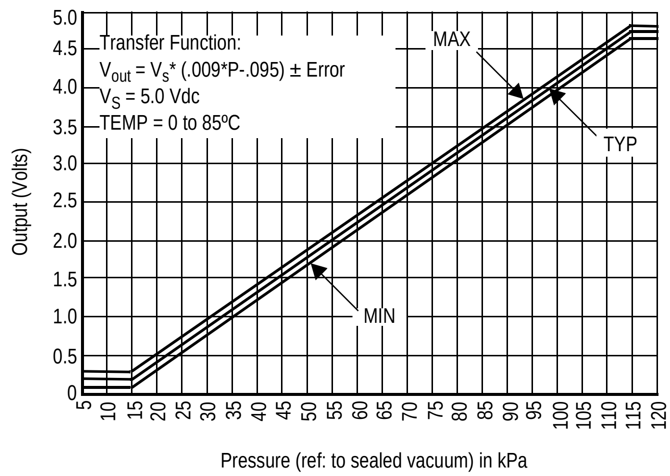


Figure 4. Output versus Absolute Pressure

Figure 4 shows the sensor output signal relative to pressure input. Typical minimum and maximum output curves are shown for operation over 0 to 85°C temperature range. The output will saturate outside of the rated pressure range.

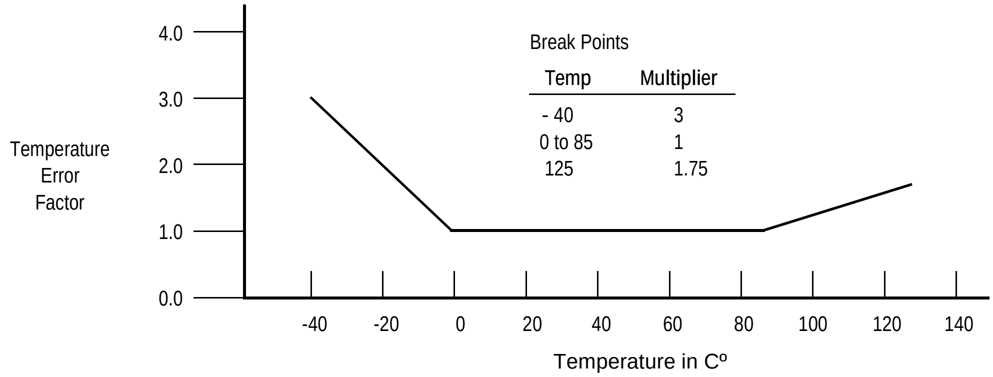
A gel die coat isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. The gel die coat and durable polymer package provide a media resistant barrier that allows the sensor to operate reliably in high humidity conditions as well as environments containing common automotive media. Contact the factory for more information regarding media compatibility in your specific application.

Transfer Function (MPXAZ6115A

Nominal Transfer Value: $V_{out} = V_S \times (0.009 \times P - 0.095)$
$\pm$ (Pressure Error x Temp. Factor x 0.009 x V_S)
$V_S = 5.0 \pm 0.25$ Vdc

Temperature Error Band

MPXAZ6115A Series



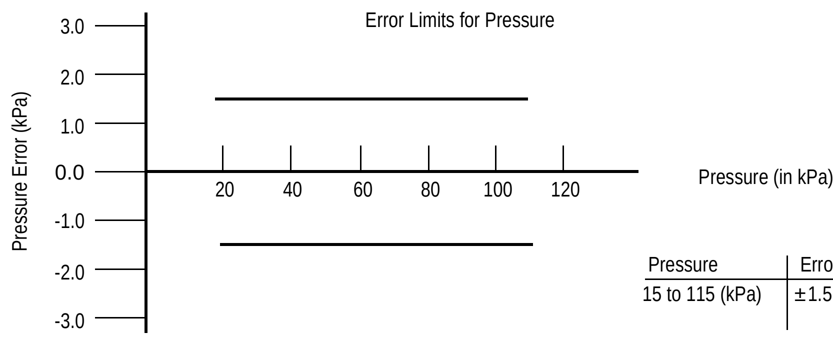
Break Points

Temp	Multiplier
- 40	3
0 to 85	1
125	1.75

NOTE: The Temperature Multiplier is a linear response from 0ºC to -40ºC and from 85ºC to 125ºC

Pressure Error Band

Error Limits for Pressure



Pressure	Error (Max)
15 to 115 (kPa)	±1.5 (kPa)

MINIMUM RECOMMENDED FOOTPRINT FOR SMALL AND SUPER SMALL PACKAGES

Surface mount board layout is a critical portion of the total design. The footprint for the semiconductor package must be the correct size to ensure proper solder connection interface between the board and the package. With the correct pad geometry, the packages will self-align when subjected to a solder reflow process. It is always recommended to fabricate boards with a solder mask layer to avoid bridging and/or shorting between solder pads, especially on tight tolerances and/or tight layouts.

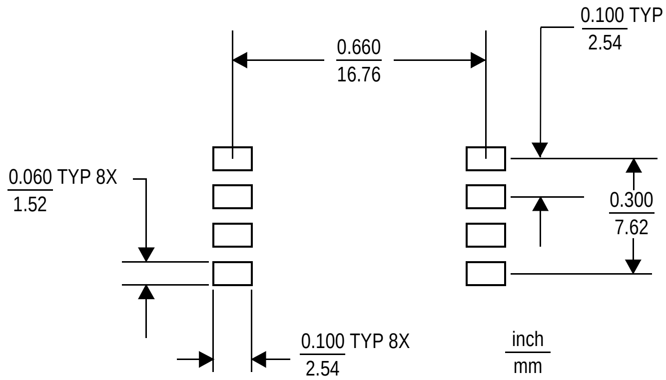


Figure 5. SOP Footprint (Case 482 and 482A)

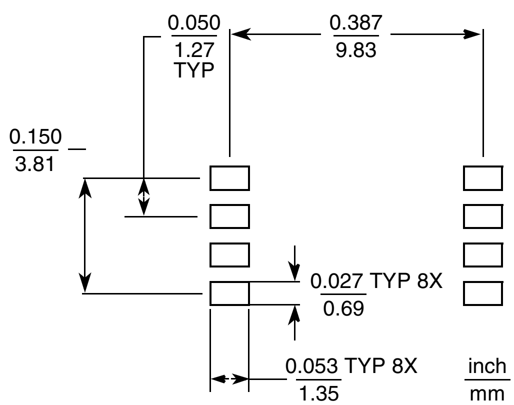


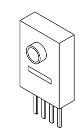
Figure 6. SSOP Footprint (Case 1317 and 1317A)

High Volume Sensor for Low Pressure Applications

MPXC2011DT1
MPXC2012DT1

PRESSURE SENSORS
0 to 75 mm HG
(0 TO 10 kPA

CHIP PAK PACKAGE



MPXC2011DT1/MPXC2012DT1
CASE 423A-03

PIN NUMBER			
1	GND	3	V_S
2	S+	4	S-

Freescale Semiconductor has developed a low cost, high volume, miniature pressure sensor package which is ideal as a sub-module component or a disposable unit. The unique concept of the Chip Pak allows great flexibility in system design while allowing an economic solution for the designer. This new chip carrier package uses Freescale Semiconductor's unique sensor die with its piezoresistive technology, along with the added feature of on-chip, thin-film temperature compensation and calibration.

NOTE: Freescale Semiconductor is also offering the Chip Pak package in application-specific configurations, which will have an “SPX” prefix, followed by a four-digit number, unique to the specific customer

Features

- Low Cost
- Integrated Temperature Compensation and Calibration
- Ratiometric to Supply Voltage
- Polysulfone Case Material (Medical, Class V Approved)
- Provided in Easy-to-Use Tape and Reel

Typical Applications

- Respiratory Diagnostics
- Air Movement Control
- Controllers
- Pressure Switching

NOTE: The die and wire bonds are exposed on the front side of the Chip Pak (pressure is applied to the backside of the device). Front side die and wire protection must be provided in the customer's housing. Use caution when handling the devices during all processes.

Freescale Semiconductor's MPXC2011DT1/ MPXC2012DT1 Pressure Sensor has been designed for medical usage by combining the performance of Freescale Semiconductor's shear stress pressure sensor design and the use of biomedically approved materials. Materials with a proven history in medical situations have been chosen to provide a sensor that can be used with confidence in applications, such as invasive blood pressure monitoring. It can be sterilized using ethylene oxide. The portions of the pressure sensor that are required to be biomedically approved are the rigid housing and the gel coating.

The rigid housing is molded from a white, medical grade polysulfone that has passed extensive biological testing including: tissue culture test, rabbit implant, hemolysis, intracutaneous test in rabbits, and system toxicity, USP.

The MPXC2011DT1 contains a silicone dielectric gel which covers the silicon piezoresistive sensing element. The gel is a nontoxic, nonallergenic elastomer system which meets all USP XX Biological Testing Class V requirements. The properties of the gel allow it to transmit pressure uniformly to the diaphragm surface, while isolating the internal electrical connections from the corrosive effects of fluids, such as saline solution. The gel provides electrical isolation sufficient to withstand defibrillation testing, as specified in the proposed Association for the Advancement of Medical Instrumentation (AAMI) Standard for blood pressure transducers. A biomedically approved opaque filler in the gel prevents bright operating room lights from affecting the performance of the sensor.

The MPXC2012DT1 is a no-gel option.

ORDERING INFORMATION			
Device Order No.	**Case No.**	**Device Description**	**Device Marking**
MPXC2011DT1	423A	Chip Pak, 1/3 Gel	Date Code, Lot ID
MPXC2012DT1	423A	Chip Pak, No Gel	Date Code, Lot ID

Packaging Information	Reel Size	Tape Width	Quantity
Tape and Reel	330 mm	24 mm	1000 pc/reel

Table 1. Maximum Ratings[1]

Rating	Symbol	Value	Unit
Maximum Pressure (Backside)	P_{max}	75	kPa
Storage Temperature	T_{stg}	-25 to +85	°C
Operating Temperature	T_A	+15 to +40	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 10 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range[1]	P_{OP}	0	—	10	kPa
Supply Voltage[2]	V_S	—	3	10	Vdc
Supply Current	I_o	—	6.0	—	mAdc
Full Scale Span[3]	V_{FSS}	24	25	26	mV
Offset[4]	V_{off}	-1.0	—	1.0	mV
Sensitivity	ΔV/ΔP	—	2.5	—	mV/kPa
Linearity[5]	—	-1.0	—	1.0	$\%V_{FSS}$
Pressure Hysteresis[5] (0 to 10 kPa)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis[5] (+15°C to +40°C)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Effect on Full Scale Span[5]	TCV_{FSS}	-1.0	—	1.0	$\%V_{FSS}$
Temperature Effect on Offset[5]	TCV_{off}	-1.0	—	1.0	mV
Input Impedance	Z_{in}	1300	—	2550	W
Output Impedance	Z_{out}	1400	—	3000	W
Response Time[6] (10% to 90%)	t_R	—	1.0	—	ms
Warm-Up	—	—	20	v	ms
Offset Stability[7]	—	—	±0.5	—	$\%V_{FSS}$

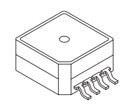
1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
    - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
    - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
    - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
    - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
    - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

High Temperature Accuracy Integrated Silicon Pressure Sensor for Measuring Absolute Pressure, On-Chip Signal Conditioned, Temperature Compensated and Calibrated

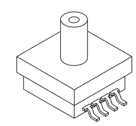
MPXH6250A SERIES

INTEGRATED PRESSURE SENSOR
20 to 250 kPa (3.0 to 36 psi)
0.3 to 4.9 V OUTPUT

SUPER SMALL OUTLINE PACKAGES



MPXH6250A6U/6T1
CASE 1317-04



MPXH6250AC6U/C6T1
CASE 1317A-01

The Freescale MPXH6250A series sensor integrates on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The small form factor and high reliability of on-chip integration make the Freescale MAP sensor a logical and economical choice for automotive system designers.

The MPXH6250A series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

Features

- Improved Accuracy at High Temperature
- Available in Small and Super Small Outline Packages
- 1.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated from –40° to +125°C
- Durable Thermoplastic (PPS) Surface Mount Package

Typical Applications

- Industrial Controls
- Engine Control/Manifold Absolute Pressure (MAP)

ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
Basic Element	Absolute, Element Only	1317	MPXH6250A6U	Rails	MPXH6250A
	Absolute, Element Only	1317	MPXH6250A6T1	Tape & Reel	MPXH6250A
Ported Element	Absolute, Axial Port	1317A	MPXH6250AC6U	Rails	MPXH6250A
	Absolute, Axial Port	1317A	MPXH6250AC6T1	Tape & Reel	MPXH6250A

PIN NUMBERS(1)

1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

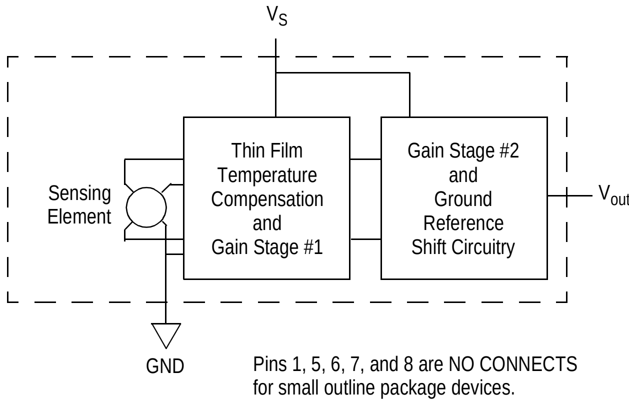


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	1000	kPa
Storage Temperature	T_{STG}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C
Output Source Current @ Full Scale Output(2)	I_o+	0.5	mAdc
Output Sink Current @ Minimum Pressure Offset2	$I_o–$	-0.5	mAdc

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.
2. Maximum Output Current is controlled by effective impedance from V_{out} to GND or V_{out} to V_S in the application circuit.

Table 2. Operating Characteristics (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	20	—	250	kPa
Supply Voltage(1)		V_S	4.74	5.1	5.46	Vdc
Supply Current		I_o	—	6.0	10	mAdc
Minimum Pressure Offset @ V_S = 5.1 Volts(2)	(0 to 85°C)	V_{off}	0.133	0.204	0.274	Vdc
Full Scale Output @ V_S = 5.1 Volts(3)	(0 to 85°C)	V_{FSO}	4.826	4.896	4.966	Vdc
Full Scale Span @ V_S = 5.1 Volts(4)	(0 to 85°C)	V_{FSS}	4.552	4.692	4.833	Vdc
Accuracy(5)	(0 to 85°C)	—	—	—	±1.5	$\%V_{FSS}$
Sensitivity		V/P	—	20.4	—	mV/kPa
Response Time(6)		t_R	—	1.0	—	ms
Warm-Up Time(7)		—	—	20	—	ms
Offset Stability(8)		—	—	±0.25	—	$\%V_{FSS}$

1. Device is ratiometric within this specified excitation range.
2. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
3. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
4. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
5. Accuracy is the deviation in actual output from nominal output over the entire pressure range and temperature range as a percent of span at 25°C due to all sources of error including the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
8. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

Figure 2 illustrates the absolute sensing chip in the basic Super Small Outline chip carrier (Case 1317). Figure 3 illustrates a typical application circuit (output source current operation).

Figure 4 shows the sensor output signal relative to pressure input. Typical minimum and maximum output curves are shown for operation over 0 to 85°C temperature range. The output will saturate outside of the rated pressure range.

A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm. The MPXH6250A series pressure sensor operating characteristics, internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

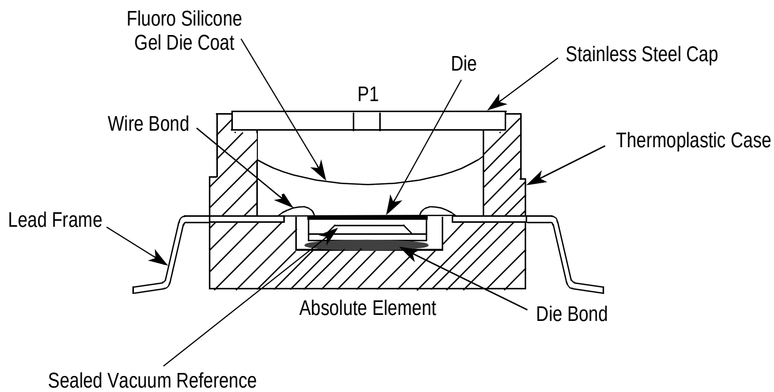


Figure 2. Cross Sectional Diagram SSOP (not to scale)

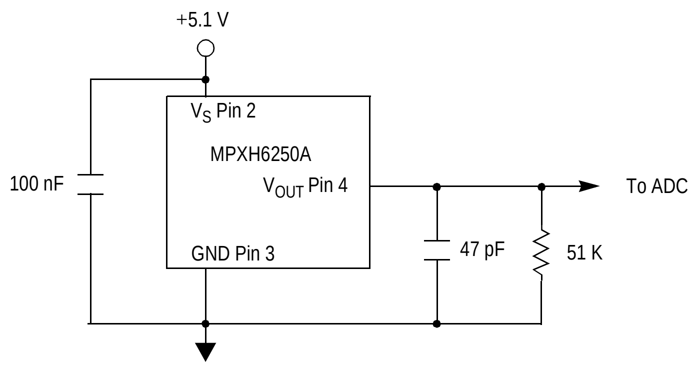


Figure 3. Typical Application Circuit (Output Source Current Operation)

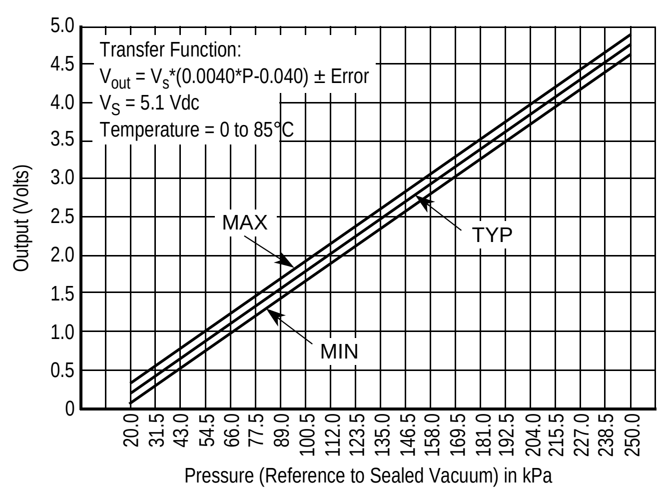
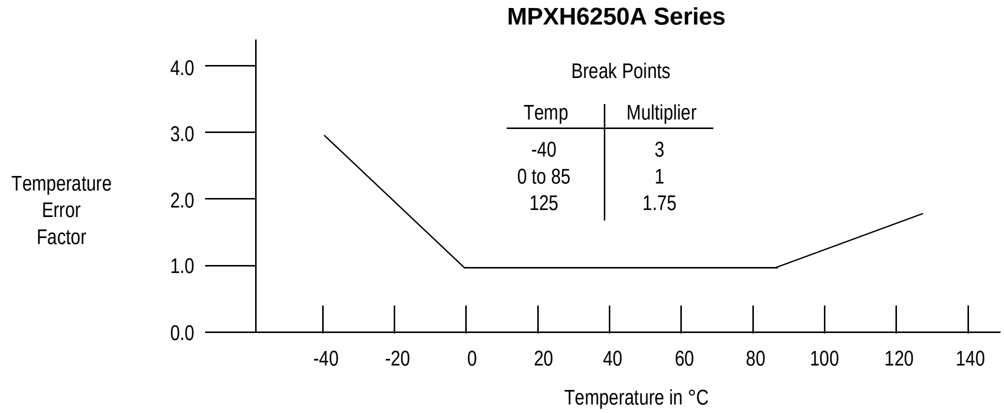


Figure 4. Output versus Absolute Pressure

Transfer Function (MPXH6250A)

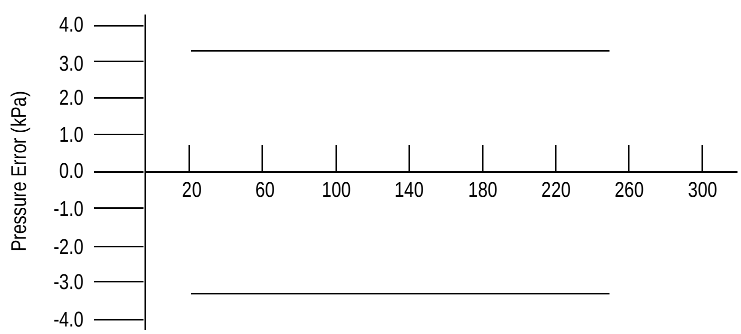
Nominal Transfer Value: $V_{out} = V_S \times (0.004 \times P - 0.040)$
$\pm$ (Pressure Error x Temp Factor x 0.004 x V_S)
$V_S = 5.1 \pm 0.36$ Vdc

Temperature Error Band



NOTE: The Temperature Multiplier is a linear response from 0°C to -40°C and from 85°C to 125°C.

Pressure Error Band



Error Limits for Pressure

Pressure (in kPa)

Pressure	Error (Max)
20 to 250 (kPa)	±3.45 (kPa)

SURFACE MOUNTING INFORMATION

Minimum Recommended Footprint for Super Small Outline Packages

Surface mount board layout is a critical portion of the total design. The footprint for the semiconductor package must be the correct size to ensure proper solder connection interface between the board and the package. With the correct pad geometry, the packages will self-align when subjected to a solder reflow process. It is always recommended to fabricate boards with a solder mask layer to avoid bridging and/or shorting between solder pads, especially on tight tolerances and/or tight layouts.

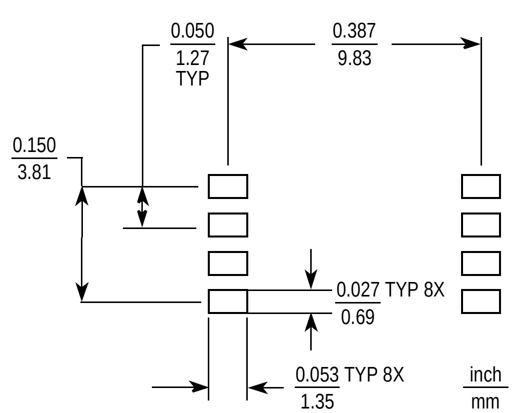


Figure 5. SSOP Footprint (Case 1317 and 1317A)

High Temperature Accuracy Integrated Silicon Pressure Sensor for Measuring Absolute Pressure, On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPXH6300A SERIES

INTEGRATED PRESSURE SENSOR
20 to 304 kPa (3.0 to 42 psi)
0.3 to 4.9 V OUTPUT

The Freescale MPXH6300A series sensor integrates on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The small form factor and high reliability of on-chip integration make the Freescale pressure sensor a logical and economical choice for the system designer.

The MPXH6300A series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

Features

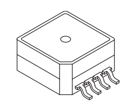
- Improved Accuracy at High Temperature
- Available in Small and Super Small Outline Packages
- 1.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated from –40° to +125°C
- Durable Thermoplastic (PPS) Surface Mount Package

Application Examples

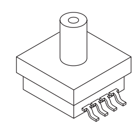
- Industrial Controls
- Engine Control/Manifold Absolute Pressure (MAP)

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
Basic Element	Absolute, Element Only	1317	MPXH63000A6U	Rails	MPXH6300A
	Absolute, Element Only	1317	MPXH6300A6T1	Tape & Reel	MPXH6300A
Ported Element	Absolute, Axial Port	1317A	MPXH6300AC6U	Rails	MPXH6300A
	Absolute, Axial Port	1317A	MPXH300AC6T1	Tape & Reel	MPXH6300A

SUPER SMALL OUTLINE PACKAGES



MPXH6300A6U/6T1
CASE 1317-04



MPXH6300AC6U/C6T1
CASE 1317A-01

PIN NUMBERS(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

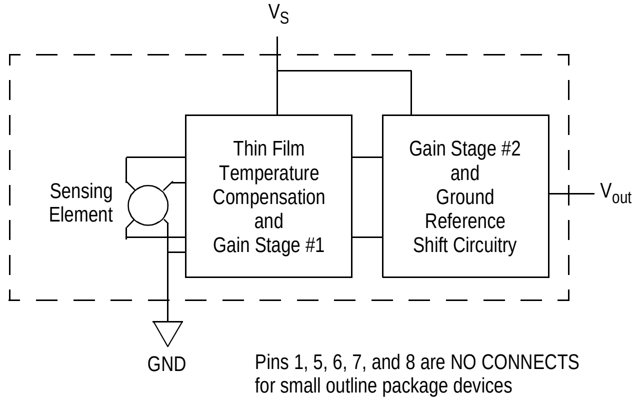


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	1200	kPa
Storage Temperature	T_{STG}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C
Output Source Current @ Full Scale Output(2)	I_o+	0.5	mAdc
Output Sink Current @ Minimum Pressure Offset2	I_o-	–0.5	mAdc

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.
2. Maximum Output Current is controlled by effective impedance from V_{out} to GND or V_{out} to V_S in the application circuit.

Table 2. Operating Characteristics (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	20	—	304	kPa
Supply Voltage(1)		V_S	4.74	5.1	5.46	Vdc
Supply Current		I_o	—	6.0	10	mAdc
Minimum Pressure Offset @ V_S = 5.1 Volts(2)	(0 to 85°C)	V_{off}	0.241	0.306	0.371	Vdc
Full Scale Output @ V_S = 5.1 Volts(3)	(0 to 85°C)	V_{FSO}	4.847	4.912	4.977	Vdc
Full Scale Span @ V_S = 5.1 Volts(4)	(0 to 85°C)	V_{FSS}	4.476	4.606	4.736	Vdc
Accuracy(5)	(0 to 85°C)	—	—	—	±1.5	$\%V_{FSS}$
Sensitivity		V/P	—	16.2	—	mV/kPa
Response Time(6)		t_R	—	1.0	—	ms
Warm-Up Time(7)		—	—	20	—	ms
Offset Stability(8)		—	—	±0.25	—	$\%V_{FSS}$

1. Device is ratiometric within this specified excitation range.
2. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
3. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
4. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
5. Accuracy is the deviation in actual output from nominal output over the entire pressure range and temperature range as a percent of span at 25°C due to all sources of error including the following:

   Linearity:Output deviation from a straight line relationship with pressure over the specified pressure range.
   Temperature Hysteresis:Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   Pressure Hysteresis:Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   TcSpan:Output deviation over the temperature range of 0 to 85°C, relative to 25°C.
   TcOffset:Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   Variation from Nominal:The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
8. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

Figure 2 illustrates the absolute sensing chip in the basic Super Small Outline chip carrier (Case 1317). Figure 3 illustrates a typical application circuit (output source current operation).

Figure 4 shows the sensor output signal relative to pressure input. Typical minimum and maximum output curves are shown for operation over 0 to 85°C temperature range. The output will saturate outside of the rated pressure range.

A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm. The MPXH6300A series pressure sensor operating characteristics, internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

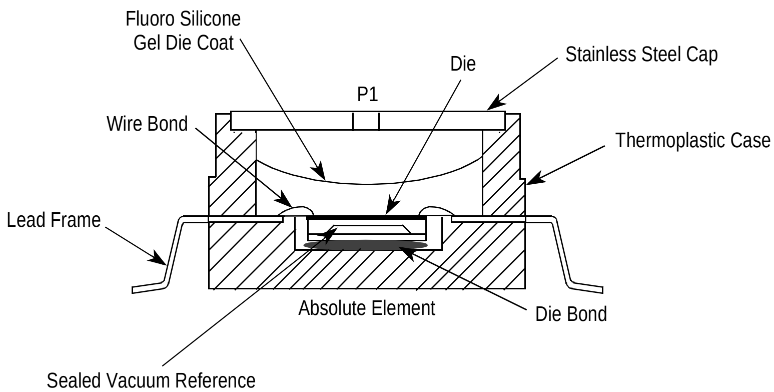


Figure 2. Cross Sectional Diagram SSOP (not to scale)

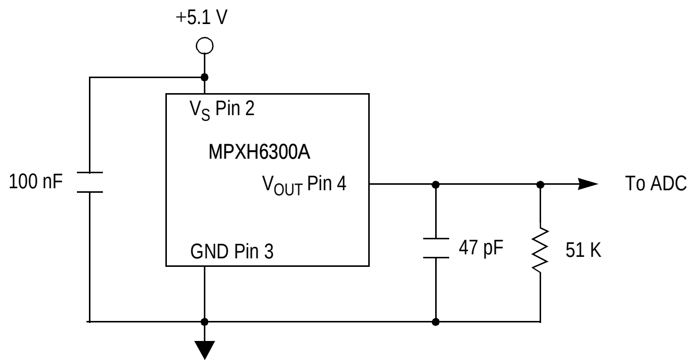


Figure 3. Typical Application Circuit (Output Source Current Operation)

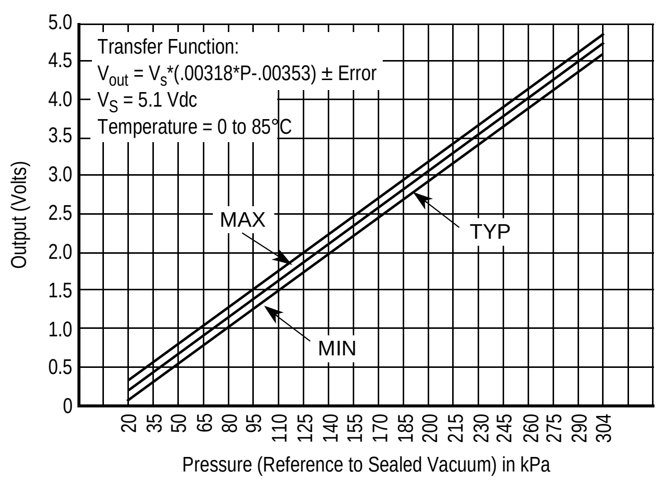
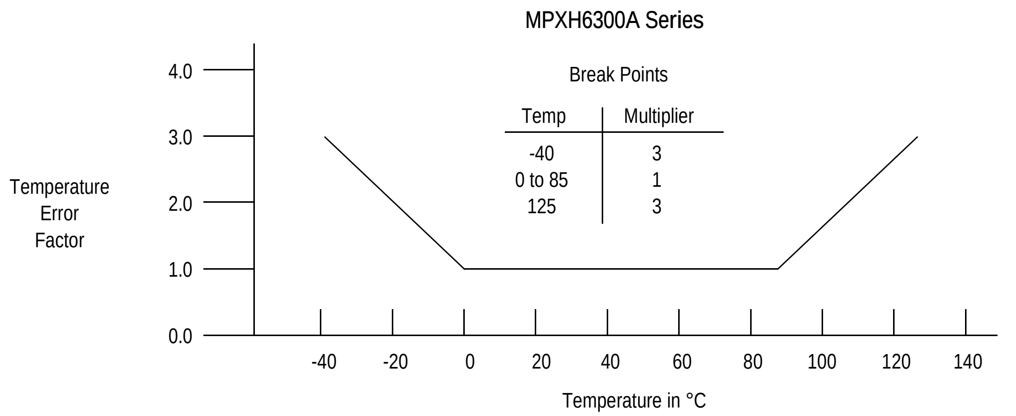


Figure 4. Output versus Absolute Pressure

Transfer Function (MPXH6300A)

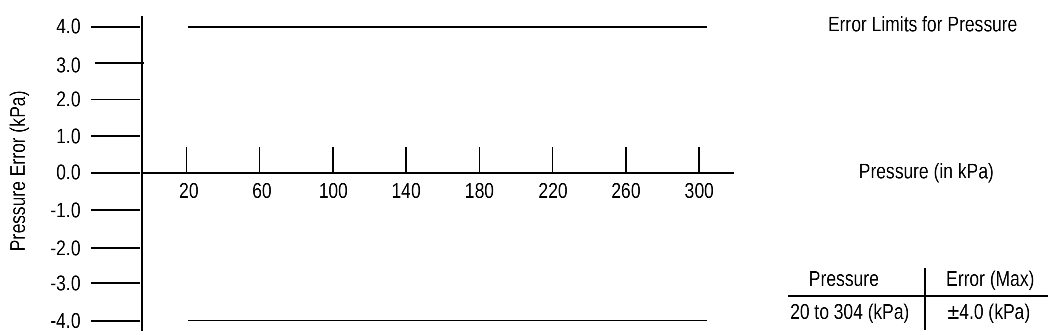
Nominal Transfer Value: $V_{out} = V_S \times (0.00318 \times P - 0.00353)$
$\pm$ (Pressure Error x Temp Factor x $0.00318 \times V_S$)
$V_S = 5.1 \pm 0.36$ Vdc

Temperature Error Band



NOTE: The Temperature Multiplier is a linear response from 0°C to -40°C and from 85°C to 125°C.

Pressure Error Band



SURFACE MOUNTING INFORMATION

Minimum Recommended Footprint for Super Small Outline Packages

Surface mount board layout is a critical portion of the total design. The footprint for the semiconductor package must be the correct size to ensure proper solder connection interface between the board and the package. With the correct pad geometry, the packages will self-align when subjected to a solder reflow process. It is always recommended to fabricate boards with a solder mask layer to avoid bridging and/or shorting between solder pads, especially on tight tolerances and/or tight layouts.

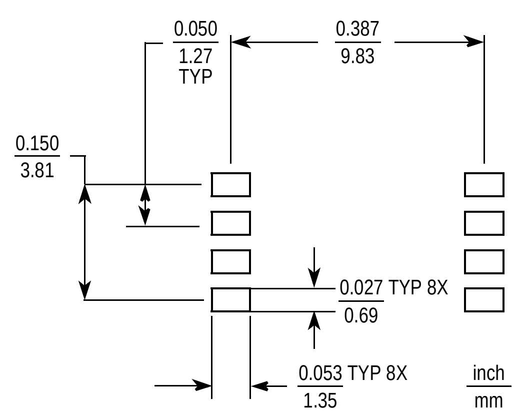


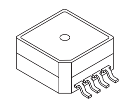
Figure 5. SSOP Footprint (Case 1317 and 1317A)

High Temperature Accuracy Integrated Silicon Pressure Sensor for Measuring Absolute Pressure, On-Chip Signal Conditioned, Temperature Compensated and Calibrated

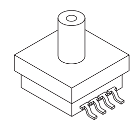
MPXH6400A SERIES

INTEGRATED PRESSURE SENSOR
20 TO 400 kPA (3.0 TO 58 psi)
0.2 TO 4.8 V OUTPUT
(3.0 TO 58 psi)

SUPER SMALL OUTLINE PACKAGES



MPXH6400A6U/6T1
CASE 1317-04



MPXH6400AC6U/C6T1
CASE 1317A-01

PIN NUMBERS[(1)]			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

The Freescale MPXH6400A series sensor integrates on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The small form factor and high reliability of on-chip integration make the Freescale pressure sensor a logical and economical choice for the system designer.

The MPXH6400A series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

Features

- Improved Accuracy at High Temperature
- Available in Small and Super Small Outline Packages
- 1.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated from –40° to +125°C
- Durable Thermoplastic (PPS) Surface Mount Package

Typical Applications

- Industrial Controls
- Engine Control/Manifold Absolute Pressure (MAP)

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
Basic Element	Absolute, Element Only	1317	MPXH6400A6U	Rails	MPXH6400A
	Absolute, Element Only	1317	MPXH6400A6T1	Tape & Reel	MPXH6400A
Ported Element	Absolute, Axial Port	1317A	MPXH6400AC6U	Rails	MPXH6400A
	Absolute, Axial Port	1317A	MPXH6400AC6T1	Tape & Reel	MPXH6400A

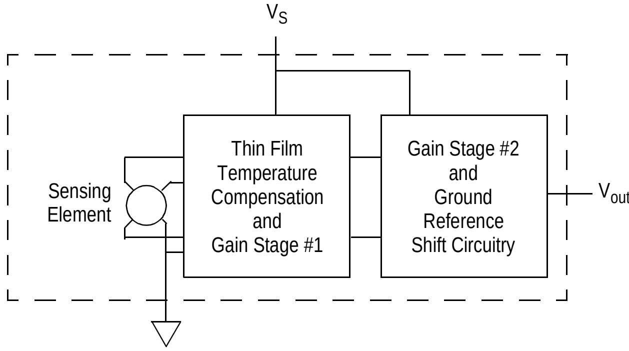


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	1600	kPa
Storage Temperature	T_{STG}	–40° to +125°	°C
Operating Temperature	T_A	–40° to +125°	°C
Output Source Current @ Full Scale Output(2)	I_o+	0.5	mAdc
Output Sink Current @ Minimum Pressure Offset(2)	I_o-	–0.5	mAdc

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.
2. Maximum Output Current is controlled by effective impedance from V_{out} to GND or V_{out} to V_S in the application circuit.

Table 2. Operating Characteristics (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	20	—	400	kPa
Supply Voltage[(1)]		V_S	4.64	5.0	5.36	Vdc
Supply Current		I_o	—	6.0	10	mAdc
Minimum Pressure Offset @ V_S = 5.1 Volts[(2)]	(0 to 85°C)	V_{off}	0.133	0.2	0.267	Vdc
Full Scale Output @ V_S = 5.1 Volts[(3)]	(0 to 85°C)	V_{FSO}	4.733	4.8	4.866	Vdc
Full Scale Span @ V_S = 5.1 Volts[(4)]	(0 to 85°C)	V_{FSS}	4.467	4.6	4.733	Vdc
Accuracy[(5)]	(0 to 85°C)	—	—	—	±1.5	$\%V_{FSS}$
Sensitivity		V/P	—	12.1	—	mV/kPa
Response Time[(6)]		t_R	—	1.0	—	ms
Warm-Up Time[(7)]		—	—	20	—	ms
Offset Stability[(8)]		—	—	±0.25	—	$\%V_{FSS}$

1. Device is ratiometric within this specified excitation range.
2. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
3. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
4. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
5. Accuracy is the deviation in actual output from nominal output over the entire pressure range and temperature range as a percent of span at 25°C due to all sources of error including the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
8. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

Figure 2 illustrates the absolute sensing chip in the basic Super Small Outline chip carrier (Case 1317). Figure 3 illustrates a typical application circuit (output source current operation).

Figure 4 shows the sensor output signal relative to pressure input. Typical minimum and maximum output curves are shown for operation over 0 to 85°C temperature range. The output will saturate outside of the rated pressure range.

A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm. The MPXH6400A series pressure sensor operating characteristics, internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

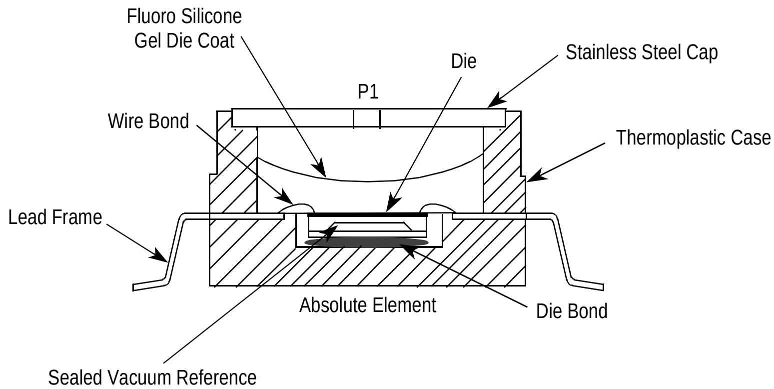


Figure 2. Cross Sectional Diagram SSOP (not to scale)

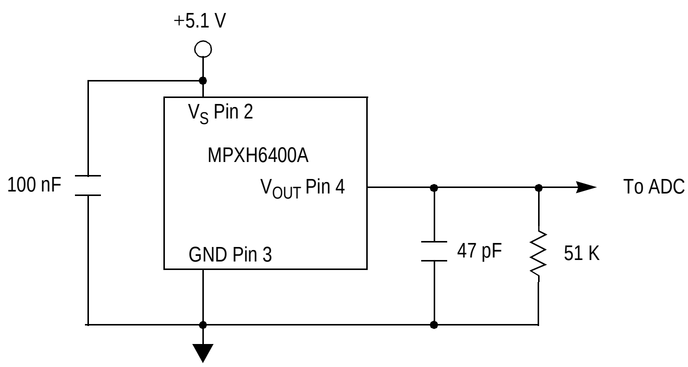


Figure 3. Typical Application Circuit (Output Source Current Operation)

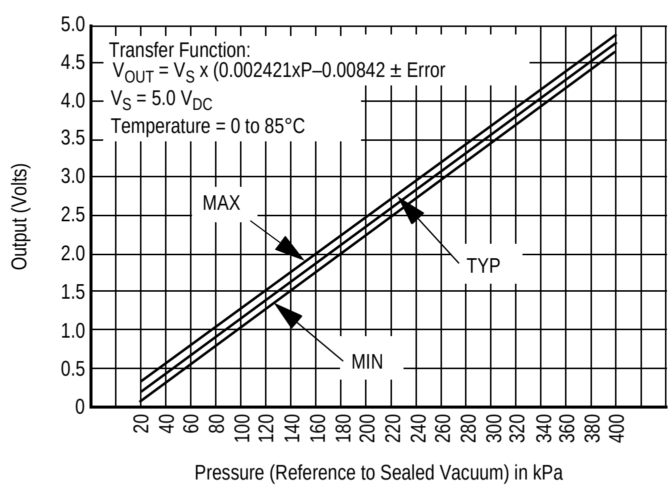


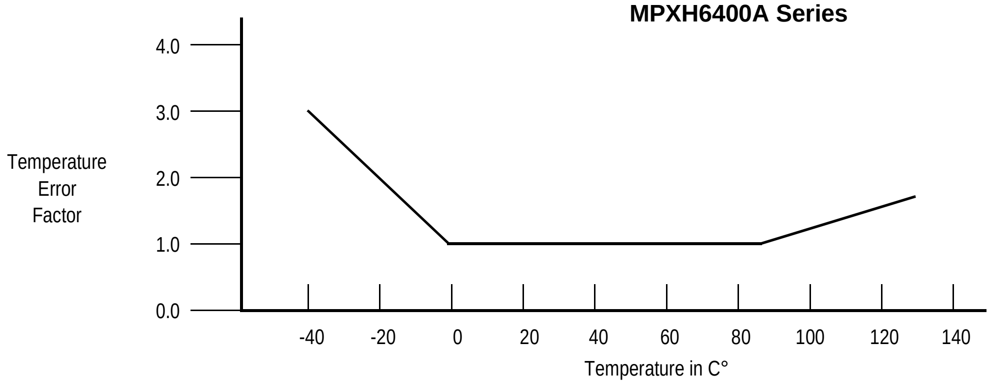
Figure 4. Output versus Absolute Pressure

Transfer Function (MPXH6400A)

Normal Transfer Value: $V_{OUT} = V_S \times (0.002421 \times P - 0.0.00842)$
$\pm$ Pressure Error x Temp. Factor x 0.002421 x V_S
$V_S = 5.0 \pm 0.36\ V_{DC}$

Temperature Error Band

MPXH6400A Series

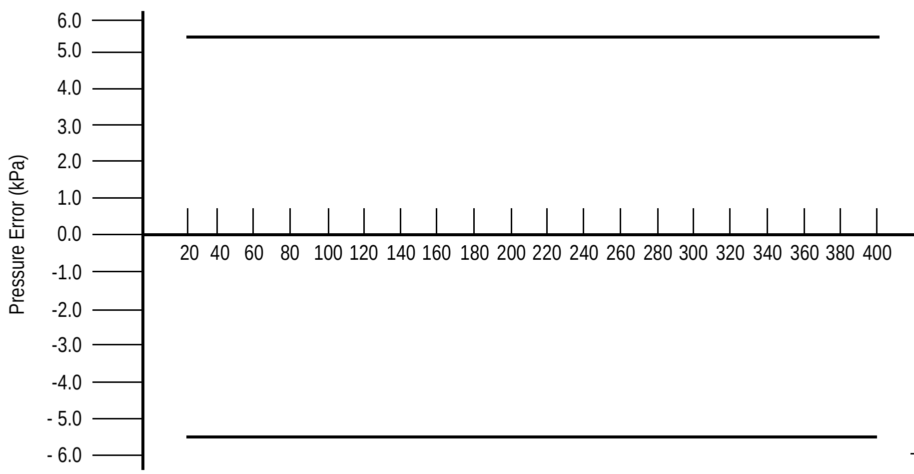


NOTE: The Temperature Multiplier is a linear response from 0°C to -40°C and from 85°C to 125°C

Break Points

Temp	Multiplier
- 40	3
0 to 85	1
125	1.75

Pressure Error Band



Error Limits for Pressure
±5.5 (kPa)

Pressure (in kPa)

Pressure	Error (Max)
20 to 400 (kPa)	±5.5 (kPa)

SURFACE MOUNTING INFORMATION

Minimum Recommended Footprint for Super Small Outline Packages

Surface mount board layout is a critical portion of the total design. The footprint for the semiconductor package must be the correct size to ensure proper solder connection interface between the board and the package. With the correct pad geometry, the packages will self-align when subjected to a solder reflow process. It is always recommended to fabricate boards with a solder mask layer to avoid bridging and/or shorting between solder pads, especially on tight tolerances and/or tight layouts.

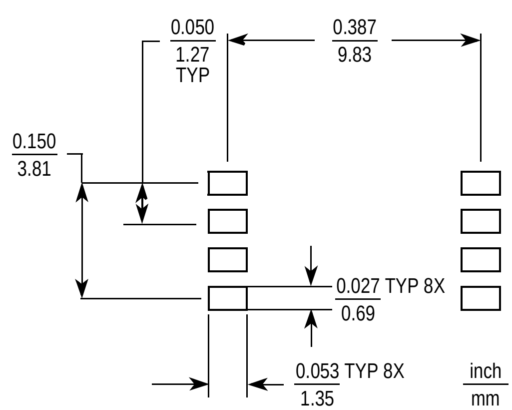


Figure 5. SSOP Footprint (Case 1317 and 1317A)

Freescale Semiconductor
Technical Data

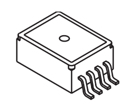
MPXM2010
Rev 3, 05/2005

10 kPa On-Chip Temperature Compensated & Calibrated Silicon Pressure Sensors

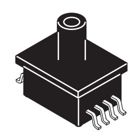
MPXM2010 SERIES

The MPXM2010 device is a silicon piezoresistive pressure sensor providing a highly accurate and linear voltage output – directly proportional to the applied pressure. The sensor is a single, monolithic silicon diaphragm with the strain gauge and a thin-film resistor network integrated on-chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation.

FREESCALE PREFERRED DEVICE
0 to 10 kPa (0 to 1.45 psi)
25 mV FULL SCALE SPAN (TYPICAL)



MPXM2010D/DT1
CASE 1320-02



MPXM2010GS/GST1
CASE 1320A-02

Features

- Temperature Compensated Over 0°C to +85°C
- Available in Easy-to-Use Tape & Reel
- Ratiometric to Supply Voltage
- Gauge Ported & Non Ported Options

Application Examples

- Respiratory Diagnostics
- Air Movement Control
- Controllers
- Pressure Switching

Figure 1 shows a block diagram of the internal circuitry on the stand-alone pressure sensor chip.

ORDERING INFORMATION		
Device Type/Order No.	**Options**	**Case No.**
MPXM2010D	Non-ported	1320
MPXM2010DT1	Non-ported, Tape and Reel	1320
MPXM2010GS	Ported	1320A
MPXM2010GST1	Ported, Tape and Reel	1320A

PIN NUMBERS			
1	GND	3	V_S
2	$+V_{out}$	4	$-V_{out}$

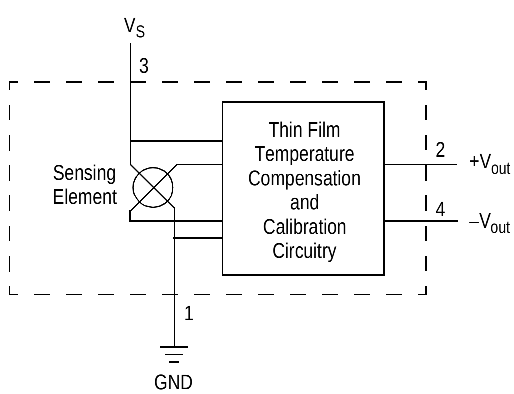


Figure 1. Fully Integrated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the sensor is directly proportional to the differential pressure applied.

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side (P1) relative to the vacuum side (P2). Similarly, output voltage increases as increasing vacuum is applied to the vacuum side (P2) relative to the pressure side (P1).

NOTE: **Preferred** devices are Freescale recommended choices for future use and best overall value.

Table 1. Maximum Ratings[1]

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	75	kPa
Storage Temperature	T_{STG}	–40° to +125°	°C
Operating Temperature	T_A	–40° to +125°	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 10 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range[(1)]	P_{OP}	0	—	10	kPa
Supply Voltage[(2)]	V_S	—	10	16	Vdc
Supply Current	I_o	—	6.0	—	mAdc
Full Scale Span[(3)]	V_{FSS}	24	25	26	mV
Offset[(4)]	V_{off}	–1.0	—	1.0	mV
Sensitivity	ΔV/ΔP	—	2.5	—	mV/kPa
Linearity[(5)]	—	–1.0	—	1.0	$\%V_{FSS}$
Pressure Hysteresis[(5)] (0 to 10 kPa)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis[5] (-–40°C to +125°C)	—	—	±0.5	—	$\%V_{FSS}$
Temperature Effect on Full Scale Span[(5)]	TCV_{FSS}	–1.0	—	1.0	$\%V_{FSS}$
Temperature Effect on Offset[(5)]	TCV_{off}	–1.0	—	1.0	mV
Input Impedance	Z_{in}	1000	—	2550	W
Output Impedance	Z_{out}	1400	—	3000	W
Response Time[(6)] (10% to 90%)	t_R	—	1.0	—	ms
Warm-Up	—	—	20	—	ms
Offset Stability[(7)]	—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the “best case” linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the “worst case” error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Freescale's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

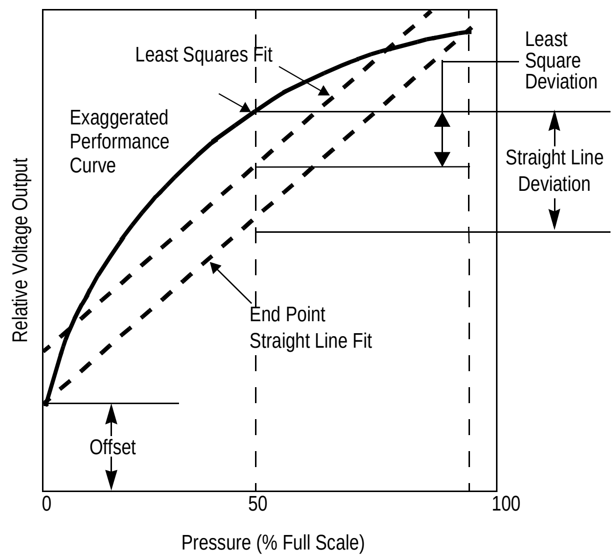


Figure 2. Linearity Specification Comparison

ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

Figure 3 shows the minimum, maximum and typical output characteristics of the MPXM2010 series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

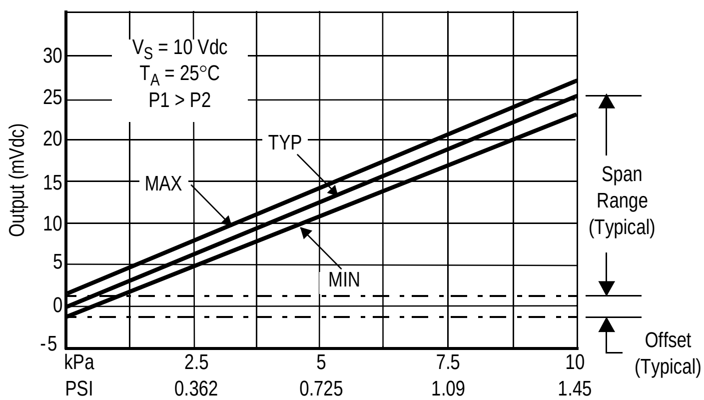


Figure 3. Output versus Pressure Differential

50 kPa On-Chip Temperature Compensated and Calibrated Silicon Pressure Sensors

MPXM2051G SERIES

COMPENSATED AND CALIBRATED PRESSURE SENSOR
0 TO 50 kPA (0 TO 7.25 psi)
40 mV FULL SCALE SPAN
(TYPICAL)

The MPXM2051G device is a silicon piezoresistive pressure sensor providing a highly accurate and linear voltage output - directly proportional to the applied pressure. The sensor is a single, monolithic silicon diaphragm with the strain gauge and a thin-film resistor network integrated on-chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation.

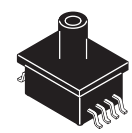
Features

- Temperature Compensated Over 0°C to +85°C
- Available in Easy-to-Use Tape & Reel
- Ratiometric to Supply Voltage
- Gauge Ported

Typical Applications

- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Non-Invasive Blood Pressure Measurement

MPAK PACKAGES



MPXM2051GS/GST1
CASE 1320A-02

ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
Ported	Absolute, Axial Port	1320A	MPXM2051GS	Rails	MPXM2051G
	Absolute, Element Only	1320A	MPXM2051GST1	Tape & Reel	MPXM2051G

Pin Number

1	Gnd	3	V_S
2	$+V_{out}$	4	$-V_{out}$

Figure 1 shows a block diagram of the internal circuitry on the stand-alone pressure sensor chip.

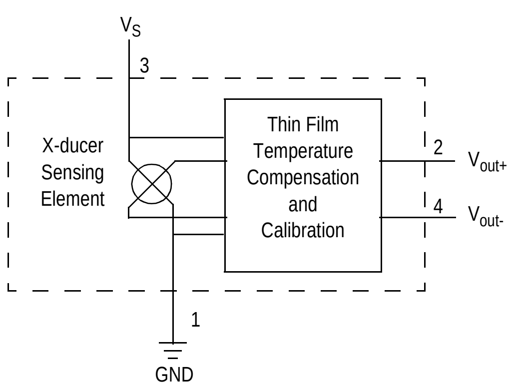


Figure 1. Temperature Compensated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the sensor is directly proportional to the differential pressure applied.

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side (P1) relative to the vacuum side (P2). Similarly, output voltage increases as increasing vacuum is applied to the vacuum side (P2) relative to the pressure side (P1).

Table 1. MAXIMUM RATINGS[1]

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{max}	200	kPa
Storage Temperature	T_{stg}	-40 to +125	°C
Operating Temperature	T_A	-40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. OPERATING CHARACTERISTICS (V_S = 10 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range[1]	P_{OP}	0	—	50	kPa
Supply Voltage[2]	V_S	—	10	16	Vdc
Supply Current	I_o	—	6.0	—	mAdc
Full Scale Span[3]	V_{FSS}	38.5	40	41.5	mV
Offset[4]	V_{off}	-1.0	—	1.0	mV
Sensitivity	$\Delta V/\Delta P$	—	0.8	—	mV/kPa
Linearity[5]	—	-0.3	—	0.3	$\%V_{FSS}$
Pressure Hysteresis[5] (0 to 50 kPa)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis[5] (-40°C to +125°C)	—	—	±0.5	—	$\%V_{FSS}$
Temperature Effect on Full Scale Span[5]	TCV_{FSS}	-1.0	—	1.0	$\%V_{FSS}$
Temperature Effect on Offset[5]	TCV_{off}	-1.0	—	1.0	mV
Input Impedance	Z_{in}	1000	—	2500	W
Output Impedance	Z_{out}	1400	—	3000	W
Response Time[6] (10% to 90%)	t_R	—	1.0	—	ms
Warm-Up	—	—	20	—	ms
Offset Stability[7]	—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. The specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

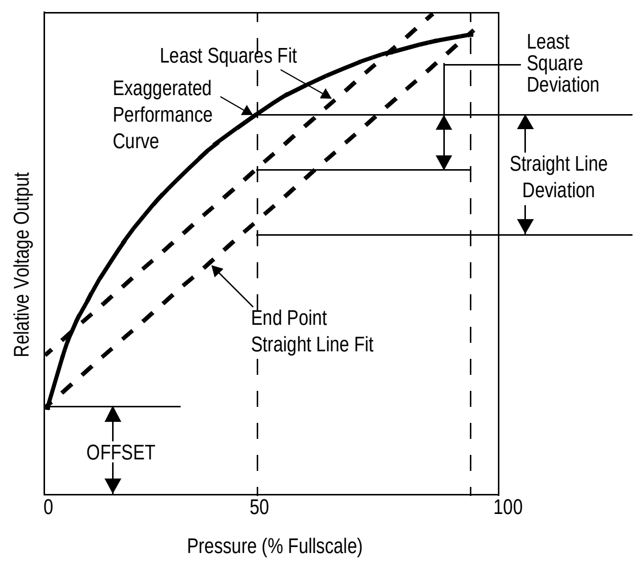


Figure 2. Linearity Specification Comparison

ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

Figure 3 shows the minimum, maximum and typical output characteristics of the MPXM2051G series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

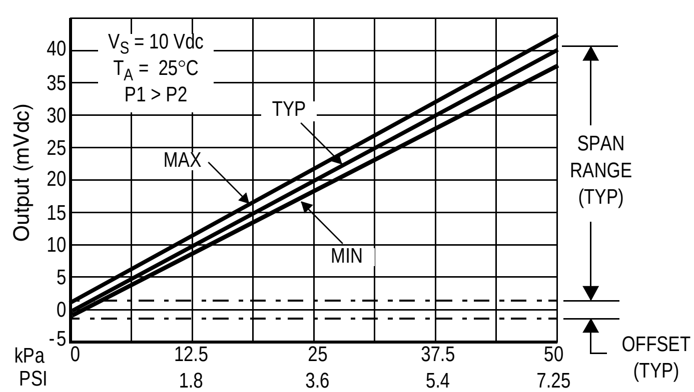


Figure 3. Output versus Pressure Differential

50 kPa On-Chip Temperature Compensated and Calibrated Silicon Pressure Sensors

The MPXM2053 device is a silicon piezoresistive pressure sensor providing a highly accurate and linear voltage output - directly proportional to the applied pressure. The sensor is a single, monolithic silicon diaphragm with the strain gauge and a thin-film resistor network integrated on-chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation.

Features

- Temperature Compensated Over 0°C to +85°C
- Available in Easy-to-Use Tape & Reel
- Ratiometric to Supply Voltage
- Gauge Ported and Non Ported Options

Typical Applications

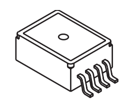
- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Non-Invasive Blood Pressure Measurement

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
Non-ported	Absolute, Element Only	1320	MPXM2053D	Rails	MPXM2053D
	Absolute, Axial Port	1320	MPXM2053DT1	Tape & Reel	MPXM2053D
Ported	Absolute, Axial Port	1320A	MPXM2053GS	Rails	MPXM2053G
	Absolute, Element Only	1320A	MPXM2053GST1	Tape & Reel	MPXM2053G

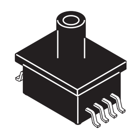
MPXM2053 SERIES

COMPENSATED AND CALIBRATED PRESSURE SENSOR
0 TO 50 kPA (0 TO 1.45 psi)
25 mV FULL SCALE SPAN (TYPICAL)

MPAK PACKAGES



MPXM2053D/DT
CASE 1320-02



MPXM2053GS/GST1
CASE 1320A-02

Pin Number			
1	Gnd	3	V_S
2	$+V_{out}$	4	$-V_{out}$

Figure 1 shows a block diagram of the internal circuitry on the stand-alone pressure sensor chip.

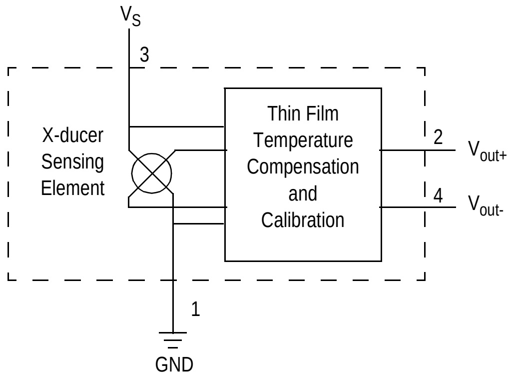


Figure 1. Temperature Compensated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the sensor is directly proportional to the differential pressure applied.

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side (P1) relative to the vacuum side (P2). Similarly, output voltage increases as increasing vacuum is applied to the vacuum side (P2) relative to the pressure side (P1).

Table 1. MAXIMUM RATINGS(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{max}	75	kPa
Storage Temperature	T_{stg}	-40 to +125	°C
Operating Temperature	T_A	-40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. OPERATING CHARACTERISTICS (V_S = 10 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range[1]	P_{OP}	0	—	50	kPa
Supply Voltage[2]	V_S	—	10	16	Vdc
Supply Current	I_o	—	6.0	—	mAdc
Full Scale Span[3]	V_{FSS}	38.5	40	41.5	mV
Offset[4]	V_{off}	-1.0	—	1.0	mV
Sensitivity	ΔV/ΔP	—	0.8	—	mV/kPa
Linearity[5]	—	-0.6	—	0.4	$\%V_{FSS}$
Pressure Hysteresis[5] (0 to 50 kPa)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis[5] (-40°C to +125°C)	—	—	±0.5	—	$\%V_{FSS}$
Temperature Effect on Full Scale Span[5]	TCV_{FSS}	-2.0	—	2.0	$\%V_{FSS}$
Temperature Effect on Offset[5]	TCV_{off}	-1.0	—	1.0	mV
Input Impedance	Z_{in}	1000	—	2500	W
Output Impedance	Z_{out}	1400	—	3000	W
Response Time[6] (10% to 90%)	t_R	—	1.0	—	ms
Warm-Up	—	—	20	—	ms
Offset Stability[7]	—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. The specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

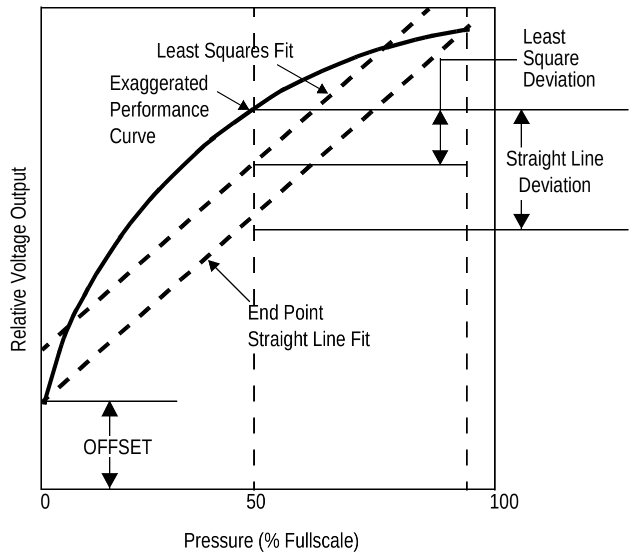


Figure 2. Linearity Specification Comparison

ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

Figure 3 shows the minimum, maximum and typical output characteristics of the MPXM2010 series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

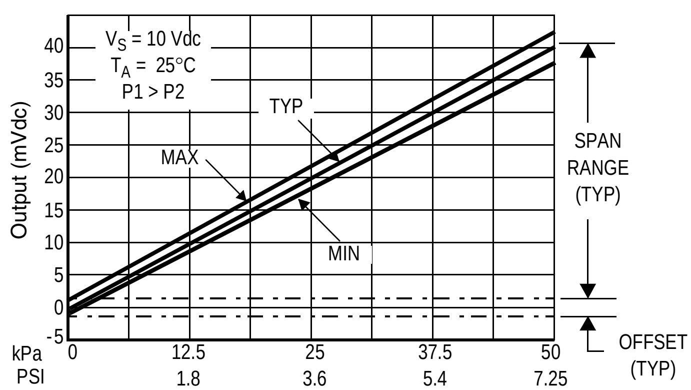


Figure 3. Output versus Pressure Differential

100 kPa On-Chip Temperature Compensated & Calibrated Silicon Pressure Sensors

The MPXM2102 device is a silicon piezoresistive pressure sensors providing a highly accurate and linear voltage output - directly proportional to the applied pressure. The sensor is a single, monolithic silicon diaphragm with the strain gauge and a thin-film resistor network integrated on-chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation.

Features

- Temperature Compensated Over 0°C to +85°C
- Available in Easy-to-Use Tape & Reel
- Ratiometric to Supply Voltage
- Gauge Ported and Non Ported Options

Typical Applications

- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Barometers
- Altimeters

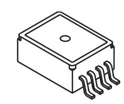
ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
Non-ported	Absolute, Element Only	1320	MPXM2102D	Rails	MPXM2102D
	Absolute, Element Only	1320	MPXM2102DT1	Tape & Reel	MPXM2102D
	Absolute, Element Only	1320	MPXM2102A	Rails	MPXM2102A
	Absolute, Element Only	1320	MPXM2102AT1	Tape & Reel	MPXM2102A
Ported	Absolute, Axial Port	1320A	MPXM2102GS	Rails	MPXM2102G
	Absolute, Axial Port	1320A	MPXM2102GST1	Tape & Reel	MPXM2102G
	Absolute, Axial Port	1320A	MPXM2102AS	Rails	MPXM2102A
	Absolute, Axial Port	1320A	MPXM2102AST1	Tape & Reel	MPXM2102A

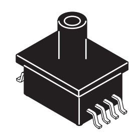
MPXM2102 SERIES

COMPENSATED AND CALIBRATED PRESSURE SENSOR
0 TO 100 kPA (0 TO 14.5 psi)
40 mV FULL SCALE SPAN (TYPICAL)

MPAK PACKAGES



MPXM2102D/A
CASE 1320-02



MPXM2102GS/AS
CASE 1320A-02

Pin Number			
1	Gnd	3	V_S
2	$+V_{out}$	4	$-V_{out}$

Figure 1 shows a block diagram of the internal circuitry on the stand-alone pressure sensor chip.

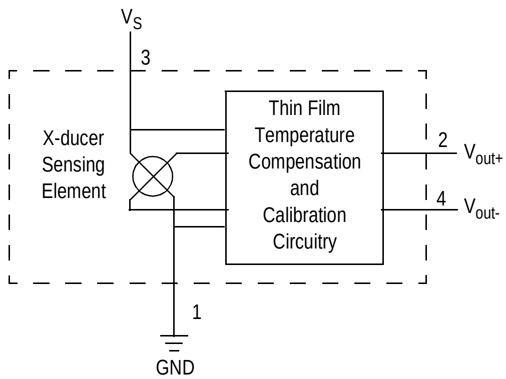


Figure 1. Temperature Compensated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the sensor is directly proportional to the differential pressure applied.

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side (P1) relative to the vacuum side (P2). Similarly, output voltage increases as increasing vacuum is applied to the vacuum side (P2) relative to the pressure side (P1).

Table 1. MAXIMUM RATINGS(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{max}	75	kPa
Storage Temperature	T_{stg}	-40 to +125	°C
Operating Temperature	T_A	-40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. OPERATING CHARACTERISTICS (V_S = 10 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	0	—	100	kPa
Supply Voltage(2)		V_S	—	10	16	Vdc
Supply Current		I_o	—	6.0	-	mAdc
Full Scale Span(3)		V_{FSS}	38.5	40	41.5	mV
Offset(4)	MPXM2102D/G Series MPXM2102A Series	V_{off}	-1.0 -2.0	— —	1.0 2.0	mV
Sensitivity		ΔV/ΔP	—	0.4	—	mV/kPa
Linearity(5)	MPXM2102D/G Series MPXM2102A Series	— —	-0.6 -1.0	— —	0.4 1.0	$\%V_{FSS}$
Pressure Hysteresis(5) (0 to 100 kPa)		—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis(5) (-40°C to +125°C)		—	—	±0.5	—	$\%V_{FSS}$
Temperature Effect on Full Scale Span(5)		TCV_{FSS}	-2.0	—	2.0	$\%V_{FSS}$
Temperature Effect on Offset(5)		TCV_{off}	-1.0	—	1.0	mV
Input Impedance		Z_{in}	1000	—	2500	W
Output Impedance		Z_{out}	1400	—	3000	W
Response Time(6) (10% to 90%)		t_R	—	1.0	—	ms
Warm-Up		—	—	20	—	ms
Offset Stability(7)		—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from thE minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. The specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

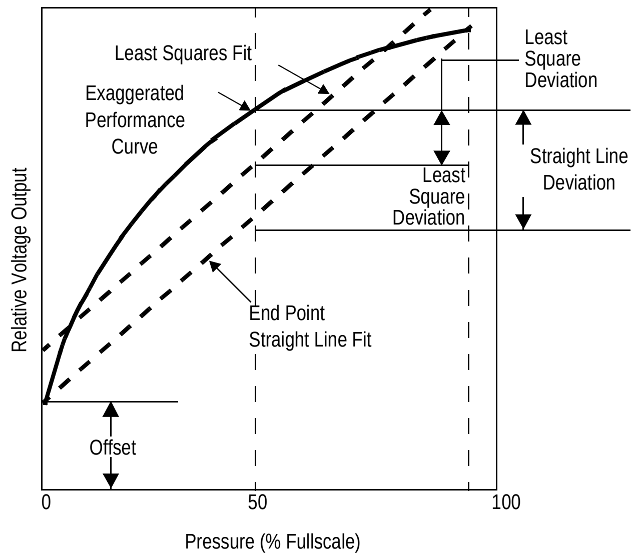


Figure 2. Linearity Specification Comparison

ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

Figure 3 shows the minimum, maximum and typical output characteristics of the MPXM2120 series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

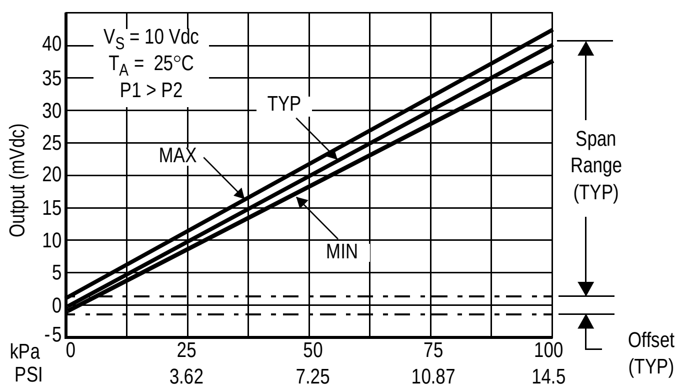


Figure 3. Output versus Pressure Differential

200 kPa On-Chip Temperature Compensated and Calibrated Silicon Pressure Sensors

The MPXM2202 device is a silicon piezoresistive pressure sensors providing a highly accurate and linear voltage output directly proportional to the applied pressure. The sensor is a single, monolithic silicon diaphragm with the strain gauge and a thin-film resistor network integrated on-chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation.

Features

- Temperature Compensated Over 0°C to + 85°C
- Available in Easy-to-Use Tape and Reel
- Ratiometric to Supply Voltage
- Gauge Ported and Non Ported Options

Typical Applications

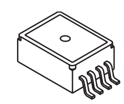
- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Barometers
- Altimeters

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
Non-ported	Absolute, Element Only	1320	MPXM2202D	Rails	MPXM2202D
	Absolute, Element Only	1320	MPXM2202DT1	Tape & Reel	MPXM2202D
	Absolute, Element Only	1320	MPXM2202A	Rails	MPXM2202A
	Absolute, Element Only	1320	MPXM2202AT1	Tape & Reel	MPXM2202A
Ported	Absolute, Axial Port	1320A	MPXM2202GS	Rails	MPXM2202G
	Absolute, Axial Port	1320A	MPXM2202GST1	Tape & Reel	MPXM2202G
	Absolute, Axial Port	1320A	MPXM2202AS	Rails	MPXM2202A
	Absolute, Axial Port	1320A	MPXM2202AST1	Tape & Reel	MPXM2202A

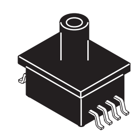
MPXM2202 SERIES

COMPENSATED AND CALIBRATED PRESSURE SENSOR
0 TO 200 kPA (0 TO 29 psi)
40 mV FULL SCALE SPAN (TYPICAL)

MPAK PACKAGE



MPXM2202D/A
CASE 1320-02



MPXM2202GS/AS
CASE 1320A-02

PIN NUMBER			
1	GND	3	V_S
2	$+V_{OUT}$	4	$-V_{OUT}$

Figure 1 shows a block diagram of the internal circuitry on the stand-alone pressure sensor chip.

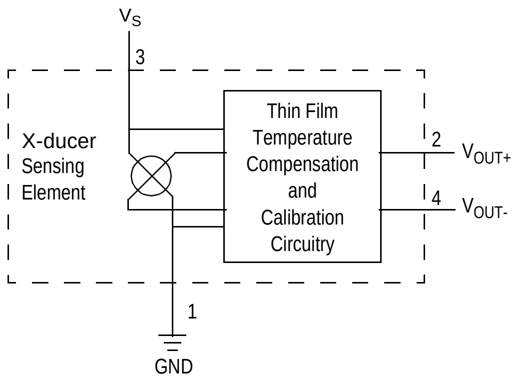


Figure 1. Temperature Compensated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the sensor is directly proportional to the differential pressure applied.

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side (P1) relative to the vacuum side (P2). Similarly, output voltage increases as increasing vacuum is applied to the vacuum side (P2) relative to the pressure side (P1).

Table 1. MAXIMUM RATINGS[(1)]

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{max}	400	kPa
Storage Temperature	T_{stg}	-40 to +125	°C
Operating Temperature	T_A	-40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. OPERATING CHARACTERISTICS (VS = 10 Vdc, TA = 25×C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	0	—	200	kPa
Supply Voltage(2)		V_S	—	10	16	Vdc
Supply Current		I_O	—	6.0	—	mAdc
Full Scale Span(3)		V_{FSS}	38.5	40	41.5	mV
Offset(4)	MPXM2202D/G Series MPXM2202A Series	V_{OFF}	-1.0 -2.0	— —	1.0 2.0	mV
Sensitivity		ΔV/ΔP	—	0.2	—	mV/kPa
Linearity(5)	MPXM2202D/G Series MPXM2202A Series	— —	-0.6 -1.0	— —	0.4 1.0	$\%V_{FSS}$
Pressure Hysteresis(5) (0 to 100 kPa)		—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis(5) (-40°C to +125°C)		—	—	±0.5	—	$\%V_{FSS}$
Temperature Effect on Full Scale Span(5)		TCV_{FSS}	-2.0	—	2.0	$\%V_{FSS}$
Temperature Effect on Offset(5)		TCV_{OFF}	-1.0	—	1.0	mV
Input Impedance		Z_{IN}	1000	—	2500	W
Output Impedance		Z_{OUT}	1400	—	3000	W
Response Time(6) (10% to 90%)		t_R	—	1.0	—	ms
Warm-Up		—	—	20	—	ms
Offset Stability(7)		—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{OUT} = V_{OFF}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. The specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

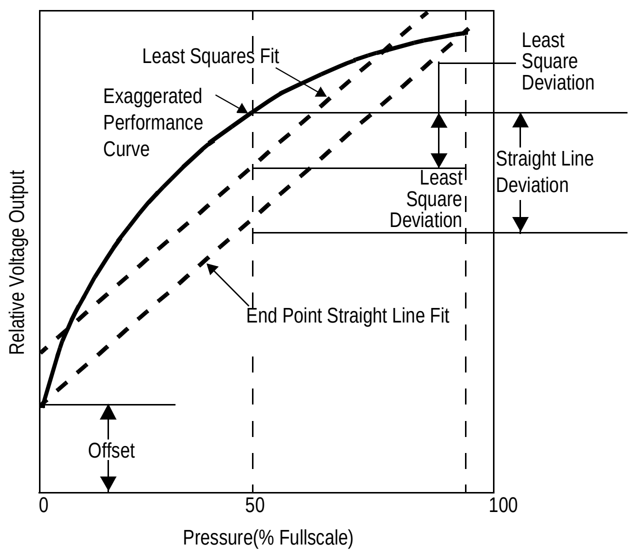


Figure 2. Linearity Specification Comparison

ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

Figure 3 shows the minimum, maximum and typical output characteristics of the MPXM2202 series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

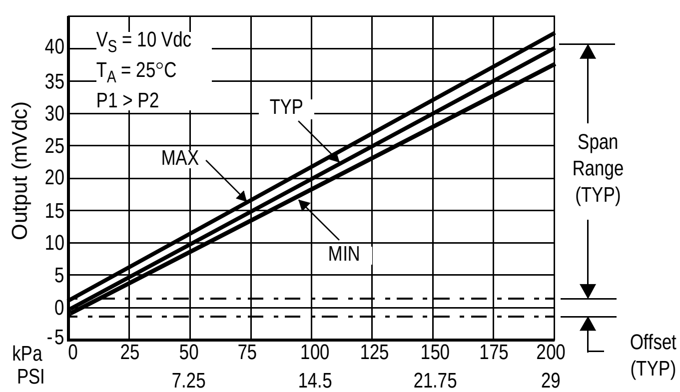


Figure 3. Output versus Pressure Differential

Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPXV4006G

INTEGRATED PRESSURE SENSOR
0 to 6 kPa (0 to 0.87 psi)
0.2 to 4.7 V OUTPUT

The MPXV4006G series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This sensor combines a highly sensitive implanted strain gauge with advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

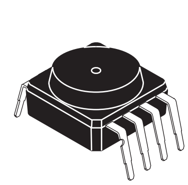
Features

- Temperature Compensated over 10° to 60°C
- Ideally Suited for Microprocessor or Microcontroller-Based Systems
- Available in Gauge Surface Mount (SMT) or Through-hole (DIP) Configurations
- Durable Thermoplastic (PPS) Package

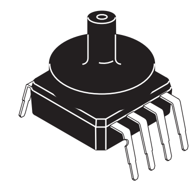
MPXV4006G series pressure sensors are available in the basic element package or with pressure ports. Two packing options are offered for the 482 and 482A case configurations.

ORDERING INFORMATION					
Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Marking
Basic Element	Element Only	482	MPXV4006G6U	Rails	MPXV4006G
	Element Only	482	MPXV4006G6T1	Tape & Reel	MPXV4006G
	Element Only	482B	MPXV4006G7U	Rails	MPXV4006G
Ported Element	Axial Port	482A	MPXV4006GC6U	Rails	MPXV4006G
	Axial Port	482A	MPXV4006GC6T1	Tape & Reel	MPXV4006G
	Axial Port	482C	MPXV4006GC7U	Rails	MPXV4006G
	Side Port	1369	MPXV4006GP	Trays	MPXV4006G
	Dual Port	1351	MPXV4006DP	Trays	MPXV4006G

SMALL OUTLINE PACKAGE THROUGH-HOLE

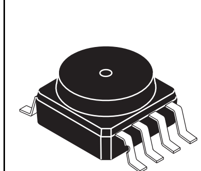


MPXV4006G7U
CASE 482B-03

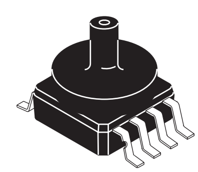


MPXV4006GC7U
CASE 482C-03

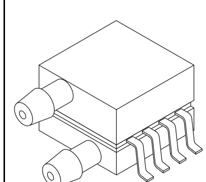
SMALL OUTLINE PACKAGE SURFACE MOUNT



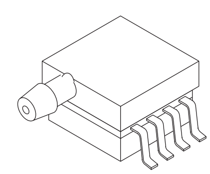
MPXV4006G6U/6T1
CASE 482-01



MPXV4006GC6U/C6T1
CASE 482A-01



MPXV4006DP
CASE 1351-01



MPXV4006GP
CASE 1369-01

PIN NUMBERS(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	Gnd	7	N/C
4	V_{out}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch i n the lead.

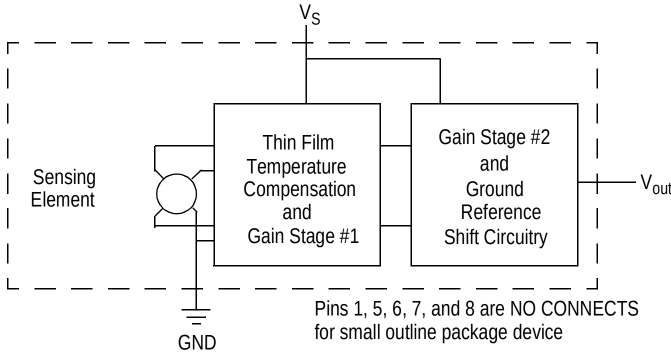


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Parametrics	Symbol	Value	Units
Maximum Pressure (P1 >P2)	P_{max}	24	kPa
Storage Temperature	T_{stg}	-30° to +100°	°C
Operating Temperature	T_A	-10° to +60°	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	0	—	6.0	kPa
Supply Voltage(1)		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_S	—	—	10	mAdc
Full Scale Output(2)	(RF = 51kΩ)	V_{FSS}	—	4.6	—	V
Offset(3)(5)	(RF = 51kΩ)	V_{off}	0.100	0.225	0.430	V
Sensitivity		V/P	—	766	—	mV/kPa
Accuracy(4)(5)	(10 to 60°C)	—	—	—	±5.0	$\%V_{FSS}$

1. Device is ratiometric within this specified excitation range.
2. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure, at 25°C.
   - Offset Stability: Output deviation, after 1000 temperature cycles, -30 to 100°C, and 1.5 million pressure cycles, with minimum rated pressure applied.
   - TcSpan: Output deviation over the temperature range of 10° to 60°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 10° to 60°C, relative to 25°C.
5. Auto Zero at Factory Installation: Due to the sensitivity of the MPXV4006G, external mechanical stresses and mounting position can affect the zero pressure output reading. To obtain the 5% FSS accuracy, the device output must be “autozeroed" after installation. Autozeroing is defined as storing the zero pressure output reading and subtracting this from the device's output during normal operations.

ON-CHIP TEMPERATURE COMPENSATION, CALIBRATION, AND SIGNAL CONDITIONING

The performance over temperature is achieved by integrating the shear-stress strain gauge, temperature compensation, calibration and signal conditioning circuitry onto a single monolithic chip.

Figure 2 illustrates the gauge configuration in the basic chip carrier (Case 482). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPXV4006G series sensor operating characteristics are based on use of dry air as pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Internal reliability and qualification test for dry air, and other media, are available from the factory. Contact the factory for information regarding media tolerance in your application.

Figure 3 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum and maximum output curves are shown for operation over a temperature range of 10°C to 60°C using the decoupling circuit shown in Figure 3. The output will saturate outside of the specified pressure range.

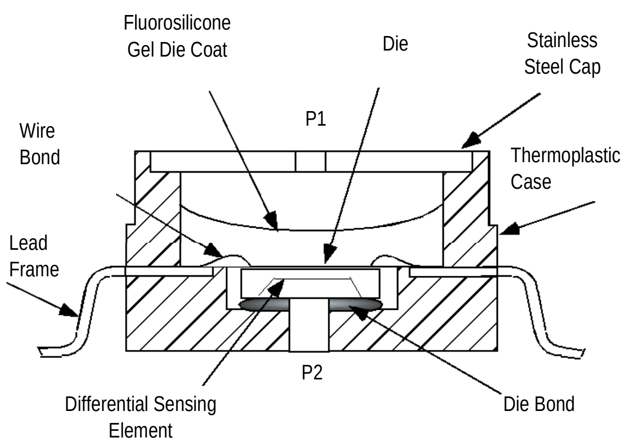


Figure 2. Cross Sectional Diagram SOP (Not to Scale)

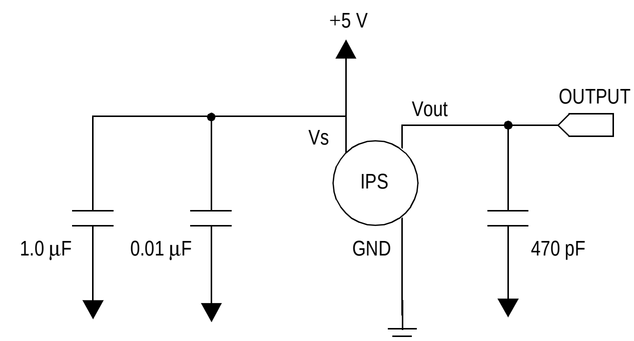


Figure 3. Recommended Power Supply Decoupling and Output Filtering Recommendations
(For additional output filtering, please refer to Application Note AN1646.)

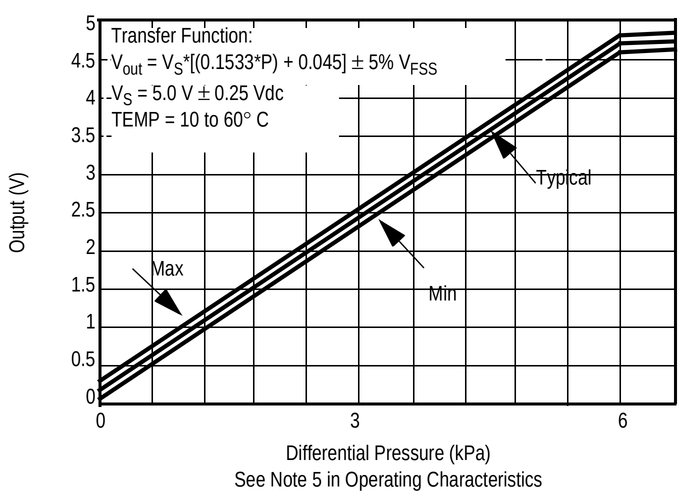


Figure 4. Output versus Pressure Differential

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing silicone gel which isolates the die from the environment. The pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Table 3. Pressure (P1)/Vacuum (P2) Side Identification Table

Part Number	Case Type	Pressure (P1) Side Identifier
MPXV4006G6U/T1	482	Stainless Steel Cap
MPXV4006GC6U/T1	482A	Side with Port Attached
MPXV4006G7U	482B	Stainless Steel Cap
MPXV4006GC7U	482C	Side with Port Attached
MPXV4006GP	1369	Side with Port Attached
MPXV4006DP	1351	Side with Part Marking

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

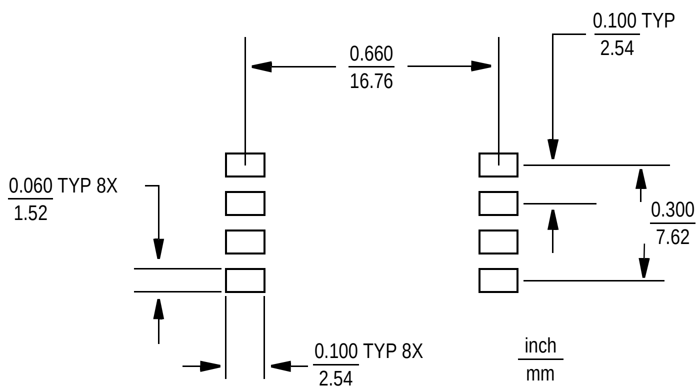


Figure 5. SOP Footprint (Case 482)

Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated, and Calibrated

The MPXV4115V series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, particularly those employing a microcontroller with A/D inputs. This transducer combines advanced micromachining techniques, thin-film metallization and bipolar processing to provide an accurate, high-level analog output signal that is proportional to the applied pressure/vacuum. The small form factor and high reliability of on-chip integration make the sensor a logical and economical choice for the automotive system designer. Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

Features

- 1.5% Maximum error over 0° to 85°C
- Temperature Compensated from –40° + 125°C
- Ideally Suited for Microprocessor or Microcontroller-Based Systems
- Durable Thermoplastic (PPS) Surface Mount Package

Typical Applications

- Vacuum Pump Monitoring
- Brake Booster Monitoring

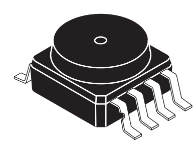
The MPXV4115V series pressure sensors are available in the basic element package or with a pressure port. Two packing options are also offered.

ORDERING INFORMATION				
Device Type	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
SMALL OUTLINE PACKAGE (MPXV4115V SERIES)				
Basic Elements	482	MPXV4115V6U	Rails	MPXV4115V
	482	MPXV4115V6T1	Tape & Reel	MPXV4115V
Ported Elements	482A	MPXV4115VC6U	Rails	MPXV4115V

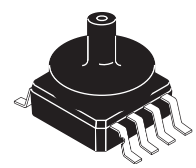
MPXV4115V SERIES

INTEGRATED PRESSURE SENSOR
–115 to 0 kPa (–16.7 to 2.2 psi)
0.2 to 4.6 V OUTPUT

SMALL OUTLINE PACKAGE



MPXV4115V6U/6T1
CASE 482-01



MPXV4115VC6U
CASE 482A-01

PIN NUMBER(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

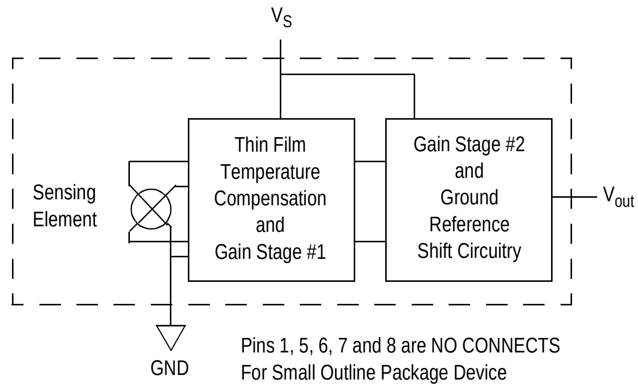


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure	P_{max}	400	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 5 Vdc, T_A = 25°C unless otherwise noted. Decoupling circuit shown in Figure 3 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range (Differential mode, Vacuum on metal cap side, Atmospheric pressure on back side)		P_{OP}	–115	—	0	kPa
Supply Voltage(1)		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	—	6.0	10	mAdc
Full Scale Output(2) (Pdiff = 0 kPa)2	(0 to 85°C)	V_{FSO}	4.535	4.6	4.665	Vdc
Full Scale Span(3) @ V_S = 5.0 V	(0 to 85°C)	V_{FSS}	—	4.4	—	Vdc
Accuracy(4)	(0 to 85°C)	—	—	—	1.5%	$\%V_{FSS}$
Sensitivity		V/P	—	38.26	—	mV/kPa
Response Time(5)		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_o	—	0.1	—	mAdc
Warm-Up Time(6)		—	—	20	—	ms
Offset Stability(7)		—	—	±0.5	—	$\%V_{FSS}$

1. Device is ratiometric within this specified excitation range.
2. Full Scale Output is defined as the output voltage at the maximum or full-rated pressure.
3. Full Scale Span is defined as the algebraic difference between the output voltage at full-rated pressure and the output voltage at the minimum-rated pressure.
4. Accuracy is the deviation in actual output from nominal output over the entire pressure range and temperature range as a percent of span at 25°C due to all sources of errors, including the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
5. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
6. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
7. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

ON-CHIP TEMPERATURE COMPENSATION, CALIBRATION, AND SIGNAL CONDITIONING

The performance over temperature is achieved by integrating the shear-stress strain gauge, temperature compensation, calibration and signal conditioning circuitry onto a single monolithic chip.

Figure 2 illustrates the gauge configuration in the basic chip carrier (Case 482). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPXV4115V series sensor operating characteristics are based on use of dry air as pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Internal reliability and qualification test for dry air, and other media, are available from the factory. Contact the factory for information regarding media tolerance in your application.

Figure 3 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

Figure 4 shows the sensor output signal relative to differential pressure input. Typical, minimum and maximum output curves are shown for operation over a temperature range of 0°C to 85°C using the decoupling circuit shown in Figure 3. The output will saturate outside of the specified pressure range.

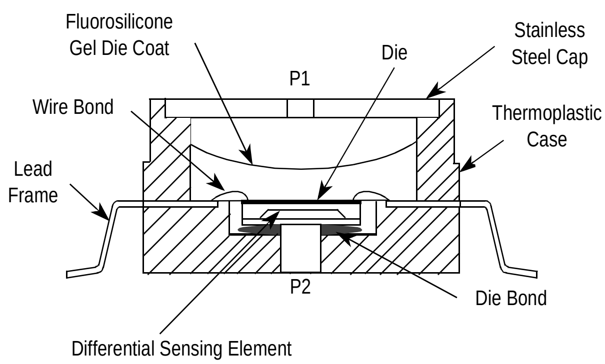


Figure 2. Cross-Sectional Diagram (not to scale)

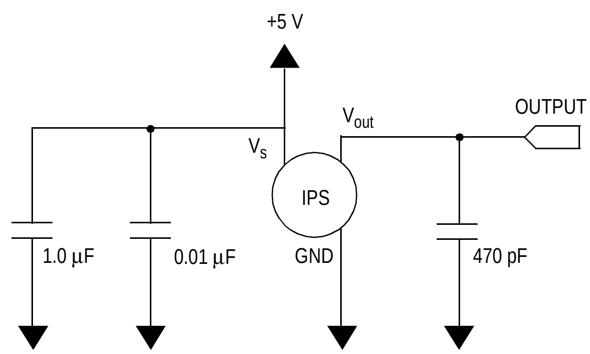


Figure 3. Recommended Power Supply Decoupling and Output Filtering

(For additional output filtering, please refer to Application Note AN1646.)

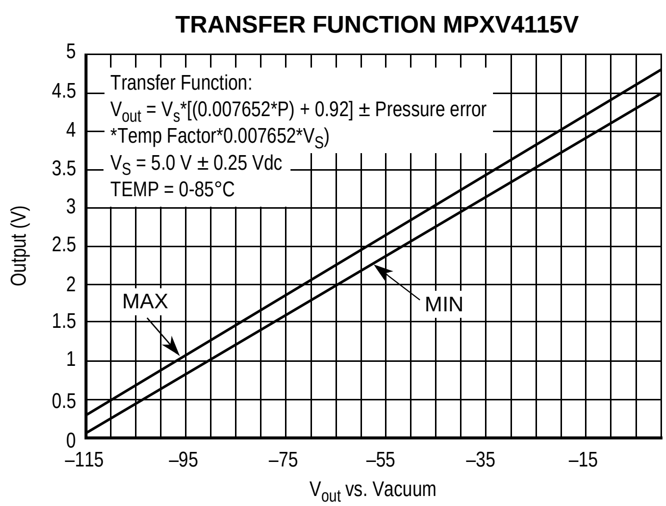


Figure 4. Applied Vacuum in kPa (below atmospheric pressure)

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

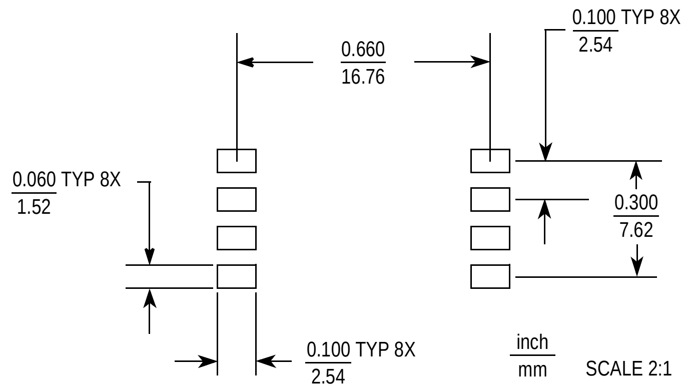
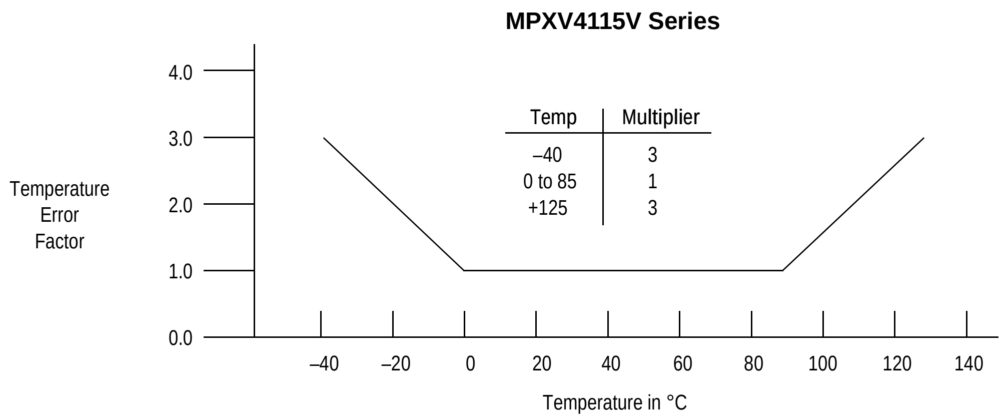


Figure 5. SOP Footprint (Case 482)

Transfer Function

Nominal Transfer Value: $V_{out} = V_S (P \times 0.007652) + 0.92)$
$\pm$ (Pressure Error x Temp. Factor x $0.007652 \times V_S$)
$V_S = 5\ V \pm 0.25$ Vdc

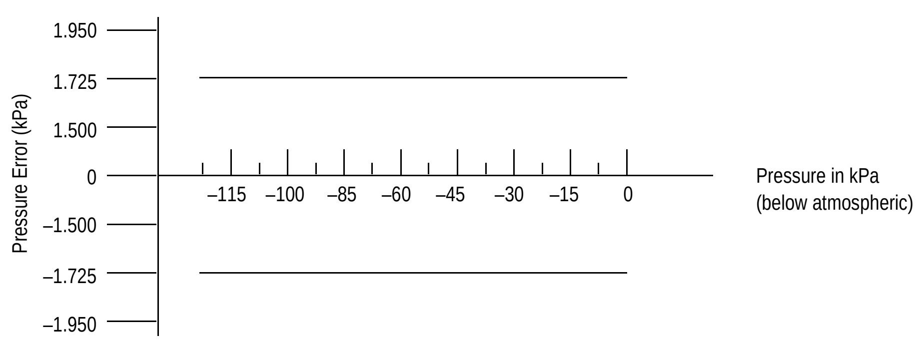
Temperature Error Band



Temp	Multiplier
–40	3
0 to 85	1
+125	3

NOTE: The Temperature Multiplier is a linear response from 0°C to –40°C and from 85°C to 125°C.

Pressure Error Band



Pressure	Error (Max)
–115 to 0 kPa	±1.725 kPa

Integrated Silicon Pressure Sensor On-Chip Signal Conditioned01, Temperature Compensated and Calibrated

The MPXV5004G series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This sensor combines a highly sensitive implanted strain gauge with advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

Features

- Temperature Compensated over 10° to 60°C
- Available in Gauge Surface Mount (SMT) or Through-Hole (DIP) Configurations
- Durable Thermoplastic (PPS) Package

Typical Applications

- Washing Machine Water Level
- Ideally Suited for Microprocessor or Microcontroller-Based Systems

ORDERING INFORMATION(1)

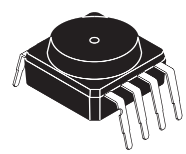
Device Type	Case No.	MPXV Series Order No.	Packing Options	Device Marking
Through-Hole	482B	MPXV5004G7U	Rails	MPXV5004G
	482C	MPXV5004GC7U	Rails	MPXV5004G
Surface Mount	482	MPXV5004G6U	Rails	MPXV5004G
	482	MPXV5004G6T1	Tape & Reel	MPXV5004G
	482A	MPXV5004GC6U	Rails	MPXV5004G
	482A	MPXV5004GC6T1	Tape & Reel	MPXV5004G
	1351	MPXV5004DP	Trays	MPXV5004G
	1368	MPXV5004GVP	Trays	MPXV5004G
	1369	MPXV5004GP	Trays	MPXV5004G

1. MPXV5004G series pressure sensors are available in the basic element package or with a pressure port. Two packing options are offered for the surface mount configuration.

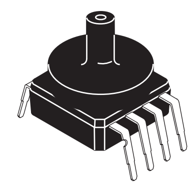
MPXV5004G SERIES

INTEGRATED PRESSURE SENSOR
0 TO 3.92 kPA
(0 TO 400 mm H_2O)
1.0 TO 4.9 V OUTPUT

SMALL OUTLINE PACKAGES THROUGH-HOLE



MPXV5004G7U
CASE 482B-03



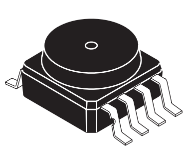
MPXV5004GC7U
CASE 482C-03

PIN NUMBERS(1)

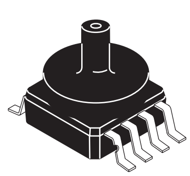
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

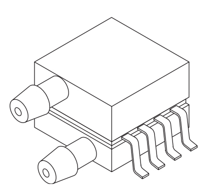
SMALL OUTLINE PACKAGES SURFACE MOUNT



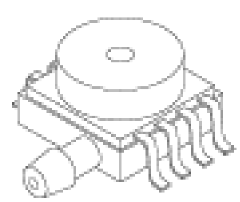
MPXV5004G6U
CASE 482-01



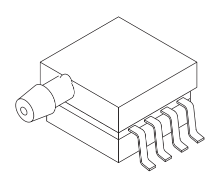
MPXV5004GC6U
CASE 482A-01



MPXV5004DP
CASE 1351-01



MPXV5004GVP
CASE 1368-01



MPXV5004GP
CASE 1369-01

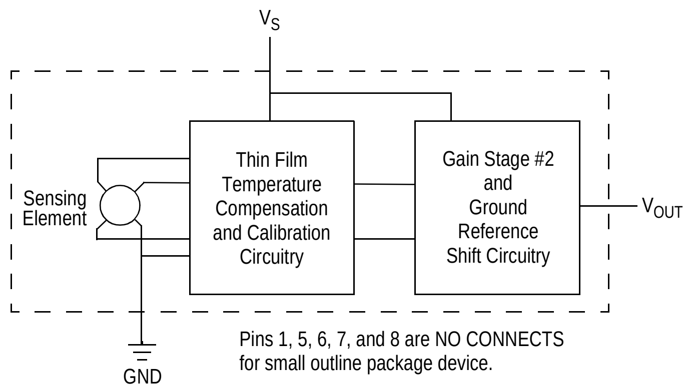


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	16	kPa
Storage Temperature	T_{STG}	–30 to +100	°C
Operating Temperature	T_A	0 to +65	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 10 V_{DC}, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Units
Pressure Range	P_{OP}	0	—	3.92 400	kPa mm H_2O
Supply Voltage(1)	V_S	4.75	5.0	5.25	V_{DC}
Supply Current	I_S	—	—	10	mAdc
Span at 306 mm H_2O (3 kPa)(2)	V_{FSS}	—	3.0	—	V
Offset(3) (4)	V_{OFF}	0.75	1.0	1.25	mV
Sensitivity	V/P	—	1.0 9.8	—	V/kPa mV/mm H_2O
Accuracy(5)	—	—	—	±1.5 ±2.5	%V_{FSS} %V_{FSS}

1. Device is ratiometric within this specified excitation range.
2. Span is defined as the algebraic difference between the output voltage at specified pressure and the output voltage at the minimum rated pressure.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - Offset Stability: Output deviation, after 1000 temperature cycles, *30 to 100°C, and 1.5 million pressure cycles, with minimum rated pressure applied.
   - TcSpan: Output deviation over the temperature range of 10 to 60°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 10 to 60°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
5. Auto Zero at Factory Installation: Due to the sensitivity of the MPXV5004G, external mechanical stresses and mounting position can affect the zero pressure output reading. Autozeroing is defined as storing the zero pressure output reading and subtracting this from the device's output during normal operations. Reference AN1636 for specific information. The specified accuracy assumes a maximum temperature change of ± 5°C between autozero and measurement.

ON-CHIP TEMPERATURE COMPENSATION, CALIBRATION AND SIGNAL CONDITIONING

The performance over temperature is achieved by integrating the shear-stress strain gauge, temperature compensation, calibration and signal conditioning circuitry onto a single monolithic chip.

Figure 2 illustrates the gauge configuration in the basic chip carrier (Case 482). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPXV5004G series sensor operating characteristics are based on use of dry air as pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Internal reliability and qualification test for dry air, and other media, are available from the factory. Contact the factory for information regarding media tolerance in your application.

Figure 3 shows the recommended decoupling circuit for interfacing the output of the MPXV5004G to the A/D input of the microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum and maximum output curves are shown for operation over a temperature range of 10°C to 60°C using the decoupling circuit shown in Figure 3 The output will saturate outside of the specified pressure range.

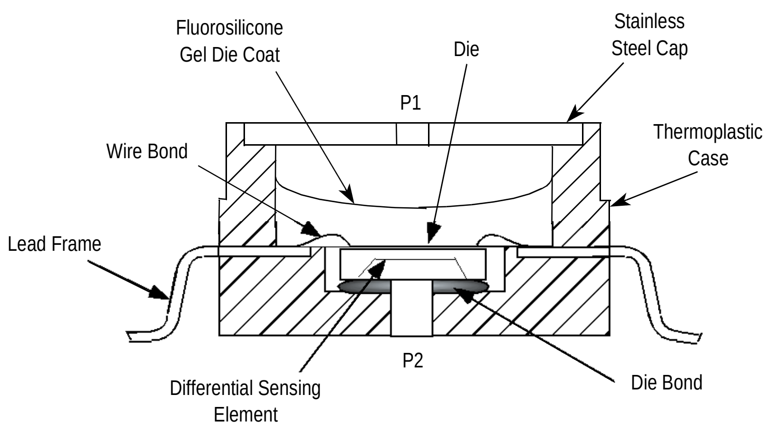


Figure 2. Cross-Sectional Diagram (Not to Scale)

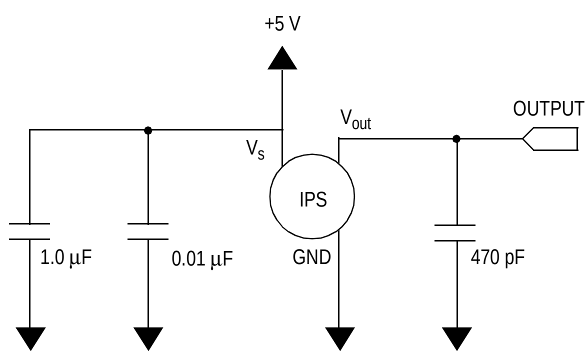


Figure 3. Recommended Power Supply Decoupling and Output Filtering.
(For additional output filtering, please refer to Application Note AN1646.)

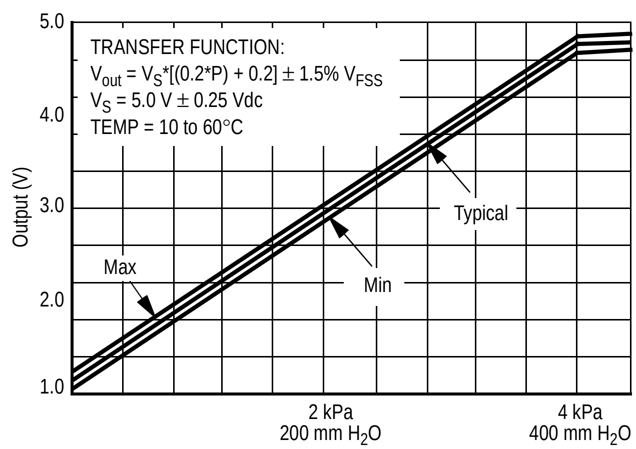


Figure 4. Output versus Pressure Differential
(See Note 5 in Operating Characteristics)

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale Semiconductor designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing silicone gel which isolates the die from the environment. The Freescale Semiconductor pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below.

Part Number	Case Type	Pressure (P1) Side Identifier
MPXV5004GC6U/T1	482A	Side with Port Attached
MPXV5004G6U/T1	482	Stainless Steel Cap
MPXV5004GC7U	482C	Side with Port Attached
MPXV5004G7U	482B	Stainless Steel Cap
MPXV5004GP	1369	Side with Port Attached
MPXV5004DP	1351	Side with Port Marking
MPXV5004GVP	1368	Stainless Steel Cap

INFORMATION FOR USING THE SMALL OUTLINE PACKAGE (CASE 482)

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

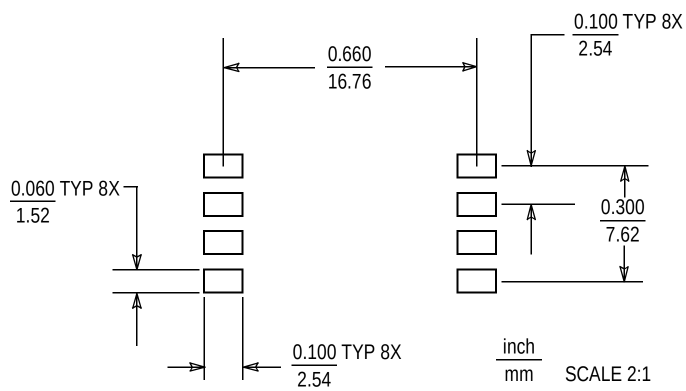


Figure 5. SOP Footprint (Case 482)

High Temperature Accuracy Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

The MPXV5050VC6T1 sensor integrates on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The small form factor and high reliability of on-chip integration make the Freescale Semiconductor, Inc. pressure sensor a logical and economical choice for the system designer.

The MPXV5050VC6T1 piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

Features

- 2.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated from Over –40° to +125°C
- Patented Silicon Shear Stress Strain Gauge
- Durable Thermoplastic (PPS) Surface Mount Package
- Easy-to-Use Chip Carrier Option
- Ideal for Automotive and Non-Automotive Applications

Typical Applications

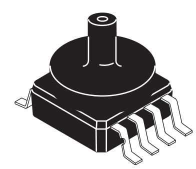
- Vacuum Pump Monitoring

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
Ported Element	Vacuum, Axial Port	482A	MPXV5050VC6T1	Tape & Reel	MPXV5050VC6T1

MPXV5050VC6T1

INTEGRATED PRESSURE SENSOR
–50 to 0 kPa (–7.25 to 0 psi)
0.1 to 4.6 Volts Output

SMALL OUTLINE PACKAGE



MPXV5050VC6T1
CASE 482A-01

PIN NUMBER(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

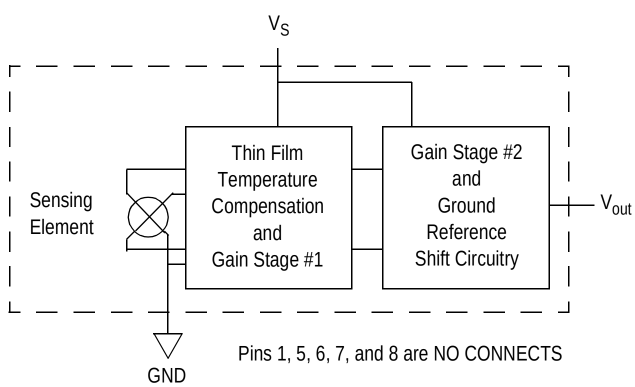


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings[1]

Rating	Symbol	Value	Units
Maximum Pressure (P1 > P2)	P_{max}	200	kPa
Storage Temperature	T_{stg}	–40° to +125°	°C
Operating Temperature	T_A	–40° to +125°	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	–50	—	0	kPa
Supply Voltage[1]		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Full Scale Output[2] @ V_S = 5.0 Volts	(0 to 85°C) (P_{diff} = 0 kPa)	V_{FSO}	4.488	4.6	4.713	Vdc
Full Scale Span[3] @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSS}	—	4.5	—	Vdc
Accuracy[4]	(0 to 85°C)	—	—	—	±2.5	$\%V_{FSS}$
Sensitivity		V/P	—	90	—-	mV/kPa
Response Time[5]		t_R	—	1.0	—-	ms
Warm-Up Time[6]		—	—	20	—-	ms
Offset Stability[7]		—	—	±0.5	—-	$\%V_{FSS}$
Pressure Offset[8]	(0 to 85°C)	V_{off}	0	0.1	0.213	Vdc

1. Device is ratiometric within this specified excitation range.
2. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Accuracy is the deviation in actual output from nominal output over the entire pressure range and temperature range as a percent of span at 25°C due to all sources of errors, including the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
5. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
6. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the pressure has been stabilized.
7. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.
8. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.

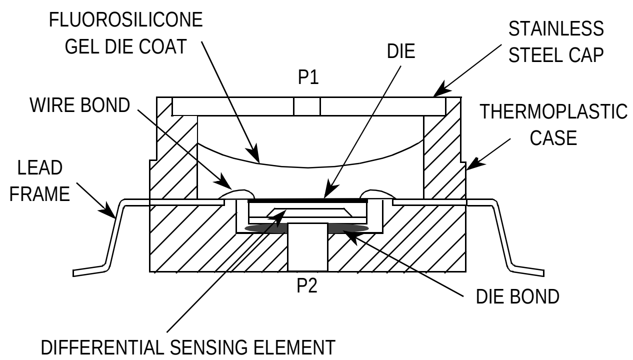


Figure 2. Cross-Sectional Diagram (not to scale)

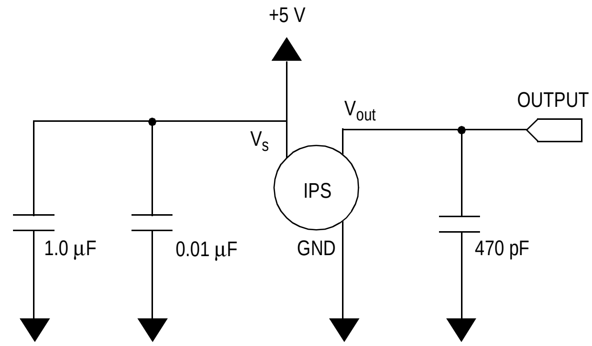


Figure 3. Typical Application Circuit (Output Source Current Operation)

TRANSFER FUNCTION MPXV5050VC6T1

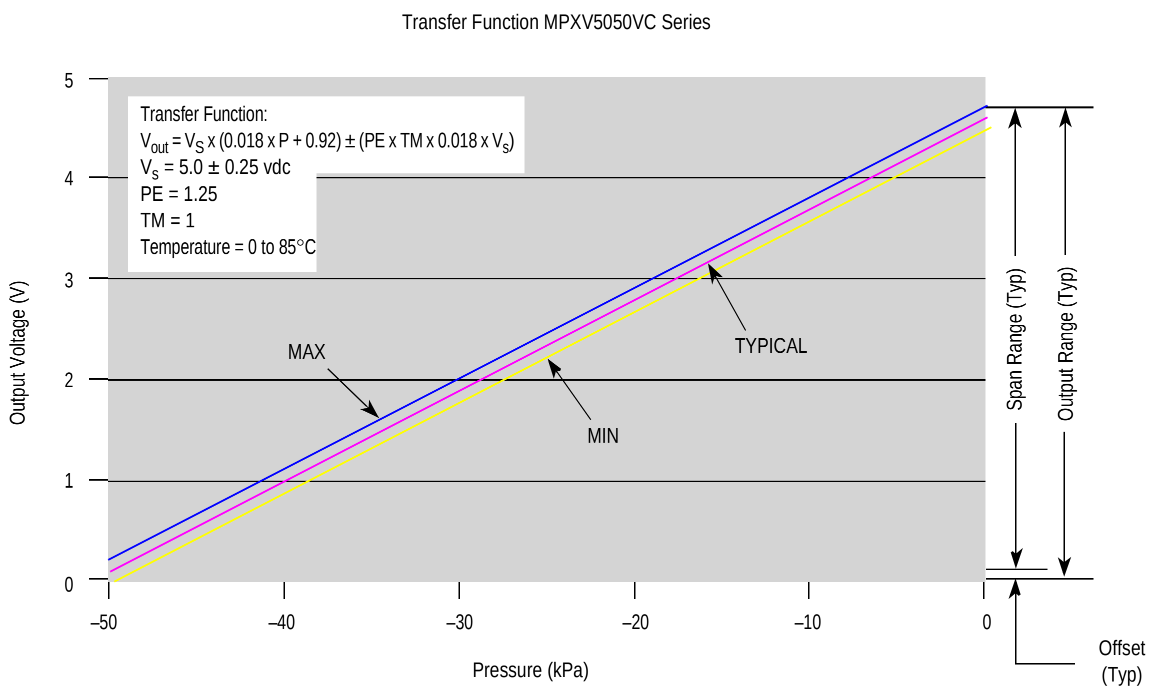


Figure 4. Output versus Absolute Pressure

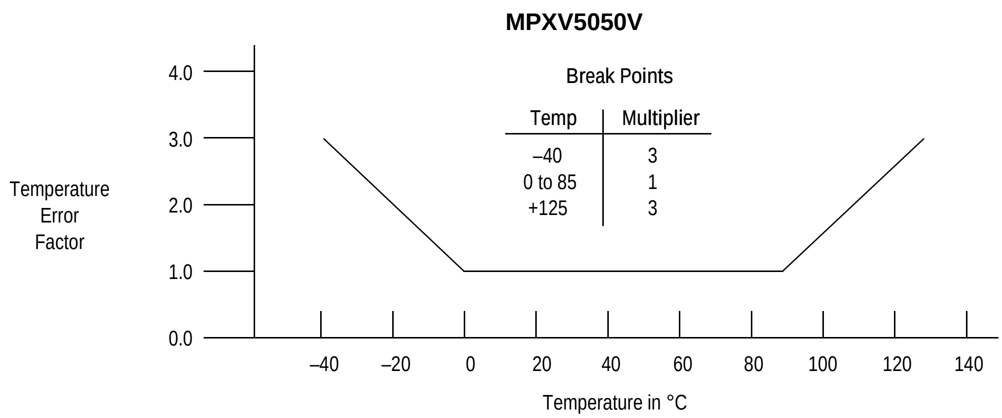
Figure 4 shows the sensor output signal relative to pressure input. Typical minimum and maximum output curves are shown for operation over 0 to 85°C temperature range. The output will saturate outside of the rated pressure range.

A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm. The MPXV5050VC6T1 pressure sensor operating characteristics, internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Transfer Function (MPXV5050VC6T1

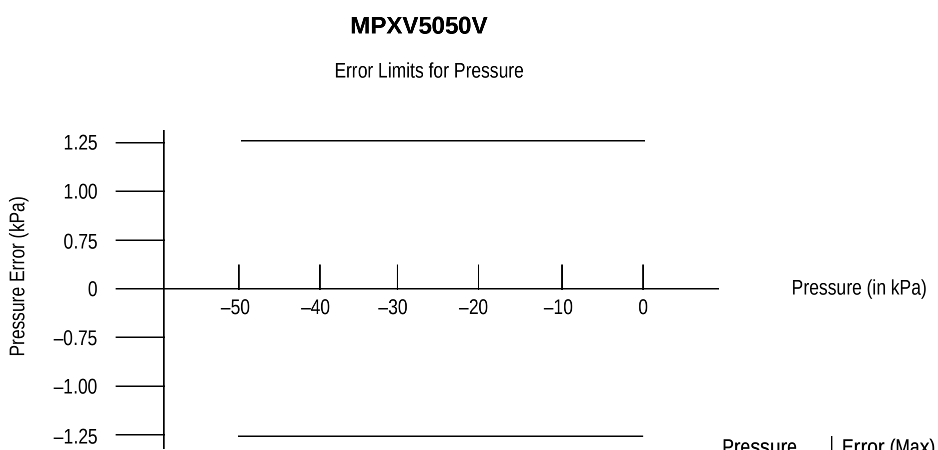
Nominal Transfer Value: $V_{out} = V_S \times (0.018 \times P + 0.92)$
$\pm$ (Pressure Error x Temp Multi x 0.018 x V_S)
$V_S = 5.0 \pm 0.25$ V

Temperature Error Band



NOTE: The Temperature Multiplier is a linear response from 0°C to –40°C and from 85°C to 125°C.

Pressure Error Band



Pressure	Error (Max)
–50 to 0 kPa	±1.25 kPa

MINIMUM RECOMMENDED FOOTPRINT FOR SMALL OUTLINE PACKAGE

Surface mount board layout is a critical portion of the total design. The footprint for the semiconductor package must be the correct size to ensure proper solder connection interface between the board and the package. With the correct pad geometry, the packages will self-align when subjected to a solder reflow process. It is always recommended to fabricate boards with a solder mask layer to avoid bridging and/or shorting between solder pads, especially on tight tolerances and/or tight layouts.

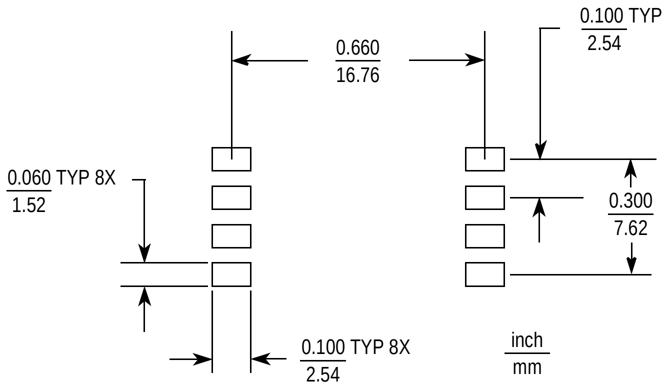


Figure 5. SOP Footprint (Case 482A)

MPXV6115VC6U
Rev 1, 05/2005

High Temperature Accuracy Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPXV6115VC6U

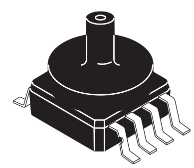
INTEGRATED PRESSURE SENSOR
-115 TO 0 kPA (-16.7 TO 2.2 psi)
0.2 TO 4.6 VOLTS OUTPUT

The MPXV6115VC6U sensor integrates on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The small form factor and high reliability of on-chip integration make the Freescale Semiconductor, Inc. pressure sensor a logical and economical choice for the system designer.

The MPXV6115VC6U piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

SMALL OUTLINE PACKAGE



MPXV6115VC6U
CASE 482A-01

Features

- Improved Accuracy at High Temperature
- 1.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated from -40° to +125°C
- Durable Thermoplastic (PPS) Surface Mount Package

Typical Applications

- Vacuum Pump Monitoring
- Brake Booster Monitoring

PIN NUMBER[1]			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is denoted by the notch in the lead.

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
Ported Element	Vacuum, Axial Port	482A	MPXV6115VC6U	Rails	MPXV6115V

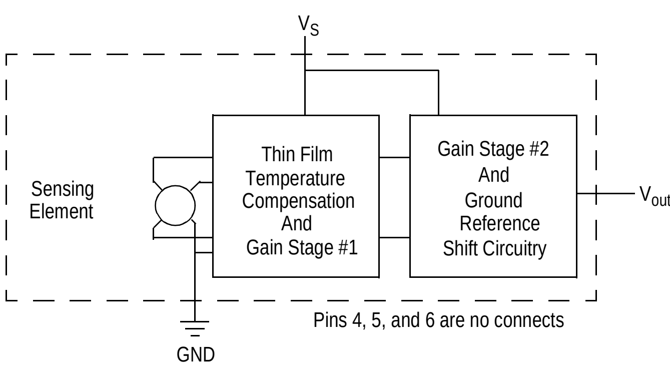


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings[1]

Rating	Symbol	Value	Units
Maximum Pressure (P1 >P2)	P_{max}	400	kPa
Storage Temperature	T_{stg}	-40° to +125°	°C
Operating Temperature	T_A	-40° to +125°	°C
Output Source Current @ Full Scale Output[2]	I_o+	0.5	mAdc
Output Sink Current @ Minimum Pressure Offset[2]	I_o-	-0.5	mAdc

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.
2. Maximum Output Current is controlled by effective impedance from V_{out} to Gnd or V_{out} to V_S in the application circuit.

Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range	P_{OP}	-115	—	0	kPa
Supply Voltage[1]	V_S	4.75	5.0	5.25	Vdc
Supply Current	I_o	—	6.0	10	mAdc
Full Scale Output[2] (0 to 85°C) @ V_S = 5.0 Volts (P_{diff} = 0 kPa)	V_{FSO}	4.534	4.6	4.665	Vdc
Full Scale Span[3] (0 to 85°C) @ V_S = 5.0 Volts	V_{FSS}	—	4.4	—	Vdc
Accuracy[4] (0 to 85°C)	—	—	—	±1.5	$\%V_{FSS}$
Sensitivity	V/P	—	38.26	—	mV/kPa
Response Time[5]	t_R	—	1.0	—	ms
Warm-Up Time[6]	—	—	20	—	ms
Offset Stability[7]	—	—	±0.5	—	$\%V_{FSS}$

1. Device is ratiometric within this specified excitation range.
2. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Accuracy is the deviation in actual output from nominal output over the entire pressure range and temperature range as a percent of span at 25°C due to all sources of error including the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
5. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
6. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the pressure has been stabilized.
7. Offset Stability is the product's output deviation when subjected to 1000 cycles of Pulsed Pressure, Temperature Cycling with Bias Test.

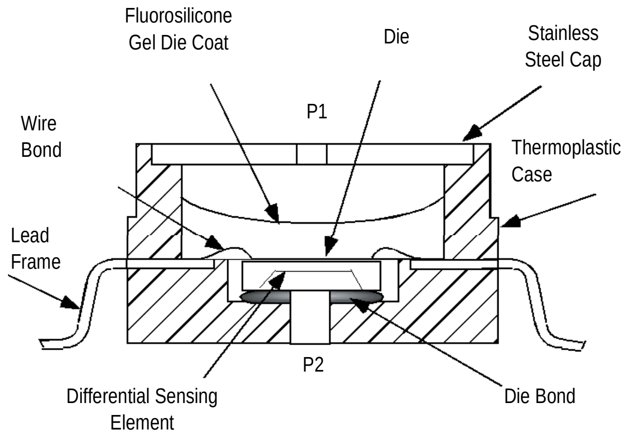


Figure 2. Cross Sectional Diagram SOP (Not to Scale)

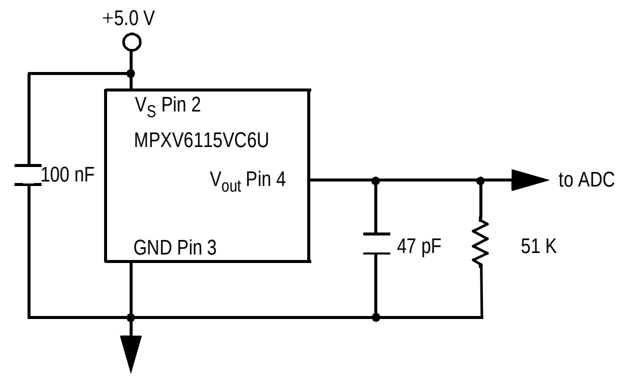


Figure 3. Typical Application Circuit (Output Source Current Operation)

Figure 2 illustrates the absolute sensing chip in the basic Small Outline chip carrier (Case 482).

Figure 3 shows a typical application circuit (output source current operation).

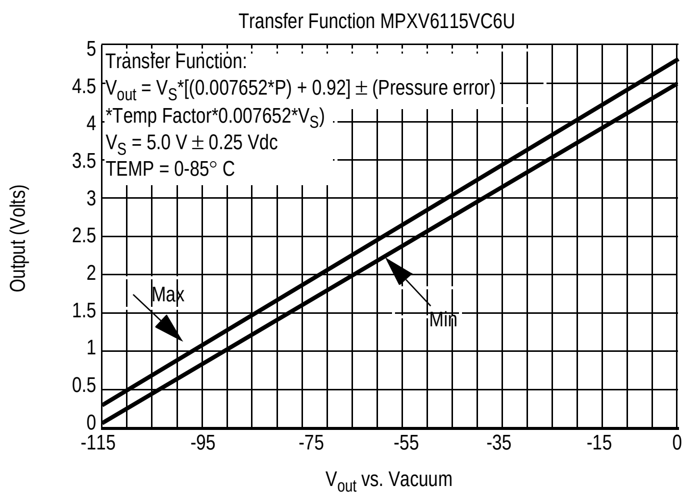


Figure 4. Output versus Absolute Pressure

Figure 4 shows the sensor output signal relative to pressure input. Typical minimum and maximum output curves are shown for operation over 0 to 85°C temperature range. The output will saturate outside of the rated pressure range.

A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm. The MPXV6115VC6U pressure sensor operating characteristics, internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Transfer Function (MPXV6115VC6U)

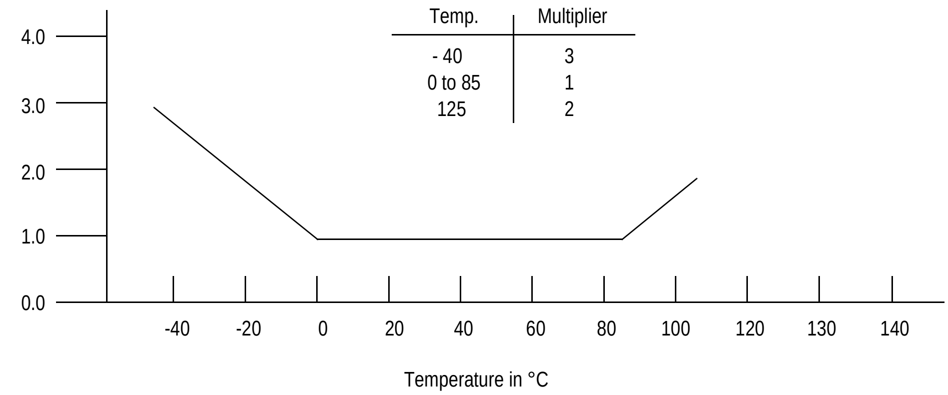
Nominal Transfer Value: $V_{out} = V_S \times (0.007652 \times P + 0.92)$

$\pm$ (Pressure Error x Temp. Factor x 0.007652 x V_S)

$V_S = 5.0 \pm 0.25$ Vdc

Temperature Error Band

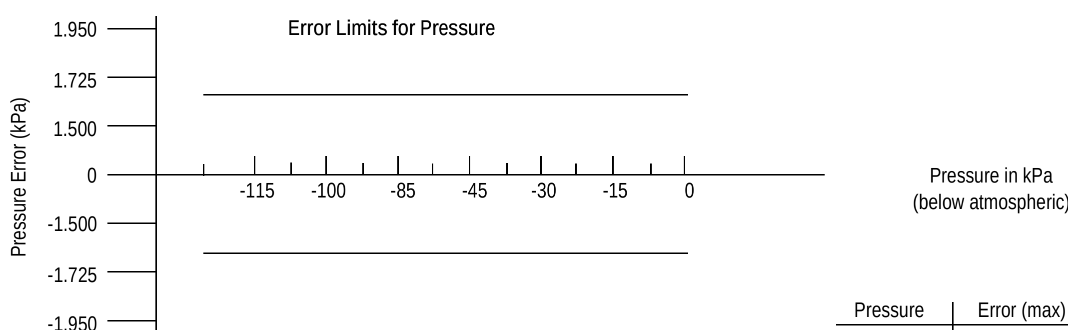
MPXV6115VC6U



Temp.	Multiplier
- 40	3
0 to 85	1
125	2

NOTE: The Temperature Multiplier is a linear response from 0° to -40°C and from 85° to 125°C.

Pressure Error Band



Pressure	Error (max)
-115 to 0 kPa	± 1.725 kPa

SURFACE MOUNTING INFORMATION

MINIMUM RECOMMENDED FOOTPRINT FOR SMALL OUTLINE PACKAGE

Surface mount board layout is a critical portion of the total design. The footprint for the semiconductor package must be the correct size to ensure proper solder connection interface between the board and the package. With the correct pad geometry, the packages will self-align when subjected to a solder reflow process. It is always recommended to fabricate boards with a solder mask layer to avoid bridging and/or shorting between solder pads, especially on tight tolerances and/or tight layouts.

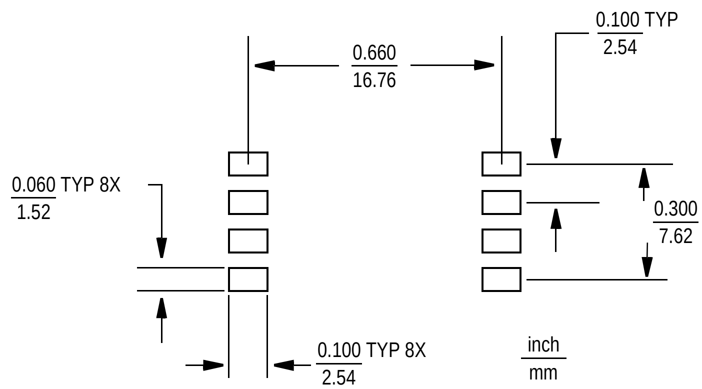


Figure 5. SOP Footprint (Case 482A)

Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

The MPXV7007G series piezoresistive transducers are state-of-the-art monolithic silicon pressure sensors designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

Features

- 5.0% Maximum Error over 0° to 85°C
- Ideally Suited for Microprocessor or Microcontroller-Based Systems
- Durable Epoxy Unibody and Thermoplastic (PPS) Surface Mount Package
- Temperature Compensated over –40° to +125°C
- Patented Silicon Shear Stress Strain Gauge
- Available in Differential and Gauge Configurations
- Available in Surface Mount (SMT)

Typical Applications

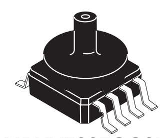
- Hospital Beds
- HVAC
- Respiratory Systems
- Process Control

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
SMALL OUTLINE PACKAGE (MPXV7007G SERIES)					
Ported Elements	Gauge, Axial Port, SMT	482A	MPXV7007GC6U	Rails	MPXV7007G
	Gauge, Axial Port, SMT	482A	MPXV7007GC6T1	Tape & Reel	MPXV7007G
	Gauge, Side Port, SMT	1369	MPXV7007GP	Trays	MPXV7007G
	Gauge, Dual Port, SMT	1351	MPXV7007DP	Trays	MPXV7007G

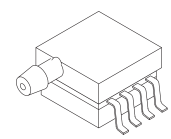
MPXV7007G SERIES

INTEGRATED PRESSURE SENSOR
-7 to 7 kPa (-1 to 1 psi)
0.5 to 4.5 V OUTPUT

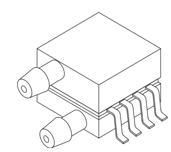
SMALL OUTLINE PACKAGE



MPXV7007GC6U
CASE 482A-01



MPXV7007GP
CASE 1369-01



MPXV7007DP
CASE 1351-01

SMALL OUTLINE PACKAGE PIN NUMBERS(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	Gnd	7	N/C
4	V_{out}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

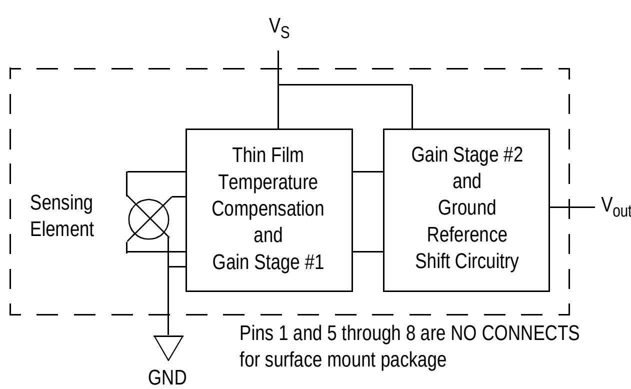


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings[1]

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{max}	75	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 3 required to meet specification.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]		P_{OP}	-7	—	+7	kPa
Supply Voltage[2]		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset[3] @ V_S = 5.0 Volts	(0 to 85°C)	V_{off}	0.32	0.5	0.67	Vdc
Full Scale Output[4] @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSO}	4.3	4.5	4.7	Vdc
Full Scale Span[5] @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSS}	—	4.0	—	Vdc
Accuracy[6]	(0 to 85°C)	—	—	—	±5.0	$\%V_{FSS}$
Sensitivity		V/P	—	286	—-	mV/kPa
Response Time[7]		t_R	—	1.0	—-	ms
Output Source Current at Full Scale Output		I_{O+}	—	0.1	—-	mAdc
Warm-Up Time[8]		—	—	20	—-	ms
Offset Stability[9]		—	—	±0.5	—-	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

ON-CHIP TEMPERATURE COMPENSATION, CALIBRATION AND SIGNAL CONDITIONING

The performance over temperature is achieved by integrating the shear-stress strain gauge, temperature compensation, calibration and signal conditioning circuitry onto a single monolithic chip.

Figure 2 illustrates the Differential or Gauge configuration in the basic chip carrier (Case 482). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm.

The MPXV7007G series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 3 shows the recommended decoupling circuit for interfacing the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit shown in Figure 3. The output will saturate outside of the specified pressure range.

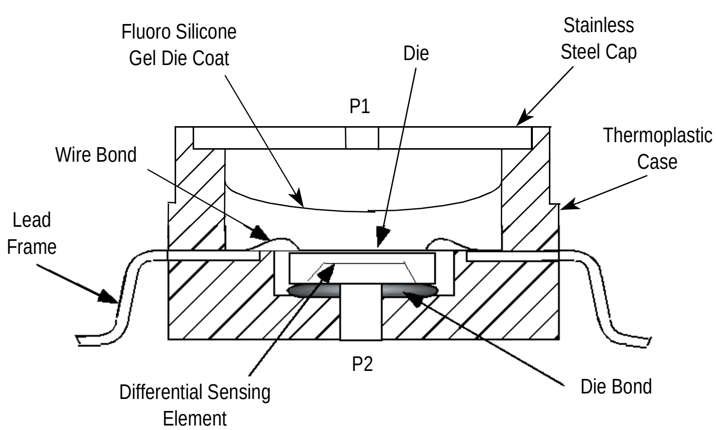


Figure 2. Cross-Sectional Diagram SOP (not to scale)

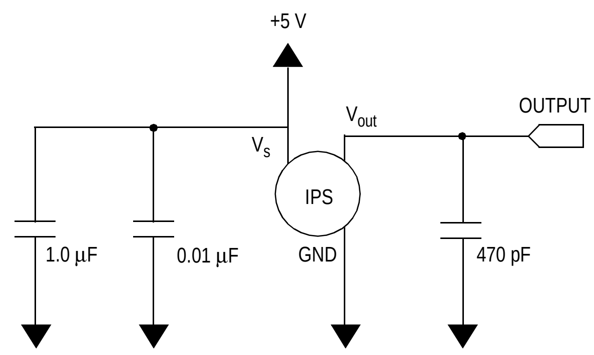


Figure 3. Recommended Power Supply Decoupling and Output Filtering

(For additional output filtering, please refer to Application Note AN1646.)

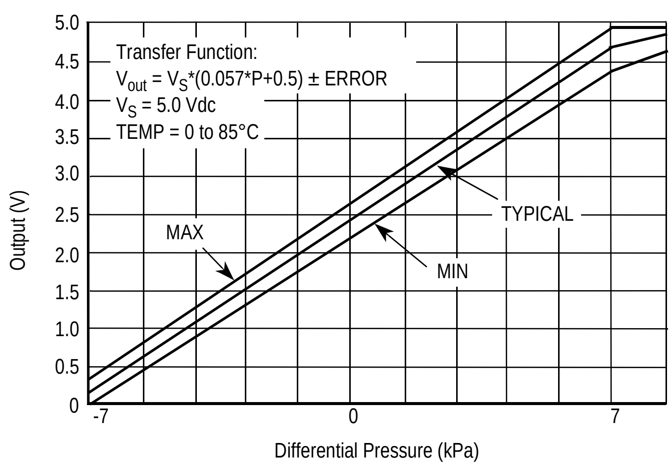


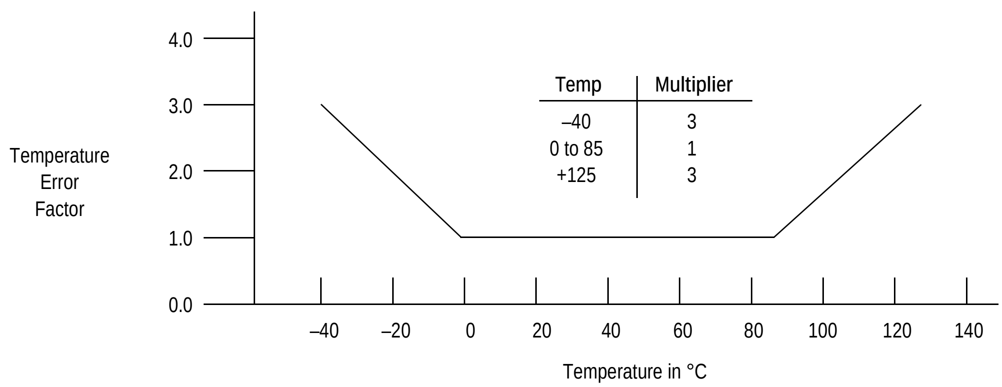
Figure 4. Output versus Pressure Differential

Transfer Function (MPXV7007G)

Nominal Transfer Value: $V_{out} = V_S \times (0.057 \times P + 0.5)$
$\pm$ (Pressure Error x Temp. Factor x $0.057 \times V_S$)
$V_S = 5.0\ V \pm 0.25\ Vdc$

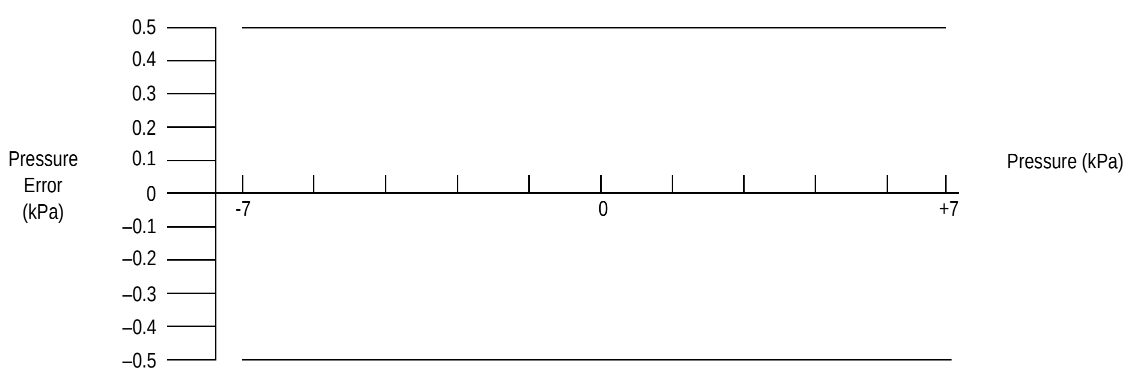
Temperature Error Band

MPXV7007G SERIES



NOTE: The Temperature Multiplier is a linear response from 0° to –40°C and from 85° to 125°C.

Pressure Error Band



Pressure	Error (Max)
- 7 to 7 (kPa)	±0.5 (kPa)

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluorosilicone gel which protects the die from harsh media. The MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPXV7007GC6U/C6T1	482A	Side with Port Attached
MPXV7007GP	1369	Side with Port Attached
MPXV7007DP	1351	Side with Part Marking

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

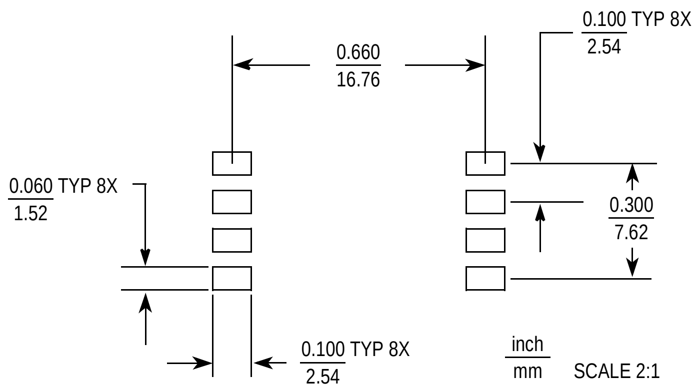


Figure 5. SOP Footprint (Case 482A)

Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPXV7025G SERIES

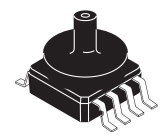
INTEGRATED PRESSURE SENSOR
-25 to 25 kPa (-3.6 to 3.6 psi)
0.2 to 4.7 V OUTPUT

The MPXV7025G series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This patented, single element transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

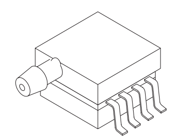
Features

- 2.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated Over –40° to +125°C
- Patented Silicon Shear Stress Strain Gauge
- Durable Epoxy Unibody Element
- Easy-to-Use Chip Carrier Option

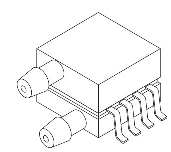
SMALL OUTLINE PACKAGE



MPXV7025GC6U
CASE 482A-01



MPXV7025GP
CASE 1369-01



MPXV7025DP
CASE 1351-01

ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
SMALL OUTLINE PACKAGE (MPXV7025G SERIES)					
Ported Elements	Gauge, Axial Port, SMT	482A	MPXV7025GC6U	Rails	MPXV7025G
	Gauge, Axial Port, SMT	482A	MPXV7025GC6T1	Tape & Reel	MPXV7025G
	Gauge, Side Port, SMT	1369	MPXV7025GP	Trays	MPXV7025G
	Gauge, Dual Port, SMT	1351	MPXV7025DP	Trays	MPXV7025G

SMALL OUTLINE PACKAGE PIN NUMBERS(1)

1	N/C	5	N/C
2	V_S	6	N/C
3	Gnd	7	N/C
4	V_{out}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

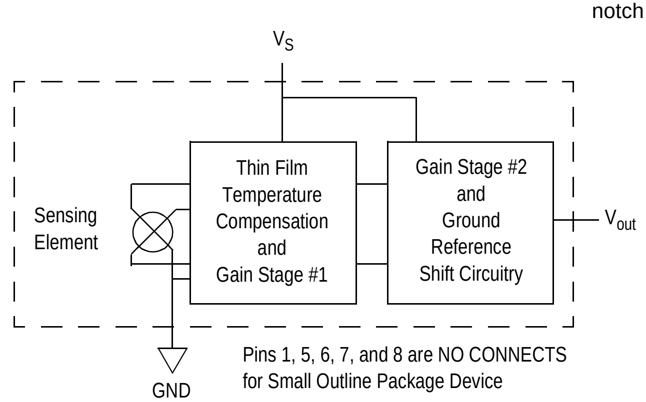


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{max}	200	kPa
Storage Temperature	T_{stg}	–40° to +125°	°C
Operating Temperature	T_A	–40° to +125°	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 3 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	-25	—	25	kPa
Supply Voltage(2)		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset(3) @ V_S = 5.0 Volts	(0 to 85°C)	V_{off}	0.115	0.25	0.384	Vdc
Full Scale Output(4) @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSO}	4.610	4.75	4.890	Vdc
Full Scale Span(5) @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSS}	—	4.5	—	Vdc
Accuracy(6)	(0 to 85°C)	—	—	—	±5.0	$\%V_{FSS}$
Sensitivity		V/P	—	90	—-	mV/kPa
Response Time(7)		t_R	—	1.0	—-	ms
Output Source Current at Full Scale Output		I_{o+}	—	0.1	—-	mAdc
Warm-Up Time(8)		—	—	20	—-	ms
Offset Stability(9)		—	—	±0.5	—-	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS} at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

The MPXV7025G series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 2 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit shown in Figure 3. The output will saturate outside of the specified pressure range.

Figure 3 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

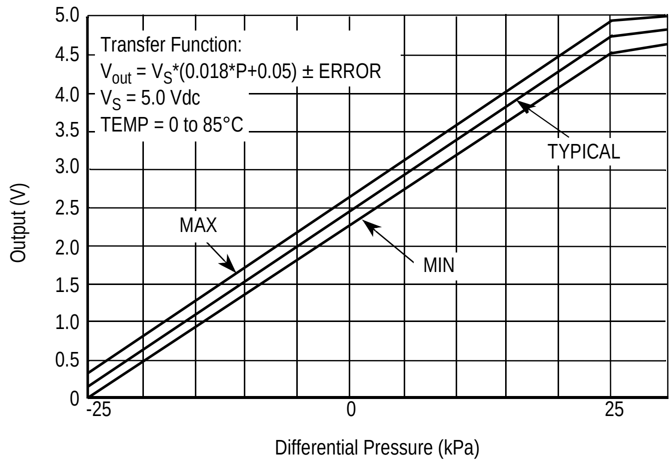


Figure 2. Output versus Pressure Differential

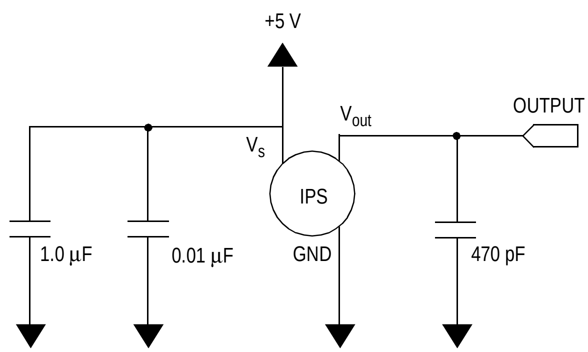


Figure 3. Recommended Power Supply Decoupling and Output Filtering

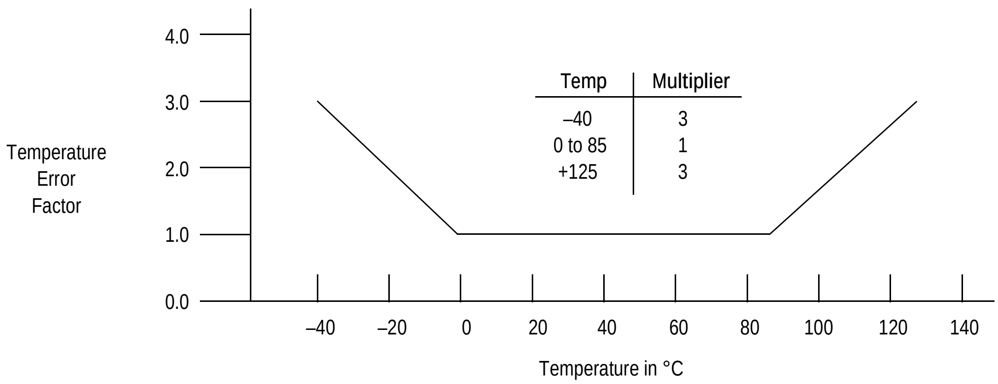
(For additional output filtering, please refer to Application Note AN1646.)

Transfer Function

Nominal Transfer Value: $V_{out} = V_S$ (P x 0.018 + 0.05)
± (Pressure Error x Temp. Factor x 0.018 x V_S)
V_S = 5.0 V ± 0.25 Vdc

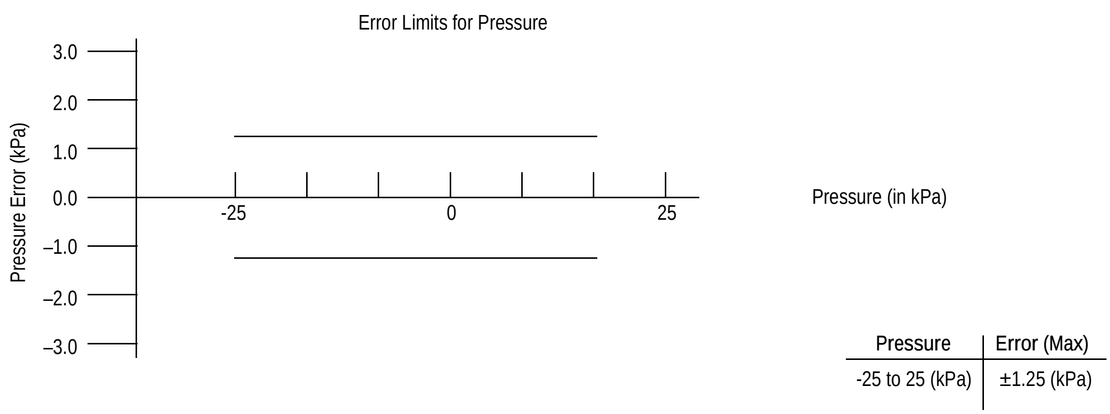
Temperature Error Band

MPXV7025G SERIES



NOTE: The Temperature Multiplier is a linear response from 0° to –40°C and from 85° to 125°C.

Pressure Error Band



PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluorosilicone gel which protects the die from harsh media. The MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

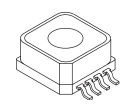
The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX7025GC6U/C6T1	482A	Gauge, Axial Port, SMT
MPXV7025GP	1369	Side with Port Attached
MPXV7025DP	1351	Side with Part Marking

Tire Pressure Monitoring Sensor Temperature Compensated and Calibrated, Fully Integrated, Digital Output

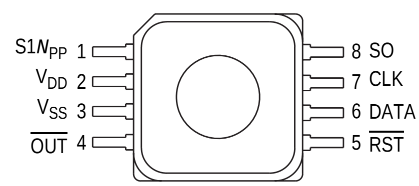
MPXY8020A
MPXY8040A

TIRE PRESSURE MONITORING SENSOR
MPXY8020A:
OPTIMIZED FOR 250 kPa – 450 kPa
MPXY8040A:
OPTIMIZED FOR 500 kPa – 900 kPa



SUPER SMALL OUTLINE PACKAGE
CASE 1352-03

PIN ASSIGNMENT



8-pin Super Small Outline Package (SSOP)

ORDERING INFORMATION	
Shipped In Rails	**Shipped in Tape & Reel**
MPXY8020A6U MPXY8040A6U	MPXY8020A6T1 MPXY8040A6T1

The Freescale Semiconductor MPXY8000 series sensor is an 8-pin tire monitoring sensor which is comprised of a variable capacitance pressure sensing element, a temperature sensing element, and an interface circuit (with a wake-up feature) all on a single chip. It is housed in a Super-Small Outline Package (SSOP), which includes a media protection filter. Specifically designed for the low power consumption requirements of tire pressure monitoring systems, it can combine with a Freescale Semiconductor remote keyless entry (RKE) system to facilitate a low-cost, highly integrated system.

DETAILED DESCRIPTION

The block diagram of the MPXY8000 series sensor is shown in Figure 1. The pressure sensor is a capacitive transducer constructed using surface micromachining, the temperature sensor is constructed using a diffused resistor, and the interface circuit is integrated onto the same die as the sensors using a standard silicon CMOS process.

The conditioning of the pressure signal begins with a capacitance to voltage conversion (C to V) followed by a switched capacitor amplifier. This amplifier has adjustable offset and gain trimming. The offset and gain are factory calibrated, with calibration values stored in the EEPROM trim register. This amplifier also has temperature compensation circuits for both sensitivity and offset, which also are factory adjusted using the EEPROM trim register.

The pressure is monitored by a voltage comparator, which compares the measured value against an 8-bit threshold adjusted by a serial input. By adjusting the threshold and monitoring the state of the OUT pin the external device can check whether a low-pressure threshold has been crossed, or perform up to 8-bit A/D conversions.

The temperature is measured by a diffused resistor with a positive temperature coefficient driven by a current source, thereby creating a voltage. The room temperature value of this voltage is factory calibrated using the EEPROM trim register. A two-channel multiplexer can route either the pressure or temperature signal to a sampling capacitor that is monitored by a voltage comparator with variable threshold adjust, providing a digital output for temperature.

An internal low frequency, low power 5.4 kHz oscillator with a 14-stage divider provides a periodic pulse to the OUT pin (divide by 16384 for 3 seconds). This pulse can be used to wake up an external MCU to begin an interface with the device. An additional 10-stage divider will provide a pulse every 52 minutes which can be used to reset an external MCU.

The power consumption can be controlled by several operational modes selected by external pins.

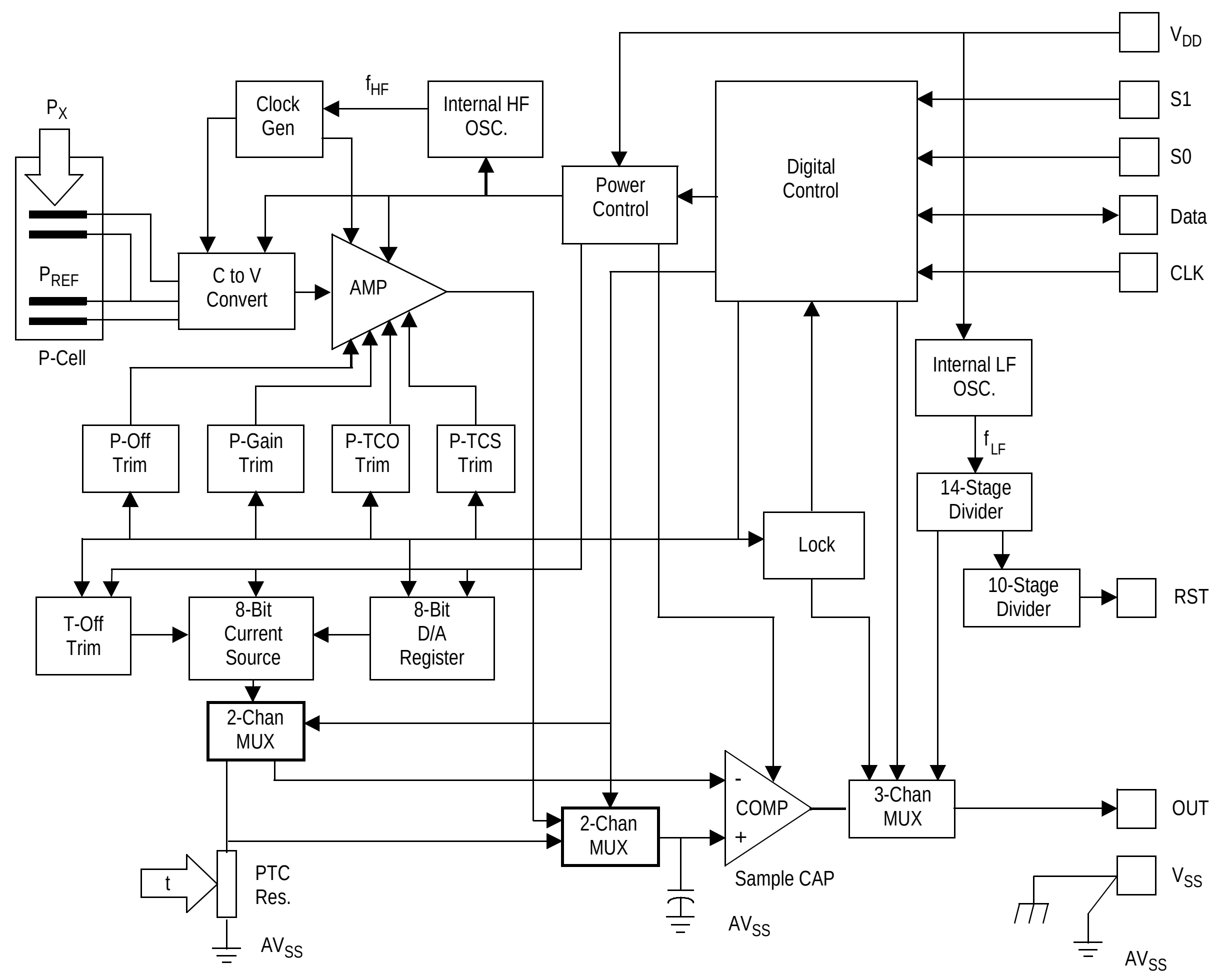


Figure 1. MPXY8000 Series Sensor Block Diagram

OPERATING MODES

The device has several operating modes dependent on the applied voltages to the S1 and S0 pins as shown in Table 1. In all the modes listed the channel multiplexers, D/A Register, LFO, and the output pulse dividers will always be powered up as long as there is a voltage source connected to the V_{DD} pin.

When only the S0 pin is at a logic one the pressure measuring circuit in the device is powered up and the pressure output signal is connected to the sample capacitor through a multiplexer. When the S0 pin returns to the low state the multiplexer will first turn off to store the signal on the sample capacitor before powering down the measuring circuitry.

When only the S1 pin is at a logic one the temperature measuring circuit in the device is powered up and the temperature output signal is connected to the sample capacitor through a multiplexer. When the S1 pin returns to the low state the multiplexer will first turn off to store the signal on the sample capacitor before powering down the measuring circuitry.

NOTE: All of the EEPROM trim bits will be powered up regardless of whether the pressure or temperature measuring circuitry is activated.

NOTE: If the voltage on the S1 pin exceeds 2.5 times the voltage on the V_{DD} pin the device will be placed into its Trim/Test Mode.

NOTE: If the V_{DD} supply source is switched off in order to reduce current consumption, it is important that all input pins be driven LOW to avoid powering up the device.

If any input pin (S1, S0, DATA, or CLK) is driven HIGH while the V_{DD} supply is switched off, the device may be powered up through an ESD protection diode. In such a case, the effective V_{DD} voltage will be about 0.3 V less than the voltage applied to the input pin, and the full device I_{DD} current will be drawn from the device driving input.

Table 1. Operating Modes

S1	S0	Operating Mode	Circuitry Powered				Serial Data Counter
			Pressure Measure System	Temp Measure System	A/D Output Comp.	LFO Oscill.	
0	0	Standby/Reset	OFF	OFF	OFF	ON	ACTIVE
0	1	Measure Pressure	ON	OFF	OFF	ON	RESET
1	0	Measure Temperature	OFF	ON	OFF	ON	RESET
1	1	Output Read	OFF	OFF	ON	ON	ACTIVE

PIN FUNCTIONS

The following paragraphs give a description of the general function of each pin.

V_{DD} and V_{SS} Pins

Power is supplied to the control IC through V_{DD} and V_{SS}. V_{DD} is the positive supply and V_{SS} is the digital and analog ground. The control IC operates from a single power supply. Therefore, the conductors to the power supply should be connected to the V_{DD} and V_{SS} pins and locally decoupled as shown in Figure 2.

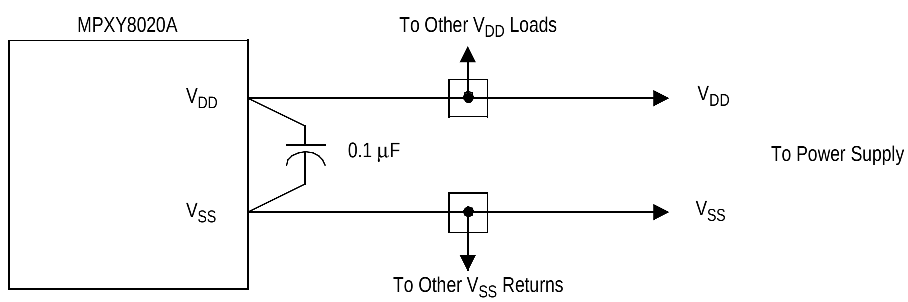


Figure 2. Recommended Power Supply Connections

OUT Pin

The OUT pin normally provides a digital signal related to the voltage applied to the voltage comparator and the threshold level shifted into an 8-bit register from an external device. When the device is placed in the standby mode the OUT pin is driven high and will be clocked low when an overflow is detected from a clock divider (divide by 16384) driven by the LFO. This allows the OUT pin to wake up an external device such as an MCU.

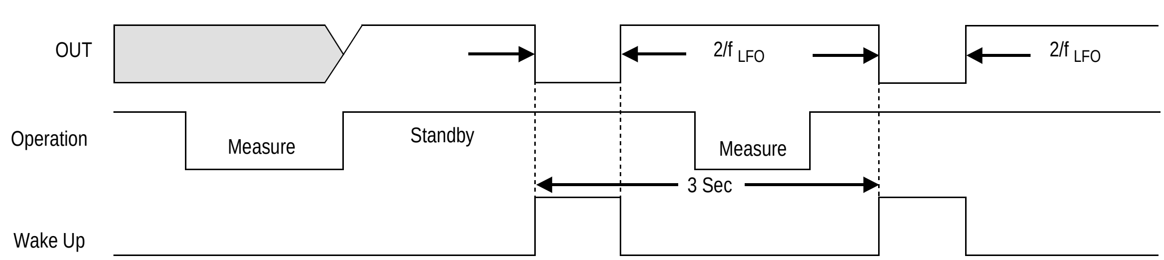


Figure 3. Pulse on OUT Pin During Standby Mode

$\overline{\text{RST}}$ Pin

The $\overline{\text{RST}}$ pin is normally driven high and will be clocked low when an overflow is detected from total clock divider (divide by 16,777,216) driven by the LFO. This allows the $\overline{\text{RST}}$ pin to reset an external device such as an MCU. This pulse will appear on the $\overline{\text{RST}}$ pin approximately every

52 minutes regardless of the operating mode of the device. The pulse lasts for two cycles of the LFO oscillator as shown in Figure 4. Since the RST pin is clocked from the same divider string as the OUT pin, there will also be a pulse on the OUT pin when the $\overline{\text{RST}}$ pin pulses every 52 minutes.

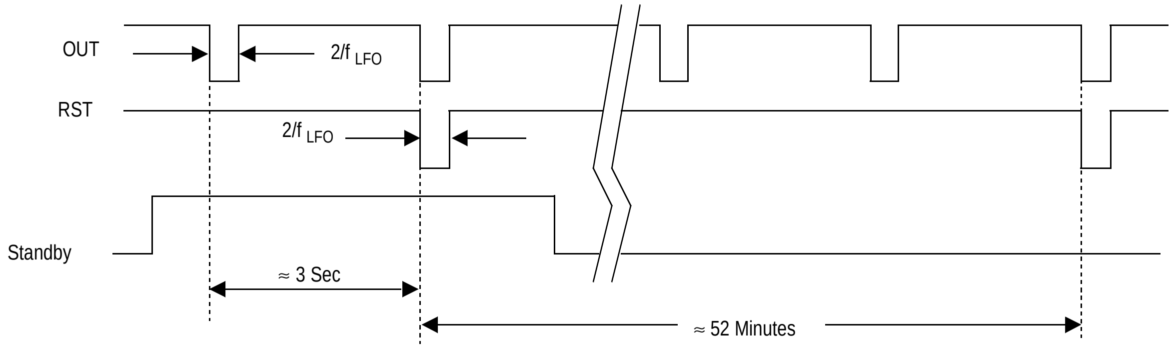


Figure 4. Pulse on $\overline{\text{RST}}$ Pin

S0 Pin

The S0 pin is used to select the mode of operation as shown in Table 1.

The S0 pin contains an internal Schmitt trigger as part of its input to improve noise immunity. The S0 pin has an internal pull-down device in order to provide a low level when the pin is left unconnected.

S1 Pin

The S1 pin is used to select the mode of operation, as shown in Table 1.

The S1 pin contains an internal Schmitt trigger as part of its input to improve noise immunity. This pin has an internal pull-down device to provide a low level when the pin is left unconnected.

The S1 pin also serves the purpose of enabling factory trim and test of the device.

The higher V_{PP} programming voltage for the internal EEPROM trim register is also supplied through the S1 pin.

DATA Pin

The DATA pin is the serial data in (SDI) function for setting the threshold of the voltage comparator.

The DATA pin contains an internal Schmitt trigger as part of its input to improve noise immunity. This pin has an internal pull-down device to provide a low level when the pin is left unconnected.

CLK Pin

The CLK pin is used to provide a clock used for loading and shifting data into the DATA pin. The data on the DATA pin is clocked into a shift register on the rising edge of the CLK pin signal. The data is transferred to the D/A Register on the eighth falling edge of the CLK pin. This protocol may be handled by the SPI or SIOP serial I/O function found on some MCU devices.

The CLK pin contains an internal Schmitt trigger as part of its input to improve noise immunity. The CLK pin has an internal pull-down device to provide a low level when the pin is left unconnected.

Output Threshold Adjust

The state of the OUT pin is driven by a voltage comparator whose output state depends on the level of the input voltage on the sample capacitor and the level of an adjustable 8-bit threshold voltage. The threshold is adjusted by shifting data bits into the D/A Register (DAR) via the DATA pin while clocking the CLK pin. The timing of this data is shown in Figure 4. Data is transferred into the serial shift register on the rising edge of the CLK pin. On the falling edge of the 8th clock the data in the serial shift register is latched into the parallel DAR register. The DAR remains powered up whenever V_{DD} is present. The serial data is clocked into the DATA pin starting with the MSB first. This sequence of threshold select bits is shown in Table 2.

Table 2. D/A Threshold Bit Assignment

Function		Bit Weight	Data Bit
	LSB	1	D0
		2	D1
		4	D2
Voltage Comparator Threshold Adjust (8 bits)		8	D3
		16	D4
		32	D5
		64	D6
	MSB	128	D7

An analog to digital (A/D) conversion can be accomplished with eight (8) different threshold levels in a successive approximation algorithm; or the OUT pin can be set to trip at some alarm level. The voltage on the sample capacitor will maintain long enough for a single 8-bit conversion, but may need to be refreshed with a new measured reading if the read interval is longer than the specified hold time, t_{SH}.

The counter that determines the number of clock pulses into the device is reset whenever the device is placed into the Measure Pressure or Measure Temperature Modes. This provides a means to reset the data transfer count in case the clock stream is corrupted during a transmission. In these two modes the DATA and CLK pins should not be clocked to reduce noise in the captured pressure or temperature data. Any change in the DAR contents should be done during the Standby or Output Read Modes.

Both the serial bit counter and the state of the DAR are undefined following power up of the device. The serial bit counter can be reset by cycling either the SO pin or the S1/VPP pin to a high level and then back low. The DAR can then be reset to the lowest level by holding the DATA pin low while bursting the CLK pin with eight (8) clock pulses.

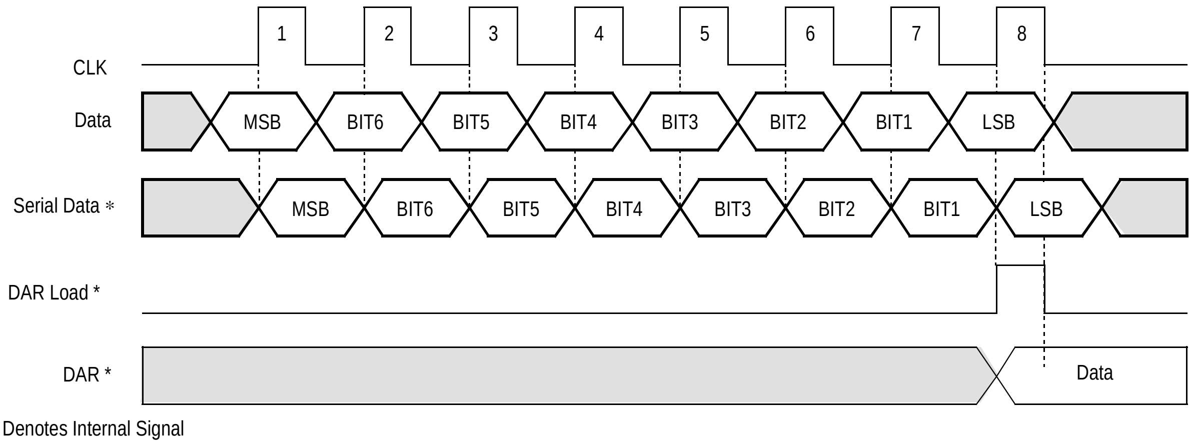


Figure 5. Serial Data Timing

Pressure Sensor Output

The pressure channel compares the output of its analog measurement circuit to the D/A reference voltage. The device is calibrated at two different nominal values depending on the calibration option.

Temperature Sensor Output

The temperature channel compares the output of a positive temperature coefficient (PTC) resistor driven by a switched current source. The current source is only active when the temperature channel is selected.

APPLICATIONS

Suggested application example is shown in Figure 6.

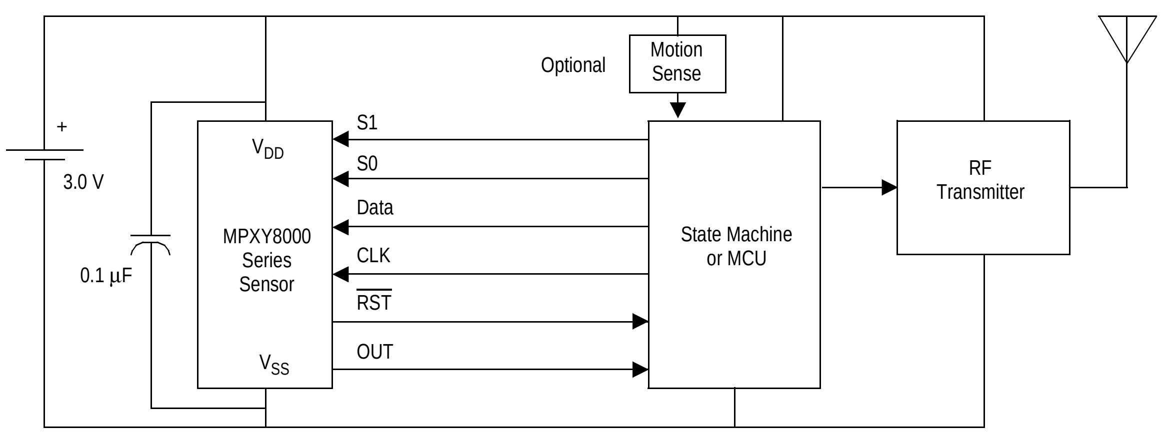


Figure 6. Application Example

ELECTRICAL SPECIFICATIONS

Maximum ratings are the extreme limits to which the device can be exposed without permanently damaging it. The device contains circuitry to protect the inputs against damage from high static voltages; however, do not apply voltages higher than those shown in the table below. Keep V_{IN} and V_{OUT} within the range $V_{SS} \leq (V_{IN} \text{ or } V_{OUT}) \leq V_{DD}$.

Table 3. Maximum Ratings

Rating	Symbol	Value	Unit
Supply Voltage	V_{DD}	–0.3 to +4.0	V
Short Circuit Capability (all pins excluding V_{DD} and V_{SS}) Maximum High Voltage for 5 minutes Minimum Low Voltage for 5 minutes	 V_{SC} V_{SC}	 V_{DD} V_{SS}	 V V
Substrate Current Injection Current from any pin to V_{SS} –0.3 VDC)	 I_{SUB}	 600	 µA
Electrostatic Discharge Human Body Model (HBM) Charged Device Model (CDM) Machine Model (MM)	 V_{ESD} V_{ESD} V_{ESD}	 ±1000 ±1000 ±200	 V V V
Storage Temperature Range Standard Temperature Range	 T_{stg}	 –40 to +150	 °C

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Extra precaution must be taken by the user to protect the chip from ESD. A charge of over 1000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the pressure sensor, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

OPERATING RANGE

These are the limits normally expected in the application which define range of operation.

Table 4. Operating Range

Characteristic	Symbol	Min	Typ	Max	Units
Supply Voltage	V_{DD}	2.1	3.0	3.6	V
Operating Temperature Range Standard Temperature Range	 T_A	T_L –40	 —	T_H +125	 °C
Supply Current Drain Standby Mode –40°C to +85°C +85°C to +100°C +100°C to +125°C	 I_{STBY} I_{STBY} I_{STBY}	 — — —	 0.6 0.8 1.5	 0.9 1.2 2.2	 µA µA µA
Read Mode –40°C to +125°C	 I_{READ}	 —	 400	 600	 µA
Measure Temperature Mode –40°C to +125°C	 I_{TEMP}	 —	 400	 600	 µA
Measure Pressure Mode –40°C to +10°C +10°C to +60°C +60°C to +125°C	 I_{PRESS} I_{PRESS} I_{PRESS}	 — — —	 1400 1300 1200	 1800 1700 1700	 µA µA µA

Table 5. Electrical Characteristics
+2.1 V ≤ V_{DD} ≤ +3.6 V, T_L ≤ T_A ≤ T_H, unless otherwise specified.

Characteristic	Symbol	Min	Typ	Max	Units
Output High Voltage DATA, OUT, $\overline{RST}$ (I_{Load} = 100 μA)	V_{OH}	V_{DD} –0.8	—	—	V
Output Low Voltage DATA, OUT, $\overline{RST}$ (I_{Load} = -100 μA)	V_{OL}	—	—	0.4	V
Input High Voltage S0, S1, DATA, CLK	V_{IH}	0.7 x V_{DD}	—	—	V
Input Low Voltage S0, S1, DATA, CLK	V_{IL}	V_{SS}	—	0.3 x V_{DD}	V
Input Hysteresis (V_{IH} — V_{IL}) S0, S1, DATA, CLK	V_{HYS}	100	200	—	mV
Input Low Current (at V_{IL}) S0, S1, DATA, CLK	I_{IL}	–5	–25	–100	μA
Input High Current (at V_{IH}) S0, S1, DATA, CLK	I_{IH}	–5	–35	–140	μA (2)
Temperature Measurement (+2.5 V ≤ V_{DD} ≤ 3.0 V) D/A Conversion Code at –40°C D/A Conversion Code at –20°C D/A Conversion Code at 25°C D/A Conversion Code at 70°C D/A Conversion Code at 100°C D/A Conversion Code at 120°C D/A Conversion Code at 125°C	$T_{–40}$ $T_{–20}$ T_{25} T_{70} T_{100} T_{120} T_{125}	36 52 97 155 204 241 249	42 57 102 163 214 252 255	47 62 107 171 224 255 255	counts counts counts counts counts counts counts
Temperature Measurement (+2.1 V ≤ V_{DD} ≤ 3.6 V) D/A Conversion Code at –40°C D/A Conversion Code at –20°C D/A Conversion Code at 25°C D/A Conversion Code at 70°C D/A Conversion Code at 100°C D/A Conversion Code at 120°C D/A Conversion Code at 125°C	$T_{–40}$ $T_{–20}$ T_{25} T_{70} T_{100} T_{120} T_{125}	36 52 97 154 203 240 249	42 57 102 163 214 252 255	49 64 107 172 225 255 255	counts counts counts counts counts counts counts
Temperature Sensitivity at 25°C		—	0.80		°C/bit
Approximate Temperature Output Response	OUT = 74.7461 + 0.9752 x Ta + 0.0041 x Ta^2				counts

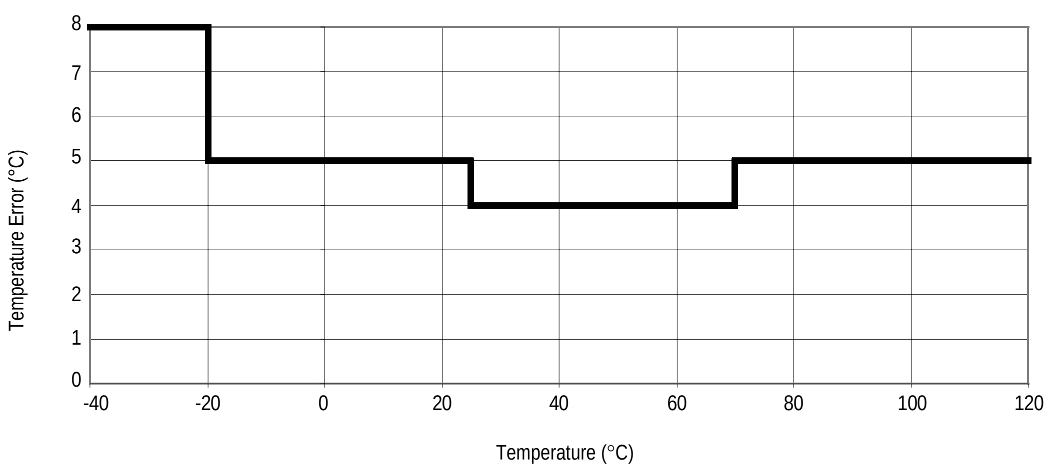


Figure 7. Temperature Error vs Temperature at V_{DD} = 3.0 V

Table 6. Control Timing
+2.1 V ≤ V_{DD} ≤ +3.6 V, T_L ≤ T_A ≤ T_H, unless otherwise specified.

Characteristic	Symbol	Min	Typ	Max	Units
HFO Measurement Clock Frequency	f_{HF}	100	135	150	kHz
LFO Wake Up Clock Frequency Ta = –40°C, +2.1V ≤ V_{DD} ≤ +3.6 Ta = +25°C, +2.1V ≤ V_{DD} ≤ +3.6 Ta = +125°C, +2.1V ≤ V_{DD} ≤ +3.6	 f_{LF} f_{LF} f_{LF}	 3300 3900 3800	 5400 5400 5300	 8000 7700 7000	 Hz Hz Hz
Wake Up Pulse Pulse Timing Pulse Width	 t_{WAKE} t_{WPW}	 — —	 16384 2	 — —	 LFO clocks LFO clocks
Reset Pulse Pulse Timing Pulse Width	 t_{RESET} t_{RPW}	 — —	 16,777,216 2	 — —	 LFO clocks LFO clocks
Minimum Setup Time (DATA edge to CLK rise)	t_{SETUP}	100	—	—	nSec
Minimum Hold Time (CLK rise to DATA change)	t_{HOLD}	100	—	—	nSec
Measurement Response Time Recommended time to hold device in measurement mode Temperature Pressure	 t_{TMEAS} t_{PMEAS}	 — —	 200 500	 — —	 µSec µSec
Read Response Time (see Figure 8) From 90% V_{DD} on S0 to OUT less than V_{OL} or greater than V_{OH}	 t_{READ}	 —	 50	 100	 µSec
Sample Capacitor Discharge Time From initial full scale D/A count (255) to drop 2 counts (253)	 t_{SH}	 20	 —	 —	 mSec

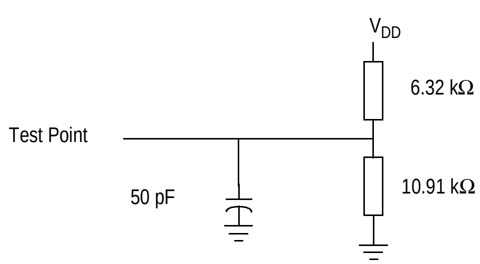


Figure 8. Control Timing Test Load for OUT and $\overline{RST}$ Pins

SENSOR CHARACTERISTICS (MPXY8020A)

Pressure Transfer Function

kPa = 2.5 x Output ± (Pressure Error)
Output = 8-bit digital pressure measurement (between 0-255)

Pressure Error (±kPa): 50 kPa ≤ P < 250 kPa

T[°C] \ V_{DD}[V]	2.1	2.5	2.7	3.0	3.3	3.6
–40	72.5	72.5	32.5	32.5	32.5	35.0
–20	57.5	57.5	25.0	25.0	25.0	27.5
0	57.5	57.5	25.0	25.0	25.0	27.5
25	57.5	57.5	25.0	25.0	25.0	27.5
70	57.5	57.5	27.5	25.0	25.0	27.5
100	72.5	72.5	37.5	37.5	37.5	37.5
125	95.0	92.5	57.5	47.5	47.5	47.5

Pressure Error (±kPa): 250 kPa ≤ P ≤ 450 kPa

T[°C] \ V_{DD}[V]	2.1	2.5	2.7	3.0	3.3	3.6
–40	40.0	40.0	25.0	25.0	25.0	30.0
–20	32.5	25.0	15.0	15.0	15.0	20.0
0	30.0	25.0	10.0	10.0	10.0	15.0
25	30.0	25.0	7.5	7.5	7.5	15.0
70	35.0	25.0	10.0	7.5	7.5	15.0
100	40.0	40.0	25.0	25.0	25.0	30.0
125	62.5	60.0	35.0	35.0	35.0	35.0

Pressure Error (±kPa): 450 kPa < P ≤ 600 kPa

T[°C] \ V_{DD}[V]	2.1	2.5	2.7	3.0	3.3	3.6
–40	70.0	70.0	37.5	37.5	37.5	40.0
–20	55.0	55.0	25.0	25.0	25.0	35.0
0	55.0	55.0	22.5	22.5	22.5	35.0
25	55.0	55.0	22.5	22.5	22.5	35.0
70	55.0	55.0	25.0	25.0	25.0	35.0
100	70.0	70.0	32.5	32.5	32.5	40.0
125	90.0	90.0	47.5	47.5	47.5	52.5

Areas marked in grey indicate the typical operating range.

SENSOR CHARACTERISTICS (MPXY8020A)

Pressure Error

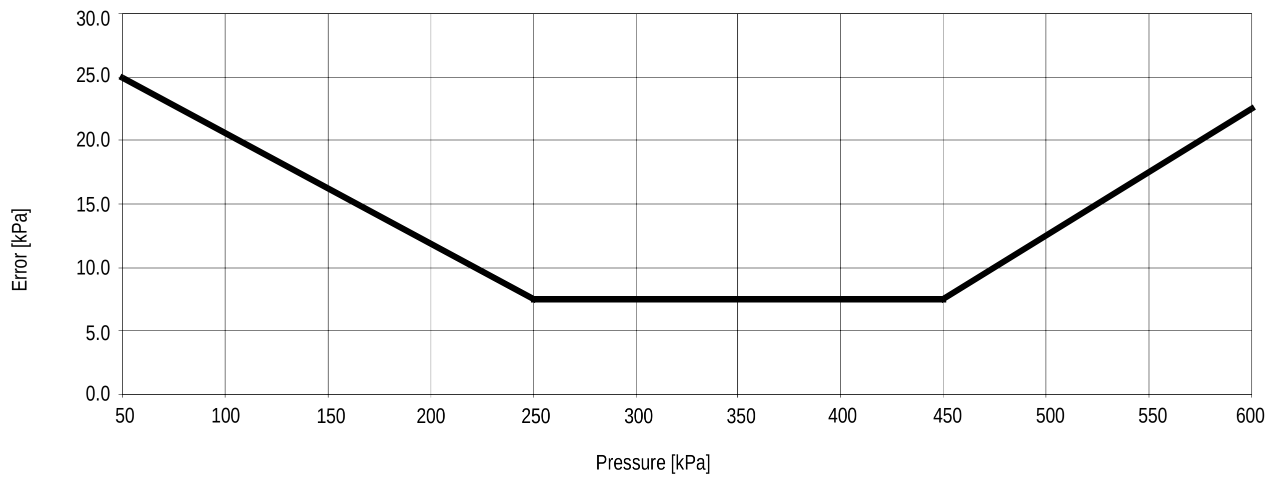


Figure 9. Pressure Error vs Pressure at T = 25°C, 2.7 V ≤ V_{DD} ≤ 3.3 V

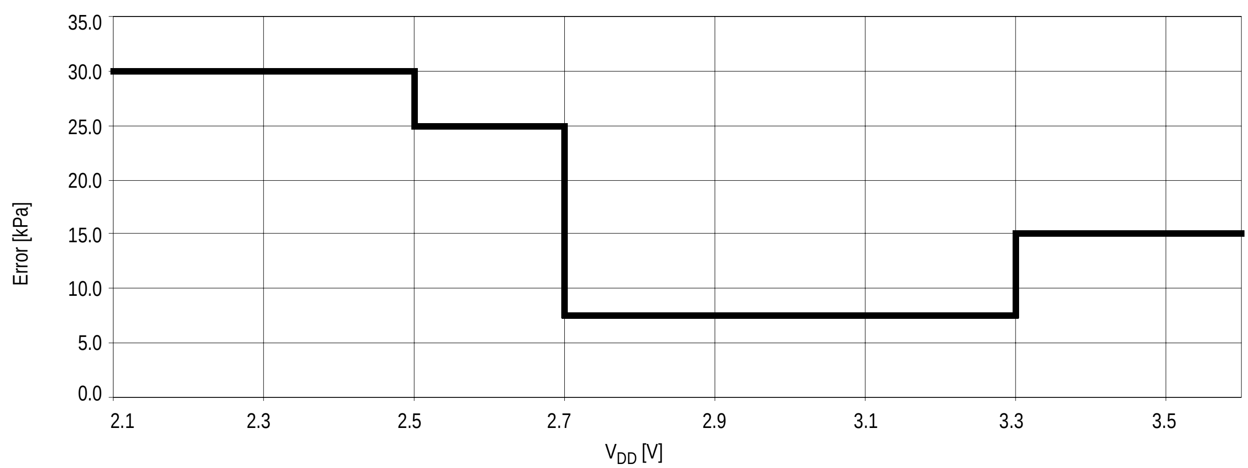


Figure 10. Pressure Error vs V_{DD} at T = 25°C, 250 kPa ≤ P ≤ 450 kPa

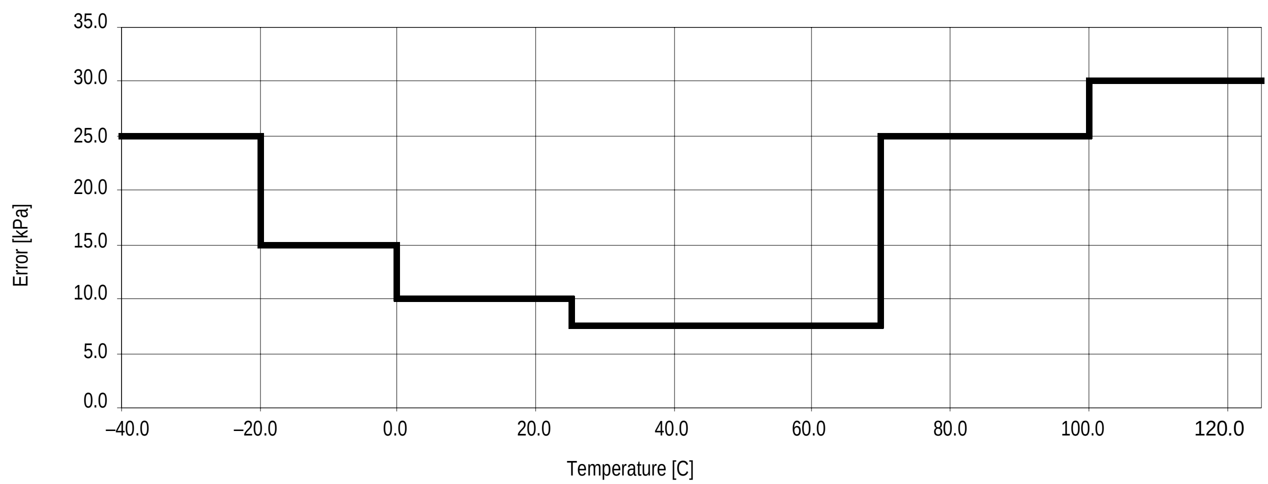


Figure 11. Pressure Error vs Temperature at V_{DD} = 3.0 V, 250 kPa ≤ P ≤ 450 kPa

SENSOR CHARACTERISTICS (MPXY8040A)

Pressure Transfer Function

kPa = 5.0 x Output ± (Pressure Error)
Output = 8-bit digital pressure measurement (between 0-255)

Pressure Error [±kPa]: 50 kPa ≤ P < 500 kPa

T[°C] \ V_{DD}[V]	2.1	2.3	2.5	2.7	3.0	3.3	3.6
–40	80	75	70	70	70	70	75
–20	70	60	55	55	55	55	60
0	60	50	45	45	45	45	55
25	55	45	40	40	40	45	50
70	70	55	50	50	50	50	55
100	80	70	65	65	65	65	70
125	90	85	80	80	80	80	80

Pressure Error [±kPa]: 500 kPa ≤ P < 900 kPa

T[°C] \ V_{DD}[V]	2.1	2.3	2.5	2.7	3.0	3.3	3.6
–40	75	65	60	60	60	60	65
–20	50	35	25	25	25	40	50
0	40	30	20	20	20	25	35
25	40	30	20	20	20	25	35
70	40	30	20	20	20	25	35
100	60	45	35	35	35	45	60
125	90	85	80	80	80	80	80

Pressure Error [±kPa]: 900 kPa < P < 1000 kPa

T[°C] \ V_{DD}[V]	2.1	2.3	2.5	2.7	3.0	3.3	3.6
–40	120	110	110	100	100	110	120
–20	100	80	80	60	60	80	100
0	90	60	60	40	40	60	90
25	90	60	60	40	40	60	90
70	90	75	75	60	60	75	90
100	90	90	90	75	75	90	90
125	130	120	120	110	110	120	130

Pressure Error [±kPa]: 1000 kPa ≤ P < 1100 kPa

T[°C] \ V_{DD}[V]	2.1	2.3	2.5	2.7	3.0	3.3	3.6
–40	130	120	120	100	100	120	130
–20	110	90	90	60	70	90	110
0	90	80	80	50	50	80	90
25	90	80	80	50	50	80	90
70	90	75	75	60	60	75	90
100	130	110	110	100	100	110	130
125	140	130	130	120	120	130	140

Pressure Error [±kPa]: 1100 kPa ≤ P ≤1275 kPa

T[°C] \ V_{DD}[V]	2.1	2.3	2.5	2.7	3.0	3.3	3.6
–40	150	140	140	120	120	140	150
–20	120	100	100	80	80	100	120
0	110	90	90	80	80	90	110
25	110	90	90	80	80	90	110
70	120	120	120	120	120	130	150
100	160	140	140	140	140	160	160
125	210	200	200	200	200	210	210

Areas marked in grey indicate the typical operating range.
(*) Output will max out (255 counts) at 1,275 kPa or higher.
Pressure values beyond 900 kPa are from characterization only. Pressure readings above 900 kPa are not tested in production

SENSOR CHARACTERISTICS (MPXY8040A)

Pressure Error

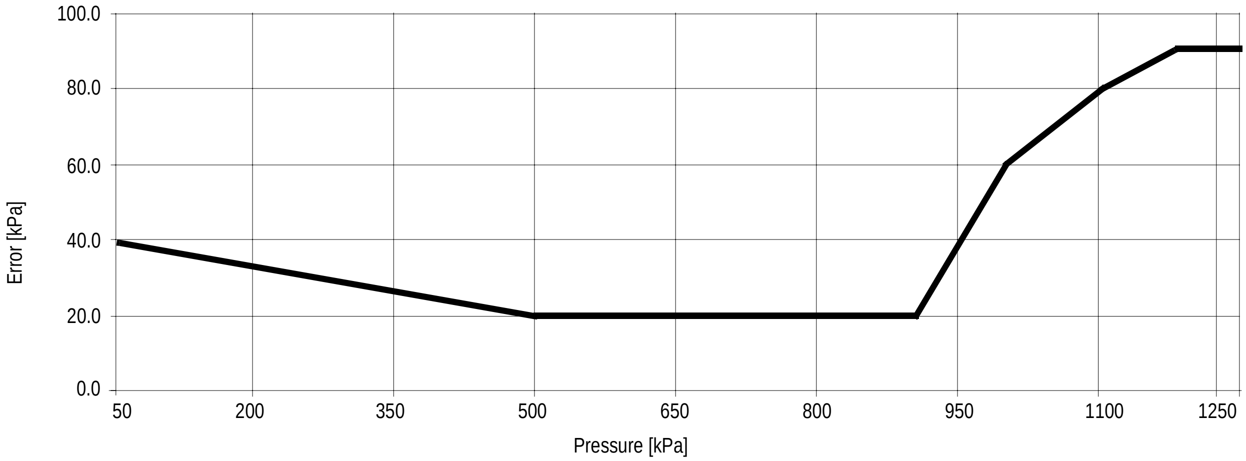


Figure 12. Pressure Error vs Pressure at T= 25°C, 2.5 V ≤ V_{DD} ≤ 3.0 V

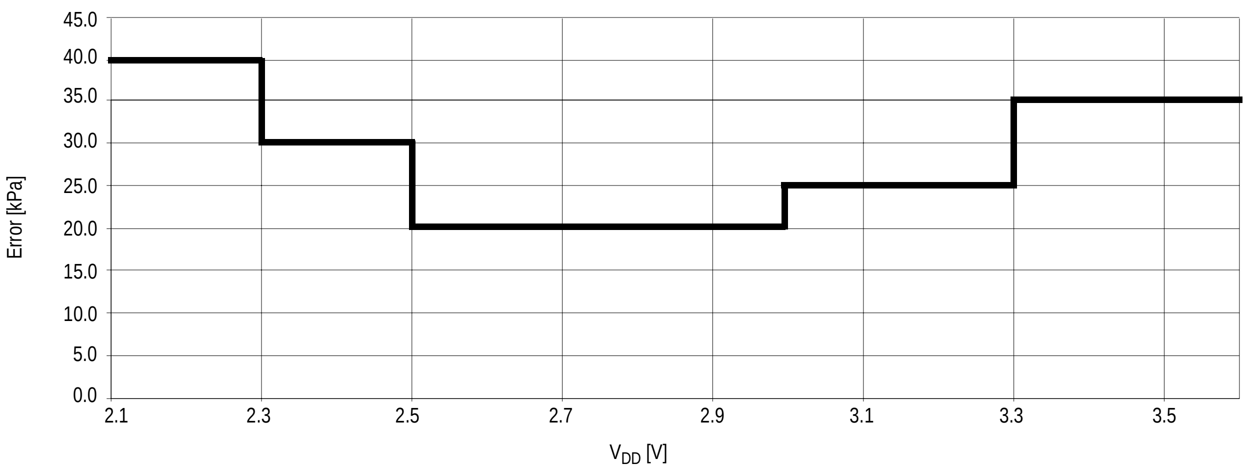


Figure 13. Pressure Error vs V_{DD} at T = 25°C, 500 kPa ≤ P ≤ 900kPa

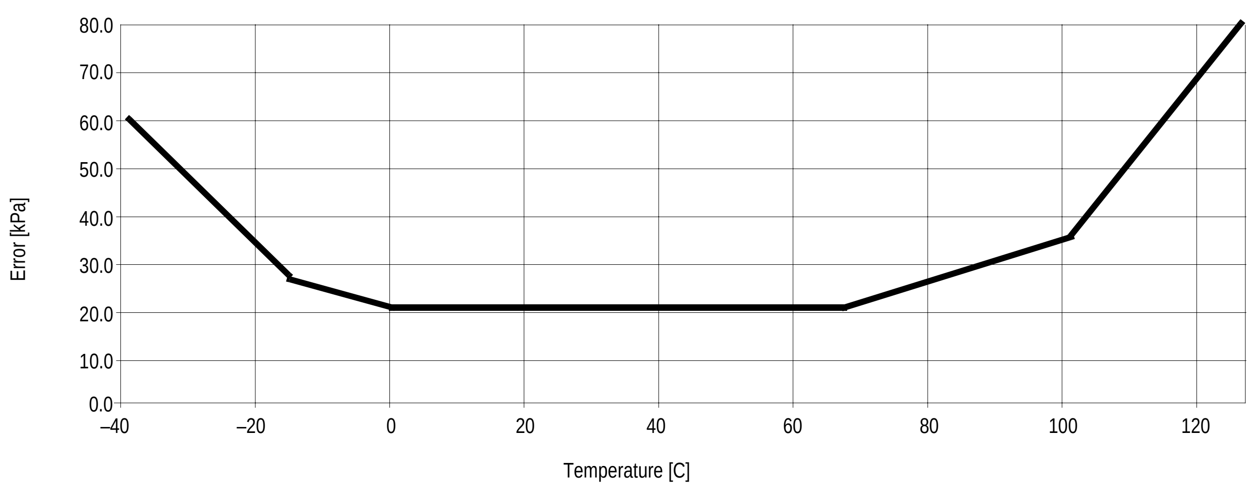


Figure 14. Pressure Error vs Temperature at V_{DD} = 3.0 V, 500 kPa ≤ P ≤ 900kPa

MECHANICAL SPECIFICATIONS

Maximum ratings are the extreme limits to which the device can be exposed without permanently damaging it.

Keep V_{IN} and V_{OUT} within the range $V_{SS} \leq (V_{IN}$ or $V_{OUT}) \leq V_{DD}$.

Table 7. Maximum Ratings

Rating	Symbol	Value	Unit
Maximum Pressure(1)	p_{max}	1400	kPa(1)
Centrifugal Force Effects (3 axis) Pressure measurement change less than 1% FSS	g_{CENT}	2000	g
Unpowered Shock (three sides, 0.5 mSec duration)	g_{shock}	2000	g

1. Tested for 5 minutes at 25°C.

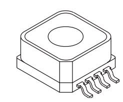
MEDIA COMPATIBILITY

Media compatibility is as specified in Freescale Semiconductor document "SPD TPM Media Test."

Tire Pressure Monitoring Sensor Temperature Compensated and Calibrated, Fully Integrated, Digital Output

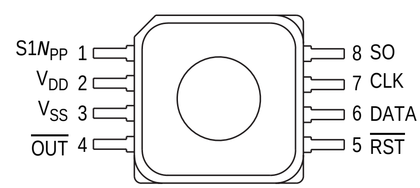
MPXY8021A

TIRE PRESSURE MONITORING SENSOR MPXY8021A: OPTIMIZED FOR 250 kPA – 450 kPA



SUPER SMALL OUTLINE PACKAGE CASE 1352-03

PIN ASSIGNMENT



8-pin Super Small Outline Package (SSOP)

ORDERING INFORMATION	
Shipped In Rails	**Shipped in Tape & Reel**
MPXY8021A6U	MPXY8021A6T1

The Freescale Semiconductor, Inc. MPXY8021A sensor is an 8-pin tire monitoring sensor which is comprised of a variable capacitance pressure sensing element, a temperature sensing element, and an interface circuit (with a wake-up feature) all on a single chip. It is housed in a Super-Small Outline Package (SSOP), which includes a media protection filter. Specifically designed for the low power consumption requirements of tire pressure monitoring systems, it can combine with a Freescale remote keyless entry (RKE) system to facilitate a low-cost, highly integrated system.

DETAILED DESCRIPTION

The block diagram of the MPXY8021A sensor is shown in Figure 1. The pressure sensor is a capacitive transducer constructed using surface micromachining, the temperature sensor is constructed using a diffused resistor, and the interface circuit is integrated onto the same die as the sensors using a standard silicon CMOS process.

The conditioning of the pressure signal begins with a capacitance to voltage conversion (C to V) followed by a switched capacitor amplifier. This amplifier has adjustable offset and gain trimming. The offset and gain are factory calibrated, with calibration values stored in the EEPROM trim register. This amplifier also has temperature compensation circuits for both sensitivity and offset, which also are factory adjusted using the EEPROM trim register.

The pressure is monitored by a voltage comparator, which compares the measured value against an 8-bit threshold adjusted by a serial input. By adjusting the threshold and monitoring the state of the OUT pin the external device can check whether a low-pressure threshold has been crossed, or perform up to 8-bit A/D conversions.

The temperature is measured by a diffused resistor with a positive temperature coefficient driven by a current source, thereby creating a voltage. The room temperature value of this voltage is factory calibrated using the EEPROM trim register. A two-channel multiplexer can route either the pressure or temperature signal to a sampling capacitor that is monitored by a voltage comparator with variable threshold adjust, providing a digital output for temperature.

An internal low frequency, low power 5.4 kHz oscillator with a 14-stage divider provides a periodic pulse to the OUT pin (divide by 16384 for 3 seconds). This pulse can be used to wake up an external MCU to begin an interface with the device. An additional 10-stage divider will provide a pulse every 52 minutes which can be used to reset an external MCU.

The power consumption can be controlled by several operational modes selected by external pins.

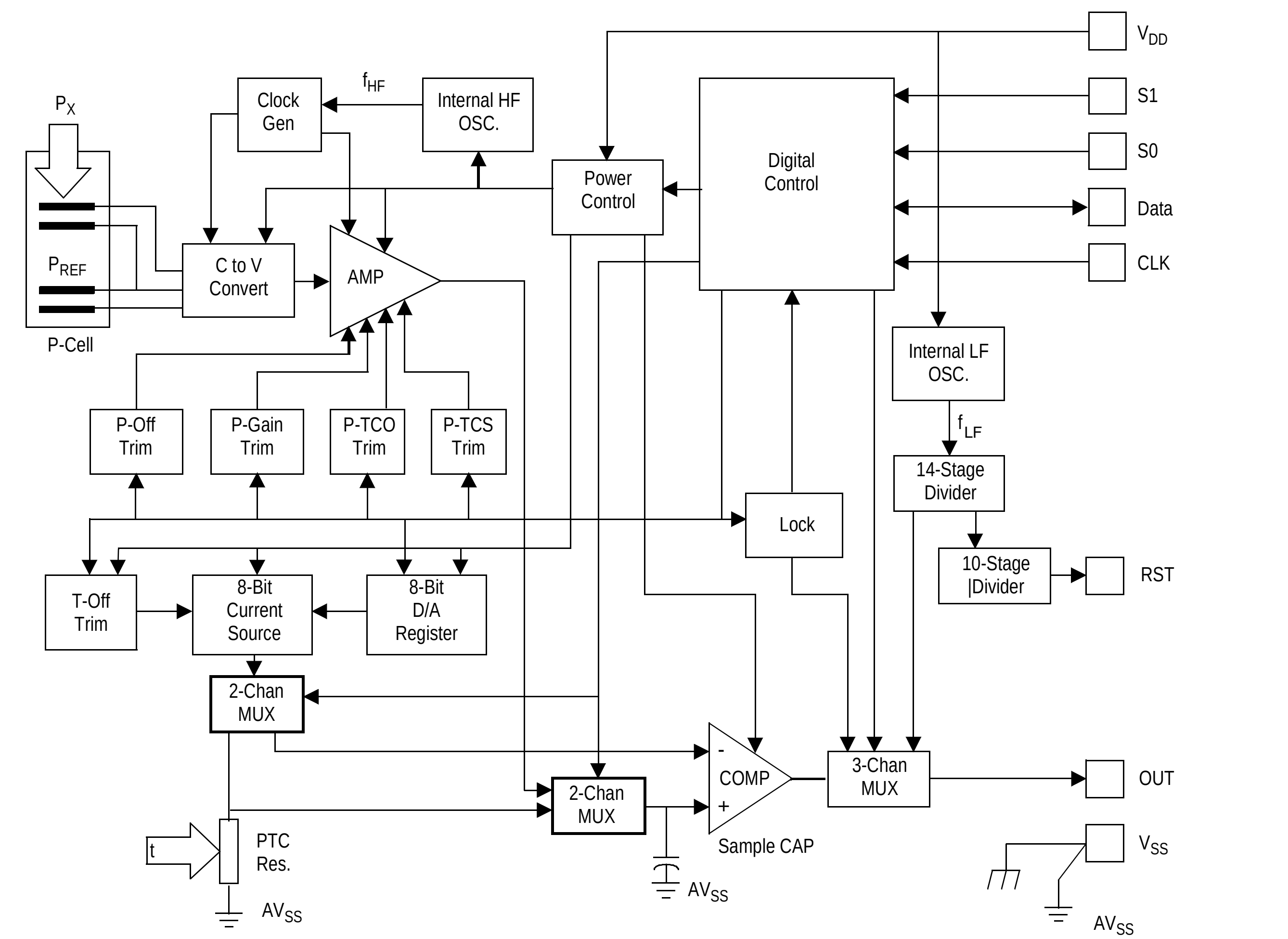


Figure 1. MPXY8021A Sensor Block Diagram

OPERATING MODES

The device has several operating modes dependent on the applied voltages to the S1 and S0 pins as shown in Table 1. In all the modes listed the channel multiplexers, D/A Register, LFO, and the output pulse dividers will always be powered up as long as there is a voltage source connected to the V_{DD} pin.

When only the S0 pin is at a logic one the pressure measuring circuit in the device is powered up and the pressure output signal is connected to the sample capacitor through a multiplexer. When the S0 pin returns to the low state the multiplexer will first turn off to store the signal on the sample capacitor before powering down the measuring circuitry.

When only the S1 pin is at a logic one the temperature measuring circuit in the device is powered up and the temperature output signal is connected to the sample capacitor through a multiplexer. When the S1 pin returns to the low state the multiplexer will first turn off to store the signal on the sample capacitor before powering down the measuring circuitry.

NOTE: All of the EEPROM trim bits will be powered up regardless of whether the pressure or temperature measuring circuitry is activated.

NOTE: If the voltage on the S1 pin exceeds 2.5 times the voltage on the V_{DD} pin the device will be placed into its Trim/Test Mode.

NOTE: If the V_{DD} supply source is switched off in order to reduce current consumption, it is important that all input pins be driven LOW to avoid powering up the device.

If any input pin (S1, S0, DATA, or CLK) is driven HIGH while the V_{DD} supply is switched off, the device may be powered up through an ESD protection diode. In such a case, the effective V_{DD} voltage will be about 0.3 V less than the voltage applied to the input pin, and the full device I_{DD} current will be drawn from the device driving input.

Table 1. Operating Modes

S1	S0	Operating Mode	Circuitry Powered				Serial Data Counter
			Pressure Measure System	Temp Measure System	A/D Output Comp.	LFO Oscill.	
0	0	Standby/Reset	OFF	OFF	OFF	ON	ACTIVE
0	1	Measure Pressure	ON	OFF	OFF	ON	RESET
1	0	Measure Temperature	OFF	ON	OFF	ON	RESET
1	1	Output Read	OFF	OFF	ON	ON	ACTIVE

PIN FUNCTIONS

The following paragraphs give a description of the general function of each pin.

V_{DD} and V_{SS} Pins

Power is supplied to the control IC through V_{DD} and V_{SS}. V_{DD} is the positive supply and V_{SS} is the digital and analog ground. The control IC operates from a single power supply. Therefore, the conductors to the power supply should be connected to the V_{DD} and V_{SS} pins and locally decoupled as shown in Figure 2.

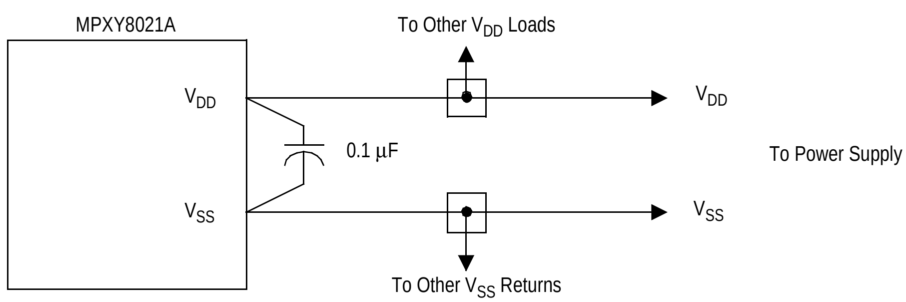


Figure 2. Recommended Power Supply Connections

OUT Pin

The OUT pin normally provides a digital signal related to the voltage applied to the voltage comparator and the threshold level shifted into an 8-bit register from an external device. When the device is placed in the standby mode the OUT pin is driven high and will be clocked low when an overflow is detected from a clock divider (divide by 16384) driven by the LFO. This allows the OUT pin to wake up an external device such as an MCU.

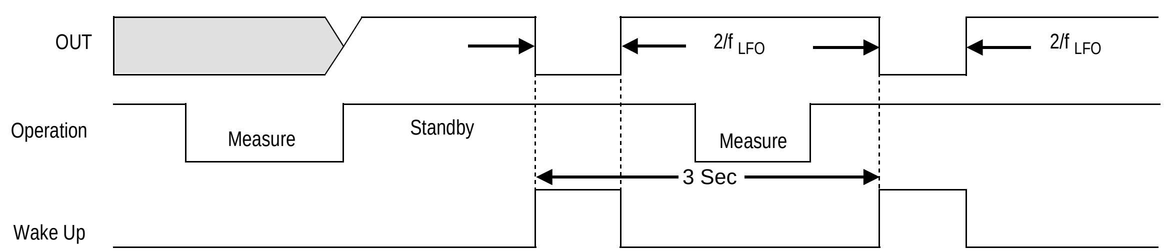


Figure 3. Pulse on OUT Pin During Standby Mode

$\overline{RST}$ Pin

The $\overline{RST}$ pin is normally driven high and will be clocked low when an overflow is detected from total clock divider (divide by 16,777,216) driven by the LFO. This allows the $\overline{RST}$ pin to reset an external device such as an MCU. This pulse will appear on the $\overline{RST}$ pin approximately every 52 minutes regardless of the operating mode of the device. The pulse lasts for two cycles of the LFO oscillator as shown in Figure 4. Since the RST pin is clocked from the same divider string as the $\overline{OUT}$ pin, there will also be a pulse on the OUT pin when the $\overline{RST}$ pin pulses every 52 minutes.

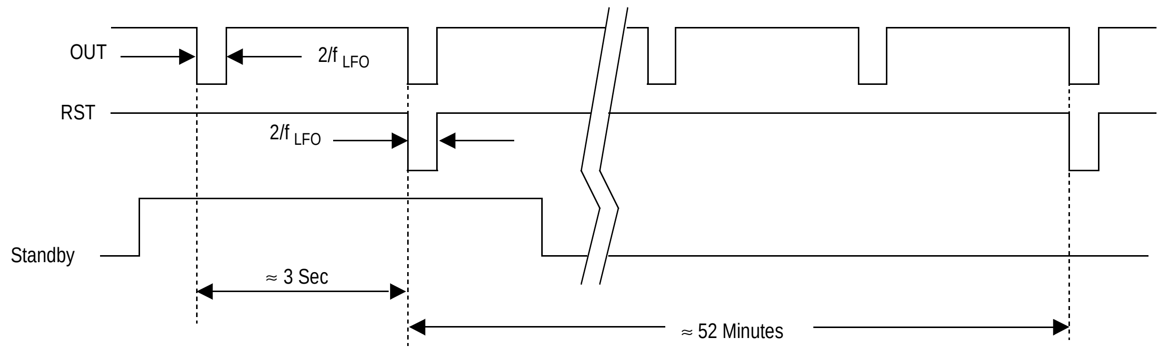


Figure 4. Pulse on RST Pin

S0 Pin

The S0 pin is used to select the mode of operation as shown in Table 1.

The S0 pin contains an internal Schmitt trigger as part of its input to improve noise immunity. The S0 pin has an internal pull-down device in order to provide a low level when the pin is left unconnected.

S1 Pin

The S1 pin is used to select the mode of operation, as shown in Table 1.

The S1 pin contains an internal Schmitt trigger as part of its input to improve noise immunity. This pin has an internal pull-down device to provide a low level when the pin is left unconnected.

The S1 pin also serves the purpose of enabling factory trim and test of the device.

The higher V_{PP} programming voltage for the internal EEPROM trim register is also supplied through the S1 pin.

DATA Pin

The DATA pin is the serial data in (SDI) function for setting the threshold of the voltage comparator.

The DATA pin contains an internal Schmitt trigger as part of its input to improve noise immunity. This pin has an internal pull-down device to provide a low level when the pin is left unconnected.

CLK Pin

The CLK pin is used to provide a clock used for loading and shifting data into the DATA pin. The data on the DATA pin is clocked into a shift register on the rising edge of the CLK pin signal. The data is transferred to the D/A Register on the eighth falling edge of the CLK pin. This protocol may be handled by the SPI or SIOP serial I/O function found on some MCU devices.

The CLK pin contains an internal Schmitt trigger as part of its input to improve noise immunity. The CLK pin has an internal pull-down device to provide a low level when the pin is left unconnected.

Output Threshold Adjust

The state of the OUT pin is driven by a voltage comparator whose output state depends on the level of the input voltage on the sample capacitor and the level of an adjustable 8-bit threshold voltage. The threshold is adjusted by shifting data bits into the D/A Register (DAR) via the DATA pin while clocking the CLK pin. The timing of this data is shown in Figure 5. Data is transferred into the serial shift register on the rising edge of the CLK pin. On the falling edge of the 8^{th} clock the data in the serial shift register is latched into the parallel DAR register. The DAR remains powered up whenever V_{DD} is present. The serial data is clocked into the DATA pin starting with the MSB first. This sequence of threshold select bits is shown in Table 2.

Table 2. D/A Threshold Bit Assignment

Function		Bit Weight	Data Bit
	LSB	1	D0
		2	D1
		4	D2
Voltage Comparator Threshold Adjust (8 bits)		8	D3
		16	D4
		32	D5
		64	D6
	MSB	128	D7

An analog to digital (A/D) conversion can be accomplished with eight (8) different threshold levels in a successive approximation algorithm; or the OUT pin can be set to trip at some alarm level. The voltage on the sample capacitor will maintain long enough for a single 8-bit conversion, but may need to be refreshed with a new measured reading if the read interval is longer than the specified hold time, t_{SH}.

The counter that determines the number of clock pulses into the device is reset whenever the device is placed into the Measure Pressure or Measure Temperature Modes. This provides a means to reset the data transfer count in case the clock stream is corrupted during a transmission. In these two modes the DATA and CLK pins should not be clocked to reduce noise in the captured pressure or temperature data. Any change in the DAR contents should be done during the Standby or Output Read Modes.

Both the serial bit counter and the state of the DAR are undefined following power up of the device. The serial bit counter can be reset by cycling either the SO pin or the S1/VPP pin to a high level and then back low. The DAR can then be reset to the lowest level by holding the DATA pin low while bursting the CLK pin with eight (8) clock pulses.

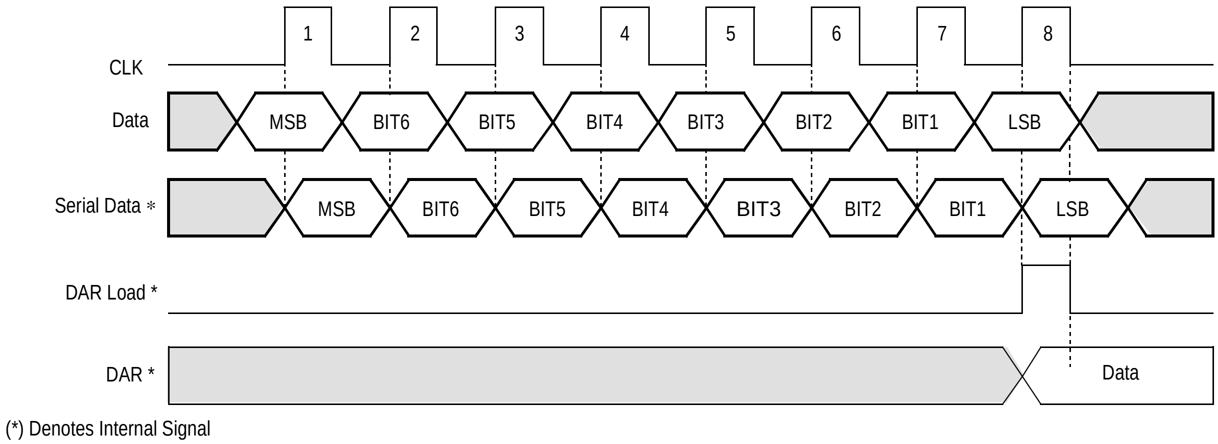


Figure 5. Serial Data Timing

Pressure Sensor Output

The pressure channel compares the output of its analog measurement circuit to the D/A reference voltage. The device is calibrated at two different nominal values depending on the calibration option.

Temperature Sensor Output

The temperature channel compares the output of a positive temperature coefficient (PTC) resistor driven by a switched current source. The current source is only active when the temperature channel is selected.

APPLICATIONS

Suggested application example is shown in Figure 6.

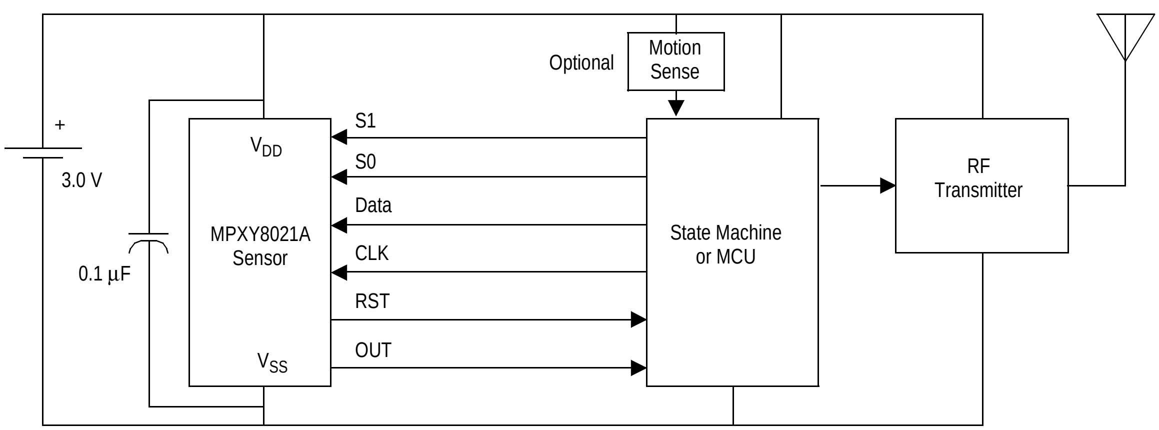


Figure 6. Application Example

ELECTRICAL SPECIFICATIONS

Maximum ratings are the extreme limits to which the device can be exposed without permanently damaging it. The device contains circuitry to protect the inputs against damage from high static voltages; however, do not apply voltages higher than those shown in the table below. Keep V_{IN} and V_{OUT} within the range $V_{SS} \leq (V_{IN} \text{ or } V_{OUT}) \leq V_{DD}$.

Table 3. Maximum Ratings

Rating	Symbol	Value	Unit
Supply Voltage	V_{DD}	–0.3 to +4.0	V
Short Circuit Capability (all pins excluding V_{DD} and V_{SS}) Maximum High Voltage for 5 minutes Minimum Low Voltage for 5 minutes	 V_{SC} V_{SC}	 V_{DD} V_{SS}	 V V
Substrate Current Injection Current from any pin to V_{SS} –0.3 VDC)	 I_{SUB}	 600	 µA
Electrostatic Discharge Human Body Model (HBM) Charged Device Model (CDM) Machine Model (MM)	 V_{ESD} V_{ESD} V_{ESD}	 ±1000 ±1000 ±200	 V V V
Storage Temperature Range Standard Temperature Range	 T_{stg}	 –40 to +150	 °C

OPERATING RANGE

The limits normally expected in the application which define range of operation.

Table 4. Operating Range

Characteristic	Symbol	Min	Typ	Max	Units
Supply Voltage	V_{DD}	2.1	3.0	3.3	V
Operating Temperature Range Standard Temperature Range	 T_A	T_L –40	 —	T_H +125	 °C
Pressure Operating Range MPXY8021A	 $P_{637.5}$	 50	 —	 637.5	 kPa
Supply Current Drain Standby Mode –40°C to +85°C +85°C to +100°C +100°C to +125°C	 I_{STBY} I_{STBY} I_{STBY}	 — — —	 0.6 0.8 1.5	 0.9 1.2 2.2	 µA µA µA
Read Mode –40°C to +125°C	 I_{READ}	 —	 400	 600	 µA
Measure Temperature Mode –40°C to +125°C	 I_{TEMP}	 —	 400	 600	 µA
Measure Pressure Mode –40°C to +10°C +10°C to +60°C +60°C to +125°C	 I_{PRESS} I_{PRESS} I_{PRESS}	 — — —	 1400 1300 1200	 1800 1700 1700	 µA µA µA

Table 5. Electrical Characteristics
+2.1 V ≤ VDD ≤ +3.6 V, TL ≤ TA ≤ TH, unless otherwise specified

Characteristic	Symbol	Min	Typ	Max	Units
Output High Voltage DATA, OUT, $\overline{RST}$ (I_{Load} = 100 µA)	V_{OH}	V_{DD} –0.8	—	—	V
Output Low Voltage DATA, OUT, $\overline{RST}$ (I_{Load} = -100 µA)	V_{OL}	—	—	0.4	V
Input High Voltage S0, S1, DATA, CLK	V_{IH}	0.7 x V_{DD}	—	—	V
Input Low Voltage S0, S1, DATA, CLK	V_{IL}	V_{SS}	—	0.3 x V_{DD}	V
Input Hysteresis (V_{IH} — V_{IL}) S0, S1, DATA, CLK	V_{HYS}	100	200	—	mV
Input Low Current (at V_{IL}) S0, S1, DATA, CLK	I_{IL}	-5	-25	-100	µA
Input High Current (at V_{IH}) S0, S1, DATA, CLK	I_{IH}	-5	-35	-140	µA (2)
Temperature Measurement (+2.1 V ≤ V_{DD} < +2.5 V) D/A Conversion Code at -40°C D/A Conversion Code at -20°C D/A Conversion Code at 25°C D/A Conversion Code at 70°C D/A Conversion Code at 100°C D/A Conversion Code at 120°C D/A Conversion Code at 125°C	T_{-40} T_{-20} T_{25} T_{70} T_{100} T_{120} T_{125}	34 52 97 154 203 240 249	42 57 102 163 214 252 255	51 67 107 172 225 255 255	counts counts counts counts counts counts counts
Temperature Measurement (+2.5 V ≤ V_{DD} ≤ +3.0 V) D/A Conversion Code at -40°C D/A Conversion Code at -20°C D/A Conversion Code at 25°C D/A Conversion Code at 70°C D/A Conversion Code at 100°C D/A Conversion Code at 120°C D/A Conversion Code at 125°C	T_{-40} T_{-20} T_{25} T_{70} T_{100} T_{120} T_{125}	36 52 97 155 204 241 249	42 57 102 163 214 252 255	50 64 107 171 224 255 255	counts counts counts counts counts counts counts
Temperature Measurement (+3.0 V < V_{DD} ≤ +3.6 V) D/A Conversion Code at -40°C D/A Conversion Code at -20°C D/A Conversion Code at 25°C D/A Conversion Code at 70°C D/A Conversion Code at 100°C D/A Conversion Code at 120°C D/A Conversion Code at 125°C	T_{-40} T_{-20} T_{25} T_{70} T_{100} T_{120} T_{125}	36 52 97 154 203 240 249	42 57 102 163 214 252 255	49 64 107 172 225 255 255	counts counts counts counts counts counts counts
Temperature Sensitivity at 25°C		—	0.80		°C/bit
Approximate Temperature Output Response	OUT = 74.7461 + 0.9752 x Ta + 0.0041 x Ta^2				counts

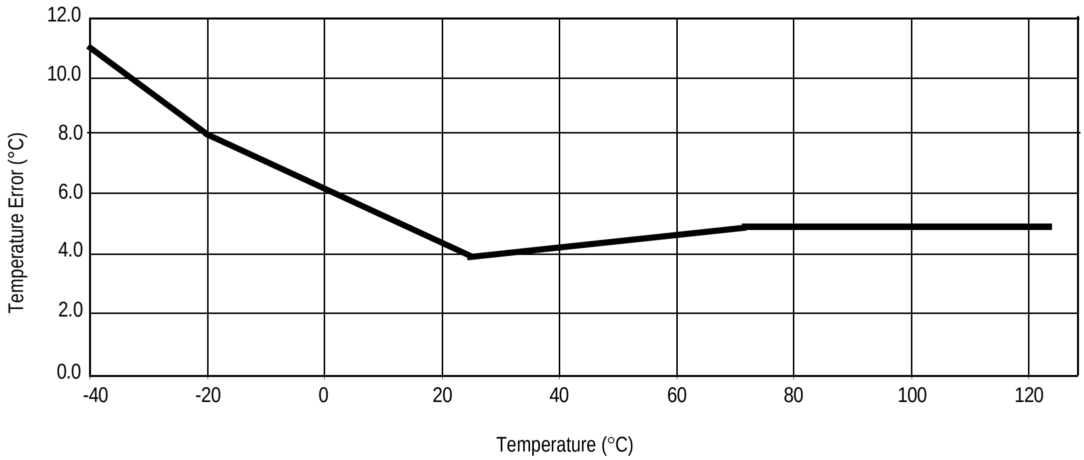


Figure 7. Temperature Error vs Temperature at V_{DD} = 3.0 V

Table 6. Control Timing

+2.1 V ≤ V_{DD} ≤ +3.6 V, $T_L \le T_A \le T_H$, unless otherwise specified.

Characteristic	Symbol	Min	Typ	Max	Units
HFO Measurement Clock Frequency	f_{HF}	100	135	150	kHz
LFO Wake Up Clock Frequency Ta = –40°C, +2.1V ≤ V_{DD} ≤ +3.6 Ta = +25°C, +2.1V ≤ V_{DD} ≤ +3.6 Ta = +125°C, +2.1V ≤ V_{DD} ≤ +3.6	f_{LF} f_{LF} f_{LF}	3300 3900 3800	5400 5400 5300	8000 7700 7000	Hz Hz Hz
Wake Up Pulse Pulse Timing Pulse Width	t_{WAKE} t_{WPW}	— —	16384 2	— —	LFO clocks LFO clocks
Reset Pulse Pulse Timing Pulse Width	t_{RESET} t_{RPW}	— —	16,777,216 2	— —	LFO clocks LFO clocks
Minimum Setup Time (DATA edge to CLK rise)	t_{SETUP}	100	—	—	nSec
Minimum Hold Time (CLK rise to DATA change)	t_{HOLD}	100	—	—	nSec
Measurement Response Time Recommended time to hold device in measurement mode Temperature Pressure	t_{TMEAS} t_{PMEAS}	— —	200 500	— —	µSec µSec
Read Response Time (see Figure 8) From 90% V_{DD} on S0 to OUT less than V_{OL} or greater than V_{OH}	t_{READ}	—	50	100	µSec
Sample Capacitor Discharge Time From initial full scale D/A count (255) to drop 2 counts (253)	t_{SH}	20	—	—	mSec

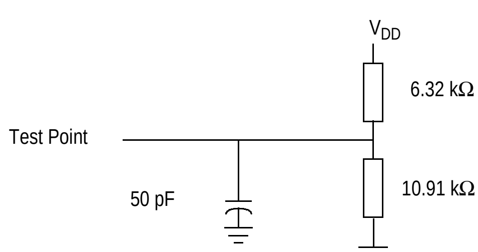


Figure 8. Control Timing Test Load for OUT and $\overline{\text{RST}}$ Pins

SENSOR CHARACTERISTICS (MPXY8021A)

PRESSURE TRANSFER FUNCTION

kPa = 2.5 x Output ± (Pressure Error)
Output = 8-bit digital pressure measurement (between 0-255)

Pressure Error (±kPa): 50 kPa ≤ P < 250 kPa

T[°C] \ V_{DD}[V]	2.1	2.5	2.7	3.0	3.3	3.6
–40	72.5	72.5	35.0	35.0	35.0	37.5
–20	57.5	57.5	30.0	30.0	30.0	35.0
0	57.5	57.5	25.0	25.0	25.0	27.5
25	57.5	57.5	25.0	25.0	25.0	27.5
70	57.5	57.5	27.5	25.0	25.0	27.5
100	72.5	72.5	37.5	37.5	37.5	37.5
125	95.0	92.5	57.5	47.5	47.5	47.5

Pressure Error (±kPa): 250 kPa ≤ P ≤ 450 kPa

T[°C] \ V_{DD}[V]	2.1	2.5	2.7	3.0	3.3	3.6
–40	40.0	40.0	30.0	30.0	30.0	35.0
–20	32.5	25.0	20.0	20.0	20.0	25.0
0	30.0	25.0	10.0	10.0	10.0	15.0
25	30.0	25.0	7.5	7.5	7.5	15.0
70	35.0	25.0	10.0	7.5	7.5	15.0
100	40.0	40.0	25.0	25.0	25.0	30.0
125	62.5	60.0	35.0	35.0	35.0	35.0

Pressure Error (±kPa): 450 kPa < P ≤ 637.5 kPa

T[°C] \ V_{DD}[V]	2.1	2.5	2.7	3.0	3.3	3.6
–40	70.0	70.0	40.0	40.0	40.0	40.0
–20	55.0	55.0	30.0	30.0	30.0	35.0
0	55.0	55.0	22.5	22.5	22.5	35.0
25	55.0	55.0	22.5	22.5	22.5	35.0
70	55.0	55.0	25.0	25.0	25.0	35.0
100	70.0	70.0	32.5	32.5	32.5	40.0
125	90.0	90.0	47.5	47.5	47.5	52.5

Areas marked in grey indicate the typical operating range.

PRESSURE ERROR

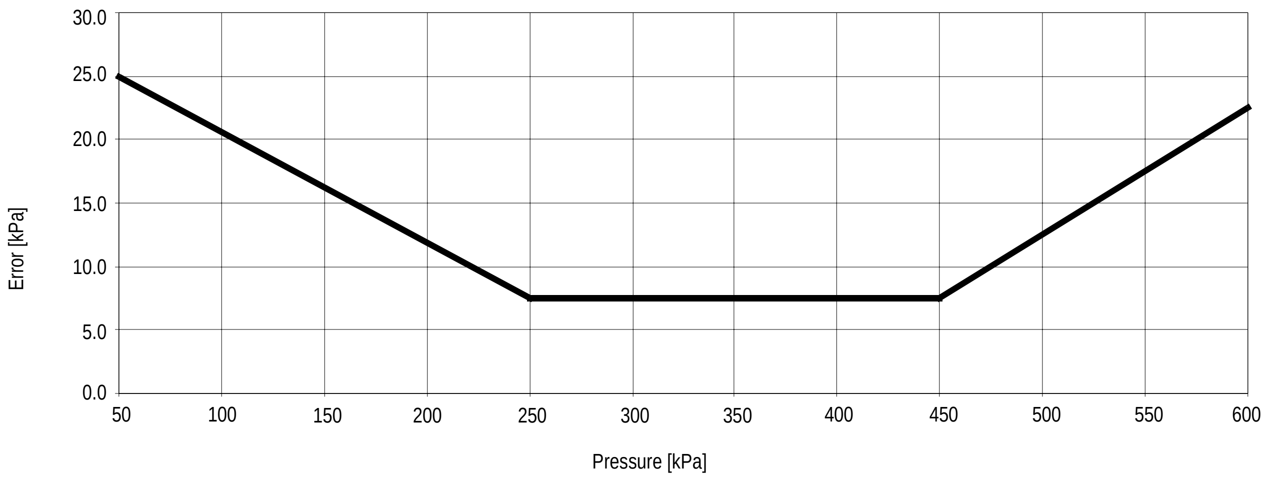


Figure 9. Pressure Error vs Pressure at T = 25°C, 2.7 V ≤ V_{DD} ≤ 3.3 V

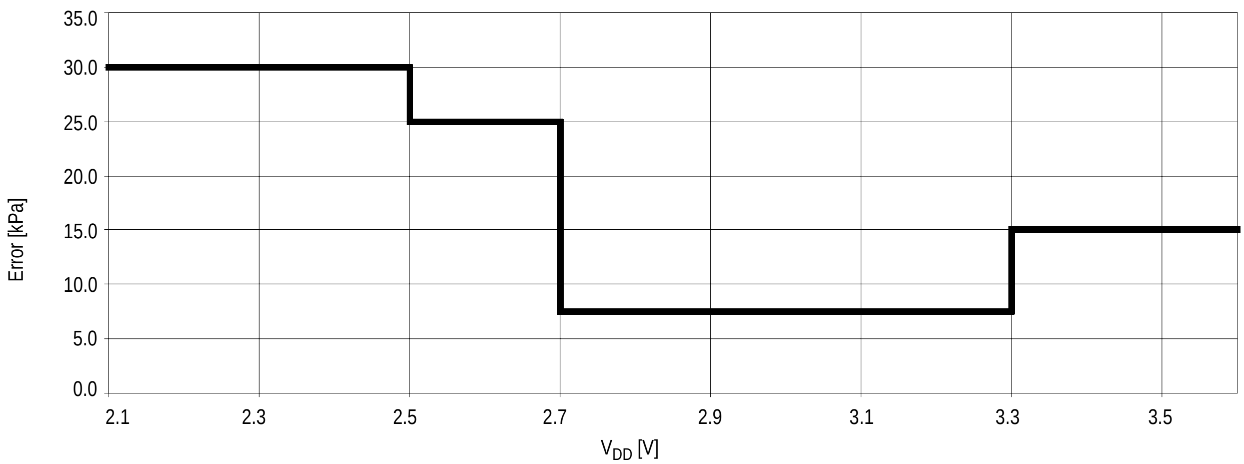


Figure 10. Pressure Error vs V_{DD} at T = 25°C, 250 kPa ≤ P ≤ 450 kPa

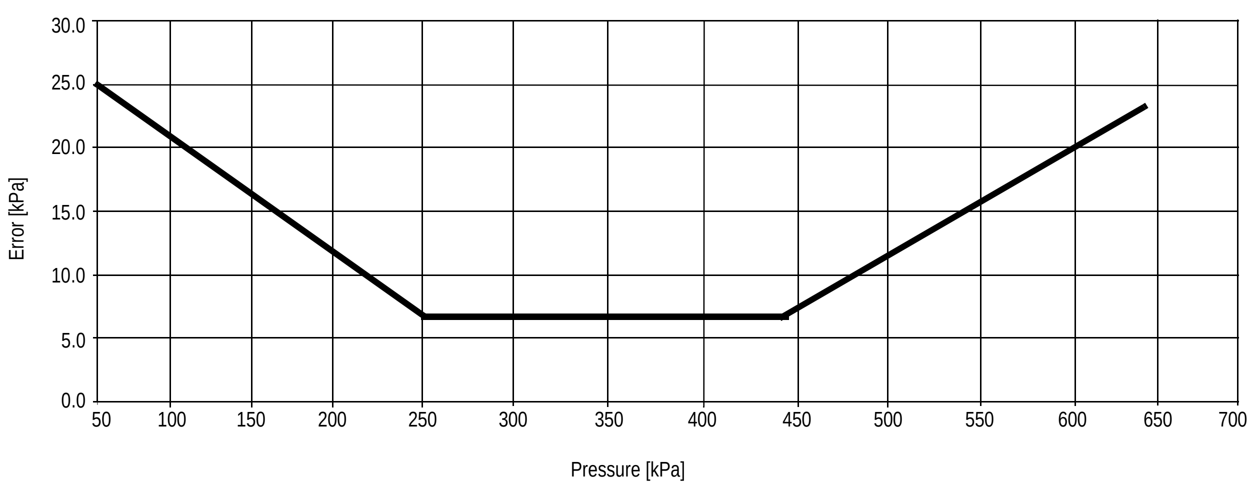


Figure 11. Pressure Error vs Temperature at V_{DD} = 3.0 V, 250 kPa ≤ P ≤ 450 kPa

MECHANICAL SPECIFICATIONS

MAXIMUM RATINGS

Maximum ratings are the extreme limits to which the device can be exposed without permanently damaging it.

Keep V_{IN} and V_{OUT} within the range:
$V_{SS} \leq (V_{IN}$ or $V_{OUT}) \leq V_{DD}$.

Table 7. Maximum Ratings

Rating	Symbol	Value	Unit
Maximum Pressure[1]	p_{max}	1400	kPa[1]
Centrifugal Force Effects (3 axis) Pressure measurement change less than 1% FSS	g_{CENT}	2000	g
Unpowered Shock (three sides, 0.5 mSec duration)	g_{shock}	2000	g

1. Tested for 5 minutes at 25°C.

MEDIA COMPATIBILITY

Media compatibility is as specified in the Freescale document “SPD TPM Media Test.”

Compensating for Nonlinearity in the MPX10 Series Pressure Transducer

by: Carl Demington
Design Engineering

INTRODUCTION

This application note describes a technique to improve the linearity of the Freescale Semiconductor, Inc. MPX10 series (i.e., MPX10, MPXV10, and MPX12 pressure sensors) pressure transducers when they are interfaced to a microprocessor system. The linearization technique allows the user to obtain both high sensitivity and good linearity in a cost effective system.

The MPX10, MPXV10 and MPX12 pressure transducers are semiconductor devices which give an electrical output signal proportional to the applied pressure over the pressure range of 0-10 kPa (0-75 mm Hg). These devices use a unique transverse voltage-diffused silicon strain-gauge which is sensitive to stress produced by pressure applied to a thin silicon diaphragm.

One of the primary considerations when using a pressure transducer is the linearity of the transfer function, since this parameter has a direct effect on the total accuracy of the system, and compensating for nonlinearities with peripheral circuits is extremely complicated and expensive. The purpose of this document is to outline the causes of nonlinearity, the trade-offs that can be made for increased system accuracy, and a relatively simple technique that can be utilized to maintain system performance, as well as system accuracy.

ORIGINS OF NONLINEARITY

Nonlinearity in semiconductor strain-gauges is a topic that has been the target of many experiments and much discussion. Parameters such as resistor size and orientation, surface impurity levels, oxide passivation thickness and growth temperatures, diaphragm size and thickness are all contributors to nonlinear behavior in silicon pressure transducers. The Freescale X-ducer was designed to minimize these effects. This goal was certainly accomplished in the MPX2000 series which have a maximum nonlinearity of 0.1percent FS. However, to obtain the higher sensitivity of the MPX10 series, a maximum nonlinearity of ±1percent FS has to be allowed. The primary cause of the additional nonlinearity in the MPX10 series is due to the stress induced in the diaphragm by applied pressure being no longer linear.

One of the basic assumptions in using semiconductor strain-gauges as pressure sensors is that the deflection of the diaphragm when pressure is applied is small compared to the thickness of the diaphragm. With devices that are very sensitive in the low pressure ranges, this assumption is no longer valid. The deflection of the diaphragm is a considerable percentage of the diaphragm thickness, especially in devices with higher sensitivities (thinner diaphragms). The resulting stresses do not vary linearly with applied pressure. This behavior can be reduced somewhat by increasing the area of the diaphragm and consequently thickening the diaphragm. Due to the constraint, the device is required to have high sensitivity over a fairly small pressure range, and the nonlinearity cannot be eliminated. Much care was given in the design of the MPX10 series to minimize the nonlinear behavior. However, for systems which require greater accuracy, external techniques must be used to account for this behavior.

PERFORMANCE OF AN MPX DEVICE

The output versus pressure of a typical MPX12 along with an end-point straight line is shown in Figure 1. All nonlinearity errors are referenced to the end-point straight line (see data sheet). Notice there is an appreciable deviation from the end-point straight line at midscale pressure. This shape of curve is consistent with MPX10 and MPXV10, as well as MPX12 devices, with the differences between the parts being the magnitude of the deviation from the end-point line. The major tradeoff that can be made in the total device performance is sensitivity versus linearity.

Figure 2 shows the relationship between full scale span and nonlinearity error for the MPX10 series of devices. The data shows the primary contribution to nonlinearity is nonproportional stress with pressure, while assembly and packaging stress (scatter of the data about the line) is fairly small and well controlled. It can be seen that relatively good accuracies (<0.5% FS) can be achieved at the expense of reduced sensitivity, and for high sensitivity the nonlinearity errors increase rapidly. The data shown in Figure 2 was taken at room temperature with a constant voltage excitation of 3.0 volts.

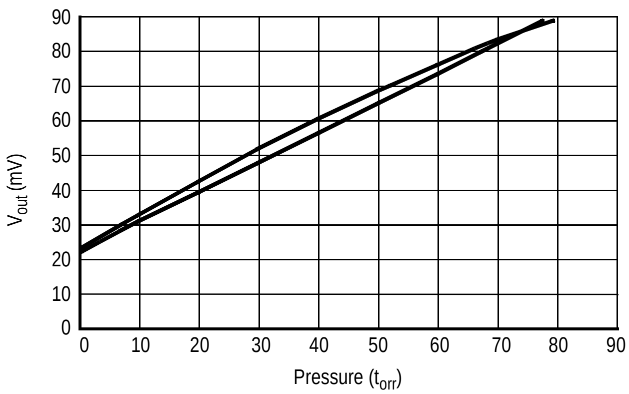


Figure 1. MPX12 Linearity Analysis Raw Data

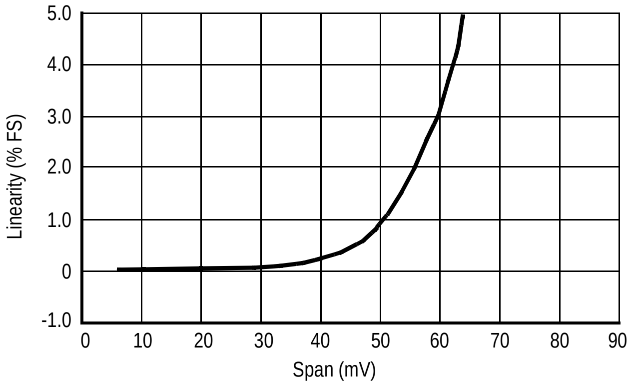


Figure 2. MPX10 Series Span versus Linearity

Compensation for Nonlinearity

The nonlinearity error shown in Figure 1 arises from the assumption that the output voltage changes with respect to pressure in the following manner:

$$V_{out} = V_{off} + sens*P \quad (1)$$

where V_{off} = output voltage at zero pressure differential
sens = sensitivity of the device
P = applied pressure

It is obvious that the true output does not follow this simple straight line equation. Therefore, if an expression could be determined with additional higher order terms that more closely described the output behavior, increased accuracies would be possible. The output expression would then become

$$V_{out} = V_{off} + (B_0 + B_1*P + B_2*P^2 + B_3*P^3 + \ldots) \quad (2)$$

where B_0, B_1, B_2, B_3, etc. are sensitivity coefficients. In order to determine the sensitivity coefficients given in equation (2) for the MPX10 series of pressure transducers, a polynomial regression analysis was performed on data taken from 139 devices with full scale spans ranging from 30 to 730 mV. It was found that second order terms are sufficient to give excellent agreement with experimental data. The calculated regression coefficients were typically 0.999999+ with the worst case being 0.99999. However, these sensitivity coefficients demonstrated a strong correlation with the full scale span of the device for which they were calculated. The correlation of B_0, B_1, and B_2 with full scale span is shown in Figure 3 through Figure 5.

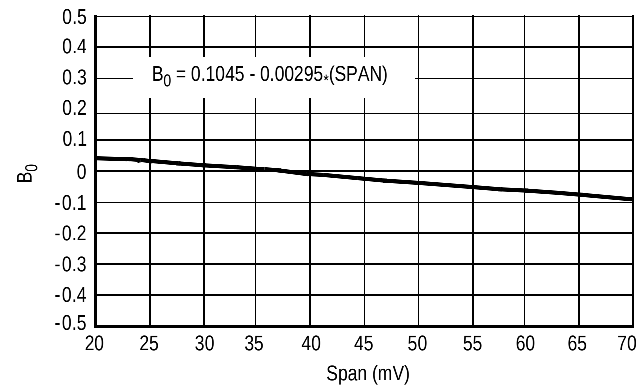


Figure 3. MPX10 Linearity Analysis — Correlation of B_0 $V_{out} = B_0 + B_1\ (P) + B_2\ (P)^2$

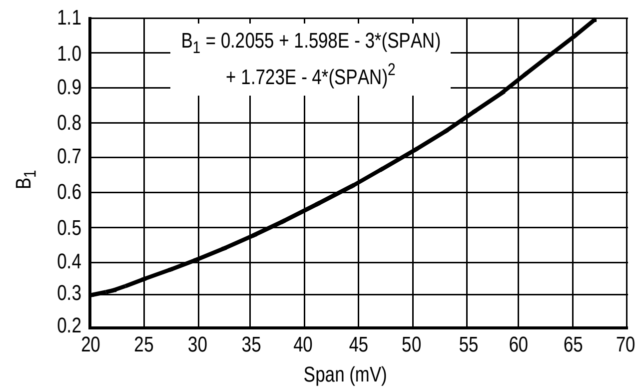


Figure 4. MPX10 Linearity Analysis — Correlation of B_1 $V_{out} = B_0 + B_1\ (P) + B_2\ (P)^2$

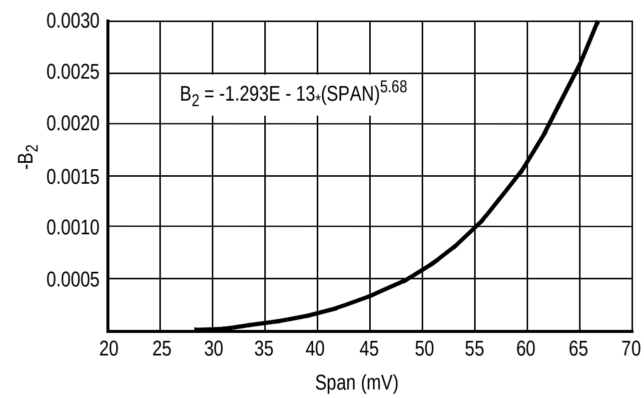


Figure 5. MPX10 Linearity Analysis — Correlation of B_2 $V_{out} = B_0 + B_1\ (P) + B_2\ (P)^2$

In order to simplify the determination of these coefficients for the user, further regression analysis was performed so that expressions could be given for each coefficient as a function of full scale span. This would then allow the user to do a single pressure measurement, a series of calculations, and analytically arrive at the equation of the line that describes the output behavior of the transducer. Nonlinearity errors were then calculated by comparing experimental data with the values calculated using equation [2] and the sensitivity coefficients given by the regression analysis. The resulting errors are shown in Figure 6 through Figure 9 at various pressure points. While using this technique has been successful in reducing the errors due to nonlinearity, the considerable spread and large number of devices that showed errors >1percent indicate this technique was not as successful as desired.

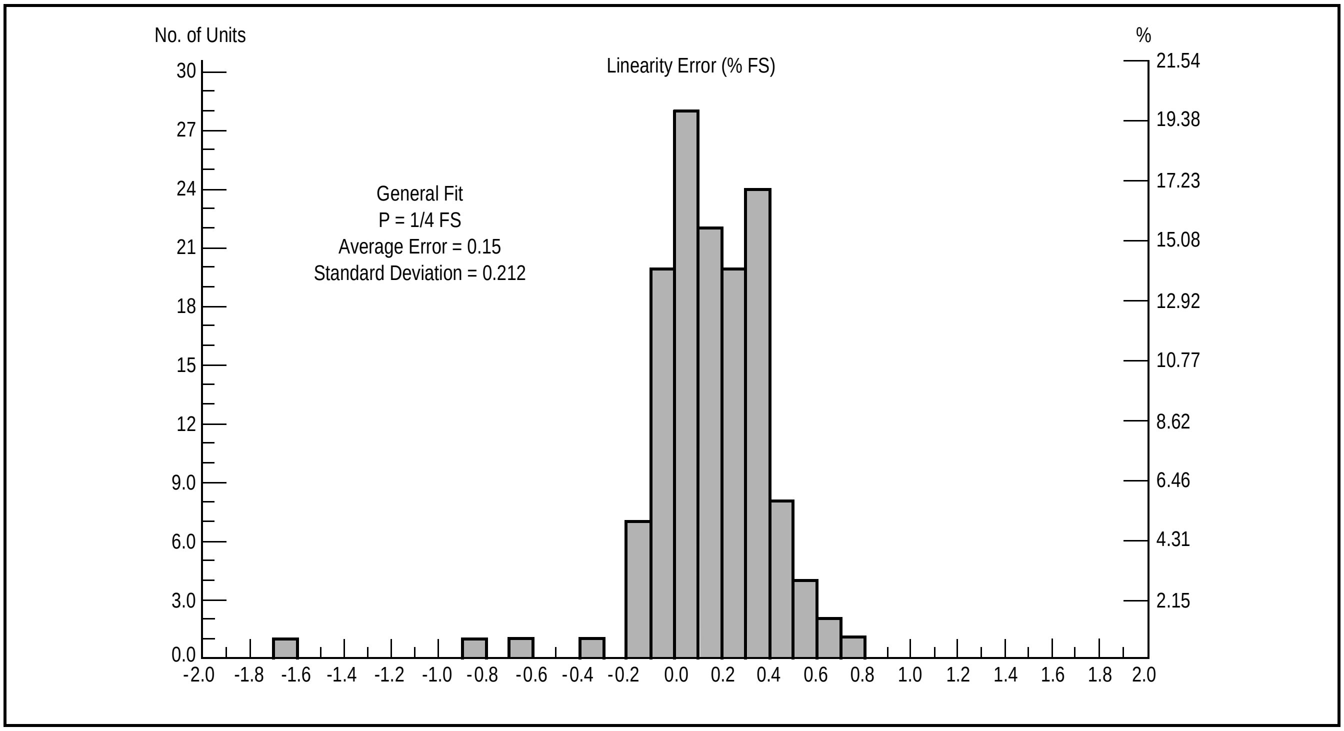


Figure 6. Linearity Error of General Fit Equation at 1/4 FS

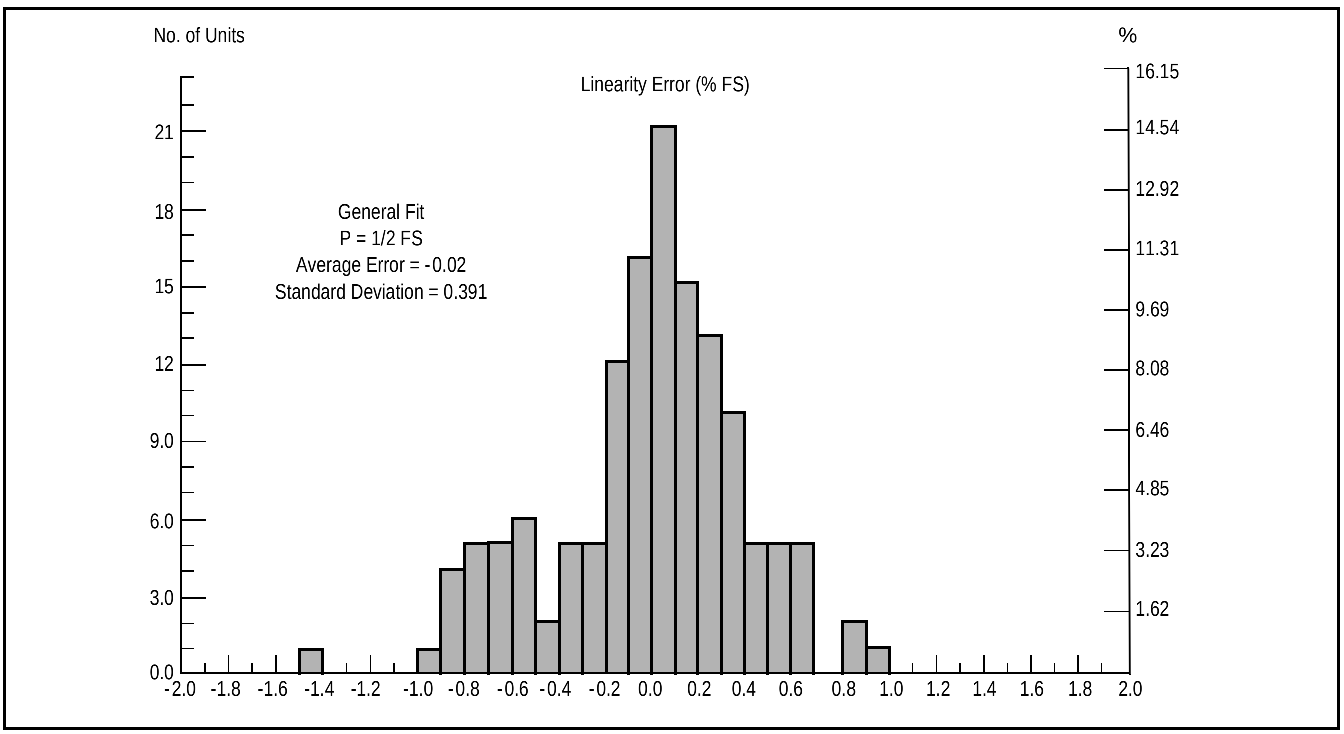


Figure 7. Linearity Error of General Fit Equation at 1/2 FS

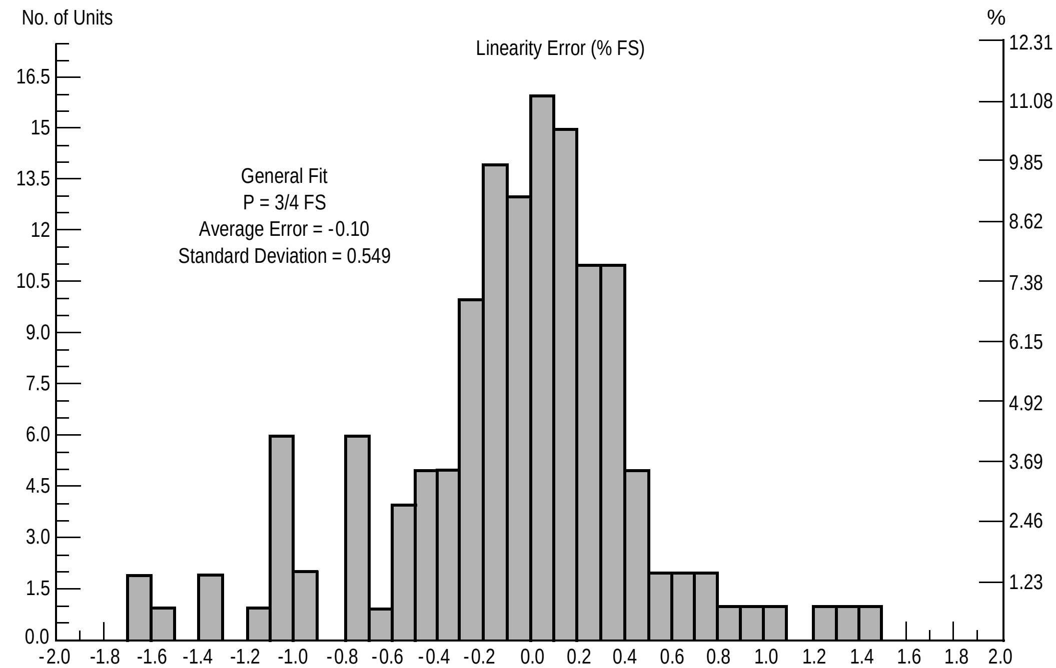


Figure 8. Linearity Error of General Fit Equation at 3/4 FS

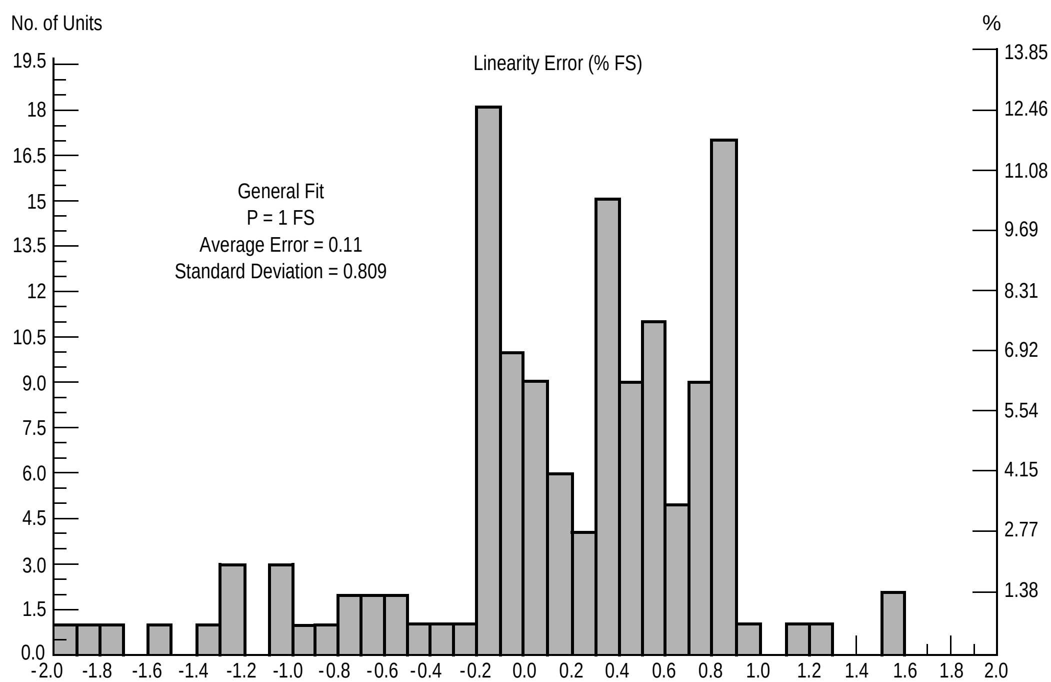


Figure 9. Linearity Error of General Fit Equation at FS

A second technique that still uses a single pressure measurement as the input was investigated. In this method, the sensitivity coefficients are calculated using a piece-wise linearization technique where the total span variation is divided into four windows of 10 mV (i.e., 30-39.99, 40-49.99, etc.) and coefficients calculated for each window. The errors that arise out of using this method are shown in Figure 10 through Figure 13. This method results in a large majority of the devices having errors <0.5%, while only one of the devices was >1%. The sensitivity coefficients that are substituted into equation [2] for the different techniques are given in Table 1. It is important to note that for either technique the only measurement that is required by the user in order to clearly determine the sensitivity coefficients is the determination of the full scale span of the particular pressure transducer.

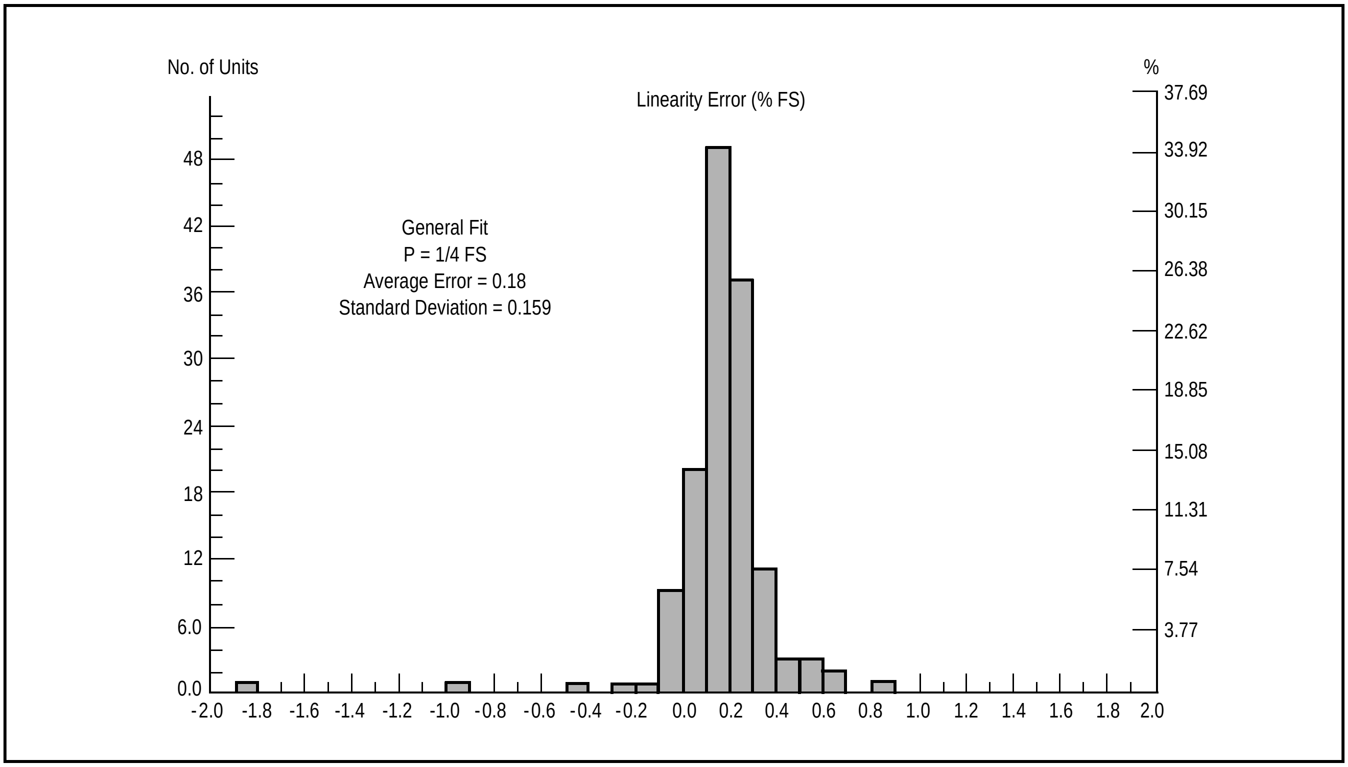


Figure 10. Linearity Error of Piece-Wise Linear Fit at 1/4 FS

Table 1. Comparison of Linearization Methods

Span Window	B_0	B_1	B_2
	General Fit		
	0.1045 + 2.95E - 3X	0.2055 + 1.598E - 3X + 1.723E - 4X^2	1.293E - 13X$^{5.681}$
	Piece-Wise Linear Fit		
30-39.99	0.08209 - 2.246E - 3X	0.02433 = 1.430E - 2X	-1.961E - 4 + 8.816E - 6X
40-49.99	0.1803 - 4.67E - 3X	-0.119 + 1.655E - 2X	-1.572E - 3 + 4.247E - 5X
50-59.99	0.1055 - 3.051E - 3X	-0.355 + 2.126E - 2X	-5.0813 - 3 + 1.116E - 4X
60-69.99	-0.288 + 3.473E - 3X	-0.361 + 2.145E - 2X	-5.928E - 3 + 1.259E - 4X

X = Full Scale Span

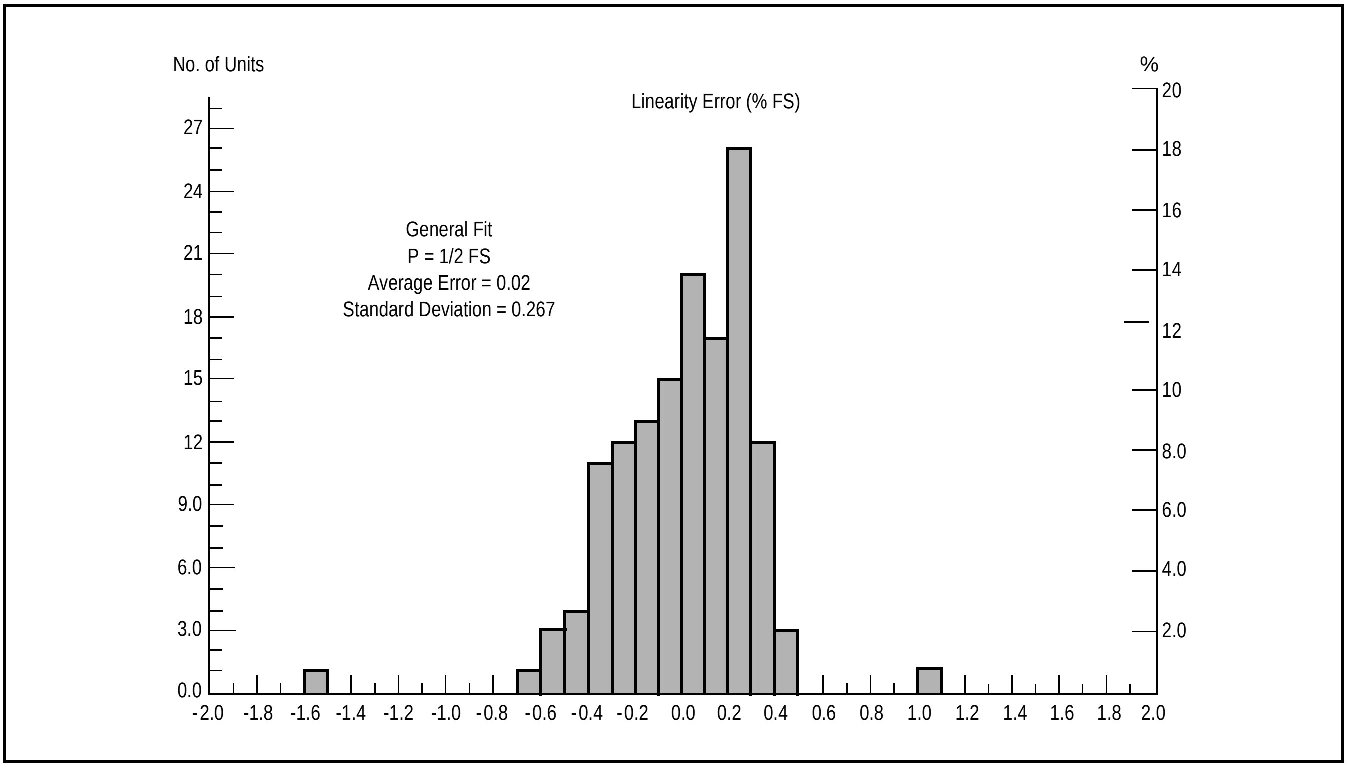


Figure 11. Linearity Error of Piece-Wise Linear Fit at 1/2 FS

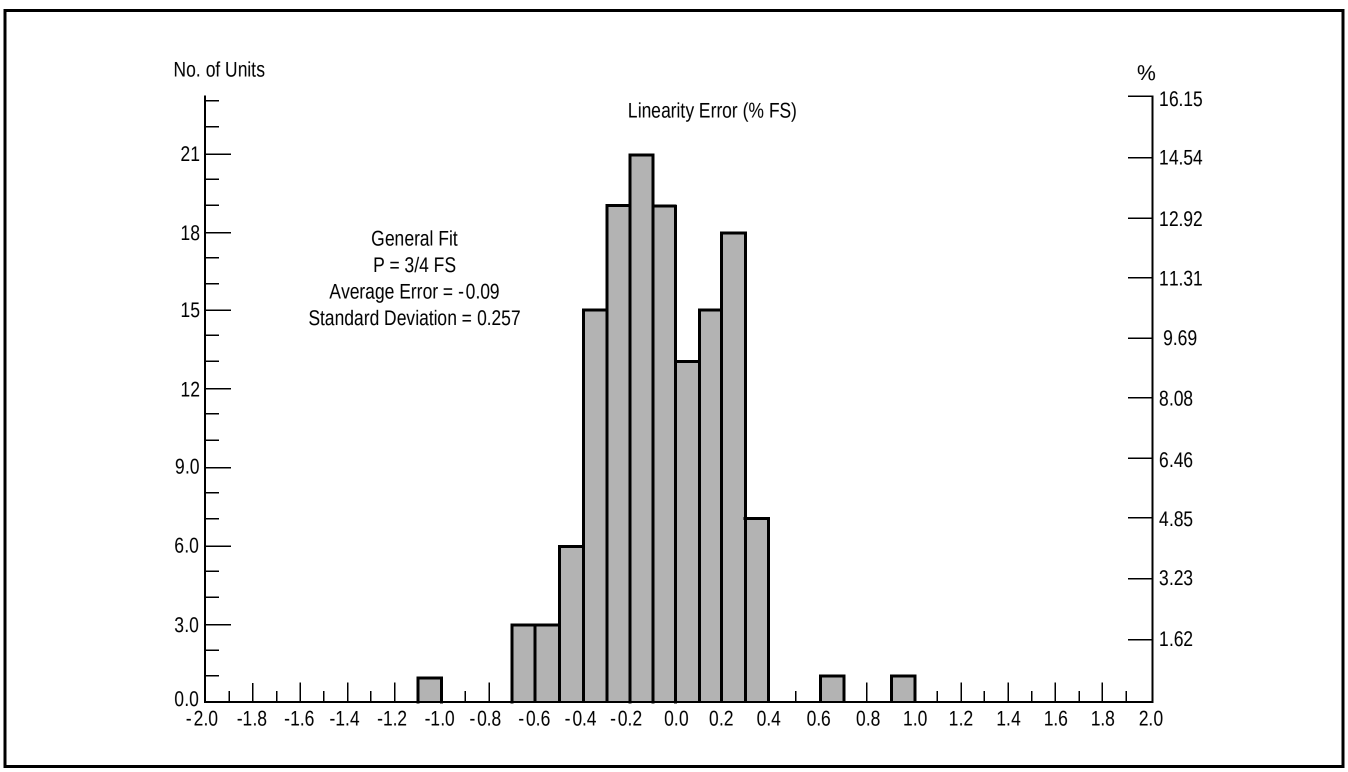


Figure 12. Linearity Error of Piece-Wise Linearity Fit at 3/4 PS

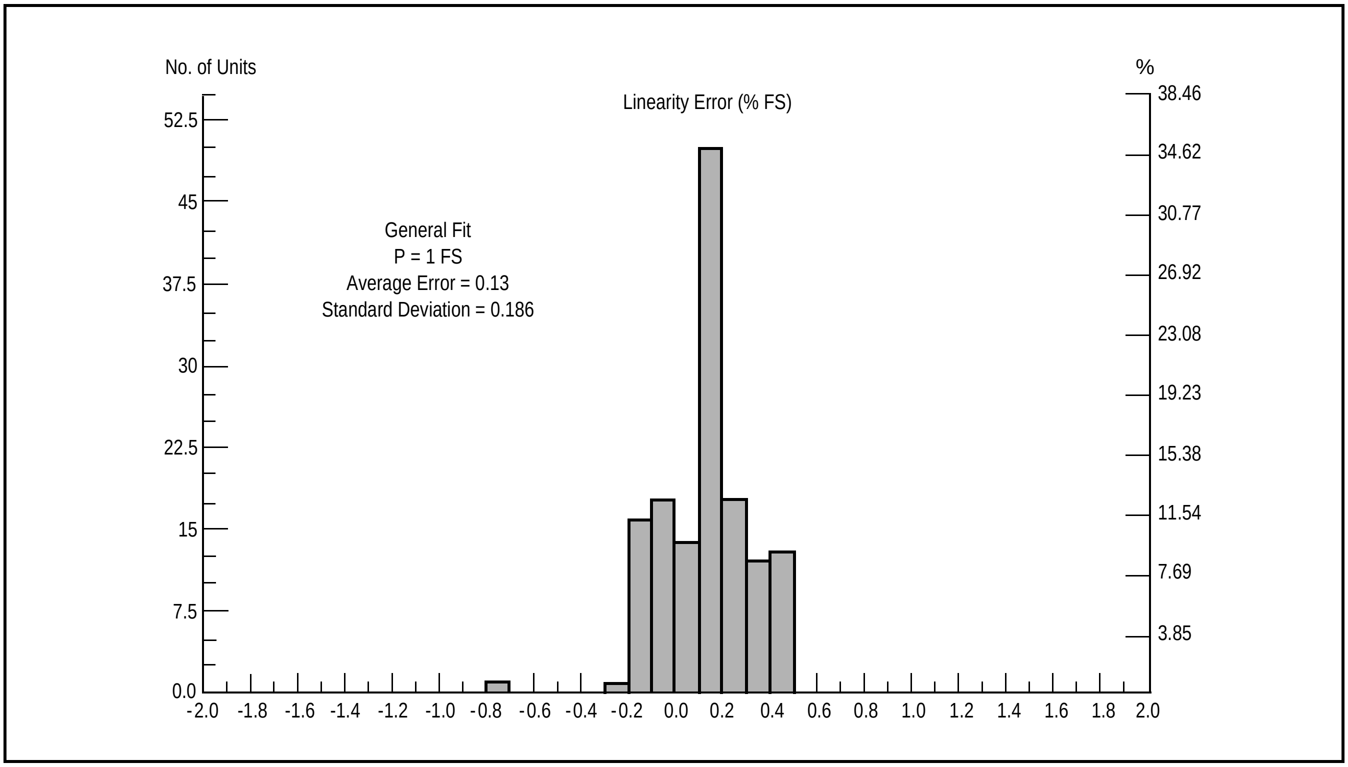


Figure 13. Linearity Error of Piece-Wise Linear Fit at FS

Once the sensitivity coefficients have been determined, a system can then be built that provides an accurate output function with pressure. The system shown in Figure 14 consists of a pressure transducer, a temperature compensation and amplification stage, an A/D converter, a microprocessor, and a display. The display block can be replaced with a control function if required. The A/D converter simply transforms the voltage signal to an input signal for the microprocessor, in which resides the look-up table of the transfer function generated from the previously determined sensitivity coefficients. The microprocessor can then drive a display or control circuit using standard techniques.

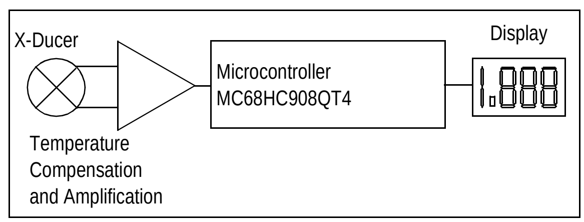


Figure 14. Linearization System Block Diagram

SUMMARY

While at first glance this technique appears to be fairly complicated, it can be a very cost effective method of building a high-accuracy, high-sensitivity pressure-monitoring system for low-pressure ranges.

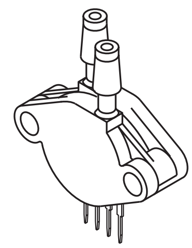
AN936
Rev 4, 05/2005

Mounting Techniques, Lead Forming, and Testing of the MPX Series Pressure Sensors

by: **Randy Frank**

INTRODUCTION

The Freescale Semiconductor, Inc. MPX series pressure sensors are silicon piezoresistive strain-gauges offered in a chip-carrier package (see Figure 1). The exclusive chip-carrier package was developed to realize the advantages of high-speed, automated assembly and testing. In addition to high volume availability and low cost, the chip-carrier package offers users a number of packaging options. This application note describes several mounting techniques, offers lead forming recommendations, and suggests means of testing the MPX series of pressure sensors.



Differential Port Option
Case 344C-01

Figure 1. MPX Pressure Sensor in Chip Carrier Package Shown with Port Options

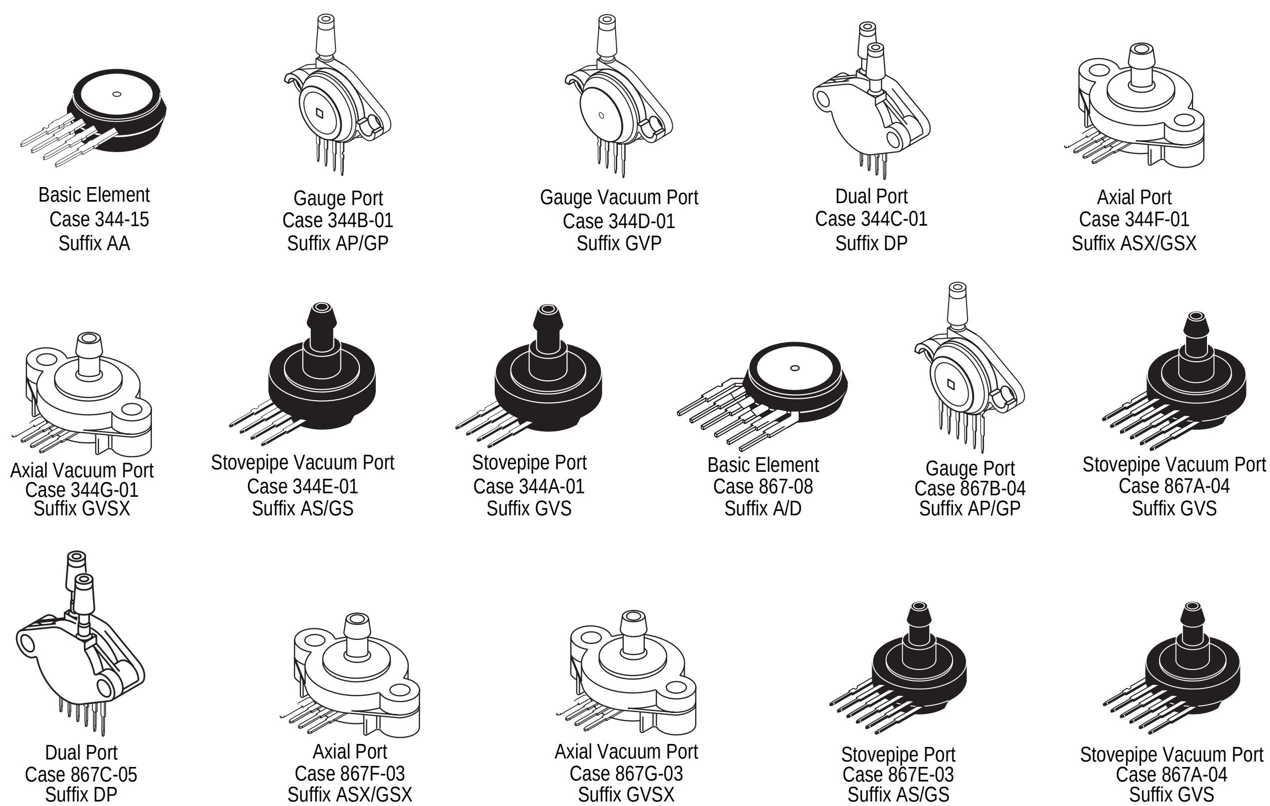


Figure 2. Chip Carrier and Available Ported Packages

PORT ADAPTERS

Available Packages

Freescale's chip-carrier package and available ports for attachment of 1/8ð I.D. hose are made from a high temperature thermoplastic that can withstand temperature extremes from -50°C to 150°C (see Figure 2). The port adapters were designed for rivet or 5/32″ screw attachment to panels, printed circuit boards, or chassis mounting.

Custom Port Adaptor Installation Techniques

The MPX silicon pressure sensor is available in a basic chip carrier cell which is adaptable for attachment to customer-specific housings/ports (Case 344 for 4-pin devices and Case 867 for 6-pin devices). The basic cell has chamfered shoulders on both sides which will accept an O-ring such as Parker Seal's silicone O-ring (p/n#2-015-S-469-40). Refer to Figure 3 for the recommended O-ring to sensor cell interface dimensions.

The sensor cell may also be glued directly to a custom housing or port using many commercial grade epoxies or RTV adhesives which adhere to grade Valox 420, 30 percent glass reinforced polyester resin plastic or Union Carbide's Udel® polysulfone (MPX2300DT1 only). Freescale recommends using Thermoset EP530 epoxy or an equivalent. The epoxy should be dispensed in a continuous bead around the case-to-port interface shoulder. Refer to Figure 4. Care must be taken to avoid gaps or voids in the adhesive bead to help ensure that a complete seal is made when the cell is joined to the port. The recommended cure conditions for Thermoset EP539 are 15 minutes at 150°C. After cure, a simple test for gross leaks should be performed to ensure the integrity of the cell to port bond. Submerging the device in water for five seconds with full rated pressure applied to the port nozzle and checking for air bubbles will provide a good indication.

TESTING MPX SERIES PRESSURE SENSORS

Pressure Connection

Testing of pressure sensing elements in the chip carrier package can be performed easily by using a clamping fixture which has an O-ring seal to attach to the beveled surface. Figure 8 shows a diagram of the fixture that Freescale uses to apply pressure or vacuum to unported elements.

When performing tests on packages with ports, a high durometer tubing is necessary to minimize leaks, especially in higher pressure range sensors. Removal of tubing must be parallel to the port since large forces can be generated to the pressure port which can break the nozzle if applied at an angle. Whether sensors are tested with or without ports, care must be exercised so that force is not applied to the back metal cap or offset errors can result.

STANDARD PORT ATTACH CONNECTION

Freescale also offers standard port options designed to accept readily available silicone, vinyl, nylon, or polyethylene tubing for the pressure connection. The inside dimension of the tubing selected should provide a snug fit over the port nozzle. Installation and removal of tubing from the port nozzle must be parallel to the nozzle to avoid undue stress which may break the nozzle from the port base. Whether sensors are used with Freescale's standard ports or customer specific housings, care must be taken to ensure that force is uniformly distributed to the package or offset errors may be induced.

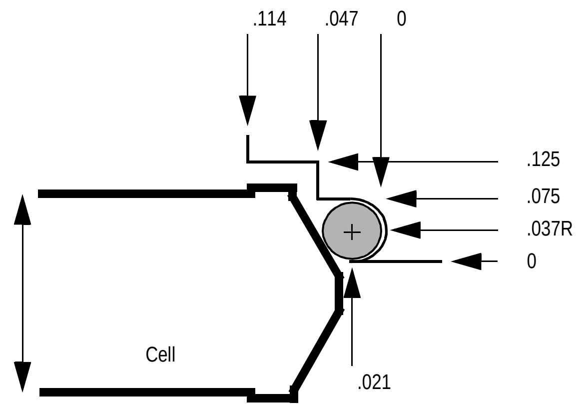


Figure 3. Examples of Sensors in Custom Housings

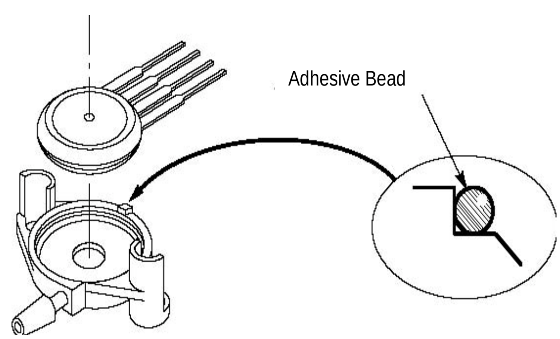


Figure 4. Case to Port Interface

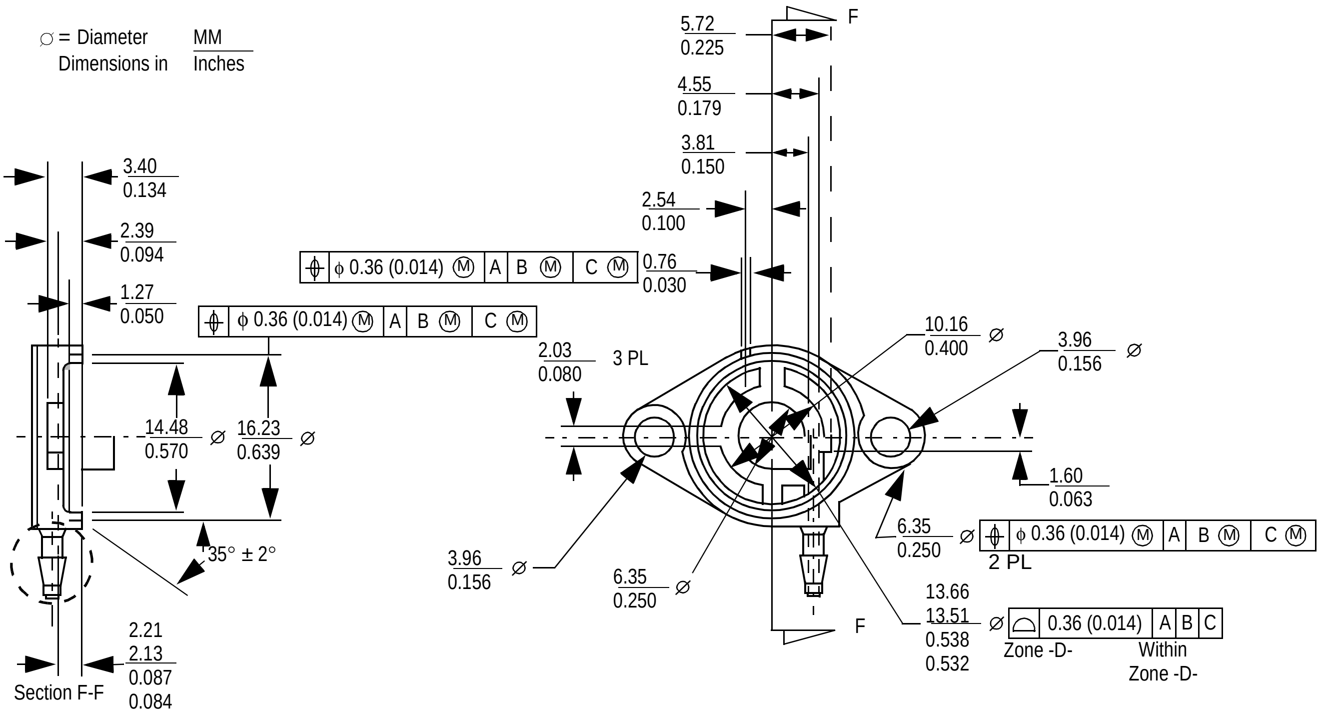
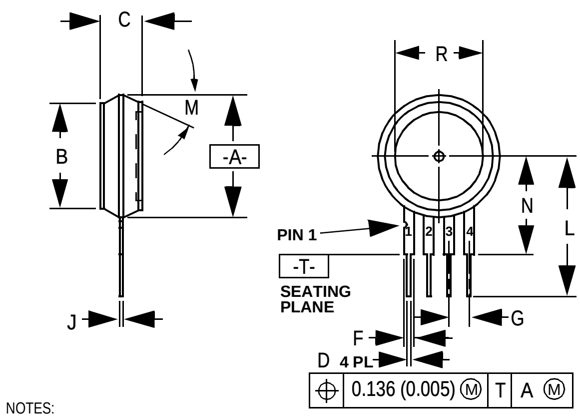


Figure 5. Port Adapter Dimensions



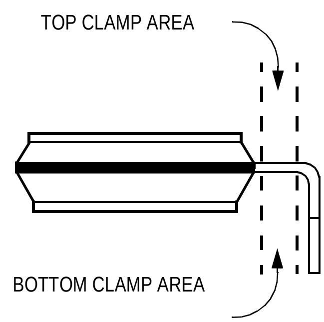
NOTES:
DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
CONTROLLING DIMENSION: INCH.
DIMENSION -A- IS INCLUSIVE OF THE MOLD STOP RING. MOLD STOP RING NOT TO EXCEED 16.00 (0.630).

STYLE 1:
PIN 1.GROUND
2.+ OUTPUT
3.+ SUPPLY
4.- OUTPUT

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.595	0.630	15.11	16.00
B	0.514	0.534	13.06	13.56
C	0.200	0.220	5.08	5.59
D	0.016	0.020	0.41	0.51
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.40
L	0.695	0.725	17.65	18.42
M	30	NOM	30	NOM
N	0.475	0.495	12.07	12.57
R	0.430	0.450	10.92	11.43

Case 344-15
All seals to be made on pressure sealing surface.

Figure 6. Chip-Carrier Package



Leads should be securely clamped top and bottom in the area between the plastic body and the form being sure that no stress is being put on plastic body. The area between dotted lines represents surfaces to be clamped.

Figure 7. Leadforming

Electrical Connection

The MPX series pressure sensor is designed to be installed on a printed circuit board (standard 0.100″ lead spacing) or to accept an appropriate connector if installed on a baseplate. The leads of the sensor may be formed at right angles for assembly to the circuit board, but one must ensure that proper leadform techniques and tools are employed. Hand or "needlenose" pliers should never be used for leadforming unless they are specifically designed for that purpose. Refer to Figure 7 for the recommended leadform technique. It is also important that once the leads are formed, they should not be straightened and reformed without expecting reduced durability. The recommended connector for off-circuit board applications may be supplied by JST Corp. (1-800-292-4243) in Mount Prospect, IL. The part numbers for the housing and pins are listed below.

CONCLUSION

Freescale's MPX series pressure sensors in the chip carrier package provide the design engineer several packaging alternatives. They can easily be tested with or without pressure ports using the information provided.

CONNECTORS FOR CHIP CARRIER PACKAGES

MFG/Address/Phone	Connector	Pin
J. S. Terminal Cop.	4 Pin Housing: SMP-04V-BCS	SHF-001T-0.8SS
1200 Business Center Dr.	6 Pin Housing: SMP-06V-BC	SHF-01T-0.8SS
Mount Prospect, IL 60056		
(800) 292-4243	Hand Crimper YC-12 Recommended	
Methode Electronics, Inc.	1300-004	1400-213
Rollling Meadows, IL 60008		1402-213
(312) 392-3500	Requires Hand Crimper	1402-214 Reel

TERMINAL BLOCKS

Molex	22-18-2043
2222 Wellington Court	22-16-2041
Lisle, IL 60532	
(312) 969-4550	
Samtec	SSW-104-02-G-S-RA
P.O. Box 1147	SSW-104-02-G-S
New Albany, IN 47150	
(812) 944-6733	

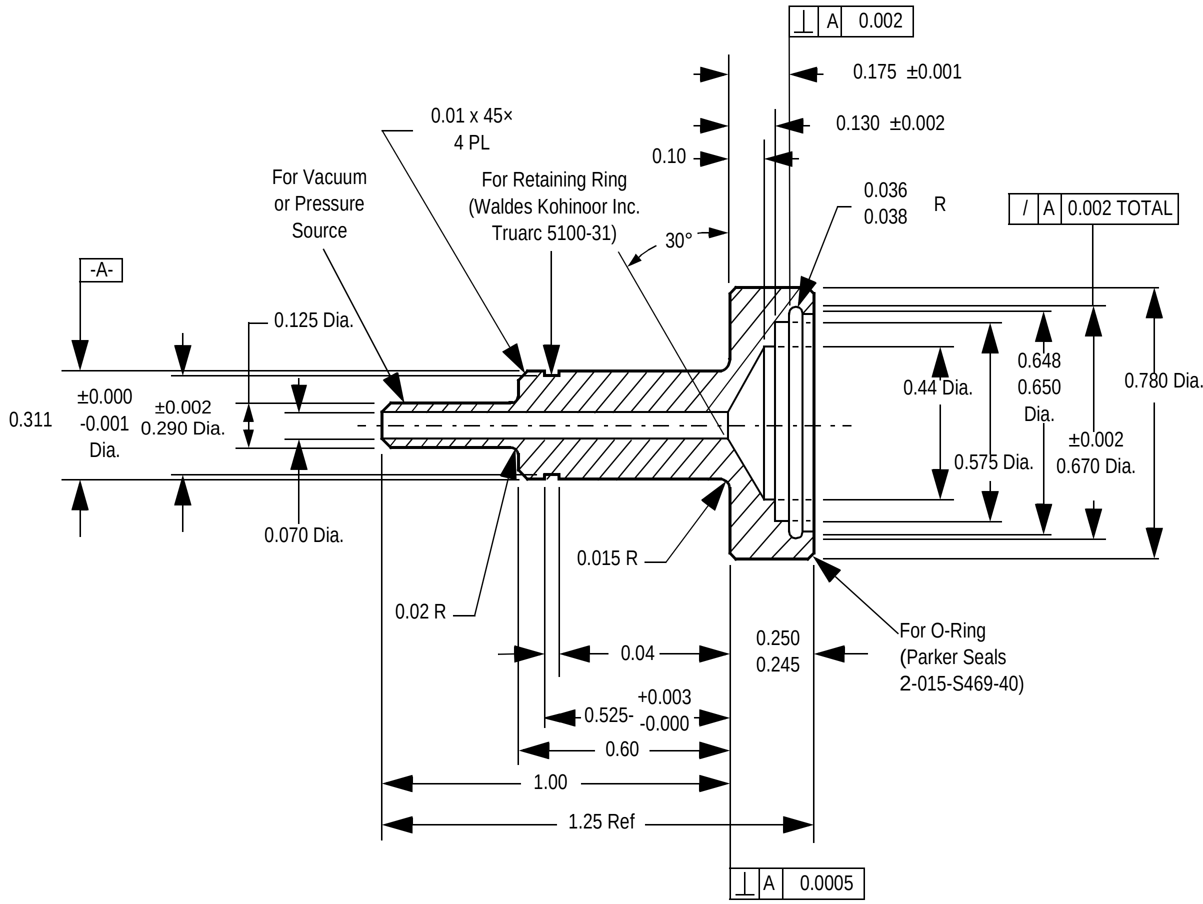


Figure 8. O-Ring Test Fixture

AN1082
Rev 4, 05/2005

Simple Design for a 4-20 mA Transmitter Interface Using a Pressure Sensor

by: Jean Claude Hamelain
Toulouse Application Lab Manager

INTRODUCTION

Pressure is a very important parameter in most industrial applications such as air conditioning, liquid level sensing and flow control.

In most cases, the sensor is located close to the measured source in a very noisy environment, far away from the receiver (recorder, computer, automatic controller, etc.)

The transmission line can be as long as a few hundred meters and is subject to electromagnetic noise when the signal is transmitted as voltage. If the signal is transmitted as a current it is easier to recover at the receiving end and is less affected by the length of the transmission line.

The purpose of this note is to describe a simple circuit which can achieve high performance, using standard pressure sensors, operational amplifiers and discrete devices.

PERFORMANCES

The following performances have been achieved using an MPXV2102DP pressure sensor and an MC33079 quad operational amplifier. The MPXV2102DP is a 100 kPa temperature compensated differential pressure sensor. The load is a 150 ohm resistor at the end of a 50 meter telephone line. The 15 volt power supply is connected at the receiver end.

Power Supply	+15 Vdc, 30 mA
Connecting Line	3 wire telephone cable
Load Resistance	150 to 400 Ohms
Temperature Range	-40 to +85°C (up to +125°C with special hardware)
Pressure Range	0 to 100 kPa
Total Maximum Error	Better than 2% full scale

Basic Circuit

The MPXV2102DP pressure sensor is a very high performance piezoresistive pressure sensor. Manufacturing technologies include standard bipolar processing techniques with state of the art metallization and on-chip laser trim for offset and temperature compensation.

This unique design, coupled with computer laser trimming, gives this device excellent performance at competitive cost for demanding applications such as automotive, industrial or healthcare.

MC33078, 79 operational amplifiers are specially designed for very low input voltage, a high output voltage swing and very good stability versus temperature changes.

First Stage

The MPXV2102 and the operational amplifier are directly powered by the 15 Vdc source. The first stage is a simple true differential amplifier made with both of the operational amplifiers in the MC33078. The potentiometer, R_G, provides adjustment for the output.

Current Generator

The voltage to current conversion is made with a unity gain differential amplifier, one of the four operational amplifiers in an MC33079. The two output connections from the first stage are connected to the input of this amplifier through R3 and R5. Good linearity is achieved by the matching between R3, R4, R5 and R6, providing a good common mode rejection. For the same reason, a good match between resistors R8 and R9 is needed.

The MC33078 or MC33079 has a limited current output; therefore, a 2N2222 general purpose transistor is connected as the actual output current source to provide a 20 mA output.

To achieve good performance with a very long transmission line it may be necessary to place some capacitors (C1, C2) between the power supply and output to prevent oscillations.

Calibration

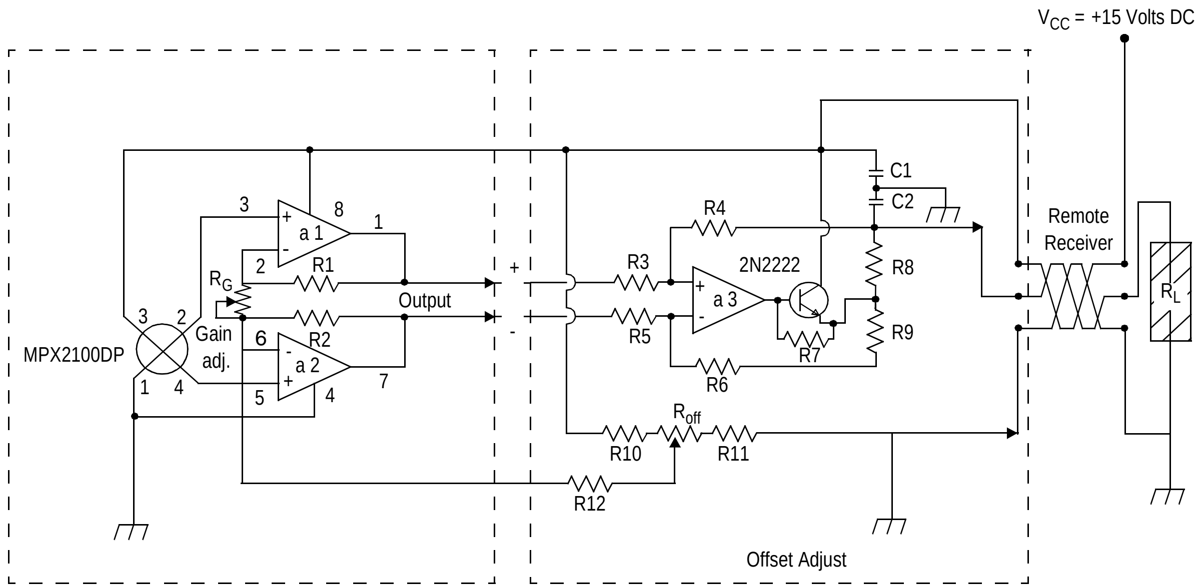
The circuit is electrically connected to the 15 Vdc power supply and to the load resistor (receiver).

The high pressure is connected to the pressure port and the low pressure (if using a differential pressure sensor), is connected to the vacuum port.

It is important to perform the calibration with the actual transmission line connected.

The circuit needs only two adjustments to achieve the 4-20 mA output current.

1. With no pressure (zero differential pressure), adjust R_{off} to read exactly 4 mA on the receiver.
2. Under the full scale pressure, adjust R_G to exactly read 20 mA on the receiver. The calibration is now complete.



Basic Circuit of SEK-1

Additional Circuit for 4 to 20 mA Current Loop
(Receiver Load Resistance: R_L = 150 to 400 Ohms)

R_G = 47 K Pot.	R7 = 1 K	Note A: If using SEK-1 a1, a2, a3 = 1/2 MC33078
R_{off} = 1 M Pot.	R10 = 110 K	R_G from 20 K to 47 K
* R1 = R2 = 330 K	R11 = 1 M	R1 and R2 from 1M to 330 K
* R3 = R4 = 27 K	R12 = 330 K	
* R5 = R6 = 27 K	C1 = C2 = 0.1 μF	
* R8 = R9 = 150	a1, a2, a3 = 1/4 MC33079	

* All resistor pairs must be matched at better than 0.5%

NOTE: The pressure sensor output is ratiometric to the power supply voltage. The output will change with the same ratio as voltage change.

Figure 1. Demo Kit with 4-20 mA Current Loop

The output is ratiometric to the power supply voltage. For example, if the receiver reads 18 mA at 80 kPa and 15 V power supply, the receiver should read 16.8 mA under the same pressure with 14 V power supply.

For best results it is mandatory to use a regulated power supply. If that is not possible, the circuit must be modified by inserting a 12 V regulator to provide a constant supply to the pressure sensor.

When using a MC78L12AC voltage regulator, the circuit can be used with power voltage variation from 14 to 30 volts.

The following results have been achieved using an MPX2100DP and two MC33078s. The resistors were regular carbon resistors, but pairs were matched at ±0.3% and capacitors were 0.1 μF. The load was 150 ohms and the transmission line was a two pair telephone line with the +15 Vdc power supply connected on the remote receiver side.

Note: Best performances in temperature can be achieved using metal film resistors. The two potentiometers must be chosen for high temperatures up to 125°C.

The complete circuit with pressure sensor is available under reference TZA120 and can be ordered as a regular product for evaluation.

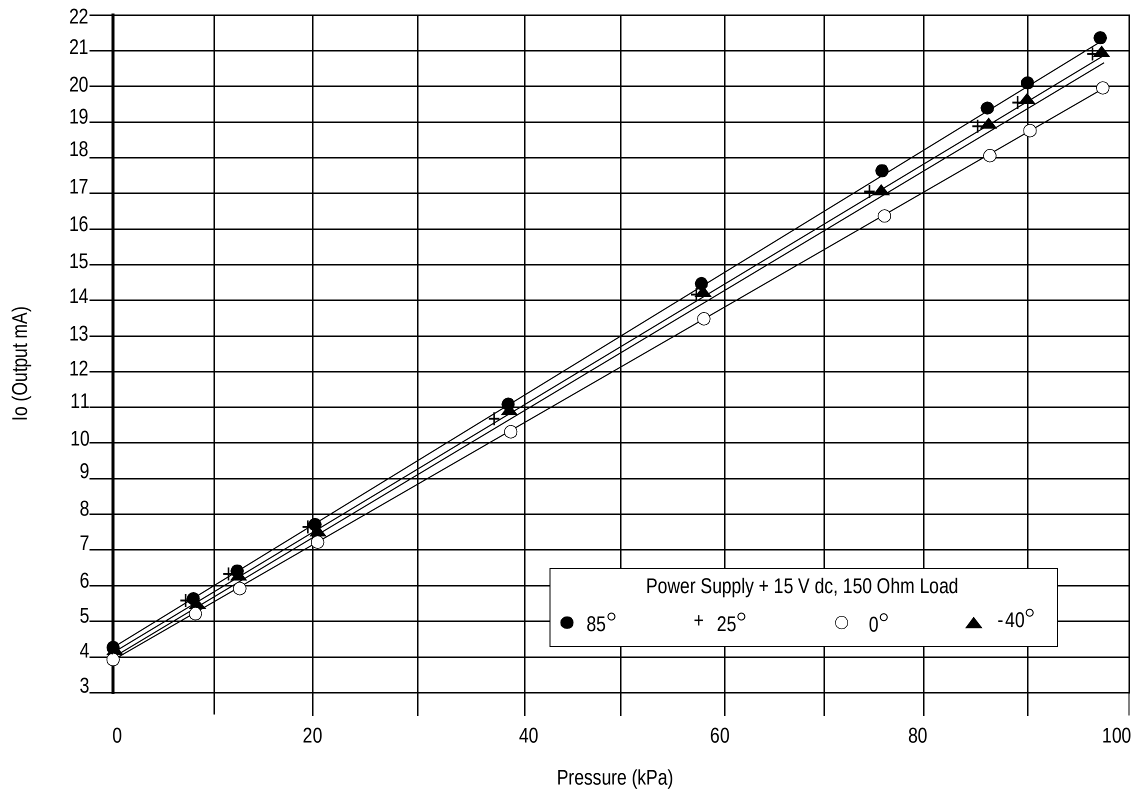


Figure 2. Output versus Pressure

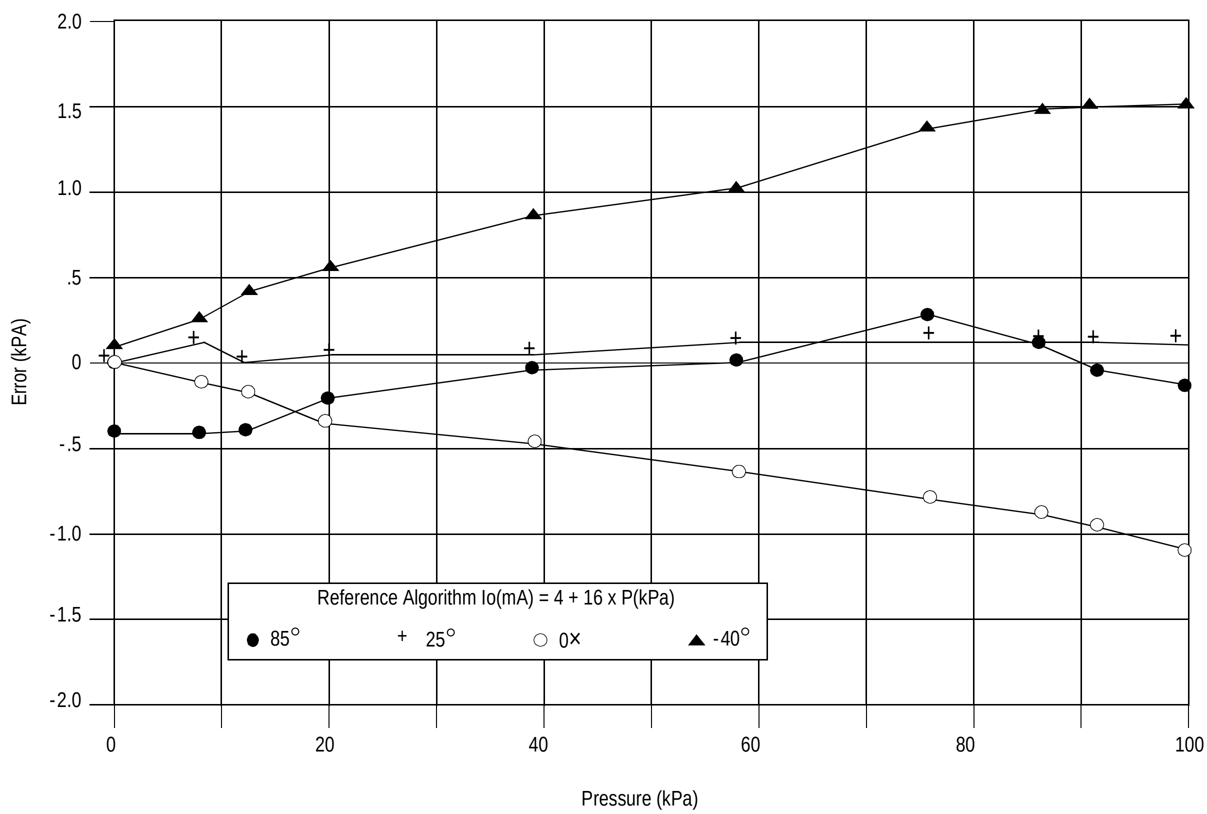


Figure 3. Absolute Error Reference to Algorithm

Calibration-Free Pressure Sensor System

by: Michel Burri, Senior System Engineer
Geneva, Switzerland

INTRODUCTION

The MPX2000 series pressure transducers are semiconductor devices which give an electrical output signal proportional to the applied pressure. The sensors are a single monolithic silicon diaphragm with strain gauge and thin-film resistor networks on the chip. Each chip is laser trimmed for full scale output, offset, and temperature compensation.

The purpose of this document is to describe another method of measurement which should facilitate the life of the design. The MPX2000 series sensors are available both as unported elements and as ported assemblies suitable for pressure, vacuum and differential pressure measurements in the range of 10 kPa through 200 kPa.

The use of the on-chip A/D converter of the MC68HC05B6 HCMOS MCU makes possible the design of an accurate and reliable pressure measurement system.

SYSTEM ANALYSIS

The measurement system is made up of the pressure sensor, the amplifiers, and the MCU. Each element in the chain has its own device-to-device variations and temperature effects which should be analyzed separately. For instance, the 8-bit A/D converter has a quantization error of about ±0.2 percent. This error should be subtracted from the maximum error specified for the system to find the available error for the rest of elements in the chain. The MPX2000 series pressure sensors are designed to provide an output sensitivity of 4.0 mV/V excitation voltage with full-scale pressure applied or 20 mV at the excitation voltage of 5.0 V_{DC}.

An interesting property must be considered to define the configuration of the system: the ratiometric function of both the A/D converter and the pressure sensor device. The ratiometric function of these elements makes all voltage variations from the power supply rejected by the system. With this advantage, it is possible to design a chain of amplification where the signal is conditioned in a different way.

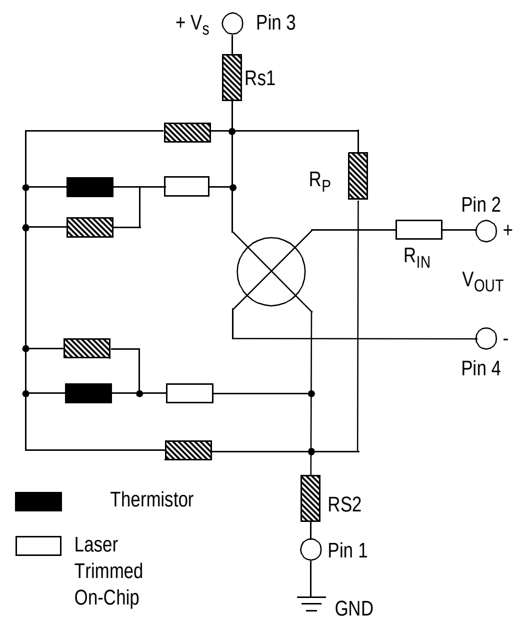


Figure 1. Seven Laser-Trimmed Resistors and Two Thermistors Calibrate the Sensor for Offset, Span, Symmetry and Temperature Compensation

The op amp configuration should have a good common-mode rejection ratio to cancel the DC component voltage of the pressure sensor element which is about half the excitation voltage value V_S. Also, the op amp configuration is important when the designer's objective is to minimize the calibration procedures which cost time and money and often don't allow the unit-to-unit replacement of devices or modules.

One other aspect is that most of the applications are not affected by inaccuracy in the region from 0 kPa to 40 kPa. Therefore, the goal is to obtain an acceptable tolerance of the system from 40 kPa through 100 kPa, thus minimizing the inherent offset voltage of the pressure sensor.

PRESSURE SENSOR CHARACTERISTICS

Figure 2 shows the differential output voltage of the MPX2100 series at +25°C. The dispersion of the output voltage determines the best tolerance that the system may achieve without undertaking a calibration procedure, if any other elements or parameters in the chain do not introduce additional errors.

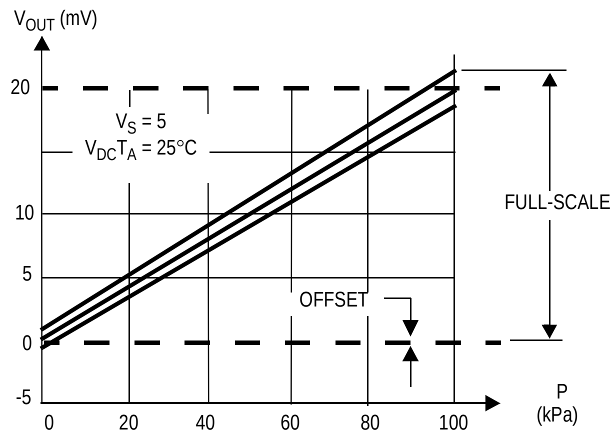


Figure 2. Spread of the Output Voltage versus the Applied Pressure at 25°C

The effects of temperature on the full scale output and offset are shown in Figure 3. It is interesting to notice that the offset variation is greater than the full scale output and both have a positive temperature coefficient respectively of +8.0 µV/degree and +5.0 µV excitation voltage. That means that the full scale variation may be compensated by modifying the gain somewhere in the chain amplifier by components arranged to produce a negative T_C of 250 PPM/°C. The dark area of Figure 3 shows the trend of the compensation which improves the full scale value over the temperature range. In the area of 40 kPa, the compensation acts in the ratio of 40/100 of the value of the offset temperature coefficient.

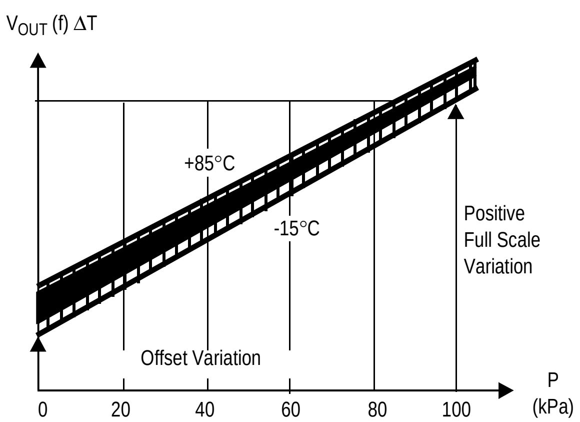


Figure 3. Output Voltage versus Temperature. The Dark Area Shows the Trend of the Compensation

OP AMP CHARACTERISTICS

For systems with only one power supply, the instrument amplifier configuration shown in Figure 4 is a good solution to monitor the output of a resistive transducer bridge.

The instrument amplifier does provide an excellent CMRR and a symmetrical buffered high input impedance at both non-inverting and inverting terminals. It minimizes the number of the external passive components used to set the gain of the amplifier. Also, it is easy to compensate the temperature variation of the Full Scale Output of the Pressure Sensor by implementing resistors "R_f" having a negative coefficient temperature of -250 PPM/°C.

The differential-mode voltage gain of the instrument amplifier is:

$$Avd = \frac{V1-V2}{Vs2-Vs4} = \left(1 + \frac{2\,R_f}{R_g}\right) \quad (1)$$

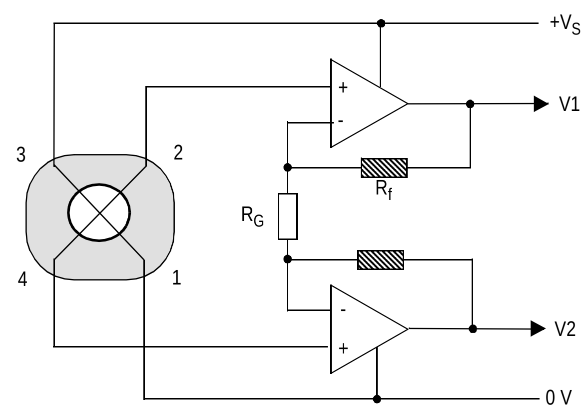


Figure 4. One Power Supply to Excite the Bridge and to Develop a Differential Output Voltage

The major source of errors introduced by the op amp is offset voltages which may be positive or negative, and the input bias current which develops a drop voltage ΔV through the feedback resistance R_f. When the op amp input is composed of PNP transistors, the whole characteristic of the transfer function is shifted below the DC component voltage value set by the Pressure Sensor as shown in Figure 5.

The gain of the instrument amplifier is calculated carefully to avoid a saturation of the output voltage, and to provide the maximum of differential output voltage available for the A/D Converter. The maximum output swing voltage of the amplifiers is also dependent on the bias current which creates a ΔV voltage on the feedback resistance R_f and on the Full Scale output voltage of the pressure sensor.

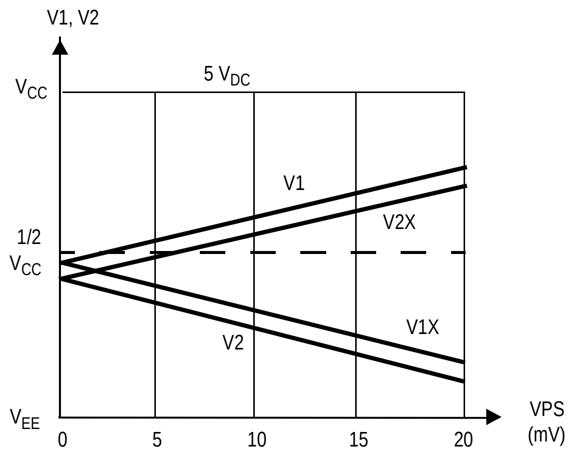


Figure 5. Instrument Amplifier Transfer Function with Spread of the Device to Device Offset Variation

Figure 5 shows the transfer function of different instrument amplifiers used in the same application. The same sort of random errors are generated by crossing the inputs of the instrument amplifier. The spread of the differential output voltage (V1-V2) and (V2x-V1x) is due to the unsigned voltage offset and its absolute value. Figure 6 and Figure 7 show the unit-to-unit variations of both the offset and the bias current of the dual op amp MC33078.

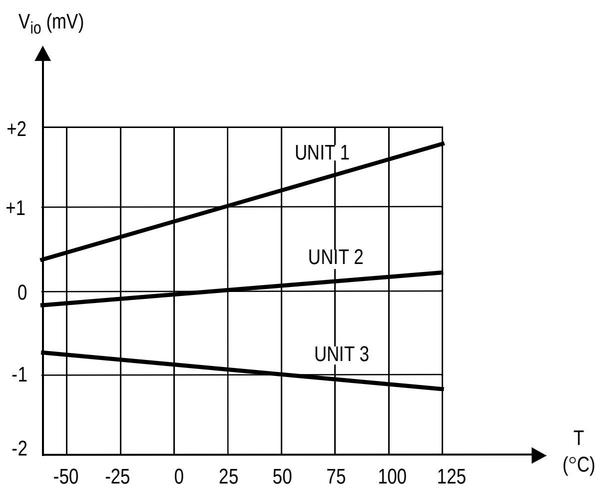


Figure 6. Input Offset Voltage versus Temperature

To realize such a system, the designer must provide a calibration procedure which is very time consuming. Some extra potentiometers must be implemented for setting both the offset and the Full Scale Output with a complex temperature compensation network circuit.

The new proposed solution will reduce or eliminate any calibration procedure.

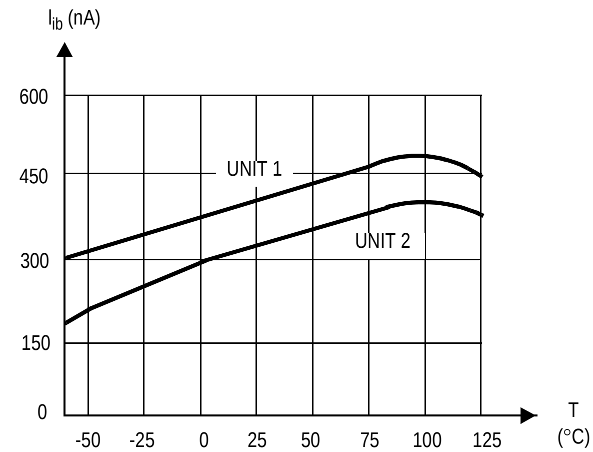


Figure 7. Input Bias Current versus Temperature

MCU CONTRIBUTION

As shown in Figure 5, crossing the instrument amplifier inputs generated their mutual differences which can be computed by the MCU.

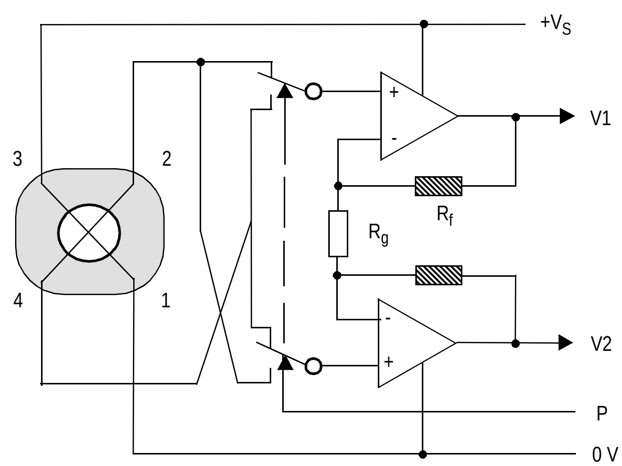


Figure 8. Crossing of the Instrument Amplifier Input Using a Port of the MCU

Figure 8 shows the analog switches on the front of the instrument amplifier and the total symmetry of the chain. The residual resistance $R_{DS(on)}$ of the switches does not introduce errors due to the high input impedance of the instrument amplifier.

With the aid of two analog switches, the MCU successively converts the output signals V1, V2.

Four conversions are necessary to compute the final result. First, two conversions of V1 and V2 are executed and stored in the registers R1, R2. Then, the analog switches are commuted in the opposite position and the two last conversions of $V2_x$ and V1x are executed and stored in the registers $R2_x$ and R1x. Then, the MCU computes the following equation:

RESULT = (R1-R2) + (R2x-R1x) (2)

The result is twice a differential conversion. As demonstrated below, all errors from the instrument amplifier are cancelled. Other averaging techniques may be used to improve the result, but the appropriated algorithm is always determined by the maximum bandwidth of the input signal and the required accuracy of the system.

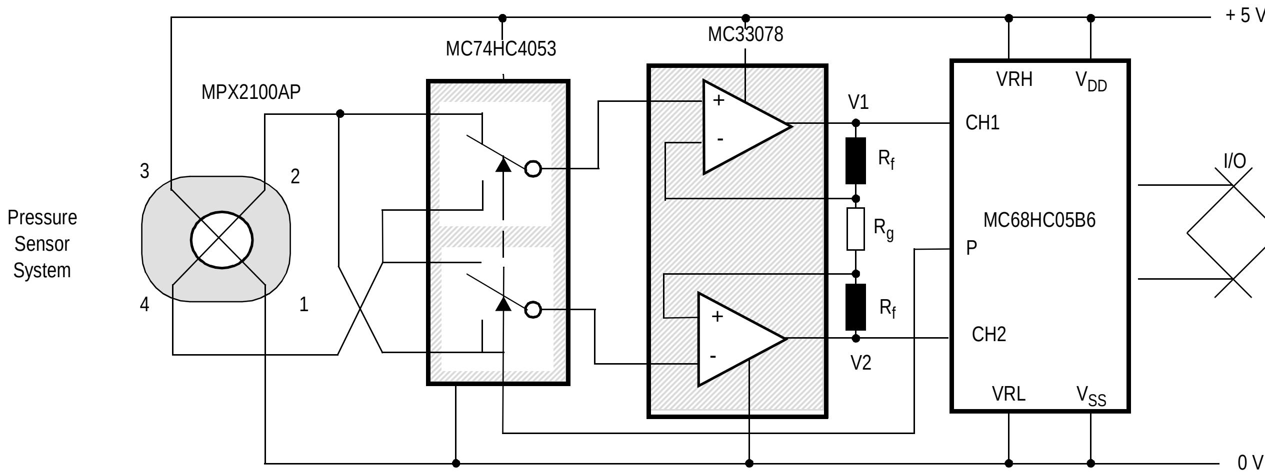


Figure 9. Two Channel Input and One Output Port Are Used by the MCU

SYSTEM CALCULATION

Sensor out 2
Vs2 = a (P) + of2

Sensor out 4
Vs4 = b (P) + of4

Amplifier out 1
V1 = Avd (Vs2 + OF1)

Amplifier out 2
V2 = Avd (Vs4 + OF2)

Inverting of the amplifier input
V1x = Avd (Vs4 + OF1) V2x = Avd (Vs2 + OF2)

Delta = V1-V2 1st differential result
= Avd * (Vs2 of OF1) - Avd * (Vs4 + OF2)

Deltax = V2x-V1x 2nd differential result
= Avd * (Vs2 + OF2) - Vdc * (Vs4 + OF1)

Adding of the two differential results

VoutV = Delta + Deltax
= Avd*Vs2 + Avd*OF2 + Avd*OF2 - Avd*OF1
+ Avd*OF1 - Avd*OF2 + Avd*OF2 - Avd*OF1
= 2 * Avd * (Vs2 -Vs4)
= 2 * Avd * [(a (P) + of2) - (b (P) + of4)]
= 2 * Avd * [V(P) + Voffset]

There is a full cancellation of the amplifier offset OF1 and OF2. The addition of the two differential results V1-V2 and V2x-V1X produce a virtual output voltage VoutV which becomes the applied input voltage to the A/D converter. The result of the conversion is expressed in the number of counts or bits by the ratiometric formula shown below:

$$\text{count} = \text{VoutV} * \frac{255}{\text{VRH-VRL}}$$

255 is the maximum number of counts provided by the A/D converter and VRH-VRL is the reference voltage of the ratiometric A/D converter which is commonly tied to the 5.0 V supply voltage of the MCU.

When the tolerance of the full scale pressure has to be in the range of ± 2.5 percent, the offset of the pressure sensor may be neglected. That means the system does not require any calibration procedure.

The equation of the system transfer is then:

count = 2 * Avd * V(P) * 51/V where:

Avd is the differential-mode gain of the instrument amplifier which is calculated using the equation (1). Then with R_f = 510 kΩ and R_g = 9.1 kΩ Avd = <u>113</u>.

The maximum counts available in the MCU register at the Full Scale Pressure is:

count (Full Scale) = 2 * 113 * 0.02 V * 51/V = <u>230</u>

knowing that the MPX2100AP pressure sensor provides 20 mV at 5.0 excitation voltage and 100 kPa full scale pressure.

The system resolution is 100 kPa/230 that give 0.43 kPa per count.

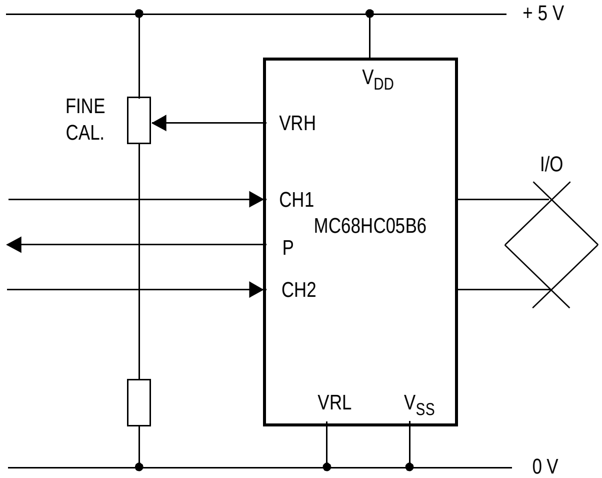


Figure 10. Full Scale Output Calibration Using the Reference Voltage VRH-VRL

When the tolerance of the system has to be in the range of ±1percent, the designer should provide only one calibration procedure which sets the Full Scale Output (counts) at 25°C 100 kPa or under the local atmospheric pressure conditions.

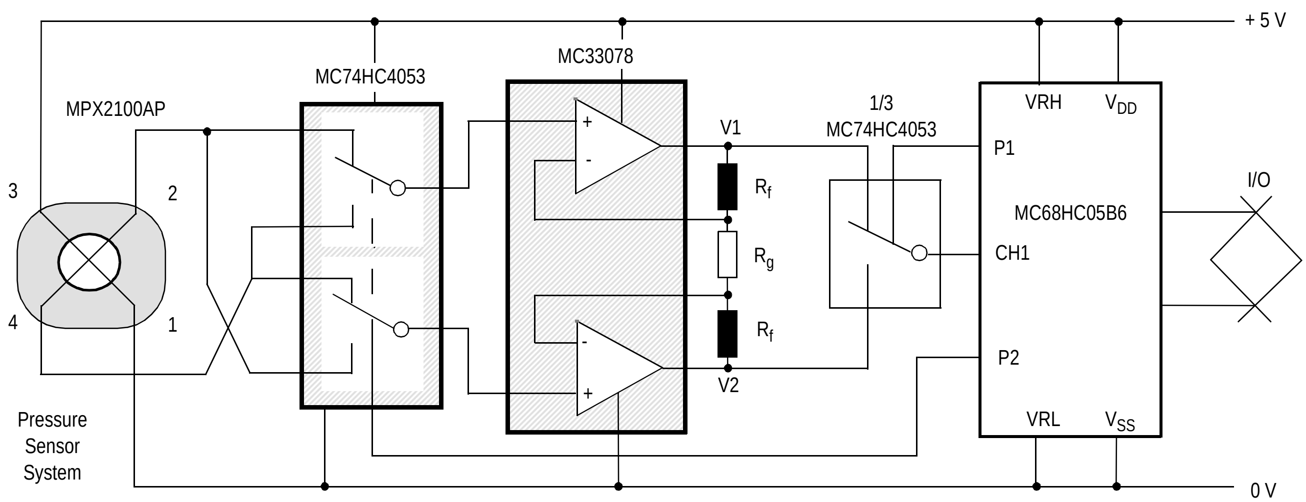


Figure 11. One Channel Input and Two Output Ports are used by the MCU

Due to the high impedance input of the A/D converter of the MC68HC05B6 MCU, another configuration may be implemented which uses only one channel input as shown in Figure 11. It is interesting to notice that practically any dual op amp may be used to do the job but a global consideration must be made to optimize the total cost of the system according to the requested specification.

When the Full Scale Pressure has to be sent with accuracy, the calibration procedure may be executed in different ways. For instance, the module may be calibrated directly using Up/Down push buttons.

The gain of the chain is set by changing the VRH voltage of the ratiometric A/D converter with the R/2R ladder network circuit which is directly driven by the ports of the MCU. (See Figure 12.)

Using a communication bus, the calibration procedure may be executed from a host computer. In both cases, the setting value is stored in the EEPROM of the MCU.

The gain may be also set using a potentiometer in place of the resistor R_f. But, this component is expensive, taking into account that it must be stable over the temperature range at long term.

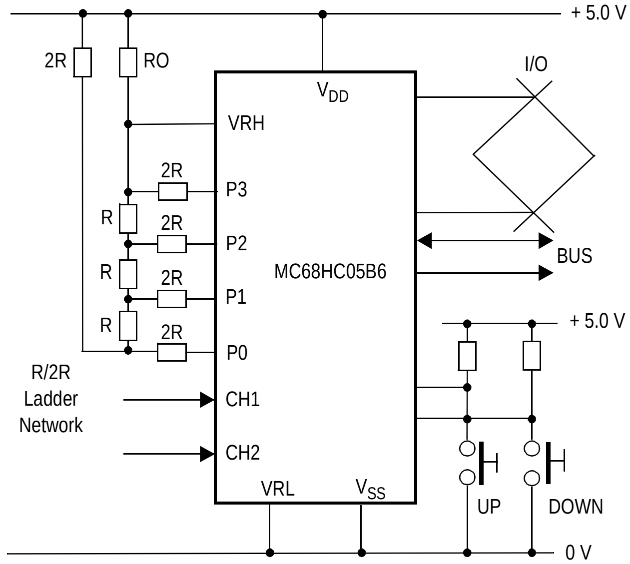


Figure 12. R/2R Ladder Network for an MCU

Table 1. Pressure Conversion Table

Unity	Pa	mbar	Torr	atm	at=kp/cm^2	mWS	psi
1 N/m2 = 1 Pascal	1	0.01	7.5 10-3	-	-	-	-
1 mbar	100	1	0.75	-	-	0.0102	0.014
1 Torr = 1 mmHg	133.32	1.333	.1	-	-	-	0.019
1 atm (1)	101325	1013.2	760	1	1.033	10.33	14.69
1 at = 1 kp/cm2(2)	98066.5	981	735.6	0.97	1	10	14.22
1 m of water	9806.65	98.1	73.56	0.097	0.1	1	1.422
1 lb/sqin = 1 psi	6894.8	68.95	51.71	0.068	-	-	1

NOTES:
1. Normal atmosphere
2. Technical atmosphere

Freescale Semiconductor
Technical Data

AN1100
Rev 3, 05/2005

Analog to Digital Converter Resolution Extension Using a Pressure Sensor

PURPOSE

This paper describes a simple method to gain more than 8-bits of resolution with an 8-bit A/D. The electronic design is relatively simple and uses standard components.

Principle

Consider a requirement to measure pressure up to 200 kPa. Using a pressure sensor and an amplifier, this pressure can be converted to an analog voltage output. This analog voltage can then be converted to a digital value and used by the microprocessor as shown in Figure 1.

If we assume for this circuit that 200 kPa results in a +4.5 V output, the sensitivity of our system is:/

$$\begin{aligned} S &= 4.5\ \text{V}/200\text{kPa} \\ &= 0.0225\ \text{V/kPa} \\ \text{or}\quad S &= 22.5\ \text{mV/kPa} \end{aligned} \qquad (1)$$

If an 8-bit A/D is used with 0 and 5 Volt low and high references, respectively, then the resolution would be:

$$\begin{aligned} S &= 5\ \text{V}/(2^8 - 1 = 5\text{V}/255) \\ &= 0.01961\ \text{V} \\ \text{or}\quad R_v &= 19.60\ \text{mV per bit} \end{aligned} \qquad (2)$$

This corresponds to a pressure resolution of:

$$\begin{aligned} R_p &= 5\ \text{V}/(19.60\ \text{mV/bit}) / (22.5\ \text{mV/kPa}) \\ &= 0.871\ \text{kPa per bit} \end{aligned} \qquad (3)$$

Assume a resolution of at least 0.1 kPa/bit is needed. This would require an A/D with at least 12 bits ($2^{12} = 4096$ steps).

One can artificially increase the A/D resolution as described below.

Refer to Figure 1 and assume a pressure of 124 kPa is to be measured. With this system, the input signal to the A/D should read (assuming no offset voltage error):

$$\begin{aligned} V_m(\text{measured}) &= 4.5\ (\text{Papp}) \times (S) \\ &= (124\ \text{kPa}) \times (22.5\ \text{mV/kPa}) \\ &= 2790\ \text{mV}, \end{aligned} \qquad (4)$$

where Papp is the pressure applied to the sensor.

Due to the resolution of the A/D, the microprocessor receives the following conversion:

$$\begin{aligned} M &= (2790\ \text{mV}) / (19.60\ \text{mV/bit}) \\ &= 142.35 \\ &= 142\ (\text{truncated to integer}) \end{aligned} \qquad (5)$$

The calculated voltage for this stored value is:

$$\begin{aligned} V_c(\text{calculated}) &= (142\ \text{count}) \times (19.60\text{mV/count}) \\ &= 2783\ \text{mV} \end{aligned} \qquad (6)$$

The microprocessor will output the stored value M to the D/A. The corresponding voltage at the analog output of the D/A, for an 8-bit D/A with same references, will be 2783 mV.

The calculated pressure corresponding to this voltage would be:

$$\begin{aligned} P_c(\text{calculated}) &= (2783\ \text{mV}) / (22.5\ \text{mV/kPa}) \\ &= 123.7\ \text{kPa} \end{aligned} \qquad (7)$$

Thus, the error would be:

$$\begin{aligned} E &= \text{Papp} - \text{Pc} \\ &= 124\ \text{kPa} - 123.7\ \text{kPa} \\ &= 0.3\ \text{kPa} \end{aligned} \qquad (8)$$

This is greater than the 0.1 kPa resolution requirement.

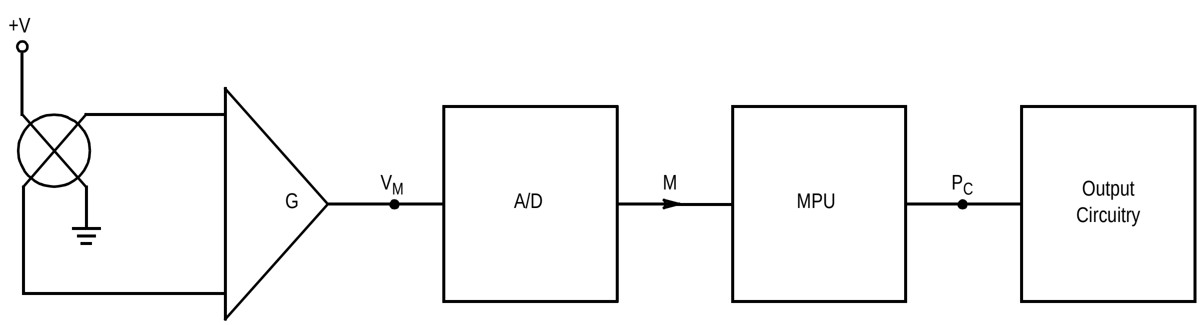


Figure 1. Figure Block Diagram

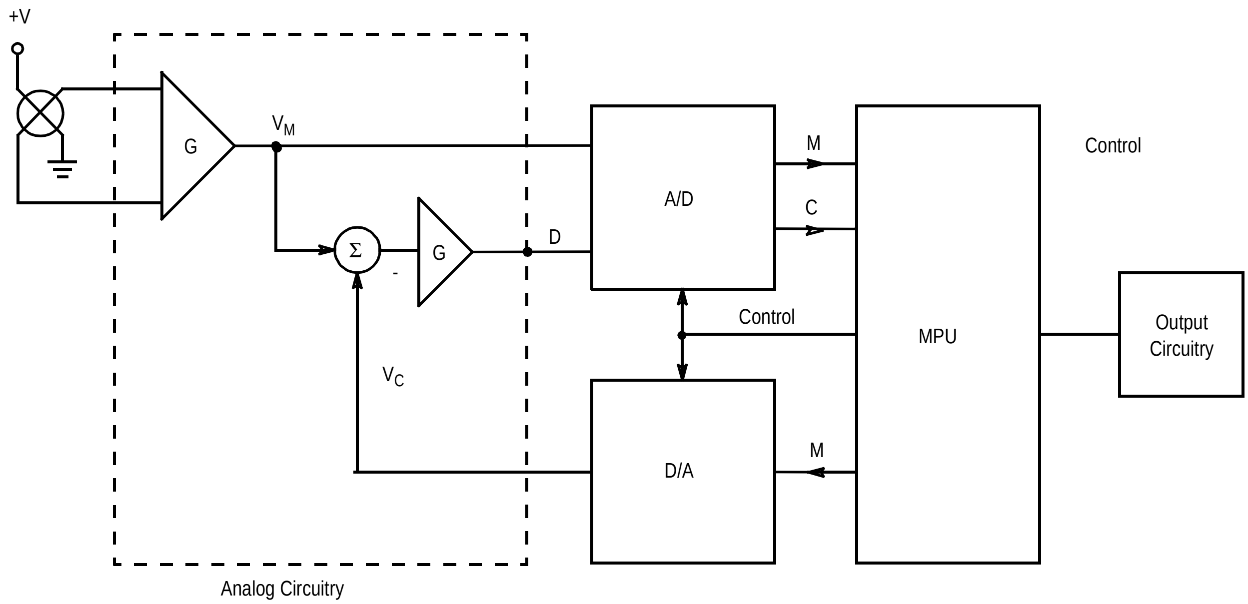


Figure 2. Expanded Block Diagram

Figure 2 shows the block diagram of a system that can be used to reduce the inaccuracies caused by the limited A/D resolution. The microprocessor would use the stored value M, as described above, to cause a D/A to output the corresponding voltage, Vc. Vc is subtracted from the measured voltage, Vm, using a differential amplifier, and the resulting voltage is amplified. Assuming a gain, G, of 10 for the amplifier, the output would be:

$$D = (Vm - Vc) \times G = (2790\ mV - 2783\ mV) \times 10 = 70\ mV \quad (9)$$

The microprocessor will receive the following count from the A/D:

$$C = 70mV/(19.60\ mV/count) = 3.6 = 3\ full\ counts \quad (10)$$

The microprocessor then computes the actual pressure with the following equations:

$$Expanded\ Voltage = Vc + ((C \times R)/G) = 2783 + ((3 \times 19.60)/10) = 2789\ mV, \quad (11)$$

NOTE: R is resolution of 8-bit d/A

$$Corresponding\ Pressure = 2789\ mV/ = 22.5\ mV/kPa = 123.9\ kPa \quad (12)$$

Thus the error is:

$$Pressure\ Error = Actual - Measured = 124\ kPa - 123.9\ kPa = 0.1\ kPa \quad (13)$$

Figure 3 and Figure 4 together provide a more detailed description of the analog portion of this system.

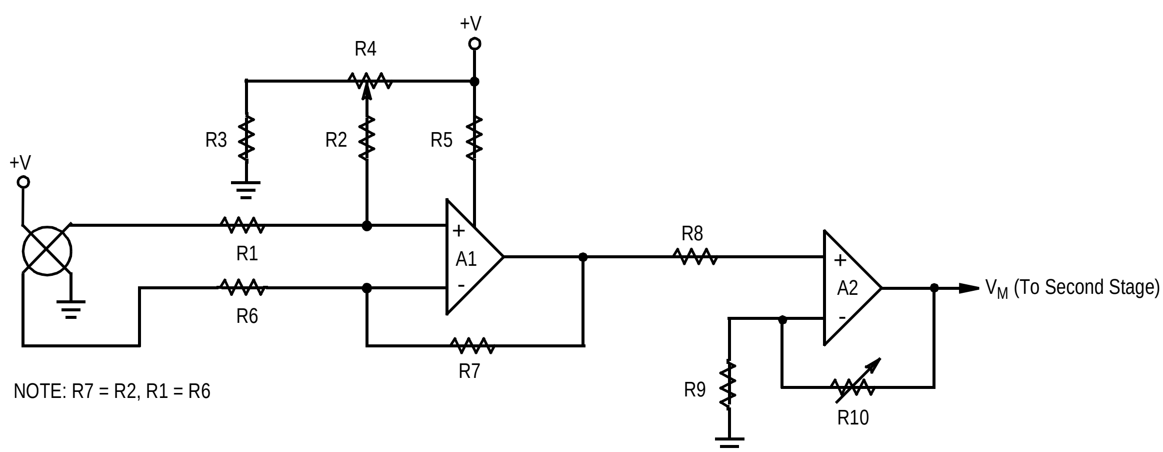


Figure 3. First Stage - Differential Amplifier, Offset Adjust and Gain Adjust

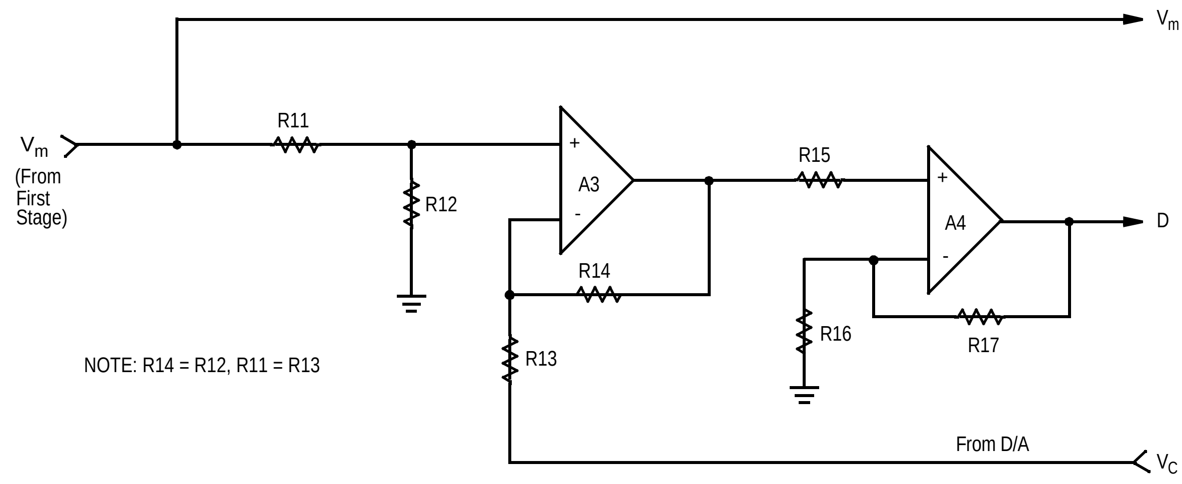


Figure 4. Second Stage - Difference Amplifier and Gains

FIRST STAGE (FIGURE 3)

The first stage consists of the pressure sensor; in this case the MPX2200 is used. This sensor typically gives a full scale span output of 40 mV at 200 kPa. The sensor output (V_S) is connected to the inputs of amplifier A1 (1/4 of the MC33079, a Quad Operational Amplifier). The gain, G1, of this amplifier is R7/R6. The sensor has a typical zero pressure offset voltage of 1 mV. Figure 3 shows offset compensation circuitry if it is needed. A1 output is fed to the non-inverting input of A2 amplifier (1/4 of a MC33079) whose gain, G2, is $1+R_{10}/R_9$. G2 should be set to yield 4.5 volts out with full-rated pressure.

THE SECOND STAGE (FIGURE 4)

The output from A2 (Vm = G1 x G2 x Vs) is connected to the non-inverting input of amplifier A3 (1/4 of a MC33079) and to the A/D where its corresponding (digital) value is stored by the microprocessor. The output of A3 is the amplified difference between Vm, and the digitized/calculated voltage Vc. Amplifier A4 (1/4 of a MC33079) provides additional gain for an amplified difference output for the desired resolution. This difference output, D, is given by:

$$D = (Vm\ V_c) \times G3$$

$$G3 = (R14/R13)\left(1 + \frac{R17}{R16}\right)$$

where G3 is the gain associated with amplifiers A3 and A4.

The theoretical resolution is limited only by the accuracy of the programmable power supply. The microprocessor used has an integrated A/D. The accuracy of this A/D is directly related to the reference voltage source stability, which can be self-calibrated by the microprocessor. $V_{expanded}$ is the system output that is the sum of the voltage due to the count and the voltage due to the difference between the count voltage and the measured voltage. This is given by the following relation:

$$V_{expanded} = V_c + D/G3$$

therefore, $$PV_{expanded} = V_{expanded}/S.$$

$P_{expanded}$ is the value of pressure (in units of kPa) that results from this improved-resolution system. This value can be output to a display or used for further processing in a control system.

CONCLUSION

This circuit provides an easy way to have high resolution using inexpensive microprocessors and converters.

A Simple 4-20 mA Pressure Transducer Evaluation Board

by: Denise Williams
Discrete Applications Engineering

INTRODUCTION

The two wire 4-20 mA current loop is one of the most widely utilized transmission signals for use with transducers in industrial applications. A two wire transmitter allows signal and power to be supplied on a single wire-pair. Because the information is transmitted as current, the signal is relatively immune to voltage drops from long runs and noise from motors, relays, switches and industrial equipment. The use of additional power sources is not desirable because the usefulness of this system is greatest when a signal has to be transmitted over a long distance with the sensor at a remote location. Therefore, the 4 mA minimum current in the loop is the maximum usable current to power the entire control circuitry.

Figure 1 is a block diagram of a typical 4-20 mA current loop system which illustrates a simple two chip solution to converting pressure to a 4-20 mA signal. This system is designed to be powered with a 24 Vdc supply. Pressure is converted to a differential voltage by the MPX5100 pressure sensor. The voltage signal proportional to the monitored pressure is then converted to the 4-20 mA current signal with the Burr-Brown XTR101 Precision Two-Wire Transmitter. The current signal can be monitored by a meter in series with the supply or by measuring the voltage drop across R_L. A key advantage to this system is that circuit performance is not affected by a long transmission line.

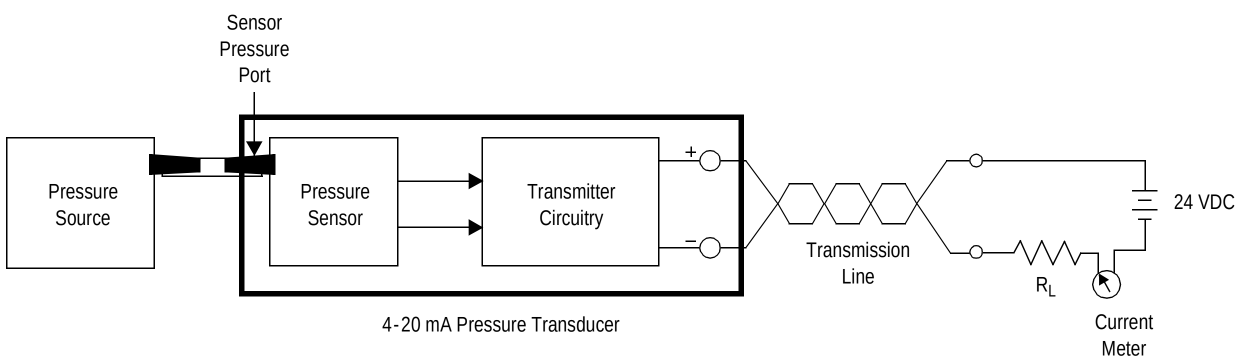


Figure 1. System Block Diagram

INPUT TERMINALS

A schematic of the 4-20 mA Pressure Transducer topology is shown in Figure 2. Connections to this topology are made at the terminals labeled (+) and (-). Because this system utilizes a current signal, the power supply, the load and any current meter must be put in series with the (+) to (-) terminals as indicated in the block diagram. The load for this type of system is typically a few hundred ohms. As described above, a typical use of a 4-20 mA current transmission signal is the transfer of information over long distances. Therefore, a long transmission line can be connected between the (+) and (-) terminals on the evaluation board and the power supply/load.

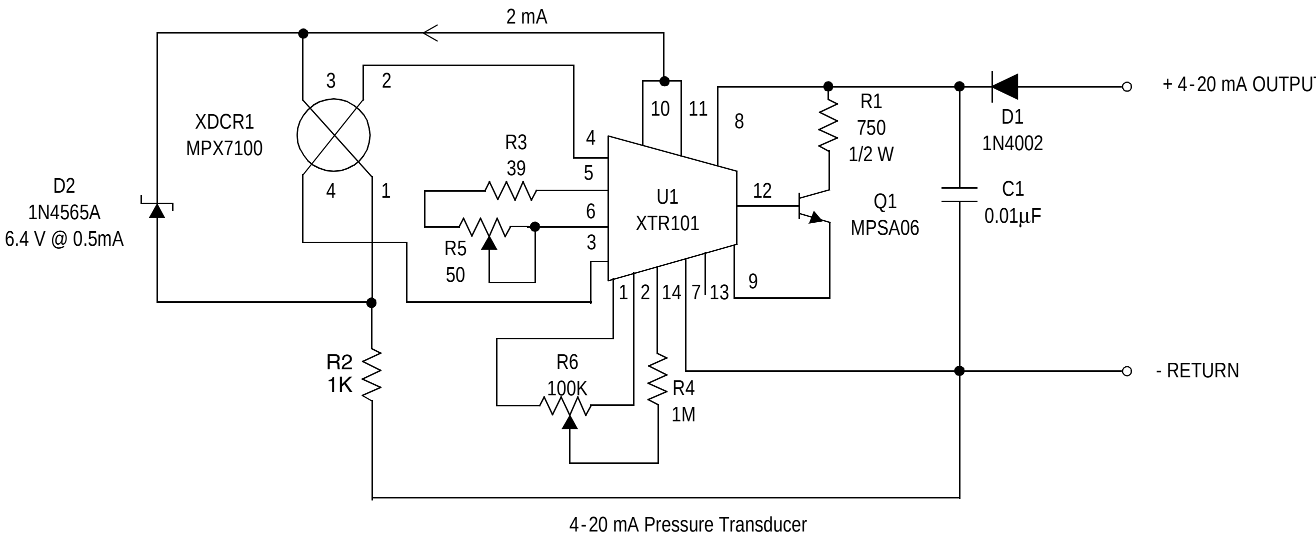


Figure 2. Schematic Diagram

PRESSURE INPUT

The device supplied on this topology is an MPX5100DP, which provides two ports. P1, the positive pressure port, is on top of the sensor and P2, the vacuum port, is on the bottom of the sensor. The system can be supplied up to 15 PSI of positive pressure to P1 or up to 15 PSI of vacuum to P2 or a differential pressure up to 15 PSI between P1 and P2. Any of these pressure applications will create the same results at the sensor output.

Circuit Description

The XTR101 current transmitter provides two one-milliamp current sources for sensor excitation when its bias voltage is between 12 V and 40 V. The MPX5100 series sensors are constant voltage devices, so a zener, D2, is placed in parallel with the sensor input terminals. Because the MPX5100 series parts have a high impedance the zener and sensor combination can be biased with just the two milliamps available from the XTR101.

The offset adjustment is composed of R4 and R6. They are used to remove the offset voltage at the differential inputs to the XTR101. R6 is set so a zero input pressure will result in the desired output of 4 mA.

R3 and R5 are used to provide the full scale current span of 16 mA. R5 is set such that a 15 PSI input pressure results in the desired output of 20 mA. Thus the current signal will span 16 mA from the zero pressure output of 4 mA to the full scale output of 20 mA. To calculate the resistor required to set the full scale output span, the input voltage span must be defined. The full scale output span of the sensor is 24.8 mV and is ΔV_{IN} to the XTR101. Burr-Brown specifies the following equation for R_{span}. The 40 and 16 mΩ values are parameters of the XTR101.

$$\text{Rspan} = 40 / [(16\text{ mA} / \Delta\text{Vin}) - 0.016\text{ mhos}]$$
$$= 64\ \Omega$$

The XTR101 requires that the differential input voltage at pins 3 and 4, V2 - V1 be less than 1V and that V2 (pin 4) always be greater than V1 (pin 3). Furthermore, this differential voltage is required to have a common mode of 4-6 volts above the reference (pin 7). The sensor produces the differential output with a common mode of approximately 3.1 volts above its reference pin 1. Because the current of both 1 mA sources will go through R2, a total common mode voltage of about 5.1 volts (1 kΩ x 2 mA + 3.1 volts = 5.1 volts) is provided.

CONCLUSION

This circuit is an example of how the MPX5000 series sensors can be utilized in an industrial application. It provides a simple design alternative where remote pressure sensing is required.

Table 1. Parts List for 4-20 mA Pressure Transducer Evaluation Board

Designator	Quantity	Description	Rating	Manufacturer	Part Number
	1 1 4 4 2 2	PC Board Input/Output Terminals 1/2″ standoffs, Nylon threaded 1/2″ screws, Nylon 5/8″ screws, Nylon 4-40 nuts, Nylon		Freescale PHX CONT	DEVB126 #1727010
C1	1	**Capacitor** 0.01 μF	50 V		
D1 D2	1 1	**Diodes** 100 V Diode 6.4 V Zener	1 A		1N4002 1N4565A
Q1	1	**Transistor** NPN Bipolar		Freescale	MPSA06
R1 R2 R3 R4	1 1 1 1	**Resistors, Fixed** 750 Ω 1 kΩ 39 Ω 1 MΩ	1/2 W		
R5 R6	1 1	**Resistors, Variable** 50 Ω, one turn 100 KΩ, one turn		Bourns Bourns	#3386P-1-500 #3386P-1-104
U1	1	**Integrated Circuit** Two wire current transmitter		Burr-Brown	XTR101
XDCR1	1	**Sensor** High Impedance	15 PSI	Freescale	MPX5100DP

NOTE: All resistors are 1/4 W with a tolerance of 5% unless otherwise noted. All capacitors are 100 volt, ceramic capacitors with a tolerance of 10% unless otherwise noted.

Integrated Sensor Simplifies Bar Graph Pressure Gauge

by: Warren Schultz
Discrete Applications Engineering

INTRODUCTION

Integrated semiconductor pressure sensors such as the MPX5100 greatly simplify electronic measurement of pressure. These devices translate pressure into a 0.5 to 4.5 volt output range that is designed to be directly compatible with microcomputer A/D inputs. The 0.5 to 4.5 volt range also facilitates interface with ICs such as the LM3914, making Bar Graph Pressure Gauges relatively simple. A description of a Bar Graph Pressure Sensor Evaluation Board and its design considerations are presented here.

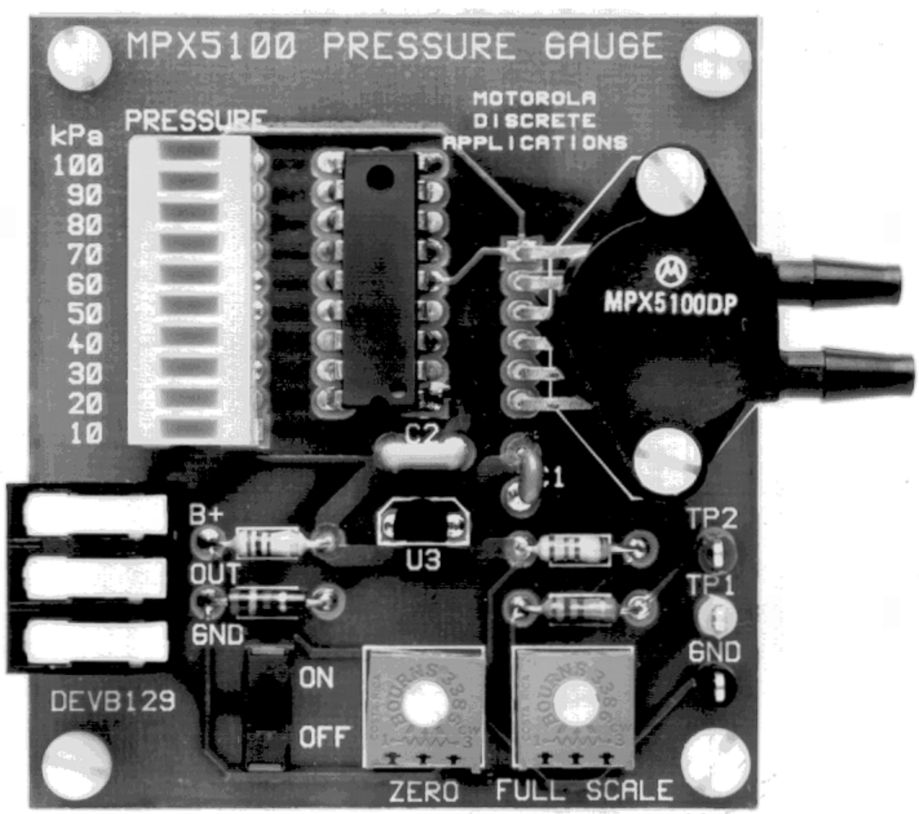


Figure 1. DEVB129 MPX5100 Bar Graph Pressure Gauge (Board No Longer Available)

EVALUATION BOARD DESCRIPTION

A summary of the information required to use evaluation board number DEVB129 is presented as follows. A discussion of the design appears under the heading Design Considerations.

Function

The evaluation board shown in Figure 1 is designed to provide a 100 kPa full scale pressure measurement. It has two input ports. P1, the pressure port is on the top side of the MPX5100 sensor, and P2, a vacuum port, is on the bottom side. These ports can be supplied up to 100 kPa (15 psi)[1] of pressure on P1 or up to 100 kPa of vacuum on P2, or a differential pressure up to 100 kPa between P1 and P2. Any of these sources will produce the same output.

The primary output is a 10 segment LED bar graph, which is labeled in increments of 10 kPa. If full scale pressure is adjusted for a value other than 100 kPa the bar graph may be read as a percent of full scale. An analog output is also provided. It nominally supplies 0.5 volts at zero pressure and 4.5 volts at 100 kPa. Zero and full scale adjustments are made with potentiometers so labeled at the bottom of the board. Both adjustments are independent of each other.

Electrical Characteristics

The following electrical characteristics are included to describe evaluation board operation. They are not specifications in the usual sense and are intended only as a guide to operation.

Characteristic	Symbol	MIn	Typ	Max	Units
Power Supply Voltage	B+	6.8	—	13.2	Volts
Full Scale Pressure	PFS	—	—	100	kPa
Overpressure	PMAX	—	—	700	kPa
Analog Full Scale	VFS	—	4.5	—	Volts
Analog Zero Pressure Offset	VOFF	—	0.5	—	Volts
Analog Sensitivity	SAOUT	—	40	—	mV/kPa
Quiescent Current	ICC	—	20	—	mA
Full Scale Current	IFS	—	140	—	mA

Content

Board contents are described in the following parts list, schematic, and silk screen plot. A pin-by-pin circuit description follows in the next section.

Pin-by-Pin Description

B+

Input power is supplied at the B+ terminal. Minimum input voltage is 6.8 volts and maximum is 13.2 volts. The upper limit is based upon power dissipation in the LM3914 assuming all 10 LED's are lit and ambient temperature is 25°C. The board will survive input transients up to 25 volts provided that power dissipation in the LM3914 does not exceed 1.3 watts.

OUT

An analog output is supplied at the OUT terminal. The signal it provides is nominally 0.5 volts at zero pressure and 4.5 volts at 100 kPa. This output is capable of sourcing 100 µA at full scale output.

GND

There are two ground connections. The ground terminal on the left side of the board is intended for use as the power supply return. On the right side of the board, one of the test point terminals is also connected to ground. It provides a convenient place to connect instrumentation grounds.

TP1

Test point 1 is connected to the zero pressure reference voltage and can be used for zero pressure calibration. To calibrate for zero pressure, this voltage is adjusted with R6 to match the zero pressure voltage that is measured at the analog output (OUT) terminal.

TP2

Test point 2 performs a similar function at full scale. It is connected to the LM3914's reference voltage which sets the trip point for the uppermost LED segment. This voltage is adjusted via R5 to set full scale pressure.

P1, P2

Pressure and Vacuum ports P1 & P2 protrude from the MPX5100 sensor on the right side of the board. Pressure port P1 is on the top and vacuum port P2 is on the bottom. Neither is labeled. Either one or a differential pressure applied to both can be used to obtain full scale readings up to 100 kPa (15 psi). Maximum safe pressure is 700 kPa.

DESIGN CONSIDERATIONS

In this type of an application the design challenge is how to interface a sensor with the bar graph output. MPX5100 Sensors and LM3914 Bar Graph Display drivers fit together so cleanly that having selected these two devices the rest of the design is quite straight forward.

A block diagram that appears in Figure 4 shows the LM3914's internal architecture. Since the lower resistor in the input comparator chain is pinned out at R_{LO}, it is a simple matter to tie this pin to a voltage that is approximately equal to the MPX5100's zero pressure output voltage. In Figure 2, this is accomplished by dividing down the 5 volt regulator's output voltage through R1, R4, and adjustment pot R6. The voltage

1. 100 kPa = 14.7 psi, 15 psi is used throughout the text for convenience.

generated at the wiper of R6 is then fed into R_{LO} which matches the sensor's zero pressure voltage and zeros the bar graph.

The full scale measurement is set by adjusting the upper comparator's reference voltage to match the sensor's output at full pressure. An internal regulator on the LM3914 sets this voltage with the aid of resistors R2, R3, and adjustment pot R5 that are shown in Figure 2.

The MPX5100 requires 5 volt regulated power that is supplied by an MC78L05. The LED's are powered directly from LM3914 outputs, which are set up as current sources. Output current to each LED is approximately 10 times the reference current that flows from pin 7 through R2, R5, and R3 to ground. In this design it is nominally (4.5 V/4.9K)10 = 9.2 mA.

Over a zero to 85°C temperature range accuracy for both the sensor and driver IC are ±2.5%, totaling ±5%. Given a 10 segment display total accuracy is approximately ±(10 kPa +5%).

CONCLUSION

Perhaps the most noteworthy aspect to the bar graph pressure gauge described here is how easy it is to design. The interface between an MPX5100 sensor, LM3914 display driver, and bar graph output is direct and straight forward. The result is a simple circuit that is capable of measuring pressure, vacuum, or differential pressure; and will also send an analog signal to other control circuitry.

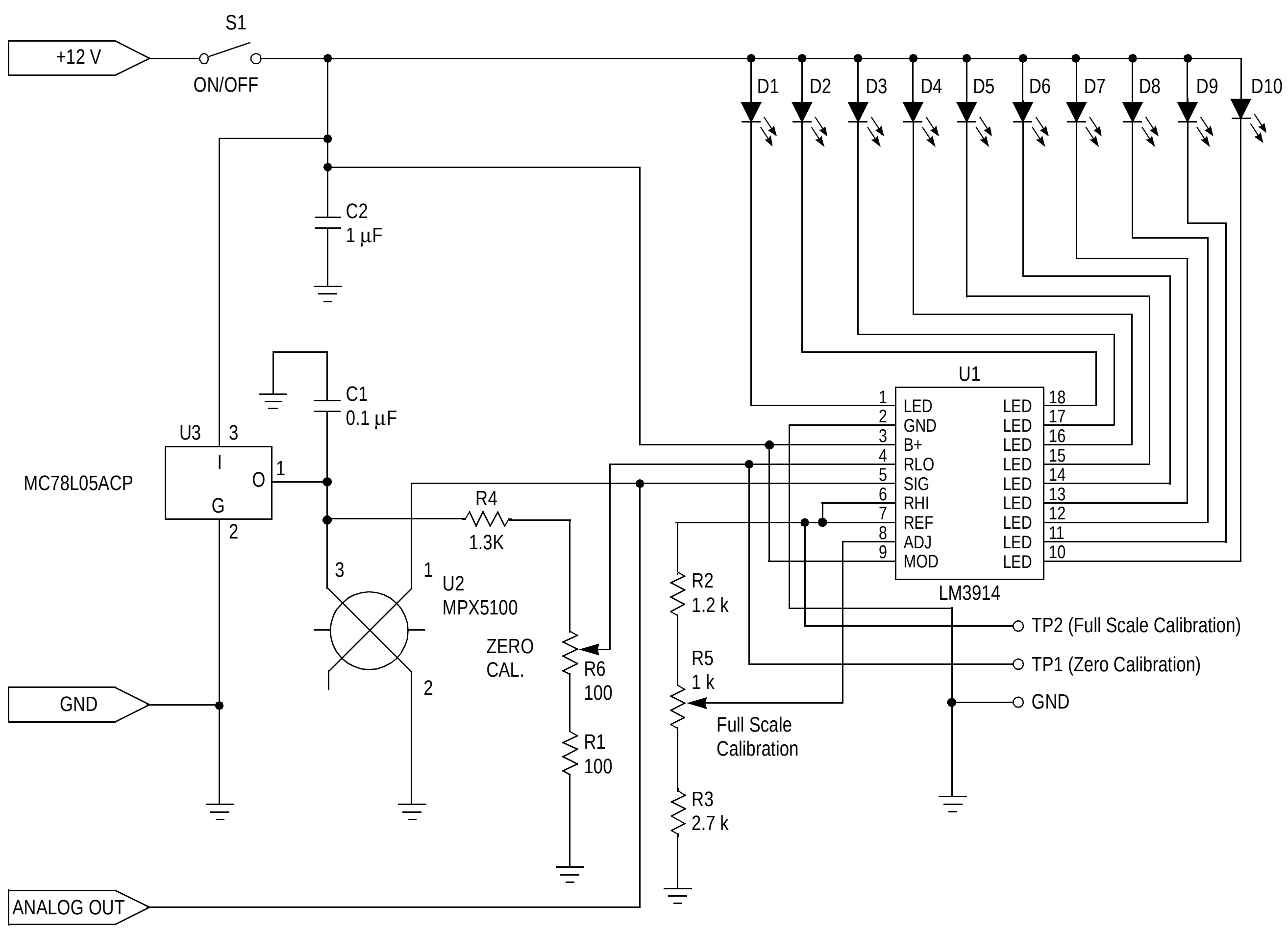


Figure 2. MPX5100 Pressure Gauge

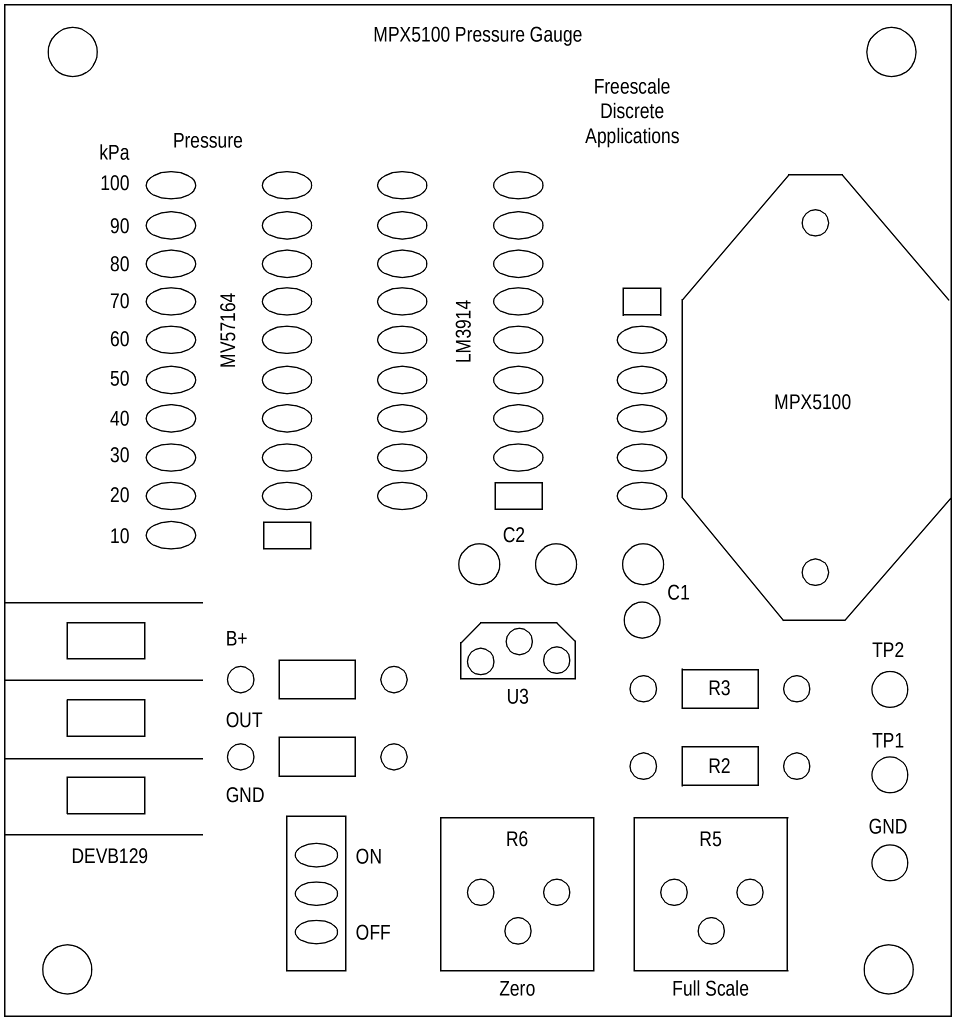


Figure 3. Silk Screen 2X

Table 1. Parts List

Designators	Quant.	Description	Rating	Manufacturer	Part Number
C1 C2	1 1	Ceramic Cap Ceramic Cap	0.1 µF 1 µF		
D1-D10	1	Bar Graph LED		GI	MV57164
R1 R2 R3 R4 R5 R6	1 1 1 1 1 1	1/4 W Film Resistor 1/4 W Film Resistor 1/4 W Film Resistor 1/4 W Film Resistor Trimpot Trimpot	100 1.2K 2.7K 1.3K 1K 100	 Bourns Bourns	
S1	1	On/Off Switch		NKK	12SDP2
U1 U2 U3	1 1 1	Bar Graph IC Pressure Sensor Voltage Regulator		National Freescale Freescale	LM3914 MPX5100 MC78L05ACP
— — — —	1 3 4 4	Terminal Block Test Point Terminal Nylon Spacer 4-40 Nylon Screw	 3/8″ 1/4″	Augat Components Corp.	25V03 TP1040104

Notes: All resistors have a tolerance of 5% unless otherwise noted.
All capacitors are 50 volt ceramic capacitors with a tolerance of 10% unless otherwise noted.

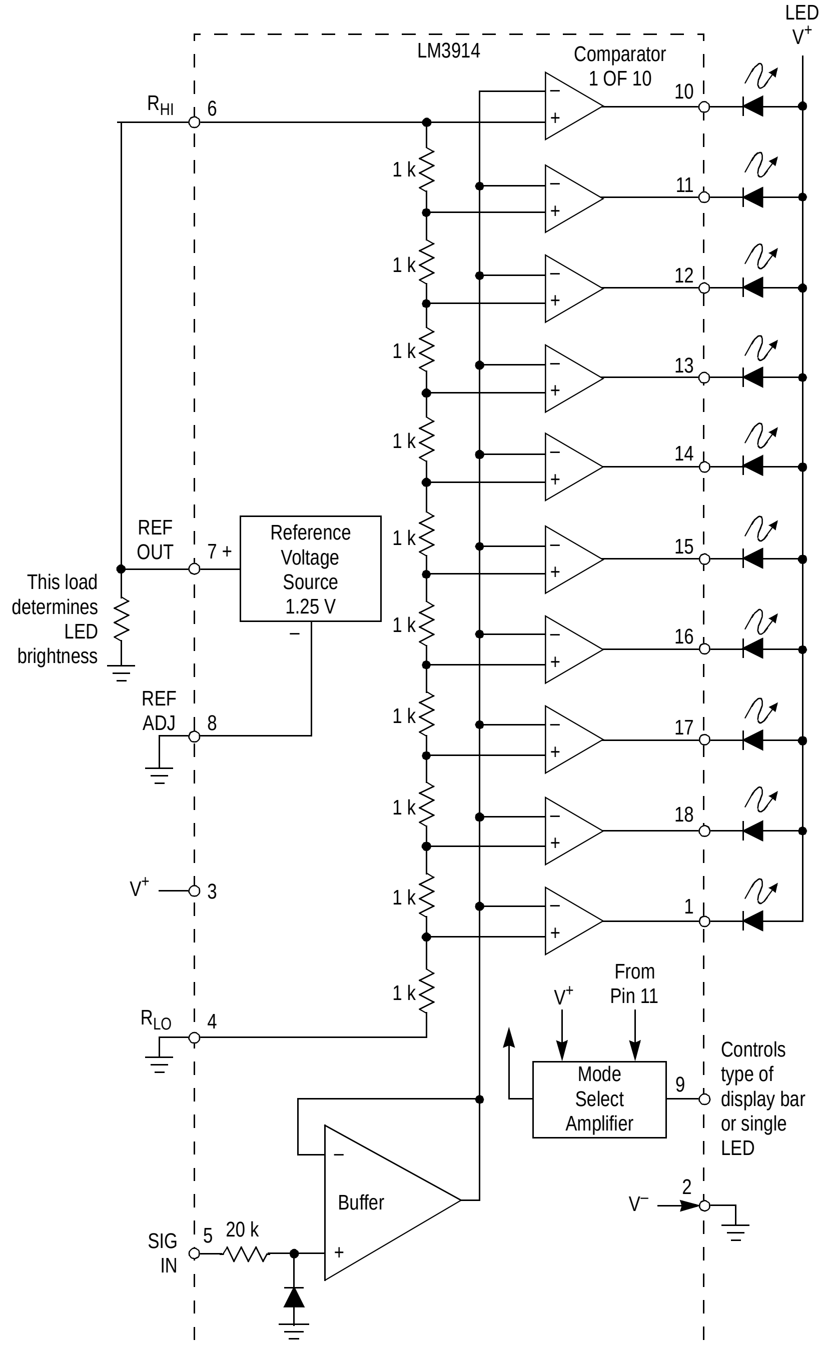


Figure 4. LM3914 Block Diagram

AN1305
Rev 2, 05/2005

An Evaluation System for Direct Interface of the MPX5100 Pressure Sensor with a Microprocessor

by: Bill Lucas
Discrete Applications Engineering

INTRODUCTION

Interfacing pressure sensors to analog-to-digital converters or microprocessors with on-chip A/D converters has been a challenge that most engineers do not enjoy accepting. Recent design advances in pressure sensing technology have allowed the engineer to directly interface a pressure sensor to an A/D converter with no additional active components. This has been made possible by integrating a temperature compensated pressure sensor element and active linear circuitry on the same die. A description of an evaluation board that shows the ease of interfacing a signal conditioned pressure sensor to an A/D converter is presented here.

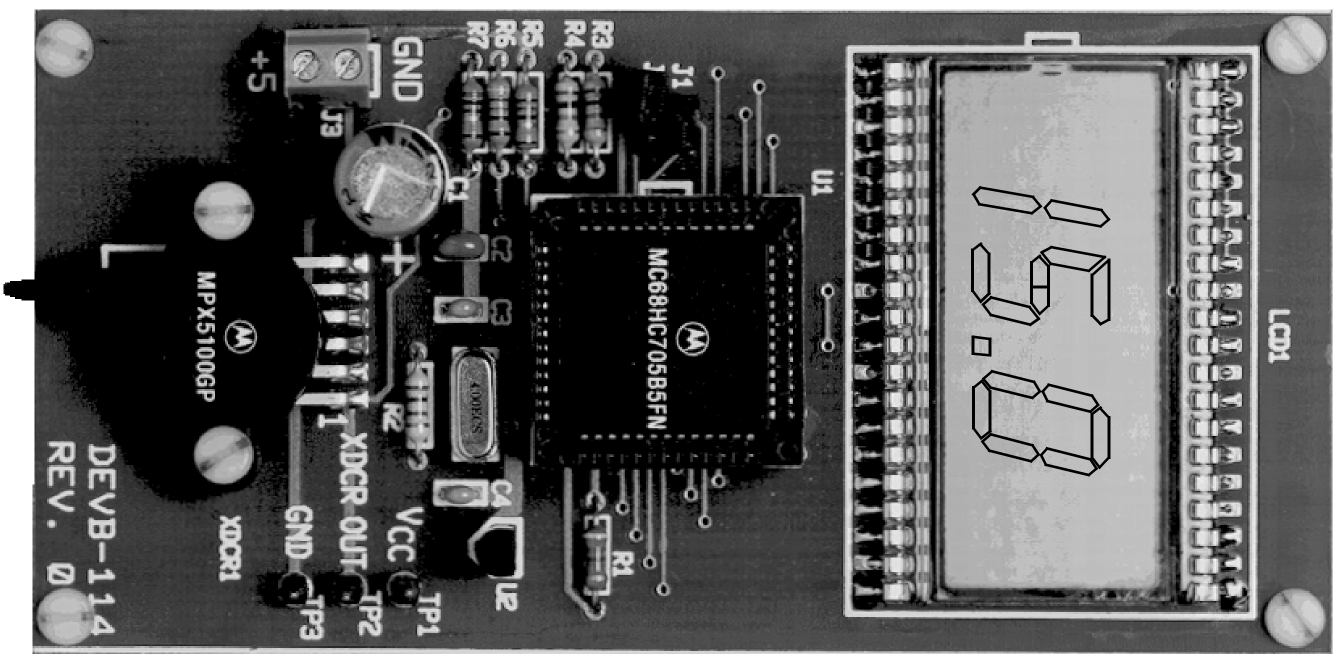


Figure 1. DEVB-114 MPX5100 Evaluation Module (Board No Longer Available)

PURPOSE

This evaluation system shown in Figure 1 demonstrates the ease of operation and interfacing of the Freescale Semiconductor, Inc. MPX5100 series pressure sensors with on-chip temperature compensation, calibration and amplification. The board may be used to evaluate the sensor's suitability for a specific application.

DESCRIPTION

The DEVB-114 evaluation board is constructed on a small printed circuit board. It is powered from a single +5 Vdc regulated power supply. The system will display the pressure applied to the MPX5100 sensor in pounds per square inch. The range is 0 PSI through 15 PSI, resolved to 0.1 PSI. No potentiometers are used in the system to adjust the span and offset. The sensor's zero offset voltage with no pressure applied to the sensor is empirically computed each time power is applied to the system and stored in RAM. The sensitivity of the MPX5100 is repeatable from unit to unit. There is a facility for a small "rubbering" of the slope constant built into the program. It is accomplished with jumpers J1 and J2, and is explained in the Operation section. The board contents are further described in the schematic, silk screen plot, and parts list that appear in Figure 2, Figure 3, and Table 1.

BASIC CIRCUIT

The evaluation board consists of three basic subsystems: an MPX5100GP pressure sensor, a four digit liquid crystal display (only three digits and a decimal are used) and a programmed microprocessor with the necessary external circuitry to support the operation of the microprocessor.

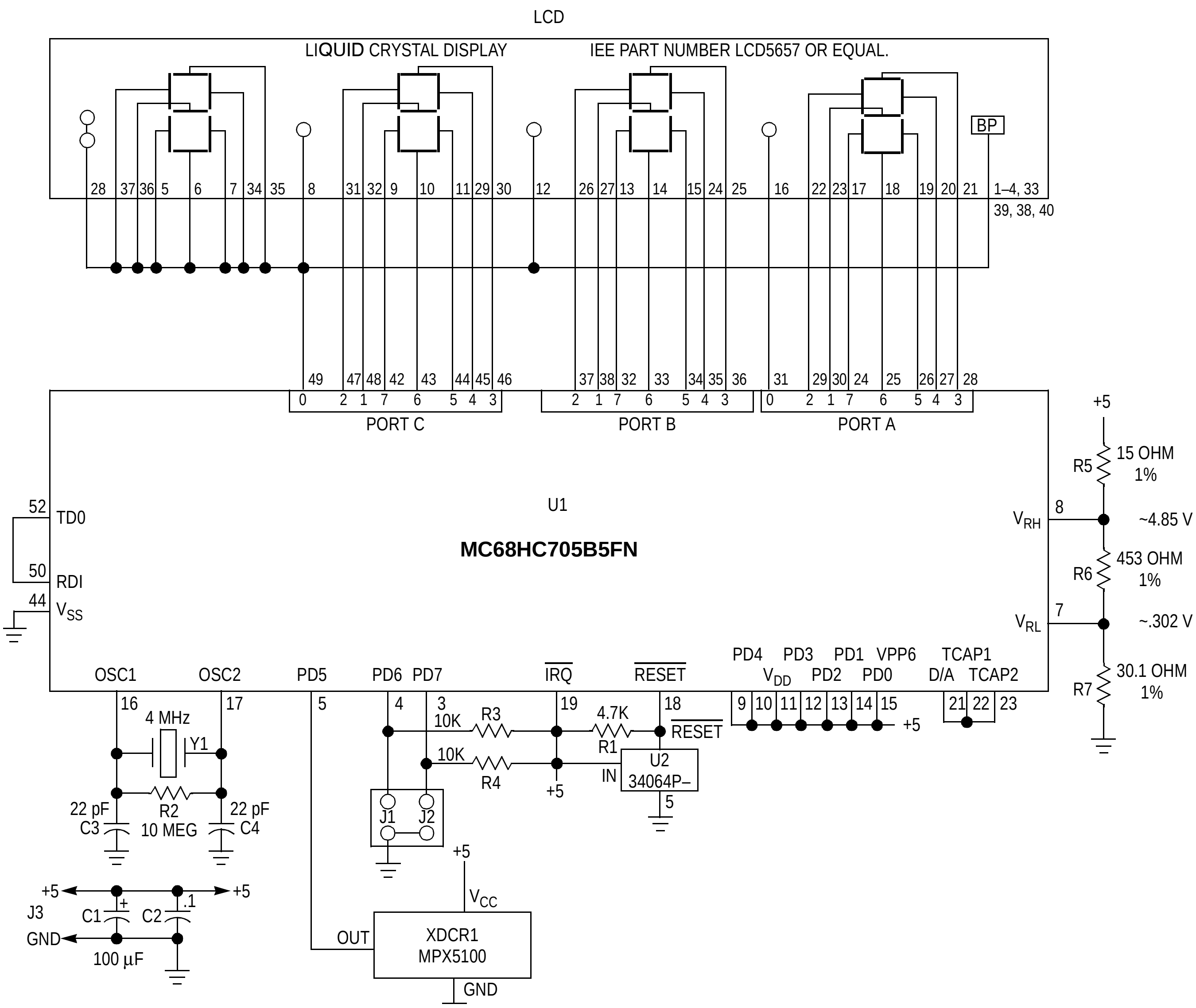


Figure 2. DEVB-114 System Schematic

Table 1. DEVB-114 Parts List

Designators	Quant.	Description	Rating	Manufacturer	Part Number
C1	1	100 µF Electrolytic Capacitor	25 Vdc	Sprague	513D107M025BB4
C2	1	0.1 µF Ceramic Capacitor	50 Vdc	Sprague	1C105Z5U104M050B
C3, C4	2	22 pF Ceramic Capacitor	100 Vdc	Mepco/Centralab	CN15A220K
J1, J2	1	Dual Row Straight .025 Pins Arranged On .1″ Grid		Molex	10-89-1043
LCD	1	Liquid Crystal Display		AMPEREX	LTD226R-12
R1	1	4.7 k Ohm Resistor			
R2	1	10 Meg Ohm Resistor			
R3, R4	2	10 k Ohm Resistor			
R5	1	15 Ohm 1% 1/4 W Resistor			
R6	1	453 Ohm 1% 1/4 W Resistor			
R7	1	30.1 Ohm 1% 1/4 W Resistor			
XDCR1	1	Pressure Sensor		Freescale	MPX5100GP
U1	1	Microprocessor		Freescale Freescale	MC68HC705B5FN or XC68HC705B5FN
U2	1	Under Voltage Detector		Freescale	MC34064P-5
Y1	1	Crystal (Low Profile)	4.0 MHz	ECS	ECS-40-S-4
No Designator	1	52 Pin PLCC Socket		AMP	821-575-1
No Designator	2	Jumpers For J1 and J2		Molex	15-29-1025
No Designator	1	Bare Printed Circuit Board			

Notes: All resistors are 1/4 W resistors with a tolerance of 5% unless otherwise noted.
All capacitors are 100 volt, ceramic capacitors with a tolerance of 10% unless otherwise noted.

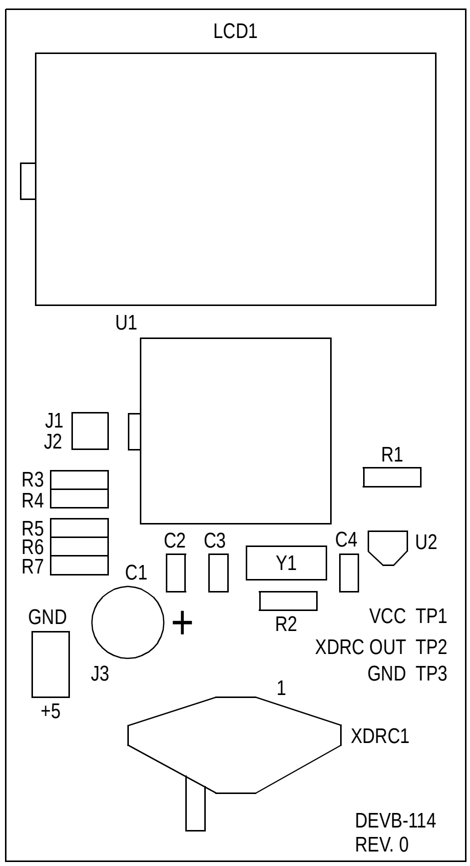


Figure 3. Silk Screen

Theory of Operation

Referring to the schematic, Figure 2, the MPX5100 pressure sensor is connected to PORT D bit 5 of the microprocessor. This port is an input to the on-chip 8 bit analog to digital converter. The pressure sensor provides a signal output to the microprocessor of approximately 0.5 Vdc at 0 psi to 4.5 Vdc at 15 psi of applied pressure as shown in Figure 4. The input range of the A to D converter is set at approximately 0.3 Vdc to 4.85 Vdc. This compresses the range of the A to D converter around the output range of the sensor to maximize the A to D converter resolution; 0 to 255 counts is the range of the A to D converter. V_{RH} and V_{RL} are the reference voltage inputs to the A to D converter. The resolution is defined by the following:

Analog-to-digital converter count =

$[(V_{xdcr}-V_{RL})/(V_{RH}-V_{RL})]\bullet 255$

The count at 0 psi = $[(.5-.302)/(4.85-.302)]\bullet 255 \approx 11$
The count at 15 psi = $[(4.5-.302)/(4.85-.302)]\bullet 255 \approx 235$
Therefore the resolution = count @ 15 psi - count @ 0 psi or the resolution is (235 - 11) = 224 counts. This translates to a system that will resolve to 0.1 psi.

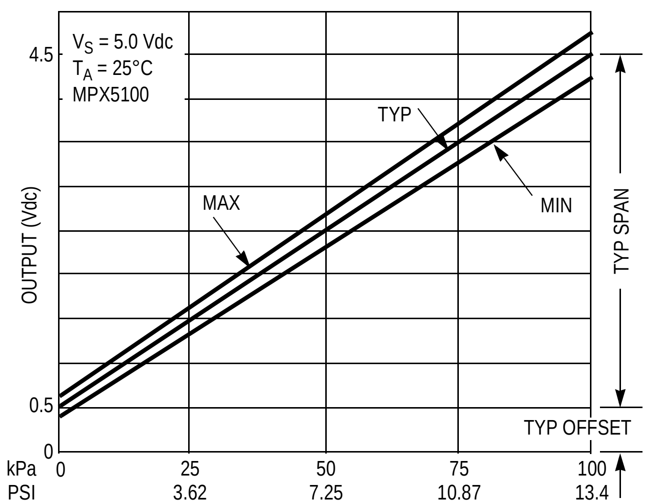


Figure 4. MPX5100 Output versus Pressure Input

The voltage divider consisting of R5 through R7 is connected to the +5 volts powering the system. The output of the pressure sensor is ratiometric to the voltage applied to it. The pressure sensor and the voltage divider are connected to a common supply; this yields a system that is ratiometric. By nature of this ratiometric system, variations in the voltage of the power supplied to the system will have no effect on the system accuracy.

The liquid crystal display is directly driven from I/O ports A, B, and C on the microprocessor. The operation of a liquid crystal display requires that the data and backplane pins must be driven by an alternating signal. This function is provided by a software routine that toggles the data and backplane at approximately a 30 Hz rate.

The microprocessor section of the system requires certain support hardware to allow it to function. The MC34064P-5 (U2) provides an under voltage sense function which is used to reset the microprocessor at system power-up. The 4 MHz crystal (Y1) provides the external portion of the oscillator function for clocking the microprocessor and provides a stable base for time based functions. Jumpers J1 and J2 are examined by the software and are used to “rubber” the slope constant.

OPERATION

The system must be connected to a 5 Vdc regulated power supply. Note the polarity marked on the power terminal J3. Jumpers J1 and J2 must either both be installed or both be removed for the normal slope constant to be used. The pressure port on the MPX5100 sensor must be left open to atmosphere anytime the board is powered-up. As previously stated, the sensor’s voltage offset with zero pressure applied is computed at power-up.

You will need to apply power to the system. The LCD will display CAL for approximately 5 seconds. After that time, the LCD will then start displaying pressure.

To improve upon the accuracy of the system, you can change the constant used by the program that constitutes the span of the sensor. You will need an accurate test gauge to measure the pressure applied to the sensor. Anytime after the display has completed the zero calculation (after CAL is no longer displayed), apply 15.0 PSI to the sensor. Make sure that jumpers J1 and J2 are either both installed or both removed. Referring to Table 2, you can increase the displayed value by installing J1 and removing J2. Conversely, you can decrease the displayed value by installing J2 and removing J1.

Table 2. J1/J2 Installation

J1	J2	Action
IN	IN	Use Normal Span Constant
OUT	OUT	Use Normal Span Constant
OUT	IN	Decrease Span Constant Approximately 1.5%
IN	OUT	Increase Span Constant Approximately 1.5%

SOFTWARE

The source code, compiler listing, and S-record output for the software used in this system are available on the Freescale Freeware Bulletin Board Service in the MCU directory under the filename DEVB-114.ARC. To access the bulletin board you must have a telephone line, a 300, 1200 or 2400 baud modem and a terminal or personal computer. The modem must be compatible with the Bell 212A standard. Call 1-512-891-3733 to access the Bulletin Board Service.

The software for the system consists of several modules. Their functions provide the capability for system calibration as well as displaying the pressure input to the MPX5100 transducer.

Figure 5 is a flowchart for the program that controls the system.

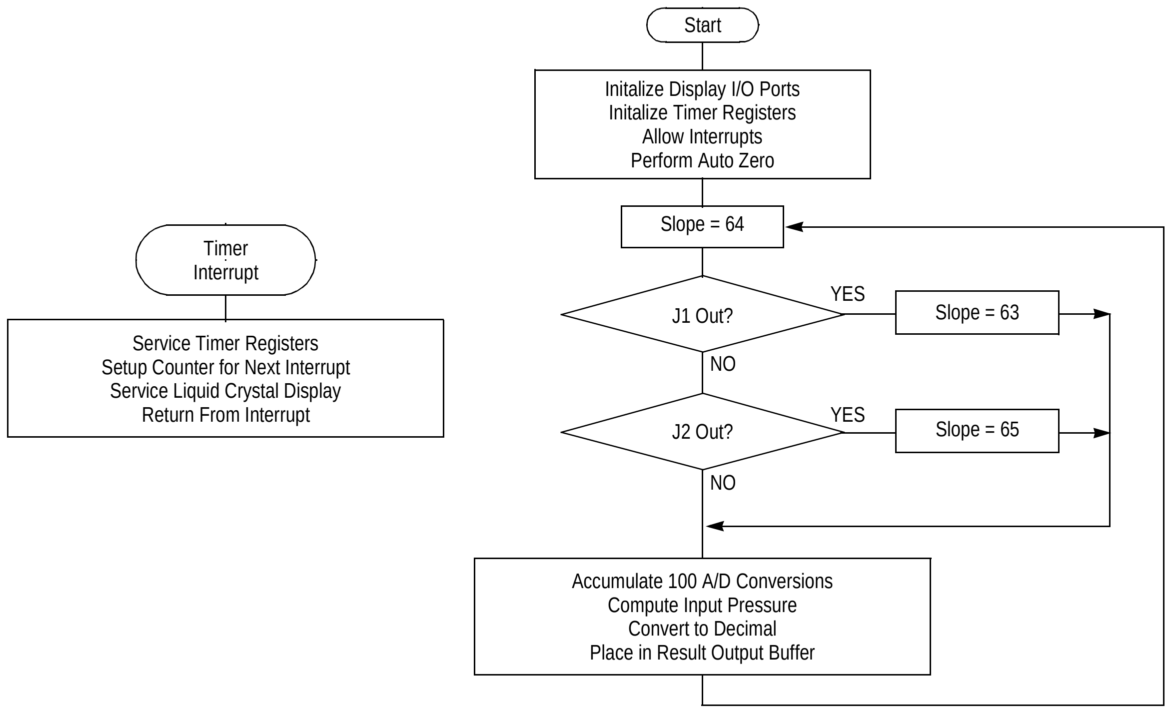


Figure 5. DEVB-114 Software Flowchart

The compiler used in this project was provided by BYTE CRAFT LTD. (519) 888-6911. A compiler listing of the program is included at the end of this document. The following is a brief explanation of the routines:

delay() Used to provide approximately a 20 ms loop.

read_a2d() Performs one hundred reads on the analog to digital converter on multiplexer channel 5 and returns the accumulation.

fixcompare() Services the internal timer for 30 ms timer compare interrupts.

TIMERCMP() Alternates the data and backplane for the liquid crystal display.

initio() Sets up the microcomputer's I/O ports, timer, allows processor interrupts, and calls adzero().

adzero() This routine is necessary at power-up time because it delays the power supply and allows the transducer to stabilize. It then calls 'read_atod()' and saves the returned value as the sensors output voltage with zero pressure applied.

cvt_bin_dec(unsigned long arg) This routine converts the unsigned binary argument passed in 'arg' to a five digit decimal number in an array called 'digit'. It then uses the decimal results for each digit as an index into a table that converts the decimal number into a segment pattern for the display. It is then output to the display.

display_psi() This routine is called from 'main()'. The analog to digital converter routine is called, the pressure is calculated, and the pressure applied to the sensor is displayed. The loop then repeats.

main() This is the main routine called from reset. It calls 'initio()' to set up the system's I/O. 'display_psi()' is called to compute and display the pressure applied to the sensor.

SOFTWARE SOURCE/ASSEMBLY PROGRAM CODE

```
                        #pragma option v ;
                        /*

                        rev 1.1 code rewritten to use the MC68HC705B5 instead of the
                        MC68HC805B6. WLL 6/17/91

                        THE FOLLOWING 'C' SOURCE CODE IS WRITTEN FOR THE DEVB-114 DEMONSTRATION
                        BOARD. IT WAS COMPILED WITH A COMPILER COURTESY OF:

                                                    BYTE CRAFT LTD.
                                                    421 KING ST.
                                                    WATERLOO, ONTARIO
                                                    CANADA  N2J 4E4
                                                    (519)888-6911

                        SOME SOURCE CODE CHANGES MAY BE NECESSARY FOR COMPILATION WITH OTHER
                        COMPILERS.
                                                     BILL LUCAS 8/5/90
                                                     FREESCALE, SPS            */

0800 1700               #pragma memory ROMPROG  [5888]  @ 0x0800 ;
0050 0096               #pragma memory RAMPAGE0 [150]   @ 0x0050 ;

                        /*       Vector assignments    */
1FFE                    #pragma vector __RESET   @ 0x1ffe ;
1FFC                    #pragma vector __SWI     @ 0x1ffc ;
1FFA                    #pragma vector IRQ       @ 0x1ffa ;
1FF8                    #pragma vector TIMERCAP  @ 0x1ff8 ;
1FF6                    #pragma vector TIMERCMP  @ 0x1ff6 ;
1FF4                    #pragma vector TIMEROV   @ 0x1ff4 ;
1FF2                    #pragma vector SCI       @ 0x1ff2 ;

                        #pragma has STOP ;
                        #pragma has WAIT ;
                        #pragma has MUL ;

                        /*       Register assignments for the 68HC705B5 microcontroller     */
0000                    #pragma portrw porta   @ 0x00;  /*                                      */
0001                    #pragma portrw portb   @ 0x01;  /*                                      */
0002                    #pragma portrw portc   @ 0x02;  /*                                      */
0003                    #pragma portrw portd   @ 0x03;  /* in  ,-  ,SS  ,SCK  ,MOSI,MISO,TxD,RxD */
0004                    #pragma portrw ddra    @ 0x04;  /* Data direction, Port A               */
0005                    #pragma portrw ddrb    @ 0x05;  /* Data direction, Port B               */
0006                    #pragma portrw ddrc    @ 0x06;  /* Data direction, Port C (all output)   */
0007                    #pragma portrw eeclk   @ 0x07;  /* eeprom/eclk cntl */
0008                    #pragma portrw addata  @ 0x08;  /* a/d data register */
0009                    #pragma portrw adstat  @ 0x09;  /* a/d stat/control */
000A                    #pragma portrw plma    @ 0x0a;  /* pulse length modulation a */
000B                    #pragma portrw plmb    @ 0x0b;  /* pulse length modulation b */
000C                    #pragma portrw misc    @ 0x0c;  /* miscellaneous register */
000D                    #pragma portrw scibaud @ 0x0d;  /* sci baud rate register */
000E                    #pragma portrw scicntl1 @ 0x0e; /* sci control 1  */
000F                    #pragma portrw scicntl2 @ 0x0f; /* sci control 2  */
0010                    #pragma portrw scistat @ 0x10;  /* sci status reg */
```

```
0011                          #pragma portrw scidata  @ 0x11;  /* SCI Data  */
0012                          #pragma portrw tcr      @ 0x12;  /* ICIE,OCIE,TOIE,0;0,0,IEGE,OLVL       */
0013                          #pragma portrw tsr      @ 0x13;  /* ICF,OCF,TOF,0; 0,0,0,0              */
0014                          #pragma portrw icaphi1  @ 0x14;  /* Input Capture Reg (Hi-0x14, Lo-0x15) */
0015                          #pragma portrw icaplo1  @ 0x15;  /* Input Capture Reg (Hi-0x14, Lo-0x15) */
0016                          #pragma portrw ocmphi1  @ 0x16;  /* Output Compare Reg (Hi-0x16, Lo-0x17)*/
0017                          #pragma portrw ocmplo1  @ 0x17;  /* Output Compare Reg (Hi-0x16, Lo-0x17)*/
0018                          #pragma portrw tcnthi   @ 0x18;  /* Timer Count Reg (Hi-0x18, Lo-0x19)   */
0019                          #pragma portrw tcntlo   @ 0x19;  /* Timer Count Reg (Hi-0x18, Lo-0x19)   */
001A                          #pragma portrw acnthi   @ 0x1A;  /* Alternate Count Reg (Hi-$1A, Lo-$1B) */
001B                          #pragma portrw acntlo   @ 0x1B;  /* Alternate Count Reg (Hi-$1A, Lo-$1B) */
001C                          #pragma portrw icaphi2  @ 0x1c;  /* Input Capture Reg (Hi-0x1c, Lo-0x1d) */
001D                          #pragma portrw icaplo2  @ 0x1d;  /* Input Capture Reg (Hi-0x1c, Lo-0x1d) */
001E                          #pragma portrw ocmphi2  @ 0x1e;  /* Output Compare Reg (Hi-0x1e, Lo-0x1f)*/
001F                          #pragma portrw ocmplo2  @ 0x1f;  /* Output Compare Reg (Hi-0x1e, Lo-0x1f)*/

                                 /* put constants and variables here...they must be global */

                              /***********************************************************************/
1EFE 74                       #pragma mor @ 0x1EFE = 0x74;/*this disables the watchdog counter and does not
                      add pull-down resistors on ports B and C */

0800 FC 30 DA 7A 36 6E E6 38 FE const char lcdtab[]={0xfc,0x30,0xda,0x7a,0x36,0x6e,0xe6,0x38,0xfe,0x3e };
0809 3E
                                /* lcd pattern table  0    1    2    3    4    5    6    7    8    9     */
080A 27 10 03 E8 00 64 00 0A    const long dectable[] = { 10000, 1000, 100, 10 };

0050 0005                       unsigned int digit[5]; /* buffer to hold results from cvt_bin_dec functio*/

0000                            registera ac;      /* processor's A register */

0055                            long atodtemp;     /* temp to accumulate 100 a/d readings for smoothing */


0059                            long slope;        /* multiplier for adc to engineering units conversion */

005B                            int adcnt;         /* a/d converter loop counter */

005C                            long xdcr_offset;  /* initial xdcr offset */

005E 0060                       unsigned long i,j; /* counter for loops */

0062                            int k;             /* misc variable */

                                struct bothbytes
                                   {  int hi;
                                       int lo;
                                   };

                                   union isboth
                                        {  long  l;
                                        struct bothbytes b;
                                        };

0063 0002                          union isboth q;  /* used for timer set-up */
```

```
                     /************************************************************************/
                                              /* code starts here */
                              /************************************************************************/
                              /* these interrupts are not used...give them a graceful return if for
                                 some reason one occurs */

1FFC 08 12                    __SWI(){}
0812 80        RTI
1FFA 08 13                    IRQ(){}
0813 80        RTI
1FF8 08 14                    TIMERCAP(){}
0814 80        RTI
1FF4 08 15                    TIMEROV(){}
0815 80        RTI
1FF2 08 16                    SCI(){}
0816 80        RTI

                              /************************************************************************/

                              void delay(void)  /* just hang around for a while */
                              {
0817 4F       CLRA            for (i=0; i<20000; ++i);
0818 3F 57     CLR    $57
081A B7 58     STA    $58
081C B6 57     LDA    $57
081E B7 5E     STA    $5E
0820 B6 58     LDA    $58
0822 B7 5F     STA    $5F
0824 B6 5F     LDA    $5F
0826 A0 20     SUB    #$20
0828 B6 5E     LDA    $5E
082A A2 4E     SBC    #$4E
082C 24 08     BCC    $0836
082E 3C 5F     INC    $5F
0830 26 02     BNE    $0834
0832 3C 5E     INC    $5E
0834 20 EE     BRA    $0824
0836 81        RTS    }
               /************************************************************************/

                        read_a2d(void)
                              {
                              /* read the a/d converter on channel 5 and accumulate the result
                                 in atodtemp */

0837 3F 56     CLR    $56     atodtemp=0;   /* zero for accumulation */
0839 3F 55     CLR    $55
083B 4F        CLRA              for ( adcnt = 0 ; adcnt<100; ++adcnt) /* do 100 a/d conversions */
083C B7 5B     STA    $5B
083E B6 5B     LDA    $5B
0840 A8 80     EOR    #$80
0842 A1 E4     CMP    #$E4
0844 24 21     BCC    $0867
```

```
                                  {
0846 A6 25      LDA    #$25                adstat = 0x25;  /* convert on channel 5 */
0848 B7 09      STA    $09
084A 0F 09 FD   BRCLR 7,$09,$084A          while (!(adstat & 0x80));  /* wait for a/d to complete */
084D B6 08      LDA    $08                 atodtemp = addata + atodtemp;
084F 3F 57      CLR    $57
0851 B7 58      STA    $58
0853 BB 56      ADD    $56
0855 B7 58      STA    $58
0857 B6 57      LDA    $57
0859 B9 55      ADC    $55
085B B7 57      STA    $57
085D B7 55      STA    $55
085F B6 58      LDA    $58
0861 B7 56      STA    $56
                                       }
0863 3C 5B      INC    $5B
0865 20 D7      BRA    $083E
0867 B6 56      LDA    $56            atodtemp = atodtemp/100;
0869 B7 58      STA    $58
086B B6 55      LDA    $55
086D B7 57      STA    $57
086F 3F 66      CLR    $66
0871 A6 64      LDA    #$64
0873 B7 67      STA    $67
0875 CD 0A 5E   JSR    $0A5E
0878 CD 0A 8F   JSR    $0A8F
087B BF 55      STX    $55
087D B7 56      STA    $56
087F 81         RTS                   return atodtemp;
                                    }

                                    /**************************************************************************/
                        void fixcompare (void) /* sets-up the timer compare for the next interrup */
                                       {
0880 B6 18      LDA    $18          q.b.hi =tcnthi;
0882 B7 63      STA    $63
0884 B6 19      LDA    $19               q.b.lo = tcntlo;
0886 B7 64      STA    $64
0888 AB 4C      ADD    #$4C              q.l +=7500;  /* ((4mhz xtal/2)/4) = counter period = 2us.*7500 = 15ms.*/
088A B7 64      STA    $64
088C B6 63      LDA    $63
088E A9 1D      ADC    #$1D
0890 B7 63      STA    $63
0892 B7 16      STA    $16               ocmphi1 = q.b.hi;
0894 B6 13      LDA    $13               ac=tsr;
0896 B6 64      LDA    $64               ocmplo1 = q.b.lo;
0898 B7 17      STA    $17
089A 81         RTS                      }


                                     /**************************************************************************/
                                     void TIMERCMP (void)               /* timer service module */
1FF6 08 9B                               {
```

```
089B 33 02     COM    $02                   portc =~ portc;       /* service the lcd */
089D 33 01     COM    $01                   portb =~ portb;
089F 33 00     COM    $00                   porta =~ porta;
08A1 AD DD     BSR    $0880                 fixcompare();
08A3 80        RTI                      }

                                     /************************************************************************/

                                     void adzero(void)  /* called by initio() to save initial xdcr's zero
                                                           pressure offset voltage output */
                                     {

08A4 4F         CLRA                   for ( j=0; j<20; ++j)  /* give the sensor time to "warm-up" and the
08A5 3F 57      CLR    $57
08A7 B7 58      STA    $58
08A9 B6 57      LDA    $57
08AB B7 60      STA    $60
08AD B6 58      LDA    $58
08AF B7 61      STA    $61
08B1 B6 61      LDA    $61
08B3 A0 14      SUB    #$14
08B5 B6 60      LDA    $60
08B7 A2 00      SBC    #$00
08B9 24 0B      BCC    $08C6
                                                             power supply time to settle down */
                                        {
08BB CD 08 17   JSR    $0817              delay();
                                        }
08BE 3C 61      INC    $61
08C0 26 02      BNE    $08C4
08C2 3C 60      INC    $60
08C4 20 EB      BRA    $08B1
08C6 CD 08 37   JSR    $0837               xdcr_offset =  read_a2d();
08C9 3F 5C      CLR    $5C
08CB B7 5D      STA    $5D
08CD 81         RTS     }

                      /************************************************************************/
                        void initio (void)     /*  setup the I/O */
                                       {
08CE A6 20      LDA    #$20              adstat = 0x20; /* power-up the A/D */
08D0 B7 09      STA    $09
08D2 3F 02      CLR    $02               porta = portb = portc = 0;
08D4 3F 01      CLR    $01
08D6 3F 00      CLR    $00
08D8 A6 FF      LDA    #$FF              ddra = ddrb = ddrc = 0xff;
08DA B7 06      STA    $06
08DC B7 05      STA    $05
08DE B7 04      STA    $04
08E0 B6 13      LDA    $13               ac=tsr;  /* dummy read */
08E2 3F 1E      CLR    $1E               ocmphi1 = ocmphi2 = 0;
08E4 3F 16      CLR    $16
08E6 B6 1F      LDA    $1F               ac = ocmplo2; /* clear out output compare 2 if it happens to be set */
08E8 AD 96      BSR    $0880             fixcompare(); /* set-up for the first timer interrupt */
```

```
08EA A6 40     LDA    #$40              tcr = 0x40;
08EC B7 12     STA    $12
08EE 9A        CLI                      CLI;  /* let the interrupts begin !  */
                                     /* write CAL to the display */
08EF A6 CC     LDA    #$CC              portc = 0xcc; /* C */
08F1 B7 02     STA    $02
08F3 A6 BE     LDA    #$BE              portb = 0xbe; /* A */
08F5 B7 01     STA    $01
08F7 A6 C4     LDA    #$C4              porta = 0xc4; /* L */
08F9 B7 00     STA    $00
08FB AD A7     BSR    $08A4             adzero();
08FD 81        RTS                     }

                                    /***************************************************************************/
                                    void cvt_bin_dec(unsigned long arg)

                                    /* First converts the argument to a five digit decimal value. The msd is in
                                    the lowest address. Then leading zero suppresses the value and writes it to
                                    the display ports.
                                       The argument value range is 0..65535 decimal. */

0069                                {
08FE BF 69     STX    $69
0900 B7 6A     STA    $6A
006B                                char i;
006C                                unsigned long l;
0902 4F        CLRA                   for ( i=0; i < 5; ++i )
0903 B7 6B     STA    $6B
0905 B6 6B     LDA    $6B
0907 A1 05     CMP    #$05
0909 24 07     BCC    $0912
                                        {
090B 97        TAX                        digit[i] = 0x0;  /* put blanks in all digit positions */
090C 6F 50     CLR    $50,X
                                        }
090E 3C 6B     INC    $6B
0910 20 F3     BRA    $0905
0912 4F        CLRA                        for ( i=0; i < 4; ++i )
0913 B7 6B     STA    $6B
0915 B6 6B     LDA    $6B
0917 A1 04     CMP    #$04
0919 24 70     BCC    $098B
                                             {
091B 97        TAX                               if ( arg  >= dectable [i] )
091C 58        LSLX
091D D6 08 0B  LDA    $080B,X
0920 B1 6A     CMP    $6A
0922 26 07     BNE    $092B
0924 D6 08 0A  LDA    $080A,X
0927 B1 69     CMP    $69
0929 27 5C     BEQ    $0987
                                                     {
092B BE 6B     LDX    $6B                             l = dectable[i];
092D 58        LSLX
092E D6 08 0A  LDA    $080A,X
```

```
0933 D6 08 0B  LDA    $080B,X
0936 B7 6D     STA    $6D
0938 B6 6A     LDA    $6A                              digit[i] = arg / 1;
093A B7 58     STA    $58
093C B6 69     LDA    $69
093E B7 57     STA    $57
0940 B6 6C     LDA    $6C
0942 B7 66     STA    $66
0944 B6 6D     LDA    $6D
0946 B7 67     STA    $67
0948 CD 0A 5E  JSR    $0A5E
094B CD 0A 8F  JSR    $0A8F
094E BF 57     STX    $57
0950 B7 58     STA    $58
0952 BE 6B     LDX    $6B
0954 E7 50     STA    $50,X
0956 BE 6B     LDX    $6B                              arg = arg-(digit[i] * 1);
0958 E6 50     LDA    $50,X
095A 3F 57     CLR    $57
095C B7 58     STA    $58
095E B6 6C     LDA    $6C
0960 B7 66     STA    $66
0962 B6 6D     LDA    $6D
0964 B7 67     STA    $67
0966 CD 0A 3F  JSR    $0A3F
0969 BF 57     STX    $57
096B B7 58     STA    $58
096D 33 57     COM    $57
096F 30 58     NEG    $58
0971 26 02     BNE    $0975
0973 3C 57     INC    $57
0975 B6 58     LDA    $58
0977 BB 6A     ADD    $6A
0979 B7 58     STA    $58
097B B6 57     LDA    $57
097D B9 69     ADC    $69
097F B7 57     STA    $57
0981 B7 69     STA    $69
0983 B6 58     LDA    $58
0985 B7 6A     STA    $6A
                                                    }
                                                }
0987 3C 6B     INC    $6B
0989 20 8A     BRA    $0915
098B B6 6A     LDA    $6A            digit[i] = arg;
098D B7 58     STA    $58
098F B6 69     LDA    $69
0991 B7 57     STA    $57
0993 BE 6B     LDX    $6B
0995 B6 58     LDA    $58
0997 E7 50     STA    $50,X

                                     /* now zero suppress and send the lcd pattern to the display */
0999 9B        SEI                SEI;
```

```
099A 3D 50      TST     $50          if ( digit[0] == 0 )   /* leading zero suppression */
099C 26 04      BNE     $09A2
099E 3F 02      CLR     $02            portc = 0;
09A0 20 07      BRA     $09A9            else
09A2 BE 50      LDX     $50                portc = ( lcdtab[digit[0]] );     /* 100's digit */
09A4 D6 08 00   LDA     $0800,X
09A7 B7 02      STA     $02
09A9 3D 50      TST     $50                  if ( digit[0] == 0 && digit[1] == 0 )
09AB 26 08      BNE     $09B5
09AD 3D 51      TST     $51
09AF 26 04      BNE     $09B5
09B1 3F 01      CLR     $01                    portb=0;
09B3 20 07      BRA     $09BC                    else
09B5 BE 51      LDX     $51                        portb = ( lcdtab[digit[1]] );      /* 10's digit */
09B7 D6 08 00   LDA     $0800,X
09BA B7 01      STA     $01
09BC BE 52      LDX     $52                        porta = ( lcdtab[digit[2]]+1 ); /* 1's digit + decimal point */
09BE D6 08 00   LDA     $0800,X
09C1 4C         INCA
09C2 B7 00      STA     $00
09C4 9A         CLI                  CLI;
09C5 CD 08 17   JSR     $0817                      delay();
09C8 81         RTS                  }

                                     /****************************************************************/

                                     void display_psi(void)
                                     /* At power-up it is assumed that the pressure port of the sensor
                                        is open to atmosphere. The code in initio() delays for the
                                        sensor and power to stabilize. One hundred A/D conversions are
                                        averaged and divided by 100. The result is called xdcr_offset.
                                        This routine calls the A/D routine which performs one hundred
                                        conversions, divides the result by 100 and returns the value.
                                        If the value returned is less than or equal to the xdcr_offset,
                                        the value of xdcr_offset is substituted. If the value returned
                                        is greater than xdcr_offset, xdcr_offset is subtracted from the
                                        returned value. That result is multiplied by a constant to yield
                                        pressure in PSI * 10 to yield a "decimal point".
                                     */
                                     {
                                      while(1)
                                        {
09C9 3F 59      CLR     $59          slope = 64;
09CB A6 40      LDA     #$40
09CD B7 5A      STA     $5A
09CF B6 03      LDA     $03               k = portd & 0xc0;  /* this lets us "rubber" the slope to closer fit
09D1 A4 C0      AND     #$C0
09D3 B7 62      STA     $62
                                                                  the slope of the sensor */
09D5 A1 80      CMP     #$80               if ( k == 0x80 )    /* J2 removed, J1 installed */
09D7 26 06      BNE     $09DF
09D9 3F 59      CLR     $59                  slope = 65;
09DB A6 41      LDA     #$41
09DD B7 5A      STA     $5A
09DF B6 62      LDA     $62                   if ( k == 0x40 ) /* J1 removed, J2 installed */
```

```
09E1 A1 40     CMP    #$40
09E3 26 06     BNE    $09EB
09E5 3F 59     CLR    $59                  slope = 63;
09E7 A6 3F     LDA    #$3F
09E9 B7 5A     STA    $5A
                                  /* else both jumpers are removed or installed... don't change the slope */
09EB CD 08 37  JSR    $0837             atodtemp = read_a2d();  /* atodtemp = raw a/d ( 0..255 ) */
09EE 3F 55     CLR    $55
09F0 B7 56     STA    $56
09F2 B0 5D     SUB    $5D                 if ( atodtemp <= xdcr_offset )
09F4 B7 58     STA    $58
09F6 B6 5C     LDA    $5C
09F8 A8 80     EOR    #$80
09FA B7 57     STA    $57
09FC B6 55     LDA    $55
09FE A8 80     EOR    #$80
0A00 B2 57     SBC    $57
0A02 BA 58     ORA    $58
0A04 22 08     BHI    $0A0E
0A06 B6 5C     LDA    $5C                   atodtemp = xdcr_offset;
0A08 B7 55     STA    $55
0A0A B6 5D     LDA    $5D
0A0C B7 56     STA    $56
0A0E B6 56     LDA    $56                 atodtemp -=  xdcr_offset; /* remove the offset */
0A10 B0 5D     SUB    $5D
0A12 B7 56     STA    $56
0A14 B6 55     LDA    $55
0A16 B2 5C     SBC    $5C
0A18 B7 55     STA    $55
0A1A B6 56     LDA    $56               atodtemp *= slope; /* convert to psi */
0A1C B7 58     STA    $58
0A1E B6 55     LDA    $55
0A20 B7 57     STA    $57
0A22 B6 59     LDA    $59
0A24 B7 66     STA    $66
0A26 B6 5A     LDA    $5A
0A28 B7 67     STA    $67
0A2A CD 0A 3F  JSR    $0A3F
0A2D BF 55     STX    $55
0A2F B7 56     STA    $56
0A31 CD 08 FE  JSR    $08FE             cvt_bin_dec( atodtemp ); /* convert to decimal and display */
0A34 20 93     BRA    $09C9          }
0A36 81        RTS                 }

                                 /*************************************************************************/

                                   main()
                                   {
0A37 CD 08 CE  JSR    $08CE         initio(); /* set-up the processor's i/o */
0A3A AD 8D     BSR    $09C9          display_psi();
0A3C 20 FE     BRA    $0A3C           while(1);   /* should never get here */
0A3E 81        RTS                 }

0A3F BE 58     LDX    $58
0A41 B6 67     LDA    $67
```

```
0A43 42         MUL
0A44 B7 70      STA     $70
0A46 BF 71      STX     $71
0A48 BE 57      LDX     $57
0A4A B6 67      LDA     $67
0A4C 42         MUL
0A4D BB 71      ADD     $71
0A4F B7 71      STA     $71
0A51 BE 58      LDX     $58
0A53 B6 66      LDA     $66
0A55 42         MUL
0A56 BB 71      ADD     $71
0A58 B7 71      STA     $71
0A5A 97         TAX
0A5B B6 70      LDA     $70
0A5D 81         RTS

0A5E 3F 70      CLR     $70
0A60 5F         CLRX
0A61 3F 6E      CLR     $6E
0A63 3F 6F      CLR     $6F
0A65 5C         INCX
0A66 38 58      LSL     $58
0A68 39 57      ROL     $57
0A6A 39 6E      ROL     $6E
0A6C 39 6F      ROL     $6F
0A6E B6 6E      LDA     $6E
0A70 B0 67      SUB     $67
0A72 B7 6E      STA     $6E
0A74 B6 6F      LDA     $6F
0A76 B2 66      SBC     $66
0A78 B7 6F      STA     $6F
0A7A 24 0D      BCC     $0A89
0A7C B6 67      LDA     $67
0A7E BB 6E      ADD     $6E
0A80 B7 6E      STA     $6E
0A82 B6 66      LDA     $66
0A84 B9 6F      ADC     $6F
0A86 B7 6F      STA     $6F
0A88 99         SEC
0A89 59         ROLX
0A8A 39 70      ROL     $70
0A8C 24 D8      BCC     $0A66
0A8E 81         RTS
0A8F 53         COMX
0A90 9F         TXA
0A91 BE 70      LDX     $70
0A93 53         COMX
0A94 81         RTS
1FFE 0A 37
```

```
SYMBOL TABLE

LABEL        VALUE  LABEL        VALUE  LABEL        VALUE  LABEL        VALUE

IRQ          0813 | SCI          0816 | TIMERCAP     0814 | TIMERCMP     089B
TIMEROV      0815 | __LDIV       0A5E | __LongIX     0066 | __MUL        0000
__MUL16x16   0A3F | __RDIV       0A8F | __RESET      1FFE | __STARTUP    0000
__STOP       0000 | __SWI        0812 | __WAIT       0000 | __longAC     0057
acnthi       001A | acntlo       001B | adcnt        005B | addata       0008
adstat       0009 | adzero       08A4 | arg          0069 | atodtemp     0055
b            0000 | bothbytes    0002 | cvt_bin_dec  08FE | ddra         0004
ddrb         0005 | ddrc         0006 | dectable     080A | delay        0817
digit        0050 | display_psi  09C9 | eeclk        0007 | fixcompare   0880
hi           0000 | i            005E | icaphi1      0014 | icaphi2      001C
icaplo1      0015 | icaplo2      001D | initio       08CE | isboth       0002
j            0060 | k            0062 | l            0000 | lcdtab       0800
lo           0001 | main         0A37 | misc         000C | ocmphi1      0016
ocmphi2      001E | ocmplo1      0017 | ocmplo2      001F | plma         000A
plmb         000B | porta        0000 | portb        0001 | portc        0002
portd        0003 | q            0063 | read_a2d     0837 | scibaud      000D
scicntl1     000E | scicntl2     000F | scidata      0011 | scistat      0010
slope        0059 | tcnthi       0018 | tcntlo       0019 | tcr          0012
tsr          0013 | xdcr_offset  005C |

MEMORY USAGE MAP ('X' = Used, '-' = Unused)

0100 : ---------------- ---------------- ---------------- ----------------
0140 : ---------------- ---------------- ---------------- ----------------
0180 : ---------------- ---------------- ---------------- ----------------
01C0 : ---------------- ---------------- ---------------- --------------X-

0800 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0840 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0880 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
08C0 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX

0900 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0940 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0980 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
09C0 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX

0A00 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0A40 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0A80 : XXXXXXXXXXXXXXXX XXXXX----------- ---------------- ----------------
0AC0 : ---------------- ---------------- ---------------- ----------------

1F00 : ---------------- ---------------- ---------------- ----------------
1F40 : ---------------- ---------------- ---------------- ----------------
1F80 : ---------------- ---------------- ---------------- ----------------
1FC0 : ---------------- ---------------- ---------------- --XXXXXXXXXXXXXX

All other memory blocks unused.
Errors            :    0
Warnings          :    0
```

AN1309
Rev 2, 05/2005

Compensated Sensor Bar Graph Pressure Gauge

by: Warren Schultz
Discrete Applications Engineering

INTRODUCTION

Compensated semiconductor pressure sensors such as the MPX2000 family are relatively easy to interface with digital systems. With these sensors and the circuitry described herein, pressure is translated into a 0.5 to 4.5 volt output range that is directly compatible with Microcomputer A/D inputs. The 0.5 to 4.5 volt range also facilitates interface with an LM3914, making Bar Graph Pressure Gauges relatively simple.

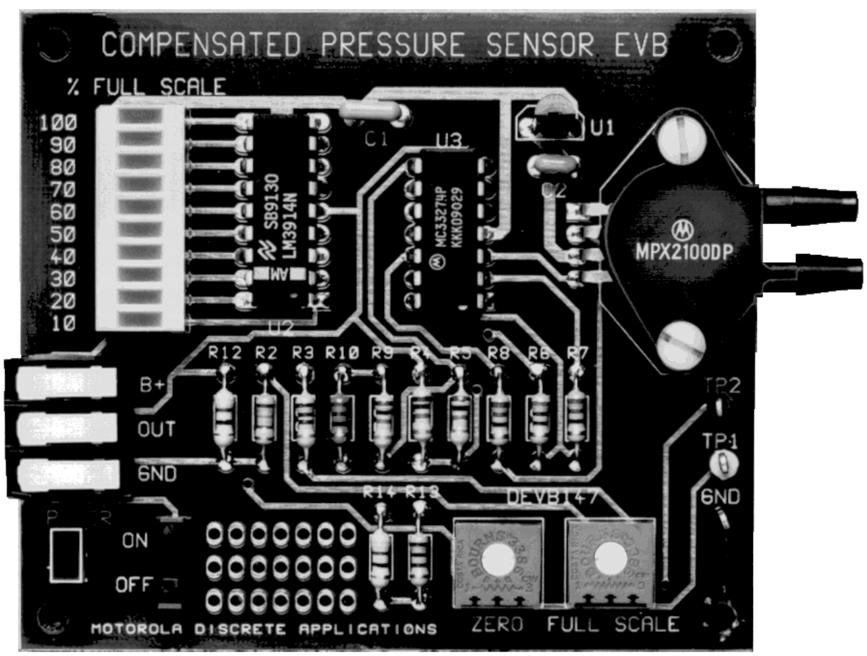


Figure 1. DEVB147 Compensated Pressure Sensor Evaluation Board (Board No Longer Available)

EVALUATION BOARD DESCRIPTION

The information required to use evaluation board number DEVB147 follows, and a discussion of the design appears in the DESIGN CONSIDERATIONS section.

Function

The evaluation board shown in Figure 1 is supplied with an MPX2100DP sensor and provides a 100 kPa full scale pressure measurement. It has two input ports. P1, the pressure port, is on the top side of the sensor and P2, a vacuum port, is on the bottom side. These ports can be supplied up to 100 kPa (15 psi) of pressure on P1 or up to 100 kPa of vacuum on P2, or a differential pressure up to 100 kPa between P1 and P2. Any of these sources will produce the same output.

The primary output is a 10 segment LED bar graph, which is labeled in increments of 10% of full scale, or 10 kPa with the MPX2100 sensor. An analog output is also provided. It nominally supplies 0.5 volts at zero pressure and 4.5 volts at full scale. Zero and full scale adjustments are made with potentiometers so labeled at the bottom of the board. Both adjustments are independent of one another.

ELECTRICAL CHARACTERISTICS

The following electrical characteristics are included as a guide to operation.

Characteristic	Symbol	MIn	Typ	Max	Units
Power Supply Voltage	B+	6.8	—	13.2	dc Volts
Full Scale Pressure	PFS	—	—	100	kPa
Overpressure	PMAX	—	—	700	kPa
Analog Full Scale	VFS	—	4.5	—	Volts
Analog Zero Pressure Offset	VOFF	—	0.5	—	Volts
Analog Sensitivity	SAOUT	—	40	—	mV/kPa
Quiescent Current	ICC	—	40	—	mA
Full Scale Current	IFS	—	160	—	mA

Content

Board contents are described in the parts list shown in Table 1. A schematic and silk screen plot are shown in Figure 2 and Figure 6. A pin by pin circuit description follows.

Pin-by-Pin Description

B+

Input power is supplied at the B+ terminal. Minimum input voltage is 6.8 volts and maximum is 13.2 volts. The upper limit is based upon power dissipation in the LM3914 assuming all 10 LED's are lit and ambient temperature is 25°C. The board will survive input transients up to 25 volts provided that average power dissipation in the LM3914 does not exceed 1.3 watts.

OUT

An analog output is supplied at the OUT terminal. The signal it provides is nominally 0.5 volts at zero pressure and 4.5 volts at full scale. Zero pressure voltage is adjustable and set with R11. This output is designed to be directly connected to a microcomputer A/D channel, such as one of the E ports on an MC68HC11.

GND

There are two ground connections. The ground terminal on the left side of the board is intended for use as the power supply return. On the right side of the board one of the test point terminals is also connected to ground. It provides a convenient place to connect instrumentation grounds.

TP1

Test point 1 is connected to the LM3914's full scale reference voltage which sets the trip point for the uppermost LED segment. This voltage is adjusted via R1 to set full scale pressure.

TP2

Test point 2 is connected to the +5.0 volt regulator output. It can be used to verify that supply voltage is within its 4.75 to 5.25 volt tolerance.

P1, P2

Pressure and Vacuum ports P1 and P2 protrude from the sensor on the right side of the board. Pressure port P1 is on the top and vacuum port P2 is on the bottom. Neither port is labeled. Maximum safe pressure is 700 kPa.

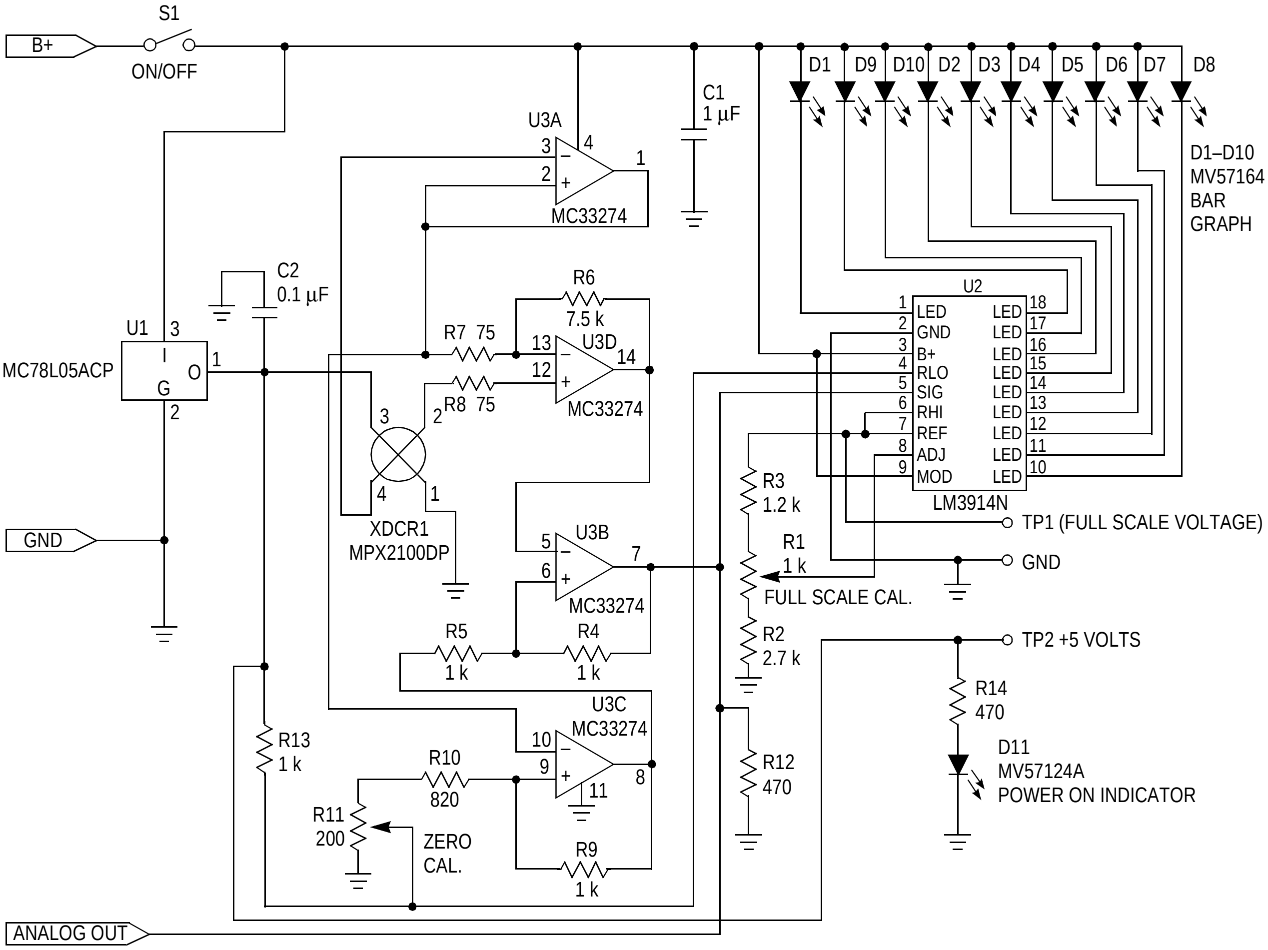


Figure 2. Compensated Pressure Sensor EVB Schematic

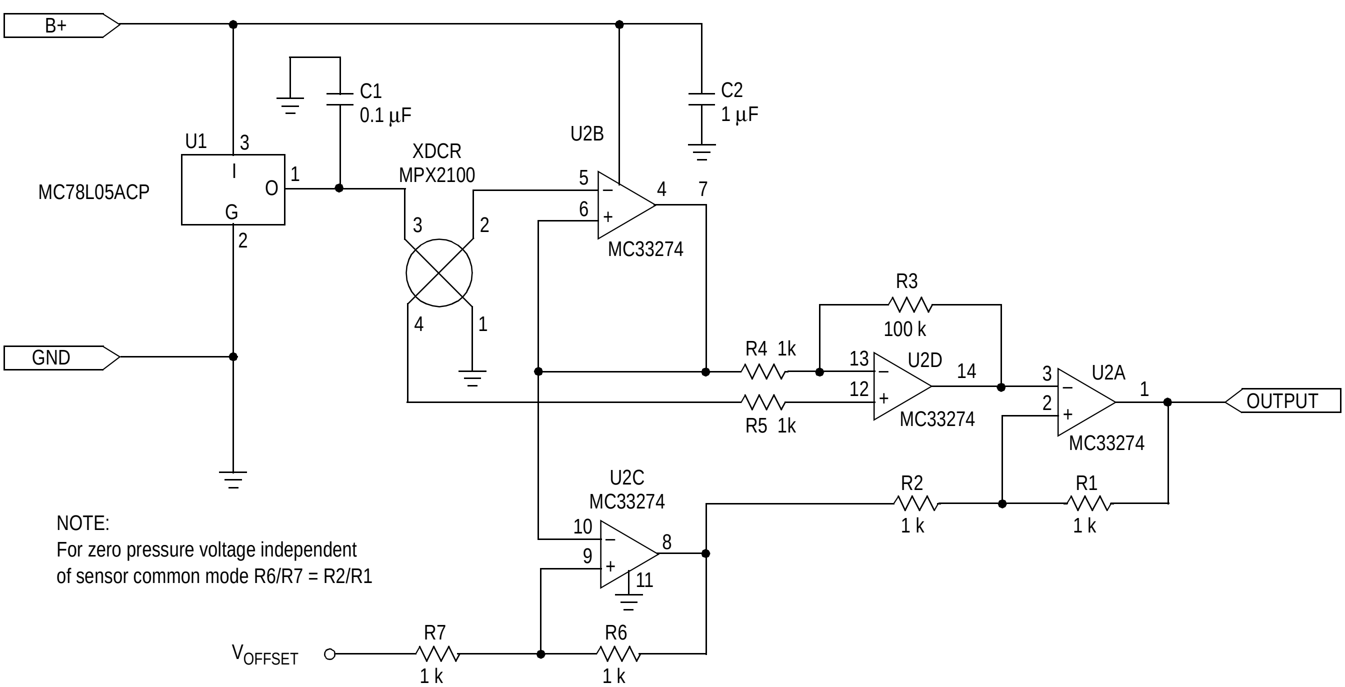


Figure 3. Compensated Sensor Interface

DESIGN CONSIDERATIONS

In this type of application the design challenge is how to take a relatively small DC coupled differential signal and produce a ground referenced output that is suitable for driving microcomputer A/D inputs. A user friendly interface circuit that will do this job is shown in Figure 3. It uses one quad op amp and several resistors to amplify and level shift the sensor's output. Most of the amplification is done in U2D which is configured as a differential amplifier. It is isolated from the sensor's positive output by U2B. The purpose of U2B is to prevent feedback current that flows through R3 and R4 from flowing into the sensor. At zero pressure the voltage from pin 2 to pin 4 on the sensor is zero volts. For example with the common mode voltage at 2.5 volts, the zero pressure output voltage at pin 14 of U2D is then 2.5 volts, since any other voltage would be coupled back to pin 13 via R3 and create a nonzero bias across U2D's differential inputs. This 2.5 volt zero pressure DC output voltage is then level translated to the desired zero pressure offset voltage (V_{OFFSET}) by U2C and U2A. To see how the level translation works, assume 0.5 volts at (V_{OFFSET}). With 2.5 volts at pin 10, pin 9 is also at 2.5 volts. This leaves 2.5 - 0.5 = 2.0 volts across R7. Since no current flows into pin 9, the same current flows through R6, producing 2.0 volts across R6 also. Adding the voltages (0.5 + 2.0 +2.0) yields 4.5 volts at pin 8. Similarly 2.5 volts at pin 3 implies 2.5 volts at pin 2, and the drop across R2 is 4.5 V - 2.5 V = 2.0 volts. Again 2.0 volts across R2 implies an equal drop across R1, and the voltage at pin 1 is 2.5 V - 2.0 V = 0.5 volts. For this DC output voltage to be independent of the sensor's common mode voltage it is necessary to satisfy the condition that R6/R7 = R2/R1.

Gain is close but not exactly equal to R3/R4(R1/R2+1), which predicts 200.0 for the values shown in Figure 3. A more exact calculation can be performed by doing a nodal analysis, which yields 199.9. Cascading the gains of U2D and U2A using standard op amp gain equations does not give an exact result, because the sensor's negative going differential signal at pin 4 subtracts from the DC level that is amplified by U2A.

The resulting 0.5 V to 4.5 V output from U2A is directly compatible with microprocessor A/D inputs. Tying this output to an LM3914 for a bar graph readout is also very straight forward. The block diagram that appears in Figure 4 shows the LM3914's internal architecture. Since the lower resistor in the input comparator chain is pinned out at R_{LO}, it is a simple matter to tie this pin to a voltage that is approximately equal to the interface circuit's 0.5 volt zero pressure output voltage. In Figure 2, this is accomplished by dividing down the 5.0 volt regulator's output voltage through R13 and adjustment pot R11. The voltage generated at R11's wiper is the offset voltage identified as V_{OFFSET} in Figure 3. Its source impedance is chosen to keep the total input impedance to U3C at approximately 1K. The wiper of R11 is also fed into R_{LO} for zeroing the bar graph.

The full scale measurement is set by adjusting the upper comparator's reference voltage to match the sensor's output at full pressure. An internal regulator on the LM3914 sets this voltage with the aid of resistors R2, R3, and adjustment pot R1 that are shown in Figure 2.

Five volt regulated power is supplied by an MC78L05. The LED's are powered directly from LM3914 outputs, which are set up as current sources. Output current to each LED is approximately 10 times the reference current that flows from pin 7 through R3, R1, and R2 to ground. In this design it is nominally (4.5 V/4.9K)10 = 9.2 mA.

Over a zero to 50°C temperature range combined accuracy for the sensor, interface and driver IC are +/- 10%. Given a 10 segment display total accuracy for the bar graph readout is approximately +/- (10 kPa +10%).

APPLICATION

Using the analog output to provide pressure information to a microcomputer is very straightforward. The output voltage range, which goes from 0.5 volts at zero pressure to 4.5 volts at full scale, is designed to make optimum use of microcomputer A/D inputs. A direct connection from the evaluation board analog output to an A/D input is all that is required. Using the MC68HC11 as an example, the output is connected to any of the E ports, such as port E0 as shown in Figure 5. To get maximum accuracy from the A/D conversion, V_{REFH} is tied to 4.85 volts and V_{REFL} is tied to 0.3 volts by dividing down a 5.0 volt reference with 1% resistors.

CONCLUSION

Perhaps the most noteworthy aspect to the bar graph pressure gauge described here is the ease with which it can be designed. The interface between an MPX2000 series sensor and LM3914 bar graph display driver consists of one quad op amp and a few resistors. The result is a simple and inexpensive circuit that is capable of measuring pressure, vacuum, or differential pressure with an output that is directly compatible to a microprocessor.

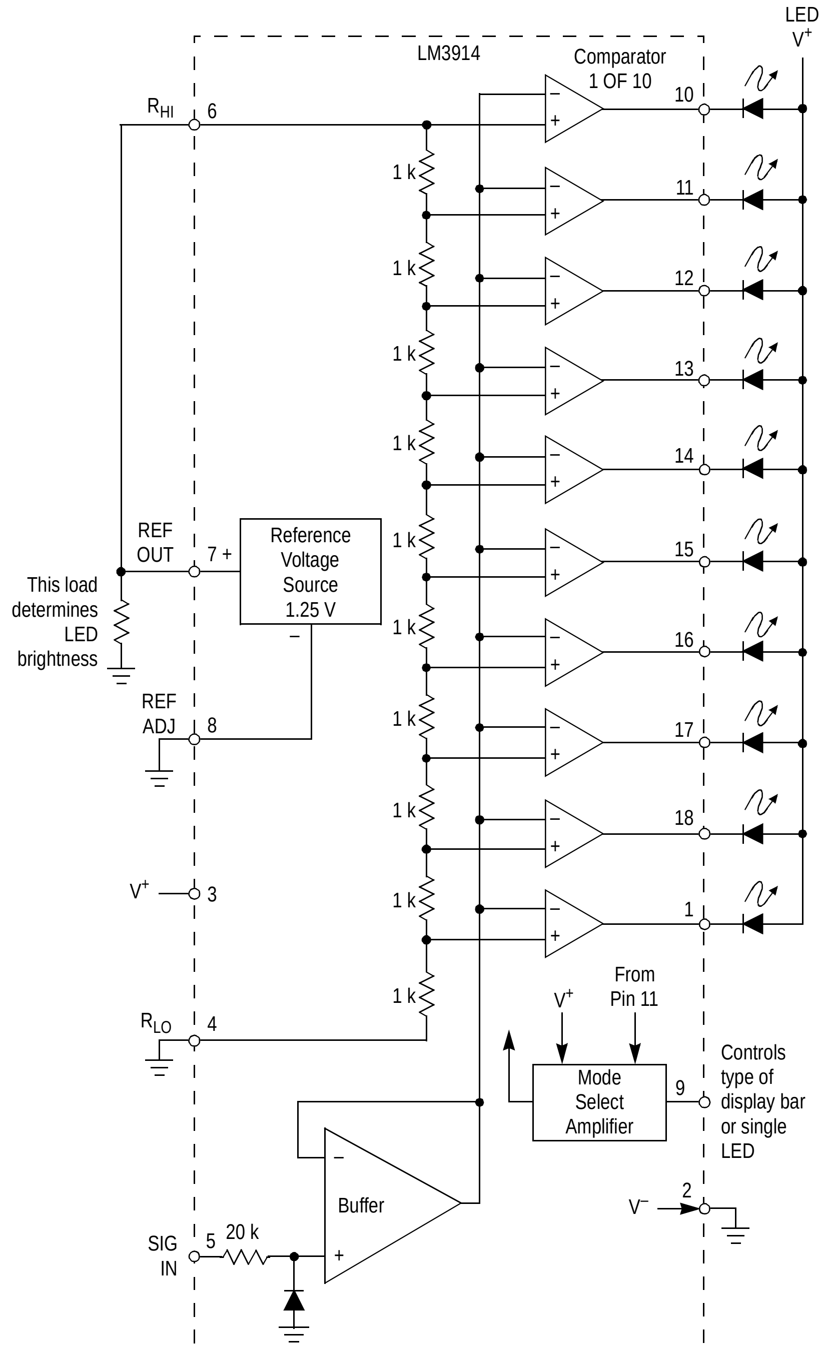


Figure 4. LM3914 Block Diagram

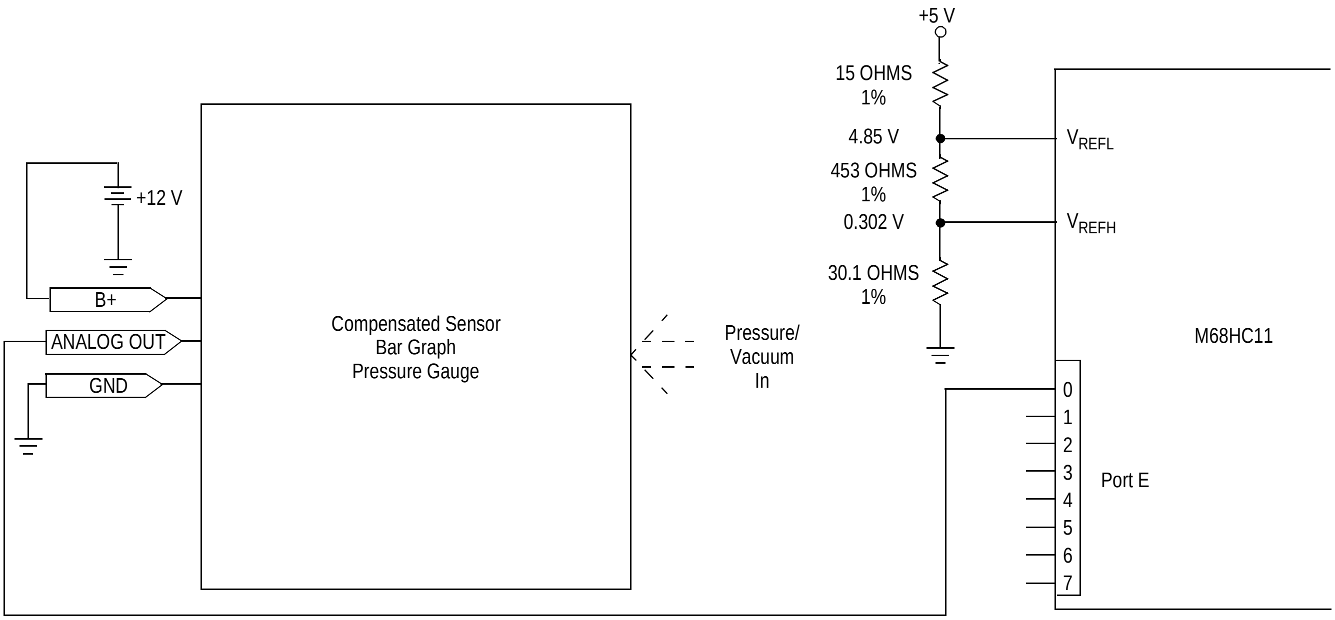


Figure 5. Application Example

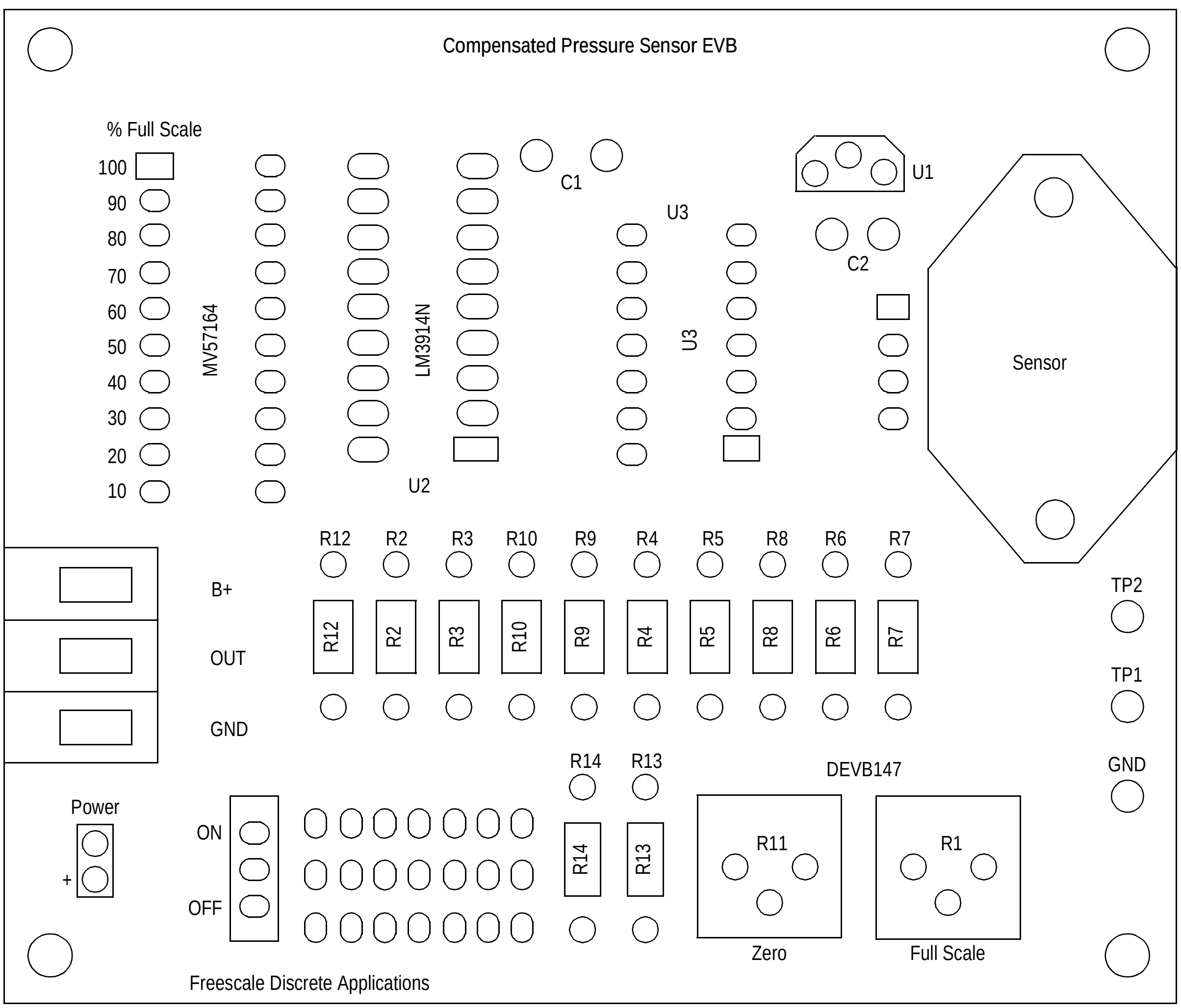


Figure 6. Silk Screen

Table 1. Parts List

Designators	Quant.	Description	Rating	Manufacturer	Part Number
C1	1	Ceramic Capacitor	1.0 µF		
C2	1	Ceramic Capacitor	0.1 µF		
D1-D10	1	Bar Graph LED		GI	MV57164
D11	1	LED		GI	MV57124A
R2	1	1/4 Watt Film Resistor	2.7K		
R3	1	1/4 Watt Film Resistor	1.2K		
R4, R5, R9, R13	4	1/4 Watt Film Resistor	1.0K		
R6	1	1/4 Watt Film Resistor	7.5K		
R7, R8	2	1/4 Watt Film Resistor	75		
R10	1	1/4 Watt Film Resistor	820		
R12, R14	2	1/4 Watt Film Resistor	470		
R1	1	Trimpot	1.0K	Bourns	3386P-1-102
R11	1	Trimpot	200	Bourns	3386P-1-201
S1	1	Switch		NKK	12SDP2
U1	1	5.0 V Regulator		Freescale	MC78L05ACP
U2	1	Bar Graph IC		National	LM3914N
U3	1	Op Amp		Freescale	MC33274P
XDCR1	1	Pressure Sensor		Freescale	MPX2100DP
—	1	Terminal Block		Augat	2SV03
—	1	Test Point Terminal (Black)		Components Corp.	TP1040100
—	1	Test Point Terminal (Red)		Components Corp.	TP1040102
—	1	Test Point Terminal (Yellow)		Components Corp.	TP1040104

An Evaluation System Interfacing the MPX2000 Series Pressure Sensors to a Microprocessor

by: **Bill Lucas**
Discrete Applications Engineering

INTRODUCTION

Outputs from compensated and calibrated semiconductor pressure sensors such as the MPX2000 series devices are easily amplified and interfaced to a microprocessor. Design considerations and the description of an evaluation board using a simple analog interface connected to a microprocessor is presented here.

PURPOSE

The evaluation system shown in Figure 1 shows the ease of operating and interfacing the Freescale Semiconductor, Inc. MPX2000 series pressure sensors to a quad operational amplifier, which amplifies the sensor's output to an acceptable level for an analog-to-digital converter. The output of the op amp is connected to the A/D converter of the microprocessor and that analog value is then converted to engineering units and displayed on a liquid crystal display (LCD). This system may be used to evaluate any of the MPX2000 series pressure sensors for your specific application.

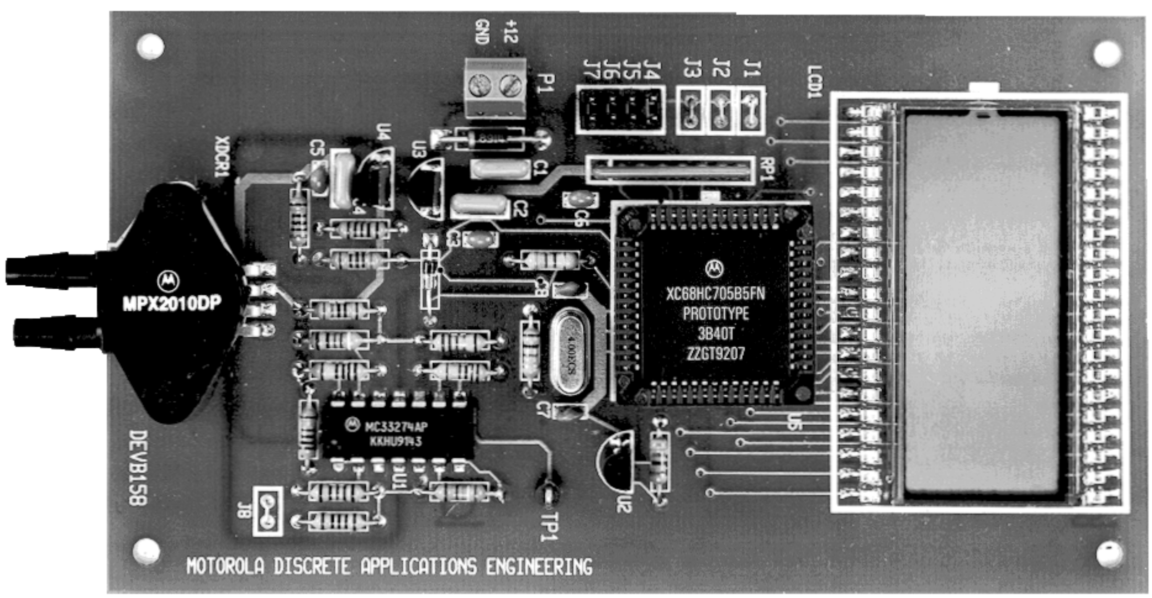


Figure 1. DEVB158 2000 Series LCD Pressure Gauge EVB (Board No Longer Available)

DESCRIPTION

The DEVB158 evaluation system is constructed on a small printed circuit board. Designed to be powered from a 12 Vdc power supply, the system will display the pressure applied to the MPX2000 series sensor in pounds per square inch (PSI) on the liquid crystal display. Table 1 shows the pressure sensors that may be used with the system and the pressure range associated with that particular sensor as well as the jumper configuration required to support that sensor. These jumpers are installed at assembly time to correspond with the supplied sensor. Should the user chose to evaluate a different sensor other than that supplied with the board, the jumpers must be changed to correspond to Table 1 for the new sensor. The displayed pressure is scaled to the full scale (PSI) range of the installed pressure sensor. No potentiometers are used in the system to adjust its span and offset. This function is performed by software.

Table 1. Missing Table Head

Sensor Type	Input Pressure PSI	Jumpers			
		J8	J3	J2	J1
MPX2010	0-1.5	IN	IN	IN	IN
MPX2050	0-7.5	OUT	IN	IN	OUT
MPX2100	0-15.0	OUT	IN	OUT	IN
MPX2200	0-30	OUT	IN	OUT	OUT

The signal conditioned sensor's zero pressure offset voltage with no pressure applied to the sensor is empirically computed each time power is applied to the system and stored in RAM. The sensitivity of the MPX2000 series pressure sensors is quite repeatable from unit to unit. There is a facility for a small adjustment of the slope constant built into the program. It is accomplished via jumpers J4 through J7, and will be explained in the OPERATION section.

Figure 2 shows the printed circuit silkscreen and Figure 3 and Figure 4show the schematic for the system.

The analog section of the system can be broken down into two subsections. These sections are the power supply and the amplification section. The power supply section consists of a diode, used to protect the system from input voltage reversal, and two fixed voltage regulators. The 5 volt regulator (U3) is used to power the microprocessor and display. The 8 volt regulator (U4) is used to power the pressure sensor, voltage references and a voltage offset source.

The microprocessor section (U5) requires minimal support hardware to function. The MC34064P-5 (U2) provides an under voltage sense function and is used to reset the microprocessor at system power-up. The 4.0 MHz crystal (Y1) provides the external portion of the oscillator function for clocking the microprocessor and providing a stable base for timing functions.

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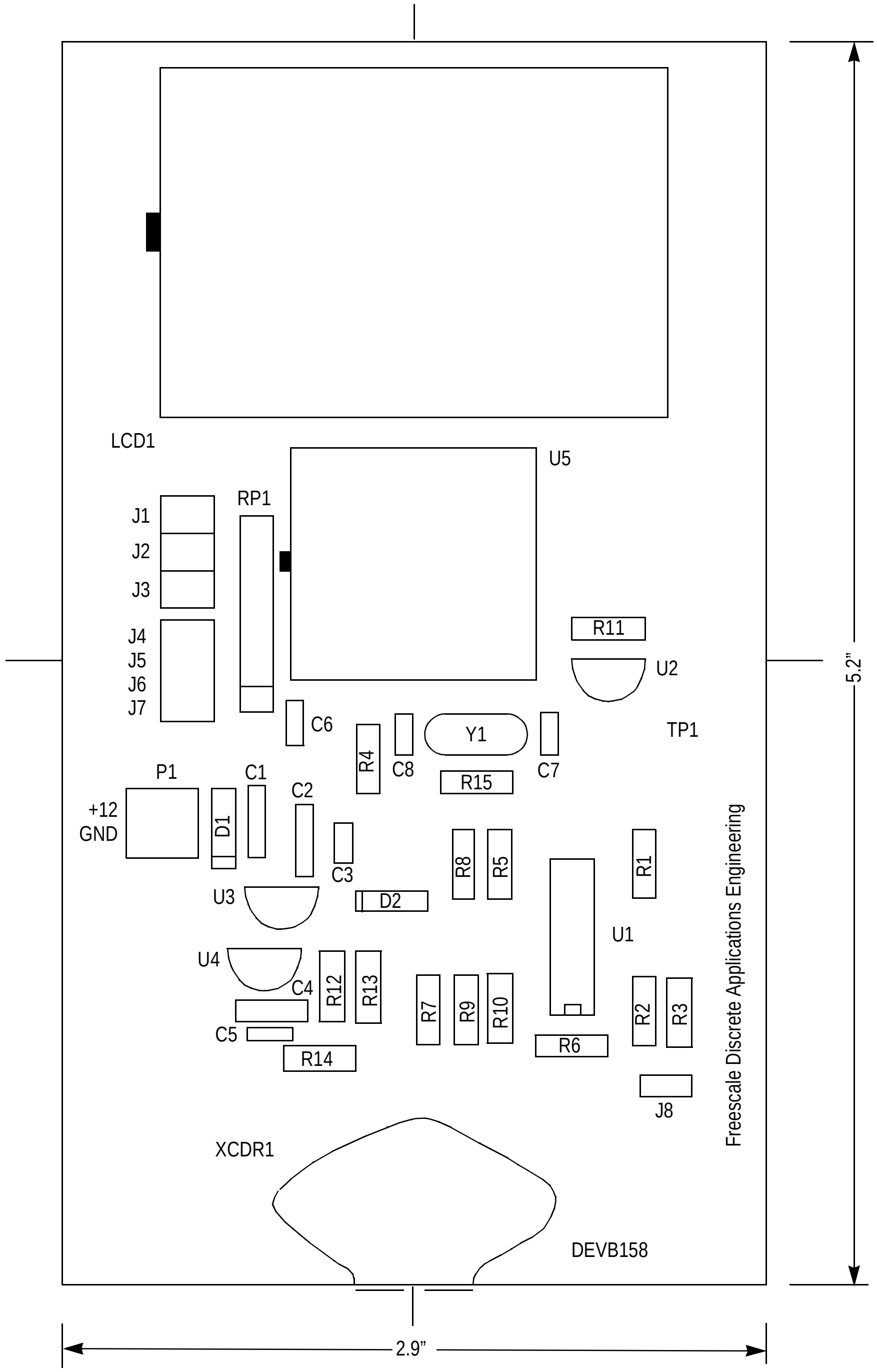

Figure 2. Printed Circuit Silkscreen

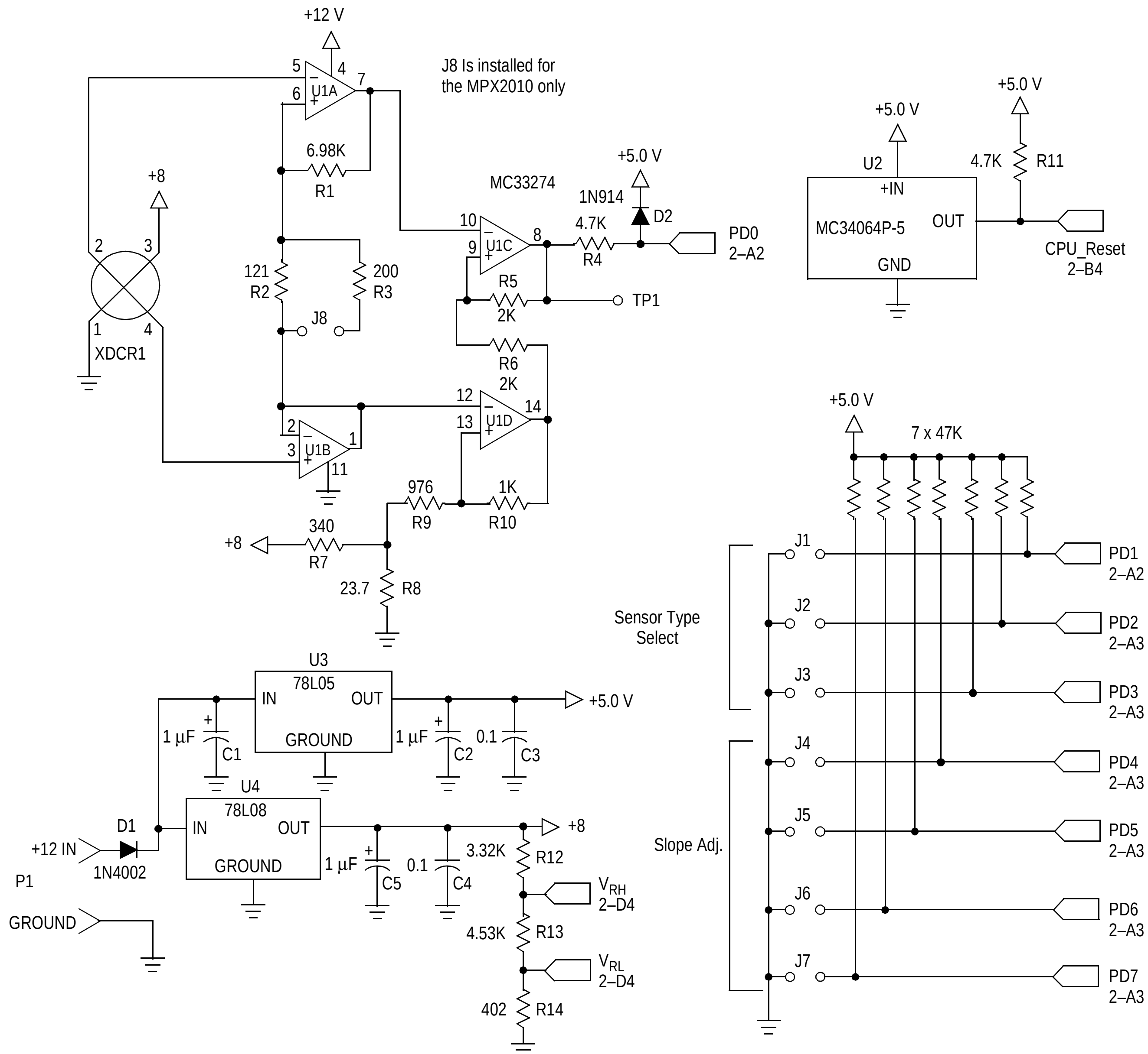

Figure 3. Schematic A

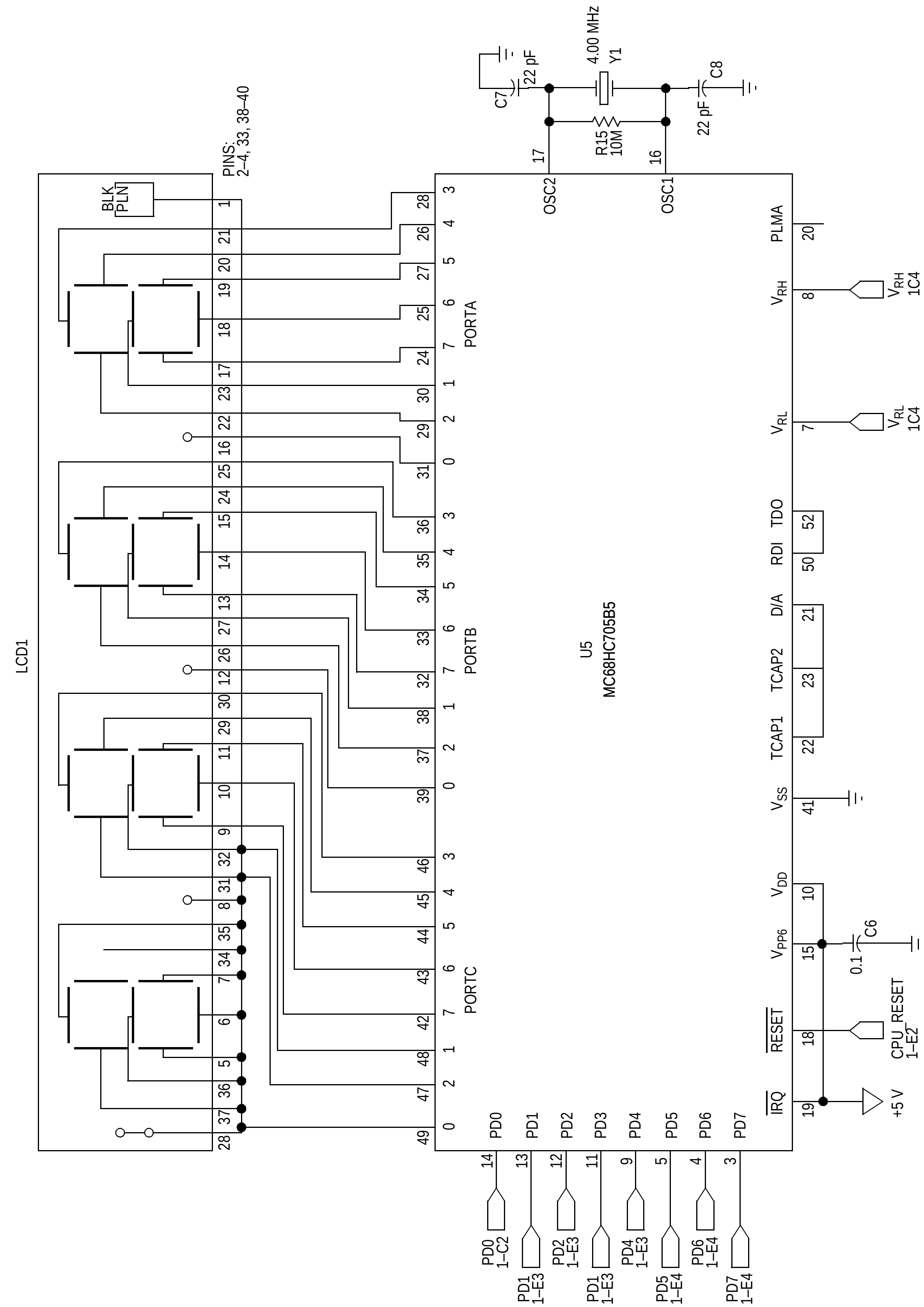

Figure 4. Schematic B

Table 2. Parts List

Designators	Quant.	Description	Rating	Manufacturer	Part Number
C3, C4, C6	3	0.1 μF Ceramic Cap.	50 Vdc	Sprague	1C105Z5U104M050B
C1, C2, C5	3	1 μF Ceramic Cap.	50 Vdc	muRATA ERIE	RPE123Z5U105M050V
C7, C8	2	22 pF Ceramic Cap.	100 Vdc	Mepco/Centralab	CN15A220K
J1-J3, J8	3 OR 4	#22 or #24 AWG Tined Copper		As Required	
J4-J7	1	Dual Row Straight 4 Pos. Arranged On 0.1″ Grid		AMP	87227-2
LCD1	1	Liquid Crystal Display		IEE	LCD5657
P1	1	Power Connector		Phoenix Contact	MKDS 1/2-3.81
R1	1	6.98K Ohm resistor 1%			
R2	1	121 Ohm Resistor 1%			
R3	1	200 Ohm Resistor 1%			
R4, R11	2	4.7K Ohm Resistor			
R7	1	340 Ohm Resistor 1%			
R5, R6	2	2.0K Ohm Resistor 1%			
R8	1	23.7 Ohm Resistor 1%			
R9	1	976 Ohm Resistor 1%			
R10	1	1K Ohm Resistor 1%			
R12	1	3.32K Ohm Resistor 1%			
R13	1	4.53K Ohm Resistor 1%			
R14	1	402 Ohm Resistor 1%			
R15	1	10 Meg Ohm Resistor			
RP1	1	47K Ohm x 7 SIP Resistor 2%		CTS	770 Series
TP1	1	Test Point	Red	Components Corp.	TP-104-01-02
U1	1	Quad Operational Amplifier		Freescale	MC33274P
U2	1	Under Voltage Detector		Freescale	MC34064P-5
U3	1	5 Volt Fixed Voltage Regulator		Freescale	MC78L05ACP
U4	1	8 Volt Fixed Voltage Regulator		Freescale	MC78L08ACP
U5	1	Microprocessor		Freescale Freescale	MC68HC705B5FN or XC68HC705B5FN
XDCR	1	Pressure Sensor		Freescale	MPX2xxxDP
Y1	1	Crystal (Low Profile)	4.0 MHz	CTS	ATS040SLV
No Designator	1	52 Pin PLCC Socket for U5		AMP	821-575-1
No Designator	4	Jumpers For J4 thru J7		Molex	15-29-1025
No Designator	1	Bare Printed Circuit Board			
No Designator	4	Self Sticking Feet		Fastex	5033-01-00-5001

Notes: All resistors are 1/4 W resistors with a tolerance of 5% unless otherwise noted.
All capacitors are 100 volt, ceramic capacitors with a tolerance of 10% unless otherwise noted.

OPERATIONAL CHARACTERISTICS

The following operational characteristics are included as a guide to operation.

Characteristic	Symbol	Min	Max	Unit
Power Supply Voltage	+12	10.75	16	Volts
Operating Current	I_{CC}		75	mA
Full Scale Pressure	P_{fs}			
MPX2010			1.5	PSI
MPX2050			7.5	PSI
MPX2100			15	PSI
MPX2200			30	PSI

Pin-by-Pin Description

+12

Input power is supplied at the +12 terminal. The minimum operating voltage is 10.75 Vdc and the maximum operating voltage is 16 Vdc.

GND

The ground terminal is the power supply return for the system.

TP1

Test point 1 is connected to the final op amp stage. It is the voltage that is applied to the microprocessor's A/D converter.

There are two ports on the pressure sensor located at the bottom center of the printed circuit board. The pressure port is on the top left and the vacuum port is on the bottom right of the sensor.

OPERATION

Connect the system to a 12 Vdc regulated power supply. (Note the polarity marked on the power terminal P1.) Depending on the particular pressure sensor being used with the system, wire jumpers J1 through J3 and J8 must be installed at board assembly time. If at some later time it is desirable to change the type of sensor that is installed on the board, jumpers J1 through J3 and J8, must be reconfigured for the system to function properly (see Table 1). If an invalid J1 through J3 jumper combination (i.e., not listed in Table 1) is used the LCD will display “SE” to indicate that condition. These jumpers are read by the software and are used to determine which sensor is installed on the board. Wire jumper J8 is installed only when an MPX2010DP pressure sensor is used on the system. The purpose of wire jumper J8 will be explained later in the text. Jumpers J4 through J7 are read by the software to allow the user to adjust the slope constant used for the engineering units calculation (see Table 3). The pressure and vacuum ports on the sensor must be left open to atmosphere anytime the board is powered-up. This is because the zero pressure offset voltage is computed at power-up.

When you apply power to the system, the LCD will display CAL for approximately 5 seconds. After that time, pressure or vacuum may be applied to the sensor. The system will then start displaying the applied pressure in PSI.

Table 3. Slope Constants

J7	J6	J5	J4	Action
IN	IN	IN	IN	Normal Slope
IN	IN	IN	OUT	Decrease the Slope Approximately 7%
IN	IN	OUT	IN	Decrease the Slope Approximately 6%
IN	IN	OUT	OUT	Decrease the Slope Approximately 5%
IN	OUT	IN	IN	Decrease the Slope Approximately 4%
IN	OUT	IN	OUT	Decrease the Slope Approximately 3%
IN	OUT	OUT	IN	Decrease the Slope Approximately 2%
IN	OUT	OUT	OUT	Decrease the Slope Approximately 1%
OUT	IN	IN	IN	Increase the Slope Approximately 1%
OUT	IN	IN	OUT	Increase the Slope Approximately 2%
OUT	IN	OUT	IN	Increase the Slope Approximately 3%
OUT	IN	OUT	OUT	Increase the Slope Approximately 4%
OUT	OUT	IN	IN	Increase the Slope Approximately 5%
OUT	OUT	IN	OUT	Increase the Slope Approximately 6%
OUT	OUT	OUT	IN	Increase the Slope Approximately 7%
OUT	OUT	OUT	OUT	Normal Slope

To improve the accuracy of the system, you can change the constant used by the program that determines the span of the sensor and amplifier. You will need an accurate test gauge (using PSI as the reference) to measure the pressure applied to the sensor. Anytime after the display has completed the zero calculation, (after CAL is no longer displayed) apply the sensor's full scale pressure (see Table 1), to the sensor. Make sure that jumpers J4 through J7 are in the “normal” configuration (see Table 3). Referring to Table 3, you can better “calibrate” the system by changing the configuration of J4 through J7. To “calibrate” the system, compare the display reading against that of the test gauge (with J4 through J7 in the “normal slope” configuration). Change the configuration of J4 through J7 according to Table 3 to obtain the best results. The calibration jumpers may be changed while the system is powered up as they are read by the software before each display update.

DESIGN CONSIDERATIONS

To build a system that will show how to interface an MPX2000 series pressure sensor to a microprocessor, there are two main challenges. The first is to take a small differential signal produced by the sensor and produce a ground referenced signal of sufficient amplitude to drive a microprocessor's A/D input. The second challenge is to understand the microprocessor's operation and to write software that makes the system function.

From a hardware point of view, the microprocessor portion of the system is straight forward. The microprocessor needs power, a clock source (crystal Y1, two capacitors and a resistor), and a reset signal to make it function. As for the A/D converter, external references are required to make it function. In this case, the power source for the sensor is divided to produce the voltage references for the A/D converter. Accurate results will be achieved since the output from the sensor and the A/D references are ratiometric to its power supply voltage.

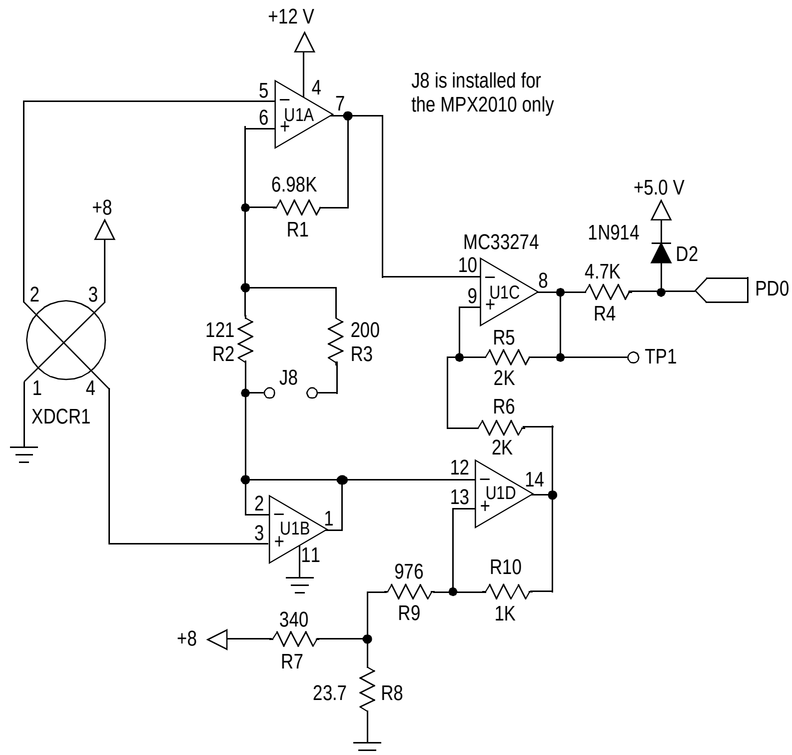

Figure 5. Analog Interface

The liquid crystal display is driven by Ports A, B and C of the microprocessor. There are enough I/O lines on these ports to provide drive for three full digits, the backplane and two decimal points. Software routines provide the AC waveform necessary to drive the display.

The analog portion of the system consists of the pressure sensor, a quad operational amplifier and the voltage references for the microprocessor's A/D converter and signal conditioning circuitry. Figure 5 shows an interface circuit that will provide a single ended signal with sufficient amplitude to drive the microprocessor's A/D input. It uses a quad operational amplifier and several resistors to amplify and level shift the sensor's output. It is necessary to level shift the output from the final amplifier into the A/D. Using single power supplied op amps, the V_{CE} saturation of the output from an op amp cannot be guaranteed to pull down to zero volts. The analog design shown here will provide a signal to the A/D converter with a span of approximately 4 volts when zero to full-scale pressure is applied to the sensor. The final amplifier's output is level shifted to approximately 0.7 volts. This will provide a signal that will swing between approximately 0.7 volts and 4.7 volts. The offset of 0.7 volts in this implementation does not have to be trimmed to an exact point. The software will sample the voltage applied to the A/D converter at initial power up time and call that value “zero”. The important thing to remember is that the span of the signal will be approximately 4 volts when zero to full scale pressure is applied to the sensor. The 4 volt swing in signal may vary slightly from sensor to sensor and can also vary due to resistor tolerances in the analog circuitry. Jumpers J4 through J7 may be placed in various configurations to compensate for these variations (see Table 3).

Referring to Figure 5, most of the amplification of the voltage from the pressure sensor is provided by U1A which is configured as a differential amplifier. U1B serves as a unity gain buffer in order to keep any current that flows through R2 (and R3) from being fed back into the sensor's negative output. With zero pressure applied to the sensor, the differential voltage from pin 2 to pin 4 of the sensor is zero or very close to zero volts. The common mode, or the voltage measured between pins 2 or 4 to ground, is equal to approximately one half of the voltage applied to the sensor, or 4 volts. The zero pressure output voltage at pin 7 of U1A will then be 4 volts because pin 1 of U1B is also at 4 volts, creating a zero bias between pins 5 and 6 of U1A. The four volt zero pressure output will then be level shifted to the desired zero pressure offset voltage (approximately 0.7 volts) by U1C and U1D.

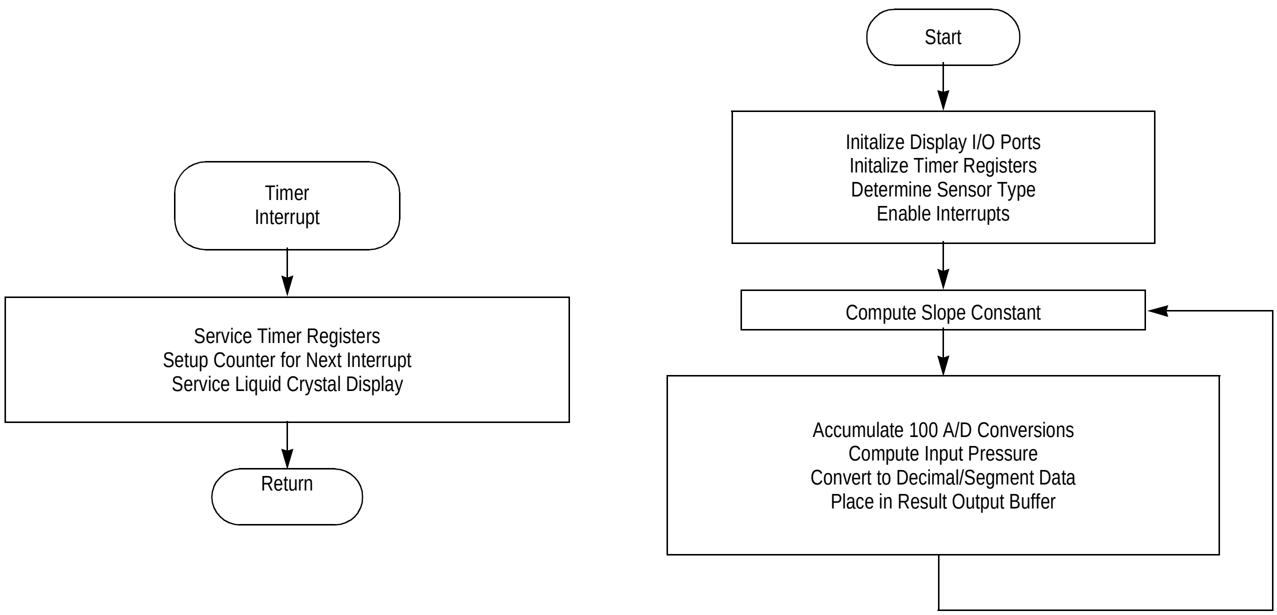

Figure 6. DEVB-158 Software Flowchart

To further explain the operation of the level shifting circuitry, refer again to Figure 5. Assuming zero pressure is applied to the sensor and the common mode voltage from the sensor is 4 volts, the voltage applied to pin 12 of U1D will be 4 volts, implying pin 13 will be at 4 volts. The gain of amplifier U1D will be (R10/(R8+R9)) +1 or a gain of 2. R7 will inject a V_{offset} (0.7 volts) into amplifier U1D, thus causing the output at U1D pin 14 to be 7.3 = (4 volts @ U1D pin 12 $\times$ 2) - 0.7 volts. The gain of U1C is also set at 2 ((R5/R6)+1). With 4 volts applied to pin 10 of U1C, its output at U1C pin 8 will be 0.7 = ((4 volts @ U1C pin 10 $\times$ 2) - 7.3 volts). For this scheme to work properly, amplifiers U1C and U1D must have a gain of 2 and the output of U1D must be shifted down by the V_{offset} provided by R7. In this system, the 0.7 volts V_{offset} was arbitrarily picked and could have been any voltage greater than the V_{sat} of the op amp being used. The system software will take in account any variations of V_{offset} as it assumes no pressure is applied to the sensor at system power up.

The gain of the analog circuit is approximately 117. With the values shown in Figure 5, the gain of 117 will provide a span of approximately 4 volts on U1C pin 8 when the pressure sensor and the 8 volt fixed voltage regulator are at their maximum output voltage tolerance. All of the sensors listed in Table 1 with the exception of the MPX2010DP output approximately 33 mV when full scale pressure is applied. When the MPX2010DP sensor is used, its full scale sensor differential output is approximately 20 mV. J8 must be installed to increase the gain of the analog circuit to still provide the 4 volts span out of U1C pin 8 with a 20 mV differential from the sensor.

Diode D2 is used to protect the microprocessor's A/D input if the output from U1C exceeds 5.6 volts. R4 is used to provide current limiting into D4 under failure or overvoltage conditions.

SOFTWARE

The source code, compiled listing, and S-record output for the software used in this system are available on the Freescale Freeware Bulletin Board Service in the MCU directory under the filename DEVB158.ARC. To access the bulletin board, you must have a telephone line, a 300, 1200 or 2400 baud modem and a personal computer. The modem must be compatible with the Bell 212A standard. Call (512) 891-3733 to access the Bulletin Board Service.

Figure 6 is a flowchart for the program that controls the system. The software for the system consists of a number of modules. Their functions provide the capability for system calibration as well as displaying the pressure input to the MPX2000 series pressure sensor.

The “C” compiler used in this project was provided by BYTE CRAFT LTD. (519) 888-6911. A compiler listing of the program is included at the end of this document. The following is a brief explanation of the routines:

delay() Used to provide a software loop delay.

read_a2d() Performs 100 reads on the A/D converter on multiplexer channel 0 and returns the accumulation.

fixcompare() Services the internal timer for 15 ms. timer compare interrupts.

TIMERCMP() Alternates the data and backplane inputs to the liquid crystal display.

initio() Sets up the microprocessor's I/O ports, timer and enables processor interrupts.

adzero() This routine is called at powerup time. It delays to let the power supply and the transducer stabilize. It then calls “read_atod()” and saves the returned value as the sensors output voltage with zero pressure applied.

cvt_bin_dec(unsigned long arg This routine converts the unsigned binary argument passed in “arg” to a five digit decimal number in an array called “digit.” It then uses the decimal results for each digit as an index into a table that converts the decimal number into a segment pattern for the display. This is then output to the display.

display_psi() This routine is called from “main()” never to return. The A/D converter routine is called, the pressure is calculated based on the type sensor detected and the pressure applied to the sensor is displayed. The loop then repeats.

sensor_type() This routine determines the type of sensor from reading J1 to J3, setting the full scale pressure for that particular sensor in a variable for use by display_psi().

sensor_slope() This routine determines the slope constant to be used by display_psi() for engineering units output.

main() This is the main routine called from reset. It calls “initio()” to setup the system's I/O. “display_psi()” is called to compute and display the pressure applied to the sensor.

```
                                  #pragma option f0;
                                  /*

                                  THE FOLLOWING 'C' SOURCE CODE IS WRITTEN FOR THE DEVB158 EVALUATION
                                  BOARD. IT WAS COMPILED WITH A COMPILER COURTESY OF:

                                                                        BYTE CRAFT LTD.
                                                                        421 KING ST.
                                                                        WATERLOO, ONTARIO
                                                                        CANADA  N2J 4E4
                                                                        (519)888-6911

                                  SOME SOURCE CODE CHANGES MAY BE NECESSARY FOR COMPILATION WITH OTHER
                                  COMPILERS.
                                                              BILL LUCAS 2/5/92
                                                              Freescale, SPS

                                  Revision history
                                  rev. 1.0 initial release 3/19/92
                                  rev. 1.1 added additional decimal digit to the MPX2010 sensor. Originally
                                  resolved the output to .1 PSI. Modified cvt_bin_dec to output PSI resolved
                                  to .01 PSI. WLL 9/25/92

                                  */
0800 1700                         #pragma memory ROMPROG  [5888]  @ 0x0800 ;
0050 0096                         #pragma memory RAMPAGE0 [150]   @ 0x0050 ;

                                  /*       Vector assignments    */
1FFE                              #pragma vector __RESET   @ 0x1ffe ;
1FFC                              #pragma vector __SWI     @ 0x1ffc ;
1FFA                              #pragma vector IRQ       @ 0x1ffa ;
1FF8                              #pragma vector TIMERCAP  @ 0x1ff8 ;
1FF6                              #pragma vector TIMERCMP  @ 0x1ff6 ;
1FF4                              #pragma vector TIMEROV   @ 0x1ff4 ;
1FF2                              #pragma vector SCI       @ 0x1ff2 ;

                                  #pragma has STOP ;
                                  #pragma has WAIT ;
                                  #pragma has MUL ;

                                  /*       Register assignments for the 68HC705B5 microcontroller     */
0000                              #pragma portrw porta   @ 0x00;  /*                                      */
0001                              #pragma portrw portb   @ 0x01;  /*                                      */
0002                              #pragma portrw portc   @ 0x02;  /*                                      */
0003                              #pragma portrw portd   @ 0x03;  /* in  ,-    ,SS   ,SCK  ,MOSI ,MISO,TxD,RxD */
0004                              #pragma portrw ddra    @ 0x04;  /* Data direction, Port A               */
0005                              #pragma portrw ddrb    @ 0x05;  /* Data direction, Port B               */
0006                              #pragma portrw ddrc    @ 0x06;  /* Data direction, Port C (all output)  */
0007                              #pragma portrw eeclk   @ 0x07;  /* eeprom/eclk cntl */
0008                              #pragma portrw addata  @ 0x08;  /* a/d data register */
0009                              #pragma portrw adstat  @ 0x09;  /* a/d stat/control */
000A                              #pragma portrw plma    @ 0x0a;  /* pulse length modulation a */
000B                              #pragma portrw plmb    @ 0x0b;  /* pulse length modulation b */
000C                              #pragma portrw misc    @ 0x0c;  /* miscellaneous register */
000D                              #pragma portrw scibaud @ 0x0d;  /* sci baud rate register */
000E                              #pragma portrw scicntl1 @ 0x0e; /* sci control 1  */
000F                              #pragma portrw scicntl2 @ 0x0f; /* sci control 2  */
0010                              #pragma portrw scistat @ 0x10;  /* sci status reg */
0011                              #pragma portrw scidata   @ 0x11;  /* SCI Data  */
0012                              #pragma portrw tcr       @ 0x12;  /* ICIE,OCIE,TOIE,0;0,0,IEGE,OLVL        */
0013                              #pragma portrw tsr       @ 0x13;  /* ICF,OCF,TOF,0; 0,0,0,0              */
0014                              #pragma portrw icaphi1   @ 0x14;  /* Input Capture Reg (Hi-0x14, Lo-0x15)   */
0015                              #pragma portrw icaplo1   @ 0x15;  /* Input Capture Reg (Hi-0x14, Lo-0x15)   */
0016                              #pragma portrw ocmphi1   @ 0x16;  /* Output Compare Reg (Hi-0x16, Lo-0x17)  */
0017                              #pragma portrw ocmplo1   @ 0x17;  /* Output Compare Reg (Hi-0x16, Lo-0x17)  */
0018                              #pragma portrw tcnthi    @ 0x18;  /* Timer Count Reg (Hi-0x18, Lo-0x19)     */
0019                              #pragma portrw tcntlo    @ 0x19;  /* Timer Count Reg (Hi-0x18, Lo-0x19)     */
001A                              #pragma portrw aregnthi    @ 0x1A;  /* Alternate Count Reg (Hi-$1A, Lo-$1B)   */
001B                              #pragma portrw aregntlo    @ 0x1B;  /* Alternate Count Reg (Hi-$1A, Lo-$1B)   */
001C                              #pragma portrw icaphi2   @ 0x1c;  /* Input Capture Reg (Hi-0x1c, Lo-0x1d)   */
001D                              #pragma portrw icaplo2   @ 0x1d;  /* Input Capture Reg (Hi-0x1c, Lo-0x1d)   */
```

```
001E                            #pragma portrw ocmphi2   @ 0x1e;  /* Output Compare Reg (Hi-0x1e, Lo-0x1f)  */
001F                            #pragma portrw ocmplo2   @ 0x1f;  /* Output Compare Reg (Hi-0x1e, Lo-0x1f)  */

1EFE 74                         #pragma mor @ 0x1efe = 0x74; /* this disables the watchdog counter and does
                                                                not add pull-down resistors on ports B and C */

                                       /* put constants and variables here...they must be global */
                                  /**************************************************************************/

0800 FC 30 DA 7A 36 6E E6 38 FE   const char lcdtab[]={0xfc,0x30,0xda,0x7a,0x36,0x6e,0xe6,0x38,0xfe,0x3e };
0809 3E
                                  /* lcd pattern table  0    1    2    3    4    5    6    7    8    9     */

080A 27 10 03 E8 00 64 00 0A      const long dectable[] = { 10000, 1000, 100, 10 };

0050 0005                         unsigned int digit[5]; /* buffer to hold results from cvt_bin_dec function */

0812 00 96 00 4B 00 96 00 1E 00   const long type[] = {  150,     75,      150,     30,      103   };
081B 67
                                  /*                  MPX2010  MPX2050  MPX2100  MPX2200  MPX2700
                                  The table above will cause the final results of the pressure to
                                  engineering units to display the 1.5, 7.3 and 15.0 devices with a
                                  decimal place in the tens position. The 30 and 103 psi devices will
                                  display in integer units.
                                  */

                                  const long slope_const[]={ 450,418,423,427,432,436,441,445,454,459,
081C 01 C2 01 A2 01 A7 01 AB 01                              463,468,472,477,481,450 };
0825 B0 01 B4 01 B9 01 BD 01 C6
082E 01 CB 01 CF 01 D4 01 D8 01
0837 DD 01 E1 01 C2

0000                              registera areg;    /* processor's A register */

0055                              long atodtemp;     /* temp to accumulate 100 a/d readings for smoothing */

0059                              long slope;        /* multiplier for adc to engineering units conversion */

005B                              int adcnt;         /* a/d converter loop counter */

005C                              long xdcr_offset;  /* initial xdcr offset */

005E                              long sensor_model; /*  installed sensor based on J1..J3 */
0060                              int sensor_index;  /*  determine the location of the decimal pt. */

0061 0063                         unsigned long i,j; /* counter for loops */

0065                              unsigned int k;    /* misc variable */

                                  struct bothbytes
                                     {  int hi;
                                        int lo;
                                     };

                                     union isboth
                                        {  long  l;
                                         struct bothbytes b;
                                        };

0066 0002                               union isboth q;  /* used for timer set-up */

                                  /**************************************************************************/

                                /* variables for add32  */
0068 0004                       unsigned long SUM[2];    /*     result        */
006C 0004                       unsigned long ADDEND[2]; /*     one input     */
0070 0004                       unsigned long AUGEND[2]; /*     second input  */

                                /* variables for sub32  */
0074 0004                       unsigned long MINUE[2];  /*     minuend       */
```

```
0078 0004                   unsigned long SUBTRA[2]; /*     subtrahend    */
007C 0004                   unsigned long DIFF[2];   /*     difference    */

                            /* variables for mul32  */
0080 0004                   unsigned long MULTP[2];  /*     multiplier    */
0084 0004                   unsigned long MTEMP[2];  /*     high order 4 bytes at return */
0088 0004                   unsigned long MULCAN[2]; /*     multiplicand at input, low 4 bytes at return */

                              /* variables for div32 */
008C 0004                   unsigned long DVDND[2];  /*     Dividend      */
0090 0004                   unsigned long DVSOR[2];  /*     Divisor       */
0094 0004                   unsigned long QUO[2];    /*     Quotient      */
0098                        unsigned int  CNT;       /*     Loop counter  */

                                                /* The code starts here */

                              /***************************************************************************/

                              void add32()
                              {
                              #asm

                  *----------------------------------------------------------------------------*
                  * Add two 32-bit values.
                  *    Inputs:
                  *       ADDEND: ADDEND[0..3]  HIGH ORDER BYTE IS ADDEND+0
                  *       AUGEND: AUGEND[0..3]  HIGH ORDER BYTE IS AUGEND+0
                  *    Output:
                  *       SUM: SUM[0..3]  HIGH ORDER BYTE IS SUM+0
                  *----------------------------------------------------------------------------*
                  *
083C B6 6F                LDA  ADDEND+3   low byte
083E BB 73                ADD  AUGEND+3
0840 B7 6B                STA  SUM+3
0842 B6 6E                LDA  ADDEND+2   medium low byte
0844 B9 72                ADC  AUGEND+2
0846 B7 6A                STA  SUM+2
0848 B6 6D                LDA  ADDEND+1   medium high byte
084A B9 71                ADC  AUGEND+1
084C B7 69                STA  SUM+1
084E B6 6C                LDA  ADDEND     high byte
0850 B9 70                ADC  AUGEND
0852 B7 68                STA  SUM
0854 81                   RTS             done
                  *
                            #endasm
0855 81       RTS           }

                              void sub32()
                              {
                              #asm
                  *----------------------------------------------------------------------------*
                  * Subtract two 32-bit values.
                  *    Input:
                  *       Minuend: MINUE[0..3]
                  *       Subtrahend: SUBTRA[0..3]
                  *    Output:
                  *       Difference: DIFF[1..0]
                  *----------------------------------------------------------------------------*
                  *
0856 B6 77                LDA  MINUE+3    low byte
0858 B0 7                 SUB  SUBTRA+3
085A B7 7F                STA  DIFF+3
085C B6 76                LDA  MINUE+2    medium low byte
085E B2 7A                SBC  SUBTRA+2
0860 B7 7E                STA  DIFF+2
0862 B6 75                LDA  MINUE+1    medium high byte
0864 B2 79                SBC  SUBTRA+1
0866 B7 7D                STA  DIFF+1
0868 B6 74                LDA  MINUE      high byte
086A B2 78                SBC  SUBTRA
086C B7 7C                STA  DIFF
```

```
086E 81                    RTS           done
                  *

                             #endasm
086F 81        RTS           }

                                 void mul32()
                                 {
                                 #asm
                  *----------------------------------------------------------------------------*
                  * Multiply 32-bit value by a 32-bit value
                  *
                  *
                  *    Input:
                  *       Multiplier:    MULTP[0..3]
                  *       Multiplicand:  MULCAN[0..3]
                  *    Output:
                  *       Product:       MTEMP[0..3] AND MULCAN[0..3] MTEMP[0] IS THE HIGH
                  *                          ORDER BYTE AND MULCAN[3] IS THE LOW ORDER BYTE
                  *
                  *   THIS ROUTINE DOES NOT USE THE MUL INSTRUCTION FOR THE SAKE OF USERS NOT
                  *   USING THE HC(7)05 SERIES PROCESSORS.
                  *----------------------------------------------------------------------------*
                  *
                  *
0870 AE 20                 LDX  #32       loop counter
0872 3F 84                 CLR  MTEMP     clean-up for result
0874 3F 85                 CLR  MTEMP+1   *
0876 3F 86                 CLR  MTEMP+2   *
0878 3F 87                 CLR  MTEMP+3   *
087A 36 88                 ROR  MULCAN    low but to carry, the rest one to the right
087C 36 89                 ROR  MULCAN+1  *
087E 36 8A                 ROR  MULCAN+2  *
0880 36 8B                 ROR  MULCAN+3  *
0882 24 18        MNEXT    BCC  ROTATE    if carry is set, do the add
0884 B6 87                 LDA  MTEMP+3   *
0886 BB 83                 ADD  MULTP+3   *
0888 B7 87                 STA  MTEMP+3   *
088A B6 86                 LDA  MTEMP+2   *
088C B9 82                 ADC  MULTP+2   *
088E B7 86                 STA  MTEMP+2   *
0890 B6 85                 LDA  MTEMP+1   *
0892 B9 81                 ADC  MULTP+1   *
0894 B7 85                 STA  MTEMP+1   *
0896 B6 84                 LDA  MTEMP     *
0898 B9 80                 ADC  MULTP     *
089A B7 84                 STA  MTEMP     *
089C 36 84        ROTATE   ROR  MTEMP    else: shift low bit to carry, the rest to the right
089E 36 85                 ROR  MTEMP+1   *
08A0 36 86                 ROR  MTEMP+2   *
08A2 36 87                 ROR  MTEMP+3   *
08A4 36 88                 ROR  MULCAN    *
08A6 36 89                 ROR  MULCAN+1  *
08A8 36 8A                 ROR  MULCAN+2  *
08AA 36 8B                 ROR  MULCAN+3  *
08AC 5A                    DEX            bump the counter down
08AD 26 D3                 BNE  MNEXT     done yet ?
08AF 81                    RTS            done

                             #endasm
08B0 81        RTS           }

                               void div32()
                               {
                               #asm
                   *
                   *----------------------------------------------------------------------------*
                   * Divide 32 bit by 32 bit unsigned integer routine
                   *
                   *    Input:
                   *       Dividend:  DVDND [+0..+3] HIGH ORDER BYTE IS DVND+0
                   *       Divisor:   DVSOR [+0..+3] HIGH ORDER BYTE IS DVSOR+0
                   *    Output:
```

```
                      *       Quotient:  QUO [+0..+3]   HIGH ORDER BYTE IS QUO+0
                      *----------------------------------------------------------------------------*
                      *
08B1 3F 94                     CLR  QUOzero result registers
08B3 3F 95                     CLR  QUO+1      *
08B5 3F 96                     CLR  QUO+2      *
08B7 3F 97                     CLR  QUO+3      *
08B9 A6 01                     LDA  #1         initial loop count
08BB 3D 90                     TST  DVSOR      if the high order bit is set..no need to shift DVSOR
08BD 2B 0F                     BMI  DIV153
                      *
08BF 4C              DIV151  INCA            bump the loop counter
08C0 38 93            ASL  DVSOR+3    now shift the divisor until the high order bit = 1
08C2 39 92                     ROL  DVSOR+2
08C4 39 91                     ROL  DVSOR+1    *
08C6 39 90                     ROL  DVSOR      *
08C8 2B 04            BMI  DIV153     done if high order bit = 1
08CA A1 21                     CMP  #33        have we shifted all possible bits in the DVSOR yet ?
08CC 26 F1                     BNE  DIV151     no
                      *
08CE B7 9            DIV153    STA  CNT        save the loop counter so we can do the divide
                      *
08D0 B6 8F           DIV163    LDA  DVDND+3    sub 32 bit divisor from dividend
08D2 B0 93                     SUB  DVSOR+3    *
08D4 B7 8F                     STA  DVDND+3    *
08D6 B6 8E                     LDA  DVDND+2    *
08D8 B2 92                     SBC  DVSOR+2    *
08DA B7 8E                     STA  DVDND+2    *
08DC B6 8D                     LDA  DVDND+1    *
08DE B2 91                     SBC  DVSOR+1    *
08E0 B7 8D                     STA  DVDND+1    *
08E2 B6 8C                     LDA  DVDND      *
08E4 B2 90                     SBC  DVSOR      *
08E6 B7 8C                     STA  DVDND      *
08E8 24 1B                     BCC  DIV165     carry is clear if DVSOR was larger than DVDND
                      *
08EA B6 8F                     LDA  DVDND+3    add the divisor back...was larger than the dividend
08EC BB 93                     ADD  DVSOR+3    *
08EE B7 8F                     STA  DVDND+3    *
08F0 B6 8E                     LDA  DVDND+2    *
08F2 B9 92                     ADC  DVSOR+2    *
08F4 B7 8E                     STA  DVDND+2    *
08F6 B6 8D                     LDA  DVDND+1    *
08F8 B9 91                     ADC  DVSOR+1    *
08FA B7 8D                     STA  DVDND+1    *
08FC B6 8C                     LDA  DVDND      *
08FE B9 90                     ADC  DVSOR      *
0900 B7 8C                     STA  DVDND      *
0902 98                        CLC             this will clear the respective bit in QUO due to
                      *                          the need to add DVSOR back to DVND
0903 20 01                     BRA  DIV167
0905 99              DIV165    SEC             this will set the respective bit in QUO
0906 39 97           DIV167    ROL  QUO+3      set or clear the low order bit in QUO based on above
0908 39 96                     ROL  QUO+2      *
090A 39 95                     ROL  QUO+1      *
090C 39 94                     ROL  QUO        *
090E 34 90                     LSR  DVSOR     divide the divisor by 2
0910 36 91                     ROR  DVSOR+1    *
0912 36 92                     ROR  DVSOR+2    *
0914 36 93                     ROR  DVSOR+3    *
0916 3A 98                     DEC  CNT        bump the loop counter down
0918 26 B6                     BNE  DIV163     finished yet ?
091A 81                        RTSyes
                      *

                                 #endasm
091B 81       RTS                }

                                   /****************************************************************************/

                                   /* These interrupts are not used...give them a graceful return if for
                                      some reason one occurs */
```

```
1FFC 09 1C                          __SWI(){}
091C 80       RTI
1FFA 09 1D                          IRQ(){}
091D 80       RTI
1FF8 09 1E                          TIMERCAP(){}
091E 80       RTI
1FF4 09 1F                          TIMEROV(){}
091F 80       RTI
1FF2 09 20                          SCI(){}
0920 80       RTI

                                      /****************************************************************************/

                                      void sensor_type()
                                      {
0921 B6 03    LDA    $03            k = portd & 0x0e;  /* we only care about bits 1..3 */
0923 A4 0E    AND    #$0E
0925 B7 65    STA    $65
0927 34 65    LSR    $65            k = k >> 1;    /* right justify the variable */
0929 B6 65    LDA    $65             if ( k > 4 )
092B A1 04    CMP    #$04
092D 23 0C    BLS    $093B

                                         { /* we have a set-up error in wire jumpers J1 - J3 */
092F 3F 02    CLR    $02                 portc = 0;     /*   */
0931 A6 6E    LDA    #$6E                portb = 0x6e;  /* S */
0933 B7 01    STA    $01
0935 A6 CE    LDA    #$CE                porta = 0xce;  /* E */
0937 B7 00    STA    $00
0939 20 FE    BRA    $0939                  while(1);
                                            }
093B B6 65    LDA    $65            sensor_index = k;
093D B7 60    STA    $60
093F 97       TAX                   sensor_model = type[k];
0940 58       LSLX
0941 D6 08 12 LDA    $0812,X
0944 B7 5E    STA    $5E
0946 D6 08 13 LDA    $0813,X
0949 B7 5F    STA    $5F
094B 81       RTS                   }

                                      /****************************************************************************/

                                      void sensor_slope()
                                      {
094C B6 03    LDA    $03            k=portd & 0xf0;  /* we only care about bits 4..7 */
094E A4 F0    AND    #$F0
0950 B7 65    STA    $65
0952 34 65    LSR    $65              k = k >> 4;    /* right justify the variable */
0954 34 65    LSR    $65
0956 34 65    LSR    $65
0958 34 65    LSR    $65
095A BE 65    LDX    $65            slope = slope_const[k];
095C 58       LSLX
095D D6 08 1C LDA    $081C,X
0960 B7 59    STA    $59
0962 D6 08 1D LDA    $081D,X
0965 B7 5A    STA    $5A
0967 81       RTS                   }

                                      /****************************************************************************/

                                      void delay(void)  /* just hang around for a while */
                                      {
0968 3F 62    CLR    $62           for (i=0; i<20000; ++i);
096A 3F 61    CLR    $61
096C B6 62    LDA    $62
096E A0 20    SUB    #$20
0970 B6 61    LDA    $61
0972 A2 4E    SBC    #$4E
0974 24 08    BCC    $097E
0976 3C 62    INC    $62
0978 26 0     BNE    $097C
097A 3C 61    IN     $61
```

```
097C 20 EE     BRA    $096C
097E 81        RTS                  }

                                      /*************************************************************************/

                                      read_a2d(void)
                                      {
                                      /* read the a/d converter on channel 5 and accumulate the result
                                      in atodtemp */

097F 3F 56     CLR    $56          atodtemp=0;   /* zero for accumulation */
0981 3F 55     CLR    $55
0983 3F 5B     CLR    $5B             for ( adcnt = 0 ; adcnt<100; ++adcnt) /* do 100 a/d conversions */
0985 B6 5B     LDA    $5B
0987 A8 80     EOR    #$80
0989 A1 E4     CMP    #$E4
098B 24 21     BCC    $09AE
                                          {
098D A6 20     LDA    #$20               adstat = 0x20;  /* convert on channel 0 */
098F B7 09      STA    $09
0991 0F 09 FD  BRCLR 7,$09,$0991          while (!(adstat & 0x80));  /* wait for a/d to complete */
0994 B6 08     LDA    $08                   atodtemp = addata + atodtemp;
0996 3F 57     CLR    $57
0998 B7 58     STA    $58
099A BB 56     ADD    $56
099C B7 58     STA    $58
099E B6 57     LDA    $57
09A0 B9 55     ADC    $55
09A2 B7 57     STA    $57
09A4 B7 55     STA    $55
09A6 B6 58     LDA    $58
09A8 B7 56     STA    $56
                                            }
09AA 3C 5B     INC    $5B
09AC 20 D7     BRA    $0985
09AE B6 56     LDA    $56             atodtemp = atodtemp/100;
09B0 B7 58     STA    $58
09B2 B6 55     LDA    $55
09B4 B7 57     STA    $57
09B6 3F 9A     CLR    $9A
09B8 A6 64     LDA    #$64
09BA B7 9B     STA    $9B
09BC CD 0B F1  JSR    $0BF1
09BF CD 0C 22  JSR    $0C22
09C2 BF 55     STX    $55
09C4 B7 56     STA    $56
09C6 81        RTS                    return atodtemp;
                                      }

                                      /*************************************************************************/

                                      void fixcompare (void)  /* sets-up the timer compare for the next interrupt */
                                         {
09C7 B6 18     LDA    $18             q.b.hi =tcnthi;
09C9 B7 66     STA    $66
09CB B6 19     LDA    $19                q.b.lo = tcntlo;
09CD B7 67     STA    $67
09CF AB 4C     ADD    #$4C                q.l +=7500;  /* ((4mhz xtal/2)/4) = counter period = 2us.*7500 = 15ms. */
09D1 B7 67     STA    $67
09D3 B6 66     LDA    $66
09D5 A9 1D     ADC    #$1D
09D7 B7 66     STA    $66
09D9 B7 16     STA    $16                 ocmphi1 = q.b.hi;
09DB B6 13     LDA    $13                areg=tsr;  /* dummy read */
09DD B6 67     LDA    $67             ocmplo1 = q.b.lo;
09DF B7 17     STA    $17
09E1 81        RTS                    }

                                      /*************************************************************************/

                                      void TIMERCMP (void)    /* timer service module */
1FF6 09 E2                            {
09E2 33 02     COM    $02                portc =~ portc;    /* service the lcd by inverting the ports */
```

```
09E4 33 01     COM    $01              portb =~ portb;
09E6 33 00     COM    $00              porta =~ porta;
09E8 AD DD     BSR    $09C7          fixcompare();
09EA 80        RTI                   }

                                     /***************************************************************************/

                                     void adzero(void)  /* called by initio() to save initial xdcr's zero
                                                             pressure offset voltage output */
                                     {

09EB 3F 64     CLR    $64            for ( j=0; j<20; ++j)  /* give the sensor time to "warm-up" and the
09ED 3F 63     CLR    $63
09EF B6 64     LDA    $64
09F1 A0 14     UB     #$14
09F3 B6 63     LDA    $63
09F5 A2 00     SBC    #$00
09F7 24 0B     BCC    $0A04
                                                               power supply time to settle down */
                                     {
09F9 CD 09 68 JSR    $0968              delay();
                                     }
09FC 3C 64     INC    $64
09FE 26 02     BNE    $0A02
0A00 3C 63     INC    $63
0A02 20 EB     BRA    $09EF
0A04 CD 09 7F JSR    $097F              xdcr_offset =  read_a2d();
0A07 3F 5C     CLR    $5C
0A09 B7 5D     STA    $5D
0A0B 81        RTS                 }

                                     /***************************************************************************/

                                     void initio (void)     /*  setup the I/O */
                                        {
0A0C A6 20     LDA    #$20              adstat = 0x20; /* power-up the A/D */
0A0E B7 09     STA    $09
0A10 3F 02     CLR    $02               porta = portb = portc = 0;
0A12 3F 01     CLR    $01
0A14 3F 00     CLR    $00
0A16 A6 FF     LDA    #$FF              ddra = ddrb = ddrc = 0xff;
0A18 B7 06     STA    $06
0A1A B7 05     STA    $05
0A1C B7 04     STA    $04
0A1E B6 13     LDA    $13               areg=tsr;  /* dummy read */
0A20 3F 1E     CLR    $1E               ocmphi1 = ocmphi2 = 0;
0A22 3F 16     CLR    $16
0A24 B6 1F     LDA    $1F               areg = ocmplo2; /* clear out output compare 2 if it happens to be set */
0A26 AD 9F     BSR    $09C7             fixcompare(); /* set-up for the first timer interrupt */
0A28 A6 40     LDA    #$40              tcr = 0x40;
0A2A B7 12     STA    $12
0A2C 9A        CLI                      CLI;  /* let the interrupts begin !  */
                                     /* write CAL to the display */
0A2D A6 CC     LDA    #$CC              portc = 0xcc; /* C */
0A2F B7 02     STA    $02
0A31 A6 BE     LDA    #$BE              portb = 0xbe; /* A */
0A33 B7 01     STA    $01
0A35 A6 C4     LDA    #$C4              porta = 0xc4; /* L */
0A37 B7 00     STA    $00
0A39 CD 09 21 JSR    $0921              sensor_type(); /* get the model of the sensor based on J1..J3 */
0A3C AD AD     BSR    $09EB             adzero();  /* auto zero */
0A3E 81        RTS                   }

                                     /***************************************************************************/

                                     void cvt_bin_dec(unsigned long arg)

                                     /* First converts the argument to a five digit decimal value. The msd is in
                                     the lowest address. Then leading zero suppress the value and write it to the
                                     display ports.
                                        The argument value is 0..65535 decimal. */
```

```
009D                            {
0A3F BF 9D     STX    $9D
0A41 B7 9E     STA    $9E

009F                            char i;
00A0                            unsigned long l;
0A43 3F 9F     CLR    $9F         for ( i=0; i < 5; ++i )
0A45 B6 9F     LDA    $9F
0A47 A1 05     CMP    #$05
0A49 24 07     BCC    $0A52

                                     {
0A4B 97        TAX                   digit[i] = 0x0;  /* put blanks in all digit positions */
0A4C 6F 50     CL     $50,X
                                     }
0A4E 3C 9F     INC    $9F
0A50 20 F3     BRA    $0A45
0A52 3F 9F     CLR    $9F              for ( i=0; i < 4; ++i )
0A54 B6 9F     LDA    $9F
0A56 A1 04     CMP    #$04
0A58 24 7A     BCC    $0AD4

                                         {
0A5A 97        TAX                         if ( arg  >= dectable [i] )
0A5B 58        LSLX
0A5C D6 08 0B  LDA    $080B,X
0A5F B0 9E     SUB    $9E
0A61 B7 58     STA    $58
0A63 B6 9D     LDA    $9D
0A65 A8 80     EOR    #$80
0A67 B7 57     STA    $57
0A69 D6 08 0A  LDA    $080A,X
0A6C A8 80     EOR    #$80
0A6E B2 57     SBC    $57

0A70 BA 58      ORA    $58
0A72 22 5C      BHI    $0AD0
                                             {
0A74 BE 9F      LDX    $9F                     l = dectable[i];
0A76 58         LSLX
0A77 D6 08 0A   LDA    $080A,X
0A7A B7 A0      STA    $A0
0A7C D6 08 0B   LDA    $080B,X
0A7F B7 A1      STA    $A1
0A81 B6 9E      LDA    $9E                     digit[i] = arg / l;
0A83 B7 58      STA    $58
0A85 B6 9D      LDA    $9D
0A87 B7 57      STA    $57
0A89 B6 A0      LDA    $A0
0A8B B7 9A      STA    $9A
0A8D B6 A1      LDA    $A1
0A8F B7 9B      STA    $9B
0A91 CD 0B F1   JSR    $0BF1
0A94 CD 0C 22   JSR    $0C22
0A97 BF 57      STX    $57
0A99 B7 58      STA    $58
0A9B BE 9F      LDX    $9F
0A9D E7 50      STA    $50,X
0A9F BE 9F      LDX    $9F                     arg = arg-(digit[i] * l);
0AA1 E6 50      LDA    $50,X
0AA3 3F 57      CLR    $57
0AA5 B7 58      STA    $58
0AA7 B6 A0      LDA    $A0
0AA9 B7 9A      STA    $9A
0AAB B6 A1      LDA    $A1
0AAD B7 9B      STA    $9B
0AAF CD 0B D2   JSR    $0BD2
0AB2 BF 57      STX    $57
0AB4 B7 58      STA    $58
0AB6 33 57      COM    $57
0AB8 30 58      NEG    $58
0ABA 26 02      BNE    $0ABE
0ABC 3C 57      INC    $57
0ABE B6 58      LDA    $58
0AC0 BB 9E      ADD    $9E
0AC2 B7 58      STA    $58
0AC4 B6 57      LDA    $57
```

```
0AC6 B9 9D     ADC    $9D
0AC8 B7 57     STA    $57
0ACA B7 9D     STA    $9D
0ACC B6 58     LDA    $58
0ACE B7 9E     STA    $9E
                                                         }
                                                    }
0AD0 3C 9F     INC    $9F
0AD2 20 80     BRA    $0A54
0AD4 B6 9E     LDA    $9E          digit[i] = arg;
0AD6 B7 58     STA    $58
0AD8 B6 9D     LDA    $9D
0ADA B7 57     STA    $57
0ADC BE 9F     LDX    $9F
0ADE B6 58     LDA    $58
0AE0 E7 50     STA    $50,X

                                     /* now zero suppress and send the lcd pattern to the display */
0AE2 9B        SEI                 SEI;
0AE3 3D 52     TST    $52          if ( digit[2] == 0 )   /* leading zero suppression */
0AE5 26 04     BNE    $0AEB
0AE7 3F 02     CLR    $02            portc = 0;
0AE9 20 07     BRA    $0AF2            else
0AEB BE 52     LDX    $52               portc = ( lcdtab[digit[2]] );     /* 100's digit */
0AED D6 08 00  LDA    $0800,X
0AF0 B7 02     STA    $02
0AF2 3D 52     TST    $52                if ( digit[2] == 0 && digit[3] == 0 )
0AF4 26 08     BNE    $0AFE
0AF6 3D 53     TST    $53
0AF8 26 04     BNE    $0AFE
0AFA 3F 01     CLR    $01                  portb=0;
0AFC 20 07     BRA    $0B05                  else
0AFE BE 53     LDX    $53                      portb = ( lcdtab[digit[3]] );    /* 10's digit */
0B00 D6 08 00  LDA    $0800,X

0B03 B7 01     STA    $01
0B05 BE 54     LDX    $54                        porta = ( lcdtab[digit[4]] );   /* 1's digit */
0B07 D6 08 00  LDA    $0800,X
0B0A B7 00     STA    $00
                                     /* place the decimal point only if the sensor is 15 psi or 7.5 psi */
0B0C B6 60     LDA    $60              if ( sensor_index < 3 )
0B0E A8 80     EOR    #$80
0B10 A1 83     CMP    #$83
0B12 24 08     BCC    $0B1C
0B14 BE 54     LDX    $54               porta = ( lcdtab[digit[4]]+1 ); /* add the decimal point to the lsd */
0B16 D6 08 00  LDA    $0800,X
0B19 4C        INCA
0B1A B7 00     STA    $00
0B1C 3D 60     TST    $60                if(sensor_index ==0) /* special case */
0B1E 26 0F     BNE    $0B2F
                                                     {
0B20 BE 54     LDX    $54                    porta = ( lcdtab[digit[4]] ); /* get rid of the decimal at lsd */
0B22 D6 08 00  LDA    $0800,X
0B25 B7 00     STA    $00
0B27 BE 53     LDX    $53                    portb = ( lcdtab[digit[3]]+1 ); /* decimal point at middle digit */
0B29 D6 08 00  LDA    $0800,X
0B2C 4C        INCA
0B2D B7 01     STA    $01
                                                     }
0B2F 9A        CLI                 CLI;
0B30 CD 09 68  JSR    $0968                    delay();
0B33 81        RTS                 }

                                     /*****************************************************************/

                                     void display_psi(void)
                                     /*
                                       At power-up it is assumed that the pressure or vacuum port of
                                       the sensor is open to atmosphere. The code in initio() delays
                                       for the sensor and power supply to stabilize. One hundred A/D
                                       conversions are averaged. That result is called xdcr_offset.
                                       This routine calls the A/D routine which performs one hundred
                                       conversions, divides the result by 100 and returns the value.
```

```
                                        If the value returned is less than or equal to the xdcr_offset,
                                        the value of xdcr_offset is substituted. If the value returned
                                        is greater than xdcr_offset, xdcr_offset is subtracted from the
                                        returned value.
                                      */

                                    {
                                      while(1)
                                         {
0B34 CD 09 7F  JSR    $097F              atodtemp = read_a2d();  /* atodtemp = raw a/d ( 0..255 ) */
0B37 3F 55     CLR    $55
0B39 B7 56     STA    $56
0B3B B0 5D     SUB    $5D                  if ( atodtemp <= xdcr_offset )
0B3D B7 58     STA    $58
0B3F B6 5C     LDA    $5C
0B41 A8 80     EOR    #$80
0B43 B7 57     STA    $57
0B45 B6 55     LDA    $55
0B47 A8 80     EOR    #$80
0B49 B2 57     SBC    $57
0B4B BA 58     ORA    $58
0B4D 22 08     BHI    $0B57
0B4F B6 5C     LDA    $5C                    atodtemp = xdcr_offset;
0B51 B7 55     STA    $55
0B53 B6 5D     LDA    $5D
0B55 B7 56     STA    $56
0B57 B6 56     LDA    $56                  atodtemp -=  xdcr_offset; /* remove the offset */
0B59 B0 5D     SUB    $5D
0B5B B7 56     STA    $56
0B5D B6 55     LDA    $55
0B5F B2 5C     SBC    $5C
0B61 B7 55     STA    $55
0B63 CD 09 4C  JSR    $094C                  sensor_slope();  /* establish the slope constant for this output */
0B66 B6 56     LDA    $56                  atodtemp *= sensor_model;
0B68 B7 58     STA    $58
0B6A B6 55     LDA    $55
0B6C B7 57     STA    $57
0B6E B6 5E     LDA    $5E

0B70 B7 9A     STA    $9A
0B72 B6 5F     LDA    $5F
0B74 B7 9B     STA    $9B
0B76 CD 0B D2  JSR    $0BD2
0B79 BF 55     STX    $55
0B7B B7 56     STA    $56
0B7D 3F 89     CLR    $89                   MULTP[0] = MULCAN[0] = 0;
0B7F 3F 88     CLR    $88
0B81 3F 81     CLR    $81
0B83 3F 80     CLR    $80
0B85 9F        TXA                            MULTP[1] = atodtemp;
0B86 B7 82     STA    $82
0B88 B6 56     LDA    $56
0B8A B7 83     STA    $83
0B8C B6 59     LDA    $59                      MULCAN[1] = slope;
0B8E B7 8A     STA    $8A
0B90 B6 5A     LDA    $5A
0B92 B7 8B     STA    $8B
0B94 CD 08 70  JSR    $0870                      mul32();   /* analog value * slope based on J1 through J3 */
0B97 3F 90     CLR    $90                         DVSOR[0] = 1;   /*  now divide by 100000 */
0B99 A6 01     LDA    #$01
0B9B B7 91     STA    $91
0B9D A6 86     LDA    #$86                         DVSOR[1] = 0x86a0;
0B9F B7 92     STA    $92
0BA1 A6 A0     LDA    #$A0
0BA3 B7 93     STA    $93
0BA5 B6 88     LDA    $88                           DVDND[0] = MULCAN[0];
0BA7 B7 8C     STA    $8C
0BA9 B6 89     LDA    $89
0BAB B7 8D     STA    $8D
0BAD B6 8A     LDA    $8A                            DVDND[1] = MULCAN[1];
0BAF B7 8E     STA    $8E
0BB1 B6 8B     LDA    $8B
0BB3 B7 8F     STA    $8F
```

```
0BB5 CD 08 B1  JSR    $08B1                        div32();
0BB8 B6 96     LDA    $96                         atodtemp = QUO[1]; /* convert to psi */
0BBA B7 55     STA    $55
0BBC B6 97     LDA    $97
0BBE B7 56     STA    $56
0BC0 BE 55     LDX    $55            cvt_bin_dec( atodtemp ); /* convert to decimal and display */
0BC2 CD 0A 3F  JSR    $0A3F
0BC5 CC 0B 34  JMP    $0B34           }
0BC8 81        RTS                 }

                                     /***************************************************************************/

                                     void main()
                                     {
0BC9 CD 0A 0C  JSR    $0A0C         initio(); /* set-up the processor's i/o */
0BCC CD 0B 34  JSR    $0B34          display_psi();
0BCF 20 FE     BRA    $0BCF           while(1);   /* should never get back to here */
0BD1 81        RTS                 }
0BD2 BE 58     LDX    $58
0BD4 B6 9B     LDA    $9B
0BD6 42        MUL
0BD7 B7 A4     STA    $A4
0BD9 BF A5     STX    $A5
0BDB BE 57     LDX    $57
0BDD B6 9B     LDA    $9B
0BDF 42        MUL
0BE0 BB A5     ADD    $A5
0BE2 B7 A5     STA    $A5
0BE4 BE 58     LDX    $58
0BE6 B6 9A     LDA    $9A
0BE8 42        MUL
0BE9 BB A5     ADD    $A5
0BEB B7 A5     STA    $A5
0BED 97        TAX
0BEE B6 A4     LDA    $A4
0BF0 81        RTS
0BF1 3F A4     CLR    $A4
0BF3 5F        CLRX
0BF4 3F A2     CLR    $A2
0BF6 3F A3     CLR    $A3
0BF8 5C        INCX
0BF9 38 58     LSL    $58


0BFB 39 57     ROL    $57
0BFD 39 A2     ROL    $A2
0BFF 39 A3     ROL    $A3
0C01 B6 A2     LDA    $A2
0C03 B0 9B     SUB    $9B
0C05 B7 A2     STA    $A2
0C07 B6 A3     LDA    $A3
0C09 B2 9A     SBC    $9A
0C0B B7 A3     STA    $A3
0C0D 24 0D     BCC    $0C1C
0C0F B6 9B     LDA    $9B
0C11 BB A2     ADD    $A2
0C13 B7 A2     STA    $A2
0C15 B6 9A     LDA    $9A
0C17 B9 A3     ADC    $A3
0C19 B7 A3     STA    $A3
0C1B 99        SEC
0C1C 59        ROLX
0C1D 39 A4     ROL    $A4
0C1F 24 D8     BCC    $0BF9
0C21 81        RTS
0C22 53        COMX
0C23 9F        TXA
0C24 BE A4     LDX    $A4
0C26 53        COMX
0C27 81        RTS
1FFE 0B C9

SYMBOL TABLE
```

```
LABEL         VALUE  LABEL         VALUE  LABEL         VALUE  LABEL         VALUE

ADDEND        006C | AUGEND        0070 | CNT           0098 | DIFF          007C
DIV151        08BF | DIV153        08CE | DIV163        08D0 | DIV165        0905
DIV167        0906 | DVDND         008C | DVSOR         0090 | IRQ           091D
MINUE         0074 | MNEXT         0882 | MTEMP         0084 | MULCAN        0088
MULTP         0080 | QUO           0094 | ROTATE        089C | SCI           0920
SUBTRA        0078 | SUM           0068 | TIMERCAP      091E | TIMERCMP      09E2
TIMEROV       091F | __LDIV        0BF1 | __LongIX      009A | __MAIN        0BC9
__MUL         0000 | __MUL16x16    0BD2 | __RDIV        0C22 | __RESET       1FFE
__STARTUP     0000 | __STOP        0000 | __SWI         091C | __WAIT        0000
__longAC      0057 | adcnt         005B | add32         083C | addata        0008
adstat        0009 | adzero        09EB | aregnthi      001A | aregntlo      001B
arg           009D | atodtemp      0055 | b             0000 | bothbytes     0002
cvt_bin_dec   0A3F | ddra          0004 | ddrb          0005 | ddrc          0006
dectable      080A | delay         0968 | digit         0050 | display_psi   0B34
div32         08B1 | eeclk         0007 | fixcompare    09C7 | hi            0000
i             0061 | icaphi1       0014 | icaphi2       001C | icaplo1       0015
icaplo2       001D | initio        0A0C | isboth        0002 | j             0063
k             0065 | l             0000 | lcdtab        0800 | lo            0001
main          0BC9 | misc          000C | mul32         0870 | ocmphi1       0016
ocmphi2       001E | ocmplo1       0017 | ocmplo2       001F | plma          000A
plmb          000B | porta         0000 | portb         0001 | portc         0002
portd         0003 | q             0066 | read_a2d      097F | scibaud       000D
scicntl1      000E | scicntl2      000F | scidata       0011 | scistat       0010
sensor_index  0060 | sensor_model  005E | sensor_slope  094C | sensor_type   0921
slope         0059 | slope_const   081C | sub32         0856 | tcnthi        0018
tcntlo        0019 | tcr           0012 | tsr           0013 | type          0812
xdcr_offset   005C |

MEMORY USAGE MAP ('X' = Used, '-' = Unused)

0800 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0840 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0880 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
08C0 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX

0900 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0940 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0980 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
09C0 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX

0A00 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0A40 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0A80 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0AC0 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX

0B00 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0B40 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0B80 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0BC0 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX

0C00 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXX-------- ----------------
0C40 : ---------------- ---------------- ---------------- ----------------
0C80 : ---------------- ---------------- ---------------- ----------------
0CC0 : ---------------- ---------------- ---------------- ----------------

1E00 : ---------------- ---------------- ---------------- ----------------
1E40 : ---------------- ---------------- ---------------- ----------------
1E80 : ---------------- ---------------- ---------------- ----------------
1EC0 : ---------------- ---------------- ---------------- --------------X-

1F00 : ---------------- ---------------- ---------------- ----------------
1F40 : ---------------- ---------------- ---------------- ----------------
1F80 : ---------------- ---------------- ---------------- ----------------
1FC0 : ---------------- ---------------- ---------------- --XXXXXXXXXXXXXX

All other memory blocks unused.

Errors            :    0
Warnings          :    0
```

Frequency Output Conversion for MPX2000 Series Pressure Sensors

by: Jeff Baum
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INTRODUCTION

Typically, a semiconductor pressure transducer converts applied pressure to a “low-level” voltage signal. Current technology enables this sensor output to be temperature compensated and amplified to higher voltage levels on a single silicon integrated circuit (IC). While on-chip temperature compensation and signal conditioning certainly provide a significant amount of added value to the basic sensing device, one must also consider how this final output will be used and/or interfaced for further processing. In most sensing systems, the sensor signal will be input to additional analog circuitry, control logic, or a microcontroller unit (MCU).

MCU-based systems have become extremely cost effective. The level of intelligence which can be obtained for only a couple of dollars, or less, has made relatively simple 8-bit microcontrollers the partner of choice for semiconductor pressure transducers. In order for the sensor to communicate its pressure-dependent voltage signal to the microprocessor, the MCU must have an analog-to-digital converter (A/D) as an on-chip resource or an additional IC packaged A/D. In the latter case, the A/D must have a communications interface that is compatible with one of the MCU's communications protocols. MCU's are adept at detecting logic-level transitions that occur at input pins designated for screening such events. As an alternative to the conventional A/D sensor/MCU interface, one can measure either a period (frequency) or pulse width of an incoming square or rectangular wave signal. Common MCU timer subsystem clock frequencies permit temporal measurements with resolution of hundreds of nanoseconds. Thus, one is capable of accurately measuring the frequency output of a device that is interfaced to such a timer channel. If sensors can provide a frequency modulated signal that is linearly proportional to the applied pressure being measured, then an accurate, inexpensive (no A/D) MCU-based sensor system is a viable solution to many challenging sensing applications. Besides the inherent cost savings of such a system, this design concept offers additional benefits to remote sensing applications and sensing in electrically noisy environments.

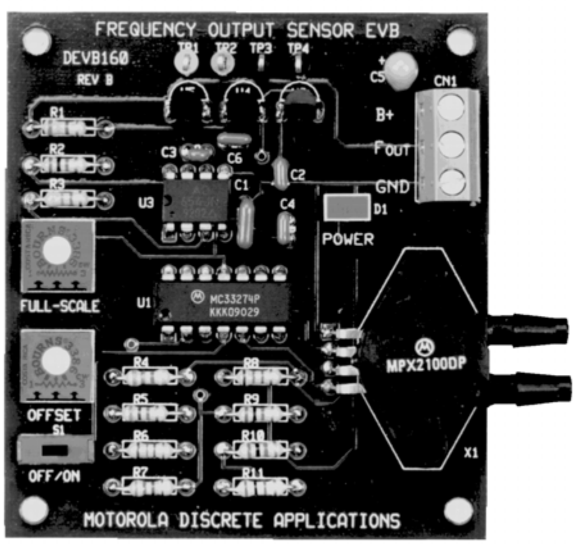


Figure 1. DEVB160 Frequency Output Sensor EVB (Board No Longer Available)

The following sections will detail the design issues involved in such a system architecture, and will provide an example circuit which has been developed as an evaluation tool for frequency output pressure sensor applications.

DESIGN CONSIDERATIONS

Signal Conditioning

The Freescale Semiconductor, Inc. MPX2000 Series sensors are temperature compensated and calibrated - i.e., offset and full-scale span are precision trimmed - pressure transducers. These sensors are available in full-scale pressure ranges from 10 kPa (1.5 psi) to 200 kPa (30 psi). Although the specifications in the data sheets apply only to a 10 V supply voltage, the output of these devices is ratiometric with the supply voltage. At the absolute maximum supply voltage specified, 16 V, the sensor will produce a differential output voltage of 64 mV at the rated full-scale pressure of the given sensor. One exception to this is that the full-scale span of the MPX2010 (10 kPa sensor) will be only 40 mV due to a slightly lower sensitivity. Since the maximum supply voltage produces the most output voltage, it is evident that even the best case scenario will require some signal conditioning to obtain a usable voltage level.

Many different “instrumentation-type” amplifier circuits can satisfy the signal conditioning needs of these devices. Depending on the precision and temperature performance demanded by a given application, one can design an amplifier circuit using a wide variety of operational amplifier (op amp) IC packages with external resistors of various tolerances, or a precision-trimmed integrated instrumentation amplifier IC. In any case, the usual goal is to have a single-ended supply, “rail-to-rail” output (i.e. use as much of the range from ground to the supply voltage as possible, without saturating the op amps). In addition, one may need the flexibility of performing zero-pressure offset adjust and full-scale pressure calibration. The circuitry or device used to accomplish the voltage-to-frequency conversion will determine if, how, and where calibration adjustments are needed. See Evaluation Board Circuit Description section for details.

Voltage-to-Frequency Conversion

Since most semiconductor pressure sensors provide a voltage output, one must have a means of converting this voltage signal to a frequency that is proportional to the sensor output voltage. Assuming the analog voltage output of the sensor is proportional to the applied pressure, the resultant frequency will be linearly related to the pressure being measured. There are many different timing circuits that can perform voltage-to-frequency conversion. Most of the “simple” (relatively low number of components) circuits do not provide the accuracy or the stability needed for reliably encoding a signal quantity. Fortunately, many voltage-to-frequency (V/F) converter IC's are commercially available that will satisfy this function.

Switching Time Reduction

One limitation of some V/F converters is the less than adequate switching transition times that effect the pulse or square-wave frequency signal. The required switching speed will be determined by the hardware used to detect the switching edges. The Freescale family of microcontrollers have input-capture functions that employ “Schmitt trigger-like” inputs with hysteresis on the dedicated input pins. In this case, slow rise and fall times will not cause an input capture pin to be in an indeterminate state during a transition. Thus, CMOS logic instability and significant timing errors will be prevented during slow transitions. Since the sensor's frequency output may be interfaced to other logic configurations, a designer's main concern is to comply with a worst-case timing scenario. For high-speed CMOS logic, the maximum rise and fall times are typically specified at several hundreds of nanoseconds. Thus, it is wise to speed up the switching edges at the output of the V/F converter. A single small-signal FET and a resistor are all that is required to obtain switching times below 100 ns.

APPLICATIONS

Besides eliminating the need for an A/D converter, a frequency output is conducive to applications in which the sensor output must be transmitted over long distances, or when the presence of noise in the sensor environment is likely to corrupt an otherwise healthy signal. For sensor outputs encoded as a voltage, induced noise from electromagnetic fields will contaminate the true voltage signal. A frequency signal has greater immunity to these noise sources and can be effectively filtered in proximity to the MCU input. In other words, the frequency measured at the MCU will be the frequency transmitted at the output of a sensor located remotely. Since high-frequency noise and 50-60 Hz line noise are the two most prominent sources for contamination of instrumentation signals, a frequency signal with a range in the low end of the kHz spectrum is capable of being well filtered prior to being examined at the MCU.

Table 1. Specifications

Characteristics	Symbol	Min	Typ	Max	Units
Power Supply Voltage	B^+	10		30	Volts
Full Scale Pressure	P_{FS}				
- MPX2010				10	kPa
- MPX2050				50	kPa
- MPX2100				100	kPa
- MPX2200				200	kPa
Full Scale Output	f_{FS}		10		kHz
Zero Pressure Offset	f_{OFF}		1		kHz
Sensitivity	S_{AOUT}		$9/P_{FS}$		kHz/kPa
Quiescent Current	I_{CC}		55		mA

EVALUATION BOARD

The following sections present an example of the signal conditioning, including frequency conversion, that was developed as an evaluation tool for Freescale's MPX2000 series pressure sensors. A summary of the information required to use evaluation board number DEVB160 is presented as follows.

Description

The evaluation board shown in Figure 1 is designed to transduce pressure, vacuum or differential pressure into a single-ended, ground referenced voltage that is then input to a voltage-to-frequency converter. It nominally provides a 1 kHz output at zero pressure and 10 kHz at full scale pressure. Zero pressure calibration is made with a trimpot that is located on the lower half of the left side of the board, while the full scale output can be calibrated via another trimpot just above the offset adjust. The board comes with an MPX2100DP sensor installed, but will accommodate any MPX2000 series sensor. One additional modification that may be required is that the gain of the circuit must be increased slightly when using an MPX2010 sensor. Specifically, the resistor R5 must be increased from 7.5 kΩ to 12 kΩ.

Circuit Description

The following pin description and circuit operation corresponds to the schematic shown in Figure 2.

Pin-by-Pin Description

B^+

Input power is supplied at the B^+ terminal of connector CN1. Minimum input voltage is 10 V and maximum is 30 V.

F_{out}

A logic-level (5 V) frequency output is supplied at the OUT terminal (CN1). The nominal signal it provides is 1 kHz at zero pressure and 10 kHz at full scale pressure. Zero pressure frequency is adjustable and set with R12. Full-scale frequency is calibrated via R13. This output is designed to be directly connected to a microcontroller timer system input-capture channel.

GND

The ground terminal on connector CN1 is intended for use as the power supply return and signal common. Test point terminal TP3 is also connected to ground, for measurement convenience.

TP1

Test point 1 is connected to the final frequency output, F_{out}.

TP2

Test point 2 is connected to the +5 V regulator output. It can be used to verify that this supply voltage is within its tolerance.

TP3

Test point 3 is the additional ground point mentioned above in the GND description.

TP4

Test point 4 is connected to the +8 V regulator output. It can be used to verify that this supply voltage is within its tolerance.

P1, P2

Pressure and Vacuum ports P1 and P2 protrude from the sensor on the right side of the board. Pressure port P1 is on the top (marked side of package) and vacuum port P2, if present, is on the bottom. When the board is set up with a dual ported sensor (DP suffix), pressure applied to P1, vacuum applied to P2 or a differential pressure applied between the two all produce the same output voltage per kPa of input. Neither port is labeled. Absolute maximum differential pressure is 700 kPa.

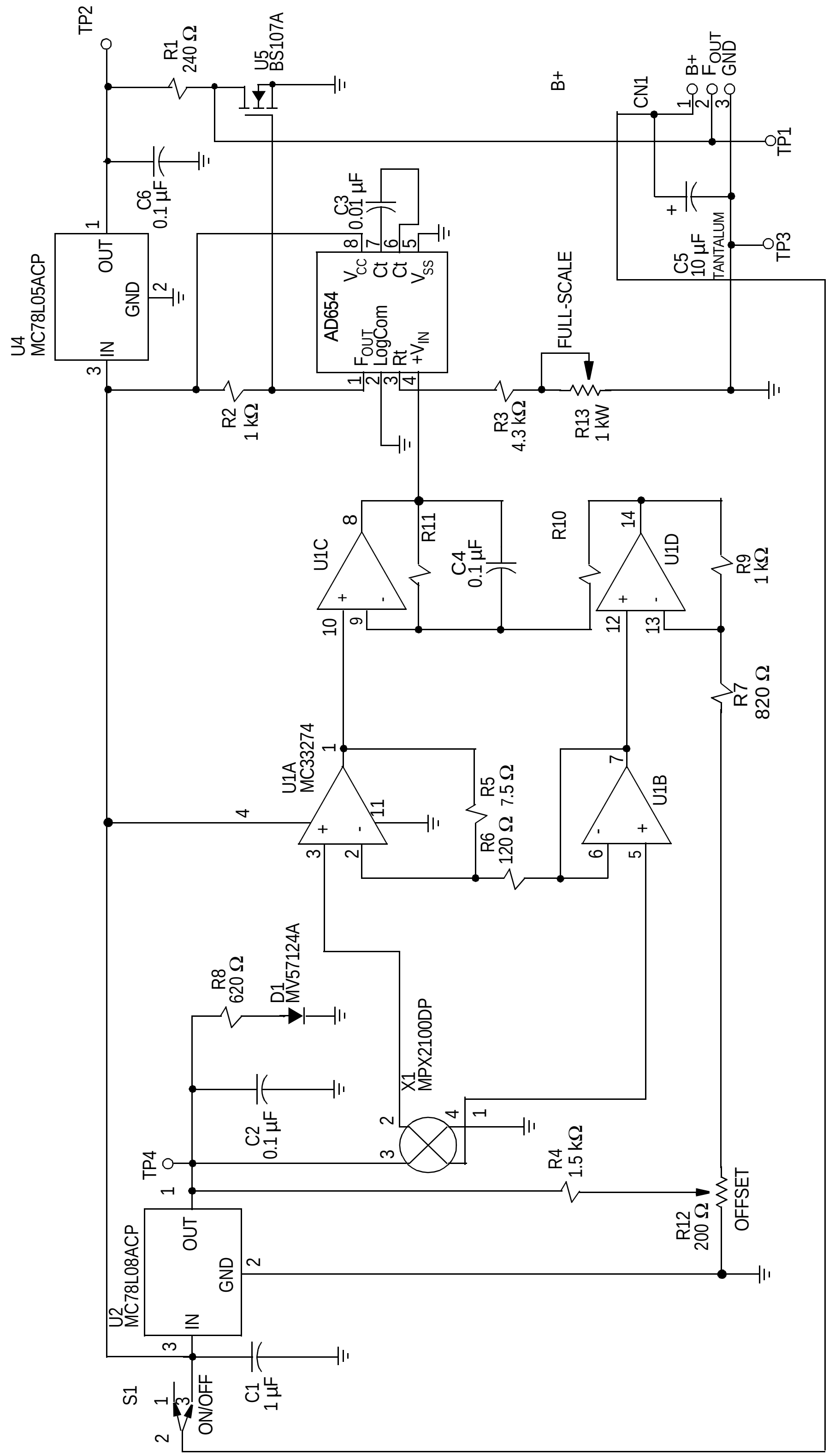


Figure 2. DEVB160 Frequency Output Sensor Evaluation Board

The following is a table of the components that are assembled on the DEVB160 Frequency Output Sensor Evaluation Board.

Table 2. Parts List

Designators	Quantity	Description	Manufacturer	Part Number
C1	1	1 μF Capacitor		
C2	1	0.1 μF Capacitor		
C3	1	0.01 μF Capacitor		
C4	1	0.1 μF Capacitor		
C5	1	10 μF Cap+		tantalum
C6	1	0.1 μF Capacitor		
CN1	1	.15LS 3 Term	PHX Contact	1727023
D1	1	RED LED	Quality Tech.	MV57124A
R1	1	240 Ω resistor		
R2, R9	2	1 kΩ resistor		
R3	1	4.3 kΩ resistor		
R4	1	1.5 kΩ resistor		
R5	1	7.5 kΩ resistor		
R6	1	120 Ω resistor		
R7	1	820 Ω resistor		
R8	1	620 Ω resistor		
R10, R11	2	2 kΩ resistor		
R12	1	200 Ω Trimpot	Bourns	3386P-1-201
R13	1	1 kΩ Trimpot	Bourns	3386P-1-102
S1	1	SPDT miniature switch	NKK	SS-12SDP2
TP1	1	YELLOW Testpoint	Control Design	TP-104-01-04
TP2	1	BLUE Testpoint	Control Design	TP-104-01-06
TP3	1	BLACK Testpoint	Control Design	TP-104-01-00
TP4	1	GREEN Testpoint	Control Design	TP-104-01-05
U1	1	Quad Op Amp	Freescale	MC33274
U2	1	8 V Regulator	Freescale	MC78L08ACP
U3	1	AD654	Analog Devices	AD654
U4	1	5 V Regulator	Freescale	MC78L05ACP
U5	1	Small-Signal FET	Freescale	BS107A
X1	1	Pressure Sensor	Freescale	MPX2100DP

NOTE: All resistors are 1/4 watt, 5% tolerance values. All capacitors are 50 V rated, ±20% tolerance values.

Circuit Operation

The voltage signal conditioning portion of this circuit is a variation on the classic instrumentation amplifier configuration. It is capable of providing high differential gain and good common-mode rejection with very high input impedance; however, it provides a more user friendly method of performing the offset/bias point adjustment. It uses four op amps and several resistors to amplify and level shift the sensor's output. Most of the amplification is done in U1A which is configured as a differential amplifier. Unwanted current flow through the sensor is prevented by buffer U1B. At zero pressure the differential voltage from pin 2 to pin 4 on the sensor has been precision trimmed to essentially zero volts. The common-mode voltage on each of these nodes is 4 V (one-half the sensor supply voltage). The zero pressure output voltage at pin 1 of U1A is then 4.0 V, since any other voltage would be coupled back to pin 2 via R5 and create a non-zero bias across U1A's differential inputs. This 4.0 V zero pressure DC output voltage is then level translated to the desired zero pressure offset voltage by U1C and U1D. The offset voltage is produced by R4 and adjustment trimpot R12. R7's value is such that the total source impedance into pin 13 is approximately 1 k. The gain is approximately (R5/R6)(1 + R11/R10), which is 125 for the values shown in Figure 2. A gain of 125 is selected to provide a 4 V span for 32 mV of full-scale sensor output (at a sensor supply voltage of 8 V).

The resulting 0.5 V to 4.5 V output from U1C is then converted by the V/F converter to the nominal 1-10 kHz that has been specified. The AD654 V/F converter receives the amplified sensor output at pin 8 of op amp U1C. The full-scale frequency is determined by R3, R13 and C3 according to the following formula:

$$F_{out}\ \text{(full-scale)} = \frac{V_{in}}{(10V)(R3 + R13)C3}$$

For best performance, R3 and R13 should be chosen to provide 1 mA of drive current at the full-scale voltage produced at pin 3 of the AD654 (U3). The input stage of the AD654 is an op-amp; thus, it will work to make the voltage at pin 3 of U3 equal to the voltage seen at pin 4 of U3 (pins 3 and 4 are the input terminals of the op amp). Since the amplified sensor output will be 4.5 V at full-scale pressure, R3 + R13 should be approximately equal to 4.5 kΩ to have optimal linearity performance. Once the total resistance from pin 3 of U3 to ground is set, the value of C3 will determine the full-scale frequency output of the V/F. Trimpot R13 should be sized (relative to R3 value) to provide the desired amount of full-scale frequency adjustment. The zero-pressure frequency is adjusted via the offset adjust provided for calibrating the offset voltage of the signal conditioned sensor output. For additional information on using this particular V/F converter, see the applications information provided in the Analog Devices Data Conversion Products Databook.

The frequency output has its edge transitions “sped” up by a small-signal FET inverter. This final output is directly compatible with microprocessor timer inputs, as well as any other high-speed CMOS logic. The amplifier portion of this circuit has been patented by Freescale Semiconductor, Inc. and was introduced on evaluation board DEVB150A. Additional information pertaining to this circuit and the evaluation board DEVB150A is contained in Freescale Application Note AN1313.[1]

TEST/CALIBRATION PROCEDURE

1. Connect a +12 V supply between B+ and GND terminals on the connector CN1.
2. Connect a frequency counter or scope probe on the F_{out} terminal of CN1 or on TP1 with the test instrumentation ground clipped to TP3 or GND.
3. Turn the power switch, S1, to the on position. Power LED, D1, should be illuminated. Verify that the voltage at TP2 and TP4 (relative to GND or TP3) is 5 V and 8 V, respectively. While monitoring the frequency output by whichever means one has chosen, one should see a 50% duty cycle square wave signal.
4. Turn the wiper of the OFFSET adjust trimpot, R12, to the approximate center of the pot.
5. Apply 100 kPa to pressure port P1 of the MPX2100DP (topside port on marked side of the package) sensor, X1.
6. Adjust the FULL-SCALE trimpot, R13, until the output frequency is 10 kHz. If 10 kHz is not within the trim range of the full-scale adjustment trimpot, tweak the offset adjust trimpot to obtain 10 kHz (remember, the offset pot was at an arbitrary midrange setting as per step 4).
7. Apply zero pressure to the pressure port (i.e., both ports at ambient pressure, no differential pressure applied). Adjust OFFSET trimpot so frequency output is 1 kHz.
8. Verify that zero pressure and full-scale pressure (100 kPa) produce 1 and 10 kHz respectively, at F_{out} and/or TP1. A second iteration of adjustment on both full-scale and offset may be necessary to fine tune the 1-10 kHz range.

CONCLUSION

Transforming conventional analog voltage sensor outputs to frequency has great utility for a variety of applications. Sensing remotely and/or in noisy environments is particularly challenging for low-level (mV) voltage output sensors such as the MPX2000 Series pressure sensors. Converting the MPX2000 sensor output to frequency is relatively easy to accomplish, while providing the noise immunity required for accurate pressure sensing. The evaluation board presented is an excellent tool for either “stand-alone” evaluation of the MPX2000 Series pressure sensors or as a building block for system prototyping which can make use of DEVB160 as a “drop-in” frequency output sensor solution. The output of the DEVB160 circuit is ideally conditioned for interfacing to MCU timer inputs that can measure the sensor frequency signal.

1. Schultz, Warren (Freescale Semiconductor, Inc.), “Sensor Building Block Evaluation Board,” Freescale Application Note AN1313.

AN1318
Rev 2, 05/2005

Interfacing Semiconductor Pressure Sensors to Microcomputers

by: Warren Schultz
Discrete Applications Engineering

INTRODUCTION

The most popular silicon pressure sensors are piezoresistive bridges that produce a differential output voltage in response to pressure applied to a thin silicon diaphragm. Output voltage for these sensors is generally 25 to 50 mV full scale. Interface to microcomputers, therefore, generally involves gaining up the relatively small output voltage, performing a differential to single ended conversion, and scaling the analog signal into a range appropriate for analog to digital conversion. Alternately, the analog pressure signal can be converted to a frequency modulated 5 V waveform or 4-20 mA current loop, either of which is relatively immune to noise on long interconnect lines.

A variety of circuit techniques that address interface design are presented. Sensing amplifiers, analog to digital conversion, frequency modulation and 4-20 mA current loops are considered.

PRESSURE SENSOR BASICS

The essence of piezoresistive pressure sensors is the Wheatstone bridge shown in Figure 1. Bridge resistors RP1, RP2, RV1 and RV2 are arranged on a thin silicon diaphragm such that when pressure is applied RP1 and RP2 increase in value while RV1 and RV2 decrease a similar amount. Pressure on the diaphragm, therefore, unbalances the bridge and produces a differential output signal. One of the fundamental properties of this structure is that the differential output voltage is directly proportional to bias voltage B+. This characteristic implies that the accuracy of the pressure measurement depends directly on the tolerance of the bias supply. It also provides a convenient means for temperature compensation. The bridge resistors are silicon resistors that have positive temperature coefficients. Therefore, when they are placed in series with zero T_C temperature compensation resistors RC1 and RC2 the amount of voltage applied to the bridge increases with temperature. This increase in voltage produces an increase in electrical sensitivity which offsets and compensates for the negative temperature coefficient associated with piezoresistance.

Since RC1 and RC2 are approximately equal, the output voltage common mode is very nearly fixed at 1/2 B+. In a typical MPX2100 sensor, the bridge resistors are nominally 425 ohms; RC1 and RC2 are nominally 680 ohms. With these values and 10 V applied to B+, a delta R of 1.8 ohms at full scale pressure produces 40 mV of differential output voltage.

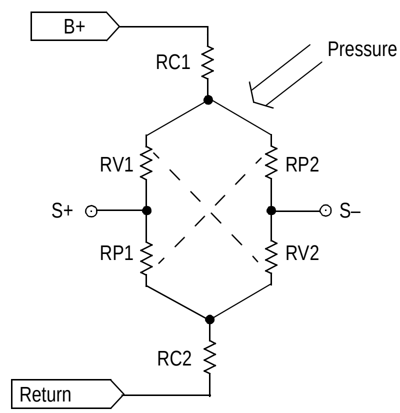


Figure 1. Sensor Equivalent Circuit

INSTRUMENTATION AMPLIFIER INTERFACES

Instrumentation amplifiers are by far the most common interface circuits that are used with pressure sensors. An example of an inexpensive instrumentation amplifier based interface circuit is shown in Figure 2. It uses an MC33274 quad operational amplifier and several resistors that are configured as a classic instrumentation amplifier with one important exception. In an instrumentation amplifier resistor R3 is normally returned to ground. Returning R3 to ground sets the output voltage for zero differential input to 0 V DC. For microcomputer interface a positive offset voltage on the order of 0.3 to 0.8 V is generally desired. Therefore, R3 is connected to pin 14 of U1D which supplies a buffered offset voltage that is derived from the wiper of R6. This voltage establishes a DC output for zero differential input. The translation is one to one. Within the tolerances of the circuit, whatever voltage appears at the wiper of R6 will also appear as the zero pressure DC offset voltage at the output.

With R10 at 240 ohms, gain is set for a nominal value of 125. This provides a 4 V span for 32 mV of full scale sensor output. Setting the offset voltage to 0.75 V results in a 0.75 V to 4.75 V output that is directly compatible with microprocessor A/D inputs. Over a zero to 50° C temperature range, combined accuracy for an MPX2000 series sensor and this interface is on the order of ± 10%.

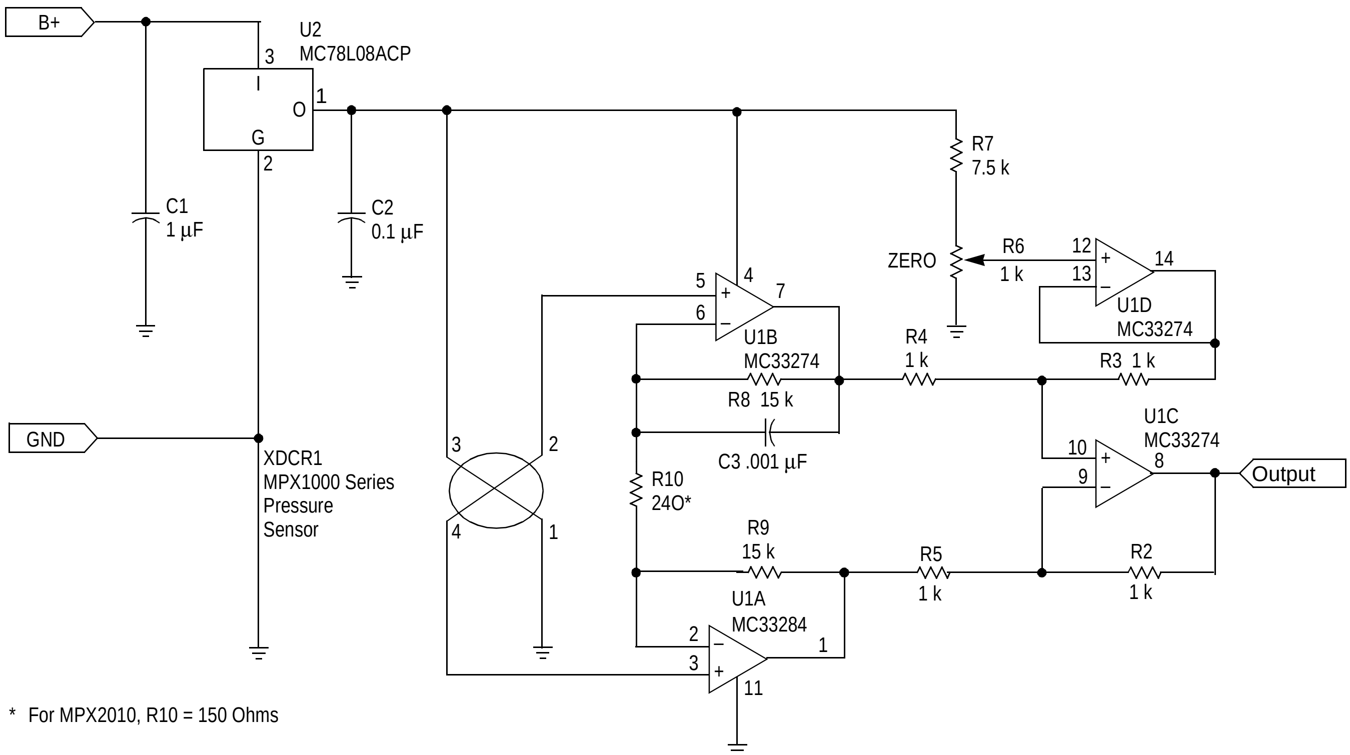


Figure 2. Instrumentation Amplifier Interface

For applications requiring greater precision a fully integrated instrument amplifier such as an LTC1100CN8 gives better results. In Figure 3 one of these amplifiers is used to provide a gain of 100, as well as differential to single ended conversion. Zero offset is provided by dividing down the precision reference to 0.5 V and buffering with U2B. This voltage is fed into the LTC1100CN8's ground pin which is equivalent to returning R3 to pin 14 of U1D in Figure 2. An additional non-inverting gain stage consisting of U2A, R1 and R2 is used to scale the sensor's full scale span to 4 V. R2 is also returned to the buffered 0.5 V to maintain the 0.5 V zero offset that was established in the instrumentation amplifier. Output voltage range is therefore 0.5 to 4.5 V.

Both of these instrumentation amplifier circuits do their intended job with a relatively straightforward tradeoff between cost and performance. The circuit of Figure 2 has the usual cumulative tolerance problem that is associated with instrumentation amplifiers that have discrete resistors, but it has a relatively low cost. The integrated instrumentation amplifier in Figure 3 solves this problem with precision trimmed film resistors and also provides superior input offset performance. Component cost, however, is significantly higher.

SENSOR SPECIFIC INTERFACE AMPLIFIER

A low cost interface designed specifically for pressure sensors improves upon the instrumentation amplifier in Figure 2. Shown in Figure 4, it uses one quad op amp and several resistors to amplify and level shift the sensor's output. Most of the amplification is done in U1A which is configured as a differential amplifier. It is isolated from the sensor's positive output by U1B. The purpose of U1B is to prevent feedback current that flows through R5 and R6 from flowing into the sensor. At zero pressure the voltage from pin 2 to pin 4 on the sensor is 0 V. For example, let's say that the common mode voltage on these pins is 4.0 V. The zero pressure output voltage at pin 1 of U1A is then 4.0 V, since any other voltage would be coupled back to pin 2 via R6 and create a non-zero bias across U1A's differential inputs. This 4.0 V zero pressure DC output voltage is then level translated to the desired zero pressure offset voltage (V_{OFFSET}) by U1C and U1D.

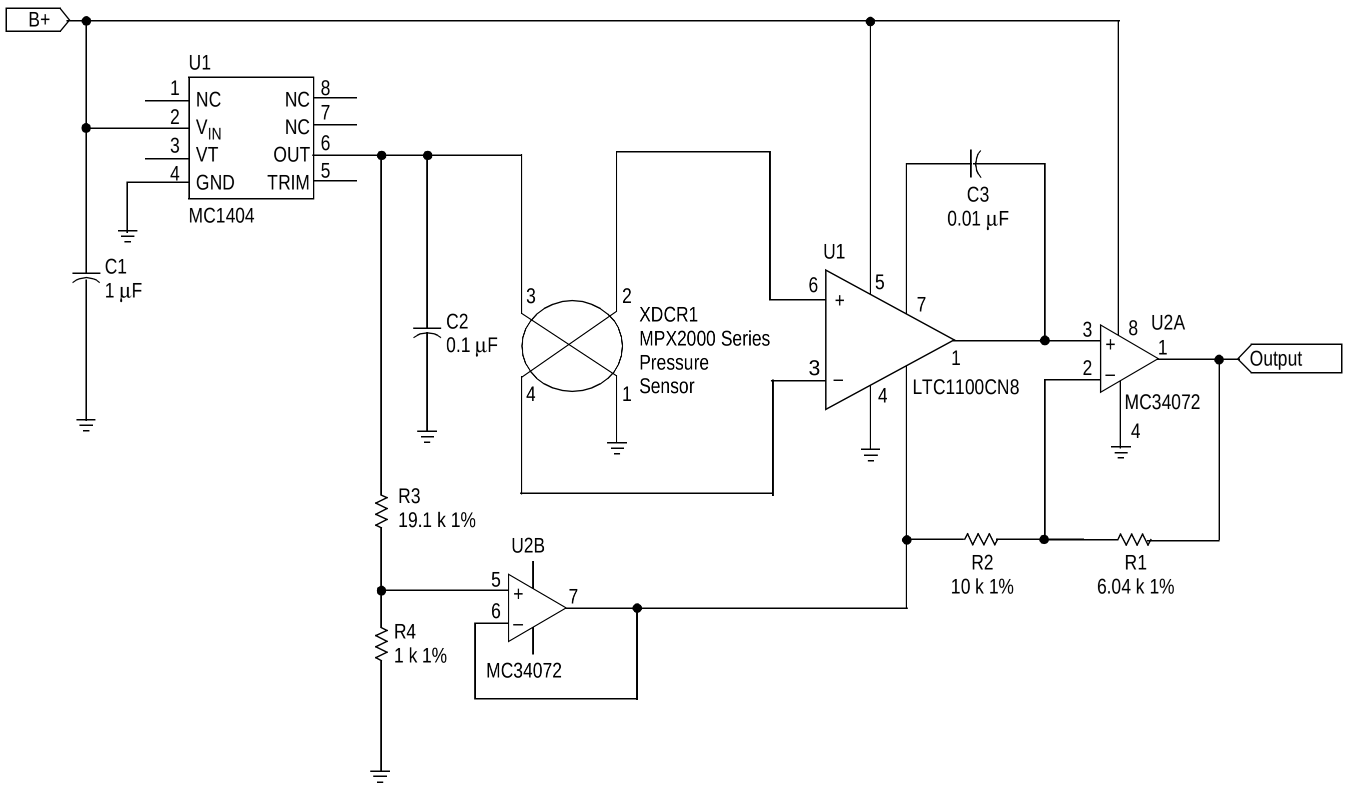
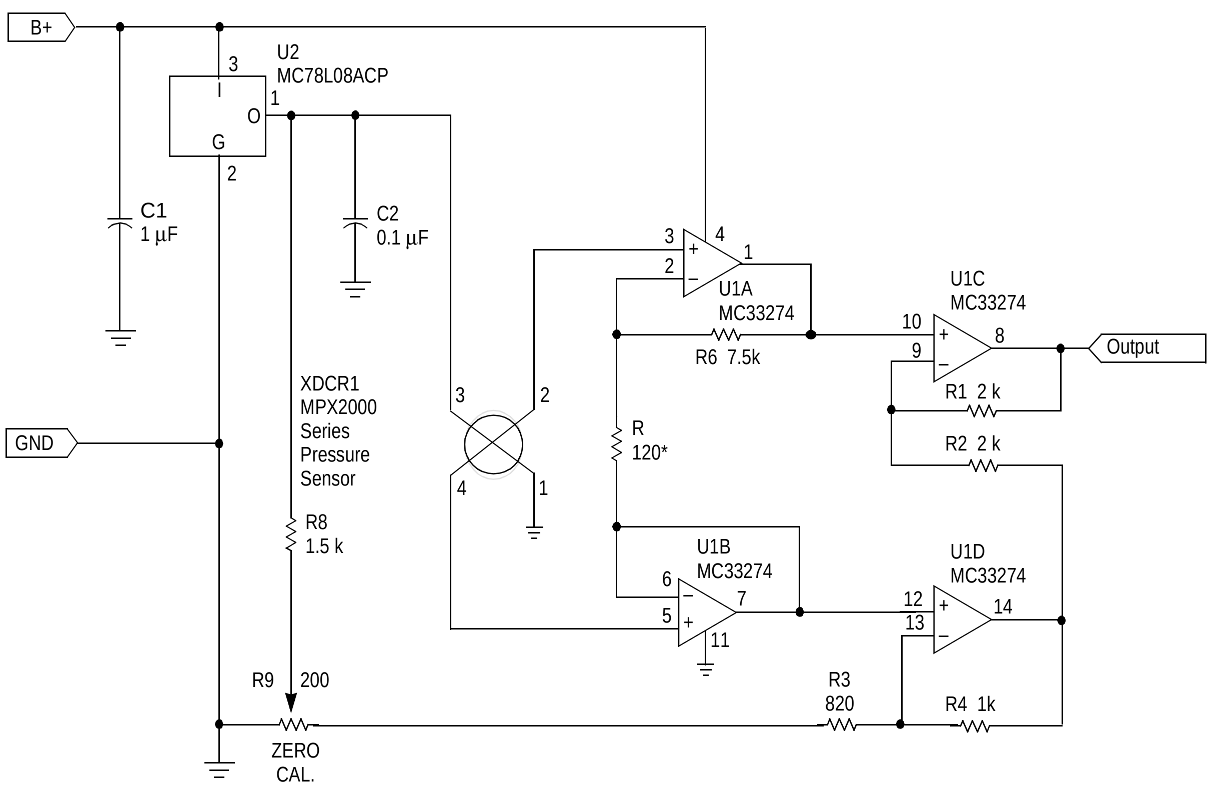


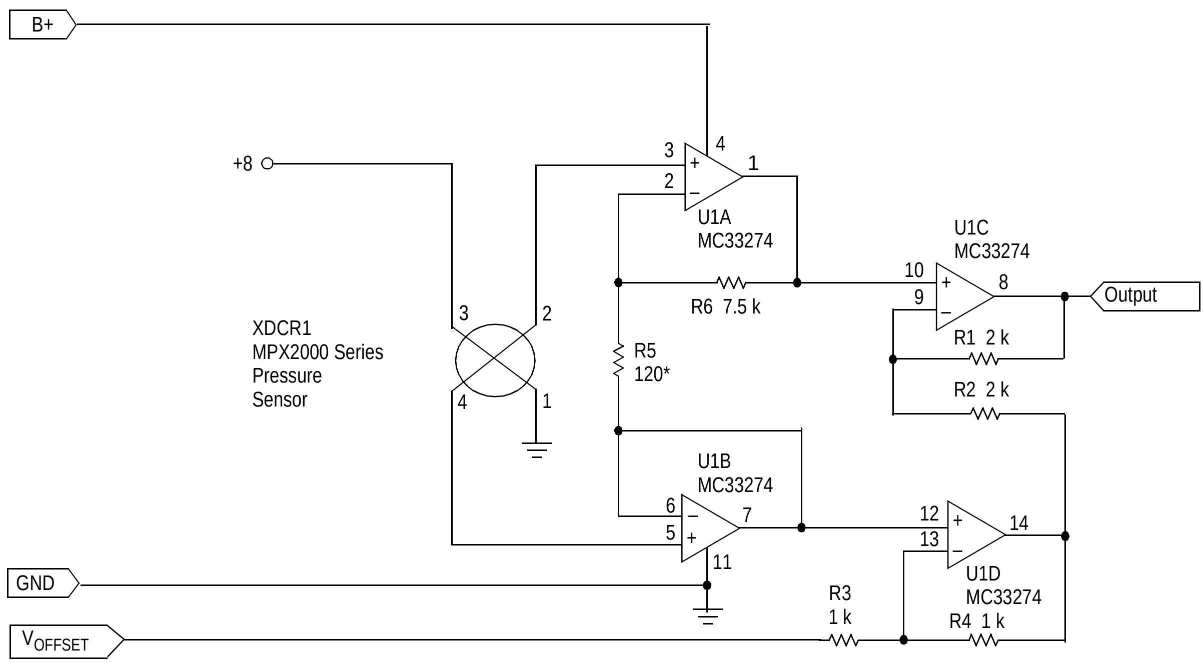
Figure 3. Precision Instrument Amplifier Interface



* NOTE: For MPX2010, R5 = 75 Ohms

Figure 4. Sensor Specific Interface Circuit

To see how the level translation works, let's look at the simplified schematic in Figure 5. Again assuming a common mode voltage of 4.0 V, the voltage applied to pin 12 of U1D is 4.0 V, implying that pin 13 is also at 4.0 V. This leaves 4.0 V - V_{OFFSET} across R3, which is 3.5 V if V_{OFFSET} is set to 0.5 V. Since no current flows into pin 13, the same current flows through both R3 and R4. With both of these resistors set to the same value, they have the same voltage drop, implying a 3.5 V drop across R4. Adding the voltages (0.5 + 3.5 + 3.5) yields 7.5 V at pin 14 of U1D. Similarly 4.0 V at pin 10 of U1C implies 4.0 V at pin 9, and the drop across R2 is 7.5 V - 4.0 V = 3.5 V. Again 3.5 V across R2 implies an equal drop across R1, and the voltage at pin 8 is 4.0 V - 3.5 V = 0.5 V. For this DC output voltage to be independent of the sensor's common mode voltage it is necessary to satisfy the condition that R4/R3 = R2/R1. In Figure 4, V_{OFFSET} is produced by R8 and adjustment pot R9. R3's value is adjusted such that the total source impedance into pin 13 is approximately 1 k.



*NOTE: For MPX2010, R5 = 75 Ohms

Figure 5. Simplified Sensor Specific Interface

Gain is approximately (R6/R5)(R1/R2+1), which is 125 for the values shown in Figure 4. A gain of 125 is selected to provide a 4 V span for the 32 mV of full scale sensor output that is obtained with 8 V B+.

The resulting 0.5 V to 4.5 V output from U1C is preferable to the 0.75 to 4.75 V range developed by the instrument amplifier configuration in Figure 2. It also uses fewer parts. This circuit does not have the instrument amplifier's propensity for oscillation and therefore does not require compensation capacitor C3 that is shown in Figure 2. It also requires one less resistor, which in addition to reducing component count also reduces accumulated tolerances due to resistor variations.

This circuit as well as the instrumentation amplifier interfaces in Figure 2 and Figure 3 is designed for direct connection to a microcomputer A/D input. Using the MC68HC11 as an example, the interface circuit output is connected to any of the E ports, such as port E0 as shown in Figure 6. To get maximum accuracy from the A/D conversion, V_{REFH} is tied to 4.85 V and V_{REFL} is tied to 0.30 V by dividing down a 5 V reference with 1% resistors.

SINGLE SLOPE A/D CONVERTER

The 8 bit A/D converters that are commonly available on chip in microcomputers are usually well suited to pressure sensing applications. In applications that require more than 8 bits, the circuit in Figure 7 extends resolution to 11 bits with an external analog-to-digital converter. It also provides an interface to digital systems that do not have an internal A/D function.

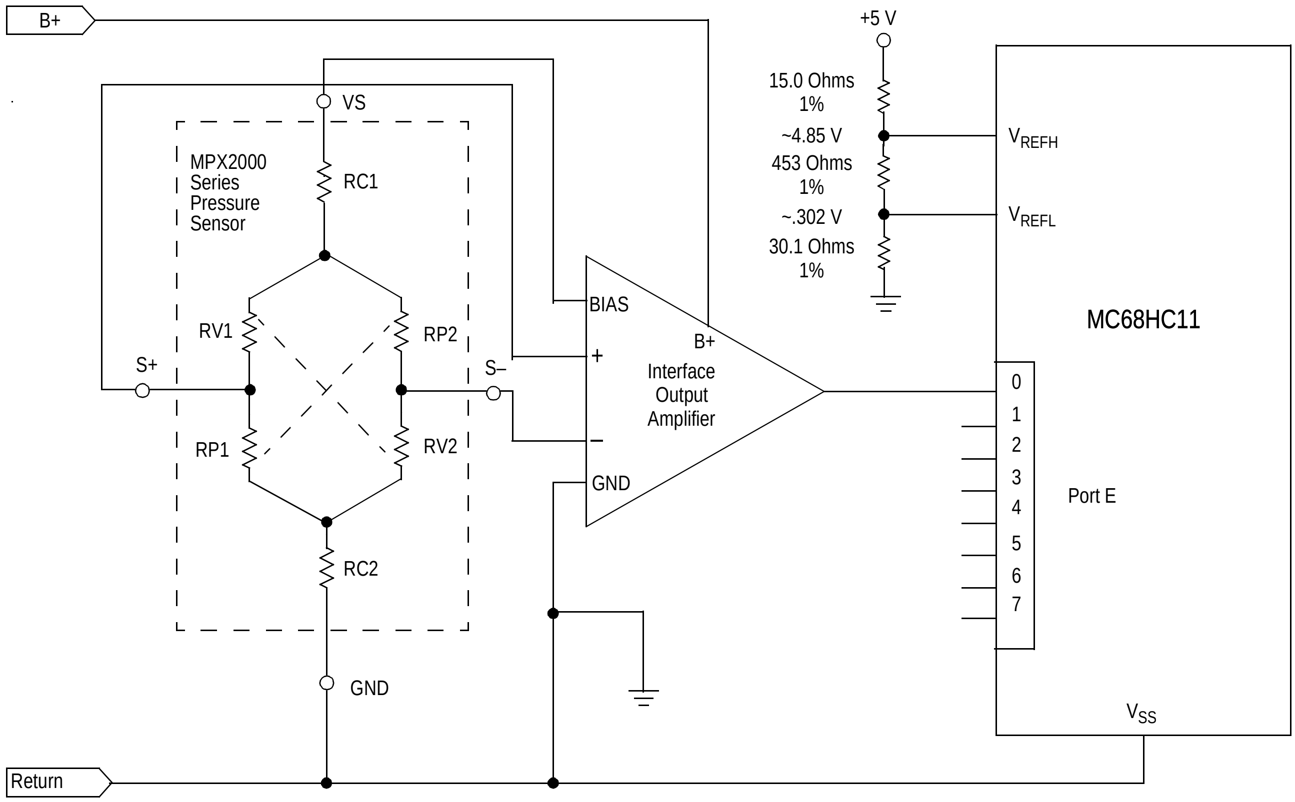


Figure 6. Application Example

Beginning with the ramp generator, a timing ramp is generated with current source U5 and capacitor C3. Initialization is provided by Q1 which sets the voltage on C3 at approximately ground. With the values shown, 470 µA flowing into 0.47 µF provide approximately a 5 msec ramp time from zero to 5 V. Assuming zero pressure on the sensor, inputs to both comparators U2A and U2B are at the same voltage. Therefore, as the ramp voltage sweeps from zero to 5 V, both PA0 and PA1 will go low at the same time when the ramp voltage exceeds the common mode voltage. The processor counts the number of clock cycles between the time that PA0 and PA1 go low, reading zero for zero pressure.

In this circuit, U4A and U4B form the front end of an instrument amplifier. They differentially amplify the sensor's output. The resulting amplified differential signal is then sampled and held in U1 and U3. The sample and hold function is performed in order to keep input data constant during the conversion process. The stabilized signals coming out of U1 and U3 feed a higher output voltage to U2A than U2B, assuming that pressure is applied to the sensor. Therefore, the ramp will trip U2B before U2A is tripped, creating a time difference between PA0 going low and PA1 going low. The processor reads the number of clock cycles between these two events. This number is then linearly scaled with software to represent the amplified output voltage, accomplishing the analog to digital conversion.

When the ramp reaches the reference voltage established by R9 and R10, comparator U2C is tripped, and a reset command is generated. To accomplish reset, Q1 is turned on with an output from PA7, and the sample and hold circuits are delatched with an output from PB1. Resolution is limited by clock frequency and ramp linearity. With the ramp generator shown in Figure 7 and a clock frequency of 2 MHz; resolution is 11 bits.

From a software point of view, the A/D conversion consists of latching the sample and hold, reading the value of the microcomputer's free running counter, turning off Q1, and waiting for the three comparator outputs to change state from logic 1 to logic 0. The analog input voltage is determined by counting, in 0.5 µsec steps, the number of clock cycles between PA0 and PA1 going low.

LONG DISTANCE INTERFACES

In applications where there is a significant distance between the sensor and microcomputer, two types of interfaces are typically used. They are frequency output and 4-20 mA loops. In the frequency output topology, pressure is converted into a zero to 5 V digital signal whose frequency varies linearly with pressure. A minimum frequency corresponds to zero pressure and above this, frequency output is determined by a Hz/unit pressure scaling factor. If minimizing the number of wires to a remote sensor is the most important design consideration, 4-20 mA current loops are the topology of choice. These loops utilize power and ground as the 4-20 mA signal line and therefore require only two wires to the sensor. In this topology 4 mA of total current drain from the sensor corresponds to zero pressure, and 20 mA to full scale.

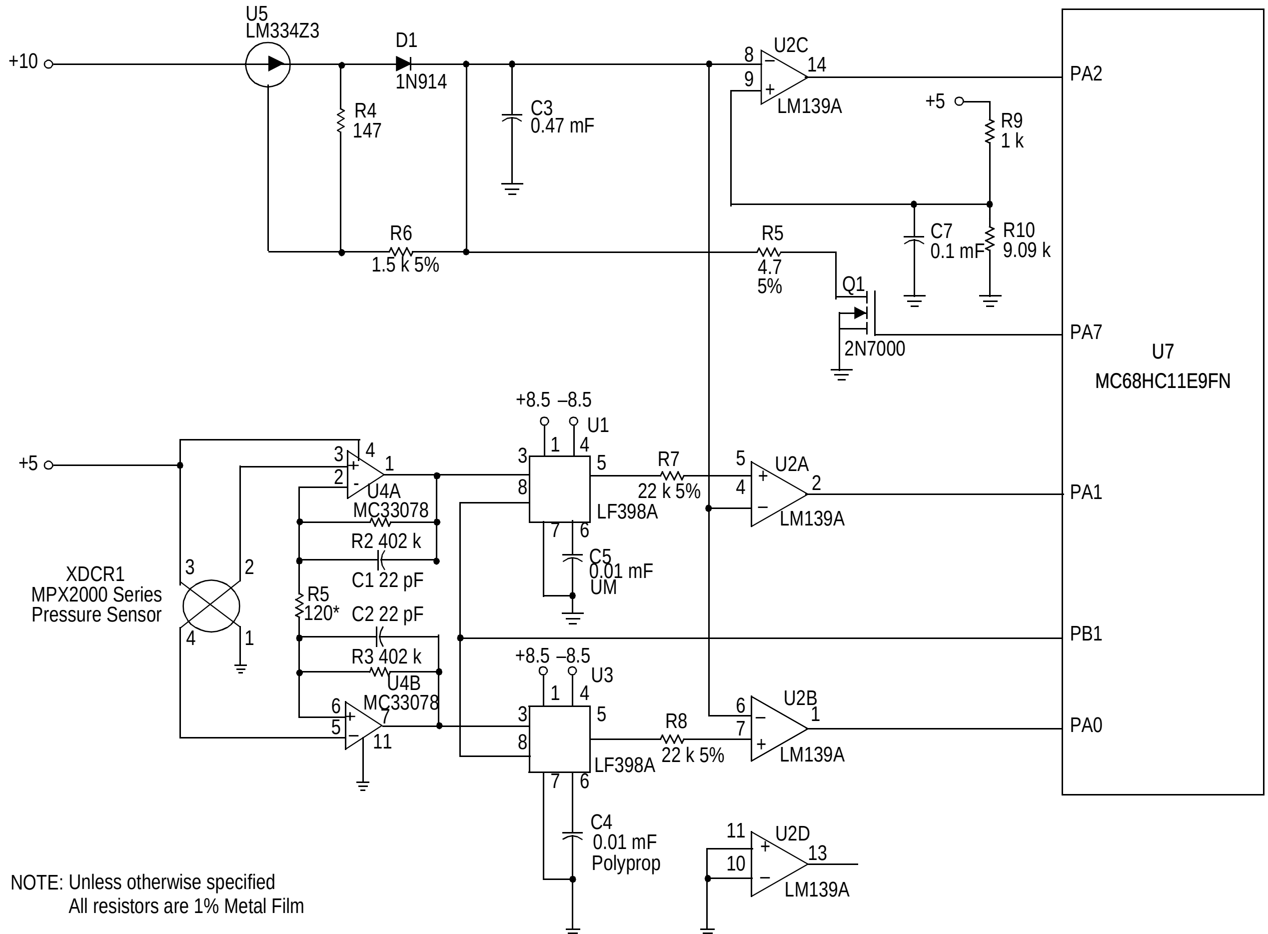


Figure 7. Single Slope A/D Converter

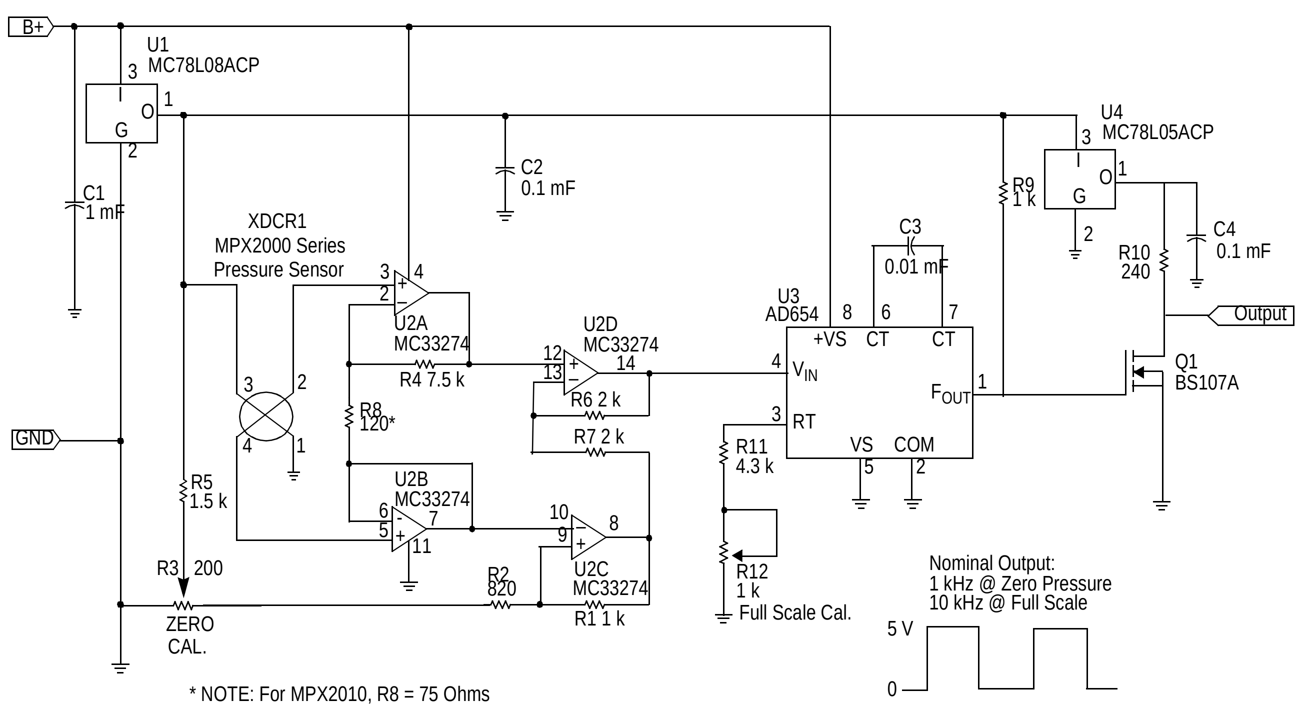


Figure 8. Frequency Output Pressure Sensor

A relatively straightforward circuit for converting pressure to frequency is shown in Figure 9. It consists of three basic parts. The interface amplifier is the same circuit that was described in Figure 4. Its 0.5 to 4.5 V output is fed directly into an AD654 voltage-to-frequency converter. On the AD654, C3 sets nominal output frequency. Zero pressure output is calibrated to 1 kHz by adjusting the zero pressure input voltage with R3. Full scale adjustments are made with R12 which sets the full scale frequency to 10 kHz. The output of the AD654 is then fed into a buffer consisting of Q1 and R10. The buffer is used to clean up the edges and level translate the output to 5 V. Advantages of this approach are that the frequency output is easily read by a microcomputer's timer and transmission over a twisted pair line is relatively easy. Where very long distances are involved, the primary disadvantage is that 3 wires (V_{CC}, ground, and an output line) are routed to the sensor.

A 4-20 mA loop reduces the number of wires to two. Its output is embedded in the V_{CC} and ground lines as an active current source. A straightforward way to apply this technique to pressure sensing is shown in Figure 10. In this figure an MPX7000 series high impedance pressure sensor is mated to an XTR101 4-20 mA two-wire transmitter. It is set up to pull 4 mA from its power line at zero pressure and 20 mA at full scale. At the receiving end a 240 ohm resistor referenced to signal ground will provide a 0.96 to 4.8 V signal that is suitable for microcomputer A/D inputs.

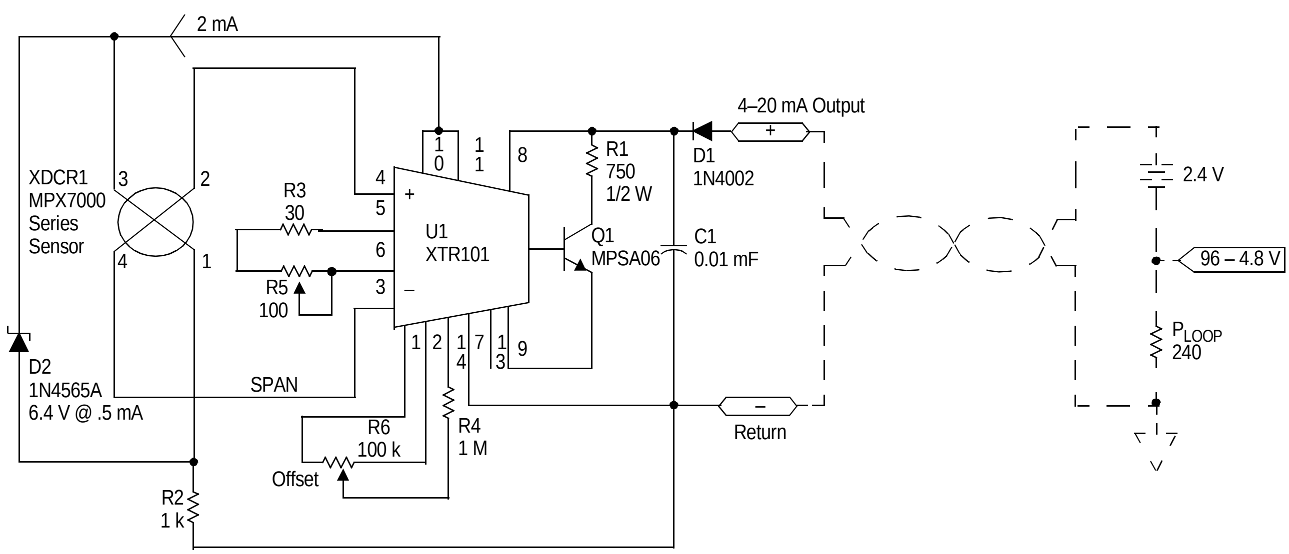


Figure 9. 4-20 mA Pressure Transducer

Bias for the sensor is provided by two 1 mA current sources (pins 10 and 11) that are tied in parallel and run into a 1N4565A 6.4 V temperature compensated zener reference. The sensor's differential output is fed directly into XTR101's inverting and non-inverting inputs. Zero pressure offset is calibrated to 4 mA with R6. Biased with 6.4 V, the sensor's full scale output is 24.8 mV. Given this input R3 + R5 nominally total 64 ohms to produce the 16 mA span required for 20 mA full scale. Calibration is set with R5.

The XTR101 requires that the differential input voltage at pins 3 and 4 has a common mode voltage between 4 and 6 V. The sensor's common mode voltage is one half its supply voltage or 3.2 V. R2 boosts this common mode voltage by 1k•2mA or 2 V, establishing a common mode voltage for the transmitter's input of 5.2 V. To allow operation over a 12 to 40 V range, dissipation is off-loaded from the IC by boosting the output with Q1 and R1. D1 is also included for protection. It prohibits reverse polarity from causing damage. Advantages of this topology include simplicity and, of course, the two wire interface.

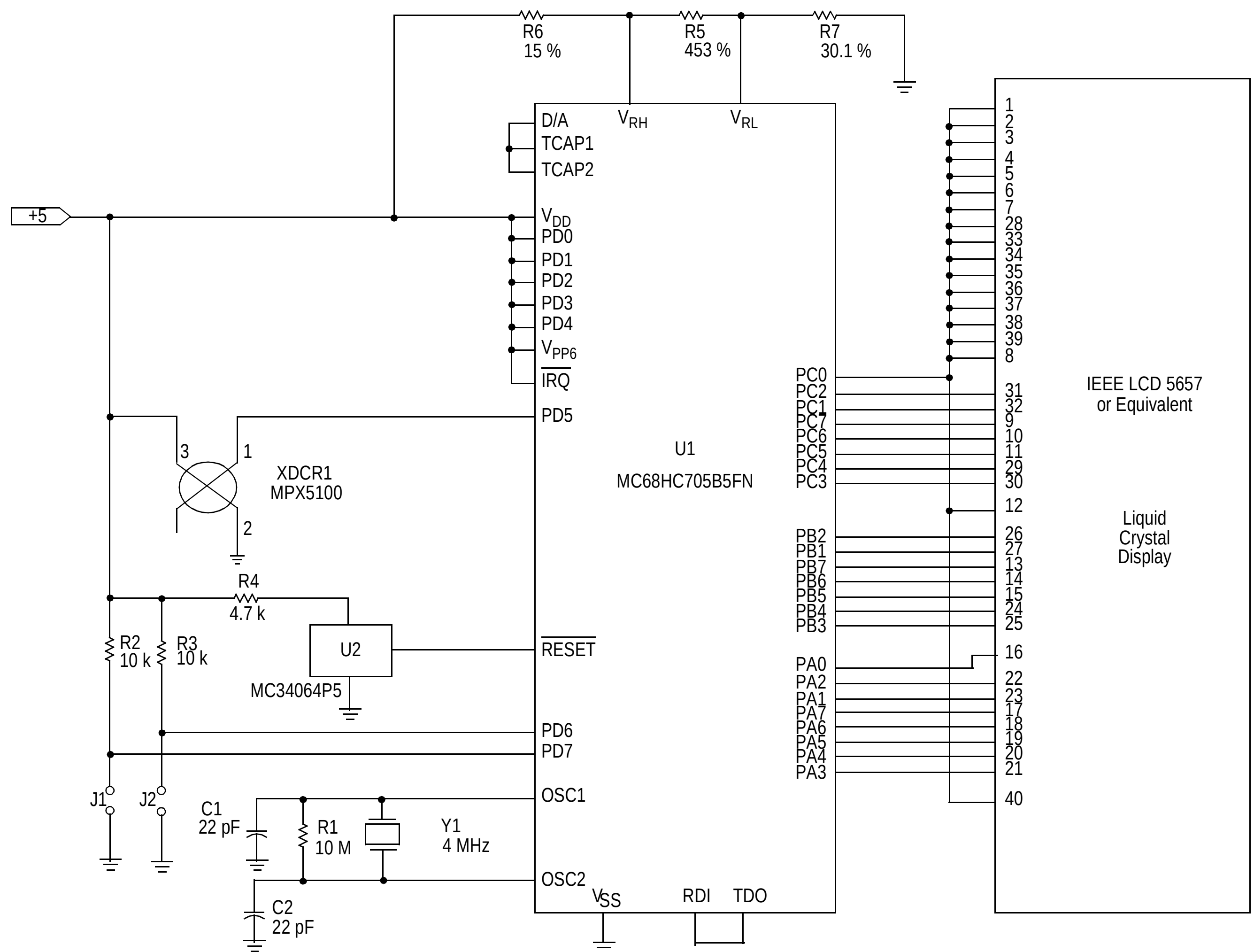


Figure 10. MPX5100 LCD Pressure Gauge

DIRECT INTERFACE WITH INTEGRATED SENSORS

The simplest interface is achieved with an integrated sensor and a microcomputer that has an on-chip A/D converter. Figure 10 shows an LCD pressure gauge that is made with an MPX5100 integrated sensor and MC68HC05 microcomputer. Although the total schematic is reasonably complicated, the interface between the sensor and the micro is a single wire. The MPX5100 has an internal amplifier that outputs a 0.5 to 4.5 V signal that inputs directly to A/D port PD5 on the HC05.

The software in this system is written such that the processor assumes zero pressure at power up, reads the sensor's output voltage, and stores this value as zero pressure offset. Full scale span is adjustable with jumpers J1 and J2. For this particular system the software is written such that with J1 out and J2 in, span is decreased by 1.5%. Similarly with J1 in and J2 out, span is increased by 1.5%. Given the ± 2.5% full scale spec on the sensor, these jumpers allow calibration to ± 1% without the use of pots.

MIX AND MATCH

The circuits that have been described so far are intended to be used as functional blocks. They may be combined in a variety of ways to meet the particular needs of an application. For example, the Frequency Output Pressure Sensor in Figure 8 uses the sensor interface circuit described in Figure 4 to provide an input to the voltage-to-frequency converter. Alternately, an MPX5100 could be directly connected to pin 4 of the AD654 or the output of Figure 3's Precision Instrumentation Amplifier Interface could by substituted in the same way. Similarly, the Pressure Gauge described in Figure 10 could be constructed with any of the interfaces that have been described.

CONCLUSION

The circuits that have been shown here are intended to make interfacing semiconductor pressure sensors to digital systems easier. They provide cost effective and relatively simple ways of interfacing sensors to microcomputers. The seven different circuits contain many tradeoffs that can be matched to the needs of individual applications. When considering these tradeoffs it is important to throw software into the equation. Techniques such as automatic zero pressure calibration can allow one of the inexpensive analog interfaces to provide performance that could otherwise only be obtained with a more costly precision interface.

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Applying Semiconductor Sensors to Bar Graph Pressure Gauges

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Discrete Applications Engineering

INTRODUCTION

Bar Graph displays are noted for their ability to very quickly convey a relative sense of how much of something is present. They are particularly useful in process monitoring applications where quick communication of a relative value is more important than providing specific data.

Designing bar graph pressure gauges based upon semiconductor pressure sensors is relatively straightforward. The sensors can be interfaced to bar graph display drive IC's, microcomputers and MC33161 voltage monitors. Design examples for all three types are included.

BAR GRAPH DISPLAY DRIVER

Interfacing semiconductor pressure sensors to a bar graph display IC such as an LM3914 is very similar to microcomputer interface. The same 0.5 to 4.5 V analog signal that a microcomputer's A/D converter wants to see is also quite suitable for driving an LM3914. In Figure 1, this interface is provided by dual op amp U2 and several resistors.

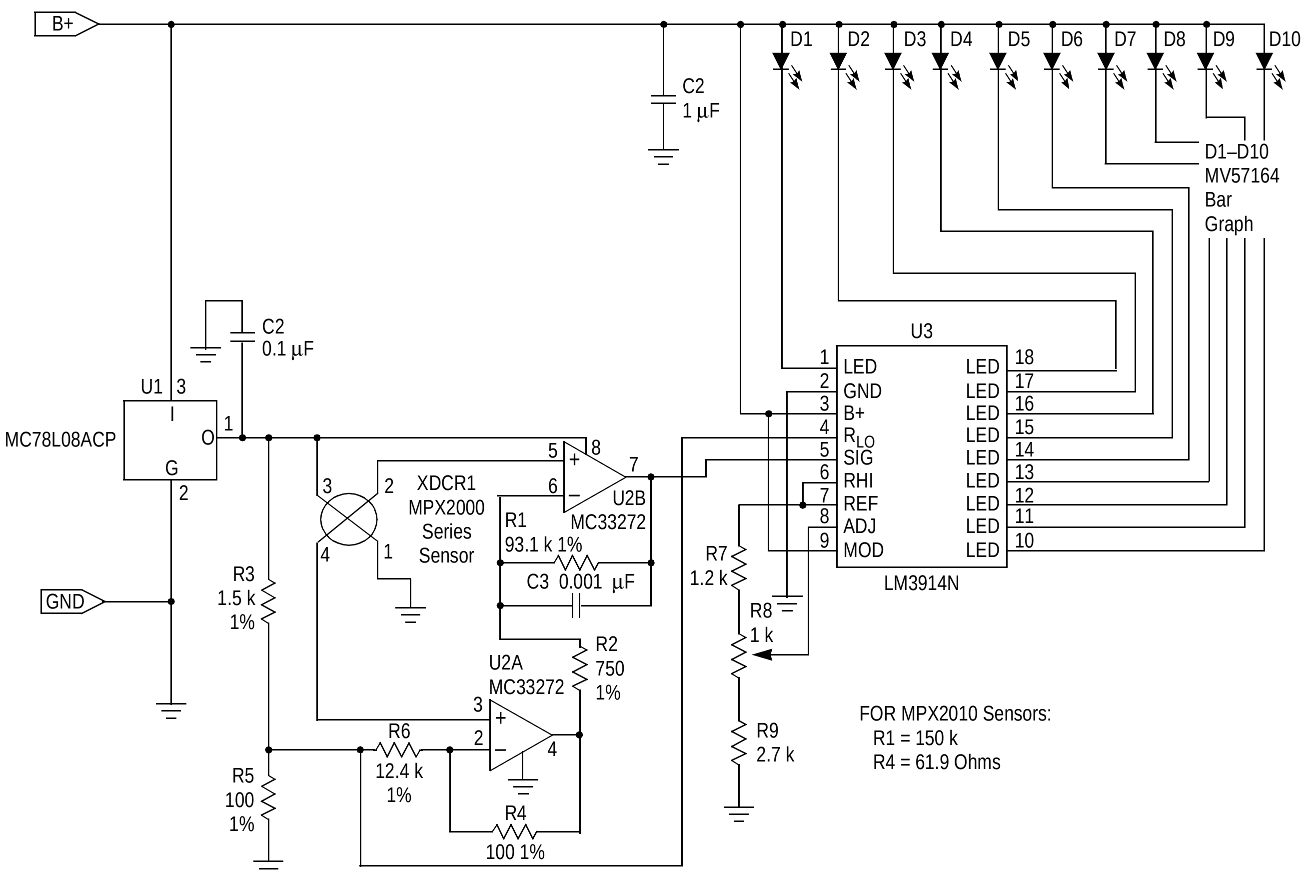

Figure 1. Compensated Sensor Bar Graph Pressure Gauge

The op amp interface amplifies and level shifts the sensor's output. To see how this amplifier works, simplify it by grounding the output of voltage divider R3, R5. If the common mode voltage at pins 2 and 4 of the sensor is 4.0 V, then pin 2 of U2A and pin 6 of U2B are also at 4.0 V. This puts 4.0 V across R6. Assuming that the current in R4 is equal to the current in R6, 323 µA • 100 ohms produces a 32 mV drop across R4 which adds to the 4.0 V at pin 2. The output voltage at pin 1 of U2A is, therefore, 4.032 V. This puts 4.032 - 4.0 V across R2, producing 43 µA. The same current flowing through R1 again produces a voltage drop of 4.0 V, which sets the output at zero. Substituting a divider output greater than zero into this calculation reveals that the zero pressure output voltage is equal to the output voltage of divider R3, R5. For this DC output voltage to be independent of the sensor's common mode voltage, it is necessary to satisfy the condition that R1/R2 = R6/R4.

Gain can be determined by assuming a differential output at the sensor and going through the same calculation. To do this assume 100 mV of differential output, which puts pin 2 of U2A at 3.95 V, and pin 6 of U2B at 4.05 V. Therefore, 3.95 V is applied to R6, generating 319 µA. This current flowing through R4 produces 31.9 mV, placing pin 1 of U2A at 3950 mV + 31.9 mV = 3982 mV. The voltage across R2 is then 4050 mV - 3982 mV = 68 mV, which produces a current of 91 µA that flows into R1. The output voltage is then 4.05 V + (91 µA • 93.1k) = 12.5 V. Dividing 12.5 V by the 100 mV input yields a gain of 125, which provides a 4.0 V span for 32 mV of full scale sensor output.

Setting divider R3, R5 at 0.5 V results in a 0.5 V to 4.5 V output that is easily tied to an LM3914. The block diagram that appears in Figure 2 shows the LM3914's internal architecture. Since the lower resistor in the input comparator chain is pinned out at R_{LO}, it is a simple matter to tie this pin to a voltage that is approximately equal to the interface circuit's 0.5 V zero pressure output voltage. Returning to Figure 1, this is accomplished by using the zero pressure offset voltage that is generated at the output of divider R3, R5.

Again looking at Figure 1, full scale is set by adjusting the upper comparator's reference voltage to match the sensor's output at full pressure. An internal regulator on the LM3914 sets this voltage with the aid of resistors R7, R9, and adjustment pot R8.

Eight volt regulated power is supplied by an MC78L08. The LED's are powered directly from LM3914 outputs, which are set up as current sources. Output current to each LED is approximately 10 times the reference current that flows from pin 7 through R7, R8, and R9 to ground. In this design it is nominally (4.5 V/4.9 k)10 = 9.2 mA.

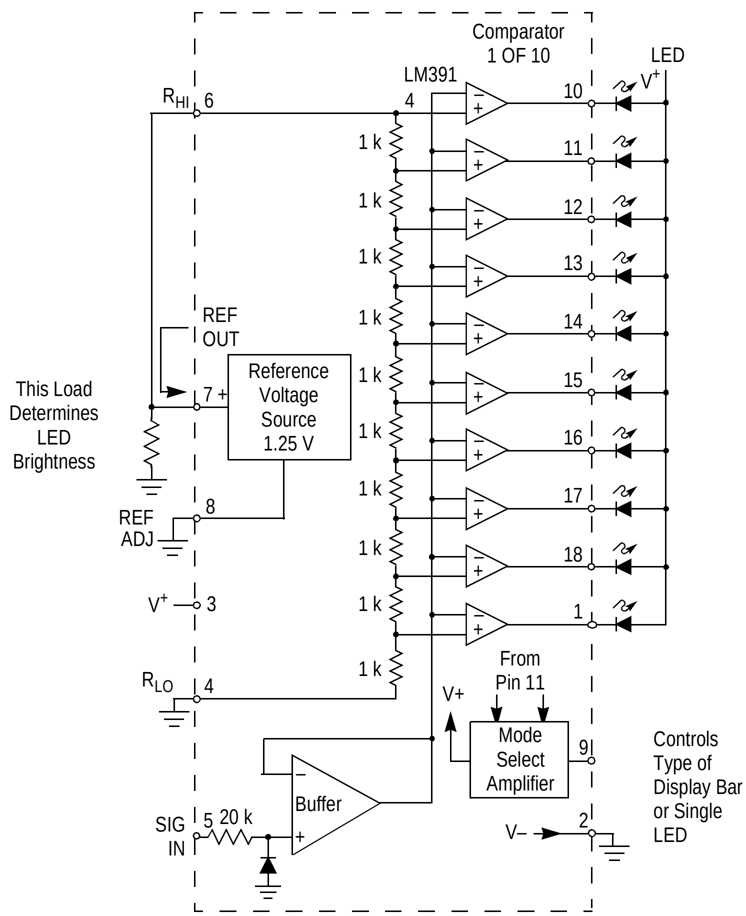

Figure 2. LM3914 Block Diagram

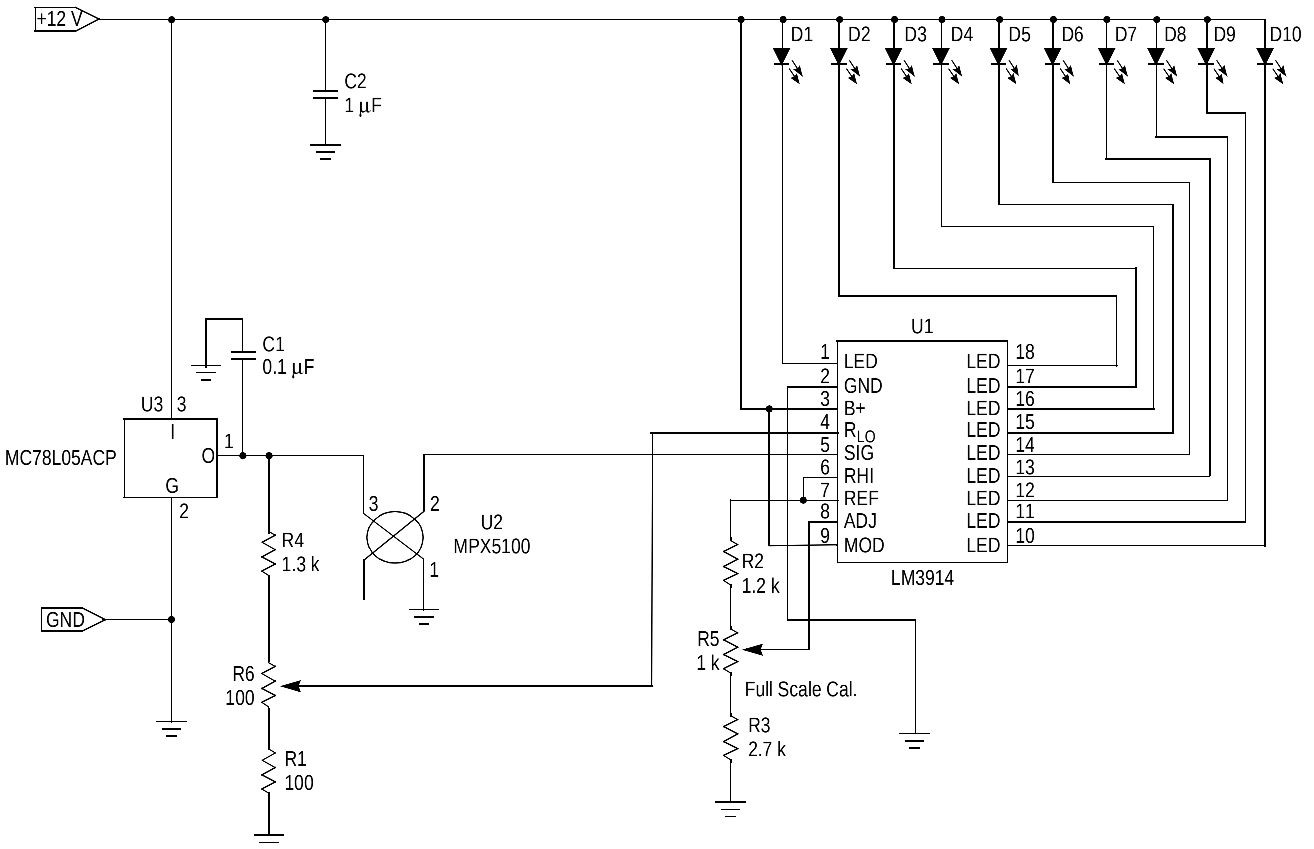

Figure 3. MPX5100 Bar Graph Pressure Gauge

Over a zero to 50°C temperature range combined accuracy for the sensor, interface, and driver IC are ±10%. Given a 10 segment display total accuracy for the bar graph readout is approximately ± (10 kPa +10%).

This circuit can be simplified by substituting an MPX5100 integrated sensor for the MPX2100 and the op amp interface. The resulting schematic is shown in Figure 3. In this case zero reference for the bar graph is provided by dividing down the 5 V regulator with R4, R1 and adjustment pot R6. The voltage at the wiper of R6 is adjusted to match the sensor's zero pressure offset voltage. It is connected to R_{LO} to zero the bar graph.

MICROCOMPUTER BAR GRAPH

Microcomputers with internal A/D converters such as an MC68HC05B5 lend themselves to easily creating bar graphs. Using the A/D converter to measure the sensor's analog output voltage and output ports to individually switch LED's makes a relatively straightforward pressure gauge. This type of design is facilitated by a new MDC4510A gated current sink. The MDC4510A takes one of the processor's logic outputs and switches 10 mA to an LED. One advantage of this approach is that it is very flexible regarding the number of segments that are used, and has the availability through software to independently adjust scaling factors for each segment. This approach is particularly useful for process monitoring in systems where a microprocessor is already in place.

Figure 4 shows a direct connection from an MPX5100 sensor to the microcomputer. Similar to the previous example, an MPX2000 series sensor with the op amp interface that is shown in Figure 1 can be substituted for the MPX5100. In this case the op amp interface's output at pin 7 ties to port PD5, and its supply needs to come from a source greater than 6.5 V.

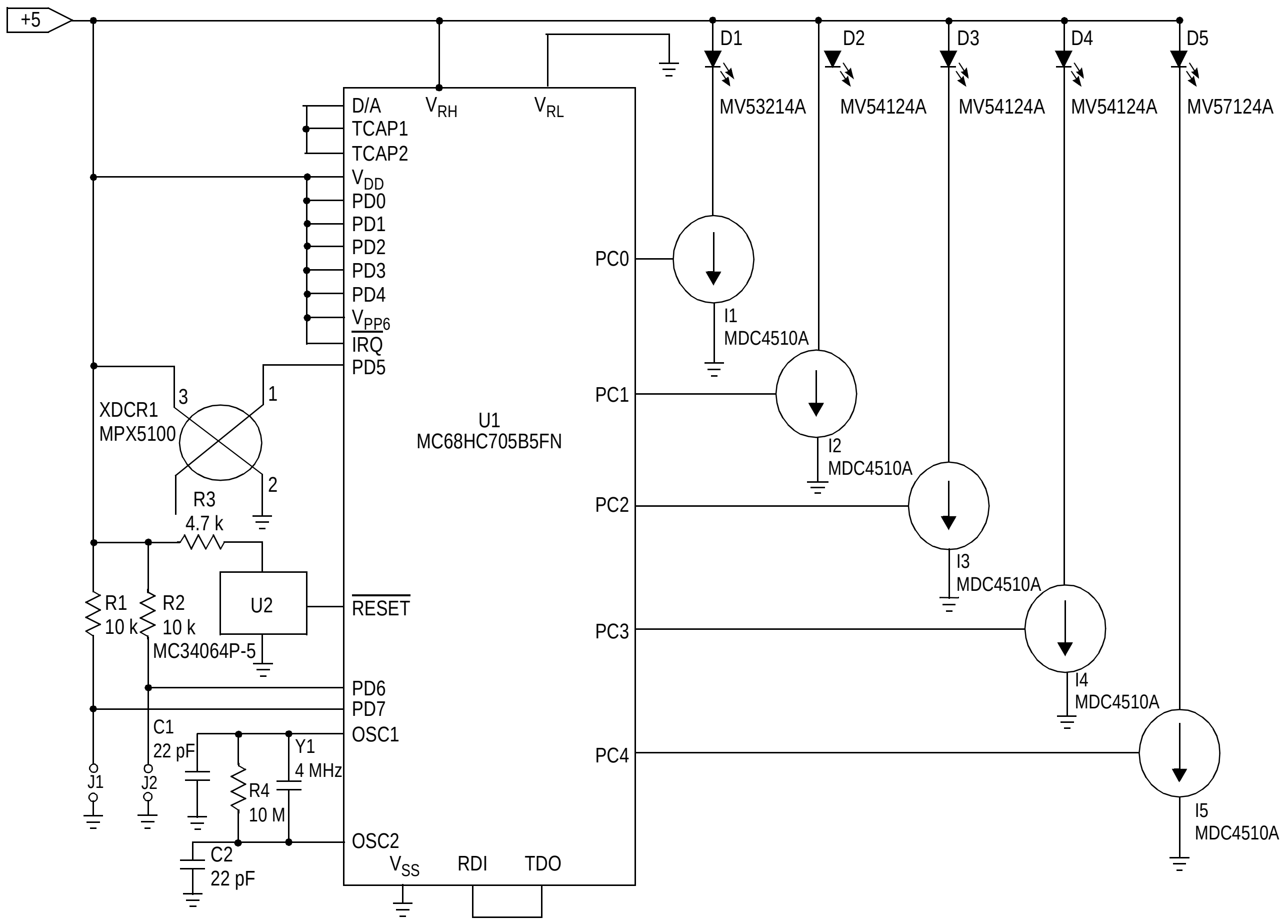

Figure 4. Microcomputer Bar Graph Pressure Gauge

PROCESS MONITOR

For applications where an inexpensive HIGH-LOW-OK process monitor is required, the circuit in Figure 5 does a good job. It uses an MC33161 Universal Voltage Monitor and the same analog interface previously described to indicate high, low or in-range pressure.

A block diagram of the MC33161 is illustrated in Figure 6. By tying pin 1 to pin 7 it is set up as a window detector. Whenever input 1 exceeds 1.27 V, two logic ones are placed at the inputs of its exclusive OR gate, turning off output 1. Therefore this output is on unless the lower threshold is exceeded. When 1.27 V is exceeded on input 2, just the opposite occurs. A single logic one appears at its exclusive OR gate, turning on output 2. These two outputs drive LED's through MDC4010A 10 mA current sources to indicate low pressure and high pressure.

Returning to Figure 5, an in-range indication is developed by turning on current source I1 whenever both the high and low outputs are off. This function is accomplished with a discrete gate made from D1, D2 and R7. Its output feeds the input of switched current source I1, turning it on with R7 when neither D1 nor D2 is forward biased.

Thresholds are set independently with R8 and R9. They sample the same 4.0 V full scale span that is used in the other examples. However, zero pressure offset is targeted for 1.3 V. This voltage was chosen to approximate the 1.27 V reference at both inputs, which avoids throwing away the sensor's analog output signal to overcome the MC33161's input threshold. In addition, R10 and R11 are selected such that at full scale output, i.e., 5.3 V on pin 7, the low side of the pots is nominally at 1.1 V. This keeps the minimum input just below the comparator thresholds of 1.27 V, and maximizes the resolution available from adjustment pots R8 and R9. When level adjustment is not desired, R8 - R11 can be replaced by a simpler string of three fixed resistors.

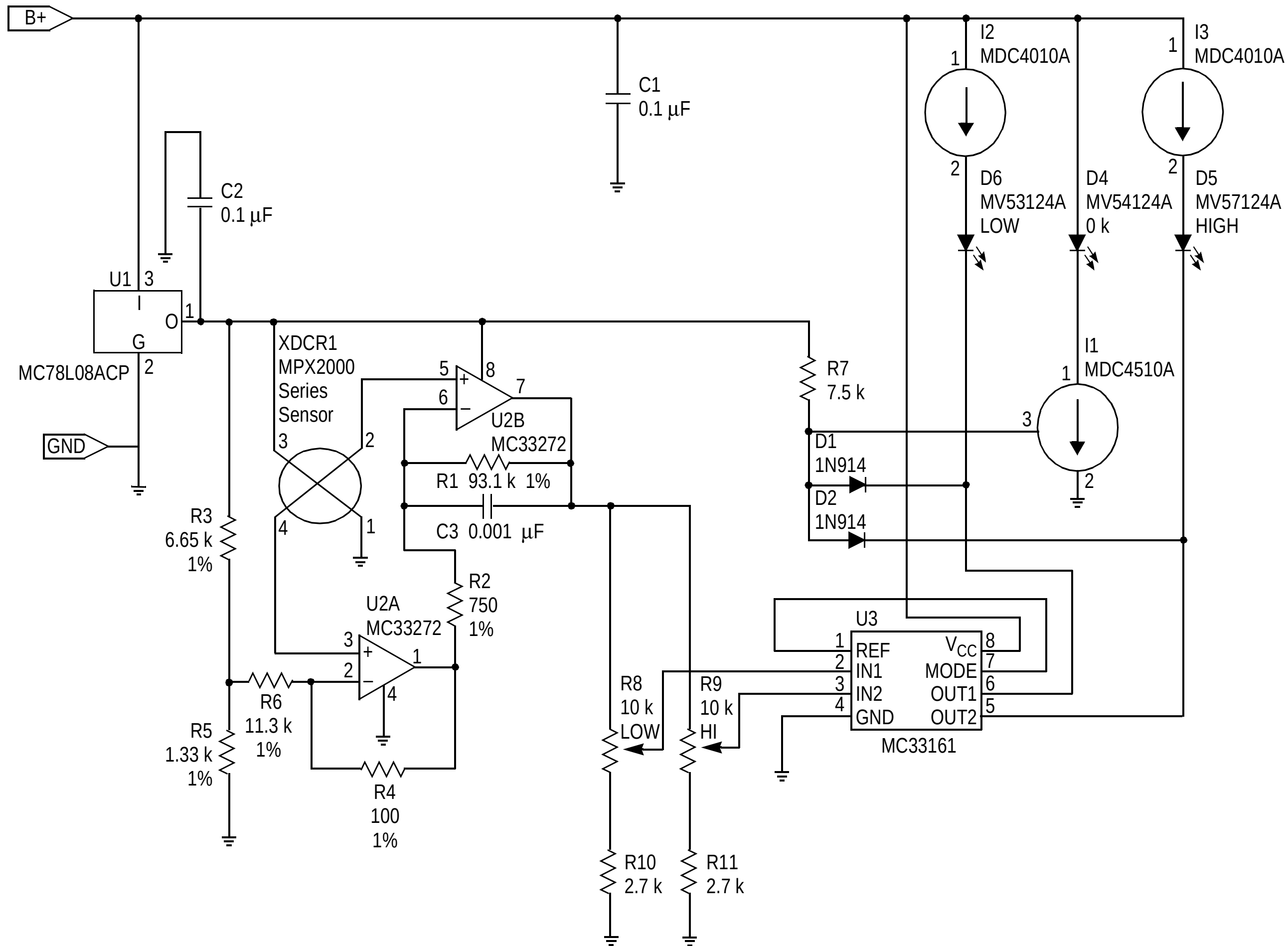

Figure 5. An Inexpensive Three-Segment Processor Monitor

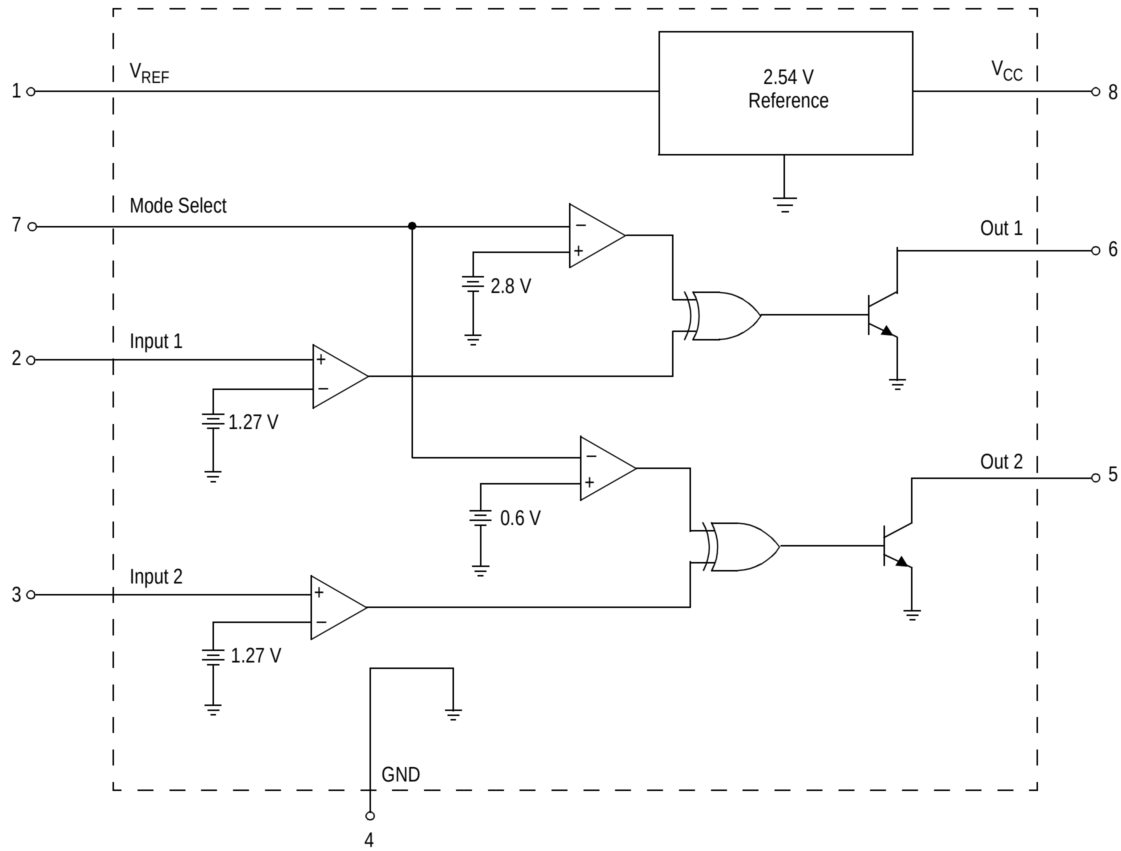

Figure 6. MC33161 Block Diagram

CONCLUSION

The circuits that have been shown here are intended to make simple, practical and cost effective bar graph pressure gauges. Their application involves a variety of trade-offs that can be matched to the needs of individual applications. In general, the most important trade-offs are the number of segments required and processor utilization. If the system in which the bar graph is used already has a microprocessor with unused A/D channels and I/O ports, tying MDC4510A current sources to the unused output ports is a very cost effective solution. On a stand-alone basis, the MC33161 based process monitor is the most cost effective where only 2 or 3 segments are required. Applications that require a larger number of segments are generally best served by one of the circuits that uses a dedicated bar graph display.

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Amplifiers for Semiconductor Pressure Sensors

by: Warren Schultz
Discrete Applications Engineering

INTRODUCTION

Amplifiers for interfacing Semiconductor Pressure Sensors to electronic systems have historically been based upon classic instrumentation amplifier designs. Instrumentation amplifiers have been widely used because they are well understood standard building blocks that also work reasonably well. For the specific job of interfacing Semiconductor Pressure Sensors to today's mostly digital systems, other circuits can do a better job. This application note presents an evolution of amplifier design that begins with a classic instrumentation amplifier and ends with a simpler circuit that is better suited to sensor interface.

INTERFACE AMPLIFIER REQUIREMENTS

Design requirements for interface amplifiers are determined by the sensor's output characteristics, and the zero to 5.0 V input range that is acceptable to microcomputer A/D converters. Since the sensor's full scale output is typically tens of millivolts, the most obvious requirement is gain. Gains from 100 to 250 are generally needed, depending upon bias voltage applied to the sensor and maximum pressure to be measured. A differential to single-ended conversion is also required in order to translate the sensor's differential output into a single ended analog signal. In addition, level shifting is necessary to convert the sensor's 1/2 B^+ common mode voltage to an appropriate DC level. For microcomputer A/D inputs, generally that level is from 0.3 - 1.0V. Typical design targets are 0.5 V at zero pressure and enough gain to produce 4.5 V at full scale. The 0.5 V zero pressure offset allows for output saturation voltage in op amps operated with a single supply (V_{EE} = 0). At the other end, 4.5 V full scale keeps the output within an A/D converter's 5 V range with a comfortable margin for component tolerances. The resulting 0.5 to 4.5 V single-ended analog signal is also quite suitable for a variety of other applications such as bar graph pressure gauges and process monitors.

CLASSIC INSTRUMENTATION AMPLIFIER

A classic instrumentation amplifier is shown in Figure 1. This circuit provides the gain, level shifting and differential to single-ended conversion that are required for sensor interface. It does not, however, provide for single supply operation with a zero pressure offset voltage in the desired range.

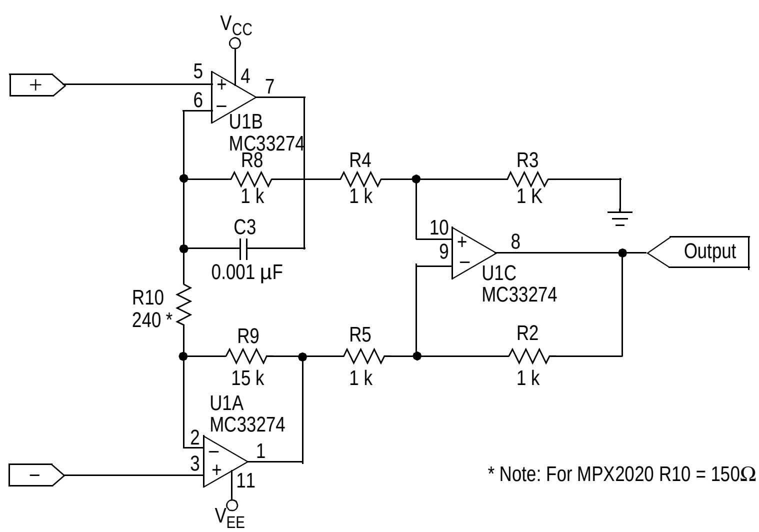


Figure 1. Classic Instrumentation Amplifier

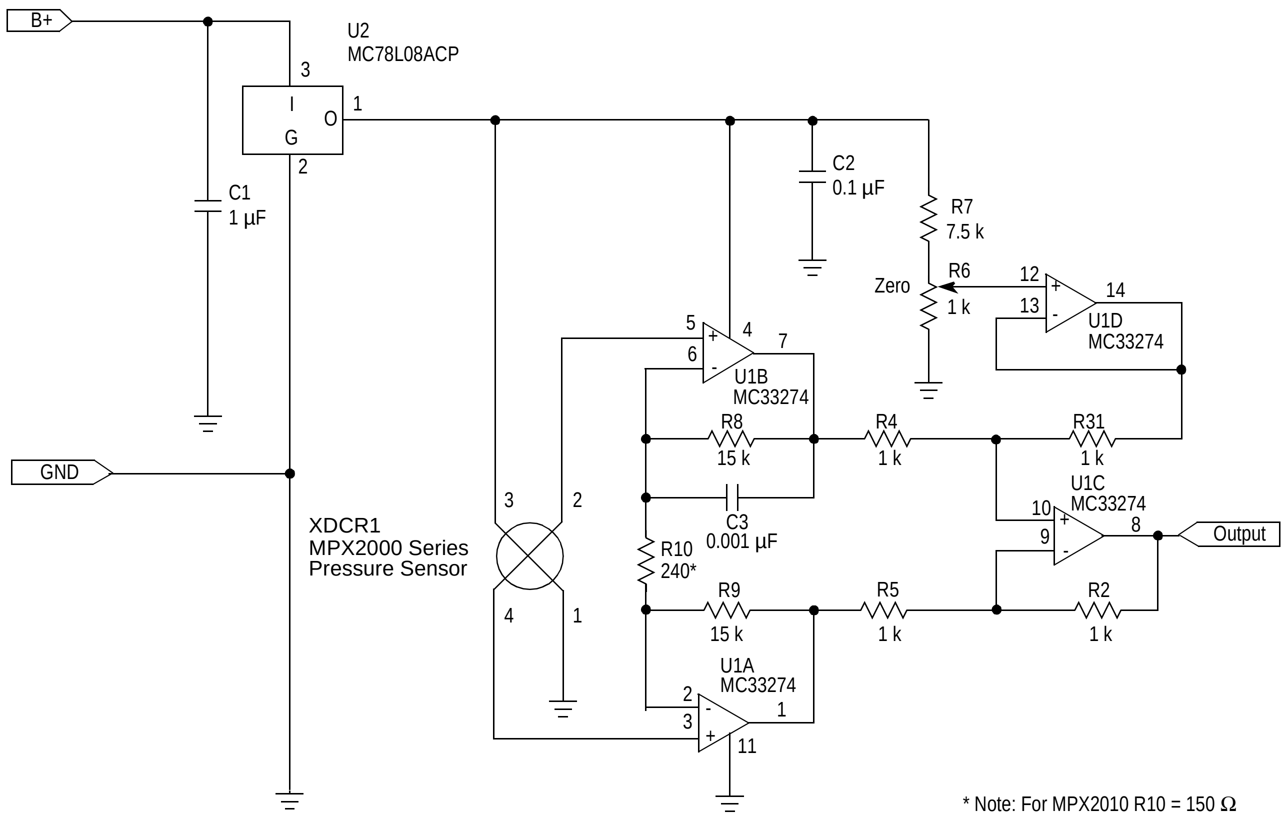


Figure 2. Instrumentation Amplifier Interface

To provide the desired DC offset, a slight modification is made in Figure 2. R3 is connected to pin 14 of U1D, which supplies a buffered offset voltage that is derived from the wiper of R6. This voltage establishes a DC output for zero differential input. The translation is one to one. Whatever voltage appears at the wiper of R6 will, within component tolerances, appear as the zero pressure DC offset voltage at the output.

With R10 at 240 Ω gain is set for a nominal value of 125, providing a 4.0 V span for 32 mV of full scale sensor output. Setting the offset voltage to 0.75 V, results in a 0.75 V to 4.75 V output that is directly compatible with microprocessor A/D inputs.

This circuit works reasonably well, but has several notable limitations when made with discrete components. First, it has a relatively large number of resistors that have to be well matched. Failure to match these resistors degrades common mode rejection and initial tolerance on zero pressure offset voltage. It also has two amplifiers in one gain loop, which makes stability more of an issue than it is in the following two alternatives. This circuit also has more of a limitation on zero pressure offset voltage than the other two. The minimum output voltage of U1D restricts the minimum zero pressure offset voltage that can be accommodated, given component tolerances. The result is a 0.75 V zero pressure offset voltage, compared to 0.5 V for each of the following two circuits.

SENSOR SPECIFIC AMPLIFIER

The limitations associated with classic instrumentation amplifiers suggest that alternate approaches to sensor interface design are worth looking at. One such approach is shown in Figure 3. It uses one quad op amp and several resistors to amplify and level shift the sensor's output.

Most of the amplification is done in U1A, which is configured as a differential amplifier. It is isolated from the sensor's minus output by U1B. The purpose of U1B is to prevent feedback current that flows through R5 and R6 from flowing into the sensor. At zero pressure the voltage from pin 2 to pin 4 on the sensor is zero V. For example, assume that the common mode voltage is 4.0 V. The zero pressure output voltage at pin 1 of U1A is then 4.0 V, since any other voltage would be coupled back to pin 2 via R6 and create a non zero bias across U1A's differential inputs. This 4.0 V zero pressure DC output voltage is then level translated to the desired zero pressure offset voltage by U1C and U1D. To see how the level translation works, assume the wiper of R9 is at ground. With 4.0 V at pin 12, pin 13 is also at 4.0 V. This leaves 4.0 V across (R3 + R9), which total essentially 1.0 kΩ. Since no current flows through R4, producing approximately 4.0 V across R4, as well. Adding the voltages (4.0 + 4.0) yields 8.0 V at pin 14. Similarly, 4.0 V at pin 10 implies 4.0 V at pin 9, and the drop across R2 is 8.0 V –4.0 = 4.0 V. Again 4.0 V across R2 implies an equal drop across R1, and the voltage at pin 8 is 4.0 V – 4.0 V. In practice, the output of U1C will not go all the way to ground, and the voltage injected by R8 at the wiper of R9 is approximately translated into a DC offset.

Gain is approximately equal to R6/R5(R1/R2+1), which predicts 125 for the values shown in Figure 3. A more exact calculation can be performed by doing a nodal analysis, which yields 127. Cascading the gains of U1A and U1C using standard op amp gain equations does not give an exact result, because the sensor's negative going differential signal at pin 4 subtracts from the DC level that is amplified by U1C. Setting offset to 0.5 V results in an analog zero to full scale range of 0.5 to 4.5 V. For this DC output voltage to be independent of the sensor's common mode voltage it is necessary to satisfy the condition that R1/R2 = (R3+R9)/R4.

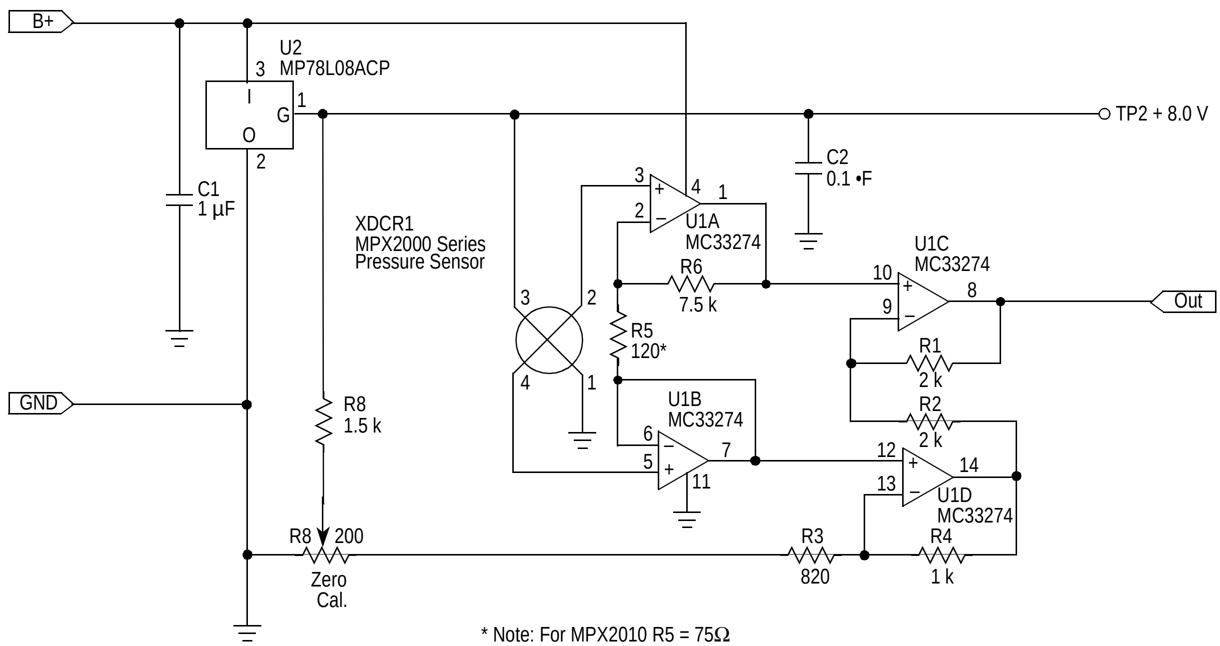


Figure 3. Sensor Specific Amplifier

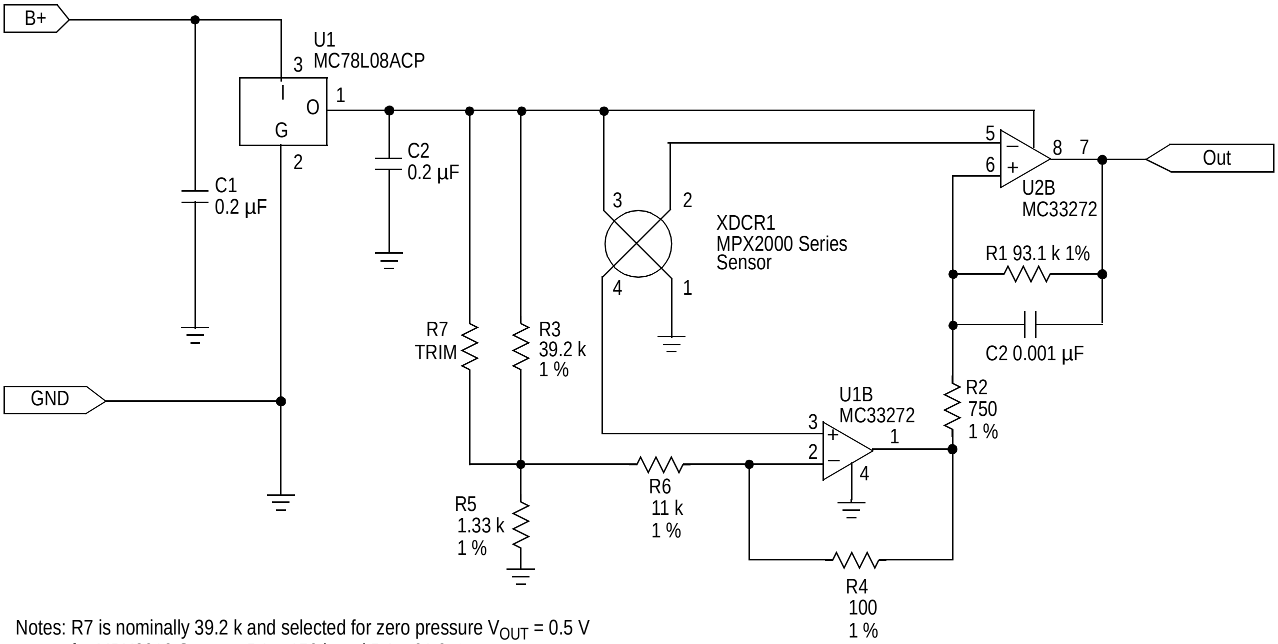
This approach to interface amplifier design is an improvement over the classic instrument amplifier in that it uses fewer resistors, is inherently more stable, and provides a zero pressure output voltage that can be targeted at 0.5 V. It has the same tolerance problem from matching discrete resistors that is associated with classic instrument amplifiers.

SENSOR MINI AMP

Further improvements can be made with the circuit that is shown in Figure 4. It uses one dual op amp and several resistors to amplify and level shift the sensor's output. To see how this amplifier works, let's simplify it by grounding the output of voltage divider R3, R5 and assuming that the divider impedance is added to R6, such that R6 = 12.4 k. If the common mode voltage at pins 2 and 4 of the sensor is 4.0 V, then pin 2 of U2A and pin 6 of U2B are also at 4.0 V. This puts 4.0 V across R6, producing 323 µA. Assuming that the current in R4 is equal to the current in R6, 323 µA • 100 Ω produces a 32 mV drop across R4 which adds to the 4.0 V at pin 2. The output voltage at pin 1 of U2A is, therefore, 4.032 V. This puts 4.032 - 4.0 V across R2, producing 43 µA. The same current flowing through R1 again produces a voltage drop of 4.0 V, which sets the output at zero. Substituting a divider output greater than zero into this calculation reveals that the zero pressure output voltage is equal to the output voltage of divider R3, R5. For this DC output voltage to be independent of the sensor's common mode voltage it is necessary to satisfy the condition that R1/R2 = R6/R4, where R6 includes the divider impedance.

Gain can be determined by assuming a differential output at the sensor and going through the same calculation. To do this assume 100 mV of differential output, which puts pin 2 of U2A at 3.95 V, and pin 6 of U2B at 4.05 V. Therefore, 3.95 V is applied to R6, generating 319 µA. This current flowing through R4 produces 31.9 mV, placing pin 1 of U2A at 3950 mV + 31.9 mV = 3982 mV. The voltage across R2 is then 4050 mV - 3982 mV = 68 mV, which produces a current of 91µA that flows into R1. The output voltage is then 4.05 V + (91 µA • 93.1 k) = 12.5 V. Dividing 12.5 V by the 100 mV input yields a gain of 125, which provides a 4 V span for 32 mV of full scale sensor output. Setting divider R3, R5 at 0.5 V results in a 0.5 V to 4.5 V output that is comparable to the other two circuits.

This circuit performs the same function as the other two with significantly fewer components and lower cost. In most cases it is the optimum choice for a low cost interface amplifier.



Notes: R7 is nominally 39.2 k and selected for zero pressure V_{OUT} = 0.5 V
for MPX2010 Sensors R1 = 150 k and R4 = 61.9 Ω

Figure 4. Sensor Mini Amp

Performance differences between the three topologies are minor. Accuracy is much more dependent upon the quality of the resistors and amplifiers that are used and less dependent on which of the three circuits are chosen. For example, input offset voltage error is essentially the same for all three circuits. To a first order approximation, it is equal to total gain times the difference in offset between the two amplifiers that are directly tied to the sensor. Errors due to resistor tolerances are somewhat dependent upon circuit topology. However, they are much more dependent upon the choice of resistors. Choosing one percent resistors rather than five percent resistors has a much larger impact on performance than the minor differences that result from circuit topology. Assuming a zero pressure offset adjustment, any of these circuits with an MPX2000 series sensor, one percent resistors and an MC33274 amplifier results in a ±5% pressure to voltage translation from 0 to 50°C. Software calibration can significantly improve these numbers and eliminate the need for analog trim.

CONCLUSION

Although the classic instrumentation amplifier is the best known and most frequently used sensor interface amplifier, it is generally not the optimal choice for inexpensive circuits made from discrete components. The circuit that is shown in Figure 4 performs the same interface function with significantly fewer components, less board space and at a lower cost. It is generally the preferred interface topology for MPX2000 series semiconductor pressure sensors.

AN1326
Rev 2, 05/2005

Barometric Pressure Measurement Using Semiconductor Pressure Sensors

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Discrete Applications Engineering

ABSTRACT

The most recent advances in silicon micromachining technology have given rise to a variety of low-cost pressure sensor applications and solutions. Certain applications had previously been hindered by the high-cost, large size, and overall reliability limitations of electromechanical pressure sensing devices. Furthermore, the integration of on-chip temperature compensation and calibration has allowed a significant improvement in the accuracy and temperature stability of the sensor output signal. This technology allows for the development of both analog and microcomputer-based systems that can accurately resolve the small pressure changes encountered in many applications. One particular application of interest is the combination of a silicon pressure sensor and a microcontroller interface in the design of a digital barometer. The focus of the following documentation is to present a low-cost, simple approach to designing a digital barometer system.

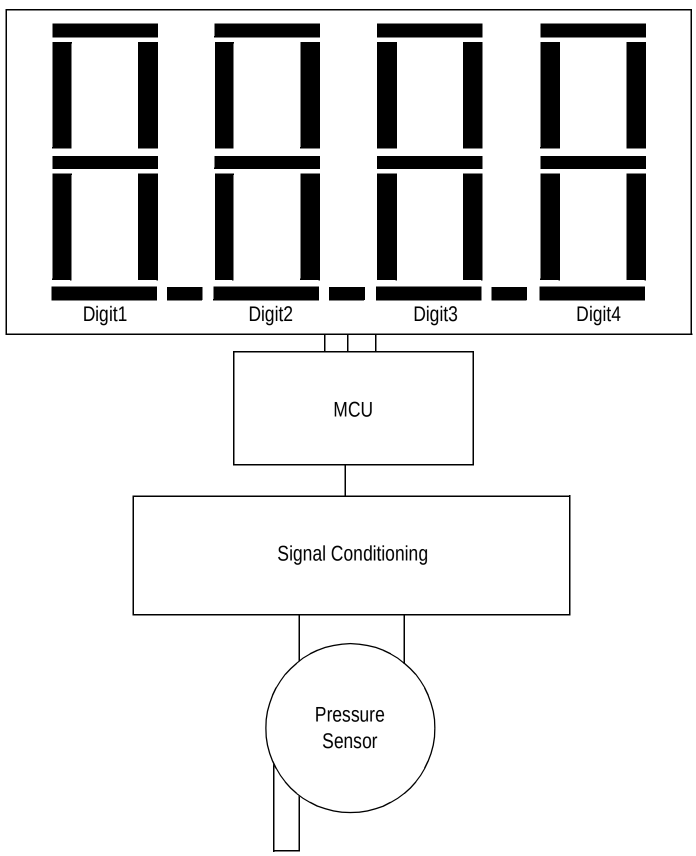

Figure 1. Barometer System

INTRODUCTION

Figure 1 shows the overall system architecture chosen for this application. This system serves as a building block, from which more advanced systems can be developed. Enhanced accuracy, resolution, and additional features can be integrated in a more complex design.

There are some preliminary concerns regarding the measurement of barometric pressure which directly affect the design considerations for this system. Barometric pressure refers to the air pressure existing at any point within the earth's atmosphere. This pressure can be measured as an absolute pressure, (with reference to absolute vacuum) or can be referenced to some other value or scale. The meteorology and avionics industries traditionally measure the absolute pressure, and then reference it to a sea level pressure value. This complicated process is used in generating maps of weather systems. The atmospheric pressure at any altitude varies due to changing weather conditions over time. Therefore, it can be difficult to determine the significance of a particular pressure measurement without additional information. However, once the pressure at a particular location and elevation is determined, the pressure can be calculated at any other altitude. Mathematically, atmospheric pressure is exponentially related to altitude. This particular system is designed to track variations in barometric pressure once it is calibrated to a known pressure reference at a given altitude.

For simplification, the standard atmospheric pressure at sea level is assumed to be 29.9 in-Hg. “Standard” barometric pressure is measured at particular altitude at the average weather conditions for that altitude over time. The system described in this text is specified to accurately measure barometric pressure variations up to altitudes of 15,000 ft. This altitude corresponds to a standard pressure of approximately 15.0 in-Hg. As a result of changing weather conditions, the standard pressure at a given altitude can fluctuate approximately ±1 in-Hg. in either direction. Table 1 indicates standard barometric pressures at several altitudes of interest.

Table 1. Altitude versus Pressure Data

Altitude (Ft.)	Pressure (in-Hg)
0	29.92
500	29.38
1,000	28.85
6,000	23.97
10,000	20.57
15,000	16.86

SYSTEM OVERVIEW

In order to measure and display the correct barometric pressure, this system must perform several tasks. The measurement strategy is outlined below in Figure 2. First, pressure is applied to the sensor. This produces a proportional differential output voltage in the millivolt range. This signal must then be amplified and level-shifted to a single-ended, microcontroller (MCU) compatible level (0.5 – 4.5 V) by a signal conditioning circuit. The MCU will then sample the voltage at the analog-to-digital converter (A/D) channel input, convert the digital measurement value to inches of mercury, and then display the correct pressure via the LCD interface. This process is repeated continuously.

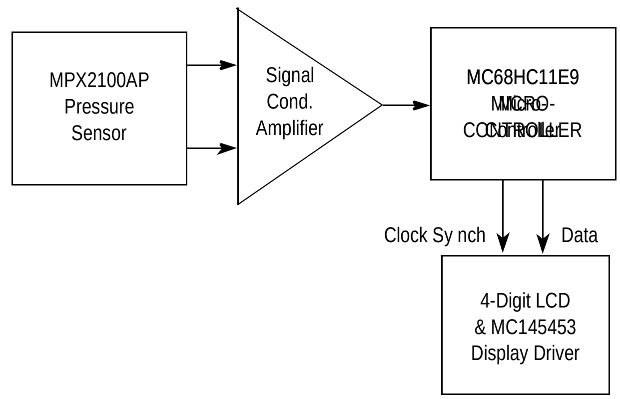

Figure 2. Barometer System Block Diagram

There are several significant performance features implemented into this system design. First, the system will digitally display barometric pressure in inches of mercury, with a resolution of approximately one-tenth of an inch of mercury. In order to allow for operation over a wide altitude range (0 – 15,000 ft.), the system is designed to display barometric pressures ranging from 30.5 in-Hg. to a minimum of 15.0 in-Hg. The display will read “lo” if the pressure measured is below 30.5 in-Hg. These pressures allow for the system to operate with the desired resolution in the range from sea-level to approximately 15,000 ft. An overview of these features is shown in Table 2.

Table 2. System Features Overview

Display Units	in-Hg
Resolution	0.1 in-Hg.
System Range	15.0 – 30.5 in-Hg.
Altitude Range	0 – 15,000 ft.

DESIGN OVERVIEW

The following sections are included to detail the system design. The overall system will be described by considering the subsystems depicted in the system block diagram, Figure 2. The design of each subsystem and its function in the overall system will be presented.

Table 3. MPX2100AP Electrical Characteristics

Characteristic	Symbol	Minimum	Typical	Max	Unit
Pressure Range	POP	0	—	100	kPa
Supply Voltage	VS	—	10	16	Vdc
Full Scale Span	VFSS	38.5	40	41.5	mV
Zero Pressure Offset	Voff	—	—	±1.0	mV
Sensitivity	S	—	0.4	—	mv/kPa
Linearity	—	—	0.05	—	%FSS
Temperature Effect on Span	—	—	0.5	—	%FSS
Temperature Effect on Offset	—	—	0.2	—	%FSS

Pressure Sensor

The first and most important subsystem is the pressure transducer. This device converts the applied pressure into a proportional, differential voltage signal. This output signal will vary linearly with pressure. Since the applied pressure in this application will approach a maximum level of 30.5 in-Hg. (100 kPa) at sea level, the sensor output must have a linear output response over this pressure range. Also, the applied pressure must be measured with respect to a known reference pressure, preferably absolute zero pressure (vacuum). The device should also produce a stable output over the entire operating temperature range.

The desired sensor for this application is a temperature compensated and calibrated, semiconductor pressure transducer, such as the MPXM2102A series sensor family. The MPX2000 series sensors are available in full-scale pressure ranges from 10 kPa (1.5 psi) to 200 kPa (30 psi). Furthermore, they are available in a variety of pressure configurations (gauge, differential, and absolute) and porting options. Because of the pressure ranges involved with barometric pressure measurement, this system will employ an MPXM2102AS (absolute with single port). This device will produce a linear voltage output in the pressure range of 0 to 100 kPa. The ambient pressure applied to the single port will be measured with respect to an evacuated cavity (vacuum reference). The electrical characteristics for this device are summarized in Table 3.

As indicated in Table 3, the sensor can be operated at different supply voltages. The full-scale output of the sensor, which is specified at 40 mV nominally for a supply voltage of 10 Vdc, changes linearly with supply voltage. All non-digital circuitry is operated at a regulated supply voltage of 8 Vdc. Therefore, the full-scale sensor output (also the output of the sensor at sea level) will be approximately 32 mV.

$$\left(\frac{8}{10} \times 40\ \text{mV}\right)$$

The sensor output voltage at the systems minimum range (15 in-Hg.) is approximately 16.2 mV. Thus, the sensor output over the intended range of operations is expected to vary from 32 to 16.2 mV. These values can vary slightly for each sensor as the offset voltage and full-scale span tolerances indicate.

Signal Conditioning Circuitry

In order to convert the small-signal differential output signal of the sensor to MCU compatible levels, the next subsystem includes signal conditioning circuitry. The operational amplifier circuit is designed to amplify, level-shift, and ground reference the output signal. The signal is converted to a single-ended, 0.5 – 4.5 Vdc range. The schematic for this amplifier is shown in Figure 3.

This particular circuit is based on classic instrumentation amplifier design criteria. The differential output signal of the sensor is inverted, amplified, and then level-shifted by an adjustable offset voltage (through $R_{offset1}$). The offset voltage is adjusted to produce 0.5 volts at the maximum barometric pressure (30.5 in-Hg.). The output voltage will increase for decreasing pressure. If the output exceeds 5.1 V, a zener protection diode will clamp the output. This feature is included to protect the A/D channel input of the MCU. Using the transfer function for this circuit, the offset voltage and gain can be determined to provide 0.1 in-Hg of system resolution and the desired output voltage level. The calculation of these parameters is illustrated below.

In determining the amplifier gain and range of the trimmable offset voltage, it is necessary to calculate the number of steps used in the A/D conversion process to resolve 0.1 in-Hg.

$$(30.5 - 15.0)\text{in-Hg} * 10\ \frac{\text{steps}}{\text{Hg}} = 155\ \text{steps}$$

The span voltage can now be determined. The resolution provided by an 8-bit A/D converter with low and high voltage references of zero and five volts, respectively, will detect 19.5 mV of change per step.

$V_{RH} = 5$ V, $V_{RL} = 0$ V

Sensor Output at 30.5 in-Hg = 32.44 mV
Sensor Output at 15.0 in-Hg = 16.26 mV
ΔSensor Output = ΔSO = 16.18 mV

$$\text{Gain} = \frac{3.04\ \text{V}}{\Delta SO} = 187$$

Note: 30.5 in-Hg and 15.0 in-Hg are the assumed maximum and minimum absolute pressures, respectively.

This gain is then used to determine the appropriate resistor values and offset voltage for the amplifier circuit defined by the transfer function shown below.

$$V_{out} = -\left[\frac{R_2}{R_1} + 1\right] * \Delta V + V_{off}$$

ΔV is the differential output of the sensor.

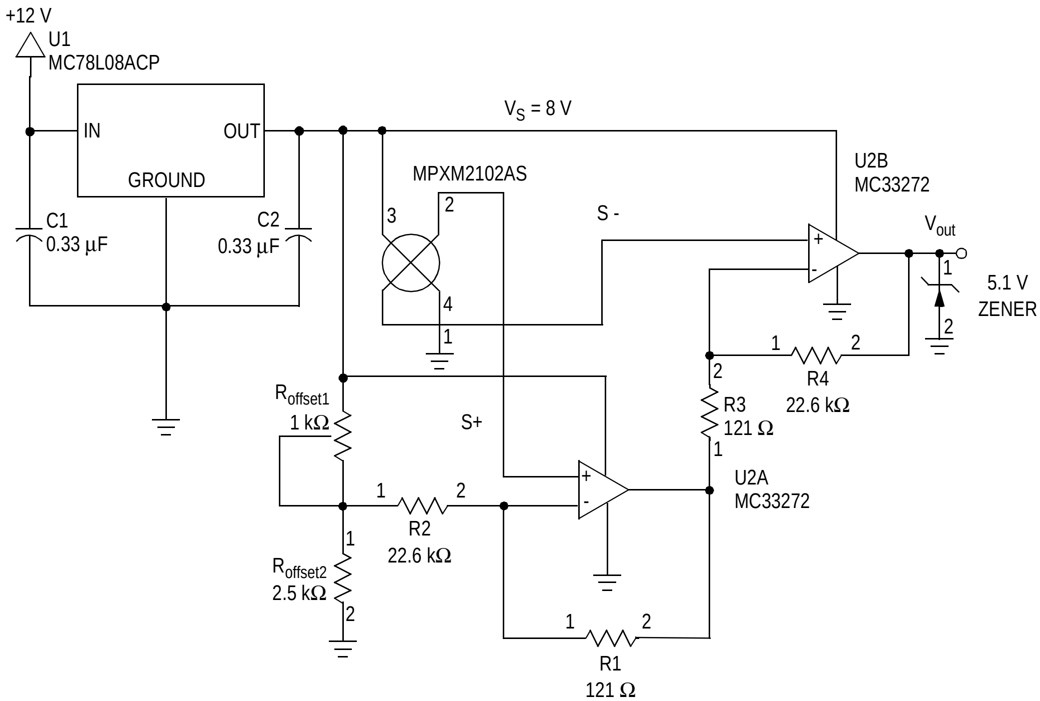

Figure 3. Signal Conditioning Circuit

The gain of 187 can be implemented with:

$R_1 \approx R_3 = 121\ \Omega$
$R_2 \approx R_4 = 22.6\ k\Omega$.

Choosing $R_{offset1}$ to be 1 kΩ and $R_{offset2}$ to be 2.5 kΩ, V_{out} is 0.5 V at the presumed maximum barometric pressure of 30.5 in-Hg. The maximum pressure output voltage can be trimmed to a value other than 0.5 V, if desired via $R_{offset1}$. In addition, the trimmable offset resistor is incorporated to provide offset calibration if significant offset drift results from large weather fluctuations.

The circuit shown in Figure 3 employs an MC33272 (low-cost, low-drift) dual operational amplifier IC. In order to control large supply voltage fluctuations, an 8 Vdc regulator, MC78L08ACP, is used. This design permits use of a battery for excitation.

Microcontroller Interface

The low cost of MCU devices has allowed for their use as a signal processing tool in many applications. The MCU used in this application, the MC68HC11, demonstrates the power of incorporating intelligence into such systems. The on-chip resources of the MC68HC11 include: an 8 channel, 8-bit A/D, a 16-bit timer, an SPI (Serial Peripheral Interface – synchronous), and SCI (Serial Communications Interface – asynchronous), and a maximum of 40 I/O lines. This device is available in several package configurations and product variations which include additional RAM, EEPROM, and/or I/O capability. The software used in this application was developed using the MC68HC11 EVB development system.

The following software algorithm outlines the steps used to perform the desired digital processing. This system will convert the voltage at the A/D input into a digital value, convert this measurement into inches of mercury, and output this data serially to an LCD display interface (through the on-board SPI). This process is outlined in greater detail below:

1. Set up and enable A/D converter and SPI interface.
2. Initialize memory locations, initialize variables.
3. Make A/D conversion, store result.
4. Convert digital value to inches of mercury.
5. Determine if conversion is in system range.

6a. Convert pressure into decimal display digits.
6b. Otherwise, display range error message.

7. Output result via SPI to LCD driver device.

The signal conditioned sensor output signal is connected to pin PE5 (Port E-A/D Input pin). The MCU communicates to the LCD display interface via the SPI protocol. A listing of the assembly language source code to implement these tasks is included in the appendix. In addition, the software can be downloaded directly from the Freescale MCU Freeware Bulletin Board (in the MCU directory). Further information is included at the beginning of the appendix.

LCD Interface

In order to digitally display the barometric pressure conversion, a serial LCD interface was developed to communicate with the MCU. This system includes an MC145453 CMOS serial interface/LCD driver, and a 4-digit, non-multiplexed LCD. In order for the MCU to communicate correctly with the interface, it must serially transmit six bytes for each conversion. This includes a start byte, a byte for each of the four decimal display digits, and a stop byte. For formatting purposes, decimal points and blank digits can be displayed through appropriate bit patterns. The control of display digits and data transmission is executed in the source code through subroutines BCDCONV, LOOKUP, SP12LCD, and TRANSFER. A block diagram of this interface is included below.

CONCLUSION

This digital barometer system described herein is an excellent example of a sensing system using solid state components and software to accurately measure barometric pressure. This system serves as a foundation from which more complex systems can be developed. The MPXM2102A series pressure sensors provide the calibration and temperature compensation necessary to achieve the desired accuracy and interface simplicity for barometric pressure sensing applications.

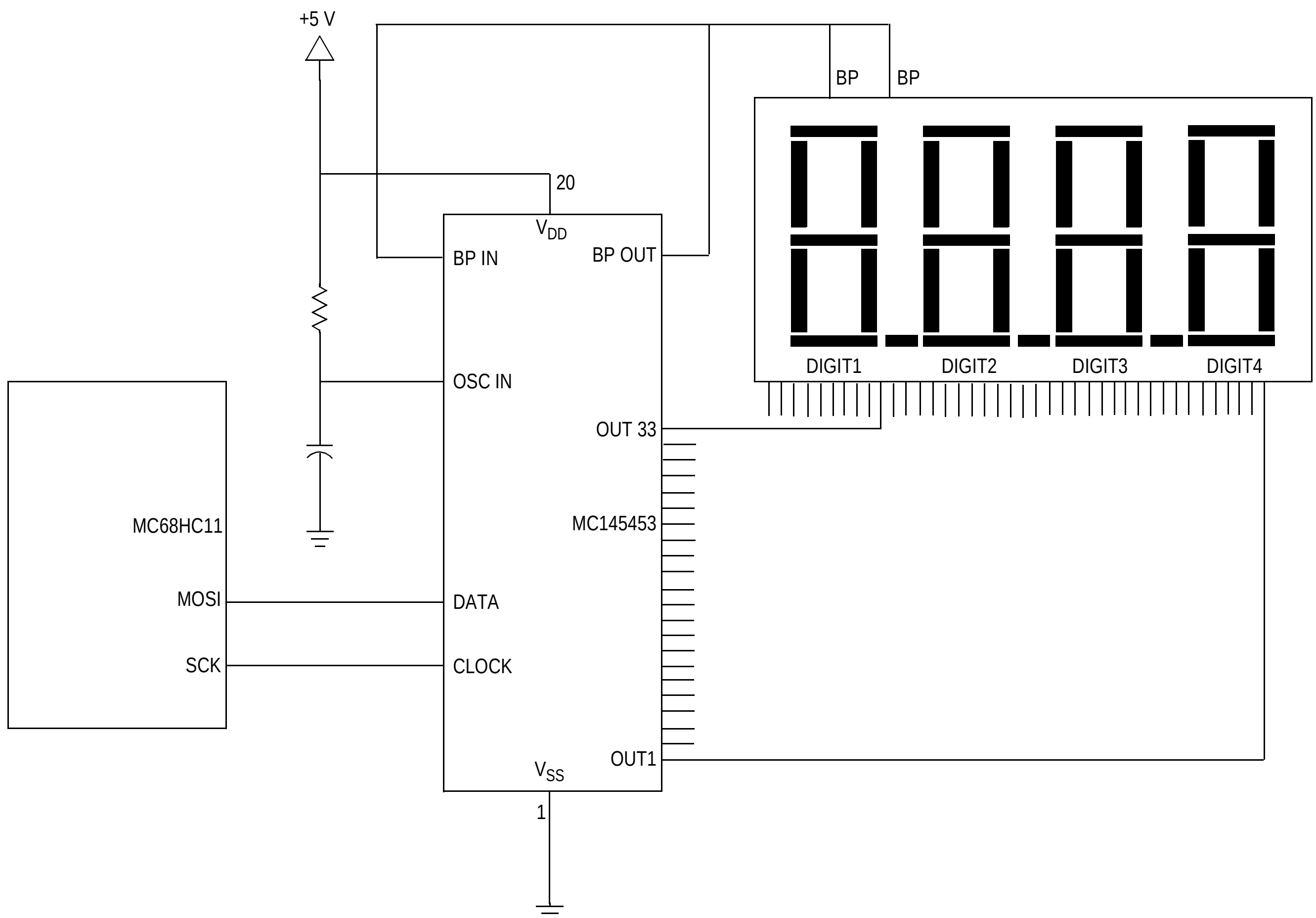

Figure 4. LCD Display Interface Diagram

APPENDIX

MC68HC11 Barometer Software Available on:
Freescale Electronic Bulletin Board
MCU Freeware Line
8-bit, no parity, 1 stop bit
1200/300 baud
(512) 891-FREE (3733)

```
* BAROMETER APPLICATIONS PROJECT - Chris Winkler
* Developed: October 1st, 1992   - Freescale Discrete Applications
* This code will be used to implement an MC68HC11 Micro-Controller
* as a processing unit for a simple barometer system.
* The HC11 will interface with an MPX2100AP to monitor,store
* and display measured Barometric pressure via the 8-bit A/D channel
* The sensor output (32mv max) will be amplified to .5 - 2.5 V dc
* The processor will interface with a 4-digit LCD (FE202) via
* a Freescale LCD driver (MC145453) to display the pressure
* within +/- one tenth of an inch of mercury.
* The systems range is 15.0 - 30.5 in-Hg

*        A/D  & CPU Register Assignment
*        This code will use index addressing to access the
*        important control registers.  All addressing will be
*        indexed off of REGBASE, the base address for these registers.

REGBASE  EQU      $1000           * register base of control register
ADCTL             EQU      $30             * offset of A/D control register
ADR2              EQU      $32             * offset of A/D results register
ADOPT             EQU      $39             * offset for A/D option register location
PORTB             EQU      $04             * Location of PORTB used for conversion
PORTD             EQU      $08             * PORTD Data Register Index
DDRD              EQU      $09             * offset of Data Direction Reg.
SPCR              EQU      $28             * offset of SPI Control Reg.
SPSR              EQU      $29             * offset of SPI Status Reg.
SPDR              EQU      $2A             * offset of SPI Data Reg.

*        User Variables
*        The following locations are used to store important measurements
*        and calculations used in determining the altitude.  They
*        are located in the lower 256 bytes of user RAM

DIGIT1   EQU      $0001           * BCD blank digit (not used)
DIGIT2   EQU      $0002           * BCD tens digit for pressure
DIGIT3   EQU      $0003           * BCD tenths digit for pressure
DIGIT4   EQU      $0004           * BCD ones digit for pressure
COUNTER  EQU      $0005           * Variable to send 5 dummy bytes
POFFSET  EQU      $0010           * Storage Location for max pressure offset
SENSOUT  EQU      $0012           * Storage location for previous conversion
RESULT   EQU      $0014           * Storage of Pressure(in Hg) in hex format
FLAG              EQU      $0016           * Determines if measurement is within range

*        MAIN PROGRAM
*        The conversion process involves the following steps:
*
*                          1.              Set-Up SPI device-                SPI_CNFG
*                          2.              Set-Up A/D, Constants             SET_UP
*                          3.              Read A/D, store sample            ADCONV
*                          4.              Convert into in-Hg                IN_HG
*                          5.              Determine FLAG conditionIN_HG
*                                  a.      Display error                     ERROR
*                                  b.      Continue Conversion               INRANGE
*                          6.              Convert hex to BCD formatBCDCONV
*                          7.              Convert LCD display digits        LOOKUP
*                          8.              Output via SPI to LCD             SPI2LCD

*        This process is continually repeated as the loop CONVERT
*        runs unconditionally through BRA (the BRANCH ALWAYS statement)
*        Repeats to step 3 indefinitely.
                  ORG      $C000                   * DESIGNATES START OF MEMORY MAP FOR USER CODE
                  LDX      #REGBASE        * Location of base register for indirect adr
                  BSR      SPI_CNFG        * Set-up SPI Module for data X-mit to LCD
                  BSR      SET_UP          * Power-Up A/D, initialize constants
CONVERT  BSR      ADCONV          * Calls subroutine to make an A/D conversion
                  BSR      DELAY                   * Delay routine to prevent LCD flickering
```

```
                BSR      IN_HG                      * Converts hex format to in of Hg

*        The value of FLAG passed from IN_HG is used to determine
*        If a range error has occurred.  The following logical
*        statements are used to either allow further conversion or jump
*        to a routine to display a range error message.

                LDAB     FLAG                       * Determines if an range Error has ocurred
                CMPB     #$80                       * If No Error detected (FLAG=$80) then
                BEQ      INRANGE          *   system will continue conversion process
                BSR      ERROR                      * If error occurs (FLAG<>80), branch to ERROR
                BRA      OUTPUT           * Branches to output ERROR code to display

*        No Error Detected, Conversion Process Continues

INRANGE  JSR    BCDCONV          * Converts Hex Result to BCD
                JSR      LOOKUP           * Uses Look-Up Table for BCD-Decimal

OUTPUT   JSR    SPI2LCD          * Output transmission to LCD
                BRA      CONVERT          * Continually converts using Branch Always

*        Subroutine SPI_CNFG
*                Purpose is to initialize SPI for transmission
*                and clear the display before conversion.

SPI_CNFG BSET   PORTD,X #$20     * Set SPI SS Line High to prevent glitch
                LDAA     #$38                       * Initializing Data Direction for Port D
                STAA     DDRD,X           * Selecting SS, MOSI, SCK as outputs only

                LDAA     #$5D                       * Initialize SPI-Control Register
                STAA     SPCR,X           * selecting SPE,MSTR,CPOL,CPHA,CPRO

                LDAA     #$5                        * sets counter to X-mit 5 blank bytes
                STAA     COUNTER

                LDAA     SPSR,X           * Must read SPSR to clear SPIF Flag

                CLRA                                * Transmission of Blank Bytes to LCD

ERASELCD JSR    TRANSFER         * Calls subroutine to transmit
                DEC      COUNTER
                BNE      ERASELCD

                RTS

*        Subroutine SET_UP
*                Purpose is to initialize constants and to power-up A/D
*                and to initialize POFFSET used in conversion purposes.
SET_UP   LDAA   #$90                      * selects ADPU bit in OPTION register
                STAA     ADOPT,X          * Power-Up of A/D complete
                LDD      #$0131+$001A     * Initialize POFFSET
                STD      POFFSET          * POFFSET = 305 - 25 in hex
                LDAA     #$00                       * or Pmax + offset voltage (5 V)
                RTS

*        Subroutine DELAY
*                Purpose is to delay the conversion process
*                to minimize LCD flickering.

DELAY           LDA      #$FF                       * Loop for delay of display
OUTLOOP  LDB    #$FF                      * Delay = clk/255*255
INLOOP   DECB
                BNE      INLOOP
                DECA
                BNE      OUTLOOP
                RTS

*        Subroutine ADCONV
*                Purpose is to read the A/D input, store the conversion into
*                SENSOUT. For conversion purposes later.
ADCONV   LDX    #REGBASE         * loads base register for indirect addressing
                LDAA     #$25
                STAA     ADCTL,X          * initializes A/D cont. register SCAN=1,MULT=0

WTCONV   BRCLR  ADCTL,X  #$80 WTCONV      * Wait for completion of conversion flag
                LDAB     ADR2,X           * Loads conversion result into Accumulator
                CLRA
                STD      SENSOUT          * Stores conversion as SENSOUT
                RTS
```

```
*        Subroutine IN_HG
*                 Purpose is to convert the measured pressure SENSOUT, into
*                 units of in-Hg, represented by a hex value of 305-150
*                 This represents the range 30.5 - 15.0 in-Hg
IN_HG             LDD      POFFSET          * Loads maximum offset for subtraction
                  SUBD     SENSOUT          * RESULT = POFFSET-SENSOUT in hex format
                  STD      RESULT           * Stores hex result for P, in Hg
                  CMPD     #305
                  BHI      TOHIGH

                  CMPD     #150
                  BLO      TOLOW

                  LDAB     #$80
                  STAB     FLAG
                  BRA      END_CONV

TOHIGH   LDAB     #$FF
                  STAB     FLAG
                  BRA      END_CONV

TOLOW             LDAB     #$00
                  STAB     FLAG
END_CONV RTS

*        Subroutine ERROR
*                          This subroutine sets the display digits to output
*                          an error message having detected an out of range
*                          measurement in the main program from FLAG

ERROR             LDAB     #$00                     * Initialize digits 1,4 to blanks
                  STAB     DIGIT1
                  STAB     DIGIT4

                  LDAB     FLAG                     * FLAG is used to determine
                  CMPB     #$00                     * if above or below range.
                  BNE      SET_HI           * If above range GOTO SET_HI

                  LDAB     #$0E                     * ELSE display LO on display
                  STAB     DIGIT2           * Set DIGIT2=L,DIGIT3=O
                  LDAB     #$7E
                  STAB     DIGIT3
                  BRA      END_ERR          * GOTO exit of subroutine

SET_HI   LDAB     #$37                      * Set DIGIT2=H,DIGIT3=1
                  STAB     DIGIT2
                  LDAB     #$30
                  STAB     DIGIT3

END_ERR  RTS

*        Subroutine BCDCONV
*                          Purpose is to convert ALTITUDE from hex to BCD
*                          uses standard HEX-BCD conversion scheme
*                          Divide HEX/10 store Remainder, swap Q & R, repeat
*                          process until remainder = 0.

BCDCONV  LDAA     #$00                      * Default Digits 2,3,4 to 0
                  STAA     DIGIT2
                  STAA     DIGIT3
                  STAA     DIGIT4
                  LDY      #DIGIT4          * Conversion starts with lowest digit
                  LDD      RESULT           * Load voltage to be converted
CONVLP   LDX      #$A                       * Divide hex digit by 10
                  IDIV                              * Quotient in X, Remainder in D
                  STAB     0,Y                      * stores 8 LSB's of remainder as BCD digit
                  DEY
                  CPX      #$0                      * Determines if last digit stored
                  XGDX                              * Exchanges remainder & quotient
                  BNE      CONVLP
                  LDX      #REGBASE         * Reloads BASE into main program
                  RTS

*        Subroutine LOOKUP
*                          Purpose is to implement a Look-Up conversion
*                          The BCD is used to index off of TABLE
*                          where the appropriate hex code to display
*                          that decimal digit is contained.
```

```
*                          DIGIT4,3,2 are converted only.

LOOKUP   LDX      #DIGIT1+4                 * Counter starts at 5
TABLOOP  DEX                                * Start with Digit4
                  LDY      #TABLE           * Loads table base into Y-pointer
                  LDAB     0,X                      * Loads current digit into B
                  ABY                               * Adds to base to index off TABLE
                  LDAA     0,Y                      * Stores HEX segment result in A
                  STAA     0,X
                  CPX      #DIGIT2          * Loop condition complete, DIGIT2 Converted
                  BNE      TABLOOP

                  RTS

*        Subroutine SPI2LCD
*                          Purpose is to output digits to LCD via SPI
*                          The format for this is to send a start byte,
*                          four digits, and a stop byte. This system
*                          will have 3 significant digits: blank digit
*                          and three decimal digits.

*                                                   Sending LCD Start Byte

SPI2LCD  LDX      #REGBASE
                  LDAA     SPSR,X           * Reads to clear SPIF flag
                  LDAA     #$02                     * Byte, no colon, start bit
                  BSR      TRANSFER         * Transmit byte

*                                                   Initializing decimal point & blank digit
                  LDAA     DIGIT3           * Sets MSB for decimal pt.
                  ORA      #$80                     * after digit 3
                  STAA     DIGIT3

                  LDAA     #$00                     * Set 1st digit as blank
                  STAA     DIGIT1

*                                                   Sending four decimal digits

                  LDY      #DIGIT1          * Pointer set to send 4 bytes
DLOOP             LDAA     0,Y                      * Loads digit to be x-mitted
                  BSR      TRANSFER         * Transmit byte
                  INY                               * Branch until both bytes sent
                  CPY      #DIGIT4+1
                  BNE      DLOOP

*                                                   Sending LCD Stop Byte

                  LDAA     #$00                     * end byte requires all 0's
                  BSR      TRANSFER         * Transmit byte

                  RTS

*        Subroutine TRANSFER
*                 Purpose is to send data bits to SPI
*                 and wait for conversion complete flag bit to be set.

TRANSFER LDX      #REGBASE
                  BCLR     PORTD,X #$20     * Assert SS Line to start X-misssion
                  STAA     SPDR,X           * Load Data into Data Reg.,X-mit
XMIT              BRCLR    SPSR,X  #$80 XMIT * Wait for flag
                  BSET     PORTD,X #$20     * DISASSERT SS Line
                  LDAB     SPSR,X           * Read to Clear SPI Flag

                  RTS

*        Location for FCB memory for look-up table
*        There are 11 possible digits: blank, 0-9

TABLE             FCB      $7E,$30,$6D,$79,$33,$5B,$5F,$70,$7F,$73,$00
                  END
```

Liquid Level Control Using a Pressure Sensor

by: J.C. Hamelain
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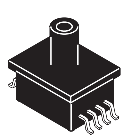
INTRODUCTION

Discrete Products provide a complete solution for designing a low cost system for direct and accurate liquid level control using an ac powered pump or solenoid valve. This circuit approach which exclusively uses Freescale semiconductor parts, incorporates a piezoresistive pressure sensor with on-chip temperature compensation and a new solid-state relay with an integrated power triac, to drive directly the liquid level control equipment from the domestic 110/220V 50/60 Hz ac main power line.

PRESSURE SENSOR DESCRIPTION

The MPXM2000 Series pressure sensor integrates on-chip, laser-trimmed resistors for offset calibration and temperature compensation. The pressure sensitive element is a patented, single piezoresistive implant which replaces the four resistor Wheatstone bridge traditionally used by most pressure sensor manufacturers.



MPAK Axial Port
Case 1320A

Depending on the application and pressure range, the sensor may be chosen from the following portfolio. For this application the MPXM2010GS was selected.

Device	Pressure Range	Application Sensitivity*
MPXM2010GS	0 to 10 kPa	± 0.01 kPa (1 mm H_2O)
MPXM2053GS	0 to 50 kPa	± 0.05 kPa (5 mm H_2O)
MPXM2102GS	0 to 100 kPa	± 0.1 kPa (10 mm H_2O)
MPXM2202GS	0 to 200 kPa	± 0.2 kPa (20 mm H_2O)
* After proper gain adjustment		

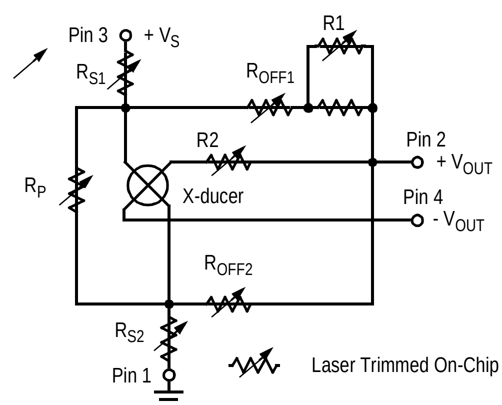


Figure 1. Pressure Sensor MPXM2000 Series

POWER ISOLATOR MOC2A60 DESCRIPTION

The MOC2A60 is a new isolator and consists of a gallium arsenide, infrared emitting diode, which is optically coupled to a zero-cross triac driver and a power triac. It is capable of driving a load of up to 2 A (rms) directly from a line voltage of 220 V (50/60 Hz).

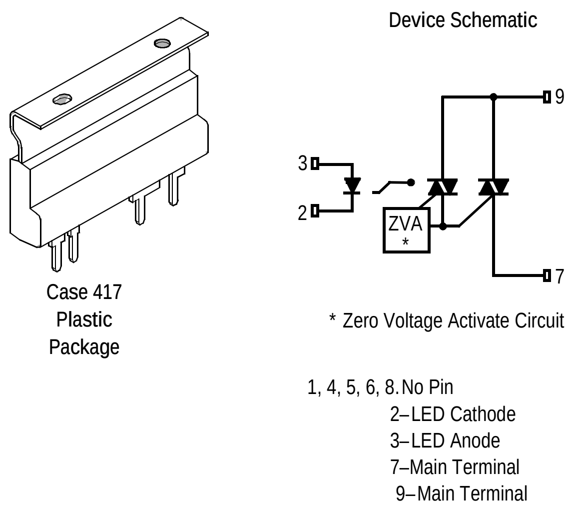


Figure 2. MOC2A60 Isolator

SIGNAL CONDITIONING

When a full range pressure is applied to the MPXM2010GS, it will provide an output of about 20 mV (at an 8 V supply). Therefore, for an application using only a few percent of the pressure range, the available signal may be as low as a few hundred microvolts. To be useful, the sensor signal must be amplified. This is achieved via a true differential amplifier (A1 and A2) as shown in Figure 4. The GAIN ADJ (500 ohm) resistor, R_G, sets the gain to about 200.

The differential output of this stage is amplified by a second stage (A3) with a variable OFFSET resistor. This stage performs a differential to single-ended output conversion and references this output to the adjustable offset voltage. This output is then compared to a voltage (V_{REF} = 4 V at TP2) at the input of the third stage (A4).

This last amplifier is used as an inverted comparator amplifier with hysteresis (Schmitt trigger) which provides a logic signal (TP3) within a preset range variation of about 10% of the input (selected by the ratio R9/(R9 + R7).

If the pressure sensor delivers a voltage to the input of the Schmitt trigger (pin 13) lower than the reference voltage (pin 12), then the output voltage (pin 14) is high and the drive current for the power stage MOC2A60 is provided. When the sensor output increases above the reference voltage, the output at pin 14 goes low and no drive current is available.

The amplifier used is an MC33179. This is a quad amplifier with large current output drive capability (more than 80 mA).

OUTPUT POWER STAGE

For safety reasons, it is important to prevent any direct contact between the ac main power line and the liquid environment or the tank. In order to maintain full isolation between the sensor circuitry and the main power, the solid-state relay is placed between the low voltage circuit (sensor and amplifier) and the ac power line used by the pump and compressor.

The output of the last stage of the MC33179 is used as a current source to drive the LED (light emitting diode). The series resistor, R8, limits the current into the LED to approximately 15 mA and guarantees an optimum drive for the power opto-triac. The LD1 (MFOE76), which is an infrared light emitting diode, is used as an indicator to detect when the load is under power.

The MOC2A60 works like a switch to turn ON or OFF the pump's power source. This device can drive up to 2 A for an ac load and is perfectly suited for the medium power motors (less than 500 watts) used in many applications. It consists of an opto-triac driving a power triac and has a zero-crossing detection to limit the power line disturbance problems when fast switching selfic loads. An RC network, placed in parallel with the output of the solid-state relay is not required, but it is good design practice for managing large voltage spikes coming from the inductive load commutation. The load itself (motor or solenoid valve) is connected in series with the solid-state relay to the main power line.

EXAMPLE OF APPLICATION: ACCURATE LIQUID LEVEL MONITORING

The purpose of the described application is to provide an electronic system which maintains a constant liquid level in a tank (within ± 5 mm H_2O). The liquid level is kept constant in the tank by an ac electric pump and a pressure sensor which provides the feedback information. The tank may be of any size. The application is not affected by the volume of the tank but only by the difference in the liquid level. Of course, the maximum level in the tank must correspond to a pressure within the operating range of the pressure sensor.

LIQUID LEVEL SENSORS

Freescale has developed a piezoresistive pressure sensor family which is very well adapted for level sensing, especially when using an air pipe sensing method. These devices may also be used with a bubbling method or equivalent.

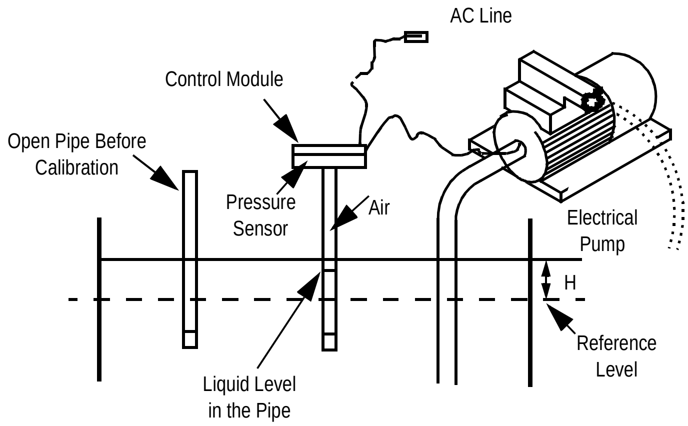


Figure 3. Liquid Level Monitoring

LEVEL SENSING THEORY

If a pipe is placed vertically, with one end dipped into a liquid and the other end opened, the level in the pipe will be exactly the same as the level in the tank. However, if the upper end of the pipe is closed off and some air volume is trapped, the pressure in the pipe will vary proportionally with the liquid level change in the tank.

For example, if we assume that the liquid is water and that the water level rises in the tank by 10 mm, then the pressure in the pipe will increase by that same value (10 mm of water).

A gauge pressure sensor has one side connected to the pipe (pressure side) and the other side open to ambient (in this case, atmospheric) pressure. The pressure difference which corresponds to the change in the tank level is measured by the pressure sensor.

PRESSURE SENSOR CHOICE

In this example, a level sensing of 10 mm of water is desired. The equivalent pressure in kilo pascals is 0.09806 kPa. In this case, Freescale's temperature compensated 0-10 kPa, MPXM2010GS is an excellent choice. The sensor output, with a pressure of 0.09806 kPa applied, will result in 2.0 mV/kPa x 0.09806 = 0.196 mV.

The sensing system is designed with an amplifier gain of about 1000. Thus, the conditioned signal voltage given by the module is 1000 x 0.196 mV = 0.196 V with 10 mm - H_2O pressure.

Table 1. Liquid Level Sensors

Method	Sensor	Advantages	Disadvantages
Liquid Weight	Magnetoresitive	Low Power, No Active Electronic	Low Resolution, Range Limited
	Magnetoresitive	Very High Resolution	Complex Electronic
	Ultrasonic	Easy to Install	Need High Power, Low Accuracy
Liquid Resistivity	No Active Electronic	No Active Electronic	Low Resolution, Liquid Dependent
String Potentionmeter	Potentionmeter	Low Power, No Active Electronic	Poor Linearity, Corrosion
Pressure	Silicon Sensors	Inexpensive, Good Resolution, Wide Range Measurements	Active Electronic, Need Power

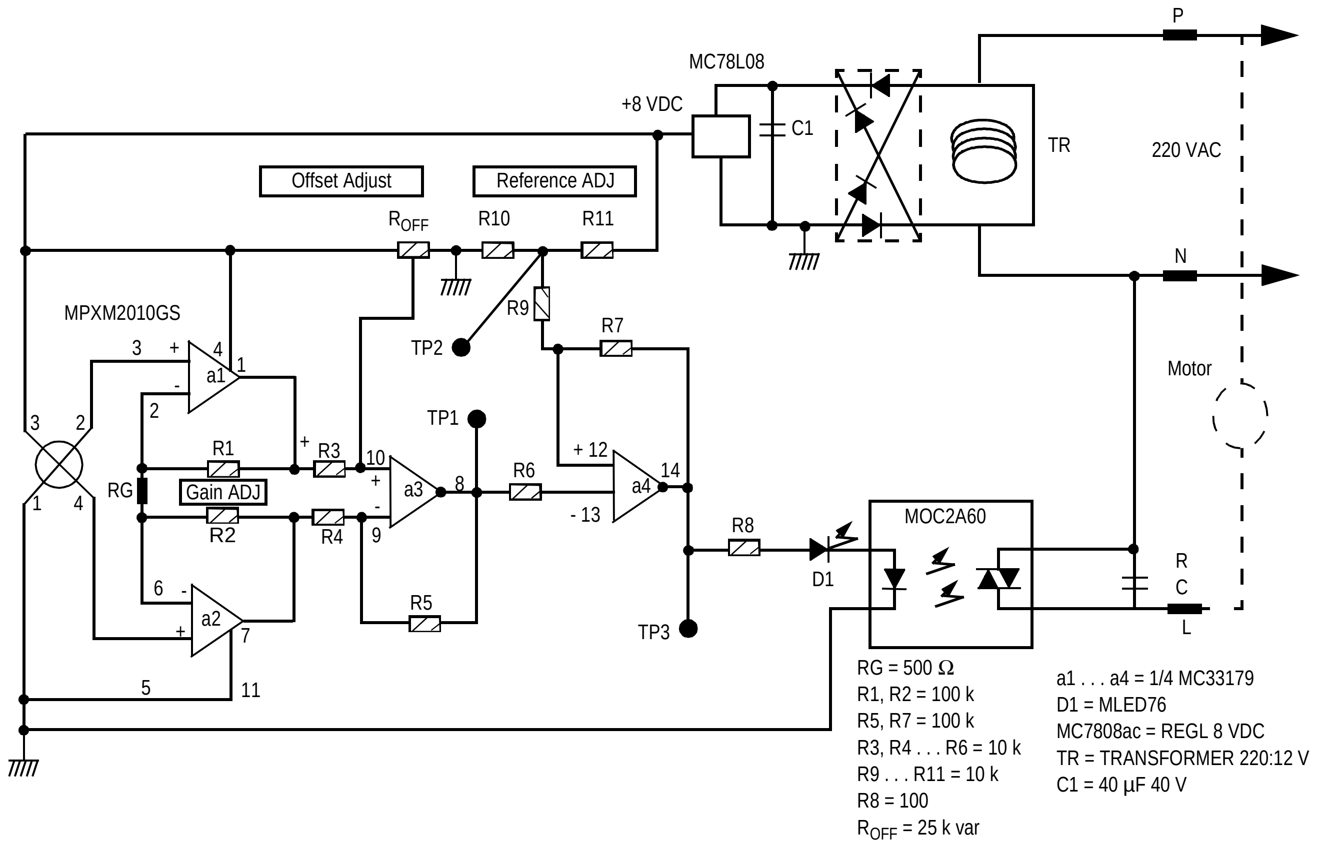
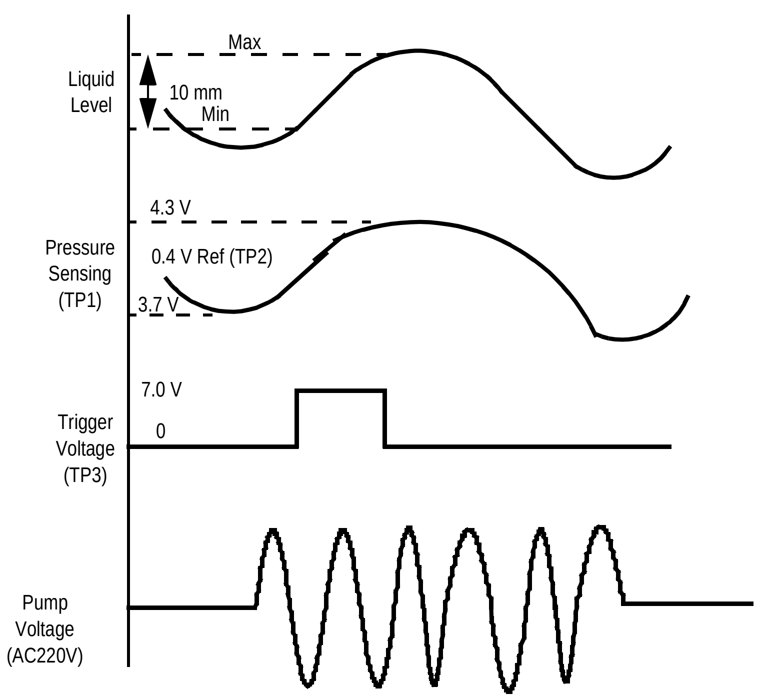


Figure 4. Electrical Circuit



Sensing for minimum level (pumping into the tank)

The sensing probe is tied to the positive pressure port of the sensor. The pump is turned on to fill the tank when the minimum level is reached.

Figure 5. Functional Diagram

LEVEL CONTROL MODES

This application describes two ways to keep the liquid level constant in the tank; first, by pumping the water out if the liquid level rises above the reference, or second, by pumping the water in if the liquid level drops below the reference.

If pumping water out, the pump must be OFF when the liquid level is below the reference level. To turn the pump ON, the sensor signal must be decreased to drop the input to the Schmitt trigger below the reference voltage. To do this, the sensing pipe must be connected to the NEGATIVE pressure port (back or vacuum side) of the sensor. In the condition when the pressure increases (liquid level rises), the sensor voltage will decrease and the pump will turn ON when the sensor output crosses the referenced level. As pumping continues, the level in the tank decreases (thus the pressure on the sensor decreases) and the sensor signal increases back up to the trigger point where the pump was turned OFF.

In the case of pumping water into the tank, the pump must be OFF when the liquid level is above the reference level. To turn ON the pump, the sensor signal must be decreased to drive the input Schmitt trigger below the reference voltage. To do this, the sensing pipe must be connected to the POSITIVE pressure port (top side) of the sensor. In this configuration when the pressure on the sensor decreases, (liquid level drops) the sensor voltage also decreases and the pump is turned ON when the signal exceeds the reference. As pumping continues, the water level increases and when the maximum level is reached, the Schmitt trigger turns the pump OFF.

ADJUSTMENTS

The sensing tube is placed into the water at a distance below the minimum limit level anywhere in the tank. The other end of the tube is opened to atmosphere. When the tank is filled to the desired maximum (or minimum) level, the pressure sensor is connected to the tube with the desired port configuration for the application. Then the water level in the tank is the reference.

After connecting the tube to the pressure sensor, the module must be adjusted to control the water level. The output voltage at TP1 is preadjusted to about 4.0 V (half of the supply voltage). When the sensor is connected to the tube, the module output is ON (lighted) or OFF. By adjusting the offset adjust potentiometer the output is just turned into the other state: OFF, if it was ON or the reverse, ON, if it was OFF, (the change in the tank level may be simulated by moving the sensing tube up or down).

The reference point TP2 shows the ON/OFF reference voltage, and the switching point of the module is reached when the voltage at TP1 just crosses the value of the TP2 voltage. The module is designed for about 10 mm of difference level between ON and OFF (hysteresis).

CONCLUSION

This circuit design concept may be used to evaluate pressure sensors used as a liquid level switch. This basic circuit may be easily modified to provide an analog signal of the level within the controlled range. It may also be easily modified to provide tighter level control (±2 mm H_2O) by increasing the gain of the first amplifier stage (decreasing RG resistor).

The circuit is also a useful tool to evaluate the performance of the power optocoupler MOC2A60 when driving ac loads directly.

Pressure Switch Design with Semiconductor Pressure Sensors

by: Eric Jacobsen and Jeff Baum
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INTRODUCTION

The Pressure Switch concept is simple, as are the additions to conventional signal conditioning circuitry required to provide a pressure threshold (or thresholds) at which the output switches logic state. This logic-level output may be input to a microcontroller, drive an LED, control an electronic switch, etc. The user-programmed threshold (or reference voltage) determines the pressure at which the output state will switch. An additional feature of this minimal component design is an optional user-defined hysteresis setting that will eliminate multiple output transitions when the pressure sensor voltage is comparable to the threshold voltage.

This paper presents the characteristics and design criteria for each of the major subsystems of the pressure switch design: the pressure sensor, the signal conditioning (gain) stage, and the comparator output stage. Additionally, an entire section will be devoted to comparator circuit topologies which employ comparator ICs and/or operational amplifiers. A window comparator design (high and low thresholds) is also included. This section will discuss the characteristics and design criteria for each comparator circuit, while evaluating them in overall performance (i.e., switching speed, logic-level voltages, etc.).

BASIC SENSOR OPERATION

The MPX2000 Series sensors are temperature compensated and calibrated (i.e., offset and full-scale span are precision trimmed) pressure transducers. These sensors are available in full-scale pressure ranges from 10 kPa (1.5 psi) to 200 kPa (30 psi). Although the specifications (see Table 1) in the data sheets apply only to a 10 V supply voltage, the output of these devices is ratiometric with the supply voltage. For example, at the absolute maximum supply voltage rating, 16 V, the sensor will produce a differential output voltage of 64 mV at the rated full-scale pressure of the given sensor. One exception to this is that the full-scale span of the MPX2010 (10 kPa sensor) will be only 40 mV due to the device's slightly lower sensitivity. Since the maximum supply voltage produces the most output voltage, it is evident that even the best case scenario will require some signal conditioning to obtain a usable voltage level. For this specific design, an MPX2100 and 5.0 V supply is used to provide a maximum sensor output of 20 mV. The sensor output is then signal conditioned to obtain a four volt signal swing (span).

Table 1. MPX2100 Electrical Characteristics for V_S = 10 V, T_A = 25°C

Characteristics	Symbol	Minimum	Typical	Maximum	Unit
Pressure Range	P_{OP}	0	—	100	kPa
Supply Voltage	V_S	—	10	16	V_{DC}
Full Scale Span	V_{FSS}	38.5	40	41.5	mV
Zero Pressure Offset	V_{OFF}	—	0.05	0.1	mV
Sensitivity	S	—	0.4	—	mV/kPa
Linearity	—	—	0.05	—	$\%F_{SS}$
Temperature Effect on Span	—	—	0.5	—	$\%F_{SS}$
Temperature Effect on Offset	—	—	0.2	—	$\%F_{SS}$

THE SIGNAL CONDITIONING

The amplifier circuitry, shown in Figure 1, is composed of two op-amps. This interface circuit has a much lower component count than conventional quad op amp instrumentation amplifiers. The two op amp design offers the high input impedance, low output impedance, and high gain desired for a transducer interface, while performing a differential to single-ended conversion. The gain is set by the following equation:

$$GAIN = 1 + \frac{R6}{R5}$$

where R6 = R3 and R4 = R5

For this specific design, the gain is set to 201 by setting R6 = 20 kΩ and R5 = 100 Ω. Using these values and setting R6 = R3 and R4 = R5 gives the desired gain without loading the reference voltage divider formed by R1 and R_{off}. The offset voltage is set via this voltage divider by choosing the value of R_{off}. This enables the user to adjust the offset for each application's requirements.

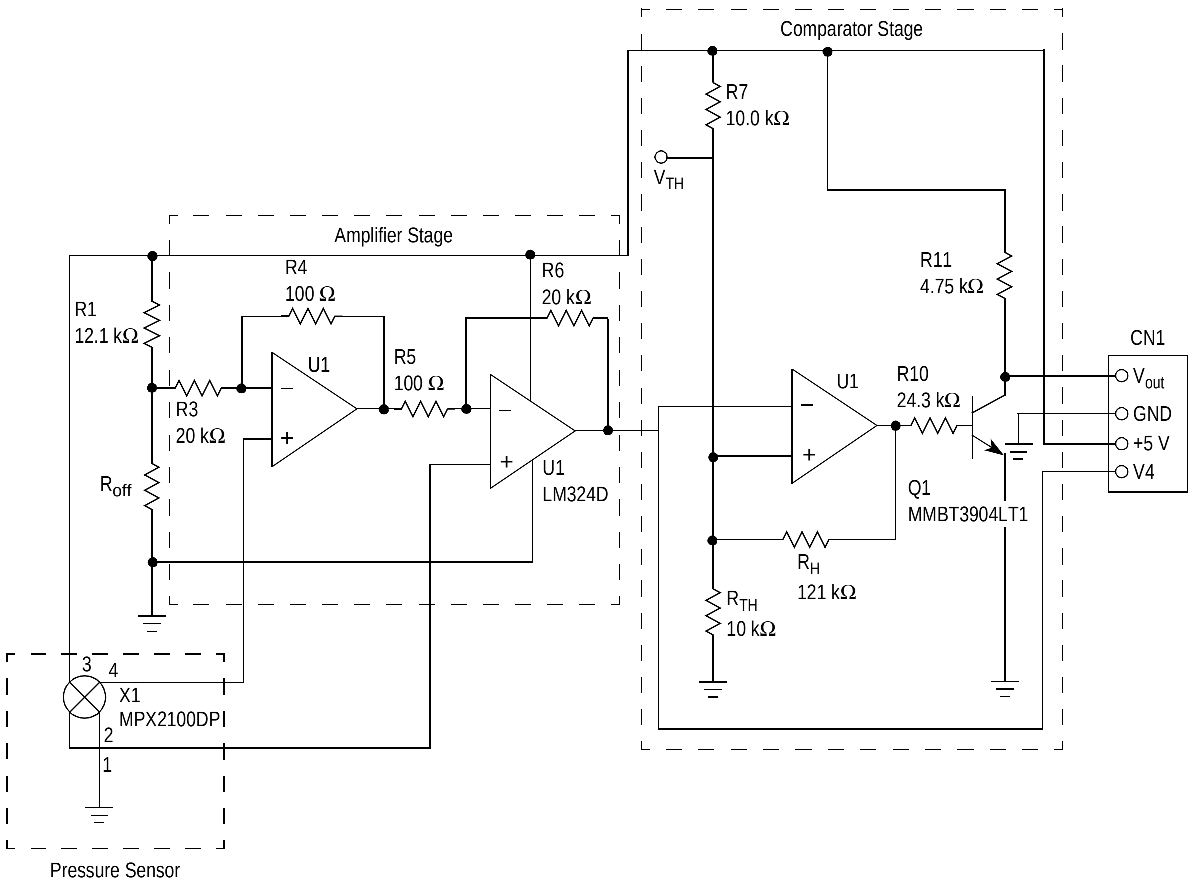

Figure 1. Pressure Switch Schematic

THE COMPARISON STAGE

The comparison stage is the "heart" of the pressure switch design. This stage converts the analog voltage output to a digital output, as dictated by the comparator's threshold. The comparison stage has a few design issues which must be addressed:

- The threshold for which the output switches must be programmable. The threshold is easily set by dividing the supply voltage with resistors R7 and R_{TH}. In Figure 1, the threshold is set at 2.5 V for R7 = R_{TH} = 10 kΩ.
- A method for providing an appropriate amount of hysteresis should be available. Hysteresis prevents multiple transitions from occurring when slow varying signal inputs oscillate about the threshold. The hysteresis can be set by applying positive feedback. The amount of hysteresis is determined by the value of the feedback resistor, R_H (refer to equations in the following section).
- It is ideal for the comparator's logic level output to swing from one supply rail to the other. In practice, this is not possible. Thus, the goal is to swing as high and low as possible for a given set of supplies. This offers the greatest

difference between logic states and will avoid having a microcontroller read the switch level as being in an indeterminate state.

- In order to be compatible with CMOS circuitry and to avoid microcontroller timing delay errors, the comparator must switch sufficiently fast.
- By using two comparators, a window comparator may be implemented. The window comparator may be used to monitor when the applied pressure is within a set range. By adjusting the input thresholds, the window width can be customized for a given application. As with the single threshold design, positive feedback can be used to provide hysteresis for both switching points. The window comparator and the other comparator circuits will be explained in the following section.

EXAMPLE COMPARATOR CIRCUITS

Several comparator circuits were built and evaluated. Comparator stages using the LM311 comparator, LM358 Op-Amp (with and without an output transistor stage), and LM339were examined. Each comparator was evaluated on output voltage levels (dynamic range), transition speed, and the relative component count required for the complete pressure switch design. This comparison is tabulated in Table 2.

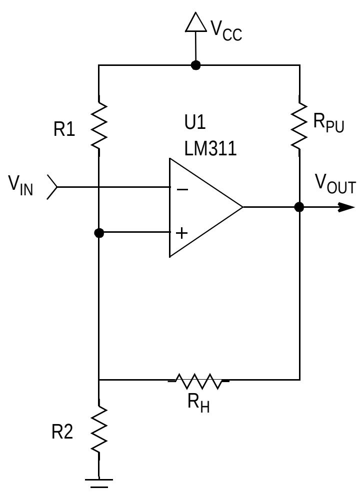

Figure 2. LM311 Comparator Circuit Schematic

LM311 USED IN A COMPARATOR CIRCUIT

The LM311 chip is designed specifically for use as a comparator and thus has short delay times, high slew rate, and an open collector output. A pull-up resistor at the output is all that is needed to obtain a rail-to-rail output. Additionally, the LM311 is a reverse logic circuit; that is, for an input lower than the reference voltage, the output is high. Likewise, when the input voltage is higher than the reference voltage, the output is low. Figure 2 shows a schematic of the LM311 stage with threshold setting resistor divider, hysteresis resistor, and the open-collector pull-up resistor. Table 2 shows the comparator's performance. Based on its performance, this circuit can be used in many types of applications, including interface to microprocessors.

The amount of hysteresis can be calculated by the following equations:

$$V_{REF} = \frac{R2}{R1 + R2} V_{CC}$$

neglecting the effect of R_H

$$VREFH = \frac{R1R2 + R2R_H}{R1R2 + R1R_H + R2R_H} V_{CC}$$

$$VREFL = \frac{R2R_H}{R1R2 + R1R_H + R2R_H} V_{CC}$$

$$HYSTERESIS = V_{REF} - V_{REFL}$$

when the normal state is below V_{REF} or

$$HYSTERESIS = V_{REFH} - V_{REF}$$

when the normal state is above V_{REF}.

Table 2. Comparator Circuits Performance Characteristics

Characteristics	LM311	LM358	LM358 w/Trans.	Unit
Switching Speeds	—	—	—	—
Rise Time	1.40	5.58	2.20	µs
Fall Time	0.04	6.28	1.30	µs
Output Levels	—	—	—	—
V_{OH}	4.91	3.64	5.00	V
V_{OL}	61.1	38.0	66.0	mV
Circuit Logic Type	NEGATIVE	NEGATIVE	POSITIVE	—

The initial calculation for V_{REF} will be slightly in error due to neglecting the effect of R_H. To establish a precise value for V_{REF} (including R_H in the circuit), recompute R1 taking into account that V_{REF} depends on R1, R2, and R_H. It turns out that when the normal state is below V_{REF}, R_H is in parallel with R1:

$$V_{REF} = \frac{R2}{R1 \parallel R_H + R2} V_{CC}$$

(Which is identical to the equation for V_{REFH})

Alternately, when the normal state is above VREF, RH is in parallel with R2:

$$V_{REF} = \frac{R2 \parallel R_H}{R1 + R2 \parallel R_H} V_{CC}$$

(Which is identical to the equation for V_{REFL})

These two additional equations for V_{REF} can be used to calculate a more precise value for V_{REF}.

The user should be aware that V_{REF}, V_{REFH} and V_{REFL} are chosen for each application, depending on the desired switching point and hysteresis values. Also, the user must specify which range (either above or below the reference voltage) is the desired normal state (see Figure 3). Referring to Figure 3, if the normal state is below the reference voltage then V_{REFL} (V_{REFH} is only used to calculate a more precise value for V_{REF} as explained above) is below V_{REF} by the desired amount of hysteresis (use V_{REFL} to calculate R_H). Alternately, if the normal state is above the reference voltage, then V_{REFH} (V_{REFL} is only used to calculate a more precise value for V_{REF}) is above V_{REF} by the desired amount of hysteresis (use V_{REFH} to calculate R_H).

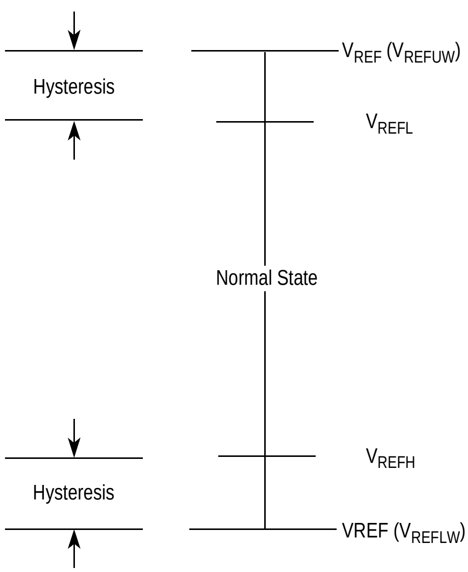

Figure 3. Setting the Reference Voltages

LM358 OP AMP USED IN A COMPARATOR CIRCUIT

Figure 4 shows the schematic for the LM358 op amp comparator stage, and Table 2 shows its performance. Since the LM358 is an operational amplifier, it does not have the fast slew-rate of a comparator IC nor the open collector output.

Comparing the LM358 and the LM311 (Table 2), the LM311 is better for logic/switching applications since its output nearly extends from rail to rail and has a sufficiently high switching speed. The LM358 will perform well in applications where the switching speed and logic-state levels are not critical (LED output, etc.). The design of the LM358 comparator is accomplished by using the same equations and procedure presented for the LM311. This circuit is also reverse logic.

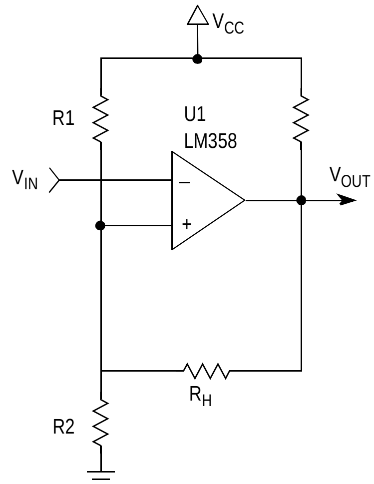

Figure 4. LM358 Comparator Circuit Schematic

LM358 OP AMP WITH A TRANSISTOR OUTPUT STAGE USED IN A COMPARATOR CIRCUIT

The LM358 with a transistor output stage is shown in Figure 5. This circuit has similar performance to the LM311 comparator: its output reaches the upper rail and its switching speed is comparable to the LM311's. This enhanced performance does, however, require an additional transistor and base resistor. Referring to Figure 1, note that this comparator topology was chosen for the pressure switch design. The LM324 is a quad op amp that has equivalent amplifier characteristics to the LM358.

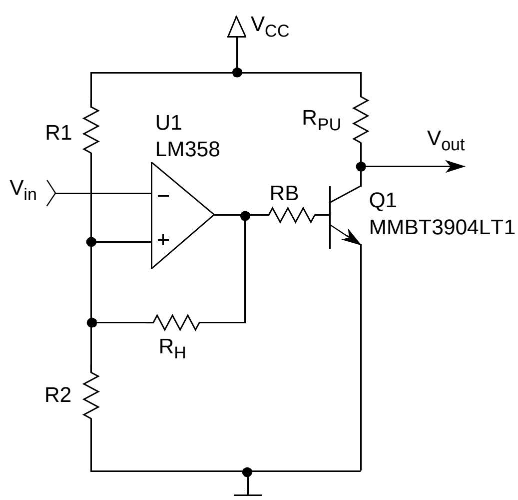

Figure 5. LM358 with a Transistor Output Stage Comparator Circuit Schematic

Like the other two circuits, this comparator circuit can be designed with the same equations and procedure. The values for R_B and R_{PU} are chosen to give a 5:1 ratio in Q1's collector current to its base current, in order to insure that Q1 is well-saturated (V_{OUT} can pull down very close to ground when Q1 is on). Once the 5:1 ratio is chosen, the actual resistance values determine the desired switching speed for turning Q1 on and off. Also, R_{PU} limits the collector current to be within the maximum specification for the given transistor (see example values in Figure 1). Unlike the other two circuits, this circuit is positive logic due to the additional inversion created at the output transistor stage.

LM339 USED IN A WINDOW COMPARATOR CIRCUIT

Using two voltage references to detect when the input is within a certain range is another possibility for the pressure switch design. The window comparator's schematic is shown in Figure 6. The LM339 is a quad comparator IC (it has open collector outputs), and its performance will be similar to that of the LM311.

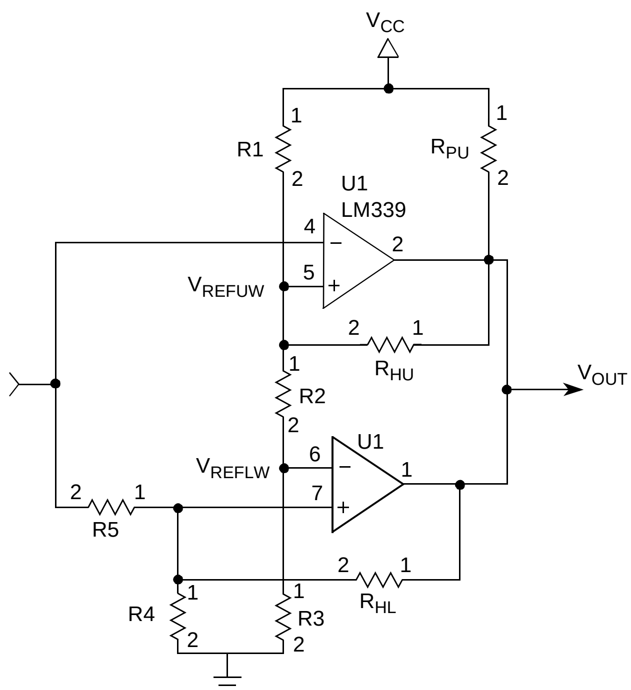

Figure 6. LM339 Window Comparator Circuit Schematic

Obtaining the correct amount of hysteresis and the input reference voltages is slightly different than with the other circuits. The following equations are used to calculate the hysteresis and reference voltages. Referring to Figure 3, V_{REFUW} is the upper window reference voltage and V_{REFLW} is the lower window reference voltage. Remember that reference voltage and threshold voltage are interchangeable terms.

For the upper window threshold:

Choose the value for V_{REFUW} and R1 (e.g., 10 kΩ). Then, by voltage division, calculate the total resistance of the combination of R2 and R3 (named R23 for identification) to obtain the desired value for V_{REFUW}, neglecting the effect of R_{HU}:

$$V_{REFUW} = \frac{R23}{R1 + R23} V_{CC}$$

The amount of hysteresis can be calculated by the following equation:

$$V_{REFUW} = \frac{R23R_{HU}}{R1R23 + R1R_{HU} + R23R_{HU}} V_{CC}$$

Notice the upper window reference voltage, V_{REFUW}, is now equal to its V_{REFL} value, since at this moment, the input voltage is above the normal state.

$$HYSTERESIS = V_{REFUW} - V_{REFL}$$

where VREFL is chosen to give the desired amount of hysteresis for the application.

The initial calculation for V_{REFUW} will be slightly in error due to neglecting the effect of R_{HU}. To establish a precise value for V_{REFUW} (including R_{HU} in the circuit), recompute R1 taking into account that V_{REFUW} depends on R2 and R3 and the parallel combination of R1 and R_{HU}. This more precise value is calculated with the following equation:

$$V_{REFUW} = \frac{R23}{R1 \parallel R_{HU} + R23} V_{CC}$$

for the lower window threshold choose the value for V_{REFLW}.

$$SetV_{REFLW} = \frac{R3}{R1 \parallel R_{HU} + R2 + R3} V_{CC}$$

where R2 + R3 = R23 from above calculation.

To calculate the hysteresis resistor:

The input to the lower comparator is one half V_{IN} (since R4 =R5) when in the normal state. When V_{REFLW} is above one half of V_{IN} (i.e., the input voltage has fallen below the window), R_{HL} parallels R4, thus loading down V_{IN}. The resulting input to the comparator can be referred to as V_{INL} (a lower input voltage). To summarize, when the input is within the window, the output is high and only R4 is connected to ground from the comparator's positive terminal. This establishes one half of V_{IN} to be compared with V_{REFLW}. When the input. When the input voltage is below V_{REFLW}, the output is low, and R_{HL} is effectively in parallel with R4. By voltage division, less of the input voltage at V_{IN} be required to make the noninverting input exceed V_{RELW}.

Therefore, the following equations are established:

$$HYSTERESIS = V_{REFLW} - V_{INL}$$

Choose R4 = R5 to simplify the design.

$$R_{HL} = \frac{R4R5(V_{REFLW} - V_{INL} - V_{CC})}{(R4 + R5)(V_{INL} - V_{REFLW})}V_{CC}$$

NOTE:

As explained above, because the input voltage is divided in half by R4 and R5, all calculations are done relative to the one half value of V_{in}. Therefore, for a hysteresis of 200 mV (relative to V_{in}), the above equations must use one half this hysteresis value (100 mV). Also, if a V_{REFLW} value of 2.0 V is desired (relative to V_{in}), then 1.0 V for its value should be used in the above equations. The value for V_{INL} should be scaled by one half also.

The window comparator design can also be designed using operational amplifiers and the same equations as for the LM339 comparator circuit. For the best performance, however, a transistor output stage should be included in the design.

TEST/CALIBRATION PROCEDURE

1. Before testing the circuit, the user-defined values for R_{TH}, R_H and R_{off} should be calculated for the desired application.

The sensor offset voltage is set by

$$V_{OFF} = \frac{V_{OFF}}{R1 + R_{OFF}}V_{CC}$$

Then, the amplified sensor voltage corresponding to a given pressure is calculated by:

$$V_{SENSOR} = 201 \times 0.0002 \times \text{APPLIED PRESSURE} + V_{OFF},$$

where 201 is the gain, 0.0002 is in units of V/kPa and APPLIED PRESSURE is in kPa.

The threshold voltage, V_{TH}, at which the output changes state is calculated by determining V_{sensor} at the pressure that causes this change of state:

$$V_{TH} = V_{SENSOR}\text{ (@ pressure threshold)} = \frac{R_{TH}}{R7 + R_{TH}}V_{CC}$$

If hysteresis is desired, refer to the LM311 *Used in a Comparator* section to determine R_H.

2. To test this design, connect a +5 volt supply between pins 3 and 4 of the connector CN1.
3. Connect a volt meter to pins 1 and 4 of CN1 to measure the output voltage and amplified sensor voltage, respectively.
4. Connect an additional volt meter to the V_{TH} probe point to verify the threshold voltage.
5. Turn on the supply voltage.
6. With no pressure applied, check to see that V_{off} is correct by measuring the voltage at the output of the gain stage (the volt meter connected to Pin 4 of CN1). If desired, V_{off} can be fine tuned by using a potentiometer for R_{off}.
7. Check to see that the volt meter monitoring V_{TH} displays the desired voltage for the output to change states. Use a potentiometer for R_{TH} to fine tune V_{TH}, if desired.
8. Apply pressure to the sensor. Monitor the sensor's output via the volt meter connected to pin 4 of CN1. The output will switch from low to high when this pressure sensor voltage reaches or exceeds the threshold voltage.
9. If hysteresis is used, with the output high (pressure sensor voltage greater than the threshold voltage), check to see if V_{TH} has dropped by the amount of hysteresis desired.

A potentiometer can be used for R_H to fine tune the amount of hysteresis.

CONCLUSION

The pressure switch design uses a comparator to create a logic level output by comparing the pressure sensor output voltage and a user-defined reference voltage. The flexibility of this minimal component, high performance design makes it compatible with many different applications. The design presented here uses an op amp with a transistor output stage, yielding excellent logic-level outputs and output transition speeds for many applications. Finally, several other comparison stage designs, including a window comparator, are evaluated and compared for overall performance.

Using a Pulse Width Modulated Output with Semiconductor Pressure Sensors

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INTRODUCTION

For remote sensing and noisy environment applications, a frequency modulated (FM) or pulse width modulated (PWM) output is more desirable than an analog voltage. FM and PWM outputs inherently have better noise immunity for these types of applications. Generally, FM outputs are more widely accepted than PWM outputs, because PWM outputs are restricted to a fixed frequency. However, obtaining a stable FM output is difficult to achieve without expensive, complex circuitry.

With either an FM or PWM output, a microcontroller can be used to detect edge transitions to translate the time-domain signal into a digital representation of the analog voltage signal. In conventional voltage-to-frequency (V/F) conversions, a voltage-controlled oscillator (VCO) may be used in conjunction with a microcontroller. This use of two time bases, one analog and one digital, can create additional inaccuracies. With either FM or PWM outputs, the microcontroller is only concerned with detecting edge transitions. If a programmable frequency, stable PWM output could be obtained with simple, inexpensive circuitry, a PWM output would be a cost-effective solution for noisy environment/remote sensing applications while incorporating the advantages of frequency outputs.

The Pulse Width Modulated Output Pressure Sensor design (Figure 1) utilizes simple, inexpensive circuitry to create an output waveform with a duty cycle that is linear to the applied pressure. Combining this circuitry with a single digital time base to create and measure the PWM signal, results in a stable, accurate output. Two additional advantages of this design are 1) an A/D converter is not required, and 2) since the PWM output calibration is controlled entirely by software, circuit-to-circuit variations due to component tolerances can be nullified.

The PWM Output Sensor system consists of a Freescale Semiconductor, Inc. MPX5000 series pressure sensor, a ramp generator (transistor switch, constant current source, and capacitor), a comparator, and an MC68HC05P9 microcontroller. These subsystems are detailed in Figure 1.

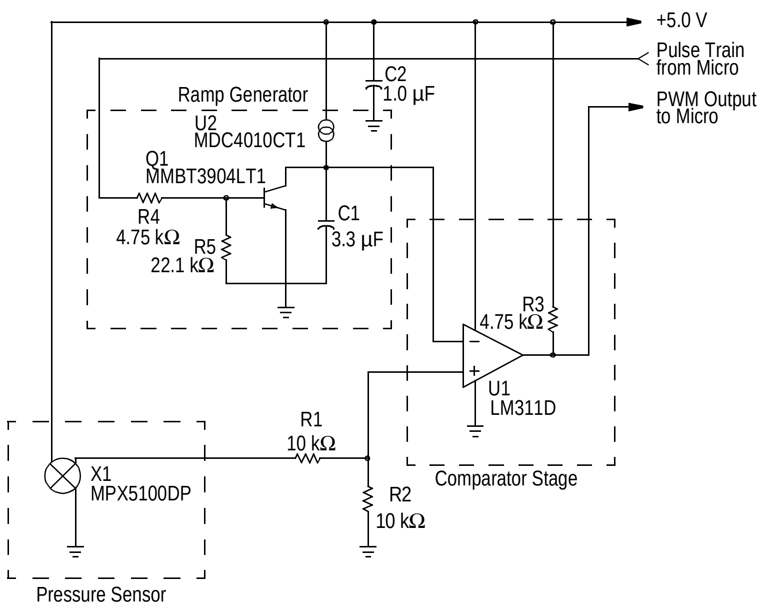

Figure 1. PWM Output Pressure Sensor Schematic

PRESSURE SENSOR

Freescale's MPX5000 series sensors are signal conditioned (amplified), temperature compensated and calibrated (i.e., offset and full-scale span are precision trimmed) pressure transducers. These sensors are available in full-scale pressure ranges of 50 kPa (7.3 psi) and 100 kPa (14.7 psi). With the recommended 5.0 V supply, the MPX5000 series produces an output of 0.5 V at zero pressure to 4.5 V at full scale pressure. Referring to the schematic of the system in Figure 1, note that the output of the pressure sensor is attenuated to one-half of its value by the resistor divider comprised of resistors R1 and R2. This yields a span of 2.0 V ranging from 0.25 V to 2.25 V at the non-inverting terminal of the comparator. Table 1 shows the electrical characteristics of the MPX5100.

Table 1. MPX5100DP Electrical Characteristics

Characteristics	Symbol	Min	Typ	Max	Unit
Pressure Range	P_{OP}	0	—	100	kPa
Supply Voltage	V_S	—	5.0	6.0	V_{DC}
Full Scale Span	V_{FSS}	3.9	4.0	4.1	V
Zero Pressure Offset	V_{OFF}	0.4	0.5	0.6	V
Sensitivity	S	—	40	—	mV/kPa
Linearity	—	– 0.5	—	0.5	$\%F_{SS}$
Temperature Effect on Span	—	– 1.0	—	1.0	$\%F_{SS}$
Temperature Effect on Offset	—	– 50	0.2	50	mV

THE RAMP GENERATOR

The ramp generator is shown in the schematic in Figure 1. A pulse train output from a microcontroller drives the ramp generator at the base of transistor Q1. This pulse can be accurately controlled in frequency as well as pulse duration via software (to be explained in the microcontroller section).

The ramp generator uses a constant current source to charge the capacitor. It is imperative to remember that this current source generates a stable current only when it has approximately 2.5 V or more across it. With less voltage across the current source, insufficient voltage will cause the current to fluctuate more than desired; thus, a design constraint for the ramp generator will dictate that the capacitor can be charged to only approximately 2.5 V, when using a 5.0 V supply.

The constant current charges the capacitor linearly by the following equation:

$$\Delta V = \frac{I\Delta t}{C}$$

where Δt is the capacitor's charging time and C is the capacitance.

Referring to Figure 2, when the pulse train sent by the microcontroller is low, the transistor is off, and the current source charges the capacitor linearly. When the pulse sent by the microcontroller is high, the transistor turns on into saturation, discharging the capacitor. The duration of the high part of the pulse train determines how long the capacitor discharges, and thus to what voltage it discharges. This is how the dc offset of the ramp waveform may be accurately controlled. Since the transistor saturates at approximately 60 mV, very little offset is needed to keep the capacitor from discharging completely.

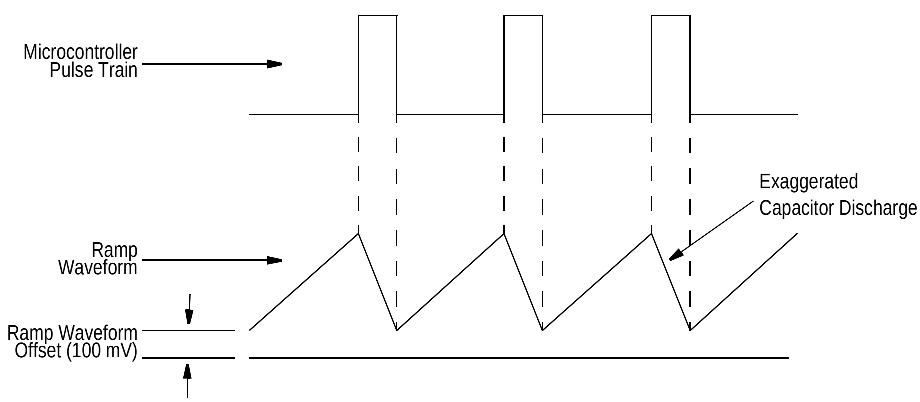

Figure 2. Ideal Ramp Waveform for the PWM Output Pressure Sensor

The PWM output is most linear when the ramp waveform's period consists mostly of the rising voltage edge (see Figure 2). If the capacitor were allowed to completely discharge (see Figure 3), a flat line at approximately 60 mV would separate the ramps, and these “flat spots” may result in non-linearities of the resultant PWM output (after comparing it to the sensor voltage). Thus, the best ramp waveform is produced when one ramp cycle begins immediately after another, and a slight dc offset disallows the capacitor from discharging completely.

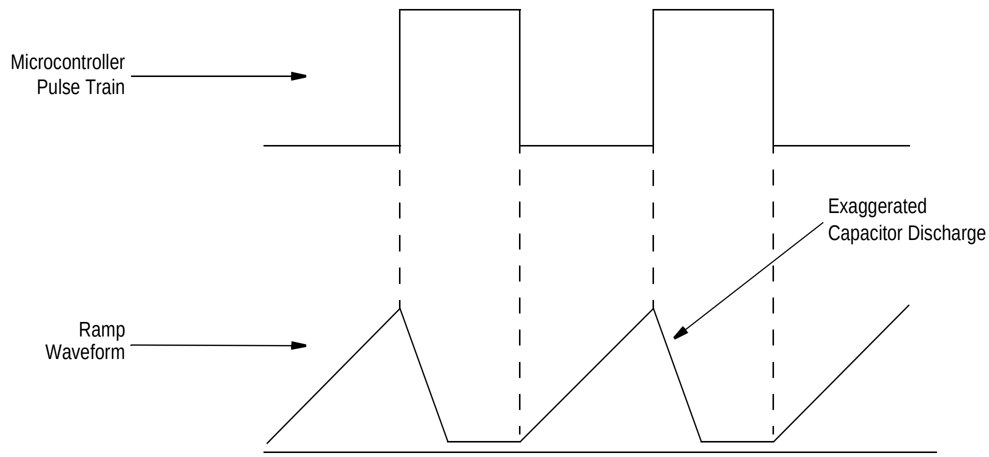

Figure 3. Non Ideal Ramp Waveform for the PWM Output Pressure Sensor

The flexibility of frequency control of the ramp waveform via the pulse train sent from the microcontroller allows a programmable-frequency PWM output. Using Equation 1 the frequency (inverse of period) can be calculated with a given capacitor so that the capacitor charges to a maximum ΔV of approximately 2.5 V (remember that the current source needs approximately 2.5 V across it to output a stable current). The importance of software control becomes evident here since the selected capacitor may have a tolerance of $\pm$20%. By adjusting the frequency and positive width of the pulse train, the desired ramp requirements are readily obtainable; thus, nullifying the effects of component variances.

For this design, the ramp spans approximately 2.4 V from 0.1 V to 2.5 V. At this voltage span, the current source is stable and results in a linear ramp. This ramp span was used for reasons which will become clear in the next section.

In summary, complete control of the ramp is achieved by the following adjustments of the microcontroller-created pulse train:

- Increase Frequency: Span of ramp decreases.The DC offset decreases slightly.
- Decrease Frequency: Span of ramp increases. The DC offset increases slightly.
- Increase Pulse Width: The DC offset decreases. Span decreases slightly.
- Decrease Pulse Width: The DC offset increases. Span increases slightly.

THE COMPARATOR STAGE

The LM311 chip is designed specifically for use as a comparator and thus has short delay times, high slew rate, and an open-collector output. A pull-up resistor at the output is all that is needed to obtain a rail-to-rail output. As Figure 1 shows, the pressure sensor output voltage is input to the non inverting terminal of the op amp and the ramp is input to the inverting terminal. Therefore, when the pressure sensor voltage is higher than a given ramp voltage, the output is high; likewise, when the pressure sensor voltage is lower than a given ramp voltage, the output is low (refer to Figure 5). As mentioned in the Pressure Sensor section, resistors R1 and R2 of Figure 1 comprise the voltage divider that attenuates the pressure sensor's signal to a 2.0 V span ranging from 0.25 V to 2.25 V.

Since the pressure sensor voltage does not reach the ramp's minimum and maximum voltages, there will be a finite minimum and maximum pulse width for the PWM output. These minimum and maximum pulse widths are design constraints dictated by the comparator's slew rate. The system design ensures a minimum positive and negative pulse width of 20 μs to avoid nonlinearities at the high and low pressures where the positive duty cycle of the PWM output is at its extremes (refer to Figure 4). Depending on the speed of the microcontroller used in the system, the minimum required pulse width may be larger. This will be explained in the next section.

THE MICROCONTROLLER

The microcontroller for this application requires input capture and output compare timer channels. The output capture pin is programmed to output the pulse train that drives the ramp generator, and the input capture pin detects edge transitions to measure the PWM output pulse width.

Since software controls the entire system, a calibration routine may be implemented that allows an adjustment of the frequency and pulse width of the pulse train until the desired ramp waveform is obtained. Depending on the speed of the microcontroller, additional constraints on the minimum and maximum PWM output pulse widths may apply. For this design, the software latency incurred to create the pulse train at the output compare pin is approximately 40 μs.

Consequently, the microcontroller cannot create a pulse train with a positive pulse width of less than 40 μs. Also, the software that measures the PWM output pulse width at the input capture pin requires approximately 20 µs to execute. Referring to Figure 5, the software interrupt that manipulates the pulse train always occurs near an edge detection on the input capture pin (additional software interrupt). Therefore, the minimum PWM output pulse width that can be accurately detected is approximately 60 µs (20 µs + 40 µs). This constrains the minimum and maximum pulse widths more than the slew rate of the comparator which was discussed earlier (refer to Figure 4)

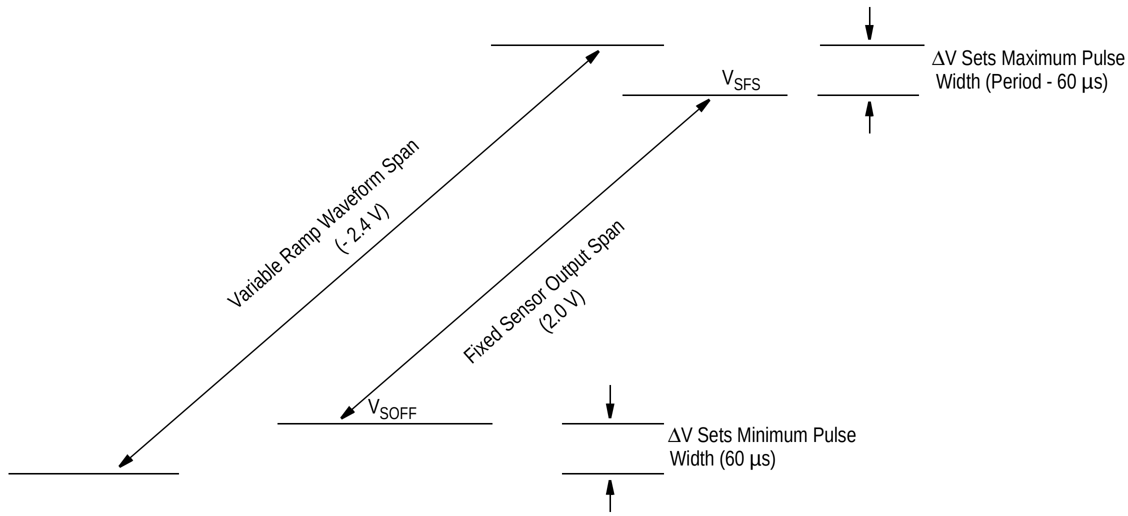

Figure 4. Desired Relationship Between the Ramp Waveform and Pressure Sensor Voltage Spans

An additional consideration is the resolution of the PWM output. The resolution is directly related to the maximum frequency of the pulse train. In our design, 512 µs are required to obtain at least 8-bit resolution. This is determined by the fact that a 4 MHz crystal yields a 2 MHz clock speed in the microcontroller. This, in turn, translates to 0.5 µs per clock tick. There are four clock cycles per timer count. This results in 2 µs per timer count. Thus, to obtain 256 timer counts (or 8-bit resolution), the difference between the zero pressure and full scale pressure PWM output pulse widths must be at least 512 µs (2 µs x 256). But since an additional 60 µs is needed at both pressure extremes of the output waveform, the total period must be at least 632 µs. This translates to a maximum frequency for the pulse train of approximately 1.6 kHz. With this frequency, voltage span of the ramp generator, and value of current charging the capacitor, the minimum capacitor value may be calculated with Equation 1.

To summarize:

The MC68HC705P9 runs off a 4 MHz crystal. The microcontroller internally divides this frequency by two to yield an internal clock speed of 2 MHz.

$$\frac{1}{2\text{ MHz}} => \frac{0.5\ \mu\text{s}}{\text{clock cycle}}$$

And,

4 clock cycles = 1 timer count.

Therefore,

$$\frac{4\text{ clock cycles}}{\text{timer count}} \times \frac{0.5\ \mu\text{s}}{\text{clock cycle}} = \frac{2\ \mu\text{s}}{\text{timer count}}$$

For 8-bit resolution,

$$\frac{2\ \mu\text{s}}{\text{timer count}} \times 256\text{ counts} = 512\ \mu\text{s}$$

Adding a minimum of 60 µs each for the zero and full scale pressure pulse widths yields

$$512\ \mu\text{s} + 60\ \mu\text{s} + 60\ \mu\text{s} = 632\ \mu\text{s}$$

which is the required minimum pulse train period to drive the ramp generator.

Translating this to frequency, the maximum pulse train frequency is thus

$$\frac{1}{632\ \mu\text{s}} = 1.58\text{ kHz}$$

CALIBRATION PROCEDURE AND RESULTS

The following calibration procedure will explain how to systematically manipulate the pulse train to create a ramp that meets the necessary design constraints. The numbers used here are only for this design example. Figure 6 shows the linearity performance achieved by following this calibration procedure and setting up the ramp as indicated by Figure 4 and Figure 5.

1. Start with a pulse train that has a pulse width and frequency that creates a ramp with about 100 mV dc offset and a span smaller than required. In this example the initial pulse width is 84 µs and the initial frequency is 1.85 kHz.
2. **Decrease** the **frequency** of the pulse train until the ramp span increases to approximately 2.4 V. The ramp span of 2.4 V will ensure that the maximum pulse width at full scale pressure will be at least 60 µs less than the total period. Note, by **decreasing** the **frequency** of the pulse train, a dc offset will begin to appear. This may result in the ramp looking nonlinear at the top.
3. If the ramp begins to become nonlinear, **increase** the **pulse width** to decrease the dc offset.
4. Repeat steps 2 and 3 until the ramp spans 2.4 V and has a dc offset of approximately 100 mV. The dc offset value is not critical, but the bottom of the ramp should have a “crisp” point at which the capacitor stops discharging and begins charging. Simply make sure that the minimum pulse width at zero pressure is at least 60 µs. Refer to Figure 4 and Figure 5 to determine if the ramp is sufficient for the application.

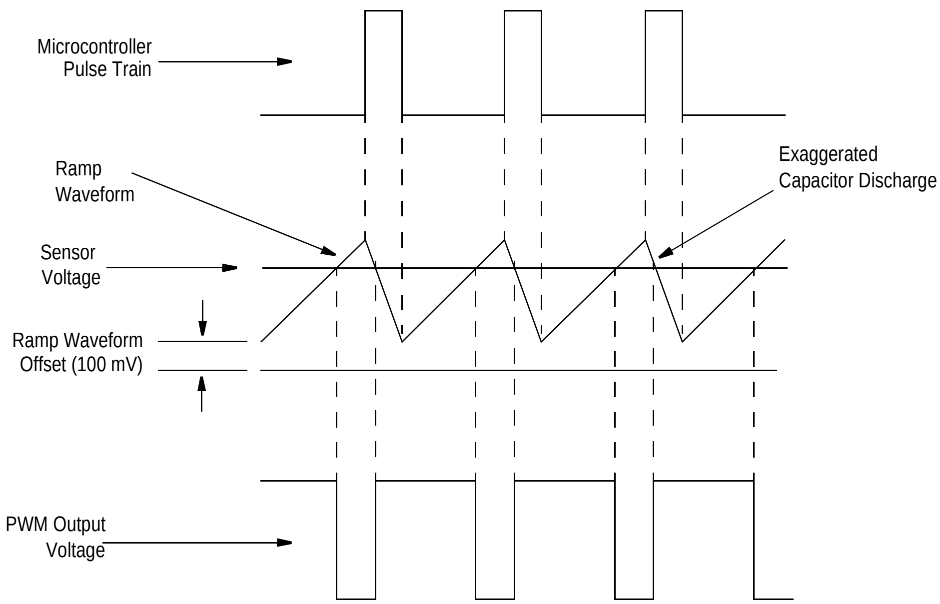

Figure 5. Relationship Between the PWM Output Pressure Sensor Voltages

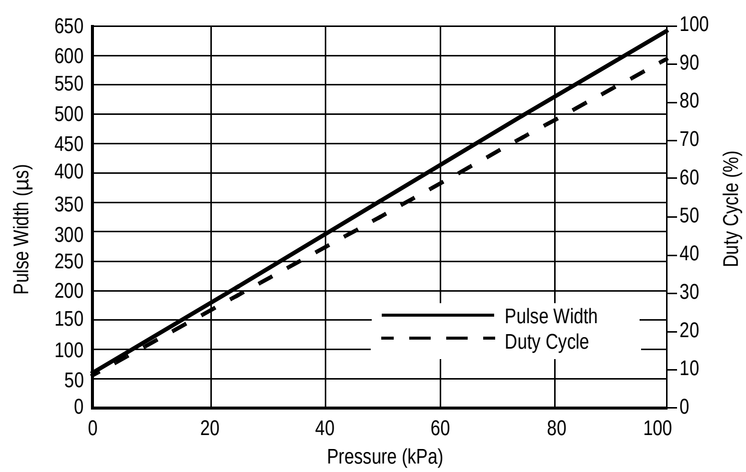

Figure 6. PWM Output Pressure Sensor Linearity Data

CONCLUSION

The Pulse Width Modulated Output Pressure Sensor uses a ramp generator to create a linear ramp which is compared to the amplified output of the pressure sensor at the input of a comparator. The resulting output is a digital waveform with a duty cycle that is linearly proportional to the input pressure. Although the pressure sensor output has a fixed offset and span, the ramp waveform is adjustable in frequency, dc offset, and voltage span. This flexibility enables the effect of component tolerances to be nullified and ensures that ramp span encompasses the pressure sensor output range. The ramp's span can be set to allow for the desired minimum and maximum duty cycle to guarantee a linear dynamic range.

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The ABCs of Signal-Conditioning Amplifier Design for Sensor Applications

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INTRODUCTION

Although fully signal-conditioned, calibrated, and temperature compensated monolithic sensor ICs are commercially available today, there are many applications where the flexibility of designing custom signal-conditioning is of great benefit. Perhaps the need for a versatile low-level sensor output is best illustrated by considering two particular cases that frequently occur: (1) the user is in a prototyping phase of development and needs the ability to make changes rapidly to the overall transfer function of the combined sensor/amplifier subsystem, (2) the specific desired transfer function does not exist in a fully signal-conditioned, precision-trimmed sensor product (e.g., a signal-conditioned device is precision trimmed over a different pressure range than that of the application of interest). In such cases, it is obvious that there will always be a need for low-level, nonsignal-conditioned sensors. Given this need, there is also a need for sensor interface amplifier circuits that can signal condition the “raw” sensor output to a usable level. These circuits should also be user friendly, simple, and cost effective.

Today's unamplified solid-state sensors typically have an output voltage of tens of millivolts (Freescale’s basic 10 kPa pressure sensor, MPX10, has a typical full-scale output of 58 mV, when powered with a 5.0 V supply). Therefore, a gain stage is needed to obtain a signal large enough for additional processing. This additional processing may include digitization by a microcontroller's analog to digital (A/D) converter, input to a comparator, etc. Although the signal-conditioning circuits described here are applicable to low-level, differential-voltage output sensors in general, the focus of this paper will be on interfacing pressure sensors to amplifier circuits.

This paper presents a basic two operational-amplifier signal-conditioning circuit that provides the desired characteristics of an instrumentation amplifier interface:

- High input impedance
- Low output impedance
- Differential to single-ended conversion of the pressure sensor signal
- High gain capability

For this two op-amp circuit, additional modifications to the circuit allow (1) gain adjustment without compromising common mode rejection and (2) both positive and negative dc level shifts of the zero pressure offset. Varying the gain and offset is desirable since full-scale span and zero pressure offset voltages of pressure sensors will vary somewhat from unit to unit. Thus, a variable gain is desirable to fine tune the sensor's full-scale span, and a positive or negative dc level shift (offset adjustment) of the pressure sensor signal is needed to translate the pressure sensor's signal-conditioned output span to a specific level (e.g., within the high and low reference voltages of an A/D converter).

For the two op-amp gain stage, this paper will present the derivation of the transfer function and simplified transfer function for pressure sensor applications, the derivation and explanation of the gain stage with a gain adjust feature, and the derivation and explanation of the gain stage with the dc level shift modification.

Adding another amplifier stage provides an alternative method of creating a negative dc voltage level shift. This stage is cascaded with the output from the two op-amp stage (*Note:* gain of the two op-amp stage will be reduced due to additional gain provided by the second amplifier stage). For this three op-amp stage, the derivation of the transfer function, simplified transfer function, and the explanation of the negative dc level shift feature will be presented.

GENERAL NOTE ON OFFSET ADJUSTMENT

Pressure sensor interface circuits may require either a positive or a negative dc level shift to adjust the zero pressure offset voltage. As described above, if the signal-conditioned pressure sensor voltage is input to an A/D, the sensor's output dynamic range must be positioned within the high and low reference voltages of the A/D; i.e., the zero pressure offset voltage must be greater than (or equal to) the low reference voltage and the full-scale pressure voltage must be less than (or equal to) the high reference voltage (see Figure 1). Otherwise, voltages above the high reference will be digitally converted as 255 decimal (for 8-bit A/D), and voltages below the low reference will be converted as 0. This creates a nonlinearity in the analog-to-digital conversion.

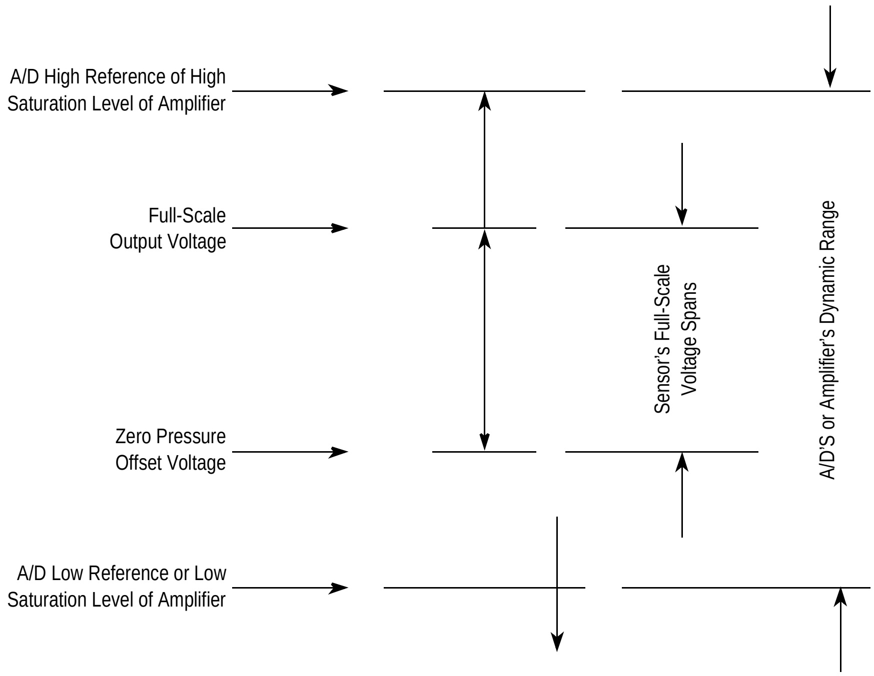

Figure 1. Positioning the Sensor's Full-Scale Span within the A/D's or Amplifier's Dynamic Range

A similar requirement that warrants the use of a dc level shift is the prevention of the pressure sensor's voltage from extending into the saturation regions of the operational amplifiers. This also would cause a nonlinearity in the sensor output measurements. For example, if an op-amp powered with a single-ended 5.0 V supply saturates near the low rail of the supply at 0.2 V, a positive dc level shift may be required to position the zero pressure offset voltage at or above 0.2 V. Likewise, if the same op-amp saturates near the high rail of the supply at 4.8 V, a negative dc level shift may be required to position the full-scale pressure voltage at or below 4.8 V. It should be obvious that if the gain of the amplifiers is too large, the span may be too large to be positioned within the 4.6 V window (regardless of ability to level shift dc offset). In such a case, the gain must be decreased to reduce the span.

THE TWO OP-AMP GAIN STAGE TRANSFER FUNCTION

The transfer function of the two op-amp signal-conditioning stage, shown in Figure 2, can be determined using nodal analysis at nodes 1 and 2. The analysis can be simplified by calculating the transfer function for each of the signals with the other two signals grounded (set to zero), and then employing superposition to realize the overall transfer function. As shown in Figure 2, V_{IN2} and V_{IN1} are the differential amplifier input signals (with $V_{IN2} > V_{IN1}$), and V_{REF} is the positive dc level adjust point. For a sensor with a small zero pressure offset and operational amplifiers powered from a single-ended supply, it may be necessary to add a positive dc level shift to keep the operational amplifiers from saturating near zero volts.

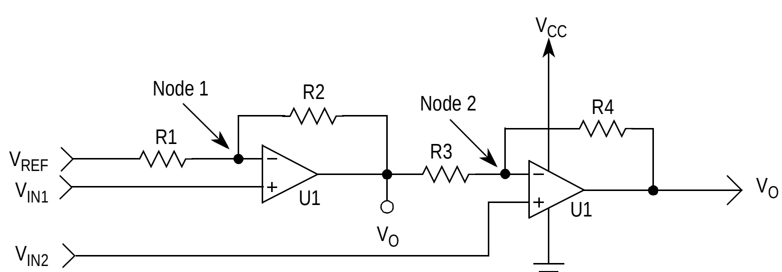

Figure 2. The Two Operational-Amplifier Gain Stage

First, the transfer function for V_{IN1} is determined by grounding V_{REF} and V_{IN2} at Node 1:

$$\frac{V_{IN1}}{R_1} = \frac{V_{O'} - V_{IN1}}{R_2} \quad (1)$$

and at Node 2:

$$\frac{V_{O'}}{R_3} = -\frac{V_O}{R_4} \quad (2)$$

By solving Equations (1) and (2) for V_O' and equating the results, Equation (3) is established:

$$\left(\frac{R_2}{R_1} + 1\right)V_{IN1} = -\frac{R_3}{R_4}\,V_O \quad (3)$$

Solving for V_O yields:

$$V_{O1} = -\frac{R_4}{R_3}\left(\frac{R_2}{R_1} + 1\right)V_{IN1} \quad (4)$$

where V_{O1} represents the part of V_O that V_{IN1} contributes.

To determine the transfer function for V_{IN2}, V_{IN1}, and V_{REF} are grounded, and a similar analysis is used, yielding:

$$V_{O2} = \left(\frac{R_4}{R_3} + 1\right)V_{IN2} \quad (5)$$

where V_{O2} represents the part of V_O that V_{IN2} contributes.

Finally, to calculate the transfer function between V_O and V_{REF}, V_{IN1}, and V_{IN2} are grounded to obtain the following transfer function:

$$V_{OREF} = \frac{R_4R_2}{R_3R_1}\,V_{REF} \quad (6)$$

where V_{OREF} represents the part of V_O that V_{REF} contributes.

Using superposition for the contributions of V_{IN1}, V_{IN2}, and V_{REF} gives the overall transfer function for the signal-conditioning stage.

$$V_O = V_{O1} + V_{O2} + V_{OREF}$$

$$V_O = \left(-\frac{R_4}{R_3}\right)\left(\frac{R_2}{R_1} + 1\right)V_{IN1} + \left(\frac{R_4}{R_3} + 1\right)V_{IN2} + \frac{R_4R_2}{R_3R_1}V_{REF} \quad (7)$$

Equation (7) is the general transfer function for the signal-conditioning stage. However, the general form is not only cumbersome, but also if care is not taken to match certain resistance ratios, poor common mode rejection results. A simplified form of this equation that provides good common mode rejection is shown in the next section.

APPLICATION TO PRESSURE SENSOR CIRCUITS

The previous section showed the derivation of the general transfer function for the two op-amp signal-conditioning circuit. The simplified form of this transfer function, as applied to a pressure sensor application, is derived in this section.

For pressure sensors, V_{IN1} and V_{IN2} are referred to as S^- and S^+, respectively. The simplification is obtained by setting

$$\frac{R_4}{R_3} = \frac{R_1}{R_2}$$

Through this simplification, Equation (7) reduces to

$$V_O = \left(\frac{R_4}{R_3} + 1\right)(S^+ - S^-) + V_{REF} \quad (8)$$

By examining Equation (8), the differential gain of the signal-conditioning stage is:

$$G = \frac{R_4}{R_3} + 1 \quad (9)$$

Also, since the differential voltage between S^+ and S^- is the pressure sensor's actual differential output voltage (V_{SENSOR}), the following equation is obtained for V_O:

$$V_O = \left(\frac{R_4}{R_3} + 1\right)V_{SENSOR} + V_{REF} \quad (10)$$

Finally, the term V_{REF} is the positive offset voltage added to the amplified sensor output voltage. V_{REF} can only be positive when using a positive single-ended supply. This offset (dc level shift) allows the user to adjust the absolute range that the sensor voltage spans. For example, if the gain established by R4 and R3 creates a span of four volts and this signal swing is superimposed upon a dc level shift (offset) of 0.5 volts, then a signal range from 0.5 V to 4.5 V results.

V_{REF} is typically adjusted by a resistor divider as shown in Figure 3. A few design constraints are required when designing the resistor divider to set the voltage at V_{REF}.

- To establish a stable positive dc level shift (V_{REF}), V_{CC} should be regulated; otherwise, V_{REF} will vary as V_{CC} varies.
- When *looking* into the resistor divider from R1, the effective resistance of the parallel combination of the resistors, R_{REF1} and R_{REF2}, should be at least an order of magnitude smaller than R1's resistance. If the resistance of the parallel combination is not small in comparison to R1, R1's value will be significantly affected by the parallel combination's resistance. This effect on R1 will consequently affect the amplifier's gain and reduce the common mode rejection.

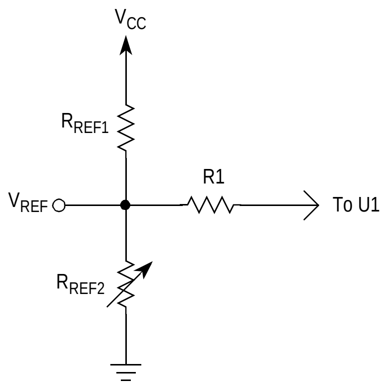

Figure 3. A Resistor Divider to Create V_{REF}

THE TWO OP-AMP GAIN STAGE WITH VARIABLE GAIN

Varying the gain of the two op-amp stage is desirable for fine-tuning the sensor's signal-conditioned output span. However, to adjust the gain in the two op-amp gain circuit in Figure 2 and to simultaneously preserve the common mode rejection, two resistors must be adjusted. To adjust the gain, it is more desirable to change one resistor. By adding an additional feedback resistor, RG, the gain can be adjusted with this one resistor while preserving the common mode rejection. Figure 4 shows the two op-amp gain stage with the added resistor, R_G.

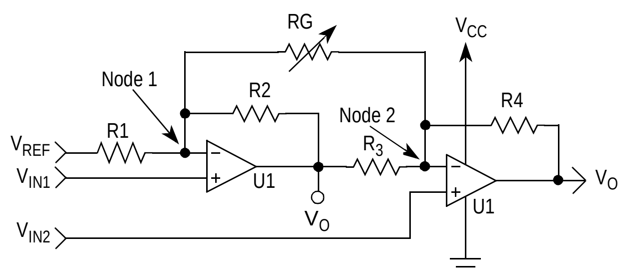

Figure 4. Two Operational-Amplifier Gain Stage with Variable Gain

As with the two op-amp gain stage, nodal analysis and superposition are used to derive the general transfer function for the variable gain stage.

$$V_O = \left(\frac{R_4}{R_3} + \frac{R_4}{R_G} + \frac{R_2R_4}{R_3R_G} + 1\right)V_{IN2} - \left(\frac{R_4}{R_3} + \frac{R_4}{R_G} + \frac{R_2R_4}{R_3R_G} + \frac{R_2R_4}{R_1R_3}\right)V_{IN1} + \left(\frac{R_2R_4}{R_1R_3}\right)V_{REF} \qquad (11)$$

This general transfer function also is quite cumbersome and is susceptible to producing poor common mode rejection without additional constraints on the resistor values. To obtain good common mode rejection, use a similar simplification as before; that is, set

$$R_1 = R_4$$

and

$$R_1 = R_4$$

Defining the voltage differential between V_{IN2} and V_{IN1} as V_{SENSOR}, the simplified transfer function is

$$V_O = \left(\frac{R_4}{R_3} + \frac{2R_4}{R_G} + 1\right)V_{SENSOR} + V_{REF} \qquad (12)$$

Thus, the gain is

$$G = \frac{R_4}{R_3} + \frac{2R_4}{R_G} + 1 \qquad (13)$$

and V_{REF} is the positive dc level shift (offset).

Use the following guidelines when determining the value for RG:

- By examining the gain equation, RG's resistance should be comparable to R4's resistance. This will allow fine tuning of the gain established by R4 and R3. If RG is too large (e.g., RG approaches ∞), it will have a negligible effect on the gain. If RG is too small (e.g., RG approaches zero), the RG term will dominate the gain expression, thus prohibiting fine adjustment of the gain established via the ratio of R4 and R3.
- Use a potentiometer for RG that has a resistance range on the order of R4 (perhaps with a maximum resistance equal to the value of R4). If a fixed resistor is preferable to a potentiometer, use the potentiometer to adjust the gain, measure the potentiometer's resistance, and replace the potentiometer with the closest one percent resistor value.
- To maintain good common mode rejection while varying the gain, RG should be the only resistor that is varied. RG equally modifies both of the resistor ratios which need to be well-matched for good common mode rejection, thus preserving the common mode rejection.

THE TWO OP-AMP GAIN STAGE WITH VARIABLE GAIN AND NEGATIVE DC LEVEL SHIFT

The last two op-amp circuits both incorporate positive dc level shift capability. Recall that a positive dc level shift is required to keep the operational amplifiers from saturating near the low rail of the supply or to keep the zero pressure offset above (or equal to) the low reference voltage of an A/D. This two op-amp stage incorporates an additional resistor, R_{OFF}, to provide a negative dc level shift. A negative dc level shift is useful when the zero pressure offset voltage of the sensor is too high. In this case, the user may be required to level shift the zero pressure offset voltage down (toward zero volts). Now, for a specified amount of gain, the full-scale pressure output voltage does not saturate the amplifier at the high rail of the voltage supply, nor is it greater than the A/D's high reference voltage. Figure 5 shows the schematic for this amplifier circuit.

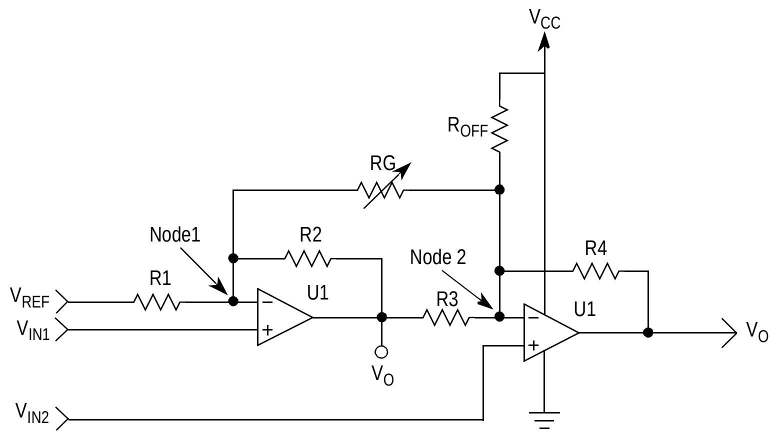

Figure 5. Two Op-Amp Signal Conditioning Stage with Variable Gain and Negative dc Level Shift Adjust

To derive the general transfer function, nodal analysis and superposition are used:

$$V_O = \left(\frac{R_4}{R_3} + \frac{R_4}{R_G} + \frac{R_2R_4}{R_3R_G} + 1\right)V_{IN2} - \left(\frac{R_4}{R_3} + \frac{R_4}{R_G} + \frac{R_2R_4}{R_1R_3} + \frac{R_2R_4}{R_3R_G}\right)V_{IN1} + \frac{R_2R_4}{R_1R_3}V_{REF} + \frac{R_4}{R_{OFF}}(V_{IN2} - V_{CC}) \quad (14)$$

As before, defining the sensor's differential output as V_{SENSOR}, defining V_{IN2} as S^+ for pressure sensor applications, and using the simplification that

$$R_1 = R_4$$

and

$$R_2 = R_3$$

obtains the following simplified transfer function:

$$V_O = \left(\frac{R_4}{R_3} + \frac{2R_4}{R_G} + 1\right)V_{SENSOR} + V_{REF} + \frac{R_4}{R_{OFF}}(S^+ - V_{CC}) \quad (15)$$

The gain is

$$G = \frac{R_4}{R_3} + \frac{2R_4}{R_G} + 1 \quad (16)$$

To adjust the gain, refer to the guidelines presented in the section on *Two Op-Amp Gain Stage with Variable Gain*.

V_{REF} is the positive dc level shift, and the negative dc level shift is:

$$V_{-shift} = \frac{R_4}{R_{OFF}}(S^+ - V_{CC}) \quad (17)$$

The following guidelines will help design the circuitry for the negative dc voltage level shift:

- To establish a stable negative dc level shift, V_{CC} should be regulated; otherwise, the amount of negative level shift will vary as V_{CC} varies.
- R_{OFF} should be the only resistor varied to adjust the negative level shift. Varying R4 will change the gain of the two op-amp circuit and reduce the common mode rejection.
- To determine the value of R_{OFF}:
  1. Determine the amount of negative dc level shifting required (defined here as V_{-SHIFT}).
  2. R_4 already should have been determined to set the gain for the desired signal-conditioned sensor output.
  3. Although V_{-SHIFT} is dependent on S^+, S^+ changes only slightly over the entire pressure range. With Freescale's MPX10 powered at a 5.0 V supply, S^+ will have a value of approximately 2.51 V at zero pressure and will increase as high as 2.53 V at full-scale pressure. This error over the full-scale pressure span of the device is negligible when considering that many applications use an 8-bit A/D converter to segment the pressure range. Using an 8-bit A/D, the 20 mV (0.02 V) error corresponds to only 1 bit of error over the entire pressure range (1 bit / 255 bits x 100% = 0.4% error).
  4. R_{OFF} is then calculated by the following equation:

$$R_{OFF} = \frac{S^+ - V_{CC}}{V_{-shift}} R_4 \quad (18)$$

An alternative to using this equation is to use a potentiometer for R_{OFF} that has a resistance range on the order of R_4 (perhaps 1 to 5 times the value of R4). Use the potentiometer to fine tune the negative dc level shift, while monitoring the zero pressure offset output voltage, V_O. As before, if a fixed resistor is preferable, then measure the potentiometer's resistance and replace the potentiometer with the closest 1% resistor value.

Important Note: The common mode rejection of this amplifier topology will be low and perhaps unacceptable in some applications. (A SPICE model of this amplifier topology showed the common mode rejection to be 28 dB.) However, this circuit is presented as a solution for applications where only two operational amplifiers are available and the common mode rejection is not critical when considering the required system performance. Adding a third op-amp to the circuit for the negative dc level shifting capability (as shown in the next section) is a solution that provides good common mode rejection, but at the expense of adding an additional op-amp.

THE THREE OP-AMP GAIN STAGE FOR NEGATIVE dc LEVEL SHIFTING

This circuit adds a third op-amp to the output of the two op-amp gain block (see Figure 6). This op-amp has a dual function in the overall amplifier circuit:

- Its non-inverting configuration provides gain via the ratio of R6 and R5.
- It has negative dc voltage level shifting capability typically created by a resistor divider at V_{-SHIFT}, as discussed in the section on Application to Pressure Sensor Circuits. Although this configuration requires a third op-amp for the negative dc level shift, it has no intrinsic error nor low common mode rejection associated with the negative level shift (as does the previous two op-amp stage). Depending on the application's accuracy requirement, this may be a more desirable configuration for providing the negative dc level shift.

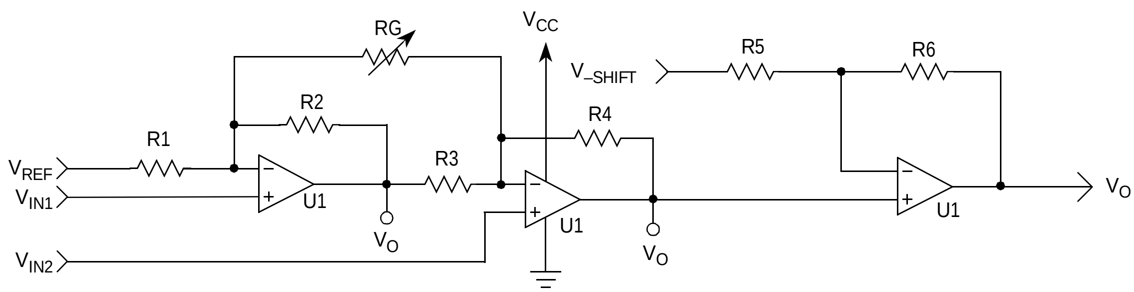

Figure 6. Three Op-Amp Gain Stage with Variable Gain and Negative DC Level Shift

The transfer function for this stage will be similar to the chosen two op-amp gain stage configuration (either the fixed gain with positive dc level shift circuit or the variable gain with positive dc level shift circuit) with additional terms for the negative level shift and gain. As an example, the variable-gain two op-amp gain circuit is used here. All of the design considerations and explanations for the variable gain two op-amp circuit apply.

The transfer function may be derived with nodal analysis and superposition.

$$V_O = \left[1+\frac{R_6}{R_5}\right]\left[\left(\frac{R_4}{R_3}+\frac{R_4}{R_G}+\frac{R_2R_4}{R_3R_G}+1\right)V_{IN2} - \left(\frac{R_4}{R_3}+\frac{R_4}{R_G}+\frac{R_2R_4}{R_3R_G}+\frac{R_2R_4}{R_1R_3}\right)V_{IN1} + \left(\frac{R_2R_4}{R_1R_3}\right)V_{REF}\right] - \frac{R_6}{R_5}V_{-shift} \quad (19)$$

First, use the same simplifications as before; that is, set

$$R_1 = R_4$$

and

$$R_2 = R_3$$

Defining the voltage differential between V_{IN2} and V_{IN1} as V_{SENSOR}, the simplified transfer function is

$$V_O = \left[1+\frac{R_6}{R_5}\right]\left[\left(\frac{R_4}{R_3}+\frac{2R_4}{R_G}+1\right)(V_{SENSOR}) + V_{REF}\right] - \frac{R_6}{R_5}V_{-shift} \quad (20)$$

The gain is

$$G = \left[1+\frac{R_6}{R_5}\right]\left[\frac{R_4}{R_3}+\frac{2R_4}{R_G}+1\right] \quad (21)$$

V_{REF} is the positive dc level shift (offset), and V_{-SHIFT} is the negative dc level shift.

The preceding simplifications have been performed in the previous sections, but by examining Equation 20, notice that the third op-amp's gain term also amplifies the positive and negative dc voltage level shifts, V_{REF} and V_{-SHIFT}. If R6 and R5 are chosen to make an arbitrary contribution to the overall system gain, designing an appropriate amount of positive and negative dc level shift can be difficult. To simplify the transfer function, set R5 = R6, and the following equation for V_O results:

$$V_O = 2\left[\left(\frac{R_4}{R_3}+\frac{2R_4}{R_G}+1\right)(V_{SENSOR}) + V_{REF}\right] - V_{-shift} \quad (22)$$

Now the third op-amp's contribution to the overall system gain is a factor of two. When designing the overall system gain and the positive dc level shift, use the following guidelines:

- Since the third op-amp contributes a gain of two to the overall system, design the gain that the two op-amp circuit contributes to the system to be one-half the desired system gain. The gain term for the two op-amp circuit is:

$$G = \frac{R_4}{R_3} + \frac{2R_4}{R_G} + 1$$

which is the same as presented in Equation 16.

- Similarly, since the third op-amp also amplifies V_{REF} by two (refer to Equation 22), the resistor divider that creates V_{REF} should be designed to provide one-half the desired positive dc voltage level shift needed for the final output. When designing the voltage divider for V_{REF}, use the same design constraints as were given in the section on Application to Pressure Sensor Circuits.

With the above simplification of $R_5 = R_6$, the negative dc level shift, V_{-SHIFT}, which is also created by a voltage divider, is now amplified by a factor of unity. When designing the voltage divider, use the same design constraints as were presented in the section on Application to Pressure Sensor Circuits.

CONCLUSION

The amplifier circuits discussed in this paper apply to pressure sensor applications, but the amplifier circuits can be interfaced to low-level, differential-voltage output sensors, in general. All of the circuits exhibit the desired instrumentation amplifier characteristics of high input impedance, low output impedance, high gain capability, and differential to single-ended conversion of the sensor signal. Each amplifier circuit provides positive dc level shift capability, while the last two circuit topologies presented are also able to provide a negative dc voltage level shift. This enables the user to position the sensor's dynamic output within a specified range (e.g., within the high and low references of an A/D converter). Also detailed is a method of using an additional feedback resistor to adjust easily the differential voltage gain, while not sacrificing common mode rejection. Combining the appropriate sensor device and amplifier interface circuit provides sensor users with a versatile system solution for applications in which the ideal fully single-conditioned sensor does not exist or in which such signal flexibility is warranted.

Digital Blood Pressure Meter

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INTRODUCTION

This application note describes a Digital Blood Pressure Meter concept which uses an integrated pressure sensor, analog signal-conditioning circuitry, microcontroller hardware/software and a liquid crystal display. The sensing system reads the cuff pressure (CP) and extracts the pulses for analysis and determination of systolic and diastolic pressure. This design uses a 50 kPa integrated pressure sensor (Freescale Semiconductor, Inc.P/N: MPXV5050GP) yielding a pressure range of 0 mm Hg to 300 mm Hg.

CONCEPT OF OSCILLOMETRIC METHOD

This method is employed by the majority of automated non-invasive devices. A limb and its vasculature are compressed by an encircling, inflatable compression cuff. The blood pressure reading for systolic and diastolic blood pressure values are read at the parameter identification point.

The simplified measurement principle of the oscillometric method is a measurement of the amplitude of pressure change in the cuff as the cuff is inflated from above the systolic pressure. The amplitude suddenly grows larger as the pulse breaks through the occlusion. This is very close to systolic pressure. As the cuff pressure is further reduced, the pulsation increase in amplitude, reaches a maximum and then diminishes rapidly. The index of diastolic pressure is taken where this rapid transition begins. Therefore, the systolic blood pressure (SBP) and diastolic blood pressure (DBP) are obtained by identifying the region where there is a rapid increase then decrease in the amplitude of the pulses respectively. Mean arterial pressure (MAP) is located at the point of maximum oscillation.

HARDWARE DESCRIPTION AND OPERATION

The cuff pressure is sensed by Freescale's integrated pressure X-ducer‰. The output of the sensor is split into two paths for two different purposes. One is used as the cuff pressure while the other is further processed by a circuit. Since MPXV5050GP is signal-conditioned by its internal op-amp, the cuff pressure can be directly interfaced with an analog-to-digital (A/D) converter for digitization. The other path will filter and amplify the raw CP signal to extract an amplified version of the CP oscillations, which are caused by the expansion of the subject's arm each time pressure in the arm increases during cardiac systole.

The output of the sensor consists of two signals; the oscillation signal ($\approx$ 1 Hz) riding on the CP signal ($\leq$ 0.04 Hz). Hence, a 2-pole high pass filter is designed to block the CP signal before the amplification of the oscillation signal. If the CP signal is not properly attenuated, the baseline of the oscillation will not be constant and the amplitude of each oscillation will not have the same reference for comparison. Figure 1 shows the oscillation signal amplifier together with the filter.

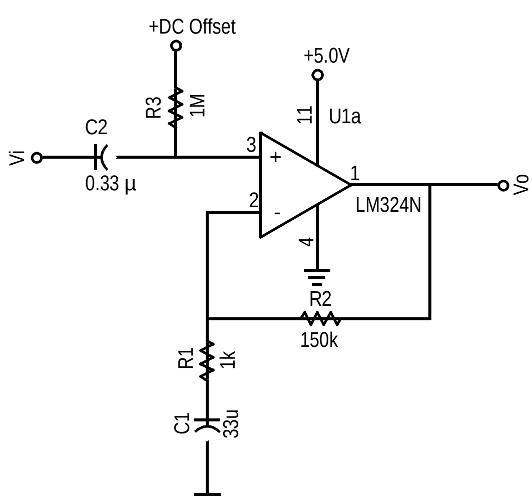

Figure 1. Oscillation Signal Amplifier

The filter consists of two RC networks which determine two cut-off frequencies. These two poles are carefully chosen to ensure that the oscillation signal is not distorted or lost. The two cut-off frequencies can be approximated by the following equations. Figure 2describes the frequency response of the filter. This plot does not include the gain of the amplifier.

$$f_{P1} = \frac{1}{2\pi R_1 C_1}$$

$$f_{P2} = \frac{1}{2\pi R_3 C_2}$$

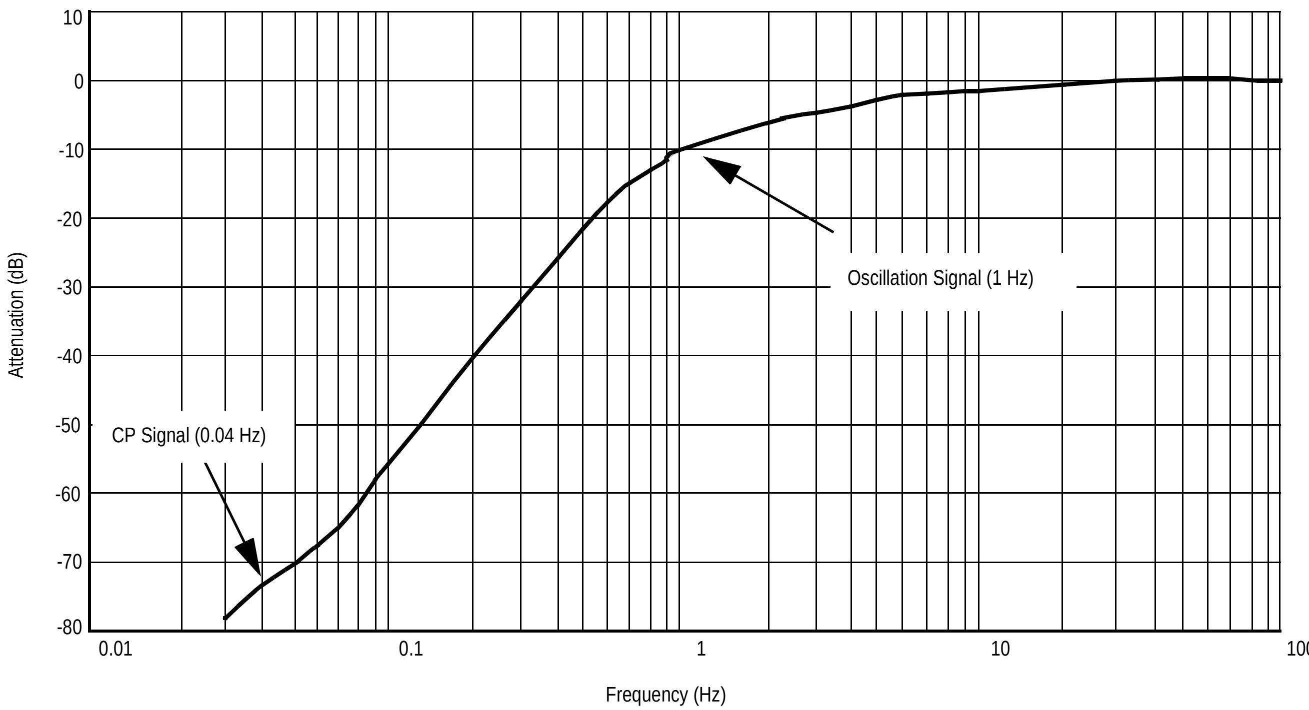

Figure 2. Filter Frequency

The oscillation signal varies from person to person. In general, it varies from less than 1 mm Hg to 3 mm Hg. From the transfer function of MPXV5050GP, this will translate to a voltage output of 12 mV to 36 mV signal. Since the filter gives an attenuation of 10 dB to the 1 Hz signal, the oscillation signal becomes 3.8 mV to 11.4 mV respectively. Experiments indicate that, the amplification factor of the amplifier is chosen to be 150 so that the amplified oscillation signal is within the output limit of the amplifier (5.0 mV to 3.5 V). Figure 3 shows the output from the pressure sensor and Figure 4 illustrates the extracted oscillation signal at the output of the amplifier.

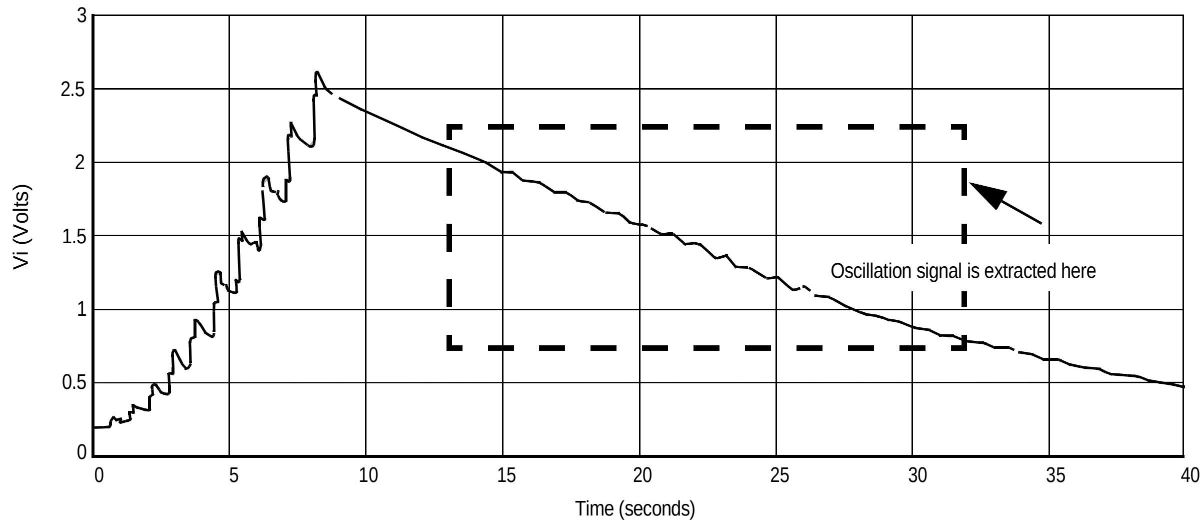

Figure 3. CP Signal at the Output of the Pressure Sensor

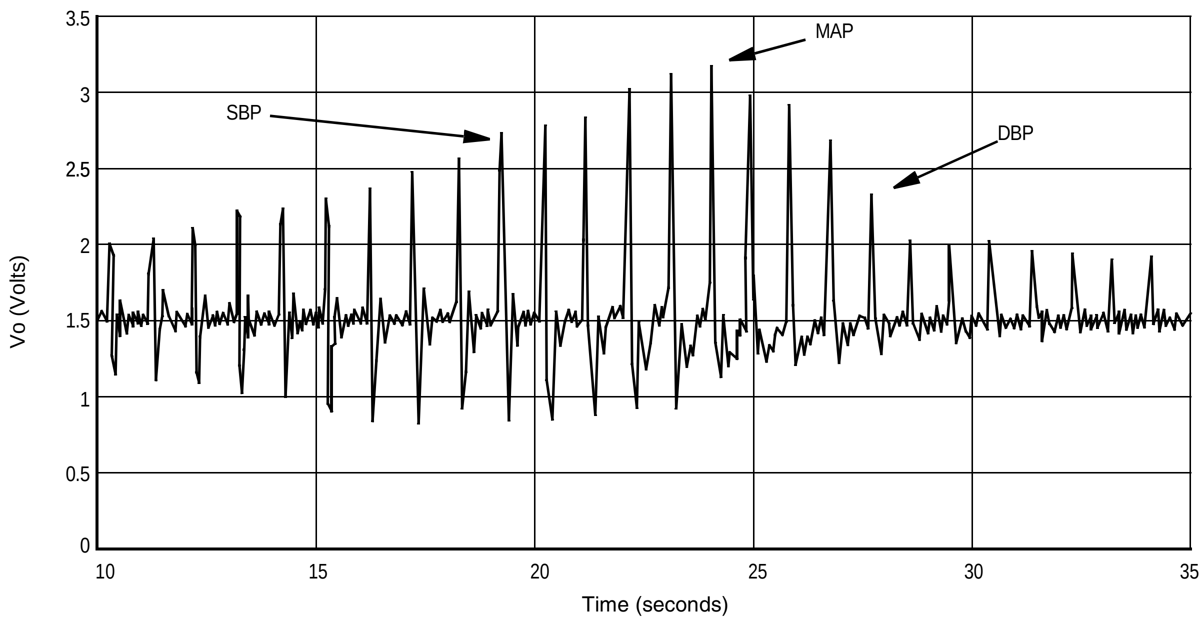

Figure 4. Extracted Oscillation Signal at the Output of Amplifier

Referring to the schematic, Figure 5, the MPX5050GP pressure sensor is connected to PORT D bit 5 and the output of the amplifier is connected to PORT D bit 6 of the microcontroller. This port is an input to the on-chip 8-bit analog-to-digital (A/D) converter. The pressure sensor provides a signal output to the microprocessor of approximately 0.2 Vdc at 0 mm Hg to 4.7 Vdc at 375 mm Hg of applied pressure whereas the amplifier provides a signal from 0.005 V to 3.5 V. In order to maximize the resolution, separate voltage references should be provided for the A/D instead of using the 5 V supply. In this example, the input range of the A/D converter is set at approximately 0 Vdc to 3.8 Vdc. This compresses the range of the A/D converter around 0 mm Hg to 300 mm Hg to maximize the resolution; 0 to 255 counts is the range of the A/D converter. V_{RH} and V_{RL} are the reference voltage inputs to the A/D converter. The resolution is defined by the following:

$$\text{Count} = [(V_{Xdcr} - V_{RL})/(V_{RH} - V_{RL})] \times 255$$

$$\text{The count at 0 mm Hg} = [(0.2 - 0)/(3.8 - 0)] \times 255 \approx 14$$

$$\text{The count at 300 mm Hg} = [(3.8 - 0)/(3.8 - 0)] \times 255 \approx 255$$

Therefore the resolution = 255 - 14 = 241 counts. This translates to a system that will resolve to 1.24 mm Hg.

The voltage divider consisting of R5 and R6 is connected to the +5 volts powering the system. The output of the pressure sensor is ratiometric to the voltage applied to it. The pressure sensor and the voltage divider are connected to a common supply; this yields a system that is ratiometric. By nature of this ratiometric system, variations in the voltage of the power supplied to the system will have no effect on the system accuracy.

The liquid crystal display (LCD) is directly driven from I/O ports A, B, and C on the microcontroller. The operation of a LCD requires that the data and backplane (BP) pins must be driven by an alternating signal. This function is provided by a software routine that toggles the data and backplane at approximately a 30 Hz rate.

Other than the LCD, there are two more I/O devices that are connected to the pulse length converter (PLM) of the microcontroller; a buzzer and a light emitting diode (LED). The buzzer, which connected to the PLMA, can produce two different frequencies; 122 Hz and 1.953 kHz tones. For instance when the microcontroller encounters certain error due to improper inflation of cuff, a low frequency tone is alarm. In those instance when the measurement is successful, a high frequency pulsation tone will be heard. Hence, different musical tone can be produced to differential each condition. In addition, the LED is used to indicate the presence of a heart beat during the measurement.

The microcontroller section of the system requires certain support hardware to allow it to function. The MC34064P-5 provides an undervoltage sense function which is used to reset the microprocessor at system power-up. The 4 MHz crystal provides the external portion of the oscillator function for clocking the microcontroller and provides a stable base for time based functions, for instance calculation of pulse rate.

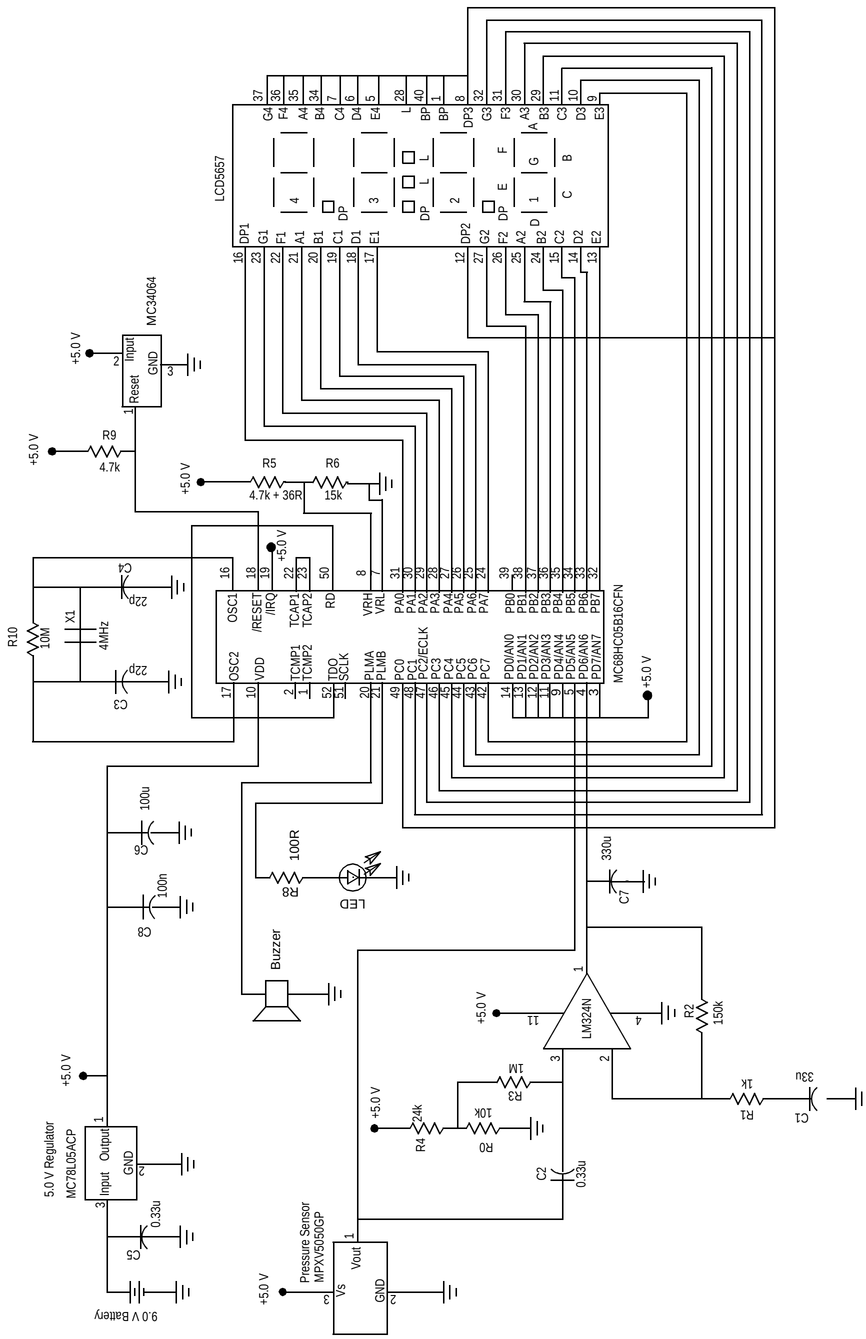

Figure 5. Blood Pressure Meter Schematic Drawing

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SOFTWARE DESCRIPTION

Upon system power-up, the user needs to manually pump the cuff pressure to approximately 160 mm Hg or 30 mm Hg above the previous SBP. During the pumping of the inflation bulb, the microcontroller ignores the signal at the output of the amplifier. When the subroutine TAKE senses a decrease in CP for a continuous duration of more than 0.75 seconds, the microcontroller will then assume that the user is no longer pumping the bulb and starts to analyze the oscillation signal. Figure 6 shows zoom-in view of a pulse.

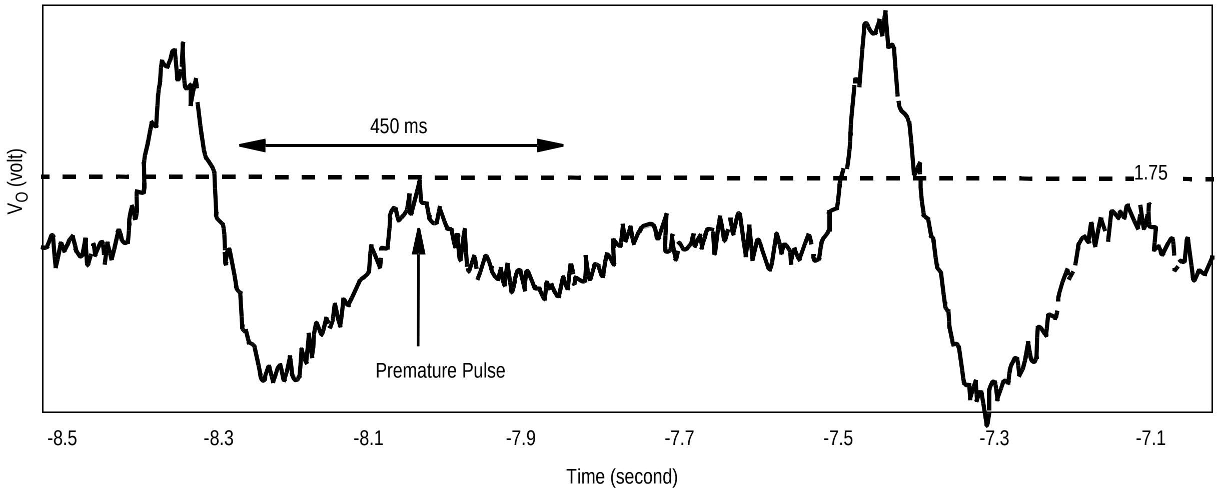

Figure 6. Zoom-In View of a Pulse

First of all, the threshold level of a valid pulse is set to be 1.75 V to eliminate noise or spike. As soon as the amplitude of a pulse is identified, the microcontroller will ignore the signal for 450 ms to prevent any false identification due to the presence of premature pulse "overshoot" due to oscillation. Hence, this algorithm can only detect pulse rate which is less than 133 beats per minute. Next, the amplitudes of all the pulses detected are stored in the RAM for further analysis. If the microcontroller senses a non-typical oscillation envelope shape, an error message (“Err”) is output to the LCD. The user will have to exhaust all the pressure in the cuff before re-pumping the CP to the next higher value. The algorithm ensures that the user exhausts all the air present in the cuff before allowing any re-pumping. Otherwise, the venous blood trapped in the distal arm may affect the next measurement. Therefore, the user has to reduce the pressure in the cuff as soon as possible in order for the arm to recover. Figure 7 on the following page is a flowchart for the program that controls the system.

SELECTION OF MICROCONTROLLER

Although the microcontroller used in this project is MC68HC05B16, a smaller ROM version microcontroller can also be used. The list below shows the requirement of microcontroller for this blood pressure meter design in this project.

- On-chip ROM space: 2 kilobytes
- On-chip RAM space: 150 bytes
- 2-channel A/D converter (min.)
- 16-bit free running counter timer
- LCD driver
- On-chip EEPROM space: 32 bytes
- Power saving Stop and Wait modes

CONCLUSION

This circuit design concept may be used to evaluate Freescale pressure sensors used in the digital blood pressure meter. This basic circuit may be easily modified to provide suitable output signal level. The software may also be easily modified to provide better analysis of the SBP and DBP of a person.

REFERENCES

Lucas, Bill (1991). “An Evaluation System for Direct Interface of the MPX5100 Pressure Sensor with a Microprocessor,” Freescale Application Note AN1305.

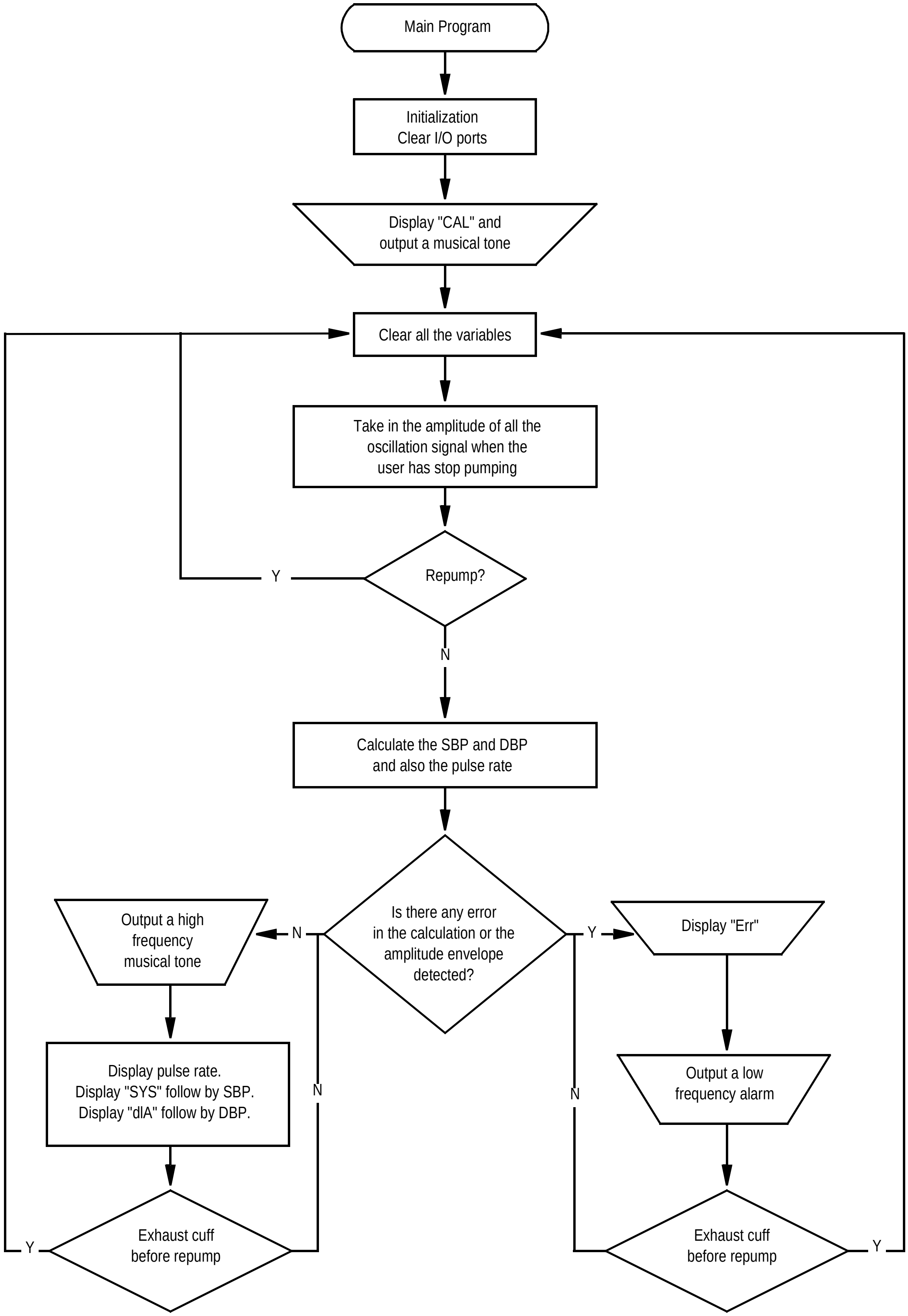

Figure 7. Main Program Flowchart

Understanding Pressure and Pressure Measurement

by: David Heeley
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INTRODUCTION

Fluid systems, pressure and pressure measurements are extremely complex. The typical college curriculum for Mechanical Engineers includes at least two semesters in fluid mechanics. This paper will define and explain the basic concepts of fluid mechanics in terms that are easily understood while maintaining the necessary technical accuracy and level of detail.

PRESSURE AND PRESSURE MEASUREMENT

What is fluid pressure? Fluid pressure can be defined as the measure of force per-unit-area exerted by a fluid, acting perpendicularly to any surface it contacts (a fluid can be either a gas or a liquid, fluid and liquid are not synonymous). The standard SI unit for pressure measurement is the Pascal (Pa) which is equivalent to one Newton per square meter (N/m^2) or the KiloPascal (kPa) where 1 kPa = 1000 Pa. In the English system, pressure is usually expressed in pounds per square inch (psi). Pressure can be expressed in many different units including in terms of a height of a column of liquid. Table 1 lists commonly used units of pressure measurement and the conversion between the units.

Pressure measurements can be divided into three different categories: *absolute pressure, gage pressure and differential pressure*. *Absolute pressure* refers to the absolute value of the force per-unit-area exerted on a surface by a fluid. Therefore the absolute pressure is the difference between the pressure at a given point in a fluid and the absolute zero of pressure or a perfect vacuum. *Gage pressure* is the measurement of the difference between the absolute pressure and the local atmospheric pressure. Local atmospheric pressure can vary depending on ambient temperature, altitude and local weather conditions. The U.S. standard atmospheric pressure at sea level and 59°F (20°C) is 14.696 pounds per square inch absolute (psia) or 101.325 kPa absolute (abs). When referring to pressure measurement, it is critical to specify what reference the pressure is related to. In the English system of units, measurement relating the pressure to a reference is accomplished by specifying pressure in terms of pounds per square inch absolute (psia) or pounds per square inch gage (psig). For other units of measure it is important to specify gage or absolute. The abbreviation ‘abs' refers to an absolute measurement. A gage pressure by convention is always positive. A ‘negative' gage pressure is defined as vacuum. Vacuum is the measurement of the amount by which the local atmospheric pressure exceeds the absolute pressure. A perfect vacuum is zero absolute pressure. Figure 1 shows the relationship between absolute, gage pressure and vacuum. *Differential pressure* is simply the measurement of one unknown pressure with reference to another unknown pressure. The pressure measured is the difference between the two unknown pressures. This type of pressure measurement is commonly used to measure the pressure drop in a fluid system. Since a differential pressure is a measure of one pressure referenced to another, it is not necessary to specify a pressure reference. For the English system of units this could simply be psi and for the SI system it could be kPa.

In addition to the three types of pressure measurement, there are different types of fluid systems and fluid pressures. There are two types of fluid systems; *static systems* and *dynamic systems*. As the names imply, a static system is one in which the fluid is at rest and a dynamic system is on in which the fluid is moving.

Table 1. Conversion Table for Common Units of Pressure

	kPa	mm Hg	millibar	in H_2O	PSI
1 atm	101.325	760.000	1013.25	406.795	14.6960
1 kPa	1.000	7.50062	10.000	4.01475	0.145038
1 mm Hg	0.133322	1.000	1.33322	0.535257	0.0193368
1 millibar	0.1000	0.750062	1.000	0.401475	0.0145038
1 in H_2O	0.249081	1.86826	2.49081	1.000	0.0361
1 PSI	6.89473	51.7148	68.9473	27.6807	1.000
1 mm H_2O	0.009806	0.07355	9.8×10^{-8}	0.03937	0.0014223

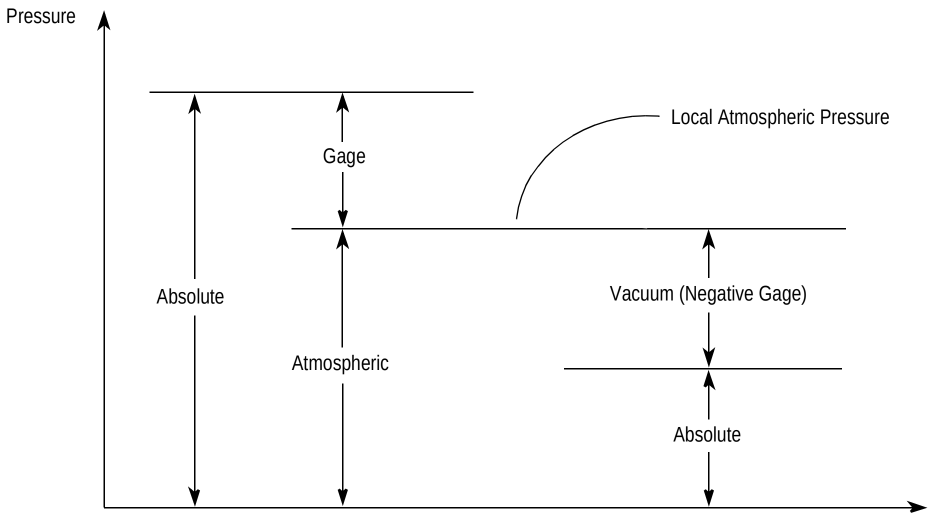

Figure 1. Pressure Term Relationships

STATIC PRESSURE SYSTEMS

The pressure measured in a static system is *static pressure*. In the pressure system shown in Figure 2 a uniform static fluid is continuously distributed with the pressure varying only with vertical distance. The pressure is the same at all points along the same horizontal plane in the fluid and is independent of the shape of the container. The pressure increases with depth in the fluid and acts equally in all directions. The increase in pressure at a deeper depth is essentially the effect of the weight of the fluid above that depth. Figure 3 shows two containers with the same fluid exposed to the same external pressure - **P**. At any equal depth within either tank the pressure will be the same. Note that the sides of the large tank are not vertical. The pressure is dependent only on depth and has nothing to do with the shape of the container. If the working fluid is a gas, the pressure increase in the fluid due to the height of the fluid is in most cases negligible since the density and therefore the weight of the fluid is much smaller than the pressure being applied to the system. However, this may not remain true if the system is large enough or the pressures low enough. One example considers how atmospheric pressure changes with altitude. At sea level the standard U.S. atmospheric pressure is 14.696 psia (101.325 kPa). At an altitude of 10,000 ft (3048 m) above sea level the standard U.S. atmospheric pressure is 10.106 psia (69.698 kPa) and at 30,000 ft (9144 m), the standard U.S. atmospheric pressure is 4.365 psia (30.101 kPa).

The pressure in a static liquid can be easily calculated if the density of the liquid is known. The absolute pressure at a depth H in a liquid is defined as:

$$P_{abs} = P + (\rho \times g \times H)$$

Where:

P_{abs} is the absolute pressure at depth H.

P is the external pressure at the top of the liquid. For most open systems this will be atmospheric pressure.

ρ is the density of the fluid.

g is the acceleration due to gravity (g = 32.174 ft/sec^2 (9.81 m/sec^2)).

H is the depth at which the pressure is desired.

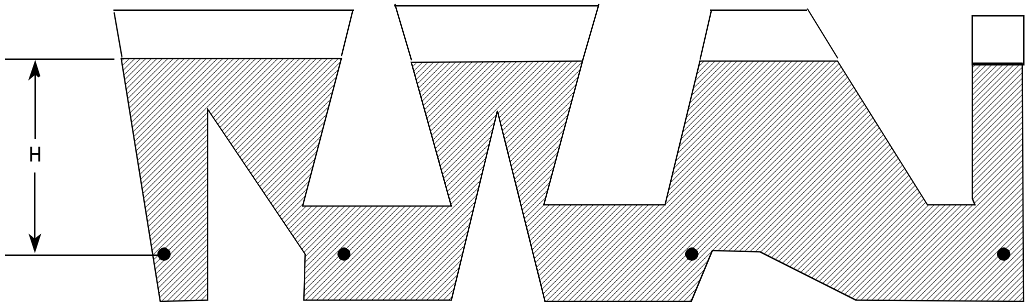

Figure 2. Continuous Fluid System

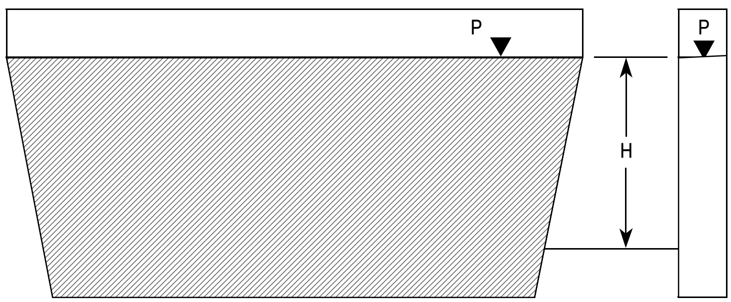

Figure 3. Pressure Measurement at a Depth in a Liquid

DYNAMIC PRESSURE SYSTEMS

Dynamic pressure systems are more complex than static systems and can be more difficult to measure. In a dynamic system, pressure typically is defined using three different terms. The first pressure we can measure is *static pressure*. This pressure is the same as the static pressure that is measured in a static system. Static pressure is independent of the fluid movement or flow. As with a static system the static pressure acts equally in all directions. The second type of pressure is what is referred to as the *dynamic pressure*. This pressure term is associated with the velocity or the flow of the fluid. The third pressure is *total pressure* and is simply the static pressure plus the dynamic pressure.

STEADY-STATE DYNAMIC SYSTEMS

Care must be taken when measuring dynamic system pressures. For a dynamic system, under steady-state conditions, accurate static pressures may be measured by tapping into the fluid stream perpendicular to the fluid flow. For a dynamic system, steady-state conditions are defined as no change in the system flow conditions: pressure, flow rate, etc. Figure 4 illustrates a dynamic system with a fluid flowing through a pipe or duct. In this example a static pressure tap is located in the duct wall at point A. The tube inserted into the flow is called a Pitot tube. The Pitot tube measures the total pressure at point B in the system. The total pressure measured at this point is referred to as the *stagnation pressure*. The stagnation pressure is the value obtained when a flowing fluid is decelerated to zero velocity in an isentropic (frictionless) process. This process converts all of the energy from the flowing fluid into a pressure that can be measured. The stagnation or total pressure is the static pressure plus the dynamic pressure. It is very difficult to accurately measure dynamic pressures. When dynamic pressure measurement is desired, the total and static pressures are measured and then subtracted to obtain the dynamic pressure. Dynamic pressures can be used to determine the fluid velocities and flow rates in dynamic systems.

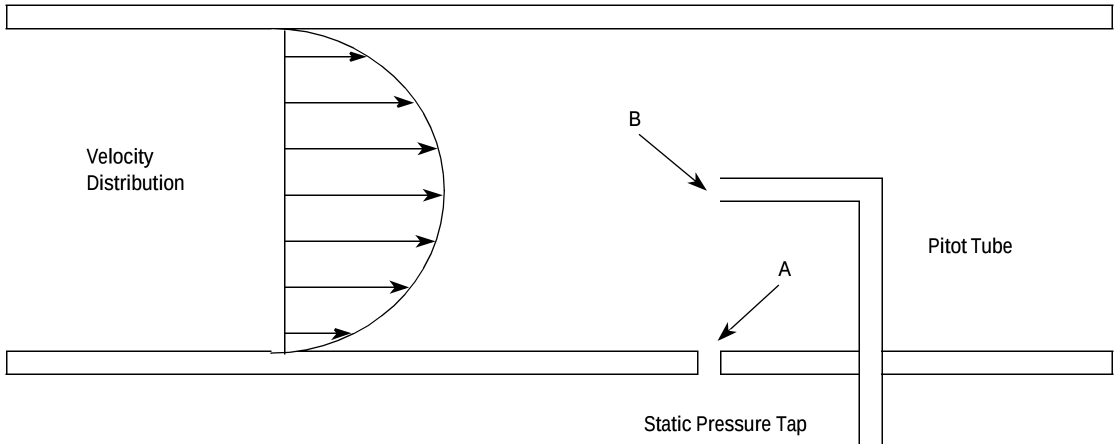

Figure 4. Static and Total Pressure Measurements Within a Dynamic Fluid System

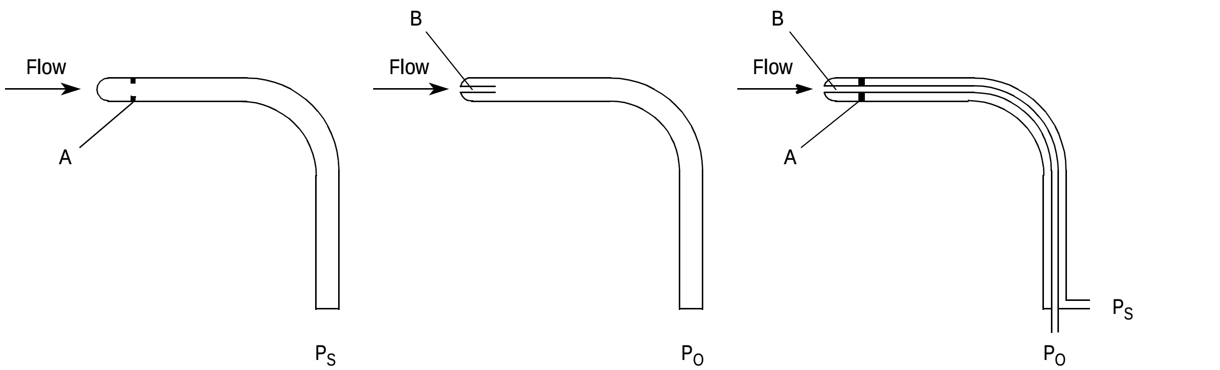

Figure 5. Types of Pressure Probes

When measuring dynamic system pressures, care must be taken to ensure accuracy. For static pressure measurements, the pressure tap location should be chosen so that the measurement is not influenced by the fluid flow. Typically, taps are located perpendicular to the flow field. In Figure 4, the static pressure tap at point A is in the wall of the duct and perpendicular to the flow field. In Figure 5 a and c the static taps (point A) in the pressure probes are also perpendicular to the flow field. These examples show the most common type of static pressure taps, however there are many different static pressure tap options. For total or stagnation pressure measurements, it is important that the Pitot or impact tube be aligned parallel to the flow field with the tip of the tube pointing directly into the flow. In Figure 5 b and c, the Pitot tube is aligned parallel with the flow, with the tube opening pointing directly into the flow. Although the static pressure is independent of direction, the dynamic pressure is a vector quantity which depends on both magnitude and direction for the total measured value. If the Pitot tube is misaligned with the flow, accuracy of the total pressure measurement may suffer. In addition, for accurate pressure measurements the pressure tap holes and probes must be smooth and free from any burrs or obstructions that could cause disturbances in the flow. The location of the pressure taps and probes, static and total, must also be selected carefully. Any location in the system where the flow field may be disturbed should be avoided, both upstream and downstream. These locations include any obstruction or change such as valves, elbows, flow splits, pumps, fans, etc. To increase the accuracy of pressure measurement in a dynamic system, allow at least 10 pipe / duct diameters downstream of any change or obstruction and at least two pipe / duct diameters upstream. In addition the pipe / duct diameter should be much larger than the diameter of the Pitot tube. The pipe / duct diameter should be at least 30 times the Pitot tube diameter. Flow straighteners can also be used to minimize any variations in the direction of the flow. Also, when using a Pitot tube, it is recommended that the static pressure tap be aligned in the same plane as the total pressure tap. On the Pitot-static tube, the difference in location is assumed to be negligible.

Flow-through pipes and ducts will result in a velocity field and dynamic pressure field that are non-uniform. At the wall of any duct or pipe there exists a no-slip boundary due to friction. This means that at the wall itself the velocity of the fluid is zero. Figure 4 shows an imaginary velocity distribution in a duct. The shape of the distribution will depend on the fluid conditions, system flow and pressure. In order to accurately determine the average dynamic pressure across a duct section, a series of total pressure readings must be taken across the duct. These pressure measurements should be taken at different radii and clock positions across the cross section of a round duct or at various width and height locations for a rectangular duct. Once this characterization has been performed for the duct, a correlation can be easily made between the total pressure measurement at the center of the duct relative to the average duct total pressure. This technique is also used to determine the velocity profile within the duct.

TRANSIENT SYSTEMS

Transient systems are systems with changing conditions such as pressures, flow rates, etc. Measurements in transient systems are the most difficult to accurately obtain. If the measurement system being used to measure the pressure has a faster response time than the rate of change in the system, then the system can be treated as quasi-steady-state. That is, the measurements will be about as accurate as those taken in the steady-state system. If the measurement of the system is assumed to be a snap shot of what is happening in the system, then you want to be able to take the picture faster than the rate of change in the system or the picture will be blurred. In other words, the measurement results will not be accurate. In a pressure measurement system, there are two factors that determine the overall measurement response: (1) the response of the transducer element that senses the pressure, and (2) the response of the interface between the transducer and the pressure system such as the pressure transmitting fluid and the connecting tube, etc. For Freescale Semiconductor, Inc. pressure sensors, the second factor usually determines the overall frequency response of the pressure measurement system. The vast majority of pressure systems that require measurements today are quasi-steady-state systems where system conditions are changing relatively slowly compared to the response rate of the measurement system or the change happens instantaneously and then stabilizes.

Two transient system examples include washing machines and ventilation ducts in buildings. In a washing machine, the height of the water in the tub is measured indirectly by measuring the pressure at the bottom of the tub. As the tub fills the pressure changes. The rate at which the tub fills and the pressure changes is much slower than the response rate of the measurement system. In a ventilation duct, the pressure changes as the duct registers are opened and closed, adjusting the air movement within the building. As more registers are opened and closed, the system pressure changes. The pressure changes are virtually instantaneous. In this case, pressure changes are essentially incremental and therefore easy to measure accurately except at the instant of the change. For most industrial and building control applications, the lag in the pressure measurement system is negligible. As the control or measurement system becomes more precise, the frequency response of the measurement system must be considered.

FREESCALE PRESSURE SENSORS

This application note has covered various types of pressures that are measured and how to tap into a system to measure the desired pressures. How are the actual pressure measurements made? There are many types of pressure measurement systems ranging from simple liquid tube manometers to bourdon-tube type gages to piezo-electric silicon based transducers. Today, as electronic control and measurement systems are replacing mechanical systems, silicon-based pressure transducers and sensors are becoming the sensors of choice. Silicon micromachined sensors offer very high accuracies at very low cost and provide an interface between the mechanical world and the electrical system. Freescale carries a complete line of silicon based pressure sensors which feature a wide range of pressures with various levels of integration on a single chip. These levels of integration start with the basic uncompensated, uncalibrated pressure sensor all the way to the fully integrated, temperature compensated, calibrated and signal conditioned pressure sensors. The response time of Freescale's MPX series silicon pressure sensors is typically 1 millisecond or less. For static or dynamic systems, Freescale's pressure sensors are an excellent solution for pressure measurement systems.

CONCLUSION

Pressures and pressure measurements can be extremely complex and complicated. However, for most systems it is relatively easy to obtain accurate pressure measurements if the proper techniques are used.

Freescale Semiconductor
Technical Data

AN1586
Rev 1, 05/2005

Designing a Homemade Digital Output for Analog Voltage Output Sensors

**by: Eric Jacobsen, Systems and Applications Engineer
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INTRODUCTION

A digital output is more desirable than an analog output in noisy environments (e.g., automotive, washing machines, etc.) and remote sensing applications (building controls, industrial applications, etc.) because a digital signal inherently has better noise immunity compared to analog signals. Additional applications requiring a sensor with a digital output include microcontroller-based systems that have no A/D in the system or that have no A/D channels available for the sensing function. For these applications, there is no other option but a digital output to further process the signal.

Via a design example this paper shows how to easily convert an analog voltage output sensor to a digital output sensor. For the design example, each of the required circuit components is discussed in detail. While the design is applicable to analog voltage output sensors (differential or single-ended output) in general, the design example and following discussions will pertain specifically to semiconductor pressure sensors.

The digital output sensor in Figure 1 consists of the following:

- MPX2000 series pressure sensor
- A two op amp gain stage to amplify the sensor's signal
- An integrator (i.e., a low pass filter consisting of one resistor and one capacitor)
- An LM311 comparator
- An MC68HC05P9 microcontroller with which only two pins are used: the output compare timer channel (TCMP) and one general I/O pin (the input capture timer channel, TCAP, can be used in place of the general I/O pin). Since only two of the MC68HC05P9's pins are used, the remaining pins are available for other system functions.

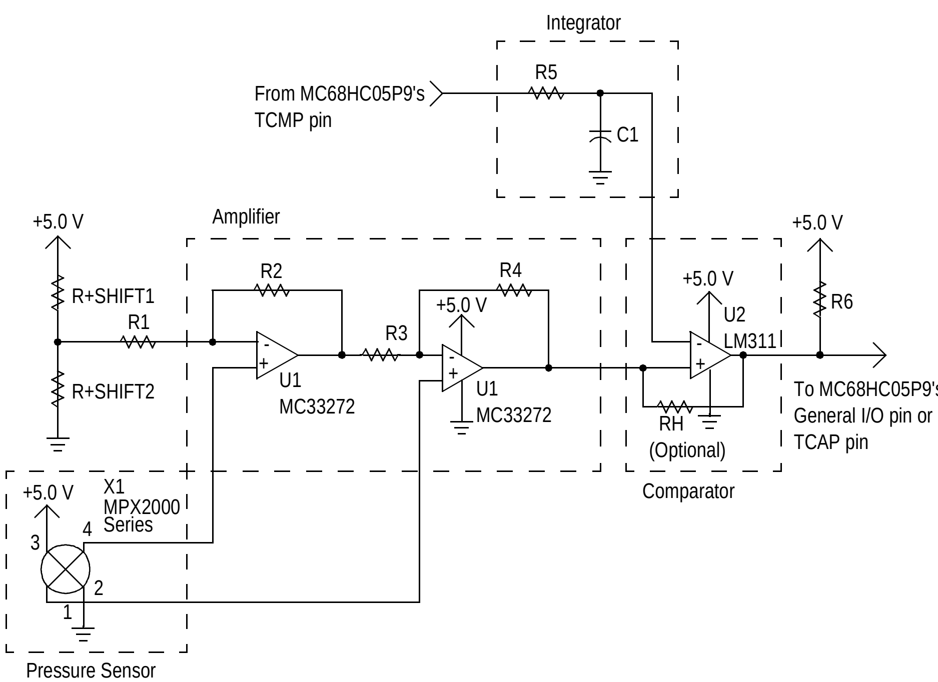

Figure 1. The Digital Output Sensor Schematic

After the discussion of the circuit components, the following system-related issues will be discussed simultaneously using the design example:

- How the system works
- Defining and designing the digital output for a desired signal resolution
- A step-by-step procedure that shows you how to digitize the signal
- A procedure to show you how to software calibrate the digital output
- Related software examples

This system, in addition to the benefits of a digital output (noise immunity, etc.), also has the following additional inherent benefits. These benefits will be addressed in more detail in the systems topics.

- The circuit topology and method of "digitizing" the sensor's analog output is very stable and accurate. The system uses the microcontroller's precise, internal, digital time base to digitize the analog signal.
- The signal resolution is user-programmable via software - i.e. the user can program whether the resolution is 8-bit, 10-bit, etc.
- The digital output is calibrated in software so that component tolerances can be nullified.
- The software required to digitize the signal requires very little CPU time and overhead.
- The required circuitry is minimal, simple, and cost-effective.

THE PRESSURE SENSOR

The Freescale Semiconductor, Inc. MPX2000 series sensors are temperature compensated and calibrated (i.e., offset and span are precision trimmed) pressure transducers. These sensors are available in full scale pressure ranges from 10 kPa (1.5 psi) to 700 kPa (100 psi). Although the specifications (see Table 1) in the data sheets apply to a 10 V supply voltage, the output of these devices is ratiometric with the supply voltage. For example, at the absolute maximum supply voltage rating, 16 V, the sensor will typically produce a differential output voltage of 64 mV at the rated full scale pressure of the given sensor. One exception to this is that the span of the MPX2010 (10 kPa sensor) will be only 40 mV due to the device's slightly lower sensitivity. Since the maximum supply voltage produces the largest output signal, it is evident that even the best case scenario will require some signal conditioning to obtain a usable signal (input to an A/D, etc.). For this specific design, an MPX2100 and 5.0 V supply are used, yielding a typical maximum sensor output of 20 mV (typical zero pressure offset is 0.0 mV and typical span is 20 mV). The sensor's output is then signal conditioned (amplified and level shifted) to provide a four volt span with a zero pressure offset of 0.5 V.

Table 1. MPX2100 Electrical Characteristics for V_S= 10 V, T_A = 25°C

Characteristics	Symbol	Min	Typ	Max	Unit
Pressure Range	P_{OP}	0	—	100	kPa
Supply Voltage	V_S	—	10	16	V_{DC}
Full Scale Span	V_{FSS}	38.5	40	41.5	mV
Zero Pressure Offset	V_{OFF}	-1.0	—	1.0	mV
Sensitivity	$\Delta V/\Delta P$	—	0.4	—	mV/kPa
Linearity	—	-0.25	—	0.25	$\%V_{FSS}$
Temperature Effect on Span	TCV_{FSS}	-1.0	—	1.0	$\%V_{FSS}$
Temperature Effect on Offset	TCV_{OFF}	-1.0	—	1.0	mV

AMPLIFIER STAGE

The amplifier circuitry, shown in Figure 1, is composed of two op amps. This interface circuit has a much lower component count than conventional quad op amp instrumentation amplifiers. The two op-amp design offers the high input impedance, low output impedance, and high gain desired for a transducer interface, while performing a differential to single-ended conversion. The amplifier incorporates level shifting capability. The amplifier has the following transfer function:

$$V_O = \left(1 + \frac{R_4}{R_3}\right) ^2 (V_{sensor}) + V + shift$$

where R1 = R4; R2 = R3,

the gain is $1 + \frac{R_4}{R_3}$

V_{sensor} is the sensor's differential output ($S^+ - S^-$)

and

V+shift is the positive dc level shift voltage created by the resistor divider comprised of R+shift1 and R+shift2.

V+shift is used to position the zero pressure offset at the desired level.

Table 2 summarizes the 1% resistor values used to obtain a four-volt span with a zero pressure offset of 0.5 V (assuming the typical sensor offset and span values of 0.0 mV and 20 mV, respectively).

Table 2. Resistor Values for the MPX2100 Amplifier Design

R+shift1	R+shift2	R1	R2	R3	R4
4.99 kΩ	549 Ω	20.0 kΩ	100 Ω	100 Ω	20.0 kΩ

THE INTEGRATOR

As shown in Figure 1, the integrator consists of a single resistor and single capacitor. A programmable duty cycle pulse train from the microcontroller is input to the integrator. Assuming that the RC time constant of the integrator is sufficiently long compared to the pulse train's frequency, the resulting output which is input to the inverting terminal of the comparator is a dc voltage that is linearly proportional to the pulse train's duty cycle, i.e.:

DC Output Voltage = Pulse Train's Duty Cycle (%) $\times$ 5.0 V

Where the Pulse Train's Duty Cycle is multiplied by the pulse train's logic-level one voltage value which is typically the same voltage as the microcontroller's 5.0 V supply.

Table 3 shows a few examples of Pulse Train Duty Cycles and the corresponding DC Output Voltage assuming a typical pulse train logic-level one value of 5.0 V.

Table 3. Example Pulse Train Duty Cycles and the Inegrator's Corresponding dc Voltage Output

Pulse Train's Duty Cycle (%)	0	25	50	75	100
DC Output Voltage (V)	0	1.25	2.5	3.75	5

To establish a stable constant dc voltage at the integrator's output, its time constant must be sufficiently long compared to the frequency of the pulse train. However, the system resolution and thus performance are directly related to the pulse train's frequency. The design of the time constant and choice of the resistor and capacitor values is discussed in *System Design: Defining and designing for a desired signal resolution.*

COMPARATOR

The LM311 chip is designed specifically for use as a comparator and thus has short delay times, high slew rate, and an open-collector output. A pull-up resistor (R6 = 5 kΩ) at the output is all that is needed to obtain a rail-to-rail output. As Figure 1illustrates, the pressure sensor's amplified output voltage is input to the non-inverting terminal of the op-amp and the integrator's dc output voltage is input to the inverting terminal. Therefore, when the pressure sensor's output voltage is greater than the integrator's dc output voltage, the comparator's output is high (logic-level one); conversely, when the pressure sensor's output voltage is less than the integrator's dc output voltage, the comparator's output is low (logic-level zero).

An optional resistor, RH is used as positive feedback around U2 in Figure 1 to provide a small amount of hysteresis to ensure a clean logic-level transition (prevents multiple transitions (squegging)) when the comparator's inputs are similar in value. The amount of hysteresis increases as the value of RH decreases. For this design, the value of RH is not critical but should be on the order of 100 kΩ.

THE MC68HC05P9 MICROCONTROLLER

The microcontroller for this application requires an output compare timer channel and one general I/O pin. The output compare pin is programmed to output the pulse train that is input to the integrator, and the general I/O pin is configured as an input to monitor the logic-level of the comparator's output. The remainder of this paper discusses the system and software requirements.

SYSTEM DESIGN: HOW THE SYSTEM WORKS

For any analog sensor voltage output, there's a pulse train with a duty cycle that when integrated will equal the sensor's output. Therefore, by incrementing via software the pulse train's duty cycle from 0% to 100%, there's a duty cycle that when integrated will be larger than the sensor's current voltage output. When the integrated pulse train voltage becomes larger than the sensor's output voltage, the comparator's output will change from a logic-level one to a logic-level zero. This logic-level, in turn, is monitored on the general I/O pin. The pulse train's duty cycle creating the integrated voltage that caused the comparator's logic-level transition is the digital representation of the sensor's voltage. Thus every sensor analog output voltage is mapped to a specific duty cycle. This design inherently has outstanding performance (very stable and accurate) since the digital representation of the sensor signal is created by the microcontroller's digital time base. Also the pressure measurement, made via software that first increments the pulse train's duty cycle and then determines if an edge transition occurred on the general I/O pin, is straightforward and easy.

In a calibration routine (discussed below) the sensor's output at two known pressures (e.g. zero and full-scale pressure) can be mapped to two corresponding pulse train duty cycles. Since the pressure sensor's output voltage is linear with the applied pressure, and the integrator's dc output voltage is linear with the input pulse train duty cycle, then the pulse train's duty cycle that causes the logic-level transition at the comparator's output will also be linear with the applied pressure. Thus by knowing the duty cycles for two known pressures, a linear interpolation of any duty cycle gives an accurate measurement of the current pressure. The following equation is used to interpolate the pressure measurement where the pressure units are in kPa.

$$\text{Current Pressure} = \frac{\text{Current Duty Cycle} - \text{Duty Cycle @ Zero Pressure}}{\text{Duty Cycle @ Full-Scale Pressure} - \text{Duty Cycle @ Zero Pressure}} \times \text{Full-Scale Pressure in kPa}$$

For example:

At zero pressure, if the pulse train's duty cycle required to cause a logic-level transition at the comparator's output is 25% and at full-scale pressure the pulse train's duty cycle is 75%, then the current pressure that corresponds to a duty cycle of 50% (required to obtain the logic-level one to logic-level zero transition at the comparator's output) is

$$\text{Current Pressure} = \frac{50\% - 25\%}{75\% - 25\%} \times 100\text{ kPa} = 50\text{ kPa}$$

Until now, the pulse train has been defined in terms of duty cycle. However, in practice duty cycle is calculated from the ratio of the high time to the total period of the pulse train. Therefore, there is a high time (typically in μs) of the pulse train that causes the logic-level transition of the comparator's output. The interpolation of the current pressure can then be calculated directly from the high time of the pulse train that is programmed by the user to be generated by the microcontroller's output compare pin. The equation is similar to the one above for Current Pressure:

$$\text{Current Pressure} = \frac{\text{Current High Time} - \text{High Time @ Zero Pressure}}{\text{High Time @ Full-Scale Pressure} - \text{High Time @ Zero Pressure}} \times \text{Full-Scale Pressure in kPa}$$

Via this equation, the digital nature of the design is revealed. The analog voltage signal has been translated into a signal in the time domain where the high time generated by the output compare pin is actually the digital time representation of the sensor's output. Since the user precisely controls the high time of the pulse train (and period) via software which is based on the accurate digital time base of the microcontroller, the digital representation of the signal is very stable and accurate. Additionally, the high accuracy of the digital representation is possible since all the user must do to digitize the signal is detect a single logic-level transition at the comparator's output.

SYSTEM DESIGN: DEFINING AND DESIGNING FOR A DESIRED SIGNAL RESOLUTION

The resolution is directly related to the period (and thus frequency) of the pulse train. In our design, the difference between the pulse train's high time at full scale pressure and the pulse train's high time and zero pressure must be 512 µs to obtain at least 8-bit resolution. This is determined by the fact that a 4.0 MHz crystal yields a 2.0 MHz clock speed in the MC68HC05P9 microcontroller. This, in turn, translates to 0.5 µs per clock tick. There are four clock cycles per timer count. This results in 2 µs per timer count. Thus, to obtain 256 timer counts (discrete high-time time intervals or 8-bit resolution), the difference between the zero pressure and full scale pressure high times must be at least 2 µs x 256 = 512 µs.

To determine the pulse train's maximum frequency (or minimum period), the sensor's analog dynamic range (span) must be known. For this design, the span is 4.0 V. Thus the 4.0 V span of the sensor must translate to 512 µs of time for 8-bit resolution. But the pulse train typically has a logic-level high value of 5.0 V, indicating that for a 100% duty cycle or a period with all high time, the integrator's output would be 5.0 V; likewise, for a duty cycle of 0% or a period with no high time, the output would be 0 V. Therefore, 512 µs accounts for only 4.0 V/5.0 V (80%) of the pulse train's total period. See Figure 2. To calculate the pulse train's total period, divide the 512 µs by 4/5 (0.8) to obtain the required minimum period for the pulse train of 640 µs. The reciprocal of this minimum period is the maximum frequency (1.56 kHz) of the pulse train to obtain at least 8-bit resolution.

To summarize:

The MC68HC05P9 runs off a 4.0 MHz crystal. The microcontroller internally divides this frequency by two to yield an internal clock speed of 2.0 MHz.

$$\frac{1}{2\text{ MHz}} => \frac{0.5\ \mu\text{s}}{\text{Clock Cycle}}$$

and

$$4\text{ Clock Cycles} = 1\text{ Timer Count}$$

Therefore,

$$\frac{4\text{ Clock Cycles}}{\text{Timer Count}} \text{ X } \frac{0.5\ \mu\text{s}}{\text{Clock Cycle}} = \frac{2\ \mu\text{s}}{\text{Timer Count}}$$

For 8-bit resolution,

$$\frac{2\ \mu\text{s}}{\text{Timer Count}} \text{ X } 256\text{ Timer Counts} = 512\ \mu\text{s}$$

which is the required minimum time into which the sensor's 4.0 V span is translated.

To calculate the required period of the pulse train to yield the 0 to 5.0 V output (from 0% to 100% duty cycle based on the pulse train's logic-level high value of 5.0 V):

$$\text{Minimum Required Period} = \frac{512\ \mu\text{s for a 4 V Sensor Span}}{4/5\text{ of Integrator's Output}} = 640\ \mu\text{s}$$

Translating this to frequency, the maximum pulse train frequency is thus:

$$\frac{1}{640\ \mu\text{s}} = 1.55\text{ KHz}$$

The above procedure can be implemented easily for other resolution requirements (i.e. a resolution of 1%, 2%, etc.).

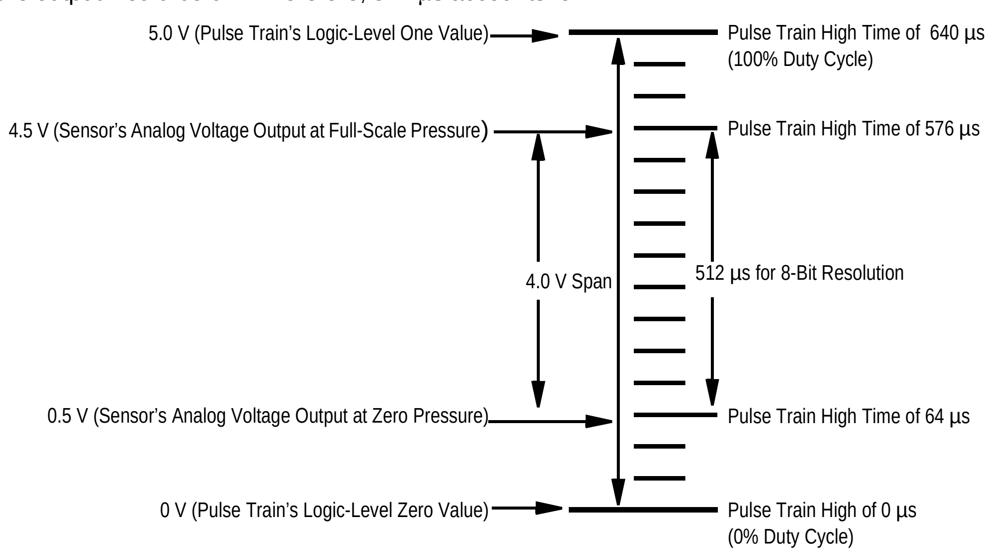

Figure 2. Designing the Pulse Train's Period for 8-Bit Resolution

NOTE: Very small and very large high times (assuming a fixed period) are typically unattainable due to the finite amount of time it takes to generate the pulse train on the output compare pin. This amount of time will vary depending on the microcontroller's clock speed and the latency of the actual software routines implemented. Thus the sensor's analog voltage to which the integrator's dc voltage is compared must be within the possible ranges of voltages created by the integrator's input pulse train - i.e. the sensor's zero pressure offset voltage must be greater than the smallest voltage created by the integrator (corresponding to the pulse train's smallest possible high time) and the sensor's full scale output voltage must be less than the largest voltage created by the integrator (corresponding to the pulse train's largest possible high time).

After establishing the frequency of the pulse train, the RC time constant for the integrator can be determined and the resistor and capacitor value can be chosen. The RC time constant should be long compared to the period of the pulse train so that a stable dc voltage (very little ripple due to the capacitor's charging and discharging) is obtained at the output of the comparator.

Follow these steps to design the RC time constant and integrator's component values. The design example's calculations are presented simultaneously.

For the resolution desired, determine the number of volts (typically mV) that corresponds to the least significant bit (one timer count). For this design example, 8-bit resolution (256 timer counts) over the desired pressure sensor span corresponds to

$$\#\text{ of } \frac{\text{mV}}{\text{timer count}} = \frac{\text{Desired Pressure Sensor Span (V)}}{\text{Number of Timer Counts}}$$

$$= \frac{4.0\text{ V}}{256\text{ timer counts}} = \frac{15.6\text{ mV}}{\text{timer counts}}$$

Therefore, the stability of the integrator's output voltage should be less than 15.6 mV (least significant bit). Choosing an RC time constant that allows a ripple of approximately one-fourth of the least significant bit is sufficient (approximately 3.9 mV).

The most ripple occurs at a 50% duty cycle pulse train. For this design the entire period is 640 µs. 50% duty cycle indicates a high time (and low time) of 320 µs. Furthermore, the capacitor should discharge no more than approximately 3.9 mV (defined as ΔV) over the 320 µs. The following equation is used to calculate the value for RC:

$$V(t) = V_{INITIAL} - \Delta V =$$

$$\text{Pulse Train Logic– level one value} \times \text{Duty Cycle} \times e^{\frac{t}{RC}}$$

where

$$V_{INITIAL} = \text{Pulse Train Logic–level one value} \times \text{Duty Cycle}$$

and

ΔV is the voltage discharge of the capacitor.

Solving for RC:

$$RC = \frac{t}{\ln\left(\frac{V(t)}{\text{Pulse Train Logic–level one value} \times \text{Duty Cycle}}\right)}$$

$$= \frac{320\ \mu\text{s}}{\ln\left(\frac{2.5\text{ V} - 3.9\text{ mV}}{5.0\text{ V} \times 50\%}\right)} = 0.205\text{ s}$$

Finally, choose the values of the resistor and capacitor. A typical resistor value is on the order of a tens of kΩ. The resistor's value can be higher (hundreds of kΩ) but care must be taken to avoid increased thermal noise.

For this design, the resistor value is chosen to be 49.9 kΩ (1% resistor). The capacitor's value is readily calculated to be

$$C = \frac{0.205\text{ s}}{49.9\text{ k}\Omega} = 4.1\ \mu\text{F}$$

Choose the values of the resistor and capacitor so that the actual time constant is equal to or greater than the calculated time constant.

NOTE: Be aware that temperature variations can create errors in the system (thus reducing system performance); therefore, be sure to use low temperature coefficient resistors, capacitors, etc.

SYSTEM DESIGN: STEP-BY-STEP PROCEDURE FOR PRESSURE MEASUREMENT AND CALIBRATION

To measure pressure (Note: there are other measurement algorithms that can be performed that in some cases may be more acceptable [see below, Additional notes]):

1. Start with a pulse train with the minimum high time feasible with the system's microcontroller. Pulse train should run at a frequency equal to or less than the frequency calculated above.
2. Make sure the general I/O pin's input is high (sensor's output voltage is greater than the integrator's output voltage).
3. Increment the high time of the pulse train by one timer count.
4. Check the general I/O pin to see if its input is low (sensor's output voltage has become less than the integrator's output voltage).
5. If the general I/O pin is reading a logic-level zero, store in memory the high time of the pulse train as the current pressure high time reading that created the logic-level transition in the comparator's output.
6. If the general I/O pin is reading a logic-level one, go back to step 3 and repeat.
7. Using the equation “Current Pressure = ...” shown above, calculate the current pressure (assuming the system has already been calibrated).
8. Repeat steps 1 through 7 for additional pressure measurements.

To calibrate the system:

At zero and full scale pressures, perform the above 8 step pressure measurement routine. Store the appropriate pulse train high times corresponding to zero and full scale pressure. These high times will be used to calculate the current pressure as mentioned in Step 7 above.

SOFTWARE EXAMPLES TO GENERATE PULSE TRAIN ON OUTPUT COMPARE TIMER CHANNEL

The following software examples are written in assembly language for the MC68HC05P9 (the code is applicable to any HC05 series microcontroller with TCMP pin).

```
* GENERATES THE PULSE TRAIN ON TCMP
GEN
LDA  PERIODL                  * LOW BYTE OF THE PERIOD
SUB  HIGHTIMEL                * LOW BYTE OF THE HIGHTIME
STA  LOWTIMEL                 * LOW BYTE OF THE LOWTIME
LDA  PERIODH                  * HIGH BYTE OF THE PERIOD
SBC  HIGHTIMEH                * HIGH BYTE OF THE HIGHTIME
STA  LOWTIMEH                 * HIGH BYTE OF THE LOWTIME
RTS

* INCREASE THE HIGH TIME (DUTY CYCLE) OF THE PULSE TRAIN
INCPW
LDA  HIGHTIMEL
ADD  #$01            * INCREMENT PULSE WIDTH BY 2 µs
STA  HIGHTIMEL
LDA  HIGHTIMEH
ADC  #$0
STA  HIGHTIMEH
RTS

* DECREASE THE HIGH TIME (DUTY CYCLE) OF THE PULSE TRAIN
DECPW
LDA  HIGHTIMEL
SUB  #$01            * DECREMENT PULSE WIDTH BY 2 µs
STA  HIGHTIMEL
LDA  HIGHTIMEH
SBC  #$0
STA  HIGHTIMEH
JSR  GEN
RTS

* INCREASE THE PERIOD (DECREASE FREQUENCY) OF THE PULSE TRAIN
INCPER
LDA  PERIODL
ADD  #$05            * INCREMENT PERIOD BY 10 µs
STA  PERIODL
LDA  PERIODH
ADC  #$0             * ADJUST HIGH BYTE OF PERIOD IF CARRY
STA  PERIODH
JSR  GEN
RTS

* DECREASE THE PERIOD (INCREASE FREQUENCY) OF THE PULSE TRAIN
DECPER
LDA  PERIODL
SUB  #$05            * DECREMENT PERIOD BY 10 µs
STA  PERIODL
LDA  PERIODH
SBC  #$0             * ADJUST HIGH BYTE OF PERIOD IF BORROW
STA  PERIODH
JSR  GEN
RTS

TIMER                         * INTERRUPT SERVICE ROUTINE FOR TCMP
LDA  TSR             * CLEAR OCF FLAG IN TSR
LDA  TCMPL

BRSET 0,TCR,ADDHIGH* HIGH OR LOW PULSE TIME NEEDED?

ADDLOW
BSET 0,TCR           * ADD LOW TIME TO THE PULSE TRAIN
LDA  LOWTIMEL
ADD  TCMPL
TAX
LDA  TCMPH
ADC  LOWTIMEH
STA  TCMPH
```

```
STX  TCMPL
RTI

ADDHIGH
BCLR 0,TCR              * ADD HIGH TIME TO THE PULSE TRAIN
LDA  HIGHTIMEL
ADD  TCMPL
TAX
LDA  TCMPH ADC          HIGHTIMEH
STA  TCMPH
STX  TCMPL
RTI
```

ADDITIONAL NOTES

This type of A/D conversion method (one type of A/D conversion) inherently takes a finite period of time to digitize the signal (incrementing the pulse train's high time while polling the general I/O pin); however, for most sensor applications the physical phenomenon being measured does not change quickly (<1 ms) enough to warrant an ultra-fast A/D conversion process.

An additional advantage of this design is that the measurement process may be performed only as necessary, keeping the CPU processing time and overhead minimal.

If an input capture timer channel (TCAP) is available, it may be configured to detect the logic-level one to logic-level zero transition of the comparator's output. When the edge transition occurs, an interrupt service routine is executed that stores the pulse train's high times, calculates the current pressure, etc. This is typically more convenient and eliminates the need to poll a general I/O pin every time the pulse train's high time is incremented (interrupt subroutine is executed only when the edge transition occurs).

SUMMARY

Shown above is a minimal component design that can convert an analog sensor's output into a digital output. Each major subsystem (sensor, amplifier, integrator, comparator, and microcontroller) is explained in detail simultaneously with a design example. Next the system operation is discussed including how it works and how to design a desired system resolution. Finally a flow chart for measuring and calibrating the sensor's output is presented.

Freescale Semiconductor
Technical Data

AN1636
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Implementing Auto Zero for Integrated Pressure Sensors

by: Ador Peodique
Sensor Systems and Applications Engineering

INTRODUCTION

This application note describes how to implement an auto-zero function when using an integrated pressure sensor with a microcontroller and an analog to digital converter (MCU and an A/D). Auto-zero is a compensation technique based on sampling the offset of the sensor at reference pressure (atmospheric pressure is a zero reference for a gauge measurement) in order to correct the sensor output for long-term offset drift or variation.

Sources of offset errors are due to device to device offset variation (trim errors), mechanical stresses (mounting stresses), shifts due to temperature and aging. Performing auto-zero will greatly reduce these errors. The amount of error correction is limited by the resolution of the A/D.

In pressure sensing applications where a zero-pressure reference condition can exist, auto-zero can be implemented easily when an integrated pressure sensor is interfaced to an MCU.

EFFECTS OF OFFSET ERRORS

Figure 1 illustrates the transfer function of an integrated pressure sensor. It is expressed by the linear function:

$$V_{OUT} = V_{OFF} + [(V_{FSO} - V_{OFF})/(P_{MAX} - P_{REF})] \times P = V_{OFF} + S \times P$$

Here, V_{OUT} is the voltage output of the sensor, V_{FSO} is the full-scale output, V_{OFF} is the offset, P_{MAX} is the maximum pressure and P_{REF} is the reference pressure. Note that ($V_{FSO} \times V_{OFF}/P_{MAX} \times P_{REF}$) can be thought of as the slope of the line and V_{OFF} as they y-intercept. The slope is also referred to as the sensitivity, S, of the sensor.

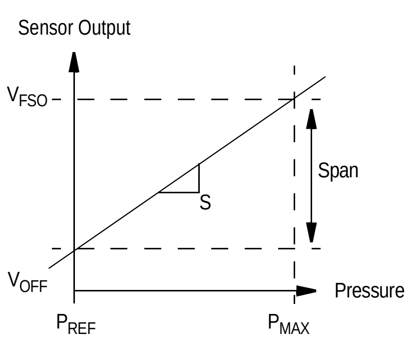

Figure 1. Definition of Span, Full-Scale Output, Offset and Sensitivity

A two-point pressure calibration can be performed to accurately determine the sensitivity and get rid of the offset calibration errors altogether. However, this can be very expensive in a high volume production due to extra time and labor involved. The system designer therefore designs a pressure sensor system by relying on the sensitivity and offset data given in the data sheet and using a linear equation to determine the pressure. Using the later, the sensed pressure is easily determined by:

$$P = (V_{OUT} - V_{OFF})/S$$

If an offset error is introduced due to device to device variation, mechanical stresses, or offset shift due to temperature (the offset has a temperature coefficient or TCO), those errors will show up as an error, DP, in the pressure reading:

$$P + \Delta P = [V_{OUT} \times (V_{OFF} + \Delta V_{OFF})]/S$$

As evident in Figure 2, offset errors, ΔV_{OFF}, have the effect of moving the intercept up and down *without* affecting the sensitivity. *We can therefore correct this error by sampling the pressure at zero reference pressure (atmosphere) and subtracting this from the sensor output.*

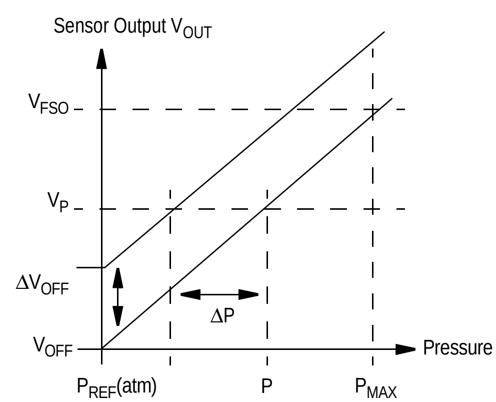

Figure 2. Effect of Offset Errors

AUTO-ZERO CONSIDERATIONS IN APPLICATIONS

There is an important consideration when implementing auto-zero. In order to use this technique, *a zero pressure reference condition must be known to exist in the system.*

There are a lot of applications that will lend themselves naturally to auto-zeroing. Typical applications are those that:

- Experience a zero-pressure condition at system start up,
- Are idle for a long time (zero pressure), take a pressure measurement then go back to idle again.

For example, in a water level measurement in a washing machine application, there is a zero pressure reference condition when the water in the tub is fully pumped out. Another application that is perfect for auto-zeroing is a beverage fill level measurement; a zero reference condition exists before the bottle is filled. HVAC air flow applications can also use auto-zeroing; before system start up, an auto-zero can be initiated. In other words, it can be used in applications where a zero pressure condition can exist in order to auto-zero the system.

An auto-zero command can be automated by the system or can be commanded manually. Each system will have a different algorithm to command an auto-zero signal. For example, using the beverage fill level measurement as an example, the system will auto zero the sensor before the bottle is filled.

IMPLEMENTATION OF AUTO-ZERO WITH A MICROCONTROLLER

Auto-zero can be implemented easily when the integrated sensor is interfaced to a microcontroller. The auto-zero algorithm is listed below:

1. Sample the sensor output when a known zero reference is applied to the sensor (atmospheric pressure is a zero reference for gauge type measurement). Store current zero pressure offset as CZPO.
2. Sample the sensor output at the current applied pressure. Call this SP.
3. Subtract the stored offset correction, CZPO, from SP. The pressure being measured is simply calculated as:

$$P_{MEAS} = (SP \times CZPO)/S$$

Note that the equation is simply a straight line equation, where S is the sensitivity of the sensor. The auto-zero algorithm is shown graphically in Figure 3.

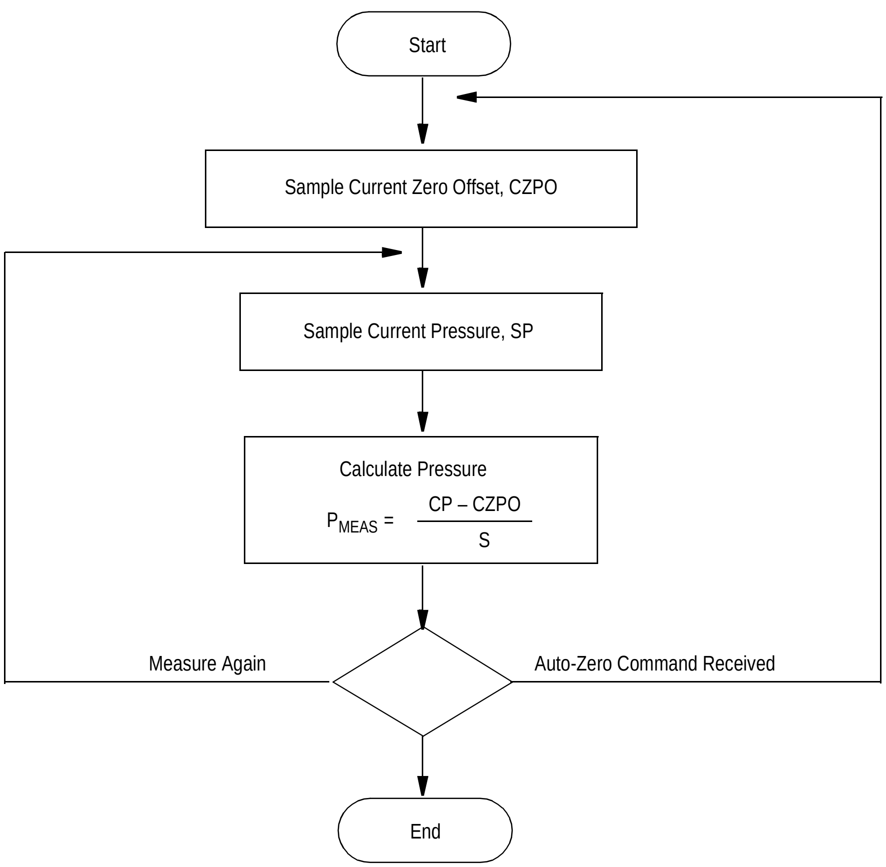

Figure 3. Flowchart of the Auto-Zero Algorithm

IMPROVEMENT ON OFFSET ERROR

In the following calculations, we will illustrate how auto-zero will improve the offset error contribution. We will use the MPXV4006G interfaced to an 8-bit A/D as an example. When auto-zero is performed, the offset errors are reduced and the *resulting offset errors are replaced with the error (due to resolution) of the A/D.* We can categorize the offset error contributions into temperature and calibration errors.

Temperature Coefficient of Offset Error

The offset error due to temperature is due to Temperature Coefficient of Offset, or TCO. This parameter is the rate of change of the offset when the sensor is subject to temperature. It is defined as:

$$TCO = (\Delta V_{OFF}/\Delta T)$$

The MPXV4006G has a temperature coefficient of offset (normalized with the span at 25°C) of:

$$\Delta TCO = (\Delta V_{OFF}/\Delta T)/V_{FS@25°C} = 0.06\%\ FS/°C$$

As an example, if the sensor is subjected to temperature range between 10°C and 60°C, the error due to TCO is:

$$\Delta TCO = (0.06\%\ FS/C)\times(60°C - 10°C) = \pm 3.0\%\ FS$$

Offset Calibration Errors

Even though the offset is laser trimmed, offset can shift due to packaging stresses, aging and external mechanical stresses due to mounting and orientation. This results in offset calibration error. For example, the MPXV4006G data sheet shows this as:

$$V_{OFF\ MIN} = 0.100\ V,$$

$$V_{OFF\ TYPICAL} = 0.225\ V \text{ and } V_{OFF\ MAX} = 0.430V$$

We can then calculate the offset calibration error with respect to the full scale span as:

$$\Delta V_{OFF\ MIN,MAX} =$$
$$(V_{OFF\ TYPICAL} - V_{OFF\ MIN,MAX})/VFS$$

This results in the following offset calibration error,

$$\Delta V_{OFF\ MIN} = 2.7\%\ FS \text{ and}$$

$$\Delta V_{OFF\ MAX} = 4.5\%\ FS$$

A/D Error

As mentioned above, we can reduce offset errors (calibration and TCO) when we perform auto-zero. These errors are replaced with the A/D error (due to its resolution),

$$\Delta OFFSET_{AUTOZERO} = \Delta TCO + \Delta OFFSET = \Delta A/D$$

Typically, a sensor is interfaced to an 8-bit A/D. With the A/D reference tied to V_{RH} = 5.0 V and V_{RL} = 0 V, the A/D can resolve 19.6 mV/bit. For example, the MXPV4006G has a sensitivity of 7.5 mV/mm H_20, the resolution is therefore

$$A/D_{RESOLUTION} = 19.6\ mV/bit)/(7.5\ mV/mm\ H_20) = 2.6\ mm\ H_20/bit$$

Assuming ± 1 LSB error, the error due to digitization *and* the resulting offset error is,

$$\Delta A/D = \Delta OFFSET_{AUTOZERO} = 2.6\ mm\ H_20/612\ mmH_20 = \pm 0.4\%\ FS$$

It can be seen that with increasing A/D resolution, offset errors can be further reduced. For example, with a 10-bit A/D, the resulting offset error contribution is only 0.1% FS when auto-zero is performed.

If auto-zero is to be performed only once and offset correction data is stored in non-volatile memory, the TCO offset error and calibration error will not be corrected *if* the sensor later experiences a wide temperature range or later experience an offset shift. However, if auto-zero is performed *at* the operating temperature, TCO error will be compensated although subsequent offset calibration error will not be compensated. It is therefore best to auto-zero as often as possible in order to dynamically compensate the system for offset errors.

CONCLUSION

Auto-zero can be used to reduce offset errors in a sensor system. This technique can easily be implemented when an integrated pressure sensor is interfaced to an A/D and a microcontroller. With a few lines of code, the offset errors are effectively reduced; the resulting offset error reduction is limited only by the resolution of the A/D.

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Technical Data

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Noise Considerations for Integrated Pressure Sensors

by: Ador Reodique, Sensor and Systems Applications Engineering and Warren Schultz, Field Engineering

INTRODUCTION

The Integrated Pressure Sensors (IPS) have trimmed outputs, built-in temperature compensation and an amplified single-ended output which make them compatible with Analog to Digital converters (A/D's) on low cost micro-controllers. Although 8-bit A/D's are most common, higher resolution A/D's are becoming increasingly available. With these higher resolution A/D's, the noise that is inherent to piezo-resistive bridges becomes a design consideration.

The two dominant types of noise in a piezo-resistive integrated pressure sensor are shot (white) noise and 1/f (flicker noise). Shot noise is the result of non-uniform flow of carriers across a junction and is independent of temperature. The second, 1/f, results from crystal defects and also due to wafer processing. This noise is proportional to the inverse of frequency and is more dominant at lower frequencies.

Noise can also come from external circuits. In a sensor system, power supply, grounding and PCB layout is important and needs special consideration.

The following discussion presents simple techniques for mitigating these noise signals, and achieving excellent results with high resolution A/D converters.

EFFECTS OF NOISE IN SENSOR SYSTEM

The transducer bridge produces a very small differential voltage in the millivolt range. The on-chip differential amplifier amplifies, level shifts and translates this voltage to a single-ended output of typically 0.2 volts to 4.7 volts. Although the transducer has a mechanical response of about 500 Hz, its noise output extends from 500 Hz to 1 MHz. This noise is amplified and shows up at the output as depicted in Figure 1.

There is enough noise here to affect 1 count on an 8-bit A/D, and 4 or 5 counts on a 10-bit A/D. It is therefore important to consider filtering. Filtering options are discussed as follows.

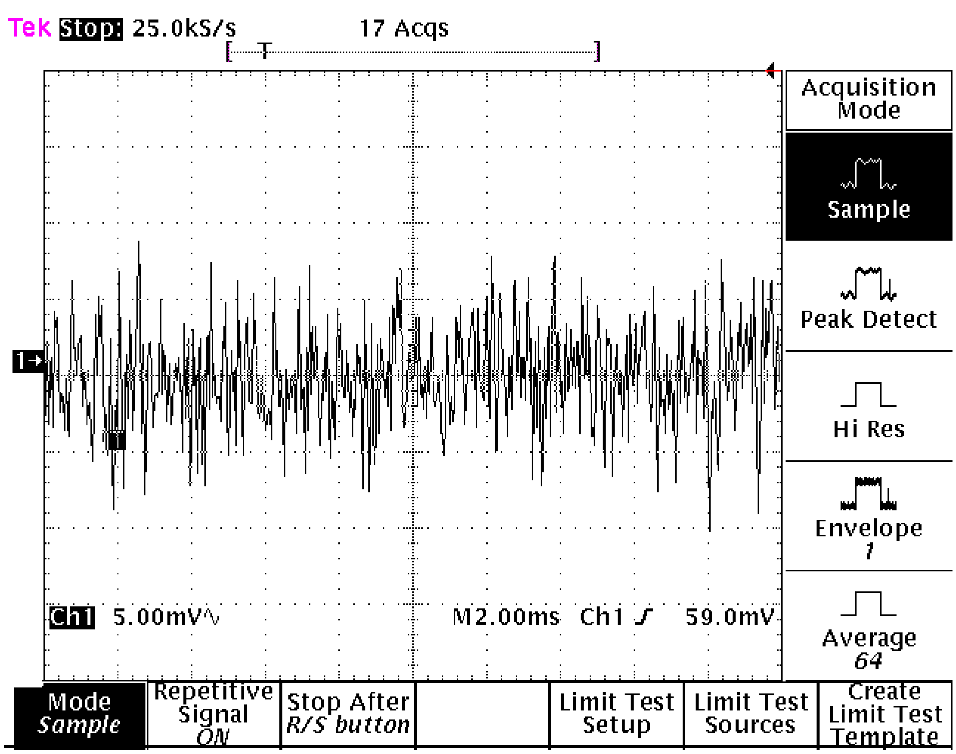

Figure 1. MPX5006 Raw Output

NOISE FILTERING TECHNIQUES AND CONSIDERATIONS

For mitigating the effects of this sensor noise, two general approaches are effective, low pass filtering with hardware, and low pass filtering with software. When filtering with hardware, a low-pass RC filter with a cutoff frequency of 650 Hz is recommended. A 750 ohm resistor and a 0.33 µF capacitor have been determined to give the best results (see Figure 2) since the 750 ohm series impedance is low enough for most A/D converters

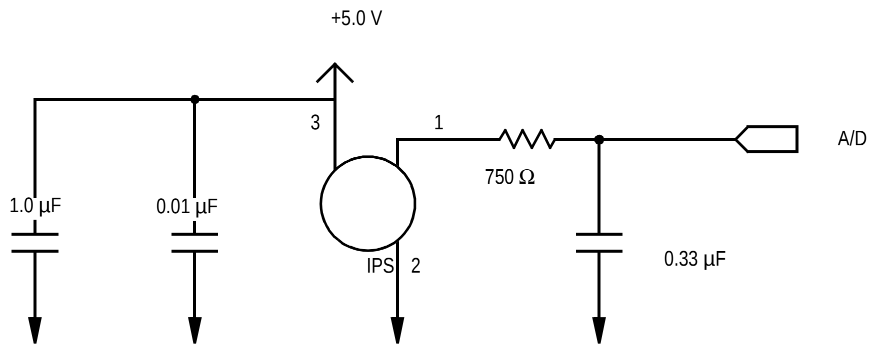

Figure 2. Integrated Pressure Sensor with RC LP Filter to Filter Out Noise

This filter has been tested with an MC68HC705P9 microcontroller which has a successive approximation A/D converter. Successive approximation A/D's are generally compatible with the DC source impedance of the filter in Figure 2. Results are shown in Figure 4.

Some A/D's will not work well with the source impedance of a single pole RC filter. Please consult your A/D converter technical data sheet if input impedance is a concern. In applications where the A/D converter is sensitive to high source impedance, a buffer should be used. The integrated pressure sensor has a rail-to-rail output swing, which dictates that a rail-to-rail operational amplifier (op amp) should be used to avoid saturating the buffer. A MC33502 rail-to-rail input and output op amp works well for this purpose (see Figure 3).

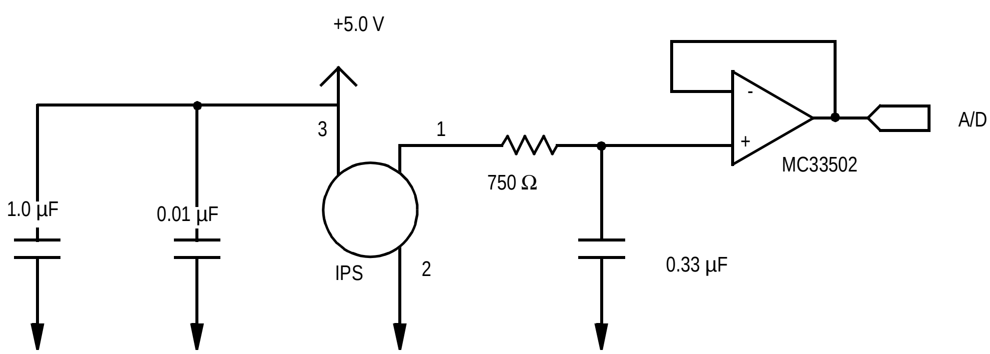

Figure 3. Use a Rail-to-Rail Buffer to Reduce Output Impedance of RC Filter

Averaging is also effective for filtering sensor noise. Averaging is a form of low pass filtering in software. A rolling average of eight to 64 samples will clean up most of the noise. A 10 sample average reduces the noise to about 2.5 mV peak to peak and a 64 sample average reduces the noise to about 1 mV peak to peak (see Figure 5 and Figure 6).

This method is simple and requires no external components. However, it does require RAM for data storage, extra computation cycles and code. In applications where the microcontroller is resource limited or pressure is changing relatively rapidly, averaging alone may not be the best solution. In these situations, a combination of RC filtering and a limited number of samples gives the best results. For example, a rolling average of four samples combined with the RC filter in Figure 2 results in a noise output on the order of 1 mV peak-to-peak.

Another important consideration is that the incremental effectiveness of averaging tends to fall off as the number of samples is increased. In other words, the signal-to-noise (S/N) ratio goes up more slowly than the number of samples. To be more precise, the S/N ratio improves as the square root of the number of samples is increased. For example, increasing the number of samples from 10 to 64, in Figure 5, and in Figure 6, reduced noise by a factor of 2.5.

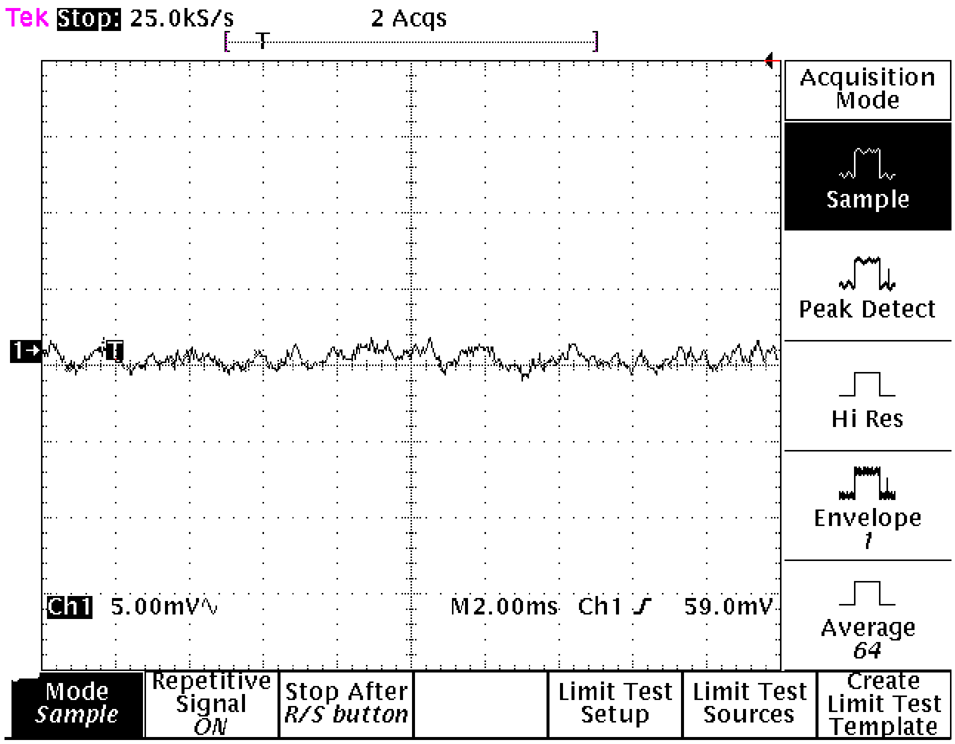

Figure 4. Output After Low Pass Filtering

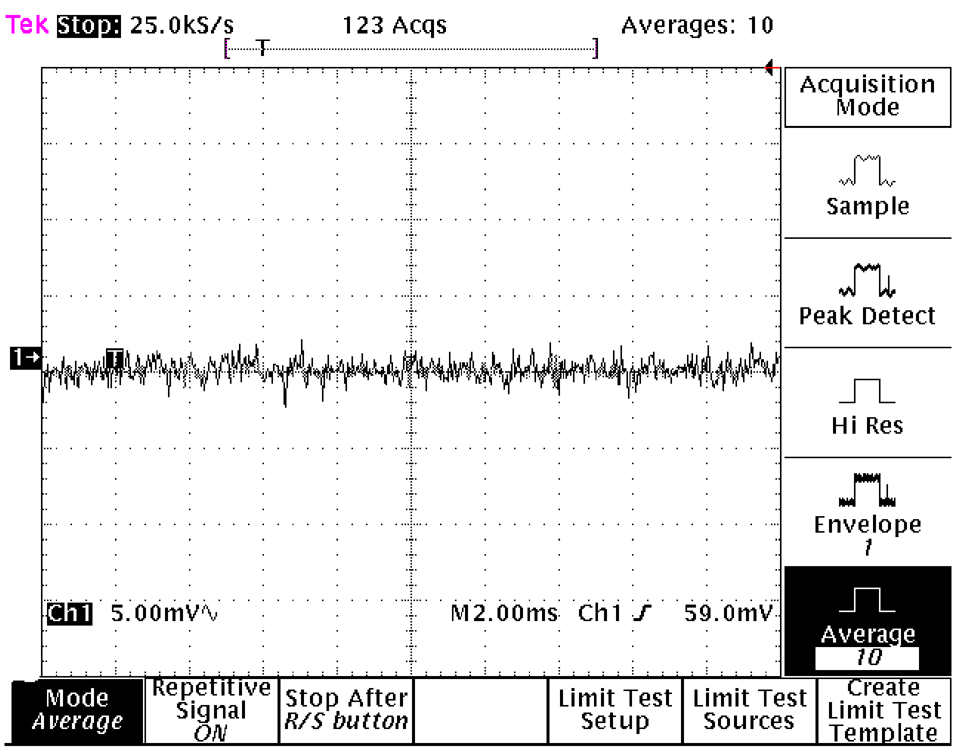

Figure 5. Output with 10 Averaged Samples

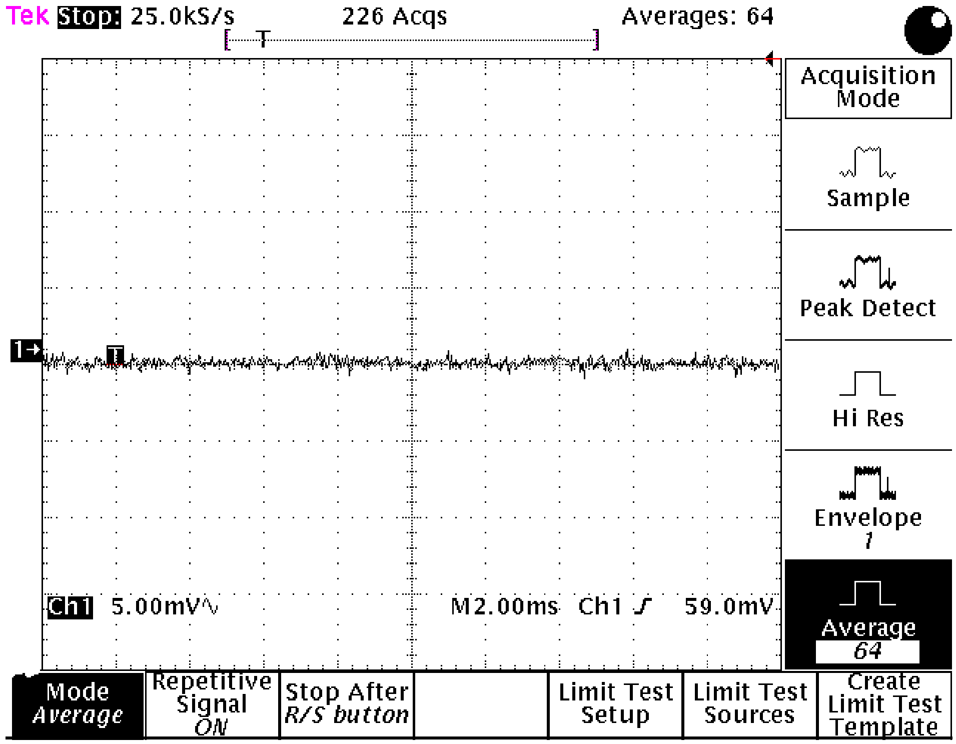

Figure 6. Output with 64 Averaged Samples

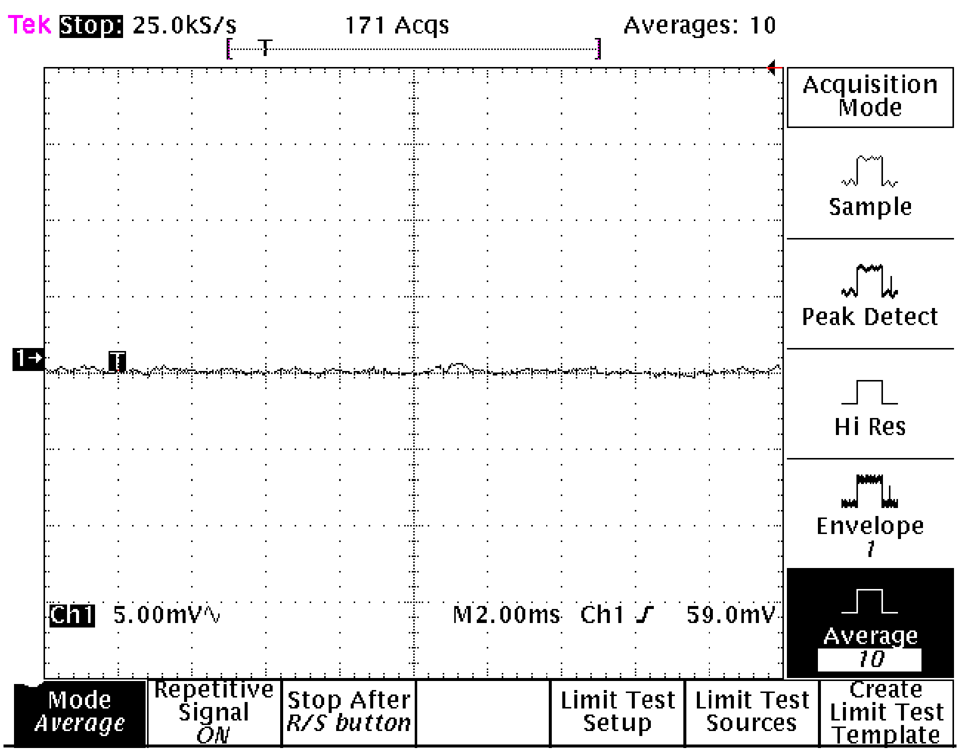

Figure 7. Filtered Sensor Output and Averaged Over 10 Samples

POWER SUPPLY

Since the sensor output is ratiometric with the supply voltage, any variation in supply voltage will also proportionally appear at the output of the sensor. The integrated pressure sensor is designed, characterized and trimmed to be powered with a 5.0 V ±5% power supply which can supply the maximum 10 mA current requirement of the sensor. Powering the integrated sensor at another voltage than specified is not recommended because the offset, temperature coefficient of offset (TCO) and temperature coefficient of span (TCS) trim will be invalidated and will affect the sensor accuracy.

From a noise point of view, adequate de-coupling is important. A 0.33 μF to 1.0 μF ceramic capacitor in parallel with a 0.01 μF ceramic capacitor works well for this purpose. Also, with respect to noise, it is preferable to use a linear regulator such as an MC78L05 rather than a relatively more noisy switching power supply 5.0 volt output. An additional consideration is that the power to the sensor and the A/D voltage reference should be tied to the same supply. Doing this takes advantage of the sensor output ratiometricity. Since the A/D resolution is also ratiometric to its reference voltage, variations in supply voltage will be canceled by the system.

LAYOUT OPTIMIZATION

In mixed analog and digital systems, layout is a critical part of the total design. Often, getting a system to work properly depends as much on layout as on the circuit design. The following discussion covers some general layout principles, digital section layout and analog section layout.

General Principles

There are several general layout principles that are important in mixed systems. They can be described as five rules.

Rule 1: Minimize loop areas.

This is a general principle that applies to both analog and digital circuits. Loops are antennas. At noise sensitive inputs, the area enclosed by an incoming signal path and its return is proportional to the amount of noise picked up by the input. At digital output ports, the amount of noise that is radiated is also proportional to loop area.

Rule 2: Cancel fields by running equal currents that flow in opposite directions as close as possible to each other.

If two equal currents flow in opposite directions, the resulting electromagnetic fields will cancel as the two currents are brought infinitely close together. In printed circuit board layout, this situation can be approximated by running signals and their returns along the same path but on different layers. Field cancellation is not perfect due to the finite physical separation, but is sufficient to warrant serious attention in critical paths. Looked at from a different perspective, this is another way of looking at Rule # 1, i.e., minimize loop areas.

Rule 3: On traces that carry high speed signals avoid 90 degree angles, including "T" connections.

If you think of high speed signals in terms of wavefronts moving down a trace, the reason for avoiding 90 degree angles is simple. To a high speed wavefront, a 90 degree angle is a discontinuity that produces unwanted reflections. From a practical point of view, 90 degree turns on a single trace are easy to avoid by using two 45 degree angles or a curve. Where two traces come together to form a "T" connection, adding some material to cut across the right angles accomplishes the same thing.

Rule 4: Connect signal circuit grounds to power grounds at only one point.

The reason for this constraint is that transient voltage drops along the power grounds can be substantial, due to high values of di/dt flowing through finite inductance. If signal processing circuit returns are connected to power ground at multiple points, then these transients will show up as return voltage differences at different points in the signal processing circuitry. Since signal processing circuitry seldom has the noise immunity to handle power ground transients, it is generally necessary to tie signal ground to power ground at only one point.

Rule 5: Use ground planes selectively.

Although ground planes are highly beneficial when used with digital circuitry, in the analog world they are better used selectively. A single ground plane on an analog board puts parasitic capacitance in places where it is not desired, such as at the inverting inputs of op amps. Ground planes also limit efforts to take advantage of field cancellation, since the return is distributed.

ANALOG LAYOUT

In analog systems, both minimizing loop areas and field cancellation are useful design techniques. Field cancellation is applicable to power and ground traces, where currents are equal and opposite. Running these two traces directly over each other provides field cancellation for unwanted noise, and minimum loop area.

Figure 8 illustrates the difference between a power supply de-coupling loop that has been routed correctly and one that has not. In this figure, the circles represent pads, the schematic symbols show the components that are connected to the pads, and the routing layers are shown as dark lines (top trace) or grey lines (bottom trace). Note, by routing the two traces one over the other, the critical loop area is minimized. In addition, it is important to keep de-coupling capacitors close to active devices such as MPX5000-series sensors and operational amplifiers. As a rule of thumb, when 50 mil ground and Vcc traces are used, it is not advisable to have more than 1 inch between a de-coupling capacitor and the active device that it is intended to be de-coupled.

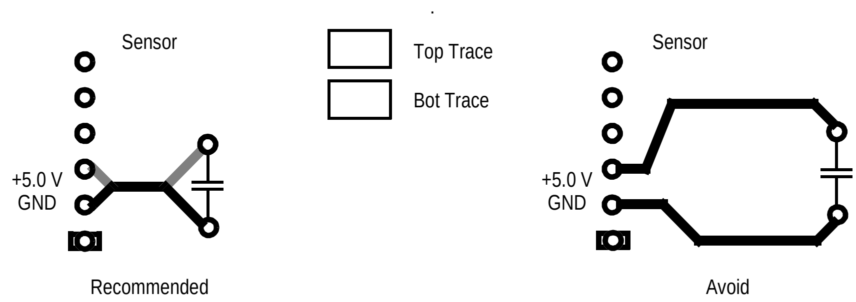

Figure 8. Minimizing Loop Areas

For similar reasons it is desirable to run sensor output signals and their return traces as close to each other as possible. Minimizing this loop area will minimize the amount of external noise that is picked up by making electrical connections to the sensor.

DIGITAL LAYOUT

The primary layout issue with digital circuits is ground partitioning. A good place to start is with the architecture that is shown in Figure 9. This architecture has several key attributes. Analog ground and digital ground are both separate and distinct from each other, and come together at only one point. For analog ground it is preferable to make the one point as close as possible to the analog to digital converter's ground reference (V_{REFL}). The power source ground connection should be as close as possible to the microcontroller's power supply return (V_{SS}). Note also that the path from V_{REFL} to V_{SS} is isolated from the rest of digital ground until it approaches V_{SS}.

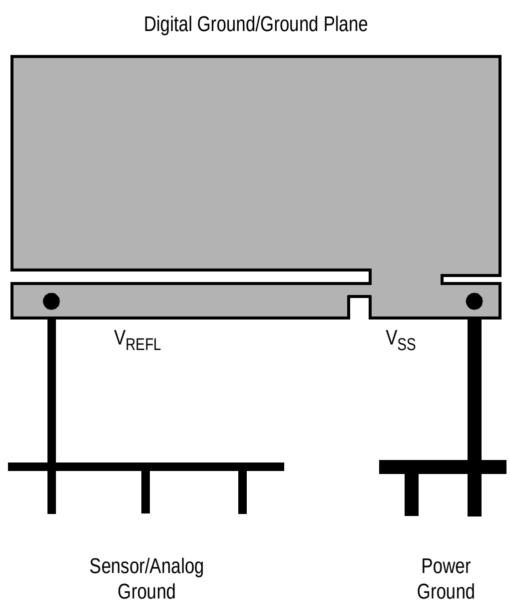

Figure 9. Ground Partitioning

In addition to grounding, the digital portion of a system benefits from attention to avoiding 90 degree angles, since there are generally a lot of high speed signals on the digital portion of the board. Routing with 45 degree angles or curves minimizes unwanted reflections, which increases noise immunity. Single traces are easy, two forty five degree angles or a curve easily accomplish a 90 degree turn. It is just as important to avoid 90 degree angles in T connections. Figure 10 illustrates correct versus incorrect routing for both cases.

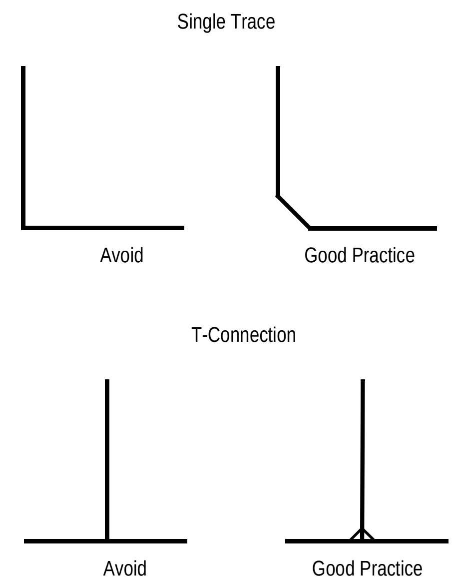

Figure 10. Degree Angles

CONCLUSION

Piezo-resistive pressure sensors produce small amounts of noise that can easily be filtered out with several methods. These methods are low pass filtering with an RC filter, averaging or a combination of both which can be implemented with minimal hardware cost.

In a mixed sensor system, noise can be further reduced by following recommended power supply, grounding and layout techniques.

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Compound Coefficient Pressure Sensor PSPICE Models

by: Warren Schultz

INTRODUCTION

PSPICE models for Uncompensated, MPX2000 series, and MPX5000 series pressure sensors are presented here. These models use compound coefficients to improve modeling of temperature dependent behavior. The discussion begins with an overview of how the models are structured, and is followed by an explanation of compound coefficients. The emphasis is on how to use these models to estimate sensor performance. They can be found electronically on a disk included in ASB200 Sensor Development Controller kits.

MODEL STRUCTURE

Models for all three sensors series share a common structure. They are complete models set up to run as is. To obtain output voltage versus pressure, it is only necessary to run the model and display V(2,4) or V(1,0). V(2,4) gives the output voltage for Uncompensated and MPX2000 series sensors. V(1,0) applies to MPX5000 sensors. In both cases, V(2,4) and V(1,0) correspond to the pin numbers where output voltage would be, if probed on an actual part.

These models are divided into five sections to facilitate ease of use. They are:

- *Input Parameters*
- *Linear to Compound Conversion*
- *Model Coefficients*
- *Circuit*
- *Stimulus*

Each of these sections is described in the following discussion.

INPUT PARAMETERS

This section contains input parameters that describe measurable sensor characteristics. Inputs such as full scale pressure (FSP), full scale span (FSS) offset voltage (VOFFSET), and temperature coefficient of offset voltage (TCOS) are made here. Characteristics that are specific to the transducer, such as bridge impedance (RBRIDGE), temperature coefficient of bridge resistance (TCRB), and temperature coefficient of span (TCSP) are also listed here.

Parameters such as VOFFSET that set an output value for the sensor are used to calculate resistance values that produce those outputs. For example, if you input 100 mV of offset voltage and a 10 µV/degree temperature coefficient of offset voltage, the model will calculate the bridge resistance values necessary to produce 100 mV of offset voltage and a 10 µV/degree temperature coefficient.

In the MPX2000 and MPX5000 models, temperature coefficient of span (TCSP) is handled differently than the other parameters. The non-linear behavior of span over temperature is calculated from the interaction of the transducer's temperature coefficient of span (TCSP), the transducer's temperature coefficient of resistance (TCRB), and the effects of inserting fixed resistance, RTCSPAN, in series with the bridge. The result is a temperature coefficient of span that closely resembles the real thing, but is not directly controlled by the user.

LINEAR TO COMPOUND CONVERSION

The compound coefficients used in these models are from equations of the form:

(1) R(Temp) = R25(1) TCR)(Temp - 25)

where R_{25} is resistance at 25 degrees Celsius, TCR is temperature coefficient of resistance, Temp is an abbreviation for Temperature in degrees Celsius, and R(Temp) is the function resistance versus temperature.

The TCR (temperature coefficient of resistance) in equation (1) is a different number than a temperature coefficient that is stated in linear terms. The three statements in this section convert linear coefficients to the compound values that the models need. This conversion is based upon a 100 degree difference between the two points at which the linear coefficients have been measured.

MODEL COEFFICIENTS

In this section most of the calculation is performed. Values for the transducer bridge resistors are determined from pressure, temperature, offset, temperature coefficient of offset, span, temperature coefficient of span, and temperature coefficient of resistance inputs. A series of parameter statements are used, as much as is practical, to do calculations that will fit in an 80 character line without wraparounds. These calculations use PSPICE's

PARAMETER function, making the models specific to PSPICE. Parameters are described as:

- KP - Pressure constant; translates pressure into a bridge resistance multiplier
- KO - Offset constant; offset component of bridge resistance
- DT - Delta temperature; Temperature *25 degrees Celsius
- KTCO - Temperature coefficient of offset constant; translates temperature coefficient of offset into bridge resistance
- TCR - Temperature coefficient of bridge resistance; shaped by a Table that accounts for cold temperature non-linearity's
- TCR2 - Temperature coefficient of contact resistance; shaped by a Table that accounts for cold temperature non-linearity's
- TCS - Temperature coefficient of Span; shaped by a Table that accounts for cold temperature non-linearity's
- RPH - Bridge Resistance (RS1 and RS3) modified by pressure and temperature
- ROH - Offset Component of Bridge Resistors RS1 and RS3
- RPL - Bridge Resistance (RS2 and RS4) modified by pressure and temperature
- ROL - Offset Component of Bridge Resistors RS2 and RS4
- KB - Bias Constant; adjusts KP for bias voltage effects of span compensation network (MPX2000 and MPX5000 series sensors)
- KBT - Bias Constant; adjusts KO for bias voltage effects of span compensation network (MPX2000 and MPX5000 series sensors)
- GAIN - Instrumentation amplifier gain; differential gain (MPX5000 series)
- ROFF - Offset resistance; determines value of RS13 (MPX5000 series)

After these calculations are made, the final bridge resistance calculation is performed in the circuit section. The value for bridge resistors RS1 and RS3 is RPH + ROH. Bridge resistors RS2 and RS4 are equal to RPL-ROL.

CIRCUIT

Three circuits are used to model the three sensor families, one each for the Uncompensated series, MPX2000 series, and MPX5000 series sensors. Schematics that are derived from the circuit netlists are shown in Figure 1, Figure 2, and Figure 3. They are discussed beginning with the Uncompensated series, which is the least complex.

Uncompensated Series

The Uncompensated Series sensors (MPX10, MPX50, and MPX100) are modeled as Wheatstone bridges. In the configuration that is shown in Figure 1, resistors RS2 and RS4 decrease in value as pressure is applied. Similarly, RS1 and RS3 increase in value as pressure is applied. Resistors RS5 and RS7 are contact resistors. They represent real physical resistors that are used to make contact to the bridge. Resistors RS6 and RS8 are included to satisfy PSPICE's requirement for no floating nodes. That's it. The netlist in this model is quite simple. The hard part is calculating the values for RS1, RS2, RS3, and RS4.

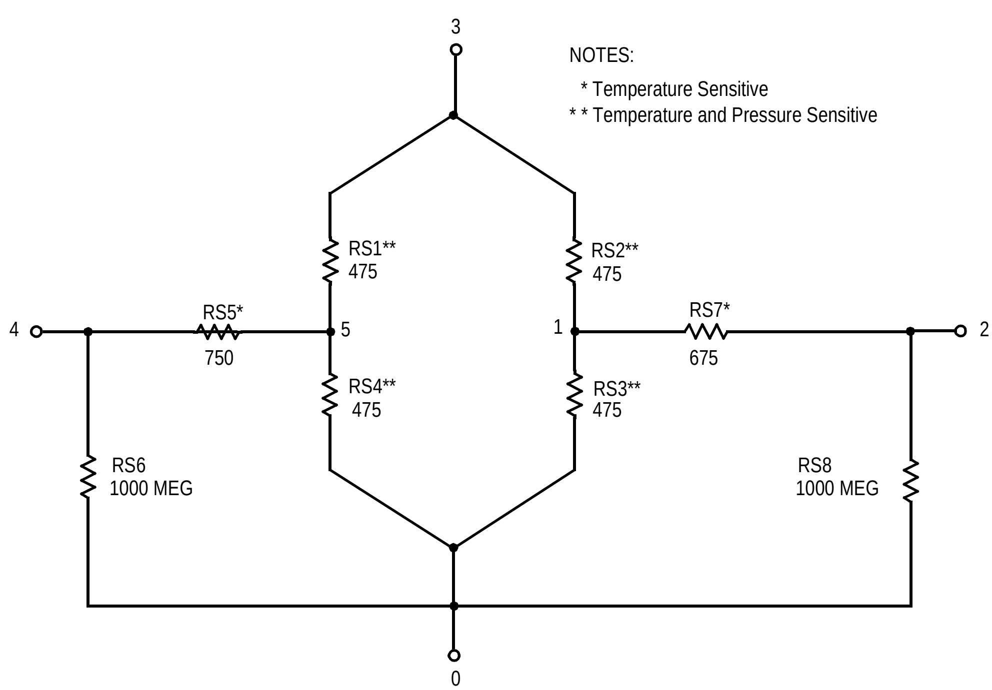

Figure 1. MPX10 and 100 PSPICE Compound Coefficient Model

MPX2000 Series:

The MPX2000 Series sensors (MPX2010, MPX2050, MPX2100, and MPX2200) add span compensation and trim resistors to the Uncompensated model. These resistors are shown in Figure 2 as RS9, RS11, and RS10. The temperature coefficient of resistance (TCR) for the bridge resistors works against fixed resistors RS9 and RS11 to produce a bias to the bridge that increases with temperature. This increasing bias compensates for the temperature coefficient of span, which is negative.

Resistor RS12 is also added to the Uncompensated model. It represents additional impedance that is associated with the MPX2000 series sensors' offset trim network. Offset performance is modeled behaviorally. Inputs for offset (VOFFSET) and temperature coefficient of offset (TCOS) are translated into bridge resistance values that produce the specified performance. This behavioral approach was chosen in order to make it easy to plug in different values for VOFFSET and TCOS.

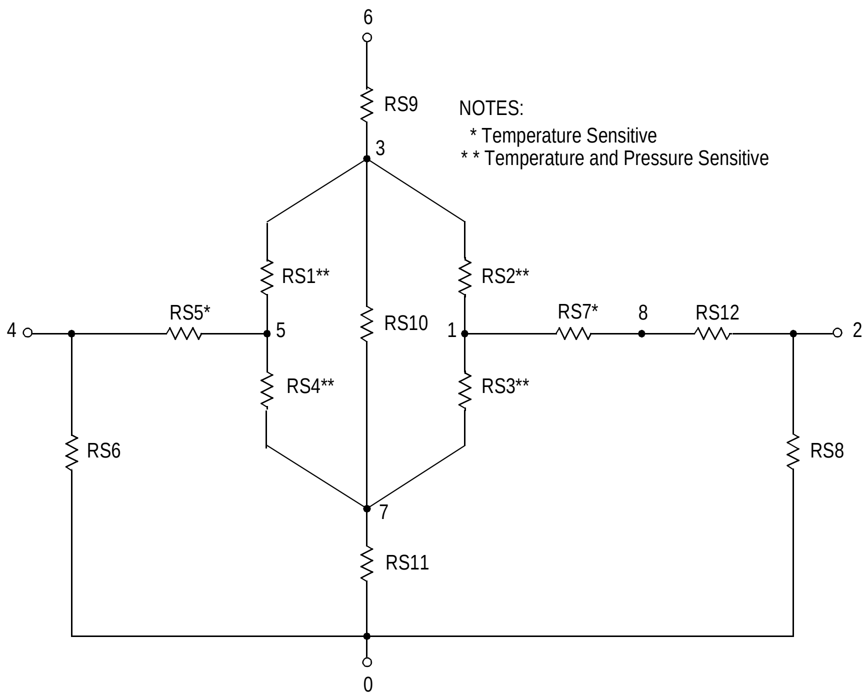

Figure 2. MPX2000 Series PSPICE Compound Coefficient Model

MPX5000 Series

The MPX5000 Series sensors (MPX5010, MPX5050, MPX5100, MPX5700, and MPX5999) add an instrumentation amplifier to the MPX2000 series model. This amplifier is shown in Figure 3. It consists of operational amplifiers ES1, ES2, ES3, and ES4. Amplifiers ES1, ES2 and ES3 are modeled as voltage controlled voltage sources with gains of 100,000. Offset voltage, input bias current effects, etc. are taken into account with the values that are used to determine offset voltage and temperature coefficient of the sensor bridge. Amplifier ES4 models saturation voltage. Its output follows the output of ES3 with saturation limits at 75 millivolts and 4.9 volts.

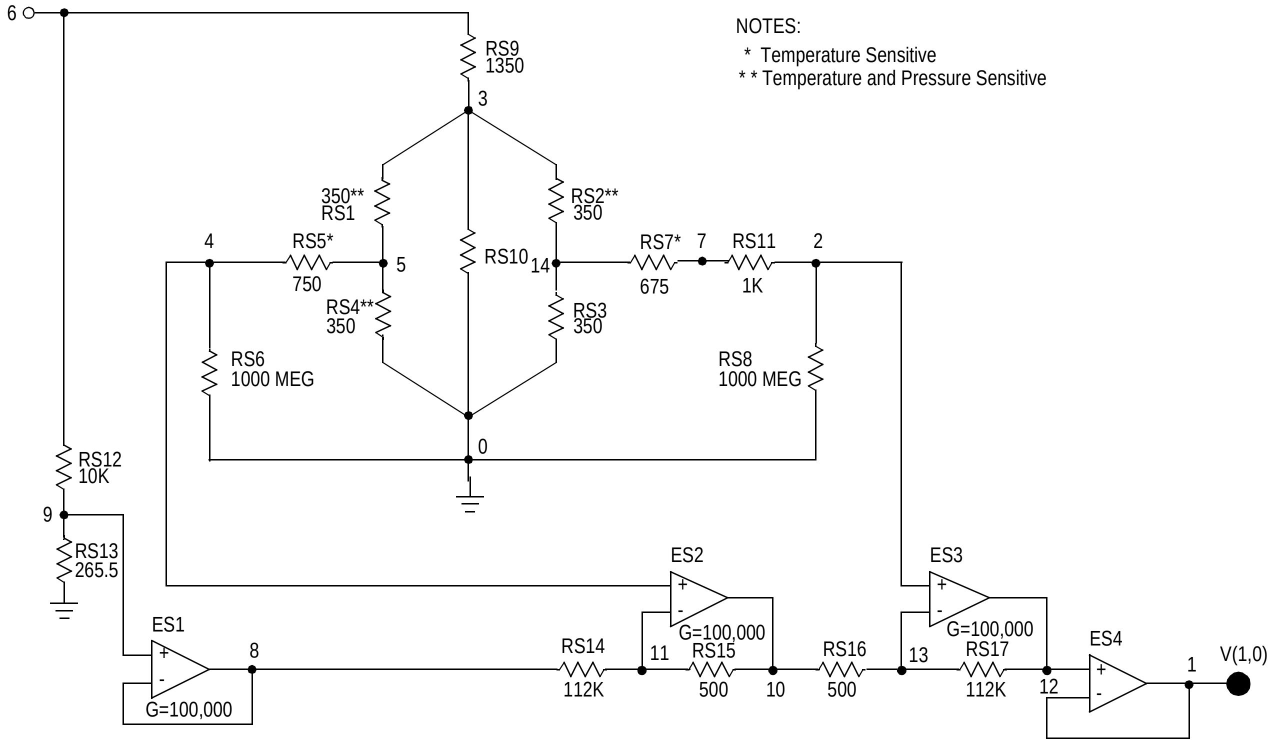

Figure 3. MPX Series PSPICE Compound Coefficient Model

STIMULUS

The last section of these models is labeled STIMULUS. Bias voltage, pressure, and temperature are applied here. Nominal bias voltage (VCC) is 3.0 volts for Uncompensated sensors, 10.0 volts for MPX2000 sensors, and 5.0 volts for MPX5000 sensors. Pressure is selected on the second line. It is effective when the asterisk (*) on line 4 is removed to command a temperature sweep. Line 3 calls for a sweep of pressure and temperature. An asterisk (*) placed in front of Line 3 allows the temperature sweep on line four to be selected.

COMPOUND COEFFICIENTS

Applying temperature coefficients to variables such as resistance is an essential part of modeling. The linear approach, that is usually used, is based upon the assumption that changes are small, and can be modeled with a linear approximation. Using temperature coefficient of resistance as (TCR) as an example, the linear expression takes the form:

(2) R(Temp) = R25(1) TCR(Temp - 25))

Provided that the TCR in equation (2) is 100 parts per million per degree Celsius or less this approach works quite well. With sensor TCR's of several thousand parts per million per degree Celsius, however, the small change assumption does not hold. To accurately model changes of this magnitude, the mathematical expression has to describe a physical process where a unit change in temperature produces a constant percentage change in resistance. For example, a 1% per degree TCR applied to a 1 K Ohm resistor should add 10 ohms to the resistor's value going from 25 to 26 degrees. At 70 degrees, where the resistor has increased to 2006 Ohms, going from 70 to 71 degrees should add 20.06 Ohms to its value. The error in the linear expression comes from that fact that it adds 10 ohms to the resistor's value at all temperatures.

A physical process whereby a unit change in temperature produces a constant percentage change in resistance is easily modeled by borrowing an expression from finance. Compound interest is a direct analog of temperature coefficients. With compound interest, a unit change in time produces a constant percentage change in the value of a financial instrument. It can be described by the expression:

(3) Future Value = Present Value (1) i)n

where i is the interest rate and n is the number of periods. Substituting R_{25} for Present Value, R(Temp) for Future Value, TCR for i, and (Temp - 25) for n yields:

(4) $R(Temp) = R_{25}(1)\ TCR)^{(Temp * 25)}$

Equation (4) works quite well, provided that TCR is constant over temperature. When modeling semiconductor resistors, it is also necessary to account for variable TCR's. At cold, the TCR for p type resistors changes with temperature. These changes are modeled using TABLE functions that have three values for TCR. Results of this modeling technique versus actual measurements and a linear model are summarized in Table 1.

Table 1. Actual versus Modeled R(Temp)

Temp	Measured R(Temp)	Compound Model	Linear Model
*40	406	406	372
*25	418	418	395
0	445	445	434
25	474	474	474
50	509	508	513
75	545	545	552
100	585	584	592
125	627	626	632
150	671	671	671

In Table 1, 25 and 150 degree Celsius data points were used to determine both linear and compound temperature coefficients. Therefore, measured values, linear model values and compound model values all match at these two temperatures. At other temperatures, the linear model exhibits errors that are significant when modeling piezoresistive pressure sensors. The compound model, however, tracks with measured values to within 1 Ohm out of 500 Ohms.

EXAMPLES

Two examples of what the model outputs look like are shown in Figure 4 and Figure 5. Figure 4 shows a sweep of pressure versus output voltage (V_{OUT}) at 0, 25, and 85 degrees Celsius, for an MPX2010 sensor. It has the expected 0 to 25 mV output voltage, given a 0 to 10 kPa pressure input. At these three temperatures, compensation is sufficiently good that all three plots look like the same straight line.

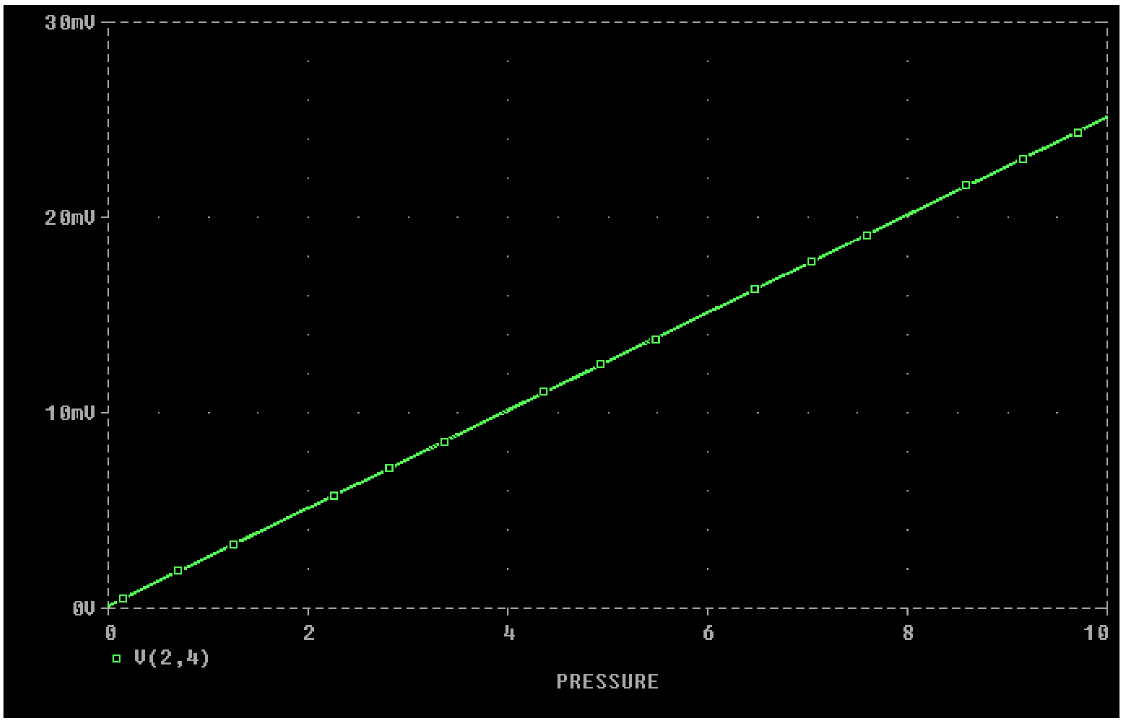

Figure 4. MPX2010 V_{OUT} versus Pressure and Temperature

To produce the plot in Figure 4, the stimulus section is set up as follows, and V(2,4) is probed.

STIMULUS

V_{CC} 6 0 DC=10;   DC BIAS FROM PIN 3 TO PIN 1
.PARAM PRESSURE=0;   INPUT PRESSURE (kPa)
.DC PARAM PRESSURE 0_Kpa 10_Kpa 0.5_Kpa TEMP LIST 0 25 85
*.DC PARAM TEMP -40 125 5
*

This is the default configuration with which the model is shipped. To change to a sweep of zero pressure voltage versus temperature, an asterisk is placed on line 3 and removed from line 4. The stimulus section then looks as follows:

STIMULUS

VCC 6 0 DC=10;   DC BIAS FROM PIN 3 TO PIN 1
.PARAM PRESSURE=0;   INPUT PRESSURE (kPa)
*.DC PARAM PRESSURE 0_Kpa 10_Kpa 0.5_Kpa TEMP LIST 0 25 85
.DC PARAM TEMP -40 125 5
*

Again, V(2,4) is probed. The resulting output appears in Figure 5.

This plot shows offset versus temperature performance that is typical of MPX2000 series sensors. From –40 to +85 degrees Celsius, offset compensation is quite good. Above 85 degrees there is a hook in this curve, that is an important attribute of the sensor's performance.

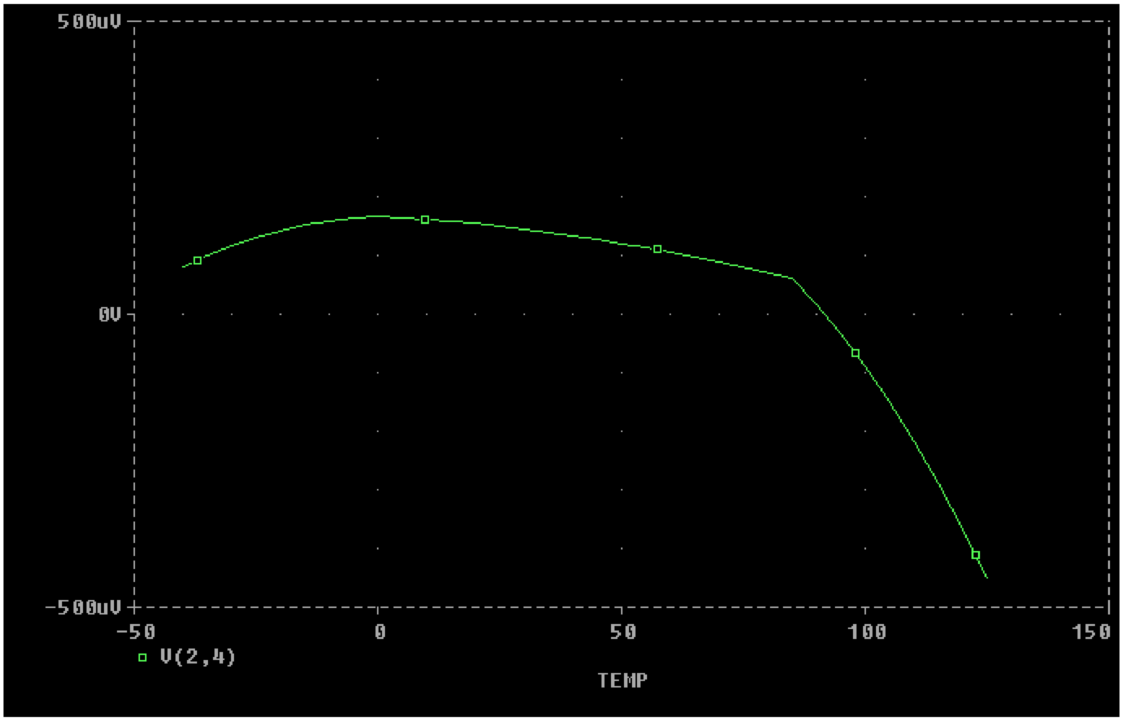

Figure 5. MPX2010 Offset versus Temperature

CONCLUSION

PSPICE models for Uncompensated, MPX2000 series, and MPX5000 series pressure sensors are available for estimating sensor performance. These models make use of the compounding concept that is used in finance to calculate compound interest. The resulting compound temperature coefficients do a better job than linear methods of modeling temperature dependent behavior. These models make extensive use of PSPICE's. PARAMETER statement, and are, therefore, specific to PSPICE. They are intended as references for determining typical sensor performance, and are structured for easy entry of alternate assumptions.

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Washing Appliance Sensor Selection

by: Ador Reodique
Sensor and Systems Applications Engineer

INTRODUCTION

North American washing machines currently in production use mechanical sensors for water level measurement function. These sensors are either purely mechanical pressure switch with discrete trip points or electromechanical pressure sensor with an on-board electronics for a frequency output.

High efficiency machines require high performance sensors (accuracy, linearity, repeatability) even at lower pressure ranges. Benchmarks indicate that these performance goals is difficult to achieve using current mechanical pressure sensors.

In Europe, where energy conservation is mandated, washing machine manufacturers have started to look at electronic solutions where accuracy, reliability, repeatability and additional functionality is to be implemented. North American and Asia Pacific manufacturers are also looking for better solutions.

From surveys of customer requirements, a typical vertical-axis machine calls for a sensor with 600 mm H_2O (24 " H_2O ~ 6 kPa) sensor with a 5% FS accuracy spec. Certain appliances call for a lower pressure range especially in Europe where horizontal axis machines are common.

SENSOR SOLUTIONS

For the typical 600 mm H_2O, 5% FS spec, an off the shelf solution available today is the MPX10/MPX12, MXP2010 and the MPXV4006G sensor. The MPX10 (or the MPX12) is 10 kPa (40 " H_2O) full-scale pressure range device. It is uncompensated for temperature and untrimmed offset and full-scale span. This means that the end user must temperature compensate as well as calibrate the full-scale offset and span of the device. The output of the device must be amplified using a differential amplifier (see Figure 1) so it can be interfaced to an A/D and to obtain the desired range.

Since the MPX10/MPX12 sensors must be calibrated, the implications of this device being used in high-volume production is expensive. Because the offset and full-scale output can vary from part to part, a two-point calibration is required as a minimum. A two point calibration is a time consuming procedure as well as possible modification to the production line to accommodate the calibration process. The circuitry must also accommodate for trimming, i.e., via trimpots and/or EEPROM to store the calibration data. This adds extra cost to the system.

The MPX2010 is a 10 kPa (40" H_2O), temperature compensated, offset and full-scale output calibrated device. A differential amplifier like the one shown in Figure 1 should be used to amplify its output. Unlike the MPX10 or MPX12, this device does not need a two-point calibration but auto-zeroing can improve its performance. This procedure is easily implemented using the system MCU.

The MPXV4006G is a fully integrated pressure sensor specifically designed for appliance water level sensing application. This device has an on board amplification, temperature compensation and trimmed span. An auto-zero procedure should be implemented with this device (refer to Application Note AN1636). Because expensive and time consuming calibration, temperature compensation and amplification is already implemented, this device is more suitable for high volume production. The MPXV4006G integrated sensor is guaranteed to be have an accuracy of ± 3% FS over its pressure and temperature range.

For washing machine applications where low cost and high volume productions are involved, both the MPX2010 and MPXV4006G are recommended. Both solutions can be used in current vertical axis machines where the water level in the 600 mm H_2O or 24 " H_2O range. In the following, a comparison is made between MPX2010 and MPXV4006G in terms of system and performance considerations to help the customer make a decision.

EXPECTED ACCURACY OF THE MPX2010 SYSTEM SOLUTION

The MPX2010 compensated sensor has an off the shelf overall RMS accuracy of ± 7.2% FS over 0 to 85°C temperature range.

Auto-zeroing can improve the sensor accuracy to ± 4.42% FS. However, since this sensor does not have an integrated amplification, its amplifier section must be designed carefully in order to meet the target accuracy requirement. The MPX2010 compensated sensor has the following specifications shown on Table 1.

Table 1. MPX2010 Specifications

Characteristic	Min	Typ	Max	Unit
Pressure Range	0		10	kPa
Supply Voltage		10	16	Vdc
Supply Current		6		mA
Full Scale Span	24	25	26	mV
Offset	*1		1	mV
Sensitivity		25		mV/kPa
Linearity	*1		1	$\%V_{FSS}$
Pressure Hysterisis		0.1		$\%V_{FSS}$
Temperature Hysterisis (*40 to 125°C)		0.5		$\%V_{FSS}$
Temperature Effect on Span	*1		1	$\%V_{FSS}$
Temperature Effect Offset (0 to 85°C)	*1		1	mV
Input Impedance	1300		2550	W
Output Impedance	1400		3000	W
Response Time (10% to 90%)		1		ms
Warm-Up		20		ms

The sensor system errors is made up of the sensor errors, amplifier errors and A/D errors. In other words,

$$\varepsilon System = \sqrt{\varepsilon Sensor^2 + \varepsilon Amplifier^2 + \varepsilon ADResolution^2} \quad (1)$$

Table 2 shows the MPX2010 with the errors converted to $\%V_{FSS}$. The expected maximum root mean squared error of the sensor is

$$\varepsilon Sensor = \sqrt{SpanCal^2 + Lin^2 + Phys^2 + Thys^2 + TCS^2 + OffCal^2 + Tco^2 + OffStab^2} \quad (2)$$

$$= \pm 7.19\% \text{ FS.}$$

With auto-zeroing, the offset calibration, temperature effect on offset and offset stability is reduced or eliminated,

$$\varepsilon Sensor = \sqrt{SpanCal^2 + Lin^2 + Phys^2 + Thys^2 + TCS^2} \quad (3)$$

= +/- 4.42% FS.

The sensor error is calculated using the full-scale pressure range of the device, 0 to 85°C temperature and 10 V excitation.

In comparison with the MPXV4006G solution, the expected accuracy of the system (MPXV4006G + 8 bit A/D) with auto-zero is 3.1% FS.

Table 2. MPX2010 Span, Offset and Calculated Maximum RMS Error*

Span Errors (converted to $\%V_{FSS}$)	Symbol	Error Value	Note	Unit
Span Calibration	SpanCal	4		$\%V_{FSS}$
Linearity	Lin	1		$\%V_{FSS}$
Pressure Hysterisis	Phys	0.1		$\%V_{FSS}$
Temperature Hysterisis	Thys	0.5		$\%V_{FSS}$
Temperature Effect on Span	Tcs	1.5		$\%V_{FSS}$
Offset Errors (converted to $\%V_{FSS}$)				
Offset Calibration	OffCal	4		$\%V_{FSS}$
Temperature Effect on Offset	Tco	4		$\%V_{FSS}$
Offset Stability	OffStab	0.5		$\%V_{FSS}$
Calculated Maximum RMS Errors		**RMS Error**		
No Compensation*		7.19		$\%_{FS}$
With auto-zero		4.42		$\%_{FS}$

* This assumes the power supply is constant.

AMPLIFIER SELECTION AND AMPLIFIER INDUCED ERRORS

A differential amplifier is needed to convert the differential output of the MPX2010 sensor to a high level ground-referenced (single-ended). The classic three-op amp instrumentation amplifier can be used. However, it requires additional components (3 op-amps and possibly a split power supply). An instrumentation topology shown in Figure 1 requires only a single supply and only 2 op-amps and 1% resistors.

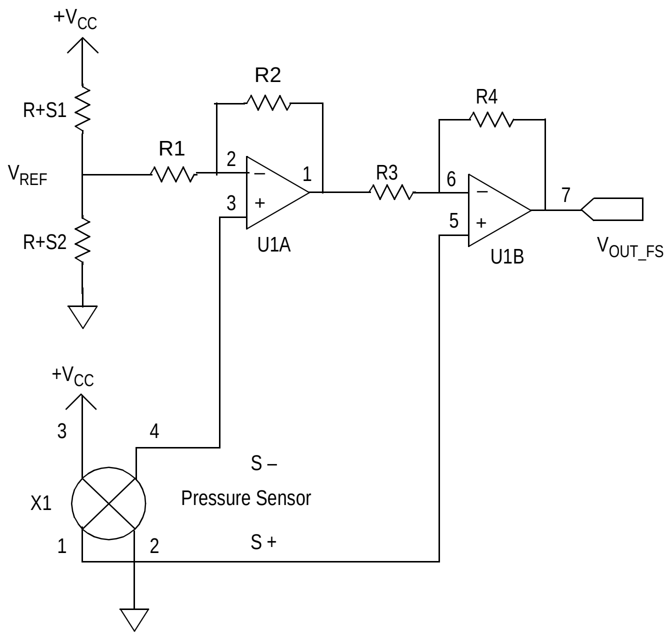

Figure 1. MPX2010 Amplifier Circuit

The circuit uses a voltage divider R+S1 and R+S2 to provide the reference (level shift), U1A and U1B are non-inverting amplifiers arranged in a differential configuration with gain resistors R1, R2, R3, and R4. Note that U1B is the main gain stage and it has the most gain. It is recommended to place a 0.015 μF capacitor in it's feedback loop (in parallel with R4) to reduce noise. The amplifier output can be characterized with the equation below:

$$Gain = \frac{R4}{R3} + 1 \qquad (4)$$

$$Voffset = VREF\left(\frac{R2 \cdot R1}{R1 \cdot R3}\right) - VSCM\left[\left(\frac{R2 \cdot R4}{R1 \cdot R3}\right)\right] - 1 \qquad (5)$$

$$Vout = (S+ - S-)\ Gain + Voffset \qquad (6)$$

where (S+ - S-) = Sensor differential output + Sensor offset (7)

Equation 4 is the differential gain of the amplifier and equation 5 is the resulting offset voltage of the amplifier.

The above equations assume that the amplifier is close to ideal (high A_{OL}, low input offset voltage and low input offset bias currents). Since an ideal op-amp is hard to come by, the customer should select an op-amp based on cost and performance. Below are some points to keep in mind when selecting an op-amp and designing the amplifier circuit.

Note that the ratio R2*R4/R1*R3 controls the system offset as well as the common mode error of the amplifier. Mismatches in these resistors will result in an offset and common mode error which appear as offset. It is therefore recommended to use 1% metal film resistors to reduce these errors. Also, V_{REF} source impedance should be minimized in comparison with R1 in order to reduce common mode error.

Amplifier input offset and input bias currents can induce errors. For example, an input offset (Vio) of the amplifier can become significant when the closed-loop gain of the amplifier is increased. Furthermore, there is also a temperature coefficient of the input voltage offset which contribute an additional error across temperature. If the input bias current of the amplifier is not taken into account in the design, it can also become a source of error. A technique to reduce this error is to match the impedance the source impedance of what the op-amp input pins sees.

It is important to note that high performance op-amps are more expensive. An MC33272 op-amp has a low input offset and low input bias current which is suitable for the two-op amp amplifier design. We can see that there is a tradeoff between accuracy and cost when designing a solution with the MPX2010.

When designing a system based on the MPX2010, it is important to take into account errors due to parametric variation of the sensor (i.e., offset calibration, span calibration, TcS, TcO), power supply and the inherent errors of the amplification circuit. The offset and span errors greatly determines the resolution of the system (which adds to the system error). Even though the system offset error can be nulled out by auto-zeroing, these errors must be accounted for when setting the system gain (refer to AN1556 for more details). This forces the total span of the system to be smaller, because we must reserve an extra headroom from the total span to account for amplifier and A/D variations (i.e., amp. sat. voltage, power supply variation, A/D quantization error, and gain errors). If these errors are not accounted for, it could, for example, result in non-linearity errors if the sensor span or offset error causes the amplified output of the sensor to reach the saturation voltage of the amplifier.

As an example, a MPX2010 sensor system is designed which has a range of 600 mm H_2O FS range with a ±5% FS RMS error. The system uses a +5.0 V ±5% linear regulated power supply, a MC33272 dual op-amp and a 1% resistors.

Table 3 shows the resulting specification and component values for the system based on MPX2010 sensor.

Table 3. MPX2010 Sensor System Values

MPX2010 Sensor Design			
Parameter	Description	Value	Units
V_{CC}	Reg Power Supply	5	V
Differential Gain	Gain	433	V/V
Vout_FS	Full Scale Span	3.02	V
V_{REF}	Offset Reference	0.66	V
Parts List			
U1A,U1B	MC33272 Op-amp		
R1	Gain Resistor	39.2K	Ω
R2	Gain Resistor	90.9	Ω
R3	Gain Resistor	909	Ω
R4	Gain Resistor	392K	Ω
R + S1	Level Shift Resistor	1K	Ω
R + S2	Level Shift Resistor	150	Ω
X1	MPX2010		

Table 4. Performance Comparison between MPX2010 and MPXV4006G Solution

Error Contribution	MPX2010 Solution Error (FS = 600 mm H_2O)		MPXV4006G Solution Error (FS = 612 mm H_2O)	
	± % FS	± mm H_2O	± % FS	± mm H_2O
Max Sensor Error	7.19	43	3.00	18
System Resolution (A/D + Amplification)	1.30	8	0.80	5
System Error (Sensor + A/D + Amplification)	7.3	44	3.10	19
System Error with Auto-Zero	4.6	28	t3	t19

Note that the error due to system resolution is higher for the MPX2010 solution (± 2 bit A/D accuracy). This is because the MPX2010 span is limited as discussed above. Also, this accuracy assumes that the amplifier does not induce significant errors. As noted MPXV4006G sensor has better overall accuracy. The system resolution is very good because of its large span (4.6 V versus 3.0 V typical).

SUMMARY

Several washing machine solutions were examined. The MPX10/12 solution can be expensive in terms of additional support circuitry and the added time and labor involved during the calibration procedure. The MPX2010 is good alternative for high volume manufacturing because is already calibrated. With this solution, however, the system amplifier design must be chosen and designed carefully in order to minimize the system error. This is a consideration when deciding to implement a high accuracy solution with the MPX2010 because the cost of the system will go up.

The MPXV4006G solution is geared towards high volume manufacturing because trimming, compensation and amplification is already on board. Besides the system simplicity and using less component, the resolution and overall accuracy of this solution is better than the MPX2010 solution. In some cases, less components can actually improve the reliability and manufacturability the system.

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Water Level Monitoring

by: Michelle Clifford, Applications Engineer
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INTRODUCTION

Many washing machines currently in production use a mechanical sensor for water level detection. Mechanical sensors work with discrete trip points enabling water level detection only at those points. The purpose for this reference design is to allow the user to evaluate a pressure sensor for not only water level sensing to replace a mechanical switch, but also for water flow measurement, leak detection, and other solutions for smart appliances. This system continuously monitors water level and water flow using the temperature compensated MPXM2010GS pressure sensor in the low cost MPAK package, a dual op-amp, and the MC68HC908QT4, eight-pin microcontroller.

SYSTEM DESIGN

Pressure Sensor

The pressure sensor family has three levels of integration — Uncompensated, Compensated and Integrated. For this design, the MPXM2010GS compensated pressure sensor was selected because it has both temperature compensation and calibration circuitry on the silicon, allowing a simpler, yet more robust, system circuit design. An integrated pressure sensor, such as the MPXV5004G, is also a good choice for the design eliminating the need for the amplification circuitry.

Figure 1. Water Level Reference Design Featuring a Pressure Sensor

The height of most washing machine tubs is 40 cm, therefore the water height range that this system will be measuring is between 0–40 cm. This corresponds to a pressure range of 0–4 kPa. Therefore, the MPXM2010GS was selected for this system. The sensor sensitivity is 2.5 mV/kPa, with a full-scale span of 25 mV at the supply voltage of 10 V_{DC}. The full-scale output of the sensor changes linearly with supply voltage, so a supply voltage of 5 V will return a full-scale span of 12.5 mV.

$$(V_{S\ actual} / V_{S\ spec}) * V_{OUT\ full\text{-}scale\ spec} = V_{OUT\ full\text{-}scale}$$

$$(5.0\ V / 10\ V) \times 25\ mV = 12.5\ mV$$

Since this application will only be utilizing 40 percent of the pressure range, 0–4kPa, our maximum output voltage will be 40 percent of the full-scale span.

$$V_{OUT\ FS} * (\text{Percent}_{FS\ Range}) = V_{OUT\ max}$$

$$12.5\ mV * 40\% = 5.0\ mV$$

The package of the pressure sensor is a ported MPAK package. This allows a tube to be connected to the sensor and the tube is connected to the bottom of the tub. This isolates the sensor from direct contact with the water. The small size and low cost are additional features making this package a perfect fit for this application.

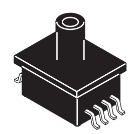

Figure 2. A Ported Pressure Sensor

Table 1. MPXM2010D OPERATING CHARACTERISTICS (V_S = 10 V_{DC}, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range	P_{OP}	0	—	10	kPa
Supply Voltage	V_S	—	10	16	Vdc
Supply Current	I_O	—	6.0	–	mAdc
Full Scale Span	V_{FSS}	24	25	26	mV
Offset	V_{off}	-1.0	—	1.0	mV
Sensitivity	DV/DP	—	2.5	—	mV/kPa
Linearity	—	-1.0	—	1.0	$\%V_{FSS}$

Amplifier Induced Errors

The sensor output needs to be amplified before being inputted directly to the microcontroller through an eight-bit A/D input pin. To determine the amplification requirements, the pressure sensor output characteristics and the 0-5 V input range for the A/D converter had to be considered.

The amplification circuit uses three op-amps to add an offset and convert the differential output of the MPXM2010GS sensor to a ground-referenced, single-ended voltage in the range of 0–5.0 V.

The pressure sensor has a possible offset of ±1 mV at the minimum rated pressure. To avoid a nonlinear response when a pressure sensor chosen for the system has a negative offset (V_{OFF}), we added a 5.0 mV offset to the positive sensor output signal. This offset will remain the same regardless of the sensor output. Any additional offset the sensor or op-amp introduces is compensated for by software routines invoked when the initial system calibration is done.

To determine the gain required for the system, the maximum output voltage from the sensor for this application had to be determined. The maximum output voltage from the sensor is approximately 12.5 mV with a 5.0 V supply since the full-scale output of the sensor changes linearly with supply voltage. This system will have a maximum pressure of 4 kPa at 40 cm of water. At a 5.0 V supply, we will have a maximum sensor output of 5 mV at 4 kPa of pressure. To amplify the maximum sensor output to 5.0 V, the following gain is needed:

Gain = (Max Output needed) / (Max Sensor Output and Initial Offset) = 5.0 V / (0.005 V + 0.005) = 500

The gain for the system was set for 500 to avoid railing from possible offsets from the pressure sensor or the op-amp.

The Voltage Outputs from the sensor are each connected to a non-inverting input of an op-amp. Each op-amp circuit has the same resistor ratio. The amplified voltage signal from the negative sensor lead is V_A. The resulting voltage is calculated as follows:

V_A = (1+R8/R6) * V_4

= (1+10/1000) * V_4

= (1.001) * V_4

The amplified voltage signal from the positive sensor lead is V_B. This amplification adds a small gain to ensure that the positive lead, V_2, is always greater than the voltage output from the negative sensor lead, V_4. This ensures the linearity of the differential voltage signal.

V_B = (1+R7/R5) * V_2 – (R7/R5) * V_{CC}

= (1+10/1000) * V_2 + (10/1000)*(5.0 V)

= (1.001) * V_2 + 0.005 V

The difference between the positive sensor voltage, V_B, and the negative sensor voltage, V_A is calculated and amplified with a resulting gain of 500.

VC = (R12/R11) * (V_B – V_A)

= (500 K/1K) * (V_B – V_A)

= 500 * (V_B – V_A)

The output voltage, V_C, is connected to a voltage follower. Therefore, the resulting voltage, V_C, is passed to an A/D pin of the microcontroller.

The range of the A/D converter is 0 to 255 counts. However, the A/D Values that the system can achieve are dependent on the maximum and minimum system output values:

Count = (V_{OUT} – VRL) / (VRH – VRL) x 255

where V_{Xdcr} = Transducer Output Voltage

V_{RH} = Maximum A/D voltage

V_{LH} = Minimum A/D voltage

Count (0 mm H20) = (2.5 – 0) / (5.0 – 0) * 255 = 127

Count (40 mm H20) = (5.0 – 0) / (5.0 – 0) * 255 = 255

Total # counts = 255 – 127 = 127 counts.

The resolution of the system is determined by the mm of water represented by each A/D count. As calculated above, the system has a span of 226 counts to represent water level up to and including 40 cm. Therefore, the resolution is:

Resolution = mm of water / Total # counts

= 400mm/127 counts = 3.1 mm per A/D count

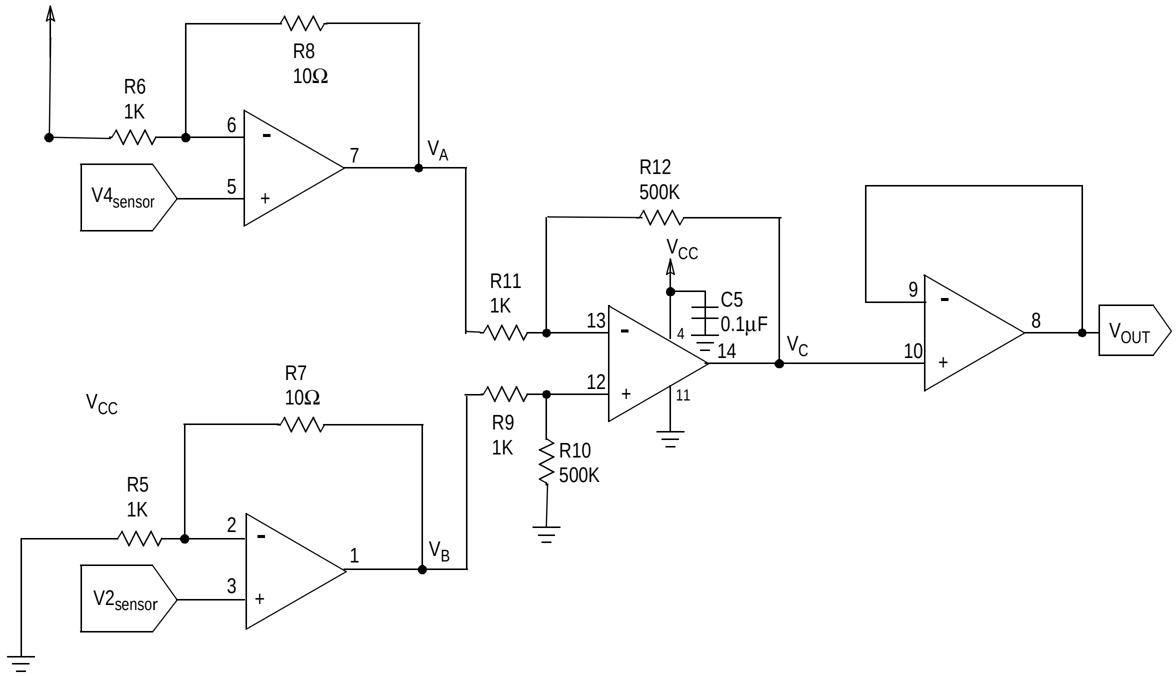

Figure 3. Amplification Scheme

Microprocessor

To provide the signal processing for pressure values, a microprocessor is needed. The MCU chosen for this application is the MC68HC908QT4. This MCU is perfect for appliance applications due to its low cost, small eight-pin package, and other on-chip resources. The MC68HC908QT4 provides: a four-channel, eight-bit A/D, a 16-bit timer, a trimmable internal timer, and in-system FLASH programming.

The central processing unit is based on the high performance M68HC08 CPU core and it can address 64 Kbytes of memory space. The MC68HC908QT4 provides 4096 bytes of user FLASH and 128 bytes of random access memory (RAM) for ease of software development and maintenance. There are five bi-directional input/output lines and one input line shared with other pin features.

The MCU is available in eight-pin as well as 16-pin packages in both PDIP and SOIC. For this application, the eight-pin PDIP was selected. The eight-pin PDIP was chosen for a small package, eventually to be designed into applications as the eight-pin SOIC. The PDIP enables the customer to reprogram the software on a programming board and retest.

Display

Depending on the quality of the display required, water level and water flow can be shown with two LEDs. If a higher quality, digital output is needed, an optional LCD interface is provided on the reference board. Using a shift register to hold display data, the LCD is driven with only three lines outputted from the microcontroller: an enable line, a data line, and a clock signal. The two LEDs are multiplexed with the data line and clock signal

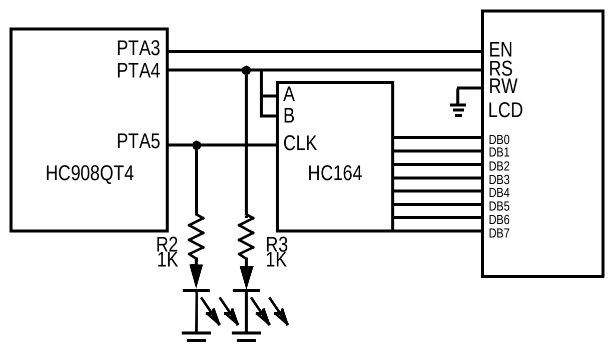

Figure 4. Multiplexed LCD Circuit

Multiplexing of the microcontroller output pins allows communication of the LCD to be accomplished with three pins instead of eight or 11 pins of I/O lines usually needed. With an eight-bit shift register, we are able to manually clock in eight bits of data. The enable line (EN) is manually accepted when eight bytes have been shifted in, telling the LCD the data on the data bus is available to execute.

The LEDs are used to show pressure output data by displaying binary values corresponding to a pressure range. Leak detection, or water-flow speed, is displayed by blinking a green LED at a speed relating to the speed of water flow. The red LED displays the direction of water flow. Turning the red LED off signifies water flowing into the tub. Turning the red LED on signifies water flowing out of the tub, or alternatively, there is a leak.

Digital values for water height, rate of water flow, and calibration values are displayed if an LCD is connected to the board

OTHER

This system is designed to run on a 9.0 V battery. It contains a 5.0 V regulator to provide 5.0 V to the pressure sensor, microcontroller, and LCD. The battery is mounted on the back of the board using a space saving spring battery clip.

Table 2. Parts List

Ref.	Qty	Description	Value	Vendor	Part No.
U2	1	Pressure Sensor	1	Freescale	MPXM2010GS
C1	1	Vcc Cap	0.1µf	Generic	—
C2	1	Op-Amp Cap	0.1µf	Generic	—
C3	1	Shift Register Cap	0.1µf	Generic	—
D1	1	Red LED	—	Generic	—
D2	1	Green LED	—	Generic	—
S2, S3	2	Pushbuttons	—	Generic	—
U1	1	Quad Op-Amp	—	ADI	AD8544
U3	1	Voltage Regulator	5.0 V	Fairchild	LM78L05ACH
U4	1	Microcontroller	8-pin	Freescale	MC68HC908QT4
R1	1	¼ W Resistor	22 K	Generic	—
R2	1	¼ W Resistor	2.4 K	Generic	—
R3, R6	2	¼ W Resistor	1.2 M	Generic	—
R4, R5	2	¼ W Resistor	1.5 K	Generic	—
R7, R8	2	¼ W Resistor	10 K	Generic	—
R9, R10	2	¼ W Resistor	1.0 K	Generic	—
U6	1	LCD (Optional)	16 x 2	Seiko	L168200J000
U5	1	Shift Registor	—	Texas Instruments	74HC164

Smart Washer Software

This application note describes the first software version available. However, updated software versions may be available with further functionality and menu selections.

Software User Instructions

When the system is turned on or reset, the microcontroller will flash the selected LED and display the program title on the LCD for five seconds, or until the select (SEL) button is pushed. Then the menu screen is displayed. Using the select (SEL) pushbutton, it is easy to scroll through the menu options for a software program. To run the water level program, use the select button to highlight the *Water Level* option, then press the enter (ENT) pushbutton. The Water Level program will display current water level, the rate of flow, a message if the container is *Filling*, *Emptying*, *Full*, or *Empty*, and a scrolling graphical history displaying data points representing the past forty level readings.

The Water Level is displayed by retrieving the digital voltage from the internal A/D Converter. This voltage is converted to pressure in millimeters of water and then displayed on the LCD.

Calibration and Calibration Software

To calibrate the system, a two-point calibration is performed. The sensor will take a calibration point at 0 mm and at 40 mm of water. Depressing both the SEL and ENT buttons on system power-up enters the calibration mode. At this point, the calibration menu is displayed with the previously sampled offset voltage. To recalibrate the system, expose the sensor to atmospheric pressure and press the SEL button (PB1). At this point, the zero offset voltage will be sampled and saved to a location in the microcontroller memory. To obtain the second calibration point, place the end of the plastic tube from the pressure sensor to the bottom of a container holding 40 mm of water. Then press the ENT button (PB2). The voltage output will be sampled, averaged and saved to a location in memory. To exit the calibration mode, press the SEL (PB1) button.

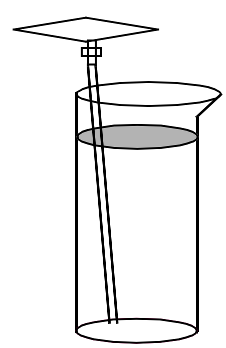

Figure 5. Water Level System Set-Up for Demonstration

Converting Pressure to Water Level

Hydrostatic pressure being measured is the pressure at the bottom of a column of fluid caused by the weight of the fluid and the pressure of the air above the fluid. Therefore, the hydrostatic pressure depends on the air pressure, the fluid density and the height of the column of fluid.

$$P = P_a + \rho\ g\ \Delta h$$

where P = pressure

Pa = pressure

ρ = mass density of fluid

g = 9.8066 m/s^2

h = height of fluid column

To calculate the water height, we can use the measured pressure with the following equation, assuming the atmospheric pressure is already compensated for by the selection of the pressure sensor being gauge:

$$\Delta h = P \backslash \rho\ g$$

Software Function Descriptions

Main Function

The main function calls an initialization function *Allinit* calls a warm-up function, *Warmup,* to allow extra time for the LCD to initialize, then checks if buttons PB1 and PB2 are depressed. If they are depressed concurrently, it calls a calibration function *Calib*. If they are not both pressed, it enters the main function loop. The main loop displays the menu, moves the cursor when the PB1 is pressed and enters the function corresponding to the highlighted menu option when PB2 is depressed.

Calibration Function

The calibration function is used to obtain two calibration points. The first calibration point is taken when the head tube is not placed in water to obtain the pressure for 0 mm of water. The second calibration point is obtained when the head tube is placed at the bottom of a container with a height of 160 mm. When the calibration function starts, a message appears displaying the A/D values for the corresponding calibration points currently stored in the flash. To program new calibration points, press PB1 to take 256 A/D readings at 0 mm of water. The average is calculated and stored in a page of flash. Then the user has the option to press PB1 to exit the calibration function or obtain the second calibration point. To obtain the second calibration point, the head tube should be placed in 160 mm of water, before depressing PB2 to take 256 A/D readings. The average is taken and stored in a page of flash. Once the two readings are taken, averaged, and stored in the flash, a message displays the two A/D values stored.

Level Function

The Level function initializes the graphics characters. Once this is complete, it continues looping to obtain an average A/D reading, displaying the Water Level, the Water Flow, and a Graphical History until simultaneously depressing both PB1 and PB2 to return to the main function.

The function first clears the 40 pressure readings it updates for the Graphical History. The history then enters the loop first displaying eight special characters, each containing five data points of water level history. The function *adcbyta* is called to obtain the current averaged A/D value. The function *LfNx* is called to convert the A/D value to a water level. It is then compared to the calibration points, the maximum and minimum points, to determine if the container is full or empty. If true, then it displays the corresponding message. The current water level is compared to the previous read and displays the message *filling* if it has increased, *emptying* if it has decreased, and *steady* if it has not changed.

The water level calculation has to be converted to decimal in order to display it in the LCD. To convert the water level calculation to decimal, the value is continually divided with the remainder displayed to the screen for each decimal place. To display the Rate of Water Flow, the sign of the value is first determined. If the value is negative, the one's complement is taken, a negative sign is displayed, and then the value is continually divided to display each decimal place. If the number is positive, a plus sign.

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The most complicated part of this function is updating the graphics history display. The characters for the 16x2 LCD chosen for this reference design are 8x5 pixels by default. Therefore, each special character that is created will be able to display five water level readings. Since the height of the special character is eight pixels, each vertical pixel position will represent a water level in increments of 20 mm.

$$\text{Resolution} = (H1 - H0) / D$$

where H1 and H2 are the maximum and minimum water levels respectively and D is the possible datapoints available per character.

Resolution = (160mm– 0mm) / 8.0 = 20 mm / data point.

The graphical history is displayed using the eight special characters. To update the graphics, all the characters have to be updated. The characters are updated by first positioning a pixel for the most recent water level reading in the first column of the first character. Then the four right columns of the first character are shifted to the right. The pixel in the last column of that character is carried to the first column of the next character. This column shifting is continued until all 40 data points have been updated in the eight special characters.

LfNx Function

The LfNx function calculates the water level from the current A/D pressure reading. The A/D Pressure value is stored in Register A before this function is called. Using the A/D value and the calibration values stored in the flash, the water level is calculated from the following function:

RBRA: = (NX –N1) * 160 / (N2 – N1),

where NX is the current A/D Value

N1 is the A/D Value at 0 mm H20

N2 is the A/D Value at 160 mm H20

To simplify the calculation, the multiplication is done first. Then the function *NdivD* is called to divide the values.

NdivD Function

The *NdivD* function performs a division by counting successive subtractions of the denominator from the numerator to determine the quotient. The denominator is subtracted from the numerator until the result is zero. If there is an overflow, the remainder from the last subtraction is the remainder of the division.

wrflash and ersflsh Functions

The *wrflash* and *ersflsh* functions are used to write to and erase values from the flash. For more information regarding flash functionality, refer to Section Four, Flash Memory from the *MC68HC908QY4/D* Databook.

ALLINIT Function

The *Allinit* function disables the COP for this version of software, sets the data direction bits, and disables the data to the LCD and turns off the LCD enable line. It also sets up the microcontroller's internal clock to half the speed of the bus clock. See Section 15, Computer Operating Properly, of the MC68908QT4 datasheet for information on utilizing the COP module to help software recover from runaway code.

WARMUP Function

The *Warmup* function alternates the blinking of the two LEDs ten times. This gives the LCD some time to warm up. Then the function *warmup* calls the LCD initialization function, *lcdinit*.

bintasc Function

The *binasc* function converts a binary value to its ascii representation.

A/D Functions

The A/D functions are used to input the amplified voltage from the pressure sensor from channel 0 of the A/D converter. The function *adcbyti* will set the A/D control register, wait for the A/D reading and load the data from the A/D data register into the accumulator. The function *adcbyta* is used to obtain an averaged A/D reading by calling *adcbyti* 256 times and returning the resulting average in the accumulator.

LCD Functions

The LCD hardware is set up for multiplexing three pins from the microcontroller using an eight-bit shift register. Channels three, four, and five are used on port A for the LCD enable (E), the LCD reset (RS), and the shift register clock bit, respectively. The clock bit is used to manually clock data from channel four into the eight-bit shift register. This is the same line as the LCD RS bit because the MSB of the data is low for a command and high for data. The RS bit prepares the LCD for instructions or data with the same bit convention. When the eight bits of data are available on the output pins of the shift register, the LCD enable (E) is toggled to receive the data.

The LCD functions consist of an initialization function *lcdinit* which is used once when the system is started and five output functions. The functions *lcdcmdo* and *lcdchro* both send a byte of data. The function *shiftA* is called by both *lcdcmdo* and *lcdchro* to manually shift eight bits of data into the shift register. The function *lcdnibo* converts the data to binary before displaying. The *lcdnibo* displays a byte of data by calling *lcdnibo* for each nibble of data. The function *lcdnibo* enables strings to be easily added to the software for display. The function accepts a comma- delimited string of data consisting of 1–2 commands for clearing the screen and positioning the cursor. It then continues to output characters from the string until the @ symbol is found, signally the end of the string.

CONCLUSION

The water level reference design uses a MPXM2010GS pressure sensor in the low cost MPAK package, the low cost, eight-pin microcontroller, and a quad op-amp to amplify the sensor output voltage. This system uses very few components, reducing the overall system cost. This allows for a solution to compete with a mechanical switch for water level detection but also offer additional applications such as monitoring water flow for leak detection, and the other applications for smart washing machines.

SOFTWARE LISTING

```
;NitroWater 2.0  24Jan03
;--------------
;
;Water Level Reference Design
;****************************
; - uses 908QT4 (MC68HC908QT4) and MPAK (MPXM2010GS)
;     CALIB: 2-point pressure calibration (0mm and 160mm)
;     LEVEL: displays water level, flow, and graphics
;     UNITS: allows user to select between cm and inches
;
;_______________________________________________________________
ram       equ    $0080          ;memory pointers
rom       equ    $EE00
vectors   equu   $FFDE
;_______________________________________________________________
porta     equ    $00            ;registers
ddra      equ    $04
config2   equ    $1E
config1   equ    $1F
tsc       equ    $20
tmodh     equ    $23
icgcr     equ    $36
adscr     equ    $3C
adr       equ    $3E
adiclk    equ    $3F
flcr      equ    $FE08
flbpr     equ    $FFBE
;_______________________________________________________________
          org    $FD00          ;flash variables
N1        db     $96            ;1st calibration pt. =   0mm
          org    $FD40
N2        db     $F6            ;2nd calibration pt. = 160mm
          org    $FD80
;_______________________________________________________________
          org    vectors
          dw     cold           ;ADC
          dw     cold           ;Keyboard
          dw     cold           ;not used
          dw     cold           ;not used
          dw     cold           ;not used
          dw     cold           ;not used
          dw     cold           ;not used
          dw     cold           ;not used
          dw     cold           ;not used
          dw     cold           ;not used
          dw     cold           ;TIM Overflow
          dw     cold           ;TIM Channel 1
          dw     cold           ;TIM Channel 0
          dw     cold           ;not used
          dw     cold           ;IRQ
          dw     cold           ;SWI
          dw     cold           ;RESET ($FFFE)
;_______________________________________________________________
          org    ram
BB        ds     1              ;variables
flshadr   ds     2
flshbyt   ds     1
memSP     ds     2
mem03     ds     2
```

```
CNT      ds    1
Lgfx     ds    1
weath    ds    1
UnitType ds    1
UnitDiv  ds    1
UnitEmpt ds    1
UnitFull ds    1
ram0     ds    1
NC       ds    1
NB       ds    1
NA       ds    1
DC       ds    1
DB       ds    1
DA       ds    1
MB       ds    1
MA       ds    1
OB       ds    1
OA       ds    1
RB       ds    1
RA       ds    1
P0C      ds    1
P0B      ds    1
P0A      ds    1
NPTR     ds    1
ramfree  ds    80          ;used both for running RAM version of wrflash & storing 40 readings
;_______________________________________________________________
;_______________________________________________________________
;_______________________________________________________________
         org   rom
cold:    rsp                 ;reset SP if any issues (all interrupt vectors point here)
         jsr   ALLINIT       ;general initialization
         jsr   WARMUP        ;give LCD extra time to initialize

         brset 1,porta,nocalib
         brset 2,porta,nocalib
         jmp   CALIB         ;only do calibration if SEL & ENT at reset

nocalib: ldhx  #msg01        ;otherwise skip and show welcome messages
         jsr   lcdstro       ;"Reference Design" msg
         jsr   del1s         ;wait 1s
         ldhx  #msg01a       ;"Water Level" msg
         jsr   lcdstro
         jsr   del1s         ;wait 1s

initCM:  ldhx  #$A014        ;initialize default units to cm ($A0=cm, $3F=in)
         sthx  UnitType      ;UnitType set to $A0; UnitDiv set to $14
         ldhx  #$039E
         sthx  UnitEmpt      ;UnitEmpt set to $03; UnitFull set to $9E

MENU:    ldhx  #msg01b
         jsr   lcdstro       ;Menu msg
         clr   RA            ;menu choice=0 to begin with
         lda   #$0D
         jsr   lcdcmdo       ;blink cursor on menu choice

luke:    ldx   RA            ;get current menu choice
         clrh
         lda   menupos,x     ;and look up corresponding LCD address
         jsr   lcdcmdo       ;reposition cursor
```

```
warm:     brclr  1,porta,PB1     ;check for SEL
          brclr  2,porta,PB2     ;or for ENT
          bclr   4,porta         ;otherwise
          bset   5,porta         ;turn on "SEL" LED
          jsr    del100ms        ;delay
          bset   4,porta         ;toggle LEDs
          bclr   5,porta         ;"ENT" now on: means choice is SEL ***or*** ENT
          jsr    del100ms        ;delay and repeat until SEL or ENT
          bra    warm

PB1:      inc    RA              ;***SEL*** toggles menu choices
          lda    RA
          cmp    #$02            ;menu choices are $00 and $01
          bne    PB1ok
          clr    RA              ;back to $00 when all others have been offered
PB1ok:    bclr   4,porta
          bclr   5,porta         ;LEDs off
          jsr    del100ms        ;wait a little bit
          brclr  1,porta,PB1ok   ;make sure they let go of SEL
          bra    luke

PB2:      bclr   4,porta         ;***ENT*** confirms menu choice
          bclr   5,porta         ;LEDs off
          lda    RA              ;get menu choice
          bne    skip00
          jmp    LEVEL           ;do ===LEVEL=== if choice=$01
skip00:   jmp    UNITS           ;do ===UNITS=== if choice=$00
;_____________________________________________________________
;_____________________________________________________________
CALIB:    lda    #$01
          jsr    lcdcmdo
          clr    ram0

          ldhx   #msg05          ;===CALIB=== 2-point calibration
          jsr    lcdstro         ;Calibration current values
          lda    N1              ;0mm
          jsr    lcdbyto
          lda    #'/'
          jsr    lcdchro
          lda    N2              ;160mm
          jsr    lcdbyto
          bset   4,porta
          bset   5,porta         ;LEDs on
lego1:    brclr  1,porta,lego1
lego2:    brclr  2,porta,lego2
          bclr   4,porta
          bclr   5,porta         ;LEDs off when both SEL & ENT are released
          jsr    del1s
          jsr    del1s           ;wait 2s
          ldhx   #msg05a
          jsr    lcdstro         ;show instructions
waitPB1:  brset  2,porta,no2     ;if ENT is not pressed, skip
          jmp    nocalib         ;if ENT is pressed then cancel calibration
no2:      brclr  1,porta,do1st   ;if SEL is pressed then do 1st point cal
          bra    waitPB1         ;otherwise wait for SEL or ENT
do1st:    ldhx   #msg05b         ;1st point cal: show values
          jsr    lcdstro
          clr    CNT             ;CNT will count 256 A/D readings
          clr    RB
          clr    RA              ;RB:RA will contain 16-bit add-up of those 256 values
```

```
do256:  lda   #$C9
        jsr   lcdcmdo     ;position LCD cursor at the right spot
        lda   CNT
        deca
        jsr   lcdbyto     ;display current iteration $FF downto $00
        lda   #':'
        jsr   lcdchro
        jsr   adcbyti     ;get reading
        add   RA
        sta   RA
        lda   RB
        adc   #$00
        sta   RB          ;add into RB:RA (16 bit add)
        jsr   lcdbyto     ;show RB
        lda   RA
        jsr   lcdbyto     ;then RA
        dbnz  CNT,do256   ;and do 256x
        lsl   RA          ;get bit7 into carry
        bcc   nochg       ;if C=0 then no need to round up
        inc   RB          ;otherwise round up
nochg:  lda   RB          ;we can discard RA: average value is in RB
        ldhx  #N1         ;point to flash location
        jsr   wrflash     ;burn it in!
        ldhx  #msg05c     ;ask for 160mm
        jsr   lcdstro
waitPB2: brset 2,porta,waitPB2 ;wait for ENT
        ldhx  #msg05d     ;2nd point cal: show values
        jsr   lcdstro
        clr   CNT         ;ditto as 1st point cal
        clr   RB
        clr   RA
do256b: lda   #$C9
        jsr   lcdcmdo
        lda   CNT
        deca
        jsr   lcdbyto
        lda   #':'
        jsr   lcdchro
        jsr   adcbyti
        add   RA
        sta   RA
        lda   RB
        adc   #$00
        sta   RB
        jsr   lcdbyto
        lda   RA
        jsr   lcdbyto
        dbnz  CNT,do256b
        lsl   RA
        bcc   nochg2
        inc   RB
nochg2: lda   RB
        cmp   N1          ;compare N2 to N1
        bne   validcal    ;if different, we are OK
        ldhx  #msg05e     ;otherwise warn of INVALID CAL!
        jsr   lcdstro
        jsr   del1s
        jsr   del1s
        jsr   del1s       ;wait 2s
        jmp   CALIB       ;try cal again
```

```
validcal: ldhx   #N2
        jsr    wrflash        ;burn N2 into flash
        ldhx   #msg05         ;and display new current cal values from flash
        jsr    lcdstro
        lda    N1             ;0mm value
        jsr    lcdbyto
        lda    #'/'
        jsr    lcdchro
        lda    N2             ;160mm value
        jsr    lcdbyto
        jsr    del1s
        jsr    del1s
        jmp    nocalib        ;done!
;____________________________________________________________
;____________________________________________________________
LEVEL:    lda    #$01         ;===LEVEL=== main routine: displays level, flow & graphics
        jsr    lcdcmdo        ;clear screen
        lda    #$0C
        jsr    lcdcmdo        ;cursor off

        lda    #$88           ;position cursor at LCD graphics portion
        jsr    lcdcmdo        ;(2nd half of first line)
        clra                  ;and write ascii $00 through $07
fillgfx:  jsr    lcdchro      ;which contain the graphics related to
        inca                  ;40 different readings
        cmp    #$08           ;do all 8
        bne    fillgfx

LVL:      ldhx   #ramfree     ;point to 40 pressure readings
        lda    #$28           ;count down from 40
purge:    clr    0,x          ;clear all those locations
        incx                  ;next (H cannot change: we are in page0 RAM)
        dbnza  purge
        jsr    adcbyta        ;get averaged A/D reading (i.e. NX)
        jsr    LfNx           ;convert to level and
        sta    Lgfx           ;store in "Level graphics"

LVLwarm:  bset   4,porta
        bset   5,porta        ;LEDs on during this cycle

        ldhx   #ramfree       ;point to 40 pressure readings
        mov    #$27,RA        ;count down from 39
shiftgfx: lda    1,x          ;take location+1
        sta    0,x            ;and move to location+0, i.e. shift graphics left
        incx                  ;next X (once again: we are in page 0, no need to worry about H)
        dbnz   RA,shiftgfx    ;do this 39x

        jsr    adcbyta        ;get averaged A/D reading (i.e. NX)
        jsr    LfNx           ;LX:=(NX-N1)*ConversionValue/(N2-N1)
        mov    RA,OA          ;store result in OA

        clr    RB             ;RB will contain graphic pixels (default=$00)
        cmp    UnitEmpt       ;if <UnitEmpty (preset value = empty or almost)
        bcs    Lzero          ;then "empty"  (no pixels)
        cmp    UnitFull       ;if >=UnitFull (preset value = full or almost)
        bcc    Lsat           ;then "full"   (pixel $80=bit 7)
        clrh                  ;otherwise determine one of 8 graphic values
        ldx    UnitDiv        ;UnitDiv is roughly full range/8
        div                   ;in order to give 8 values
        mov    #$01,RB        ;but now value has to be converted to pixel
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        cmp    #$01           ;if result is $01
        beq    Lzero          ;then display it directly
makeRB  lsl    RB             ;otherwise shift 1 pixel bit to the right place
        dbnza  makeRB         ;by counting down result of division
        bra    Lzero
Lsat:   mov    #$80,RB        ;if full then position highest pixel
Lzero:  lda    RB
        ldhx   #ramfree+$27   ;last of the 40
        sta    0,x            ;put it at then end of the 40 bytes (new value), all others were shifted left

        clr    weath          ;weath will contain dynamic change based also on value of RB
        lda    RB
        beq    donew          ;if RB=$00 then weath=$00: "empty"
        cmp    #$80
        bne    notfull        ;
        mov    #$01,weath     ;if $80 then weath=$01: "full"
        bra    donew
notfull mov    #$02,weath     ;prepare for "steady" if L(i)=L(i-1)
        lda    OA             ;get current level value L(i)
        cmp    Lgfx           ;compare to previous level value L(i-1)
        beq    donew
        mov    #$03,weath     ;"filling" if L(i)>L(i-1)
        bcc    donew
        mov    #$04,weath     ;"emptying" otherwise

donew:  lda    OA             ;current level L(i)
        sub    Lgfx           ;minus previous level L(i-1)
        sta    MA             ;establishes rate: L(i)-L(i-1)
        mov    RA,Lgfx        ;update L(i-1)
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
golevel: lda   #$80           ;******** now let's display the level in decimal ********
        jsr    lcdcmdo        ;start on 1st character of 1st line

        lda    OA             ;get current level value
        clrh
        ldx    #$64           ;and divide by 100
        div
        bne    over100        ;if result is >0 then handle "hundreds"
        lda    #$20           ;otherwise display space (remove leading 0)
        jsr    lcdchro
        bra    lnext
over100: jsr   lcdnibo        ;display "hundreds" digit
lnext:  pshh
        pula                  ;move remainder into A
        clrh
        ldx    #$0A           ;divide by 10
        div
        jsr    lcdnibo        ;display "tens" digit
        lda    #'.'
        jsr    lcdchro        ;display decimal point
        pshh
        pula
        jsr    lcdnibo        ;and first decimal
        lda    UnitType       ;check for cm ($A0) vs. in (#3F)
        cmp    #$3F
        beq    dsplIN

dsplCM: lda    #'c'
        jsr    lcdchro
        lda    #'m'
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        jsr    lcdchro       ;display "cm" for centimeters
        bra    goflow

dsplIN:  lda    #'i'
        jsr    lcdchro
        lda    #'n'
        jsr    lcdchro       ;display "in" for inches
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
goflow:  lda    #$C0          ;******** now let's display the flow in decimal ********
        jsr    lcdcmdo       ;position cursor on 1st character 2nd line
        lda    MA            ;get flow
        lsla                 ;test sign of rate (in MA)
        bcc    positiv       ;if positive, then it's easy

        lda    MA            ;otherwise 1's complement of MB
        coma
        inca
        sta    MA
        cmp    #$64          ;check to see if >100
        bcs    not2lo        ;if not we are OK
        lda    #'<'          ;otherwise display that we exceeded min rate
        jsr    lcdchro       ;that LCD can display (<9.9)
        lda    #$63          ;force value to 99
        sta    MA
        bra    goconv

not2lo:  lda    #'-'
        jsr    lcdchro       ;display that minus sign
        bra    goconv

positiv: lda    MA
        cmp    #$64          ;check to see if >100
        bcs    not2hi        ;if not we are OK
        lda    #'>'          ;otherwise display that we exceeded max rate
        jsr    lcdchro       ;that LCD can display (>9.9)
        lda    #$63          ;force value to 99
        sta    MA
        bra    goconv

not2hi:  lda    #'+'
        jsr    lcdchro       ;display the plus sign (to keep alignment)

goconv:  lda    MA            ;get flow
        clrh
        ldx    #$0A          ;and divide by 10
        div
        jsr    lcdnibo       ;display "tens" digit
        lda    #'.'
        jsr    lcdchro       ;display decimal point
        pshh
        pula
        jsr    lcdnibo       ;and first decimal
        lda    UnitType      ;check for cm ($A0) vs. in (#3F)
        cmp    #$3F
        beq    dsplINf

dsplCMf: lda    #'c'
        jsr    lcdchro
        lda    #'m'
        bra    reusef
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```
dsplINf:  lda    #'i'
          jsr    lcdchro
          lda    #'n'
reusef:   jsr    lcdchro
          lda    #'/'
          jsr    lcdchro
          lda    #'s'
          jsr    lcdchro
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
gfxupdt:  lda    #$40          ;======== Graphics Update: tough stuff ===========
          jsr    lcdcmdo        ;prepare to write 8 bytes into CGRAM starting at @ $40
ldhx#ramfree;point to 40 pressure readings (this reuses wrflash RAM)
          mov    #$08,DA        ;DA will count those 8 CGRAM addresses
cg8:      lda    0,x
  sta NC
  lda 1,x
  sta NB
  lda 2,x
  sta NA
  lda 3,x
  sta DC
  lda 4,x
staDB;readings 0-4 go into NC,NB,NA,DC,DB and will form 1 LCD special
character
          mov    #$08,RA        ;RA will count the 8 bits
fill:clrRB;start with RB=0, this will eventually contain the data for CGRAM
  rol NC
  rolRB
    rol NB
  rolRB
  rol NA
  rolRB
  rol DC
  rolRB
  rol DB
rolRB;rotate left those 5 values and use carry bits to form RB (tough part)
  lda RB
jsrlcdchro;and put it into CGRAM
dec RA            ;do this 8 times to cover all 8 bits
  bne fill
          incx
          incx
          incx
          incx
 incx ;now point to next 5 values for next CGRAM address (5 values per
 character)
          dec    DA            ;do this for all 8 CGRAM characters
          bne    cg8

ldaweath;get weather variable and decide which message to display
          cmp    #$04
          bne    try3210
          ldhx   #msg02e        ;if $04
          bra    showit
try3210:  cmp    #$03
          bne    try210
          ldhx   #msg02d        ;if $03
          bra    showit
try210:   cmp    #$02
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        bne    try10
        ldhx   #msg02c        ;if $02
        bra    showit
try10:  cmp    #$01
        bne    try0
        ldhx   #msg02b        ;if $01
        bra    showit
try0:   ldhx   #msg02a        ;otherwise this one
showit: jsr    lcdstro
        jsr    del1s          ;1s between pressure/altitude readings
        brset  1,porta,contin ;exit only if SEL
        brset  2,porta,contin ;and ENT pressed together
        jmp    MENU
contin: jmp    LVLwarm
;___________________________________________________________________
LfNx:   sub    N1             ;*** PX=f(NX,N2,N1) ***
        ldx    UnitType       ;$A0=160 for cm, $3F=63 for in
        mul
        sta    NA
        stx    NB
        clr    NC             ;NCNBNA:=(NX-N1)* (conversion value: 160 or 63)

        lda    N2
        sub    N1
        sta    DA
        clr    DB
        clr    DC
        jsr    NdivD          ;RBRA:=(NX-N1)*(conversion value)/(N2-N1)

        lda    RA
        cmp    #$C8           ;check to see if result is negative
        bcs    noovflw        ;if <$C8 we are OK
ovflw:  clr    RA             ;otherwise force level to 0!
noovflw: lda   RA
        rts
;___________________________________________________________________
NdivD:  clr    RA             ;RBRA:=NCNBNA/DCDBDA
        clr    RB             ;destroys NCNBNA and DCDBDA
keepatit: lda  RA
        add    #$01
        sta    RA
        lda    RB
        adc    #$00
        sta    RB             ;increment RB:RA
        lda    NA
        sub    DA
        sta    NA
        lda    NB
        sbc    DB
        sta    NB
        lda    NC
        sbc    DC
        sta    NC             ;NC:NB:NA:=NC:NB:NA-DC:DB:DA
        bcc    keepatit       ;keep counting how many times until overflow
        lda    RA
        sub    #$01
        sta    RA
        lda    RB
        sbc    #$00
        sta    RB             ;we counted once too many, so undo that
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        lsr    DC
        ror    DB
        ror    DA             ;divide DC:DB:DA by 2
        lda    NA
        add    DA
        sta    NA
        lda    NB
        adc    DB
        sta    NB
        lda    NC
        adc    DC
        sta    NC             ;and add into NC:NB:NA
        lsla
        bcs    nornd          ;if carry=1 then remainder<1/2 of dividend
        lda    RA
        add    #$01
        sta    RA
        lda    RB
        adc    #$00
        sta    RB             ;otherwise add 1 to result
nornd:  rts
;____________________________________________________________
;____________________________________________________________
UNITS:  brclr  2,porta,UNITS  ;let go of ENT first
        lda    #$01           ;===UNITS=== Allows user to select units: inches or cm
        jsr    lcdcmdo        ;clear screen

        ldhx   #msg03
        jsr    lcdstro        ;Unit Choice menu
        jsr    del100ms
        clr    RA             ;menu choice=0 to begin with
        lda    #$0D
        jsr    lcdcmdo        ;blink cursor on menu choice

uluke:  ldx    RA             ;get current menu choice
        clrh
        lda    menupos,x      ;and look up corresponding LCD address
        jsr    lcdcmdo        ;reposition cursor

uwarm:  brclr  1,porta,uPB1   ;check for SEL
        brclr  2,porta,uPB2   ;or for ENT
        bclr   4,porta        ;otherwise
        bset   5,porta        ;turn on "SEL" LED
        jsr    del100ms       ;delay
        bset   4,porta        ;toggle LEDs
        bclr   5,porta        ;"ENT" now on: means choice is SEL ***or*** ENT
        jsr    del100ms       ;delay and repeat until SEL or ENT
        bra    uwarm

uPB1:   inc    RA             ;***SEL*** toggles menu choices
        lda    RA
        cmp    #$02           ;menu choices are $00 and $01
        bne    uPB1ok
        clr    RA             ;back to $00 when all others have been offered
uPB1ok: bclr   4,porta
        bclr   5,porta        ;LEDs off
        jsr    del100ms       ;wait a little bit
        brclr  1,porta,uPB1ok ;make sure they let go of SEL
        bra    uluke
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uPB2:    bclr   4,porta         ;***ENT*** confirms menu choice
         bclr   5,porta         ;LEDs off
         lda    RA              ;get menu choice
         bne    SelIN

SelCM:   ldhx   #$A014          ;initialize default units to cm ($A0=cm, $3F=in)
         sthx   UnitType        ;UnitType set to $A0; UnitDiv set to $14
         ldhx   #$039E
         sthx   UnitEmpt        ;UnitEmpt set to $03; UnitFull set to $9E
         lda    #$01
         jsr    lcdcmdo         ;clear LCD
         ldhx   #msg03a
         jsr    lcdstro         ;and show choice selection to be cm
         jsr    del1s           ;wait 1s
         jmp    LEVEL           ;let's do LEVEL now...

SelIN:   ldhx   #$3F08          ;initialize default units to in ($A0=cm, $3F=in)
         sthx   UnitType        ;UnitType set to $3F; UnitDiv set to $08
         ldhx   #$033D
         sthx   UnitEmpt        ;UnitEmpt set to $03; UnitFull set to $3D
         lda    #$01
         jsr    lcdcmdo         ;clear LCD
         ldhx   #msg03b
         jsr    lcdstro         ;and show choice selection to be in
         jsr    del1s           ;wait 1s
         jmp    LEVEL           ;let's do LEVEL now...
;_____________________________________________________________________
;_____________________________________________________________________
;_____________________________________________________________________

;**********************************************************************
;**********************************************************************
;******** GENERAL Routines ********************************************
;**********************************************************************
;**********************************************************************

;-------- INITIALIZATION Routines ----------------------------------
;        ALLINIT: initializes HC08, sets I/O, resets LCD and LEDs
;        -------
ALLINIT: bset   0,config1       ;disable COP
         mov    #$38,ddra       ;PTA0=MPAK,PTA1=SEL,PTA2=ENT,PTA3=E,PTA4=RS,PTA5=clk
         mov    #$30,adiclk     ;ADC clock /2
         bclr   3,porta         ;E=0
         bclr   4,porta         ;grn=OFF; RS=0
         bclr   5,porta         ;red=OFF; CLK=0
         rts
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;        WARMUP: waits half a second while it flashes LEDs, and allows LCD to get ready
;        ------
WARMUP:  bclr   4,porta
         bclr   5,porta         ;LEDs off
         lda    #$0A            ;prepare to do this 10x
tenx:    jsr    del25ms         ;delay
         bclr   4,porta
         bset   5,porta         ;alternate on/off
         jsr    del25ms
         bset   4,porta
         bclr   5,porta         ;and off/on
         dbnza  tenx            ;10 times so the LCD can get ready (slow startup)
         jsr    lcdinit         ;now initialize it
```

```
        bclr   4,porta
        bclr   5,porta        ;LEDs off
        rts
;-------- WRITE TO EEPROM Routines ----------------------------------
;       wrflash: burns A into flash at location pointed by H:X
;       -------
wrflash:  sthx   flshadr        ;this is the address in the flash
        sta    flshbyt        ;and the byte we want to put there
        tsx
        sthx   memSP          ;store SP in memSP, so it can be temporarily used as a 2nd index register
        ldhx   #ramfree+1     ;SP now points to RAM (remember to add 1 to the address!!!, HC08 quirk)
        txs                   ;SP changed (careful not to push or call subroutines)
        ldhx   #ersflsh       ;H:X points to beginning of flash programming code
doall:    lda    0,x          ;get 1st byte from flash
        sta    0,sp           ;copy it into RAM
        aix    #$0001         ;HX:=HX+1
        ais    #$0001         ;SP:=SP+1
        cphx   #lastbyt       ;and continue until we reach the last byte
        bne    doall
        ldhx   memSP          ;once done, restore the SP
        txs
        jsr    ramfree        ;and run the subroutine from RAM, you cannot write the flash while
        rts                   ;running a code in it, so the RAM has to take over for that piece
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;*************** THE FOLLOWING CODE WILL BE COPIED INTO AND WILL RUN FROM RAM ******
ersflsh:  lda    #$02         ;textbook way to erase flash
        sta    flcr
        lda    flbpr
        clra
        ldhx   flshadr
        sta    0,x
        bsr    delayf
        lda    #$0A
        sta    flcr
        bsr    delayf
        lda    #$08
        sta    flcr
        bsr    delayf
        clra
        sta    flcr
        bsr    delayf
pgmflsh:  lda    #$01         ;textbook way to program flash
        sta    flcr
        lda    flbpr
        clra
        ldhx   flshadr
        sta    0,x
        bsr    delayf
        lda    #$09
        sta    flcr
        bsr    delayf
        lda    flshbyt
        ldhx   flshadr
        sta    0,x
        bsr    delayf
        lda    #$08
        sta    flcr
        bsr    delayf
        clra
        sta    flcr
```

```
         bsr    delayf
         rts
delayf:   ldhx   #$0005         ;wait 5x20us
         mov    #$36,tsc       ;stop TIM & / 64
         sthx   tmodh          ;count H:X x 20us
         bclr   5,tsc          ;start clock
delayfls: brclr  7,tsc,delayfls
         rts                   ;this RTS will move from RAM back into EEPROM
lastbyt:  nop
;*************** END OF CODE THAT WILL BE COPIED INTO AND WILL RUN FROM RAM ******
;-------- DELAY Routines -------------------------------------------
;        del1s: generates a 1s delay
;        -----
del1s:    pshh
         pshx
         ldhx   #$C350         ;1 second delay=$C350=50000 x 20us
         bra    delmain
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;        del100ms: generates a 100ms delay
;        --------
del100ms: pshh
         pshx
         ldhx   #$1388
         bra    delmain
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;        del50ms: generates a 50ms delay
;        -------
del50ms:  pshh
         pshx
         ldhx   #$09C4
         bra    delmain
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;        del25ms: generates a 25ms delay
;        -------
del25ms:  pshh
         pshx
         ldhx   #$04E2
         bra    delmain
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;        del5ms: generates a 5ms delay
;        ------
del5ms:   pshh
         pshx
         ldhx   #$00FA
         bra    delmain
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;        del1ms: generates a 1ms delay
;        ------
del1ms:   pshh
         pshx
         ldhx   #$0032
         bra    delmain
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;        del100us: generates a 100us delay
;        -----
del100us: pshh
         pshx
         ldhx   #$0005
         bra    delmain
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

```
;        delmain: main delay routine; generates delay equal to H:X x 20us
;        -------
delmain:  mov    #$36,tsc       ;stop TIM & / 64
         sthx   tmodh          ;count H:X x 20us
         bclr   5,tsc          ;start clock
delwait:  brclr  7,tsc,delwait  ;wait for end of countdown
         pulx
         pulh
         rts                   ;this RTS serves for all delay routines!
;-------- A/D Routines ---------------------------------------------
;        adcbyti: gets single A/D reading from PTA0 and returns it in A
;        -------
adcbyti:  mov    #$00,adscr     ;ADC set to PTA0
         brclr  7,adscr,*      ;wait for ADC reading
         lda    adr            ;result in adr
         rts
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;        adcbyta: gets averaged A/D reading from PTA0 and returns it in A
;        -------
adcbyta:  clr    CNT            ;average 256 readings
         clr    RB             ;will be addint them up
         clr    RA             ;in RB:RA
do256a:   bsr    adcbyti
         add    RA
         sta    RA
         lda    RB
         adc    #$00
         sta    RB             ;16-bit add into RB:RA
         dbnz   CNT,do256a     ;do all 256
         lsl    RA             ;if RA<$80
         bcc    nochga         ;then RB result is correctly rounded
         inc    RB             ;otherwise round off to next value
nochga:   lda    RB
         rts
;-------- LCD Routines ---------------------------------------------
;        lcdinit: initializes LCD
;        -------
lcdinit:  lda    #$3C           ;set 8-bit interface, 1/16 duty, 5x10 dots
         bsr    lcdcmdo
         lda    #$0C           ;display on, cursor off, blink off
         bsr    lcdcmdo
         lda    #$06           ;increment cursor position, no display shift
         bsr    lcdcmdo
         lda    #$01           ;clear display
         bsr    lcdcmdo
         rts
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;        lcdcmdo: sends a command to LCD
;        -------
lcdcmdo:  bsr    shiftA
         bclr   4,porta        ;RS=0 for command
         bset   3,porta
         bclr   3,porta        ;toggle E
         bsr    del5ms         ;some commands require 2ms for LCD to execute
         rts                   ;so let's play it safe
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;        lcdchro: sends a character (data) to LCD
;        -------
lcdchro:  bsr    shiftA
         bset   4,porta        ;RS=1 for data
```

```
        bset   3,porta
        bclr   3,porta        ;toggle E
        bsr    del100us       ;data only requires 40us for LCD to execute
        rts
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;       shiftA: shifts A into shift register and provides 8-bits to LCD
;       ------
shiftA:  psha
        mov    #$08,BB        ;will be shifting 8 bits
all8:    lsla                 ;get bit
        bcc    shift0         ;if bit=0 then shift a 0
shift1:  bset   4,porta        ;otherwise shift a 1
        bra    shift
shift0:  bclr   4,porta        ;bit 4 is data to shift register
shift:   bclr   5,porta        ;bit 5 is shift register clock
        bset   5,porta
        bclr   5,porta        ;toggle CLK
        dbnz   BB,all8        ;do all 8 bits
        pula
        rts
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;       lcdnibo: displays 1 character (0-9,A-F) based on low-nibble value in A
;       -------
lcdnibo:  psha                 ;convert 4 bits from binary to ascii
        add    #$30           ;add $30 (0-9 offset)
        cmp    #$39           ;is it a number (0-9) ?
        bls    d0to9b         ;if so skip
        add    #$07           ;else add $07 = total of $37 (A-F offset)
d0to9b:  bsr    lcdchro
        pula
        rts
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;       lcdbyto: displays 2 characters based on hex value in A
;       -------
lcdbyto:  psha
        psha                  ;remember A (for low nibble)
        lsra                  ;shift right 4 times
        lsra
        lsra
        lsra
        bsr    lcdnibo        ;high nibble
        pula
        and    #$0F
        bsr    lcdnibo        ;low nibble
        pula
        rts
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;       lcdstro: displays message ending in '@', but also sends commands to LCD
;       -------
lcdstro:  psha
        lda    0,x
lcon:    cmp    #$80           ;if ASCII >=$80
        bhs    iscmd
        cmp    #$1F           ;or <=$1F then
        bls    iscmd          ;assume it is a command to LCD
isdta:   bsr    lcdchro        ;otherwise it is data to LCD
reuse1:  aix    #$0001         ;next character
        lda    0,x            ;indexed by x
        cmp    #$40           ;continue until
        bne    lcon           ;character = '@'
```

```
        pula              ;we are done
        bclr   4,porta    ;so
        bclr   5,porta    ;turn off LEDs
        rts
iscmd:  bsr    lcdcmdo
        bra    reuse1
;-------- ROM DATA: contains all LCD messages ----------------------
msg01    db    $01,$80,'*MPAK & 908QT4* '
        db     $C0,'Reference Design','@'
msg01a   db    $01,$80,'Water Level &   '
        db     $C0,'Flow       v2.0','@'
msg01b   db    $01,$80,'1:Level/Flow    '
        db     $C0,'2:Set Units     ','@'
msg05    db    $01,$80,'* Calibration! *'
        db     $C0,'Curr lo/hi:','@'
msg05a   db    $01,$80,'1st point:   0mm'
        db     $C0,'SEL:cal ENT:quit','@'
msg05b   db    $01,$80,'Calibrating...  '
        db     $C0,'    0mm: ','@'
msg05c   db    $01,$80,'2nd point: 160mm'
        db     $C0,'ENT:continue    ','@'
msg05d   db    $01,$80,'Calibrating...  '
        db     $C0,'  160mm: ','@'
msg05e   db    $01,$80,'INVALID         '
        db     $C0,'CALIBRATION!    ','@'
msg02a   db        $C8,'   EMPTY','@'
msg02b   db        $C8,'    FULL','@'
msg02c   db        $C8,'  steady','@'
msg02d   db        $C8,' H20  in','@'
msg02e   db        $C8,' H20 out','@'
msg03    db    $01,$80,'1: unit=cm H20 '
        db     $C0,'2: unit=in H20 ','@'
msg03a   db        $80,'Unit is now: cm','@'
msg03b   db        $80,'Unit is now: in','@'
menupos  db    $80,$C0

        end
```

REFERENCES

Baum, Jeff, “Frequency Output Conversion for MPX2000 Series Pressure Sensors,” Application Note AN1316/D.

Hamelain, JC, “Liquid Level Control Using a Pressure Sensor,” Application Note AN1516/D.

AN1979
Rev 3, 05/2005

Altimeter and Barometer System

by: Michelle Clifford and Fernando Gonzalez
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INTRODUCTION

With smaller packages and lower costs, pressure sensors can be designed into more consumer applications. This document describes a reference design for a digital barometer and altimeter using the MPXM2102A pressure sensor in the low cost MPAK package, a quad op-amp, and the MC68HC908QT4 microcontroller. This system continuously monitors the barometric pressure and compares it to previous pressure readings to update altitude and weather predictions. This reference design enables the user to evaluate a Freescale Semiconductor, Inc. pressure sensor for barometer, personal weather station and altimeter applications. This reference design also allows customers to evaluate barometer pressure readings obtainable from the MPXM2102A sensor for watches or GPS systems with this feature. In addition, many systems require barometric pressure data to correct system response errors. This application note describes the reliability and accuracy that our sensors can provide in this system.

SYSTEM DESIGN

Pressure Sensor

The barometer/altimeter system requires a pressure sensor that has a pressure range of 64 kPa to 105 kPa. Freescale Semiconductor, Inc. has a broad portfolio of silicon piezo-resistive pressure sensors. They provide a very accurate and linear voltage output directly proportional to the applied pressure. By evaluating the application design and cost, the right pressure sensor can be selected from our portfolio.

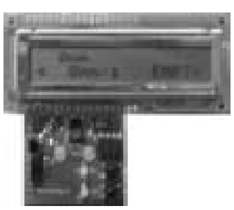


Figure 1. Pressure Sensor

There are three types of pressure measurements: gauge, absolute, and differential. Since this reference design measures changes in ambient pressure, we need a known pressure reference. Therefore, an absolute pressure sensor was selected. Freescale offers three levels of integration: uncompensated, compensated, and integrated. Since there can be large temperature changes from one elevation to another the sensor for this reference design needs to be offset calibrated and temperature compensated. Therefore a compensated sensor was selected requiring external amplification circuitry. However, integrated solutions such as the MPXM5100A, can also be considered, thereby eliminating the need for the external amplification circuitry.

Knowing the range of pressure, the type of pressure measurement, and the level of integration required for this application, the MPXM2102A sensor was selected. The sensor has both temperature compensation and calibration circuitry on the silicon and is capable of producing a linear output voltage in the range of 0 to 100 kPa, but can be pushed further up to 105 kPa with linear results. The characteristics of this sensor are described in greater detail in Table 2. A 5-volt supply was used throughout the circuit to power the components. Since the MPXM2102A is ratio metric, meaning the output voltage changes linearly with the supply voltage, the sensor will have a full scale span of 20 mV instead of the specified 40 mV at a 10 V supply. The calculation of the full scale span is shown below:

$$(V_{S\ actual}/V_{S\ spec}) \times V_{OUT\ full\text{-}scale\ spec} = V_{OUT\ full\text{-}scale}$$

$$(5.0\ V/\ 10\ V) \times 40\ mV = 20\ mV$$

One of the most important decisions for a pressure application is the packaging. Freescale has a large offering of pressure packaging options. To minimize the space of a final application, the MPAK package was selected. A non-ported MPAK is the ideal pressure sensor package for hand held GPS units or altimeter watches due to its small size. However, a ported MPAK package can also be selected, allowing a tube to be attached to the port for testing and demonstration purposes.

Figure 2. MPXM2102A Case 1320A-02

Table 1. MPXM2102A Operating Characteristics

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	0	—	100	kPa
Supply Voltage		V_S	—	10	15	Vdc
Supply Current		I_O	—	6.0	—	mAdc
Full Scale Span		V_{FSS}	38.5	40	41.5	mV
Offset		V_{off}	-1.0 -2.0	— —	1.0 2.0	mV
Sensitivity	MPX2102D Series MPX2102A Series	$\Delta V/\Delta P$	—	0.4	—	MV/kPa
Linearity	MPX2102D Series MPX2102A Series	— —	-0.6 -1.0	— —	0.4 1.0	$\%V_{FSS}$

Amplifier Selection and Amplifier Induced Errors

The main goal of the signal conditioning circuit is to convert the MPX2102A differential output to a single-ended, ground-referenced output. The differential output is extremely small for the MCU to process so a conditioning circuit also needs to provide amplification.

This reference design has a barometric pressure range of 64 kPa to 105 kPa. The output of the sensor is ratiometric to the supply voltage and the supply voltage is 5.0 V, the FSS, Sensitivity, and Offset are 5.0 V/10 V, or half, of the specified values at a 10 V supply. Using these calculated sensitivity and offset ranges, the lowest and highest possible values were calculated.

V_{OUT} = (Applied Pressure * Sensitivity) ± Offset

V_{OUT} at 64 kPa = 64 kPa * 0.2 mV/kPa — 1 mV = 11.32 mV

V_{OUT} at 105 kPa = 105 kPa * 0.2 mV/kPa + 1 mV = 21.0 mV

These values were found to be 11.32 mV to 22.79 mV differential output from the sensor.

Two-Stage Design

This two-stage design level shifts the differential output voltage of the sensor by subtracting an offset voltage from each of the sensor outputs, then uses a differential amplification as shown in Figure 2.

After the first stage of amplification, the output of op-amp A is:

V_A = (1+R8/R6) x V_4 – (R8/R6) x V_S(1)

= (1+10/4.42k) x V_4 – (10/4.42k) x 5.0 V

= (1+10/4.42k) x V_4 – 11.3 mV

and the output of op-amp B is:

V_B = (1+R7 / R5) x V_2 – (R7 / R5) x V_S(2)

= (1+10/4.42 k) x V_2 – (10/4.42 k) x 0 V

= (1+10/4.42 k) x V_2 – 0

The second stage of amplification connects these two outputs to a common differential amplifier (op-amp C) also shown in Figure 3. With some algebraic manipulation, the output voltage (V_{OUT}) of the entire amplification circuit is

V_C = (R12/R11) x [(1+R8/R6) x (V_2 - V_4) – (R8/R6) x V_S](3)

= (412K/1 k) x [(1+10/4.42 K) x (V_2 - V_4) – (10/4.42 K) * 5 V]

= (412) x [(1.002) x (V_2 - V_4) – 11.3 mV]

= 412 x (V_2 - V_4) –11.3 mV

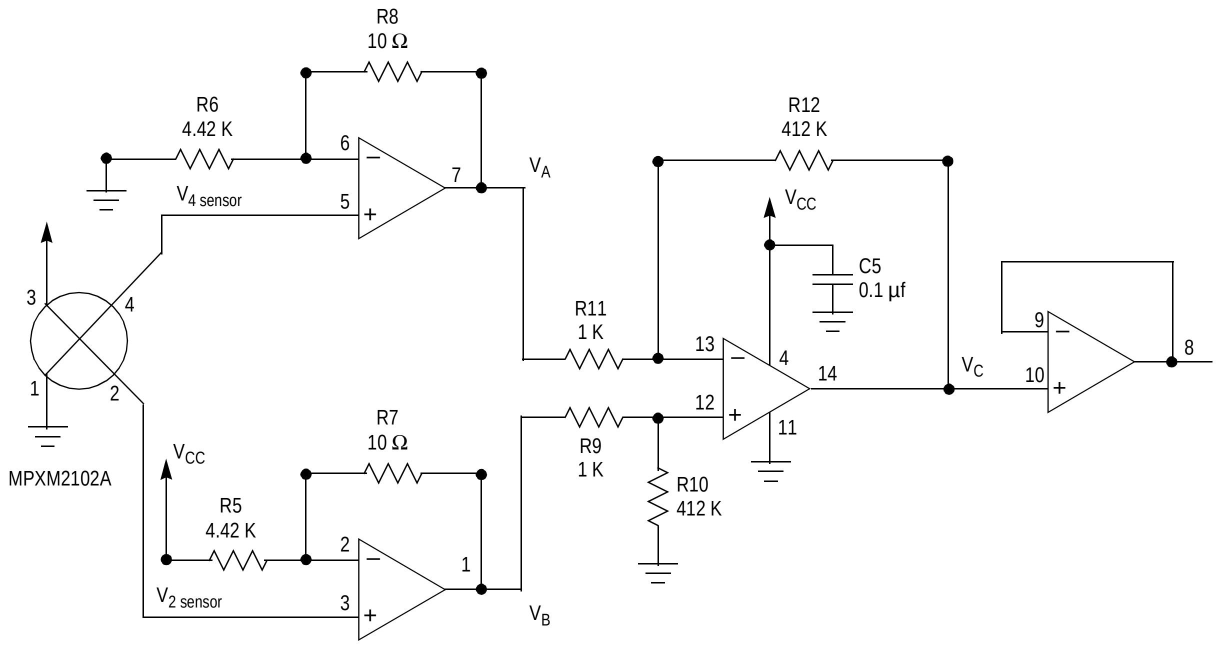


Figure 3. Amplification Scheme

The range of the A/D converter is 0 to 255 counts. However, the A/D values that the system can achieve are dependent on the maximum and minimum system output values:

Count = $(V_{OUT} - V_{RL}) / (V_{RH} - V_{RL}) \times 255$(4)

where V_{Xdcr} = Transducer Output Voltage

V_{RH} = Maximum A/D voltage

V_{LH} = Minimum A/D voltage

Count (64 kPa) = (0.03 – 0.0) / (5.0 – 0.0) x 255 = 2

Count (105 kPa) = (4.85 – 0.0) / (5.0 – 0.0) x 255 = 247

Total # counts = 247 – 2 = 245 counts.

The resolution of the system is determined by the barometric pressure represented by each A/D count. As calculated above, the system has a span of 247 counts to represent a pressure from 64 kPa to 105 kPa. Therefore, the resolution is:

Resolution = (System Pressure Range) / Total # counts (5)

= (105 kPa — 64 kPa)/245 counts

= 0.17 kPa per A/D count

Microprocessor

To provide the signal processing for pressure values, a microprocessor is needed. The MCU chosen for this application is the MC68HC908QT4. This MCU is perfect for appliance applications due to its low cost, small eight-pin package, and other on-chip resources. The MC68HC908QT4 provide: a four-channel, eight-bit A/D, a 16-bit timer, a trimmable internal timer, and in-system FLASH programming.

The central processing unit is based on the high performance M68HC08 CPU core and it can address 64 Kbytes of memory space. The MC68HC908QT4 provides 4096 bytes of user FLASH and 128 bytes of random access memory (RAM) for ease of software development and maintenance. There are five bi-directional input/output lines and one input line that are shared with other pin features.

The MCU is available in eight-pin as well as 16-pin packages in both PDIP and SOIC. For this application, the eight-pin PDIP was selected. The eight-pin PDIP was chosen for a small package, eventually to be designed into applications as the eight-pin SOIC. If added circuitry for programming the microcontroller is added, a cyclone could be used to program an SOIC on the PCB. If your design requires software updates, consult the MC68HC908QT4 handbook for adding this option.

IMPROVEMENTS

The resolution of this design is limited by the eight-bit A/D converter on the microcontroller. Theoretically, the accuracy achieved by this device should produce an output when altitude change differs by about 41.54 feet (ΔZ). This occurs at approximately 1000 feet below sea level. Due to the logarithmic relationship between pressure and elevation, the accuracy of the results decreases as the device is elevated. At 12,000 feet above sea level, the device should recognize a change of about 65.53 feet (ΔZ) as shown in Table 3. A 10-bit, 12-bit or even a 16-bit A/D converter could be implemented in order to increase the resolution of this reference design.

Table 2. Microcontroller Accuracy Comparisons

Z (ft)	P (kPa)	V (mV)	Amp scheme	Vamp (mV)	Vamp – 1 bit	P0	Px	ΔZ (m)	ΔZ (ft)	Micro
-1000	105	20.265	(Vx–12.8)*650	4852.3	4832.6	20.265	20.235	12.66	41.54	8 bits
12000	64.259	12.852		33.8	14.2	12.852	12.822	19.97	65.53	8 bits
-1000	105	20.265	(Vx–12.8)*650	4852.3	4847.4	20.265	20.257	3.15	10.35	10 bits
12000	64.259	12.852		33.8	28.9	12.852	12.844	4.97	16.32	10 bits
-1000	105	20.265	(Vx–12.8)*650	4852.3	4851	20.265	20.263	0.79	2.59	12 bits
12000	64.259	12.852		33.8	32.6	12.852	12.85	1.24	4.08	12 bits
-1000	105	20.265	(Vx–12.8)*650	4852.3	4852.2	20.265	20.265	0.05	0.16	16 bits
12000	64.259	12.852		33.8	33.7	12.852	12.852	0.08	0.25	16 bits

Table 2 shows the theoretical maximum resolution that this reference design can achieve. However, factors such as noise within the circuit, sensitivity of the sensor, and voltage offsets in the amplification scheme should be taken into consideration. Accommodating for these factors in the software can filter out some of these factors.

Further testing is required to determine the accuracy of the reference design without the limiting A/D converter.

DISPLAY

The display of the barometric pressure, barometric pressure history, current calculated altitude, and a simple weather prediction is displayed on a 16x2 LCD.

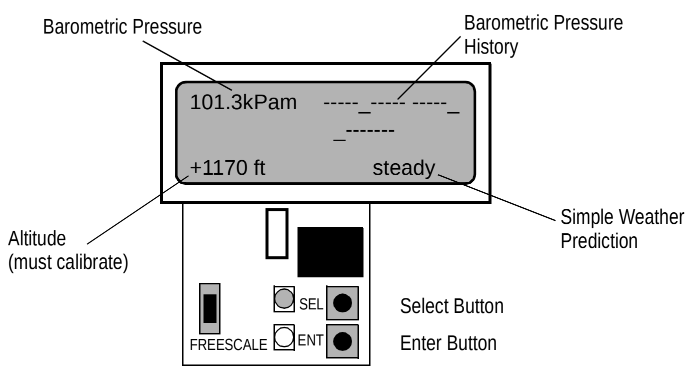


Figure 4. Barometric Display

Due to the limited number of bi-directional data pins on the microcontroller, a system was designed to serially buffer the display data. Using a shift register to hold display data, the LCD is driven with only three lines of output from the microcontroller: an enable line, a data line, and a clock signal while the two LEDs are multiplexed with the data line and clock signal.

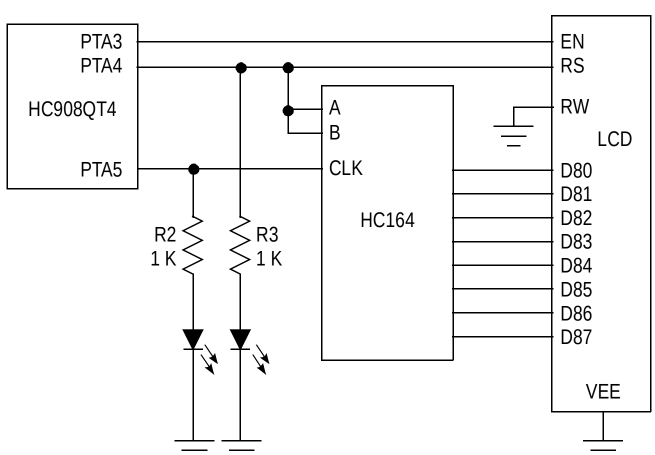


Figure 5. Multiplexed LCD Circuit

Multiplexing of the microcontroller output pins allows communication of the LCD to be accomplished with three pins instead of eight or 11 I/O pins usually required. With an eight-bit shift register, we are able to manually clock in eight bits of data. The enable line, EN, is manually enabled when eight bytes have been shifted in, telling the LCD the data on the data bus is available to execute. The LCD will only be written to and the contrast can be held at a constant brightness, allowing the read/write and the VEE bits to be held low, also minimizing additional I/O lines.

Table 3. Parts List

Ref	Qty.	Description	Value	Vendor	Part No.
U3	1	Pressure Sensor	1.0	Freescale	MPXM2102A
C1	1	V_{CC} Cap	0.1 µF	Generic	
C2	1	Op-Amp Cap	0.1 µF	Generic	
C3	1	Shift Register Cap	0.1 µF	Generic	
D1	1	Red LED	—	Generic	
D2	1	Green LED	—	Generic	
S2, S3	1	Push buttons	—	Generic	
U1	1	Microcontroller	8-Pin	Freescale	MC68HC908QT4
U2	1	16x2 B&W LCD	16x2	Seiko	L168200J000
U4	1	Shift Register	—	Texas	74HC164
U5	1	Voltage Regulator	5.0 V	Fairchild	LM78L05ACH
U6	1	Quad Op-Amp	—	ADI	AD8544
R1, R4	1	1/4 W Resistor	10 K	Generic	
R2, R3	2	1/4 W Resistor	1.0 K	Generic	
R5, R6	2	1/4 W Resistor	3.65 K	Generic	
R7, R8	2	1/4 W Resistor	10 K	Generic	
R9, R11	2	1/4 W Resistor	1.0 K	Generic	
R10, R12	2	1/4 W Resistor	200 K	Generic	

OTHER

This system is designed to run on a 9.0 V battery. It contains a 5.0 V Regulator to provide a 5.0 V supply to the pressure sensor, microcontroller, and LCD. The battery is mounted on the back of the board using a space saving spring battery clip.

ALTIMETER/BAROMETER SOFTWARE

This application note describes the software version that was available during publication. However updated software versions may be available with further functionality and menu selections. Check our website update for updates to Sensor Products Reference designs.

Software User Instructions

When the system is turned on or reset, the microcontroller will flash the select LED and display the program title on the LCD for five seconds or until the select (SEL) button is pushed. Then the menu screen is displayed. Using the select (SEL) push button, the user can scroll through the menu options for a software program. To run the altimeter program, use the (SEL) select button to high-light the “Alti/Barometer” option, then press the enter (ENT) push button. The Altimeter program will display current barometric pressure reading, the calculated altitude in feet, a message displaying a simple weather prediction such as “sunny”, “rainy”, “steady” without a pressure change, and “history” before enough history is collected to make a prediction. In the top right corner of the display, a scrolling graphical history displays data points representing the past forty pressure readings.

Calibration and Calibration Software

There are two forms of calibration for this system. The first calibration is used for the barometer part of the system. This calibration was already done before you received the reference design and only needs to be done once per system. To calibrate the barometer module, a two-point calibration is performed using a highly accurate pressure generator. The system takes a calibration point at 64 kPa and another at 105 kPa. Holding down both the SEL and ENT buttons on system power-up will put the system into calibration mode. At this point, the calibration menu will be displayed with the previously sampled offset voltage. To recalibrate the system, apply a pressure of 64 kPa and press the SEL button (PB1). This A/D value is then saved to a location in the microcontroller memory. To obtain the second calibration point, using the accurate pressure generator apply a pressure of 105 kPa directly to the sensor. Then press the ENT button (PB2). This signal is similarly sampled, averaged and saved to a location in FLASH. To exit the calibration mode, press the SEL (PB1) button.

The second calibration is done for the altimeter. The Altimeter requires a one-point calibration where a known altitude is entered with a known pressure. This ensures that changes in atmospheric pressure are due to increases or decreases in altitude and not changes in barometric pressure. By returning to the main menu, and selecting the “Set Elevation”, the user can select an elevation by pressing the SEL button to cycle through the Elevation options from 0 to 12000 feet in 100-foot increments. Once the selection has been made the elevation is flashed into the microcontroller and the user is brought to the Altimeter/Barometer function. Calibration is required for each use of the altimeter module.

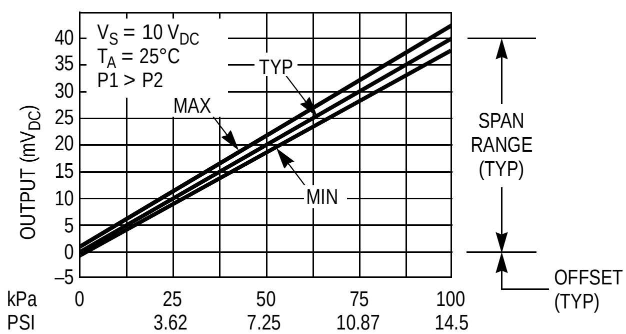


Figure 6. Analog Output to Pressure

CONVERTING ANALOG OUTPUT TO PRESSURE

Freescale pressure sensors have an extremely linear analog voltage output that is proportional to the pressure input. Since the sensor output is linear, the pressure can be calculated by using the equation of a line, y = mx + b, where y is the output voltage, the slope, m, is the Sensitivity, and the y intercept, b, is the Offset:

V_{OUT} = Sensitivity x Pressure + Offset

With algebraic manipulation, pressure can be determined by:

Pressure = (V_{OUT} – Offset)/Sensitivity

Below is an example of determining the pressure from the analog output of 9.5 mV using the Sensitivity and Offset of the MPX2102a sensor specified in the datasheet:

Pressure = (V_{OUT} – Offset)/Sensitivity

= (9.5 mV – 0.5 mV) / 0.1 mV/kPa

= (9.0)/0.1 mV/kPa

= 90 kPa

where 0.5 mV is the typical offset for the MPX2102 and 0.1 mV/kPa is the sensitivity with a 5.0 V supply

This system uses additional amplifiers and an A/D converter that all add additional offset and gain errors; however, the translation function was corrected with the two-point calibration. The known pressure values that are used for calibration are the maximum and minimum pressures for the system, 105 kPa and 64 kPa respectively. The A/D values for these known pressures are saved in the flash memory of the microcontroller.

ATD = (Po – P_{64kPa})/(P_{105kPa} - P_{64kPa}) x 255

By algebraic manipulation, the following equation is reached to find the barometric pressure:

Po = (ATD/255) x (P_{105kPa} - P_{64kPa}) + P_{64kPa}

Converting Pressure to Altitude

The method of determining altitude for this reference design is measuring the changes in barometric pressure. The relationship of pressure vs. altitude is not linear. As pressure decreases, altitude increases, but the higher the altitude gets the less pressure changes. The equation that was used for this reference design is:

P = (P0) e^[-(g/(RT)) x (Z — Z0),

where P = pressure at an unknown altitude,

P0 = pressure at a known altitude,

e = a constant,

g = gravitational constant 9.8 (m/s^2),

R = dry air constant 287 J/(kg x K),

T = temperature at unknown elevation in Kelvin,

Z = unknown altitude in meters,

and Z0 = known altitude also in meters.

This equation originates from the hydrostatic equation:

dP = -ρgdZ

in conjunction with the ideal gas law:

P = ρRT

After some algebraic manipulation, plugging in constant values and converting meters to feet, the following equation was generated:

Z = Z0 — 27,887 in (P/P0),

where Z = unknown altitude in feet,

Z0 = known altitude also in feet,

P = known pressure at unknown altitude,

and P0 = known pressure at known altitude.

For this system to calculate an altitude, Z, at a known pressure P, the user must enter a known pressure, P0, and its corresponding altitude, Z0. To accommodate for changes in barometric conditions, the known pressure and altitude data must be re-entered during each use to ensure accuracy.

Simple Weather Prediction

Atmospheric pressure at the Earth’s surface is one of the measurements used to make weather predictions. Air in a high-pressure area compresses and warms as it descends. The warming air inhibits the formation of clouds. Therefore, the sky is normally sunny in high-pressure areas with a small chance of haze or fog. However, in an area of low atmospheric pressure, the air rises and cools. With enough humidity in the air, the rising air will cool, the air will condense forming clouds and precipitation in the form of rain or snow.

This reference design saves the current pressure reading and compares it to past pressure measurements. It determines if there was a pressure drop or a pressure increase. Using this information, it makes a simple weather prediction by sending a message of ‘sunny’ for a pressure increase, ‘rainy for a pressure drop, and ‘steady’ for no significant change in pressure.[1]

CONCLUSION

The Altimeter is one of many applications for the MPXM2102AS pressure sensor. This reference design can be used as a reference for developing more integrated barometer applications such as hand-held weather stations, altimeter features for camera or GPS systems, as well as barometric pressure monitoring systems for industrial systems. The MPXM2102AS is an excellent pressure sensor for this application since it is calibrated and temperature compensated. By having these features available on-chip, there is a large savings in PCB real estate in addition to savings in cost for external components

.

Table 4. Elevation Pressure and Temperature Changes

Altitude Above Sea Level		Temperature		Barometer	Atmospheric Pressure	
Feet	**Meters**	**F**	**C**	**mm * Hg**	**psi**	**kPa**
-1000	-305	63	17	787.9	15.23	105.0
-500	-153	61	16	773.9	14.96	103.1
0	0	59	15	760.0	14.69	101.33
500	153	57	14	746.3	14.43	99.49
1000	305	55	13	733.0	14.16	97.63
1500	458	54	12	719.6	13.91	95.91
2000	610	52	11	706.6	13.66	94.19
2500	763	50	10	693.9	13.41	92.46
3000	915	48	9	681.2	13.17	90.81
3500	1068	47	8	668.8	12.93	89.15
4000	1220	45	7	656.3	12.69	87.49
4500	1373	43	6	644.4	12.46	85.91
5000	1526	41	5	632.5	12.23	84.33
6000	1831	38	3	609.3	11.78	81.22
7000	2136	34	1	586.7	11.34	78.19
9000	2441	31	-1	564.6	10.91	75.22
9000	2746	27	-3	543.3	10.5	72.40
10,000	3050	23	-5	522.7	10.1	69.64
15,000	4577	6	-14	429.0	8.29	57.16

1. This information was found from the USA Today Weather Book from USAToday.com.

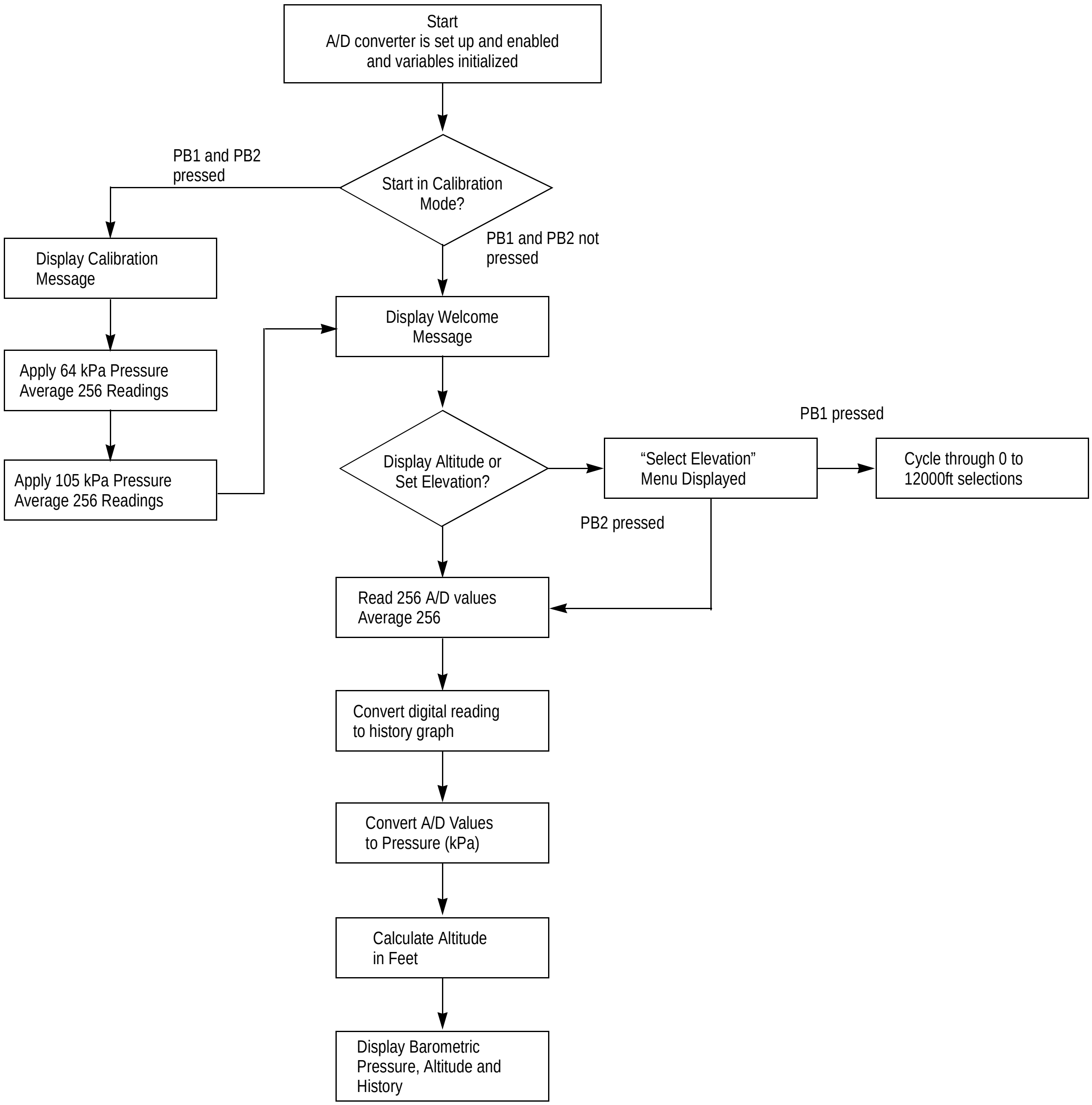


Figure 7. Altimeter/Barometer Software Flow Diagram

REFERENCES

Williams, Jack. (2001). Understanding Air Pressure. *The Weather Book*, 5, 117–123. Retrieved April 4, 2003, from http://www.usatoday.com/weather/wfront.htm

AN1984
Rev 3, 05/2005

Handling Freescale Pressure Sensors

by: William McDonald

INTRODUCTION

Smaller package outlines and higher board densities require the need for automated placement of components. These components are supplied in embossed carrier tape on plastic reels to meet the increased demand and facilitate ease of handling. This application note is intended to provide general information and understanding for handling Freescale's surface mount pressure sensors. Equipment details are not provided in this document and it is recommended that end users contact suppliers of equipment for specific applications.

METHODS OF HANDLING

Components can be picked from the carrier tape using either the vacuum assist or the mechanical type pick up heads. A vacuum assist nozzle type is most common due to its lower cost of maintenance and ease of operation. The recommended vacuum nozzle configuration should be designed to make contact with the device directly on the metal cover and avoid vacuum port location directly over the vent hole in the metal cover of the device. To provide a more secure hold on the device, contact with the plastic ridge around the perimeter of the metal cover should be avoided to prevent loss of vacuum pressure. Multiple vacuum ports within the nozzle may be required to effectively handle the device and prevent shifting during movement to placement position.

Figure 1 shows two styles of multiple port vacuum nozzles for the MPXH series device as an example. Figure 2 represents the nozzle location on the device.

Vacuum pressure required to adequately support the component should be approximately 25 in Hg (85kPa). This level is typical of in-house vacuum supply.

Pick up nozzles are available in various sizes and configurations to suit a variety of component geometries. To select the nozzle best suited for the specific application, it is recommended that the customer consult their pick and place equipment supplier to determine the correct nozzle. In some cases it may be necessary to fabricate a special nozzle depending on the equipment and speed of operation.

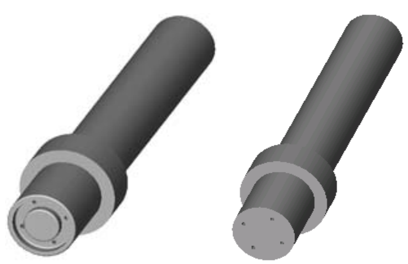


Figure 1. MPXH Series Multiple Port Vacuum Nozzles

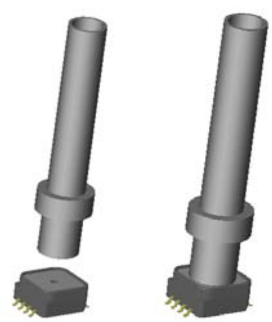


Figure 2. Nozzle Location

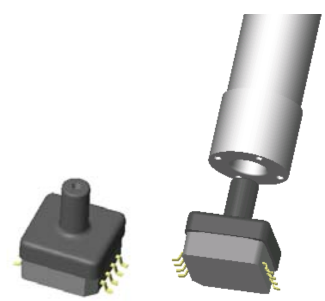


Figure 3. SSOP Axial Style Port

AVAILABLE PACKAGES

Freescale offers several small outline surface mount device families. These are MPXA, MPXH, MPXM, and MPXY series of devices.

These devices are also available in axial ported versions to allow pressure to be interfaced to a device via a hose connection.

Pick up nozzles for these packages should be configured to apply vacuum only to the flat surface of a port base. An access clearance in the nozzle for a port shank is necessary to properly handle these device configurations. See Figure 3.

Figure 2. Available Packages

Table 1. Tape and Reel Information

	Case	**423A**	**1317**	**1317A**	**1320**	**1320A**	**482**	**482A**	**1369**
Carrier Tape		**Chip Pak**	**SSOP**	**SSOP Ported**	**M-Pak**	**M-Pak Ported**	**SOP**	**SOP Ported**	**SOP Side Port**
Tape Width	W	24.0+/-0.3	24.0+/-0.3	24.0+/-0.3	24.0+/-0.3	24.0+/-0.3	32+/-0.3	32+/-0.3	32+/-0.3
Pocket Width	A_o	8.5+/-0.2	7.7+/-0.1	8.8+/-0.1	6.8+/-0.1	7.2+/-0.1	11.3+/-0.1	12.0+/-0.2	12.6+/-0.2
Length	B_o	14.2+/-0.2	10.7+/-0.1	11.8+/-0.1	12.6+/-0.1	13.2+/-0.1	18.9+/-0.1	18.8+/-0.2	18.8+/-0.2
Depth	K_o	4.7+/-0.1	5.0+/-0.1	10.8+/-0.1	4.6+/-0.1	10.5+/-0.1	6.4+/-0.1	13.8+/-0.1	9.2+/-0.2
Sprocket Hole Pitch	P_o	4.0 +/-0.1	4.0+/-0.1	4.0+/-0.1	4.0+/-0.1	4.0+/-0.1	4.0+/-0.1	4.0+/-0.1	4.0+/-0.1
Sprocket Hole Diagram	D_o	1.55+/-0.05	1.55+/-0.05	1.55+/-0.05	1.55+/-0.05	1.55+/-0.05	1.5+/-0.05	1.5+/-0.1	1.5+/-0.1
Edge to Hole	E_1	1.75+/-0.1	1.75+/-0.1	1.75+/-0.1	1.75+/-0.1	1.75+/-0.1	1.75+/-0.1	1.75+/-0.1	1.75+/-0.1
Hole to Edge	E_2	22.2 min	22.2 min	22.2 min	22.2 min	22.2 min	N/A	N/A	N/A
Distance between Holes	S_o	N/A	N/A	N/A	N/A	N/A	28.4+/-0.1	28.4+/-0.1	28.4+/-0.1
Pocket Pitch	P_1	12.0+/-0.1	12.0+/-0.1	16.0+/-0.1	12.0+/-0.1	16.0+/-0.1	16.0+/-0.1	20.0+/-0.1	24.0+/-.01
Pocket Position	P_2	2.0+/-0.1	2.0+/-0.1	2.0+/-0.1	2.0+/-0.1	2.0+/-0.1	2.0+/-0.1	2.0+/-0.1	2.0+/-0.1
	F	11.5+/-0.1	11.5+/-0.1	11.5+/-0.1	11.5+/-0.1	11.5+/-0.1	14.2+/-0.1	14.2+/-0.1	14.2+/-0.1
Tape Thickness	T	0.40+/-0.05	0.40+/-0.05	0.40+/-0.05	0.40+/-0.05	0.40+/-0.05	0.30+/-0.05	0.35+/-0.05	0.40+/-0.05
Distance Pocket to Edge	S_1	0.6 min.	0.6 min	0.6 min	0.6 min	0.6 min	N/A	N/A	N/A
Pocket Hole Diagram	D_1	N/A	1.5+/-0.1	1.5+/-0.1	1.5+/-0.1	1.5+/-0.1	2.0+/-0.1	2.0+/-0.1	2.0+/-0.1
Cover Tape									
Thickness	T_1	0.052 +/-0.01	0.052 +/-0.01	0.052 +/-0.01	0.052 +/-0.01	0.052 +/-0.01	0.052 +/-0.01	0.052 +/-0.01	0.052 +/-0.01
Width	W_4	21.1+/-0.1	21.1+/-0.1	21.1+/-0.1	21.1+/-0.1	21.1+/-0.1	21.1+/-0.1	25.5+/-0.1	25.5+/-0.1
Reel									
Width at Hub	W_1	23.7 - 25.2	23.7 - 25.2	23.7 - 25.2	23.7 - 25.2	23.7 - 25.2	23.7 - 25.2	31.7 - 33.2	31.7 - 33.2
Width at outer flange	W_3	23.7 - 28.0	23.7 - 28.0	23.7 - 28.0	23.7 - 28.0	23.7 - 28.0	23.7 - 28.0	31.7 - 36.0	31.7 - 36.0
Overall Width	W_2	30.4 max.	30.4 max.	30.4 max.	30.4 max.	30.4 max.	30.4 max.	38.4 max.	38.4 max
Hub Diagram	N	100+/-2.50	100+/-2.50	100+/-2.50	100+/-2.50	100+/-2.50	100+/-2.50	178+/-2.50	178+/-2.50
Arbor Hole Diagram	C	13.0+ 0.5/-0.2	13.0+ 0.5/-0.2	13.0+ 0.5/-0.2	13.0 +0.5/-0.2	13.0 +0.5/-0.2	13.0 +0.5/-0.2	13.0 +0.5/-0.2	13.0 +0.5/-0.2
Slot of Arbor Hole	B	1.50/2.50	1.50/2.50	1.50/2.50	1.50/2.50	1.50/2.50	1.50/2.50	1.50/2.50	1.50/2.50
Reel Diagram	A	330+/-0.76	330+/-0.76	330+/-0.76	330+/-0.76	330+/-0.76	330+/-0.76	330+/-0.76	330+/-0.76
DEVICE QTY/REEL	MPQ	1000	1000	300	1000	400	600	100	200

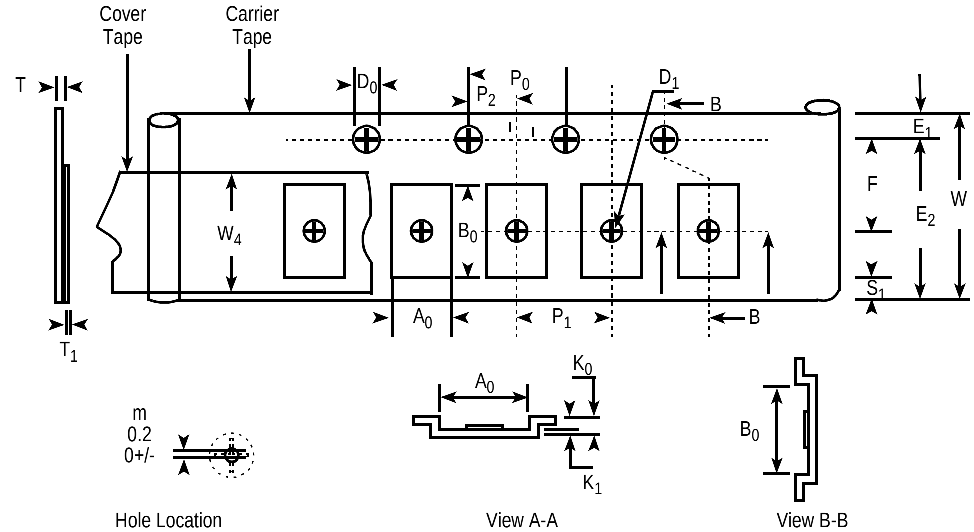


Figure 3. Carrier Tape

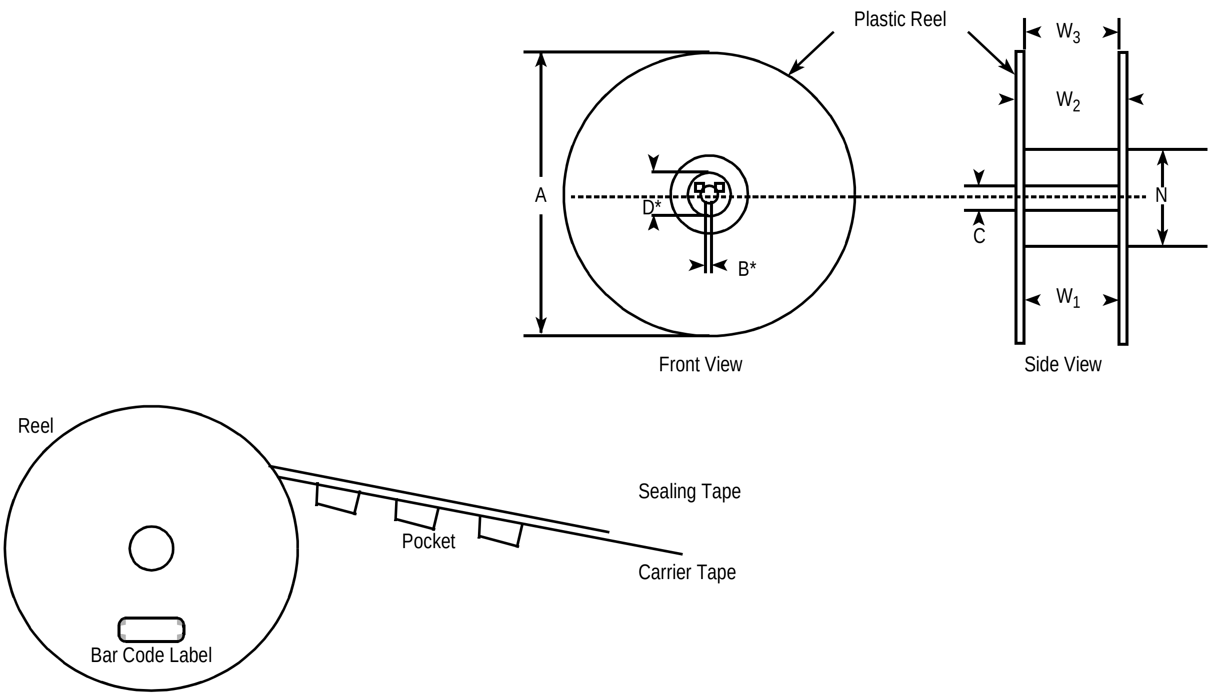


Figure 4. Reel

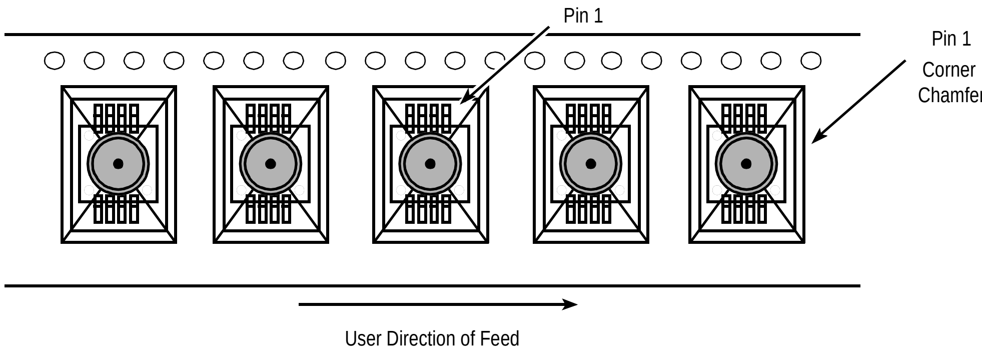
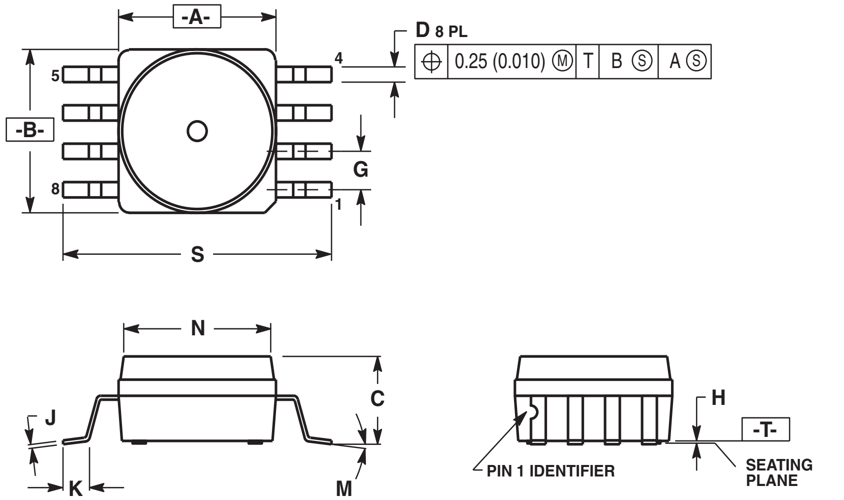


Figure 5. Orientation of Small Outline Package Sensor Device

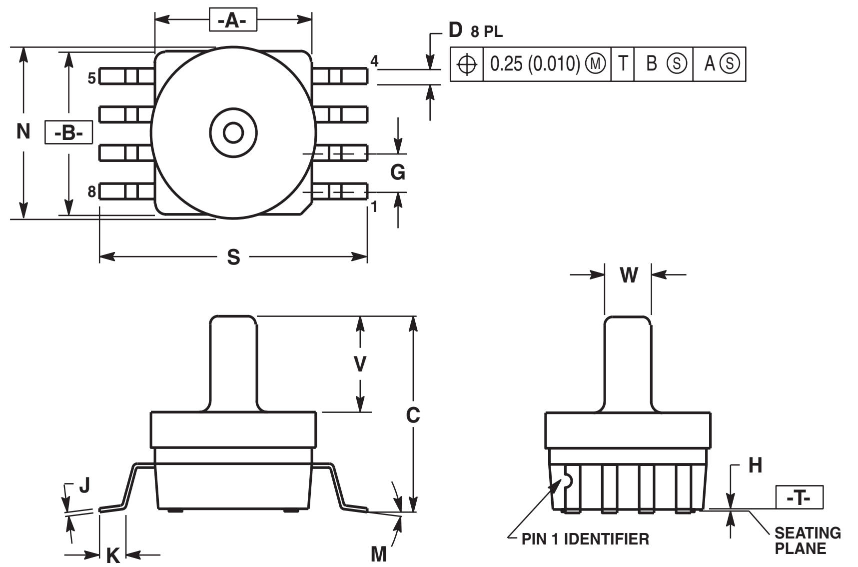
OUTLINE DIMENSION



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006).
5. ALL VERTICAL SURFACES 5° TYPICAL DRAFT.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.415	0.425	10.54	10.79
B	0.415	0.425	10.54	10.79
C	0.212	0.230	5.38	5.84
D	0.038	0.042	0.96	1.07
G	0.100 BSC		2.54 BSC	
H	0.002	0.010	0.05	0.25
J	0.009	0.011	0.23	0.28
K	0.061	0.071	1.55	1.80
M	0°	7°	0°	7°
N	0.405	0.415	10.29	10.54
S	0.709	0.725	18.01	18.41

SOP PACKAGE
CASE 482-01
ISSUE O

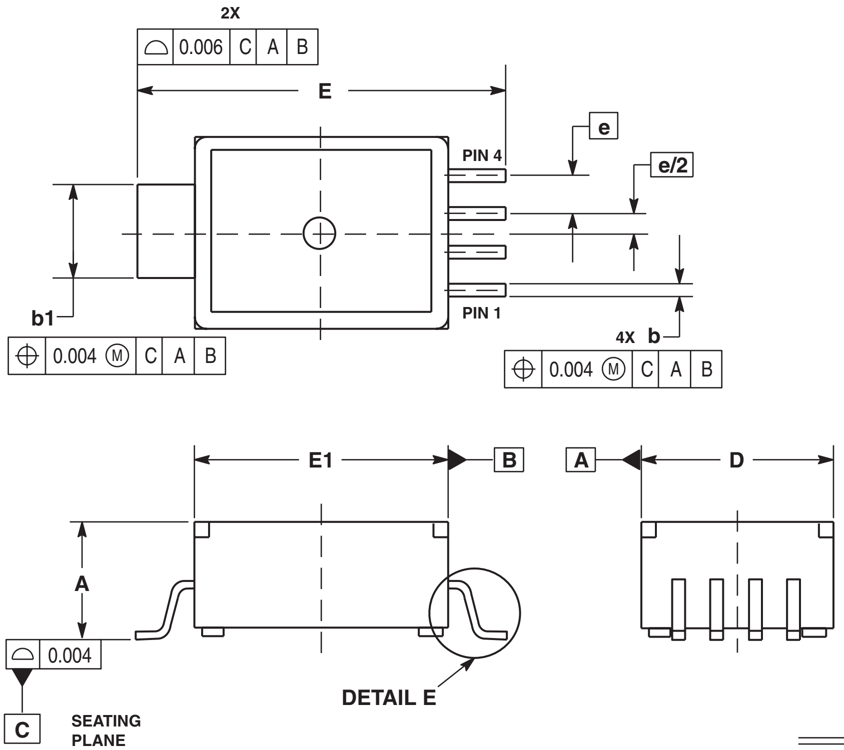


NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006).
5. ALL VERTICAL SURFACES 5° TYPICAL DRAFT.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.415	0.425	10.54	10.79
B	0.415	0.425	10.54	10.79
C	0.500	0.520	12.70	13.21
D	0.038	0.042	0.96	1.07
G	0.100 BSC		2.54 BSC	
H	0.002	0.010	0.05	0.25
J	0.009	0.011	0.23	0.28
K	0.061	0.071	1.55	1.80
M	0°	7°	0°	7°
N	0.444	0.448	11.28	11.38
S	0.709	0.725	18.01	18.41
V	0.245	0.255	6.22	6.48
W	0.115	0.125	2.92	3.17

SOP PACKAGE
CASE 482A-01
ISSUE A

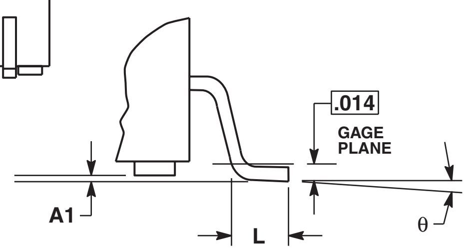
OUTLINE DIMENSION



NOTES:
1. DIMENSIONS ARE IN INCHES.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS "D" AND "E1" DO NOT INCLUDE MOLD FLASH OR PROTRUSION. MOLD FLASH OR PROTRUSION SHALL NOT EXCEED .006" PER SIDE.
4. ALL VERTICAL SURFACES TO BE 55 MAXIMUM.
5. DIMENSIONS "b" DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE .008 MAXIMUM.

	INCHES	
DIM	MIN	MAX
A	.155	.165
A1	.002	.010
b	.014	.018
b1	.120	.130
D	.245	.255
E	.475	.485
E1	.325	.335
e	.050 BSC	
e/2	.025 BSC	
L	.038	.048
q	5˚	7˚

STYLE 1:
PIN 1. GND
2. +Vout
3. Vs
4. -Vout



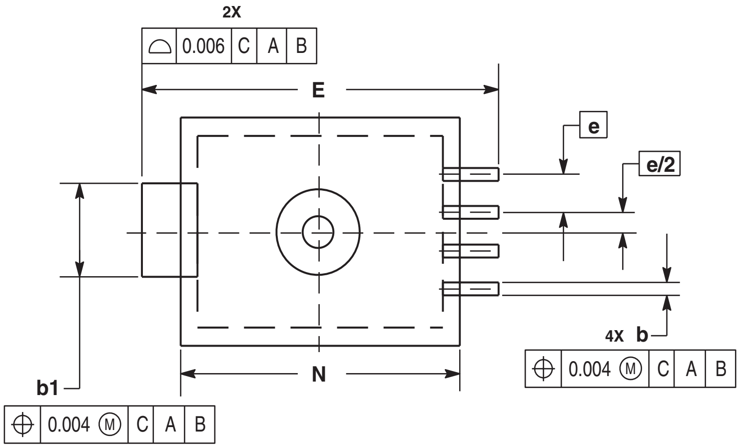
DETAIL E

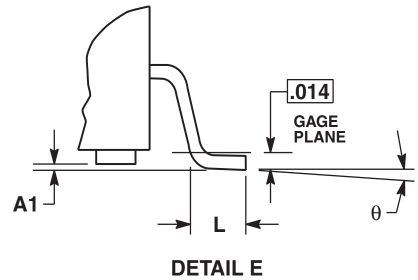
MPAK PACKAGE

CASE 1320-02

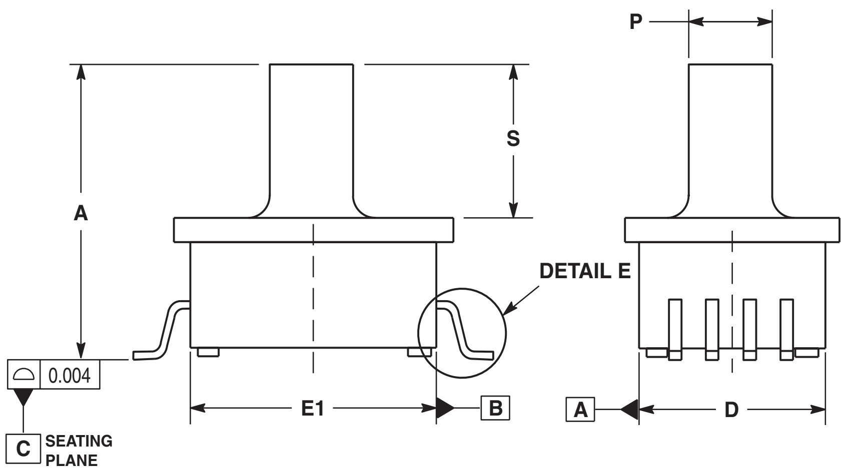
ISSUE A

OUTLINE DIMENSION





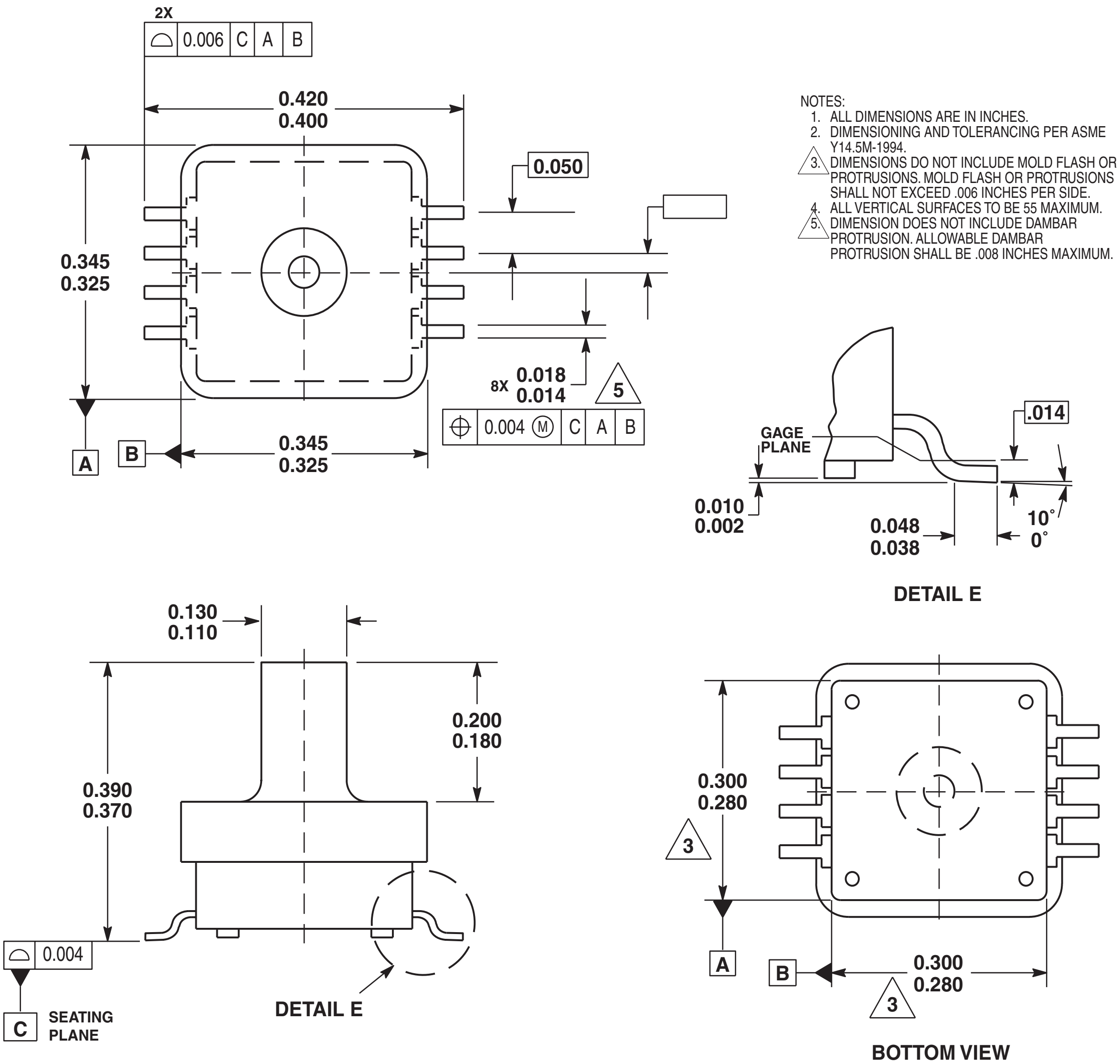
NOTES:
1. DIMENSIONS ARE IN INCHES.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS "D" AND "E1" DO NOT INCLUDE MOLD FLASH OR PROTRUSION. MOLD FLASH OR PROTRUSION SHALL NOT EXCEED .006" PER SIDE.
4. ALL VERTICAL SURFACES TO BE 55 MAXIMUM.
5. DIMENSIONS "b" DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE .008 MAXIMUM.



	INCHES	
DIM	MIN	MAX
A	.377	.397
A1	.002	.010
b	.014	.018
b1	.120	.130
D	.245	.255
E	.475	.485
E1	.325	.335
e	.050 BSC	
e/2	.025 BSC	
L	.013	.023
M	.283	.293
N	.363	.373
P	.107	.117
S	.192	.202
q	0˚	7˚

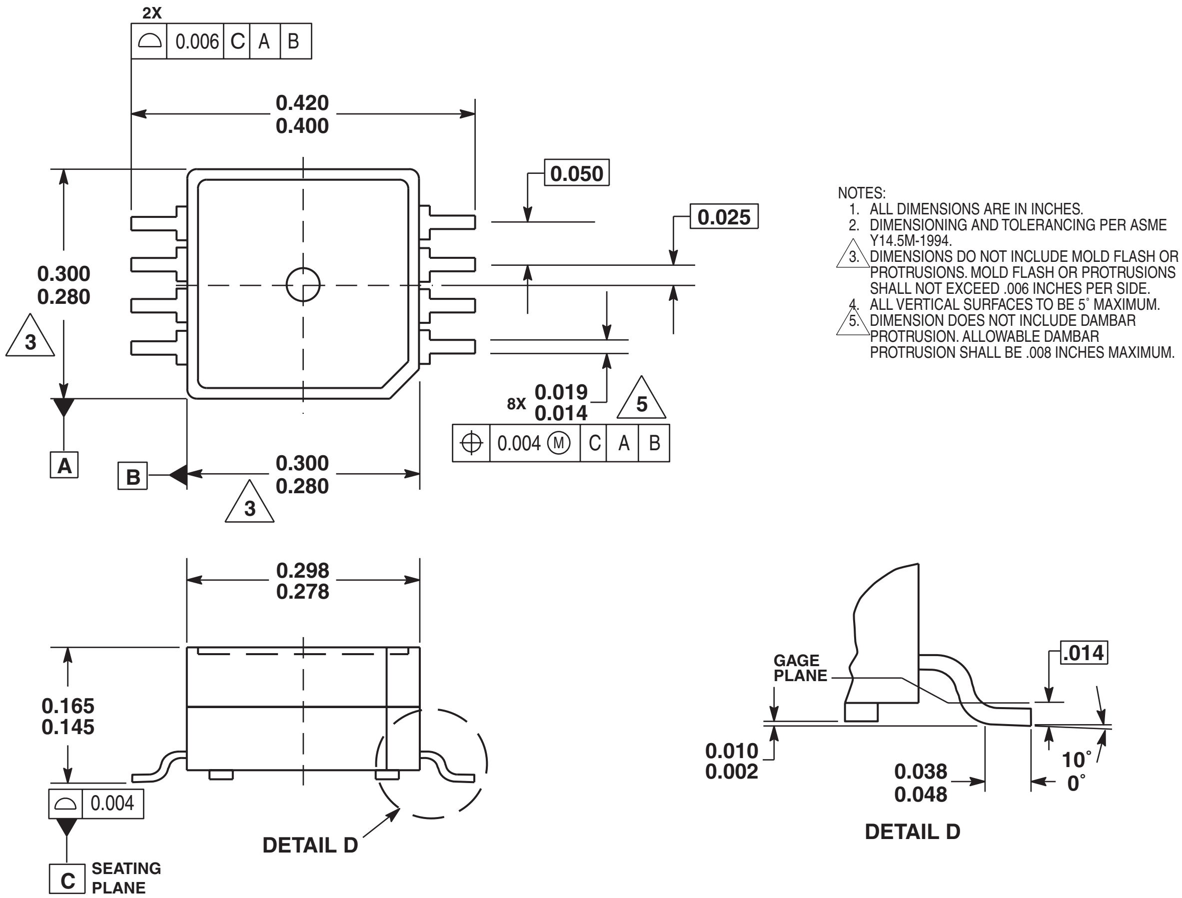
MPAK PACKAGE
CASE 1320A-02
ISSUE O

OUTLINE DIMENSION



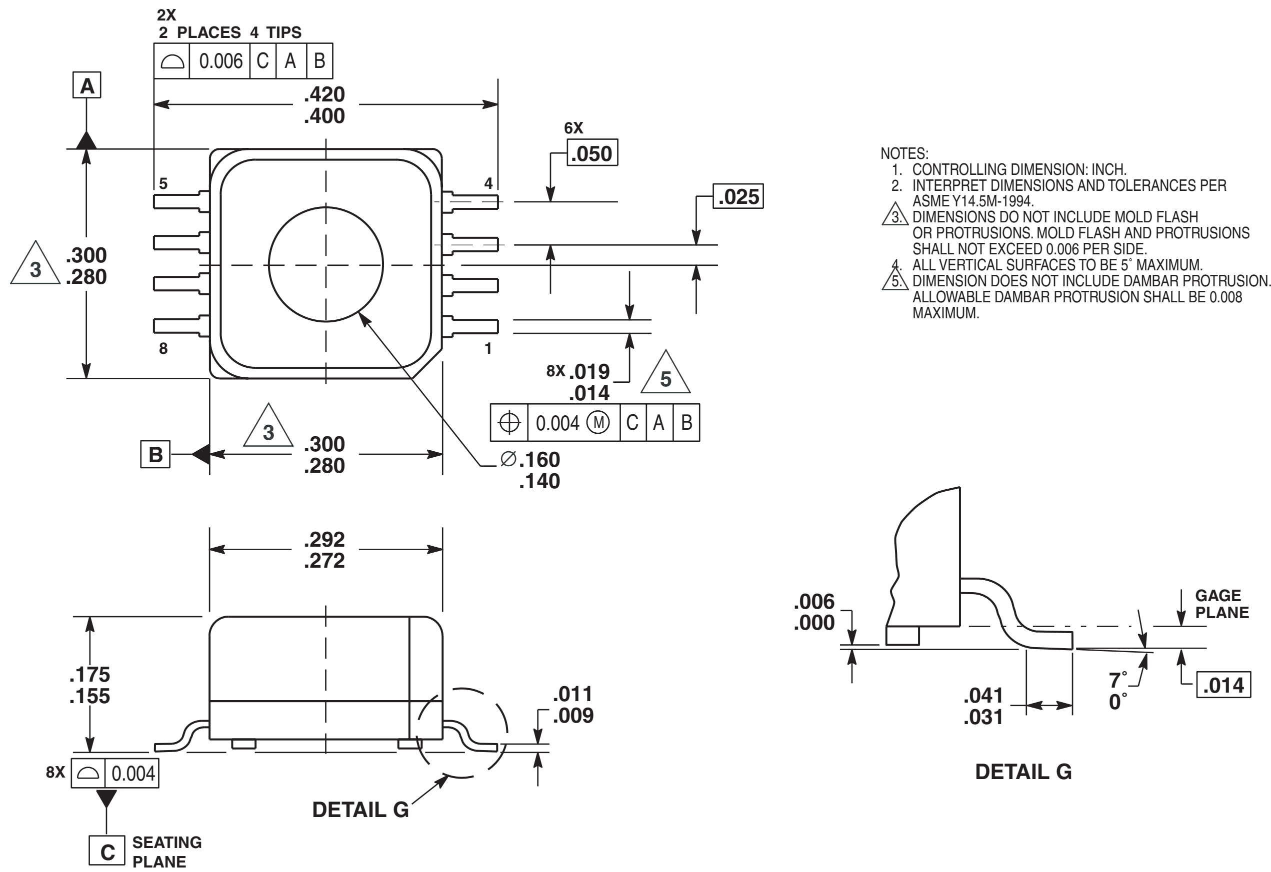
SSOP PACKAGE
CASE 1317A-01
ISSUE A

OUTLINE DIMENSION



SSOP PACKAGE
CASE 1317-04
ISSUE D

OUTLINE DIMENSION



NOTES:
1. CONTROLLING DIMENSION: INCH.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS. MOLD FLASH AND PROTRUSIONS SHALL NOT EXCEED 0.006 PER SIDE.
4. ALL VERTICAL SURFACES TO BE 5° MAXIMUM.
5. DIMENSION DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.008 MAXIMUM.

SSOP PACKAGE
CASE 1352-03
ISSUE B

MPXY80XX Application Mounting

by: Michael Agic
Freescale Semiconductor, Inc.
Sensor Products

SYNOPSIS

Tire pressure has long been known to be a significant factor in the driving experience and vehicle performance. Keeping the recommended level of pressure, as specified by tire and/or car manufacturers, is a very important part of the overall vehicle maintenance affecting the vehicle's suspension, steering, braking systems, and tire wear among others.

Following popular concerns regarding tire pressure security and in response to a mandate in the Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act of 2000, the National Traffic Highway Safety Administration (NHTSA) issued a ruling mandating installation of Tire Pressure Monitoring Systems (TPMS) that warn drivers when a tire is significantly under-inflated. This new Federal Motor Safety Standard mandates that vehicle manufacturers and TPMS suppliers, over time, equip all light vehicles with such systems. For the newest timeline and for more information on TPMS requirements, please refer to http://www.nhtsa.dot.gov/.

Within its extensive portfolio of pressure sensors, Freescale Semiconductor, Inc. offers highly integrated solutions for tire pressure monitoring systems – the MPXY80xx family.

This application note deals with considerations pertaining to the mounting of the MPXY80xx family sensors in the end user's applications.

MPXY80XX FAMILY

Freescale's MPXY80xx tire pressure monitoring sensor is a capacitive pressure sensing element, a temperature-sensing element, and an interface circuit with a wake-up feature, all on a single chip. The die is housed in Freescale's Super Small Outline Package (SSOP). The SSOP's size and enhanced media protection make it the perfect package solution for the TPMS.

Tire pressure monitoring systems operate in potentially corrosive environments that could lead to device failures if no protection is implemented. For that reason, the MPXY80xx family sensors use a media filter as the protection method. The filter allows pressure equalization on both sides of the filter. This, in turn, subjects the sensor's silicon diaphragm to the true tire pressure.

Despite these precautions, the tire's rapid and wide temperature variation, in concert with high humidity levels, present a major challenge in terms of pressure sensor operability.

Figure 1. MPXY80XX Sensor Package

MODULE MOUNTING CONSIDERATIONS

MPXY80xx sensors are designed to be mounted inside the tire either in valve stems or on the rim.

On-rim module installation typically requires that the module's case, containing the sensor and the rest of the system components, is mounted on the rim inside the tire as depicted in Figure 2.

Valve-stem installation typically involves mounting the combination of the valve stem and module casing on the outside rim as depicted in Figure 3.

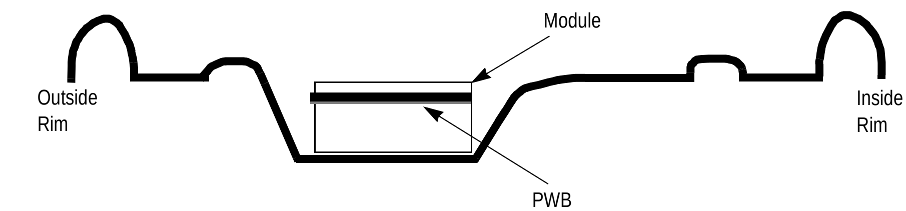


Figure 2. In-Rim Mounting Conceptual Depiction

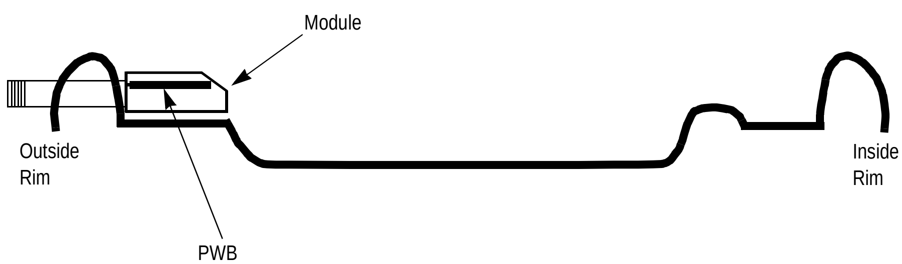


Figure 3. Valve-Stem Conceptual Depiction

SENSOR MOUNTING CONSIDERATIONS

Moisture Related Considerations

The MPXY80xx family integrated filter provides media and humidity protection needed for demanding automotive environments. The devices have been successfully qualified to a stringent list of qualification tests based on the Automotive Electronics Council (AEC) – Q100 requirements. These tests include accelerated humidity testing, long-term pressure and temperature cycling, as well as exposure to chemicals commonly found in Tire Pressure Monitoring applications. The integrated filter's ability to provide sensors with sufficient humidity and media protection, while not causing any false electrical signals from the devices due to acceleration forces in system applications, demonstrates the capabilities of this innovative packaging solution.

In order to maximize the media protection benefits from the integrated filter, the sensor's position needs to be carefully considered. Position of the MPXY80xx sensor in its final application is an important design decision since, in the extreme case where liquid would accumulate inside the tire and settle on top of the sensor package, the media filter may become obstructed (see Figure 4).

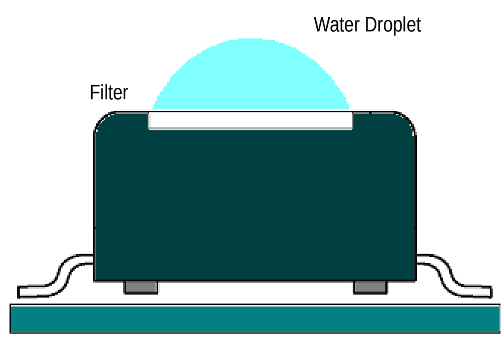


Figure 4. Filter Blockage

In addition to liquid possibly obstructing pressure transmission, liquid can be forced through the filter if it is present on the filter's exterior surface at a time when the device sees rapid pressurization such as when a tire is first installed on a rim.

In order to minimize the likelihood of liquid impacting the device's performance, it is suggested that the media filter on MPXY80xx family sensors faces outward and away from the wheel axis as depicted in Figure 5. This position of the sensor will take advantage of the strong radial forces experienced by the tire allowing for removal of water captured on top of, or inside, the package.

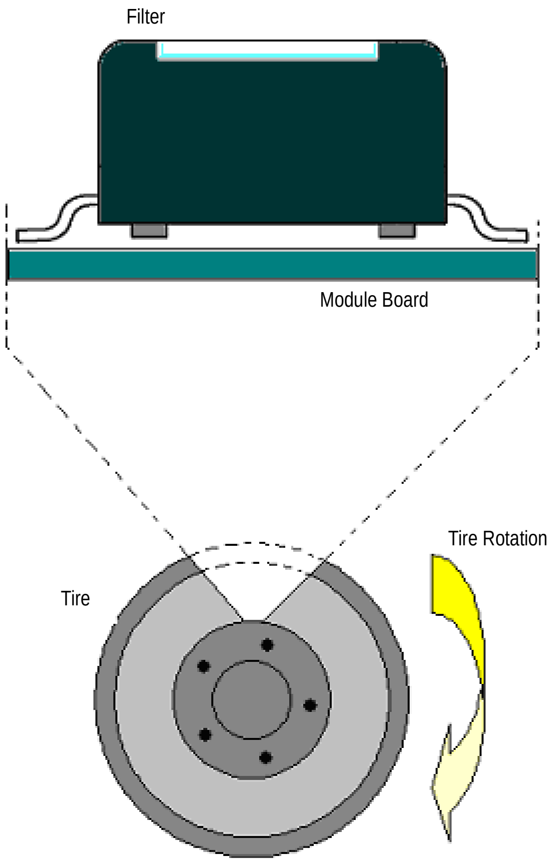


Figure 5. Filter Orientation

Vibration Related Considerations

During normal driving conditions, tire pressure monitoring systems are subjected to high levels of vibrations and strong dynamic forces as shown in an example of the P215/50R16 tire (refer to Figure 6). To ensure that the MPXY80xx family of sensors can withstand these harsh conditions, they are tested to acceleration and shock forces of up to 2000g.

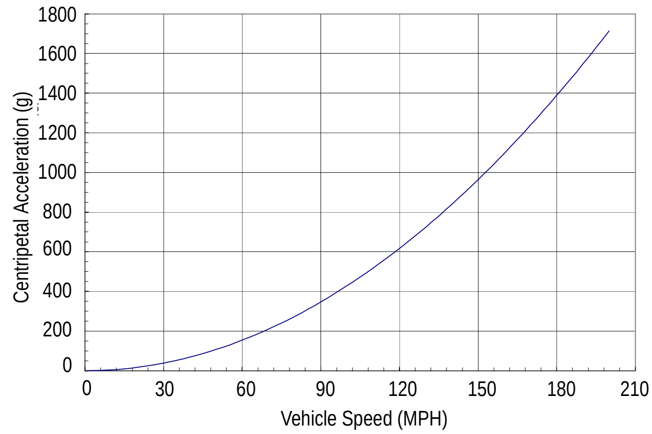


Figure 6. Centripetal Acceleration On a Rim Mounted Pressure Sensor for a P215/50R16 Tire

Due to these dynamic forces caused by the road conditions, the package leads may oscillate with the varying frequency. In order to prevent the board-level vibration failure caused by the driving dynamics, appropriate steps need to be taken when mounting the MPXY80xx family sensors to the system board. Quality automotive-grade components and assembly need to be used in order to prevent such failures. In addition to electrically protecting the MPXY80xx sensor's pins, potting and/or conformal coating techniques may help with the vibration failures and are commonly used as the final step in manufacturing the tire pressure monitoring systems.

SUMMARY

There are several important mounting considerations for the MPXY80xx family of sensors. In-tire environment demands that the sensor faces away from the wheel axis; this position takes advantage of the radial forces which will help remove any possible accumulated liquid off the integrated filter. The sensor position within the tire needs to be chosen such that the sensor is not immersed in the liquid for prolonged periods of time.

Dynamic forces induced by the driving conditions require that the board housing the MPXY80xx family of sensors is made with quality, automotive-grade materials. A non-conductive, potting material needs to be applied in order to protect electrically active parts on the system board from creation of unintended, electrically conductive paths.

ACKNOWLEDGMENTS

I would like to acknowledge the expert advice, and inputs given to me by Dave Monk, PhD., the design manager from Freescale Semiconductor, Inc., Sensor Products Division (SPD). I would also like to acknowledge inputs, and review contributed to creation of this application note by Carl Lopez, the new product development manager from Freescale Semiconductor, Inc., Sensor Products Division (SPD).

New Small Amplified Automotive Vacuum Sensors

A Single Chip Sensor Solution for Brake Booster Monitoring

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BRAKING SYSTEM

Different types of braking principles can be found in vehicles depending on whether the brake system is only activated by muscular energy or power assisted (partially or completely).

Muscular activated brakes are mostly found on motorcycles and very light vehicles. The driver's effort on the hand lever or pedal is directly transmitted via a hydraulic link to the brake pads.

Power assisted brakes are found on most passenger cars and some light vehicle trucks. In this case, the driver's effort is amplified by a *brake booster* to increase the force applied to the brake pedal.

BRAKE BOOSTER OPERATION PRINCIPLE

The vacuum brake booster is a system using the differential between atmospheric pressure and a lower pressure source (vacuum) to assist the braking operation. The brake booster is located between the brake pedal and the master cylinder. Figure 1 shows a simplified schematic of a vacuum brake booster.

When no brake pressure is applied on the push rod (brake pedal side), the air intake valve is closed and the vacuum valve open. Thus, both the vacuum and working chambers are at the same pressure, typically around -70 kPa (70 kPa below atmospheric pressure). Vacuum is generated by either the engine intake manifold or by an auxiliary vacuum pump.

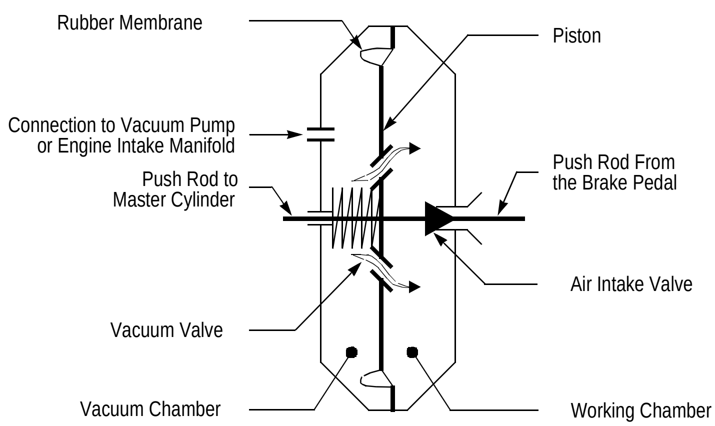


Figure 1. Brake Booster Simplified Schematic

Once the brake pedal is activated (force Fp), the vacuum valve is closed and the air intake valve is open proportionally to the displacement of the push rod (Figure 2). The working chamber is progressively open to atmospheric pressure, which creates a differential between the vacuum chamber and the working chamber. This differential pressure applied to the surface (S) of the piston results in a force $Fb = (Pw - Pv) \times S$. The forces Fb + Fp are then applied to the brake pads through the master cylinder and hydraulic links.

When the brake pedal is released, the spring moves the piston back, closing the air intake valve and opening the vacuum valve to rebalance the pressure between the two chambers.

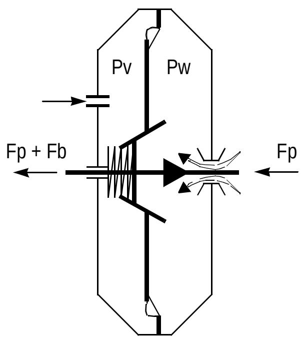


Figure 2. Braking Phase

VACUUM GENERATION

On most passenger cars, vacuum is generated by the engine itself. When the engine throttle valve is closed, the displacement of the pistons produces vacuum in the intake manifold. Thanks to a tube or hose connected between the engine intake manifold and the brake booster, vacuum can be applied to the chambers. A backslash valve inserted between the intake manifold and the booster maintains the vacuum in the booster when the engine throttle valve is open.

This principle has some limitations, however. For example, it can be only used on engines that have the ability to generate enough vacuum. On diesel engines, which have no throttle valve, it is necessary to use an auxiliary pump to generate vacuum. This will also be the case on the Gasoline Direct Injection (GDI) engine, where in some driving conditions (idle, lean burn) the electrically assisted throttle valve will be maintained slightly open. In this situation, the vacuum available on the intake manifold is not sufficient to provide an efficient braking.

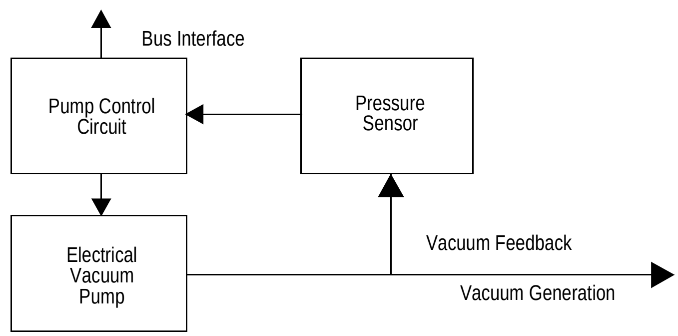


Figure 3. Vacuum Pump Monitoring

Therefore, it is necessary and desirable to use an electrical pump that will generate the vacuum for the brake booster. The use of an auxiliary electrical pump (Figure 3) provides several advantages over the “intake manifold” vacuum.

- Vacuum generation is no longer related to the engine running condition. Vacuum is only generated and controlled by the pump thanks to a vacuum pressure sensor that provides an accurate reading to the pump electrical control circuit.
- The electrical pump can be switched on and off based on the required vacuum. To compensate atmospheric pressure variation in order to maintain a constant booster effect, the pump also can be switched on independently from the atmospheric pressure. Various algorithms for driving the pump can be implemented depending on the required braking conditions.
- Pressure variations during braking can be measured, and the pump can be activated to generated additional vacuum if required to increase the braking force.
- Leakage can be detected by the pressure sensors and the pump can be switched on to compensate them. The driver can be informed of any type of failure thanks to the bus interface. Vacuum level, and thus available braking force can be communicated through the bus to other braking systems such as, for example, ABS or ESP.

Freescale Semiconductor, Inc., a worldwide leader in automotive semiconductors, has introduced a new integrate pressure sensor dedicated to vacuum measurements in applications such as brake booster monitoring. The single-chip vacuum sensor may be placed directly onto the pump electronic control unit or integrated as component within the brake booster, thus providing flexibility, system integration and reduced system cost.

FREESCALE’S NEW MPXV6115VC6U VACUUM SENSOR

PIEZORESISTIVE/AMPLIFIED SENSORS

Freescale's pressure sensors are based on a piezoresistive technology that consists of a silicon micromachined diaphragm and a diffused piezoresistive strain gauge. When vacuum or pressure is applied on the die, the diaphragm is deformed and stressed. The resulting constraints create a variation of resistance in the piezoresistive strain gauge. In order to read this variation, an excitation current passes through the gauge, and a voltage proportional to the applied pressure and excitation current appears between the voltage taps. To get an accurate pressure reading, such a sensing element needs usually to be calibrated, temperature compensated and amplified.

In order to solve the inherent limitation of the basic sensing element, Freescale produces an entire family of calibrated, thermally compensated and amplified pressure sensors (see Figure 4) called Integrated Pressure Sensors (IPS).

The IPS is a state of the art, monolithic, amplified and signal-conditioned silicon pressure sensor. The sensor combines advanced micromachining techniques, thin film memorization and bipolar semiconductor processing to provide an accurate, high-level analog output that is proportional to the applied pressure. IPS sensors can be directly connected to an A/D converter.

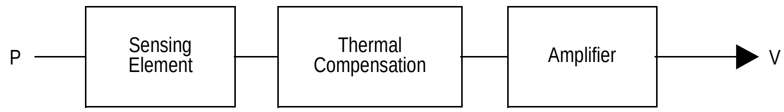


Figure 4. Integrated Pressure Sensor Block Diagram

PRESSURE MEASUREMENT CONVENTION

Pressure measurements can be divided into three different categories: absolute, gage and differential pressure.

Absolute pressure refers to the absolute value of the force per unit area exerted on a surface by a fluid. Therefore, the absolute pressure is the difference between the pressure at a given point in a fluid and the absolute zero of pressure or a perfect vacuum.

Gage pressure is the measurement of the difference between the absolute pressure and the local atmospheric pressure. Local atmospheric pressure can vary depending on ambient temperature, altitude and local weather conditions. The standard atmospheric pressure at sea level and 20°C is 101.325 kPa absolute. When referring to pressure measurement, it is critical to specify what reference the pressure is related to: gage or absolute. A gage pressure by convention is always positive. A ‘negative' gage pressure is defined as vacuum. Figure 5 shows the relationship between absolute, gage pressure and vacuum.

Differential pressure is simply the measurement of one unknown pressure with reference to another unknown pressure. The pressure measured is the difference between the two unknown pressures. Since a differential pressure is a measure of one pressure referenced to another, it is not necessary to specify a pressure reference.

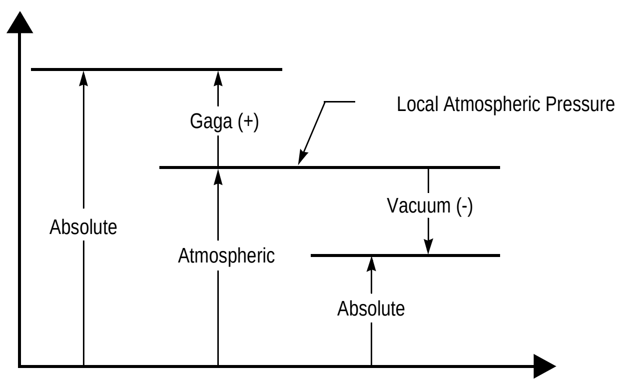


Figure 5. Pressure Convention

TRANSFER FUNCTION

The behavior of an IPS is defined by a linear transfer function. This transfer function applies to all Freescale’s Integrated Pressure Sensors whatever the pressure range and type of sensing element (absolute or differential).

$$V_{out} = V_S \times (P \times K1 + K2)$$
$$\pm (PE \times TM \times V_S \times K1)$$

- V_{out}: Sensor output voltage
- P: Applied pressure in kPa
- Vs: Sensor supply voltage in V
- K1: Sensitivity constant in V/V/kPa
- K2: Offset Constant inV/V
- PE: Pressure error in kPa
- TM: Temperature multiplier

The constants, K1, K2, PE & TM are specific to each device, temperature and pressure encountered in the application.

The variables P and Vs are dependent on the user application but must remain within the operating specification of the device.

THE MPXV6115VC6U INTEGRATED PRESSURE SENSOR

The MPXV6115VC6U gauge vacuum sensor, designed to measure pressure below the atmospheric pressure, is suitable for automotive application such as vacuum pump or brake booster monitoring. The MXPV4115V is also ideal for non-automotive applications where vacuum control is required.

The MPXV6115VC6U has the following basic characteristics (Note: Detailed characteristics of Freescale's pressure sensors can be found on http://www.freescale.com/semiconductors).

MPXV6115VC6U CHARACTERISTICS

$$V_{out} = V_S \times (P \times 0.007652 + 0.92)$$
$$\pm (PE \times TM \times V_S \times 0.007652)$$

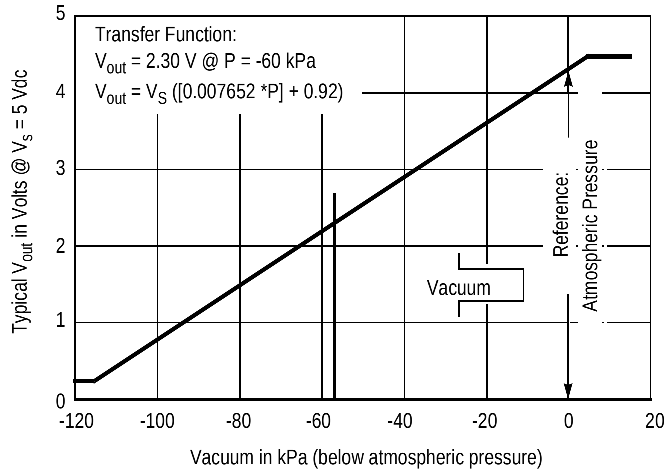


Figure 6. MPXV6115VC6U Transfer Function

- P is the applied vacuum to the sensor pressure port. Pressures below atmospheric pressure have a negative sign. For example, 50 kPa below atmospheric is P = -50 in the transfer function. For pressure higher than the atmospheric pressure, the device will electrically saturate. The sensor is designed to measure vacuum from 0 kPa (Atmospheric pressure applied to the sensor pressure port) down to -115kPa.

  Since the MPXV6115VC6U is using the atmospheric pressure as reference, -115 kPa can only be reached if the atmospheric pressure is higher or equal than 115 kPa. The device will electrically saturate for vacuum below -115 kPa.
- PE = 1.725 kPa (1.5% of full scale span) over the entire pressure range
- TM = 1 between 0 and +85°C, 3 at -40°C and +125°C. TM is a linear response from -40°C to 0°C and from 85°C to 125°C.

The real intent for the pressure-sensor user is to know the measured pressure. In this case it is preferable to express the transfer function as:

$$P = (V_{out}/V_S - 0.92)\ 0.007652 \pm (PE \times TM)$$

As an example, if Vout = 2.30 V for a 5 Vdc power supply and at 25°C ambient temperature, the measured vacuum is

$$P = -60.1 \text{ kPa} \pm 1.725 \text{ kPa}.$$

SENSOR PACKAGING

The packaging of a pressure sensor die is critical to achieve optimal performances of the final product. The package must isolate the pressure sensor die from unwanted external stress which can cause undesired drift of the electrical signal while being robust enough to support the pressure applied to the device without cracks, leaks or mechanical failures. It must be media compatible for the same reasons.

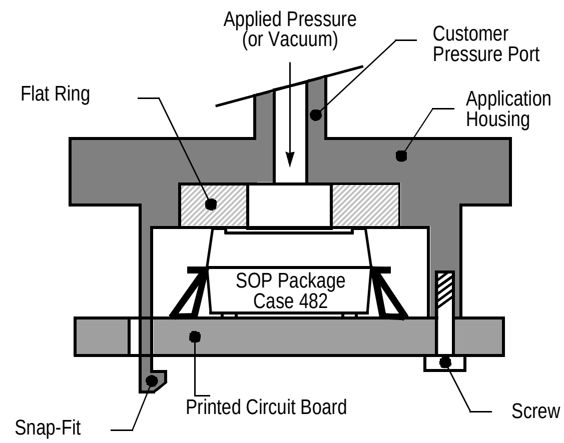


Figure 7. Mounting Suggestion

The new small pressure sensor package from Freescale addresses those requirements and lets designers mount a pressure sensor directly on a printed circuit board, thus providing great flexibility for space saving design. Figure 7 shows a typical assembly using a small outline package (SOP) Case 482-01.

The sensor can be mounted on the printed circuit board by an automatic pick and place machine as with every other surface mount component. Sealing is done by using a silicone flat ring inserted in the application housing. The printed circuit board must be maintained against the flat ring either by a snap fit, or by a screws as shown.

The new small outline package (SOP) is fabricated using poly-phenyl sulfide (PPS), a robust material, which can withstand high temperatures and is highly resistant to chemicals. Consequently, the package is ideal for harsh environment such as automotive, industrial or medical systems.

The small outline package is suitable for any of Freescale's sensor chips from the basic uncompensated sensor to the fully integrated sensing solution that include amplifiers and other circuitry all on one chip.

Freescale's sensors using this package are available in both tubes and tape and reel configuration for high productivity on your assembly line.

AN4010
Rev 1, 05/2005

Low-Pressure Sensing Using MPX2010 Series Pressure Sensors

by: Memo Romero and Raul Figueroa
Sensor Products Division
Systems and Applications Engineering

INTRODUCTION

This application note presents a design for a low pressure evaluation board using the Freescale Semiconductor, Inc. MPX2010 series pressure sensors. By providing large gain amplification and allowing for package flexibility, this board is intended to serve as a design-in tool for customers seeking to quickly evaluate this family of pressure sensors.

The MPX2010 family of pressure sensors appeals to customers needing to measure small gauge, vacuum, or differential pressures at a low cost. However, different applications present design-in challenges for these sensors. For very low pressure sensing, large signal amplification is required, with gains substantially larger than what is provided in Freescale's current integrated pressure sensor portfolio. In terms of packaging, customers often need more mechanical flexibility such as smaller size, dual porting or both. In many cases, customers often lack the engineering resources, time or expertise to evaluate the sensor. The low-pressure evaluation board, shown in Figure 1, facilitates the design-in process by providing large signal gain and by providing for different package designs in a relatively small footprint.

CIRCUIT DESCRIPTION

For adequate and stable signal gain and output flexibility, a two-stage differential op-amp circuit with analog or switch output is utilized, as shown in Figure 2. The four op-amps are packaged in a single 14 pin quad package. There are several features to note about the circuitry.

The first gain stage is accomplished by feeding both pressure sensor outputs (VS- & VS+) into the non-inverting inputs of operational amplifiers. These op-amps are used in the standard non-inverting feedback configuration. With the condition that Resistors R2=R3, and R1=R4 (as closely as possible), this configuration results in a gain of G1= R4/R3+1.

The default gain is 101, but there are provisions for easily changing this value. The signal V (op-amp Pin 7) is then calculated as:

$$V_1 = G1*(VS+ - VS-) + Voffset. \quad . . . .\text{Equation (1)}$$

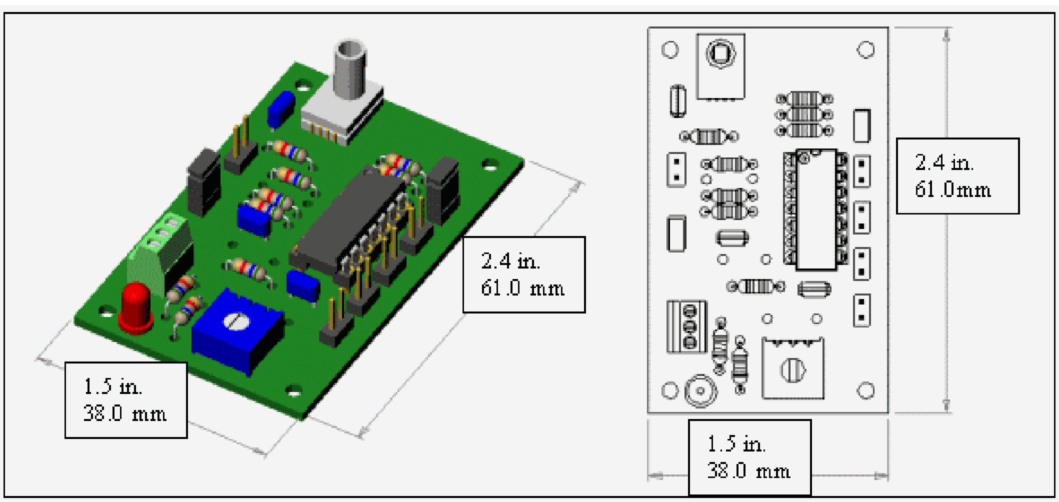


Figure 1. Low Pressure Evaluation Board

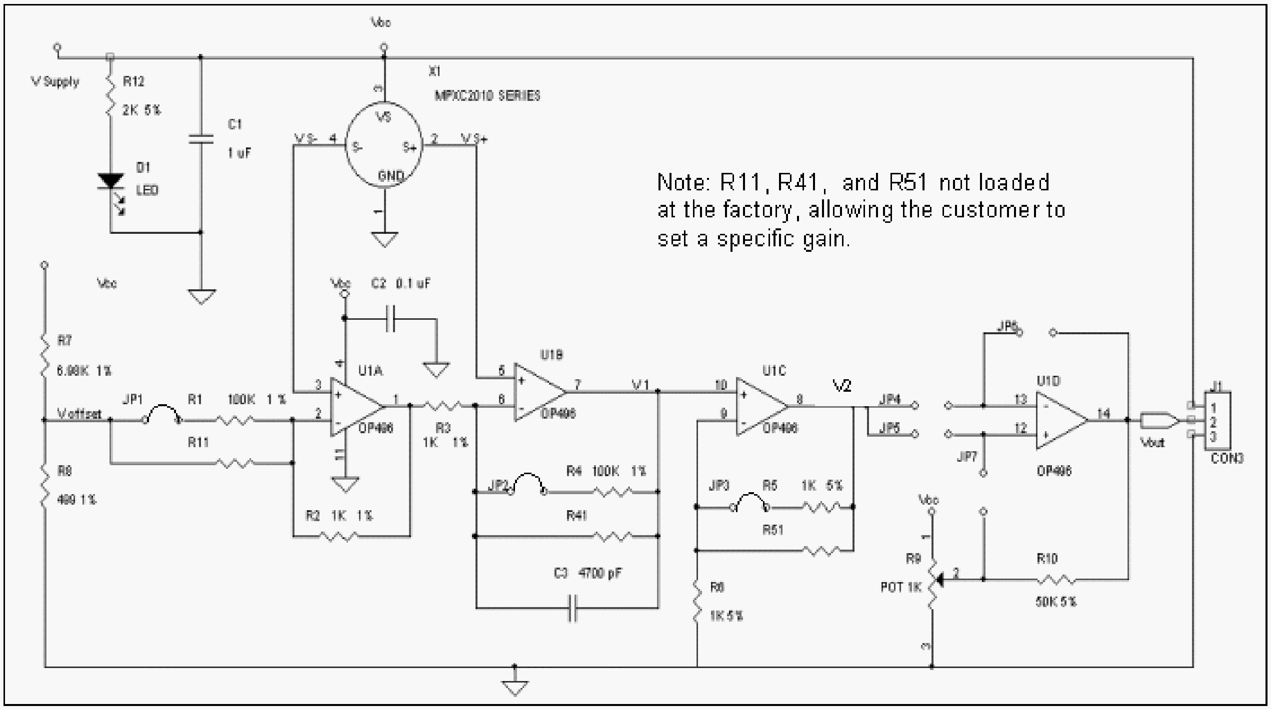


Figure 2. Circuit Schematic

Voffset is the reference voltage for the first op-amp and is pre-set with a voltage divider from the supply voltage. This value is set to be 6.7 percent of the supply voltage. It is important to keep this value relatively small simply because it too is amplified by the second gain stage. It is also desirable to have resistors R7 and R8 sufficiently large to reduce power consumption.

The second gain stage takes the signal from the first gain stage, V, and feeds it into the non-inverting input of a single op-amp. This op-amp is also configured with standard non-inverting feedback, resulting in a gain of G2=R5/R6+1. The default value is set to 2, but can easily be changed.

The signal produced at the output of the second stage amplifier, V (op-amp pin 8) is the fully amplified signal. This is calculated as

$V_2 = G2^* V_1$. . . . .Equation (2)

From this point, there are two possible output types available. One is a simple follower circuit, as shown in Figure 3, in which the circuit output, Vout (op-amp pin 14), is essentially a buffered V signal. This analog output option is available for applications in which the real time nature of the pressure signal needs to be measured. This option is selected by connecting jumpers J5 and J6. J4 and J7 are not connected for analog output.

The second output choice, a switch output as shown in Figure 4, is accomplished by setting jumpers J4 and J7, and leaving J5 and J6 unconnected. This is appropriate for applications in which a switching function is desired. In this case, the fourth op-amp is configured as a comparator, which will invert V_2, high or low, depending on whether V_2 is larger or smaller than the preset reference signal, set by trim-pot R9. This signal can be used to simulate a real world threshold.

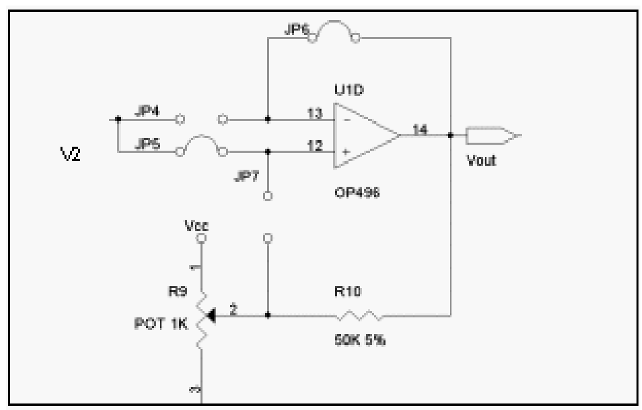


Figure 3. Analog Output Jumper Settings

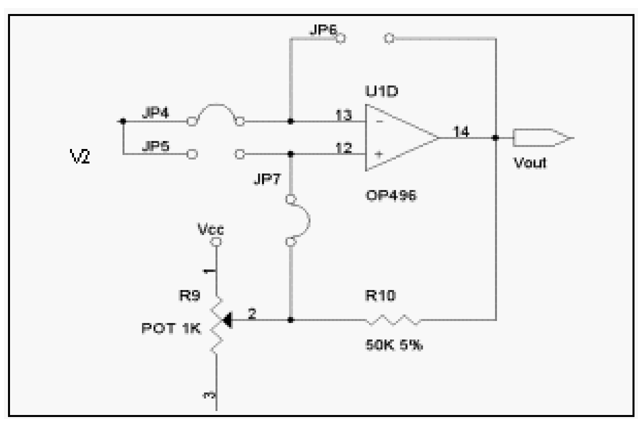


Figure 4. Switch Output Jumper Settings

Table 1 shows the jumper settings for both analog and switches outputs.

Table 1. Output Jumper Settings

Output	JP4	JP5	JP6	JP7
Analog	Out	In	In	Out
Switch	In	Out	Out	In

For the switch output option, it is desirable to apply some hysteresis on the output signal to make it relatively immune to potential noise that may be present in the voltage signal as it reaches and passes the threshold value. This is accomplished with feedback resistor R10. From basic op-amp theory, it can be shown that the amount of hysteresis is computed as follows:

V_H = Vout *[1-(10 / (R10 + R pot-eff))]

Where:

- VH is the output voltage attenuation, due to hysteresis, in volts
- Vout is the output voltage (railed hi or low)
- R10 is the feedback resistor, = 50K
- Rpot-eff is the effective potentiometer resistance

V_H may vary depending on the particular value of the potentiometer.

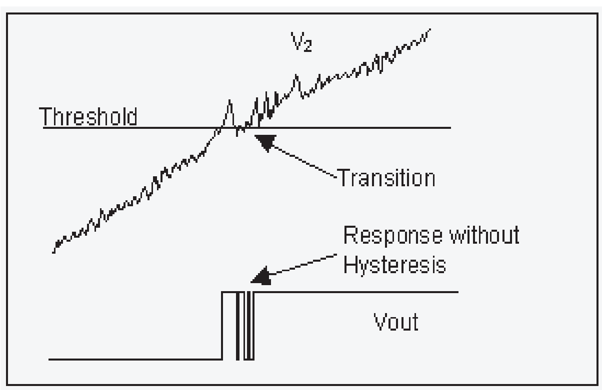


Figure 5. Output Transition without Hysteresis

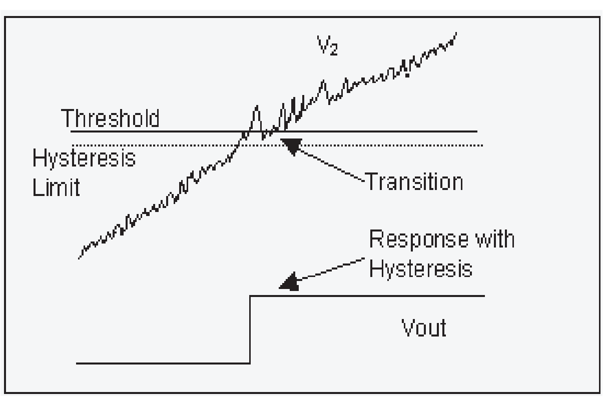


Figure 6. Output Transition with Hysteresis

To take an example, suppose that the supply voltage, Vs is 5 volts, and the threshold is set to 60 percent of Vs, or 3 volts. This corresponds to one leg of the 1K potentiometer set to 0.4K while the other is set to 0.6K. Thus the effective pot resistance is 0.4K // 0.6K = 0.24K.

Therefore,

V_H = 5V* [1- (50K/(50K + 0.24K))] = 24 mV.

Under these conditions, V signals passing through the threshold will not cause Vout to oscillate between Vs and Ground as long as noise and signal variations in V are less than 24mV during the transition. Figure 5 illustrates the benefit of having a hysteresis feedback resistor.

GAIN CUSTOMIZATION

The low-pressure evaluation board comes with default gains for both G1 and G2. G1 is factory set at 101, while G2 is set to 1. Jumpers JP1, JP2 and JP3 physically connect the resistors that produce these default gains. Three resistor sockets (R11, R41 and R51) are provided in parallel with R1, R4 and R5, respectively. By removing jumpers JP1, JP2 and JP3, and soldering different resistor values in the appropriate sockets, different gain values can be achieved. The limit on the largest overall gain that can be used is determined by op-amp saturation. Thus if gain values are chosen such that the output would be larger than the supply voltage, then the op-amp would saturate, and the pressure would not be accurately reflected. Table 2 outlines the jumper settings for customizing the gain.

Table 2. Resistor and Jumper Settings for Gain Customization

Gain		Resistors			Jumpers			Remarks
G1	*G2*	*R11*	*R41*	*R51*	*JP1*	*JP2*	*JP3*	
101	2	no load	no load	no load	In	In	In	Default
User Set	2	load	load	no load	Out	Out	In	R11=R41
101	User Set	no load	no load	load	In	In	Out	
User Set	User Set	load	load	load	Out	Out	Out	R11=R41

DESIGN CONSIDERATIONS

Since the evaluation board is primarily intended for low-pressure gage and differential applications, large gain values can be utilized for pressures less than 1.0 kPa. For example if G1 is set to 101, and G2 set to 6, then the total gain is 606.

Inherent in the MPX2010 family of pressure sensors is a zero-pressure offset voltage, which can be up to 1 mV. This offset is amplified by the circuit and appears as a DC offset at Vout with no pressure applied. The op-amp also has a voltage offset specification, though for the recommended op-amp this value is small and does not contribute significantly to the Vout offset.

For example, if the evaluation board is being used under the following conditions:

Vs = 3V

G1 = 101

G2 = 6

MPX2010 zero pressure offset = 0.3mV

At this supply voltage, VOFFSET can be calculated to be 6.7% x 3V = 0.2V. The voltage V, due simply to the zero pressure sensor offset voltage of 0.3mV, can be calculated from equation (1):

V_1 = 0.3mV * 101 + 0.2V = 0.23V

The voltage after the second gain stage comes from equation (2),

V_2 = 6 x 0.23V = 1.38 V.

Therefore, before any pressure is applied to the sensor, a 1.38V DC signal will appear at V. Since the supply voltage is 3V, the available signal for actual pressure is 1.62 V. With a total gain of G1 x G2 = 606, the largest raw pressure signal that can be accurately measured would be 1.62V/606 = 2.67 mV. For the MPX2010 family operating at Vs = 3V, this corresponds to roughly 3.5 kPa.

The board lends itself well to system integration via an A/D converter and microprocessor. For particular applications, general knowledge of the expected pressure signal can aid in choosing the proper customized gain. This will avoid op-amp saturation and will also ensure that the full-scale output signal is suitable for A/D conversion. To take another example, suppose that a particular application has the following constraints:

Supply Voltage, Vs = 5.0 V,

(thus VOFFSET = 6.7% x 5 = 0.335 V)

Sensor zero-pressure offset voltage, V_{ZP} = 0.3mV

Expected Pressure range = 0-2 kPa,

(corresponds to $\Delta V_{SENSOR\text{-}MAX}$ = 2.5mV @ 5V)

Desired maximum output range, ΔV_{2MAX} = 2V

(assume VMIN = 2V, V_{2MAX} = 4V for reasonable A/D resolution)

By manipulating equations (1) and (2) it can be shown that,

$\Delta V_{2MAX} = G_T \times \Delta V_{SENSOR\text{-}MAX}$

where GT is the total gain, equal to G1G2.

Thus GT = 2V/2.5mV = 800

To find G1 and G2, evaluate V_{2MIN} at the zero pressure condition.

$V_{2MIN} = G2\ V_{1MIN}$,

But $V_{1MIN} = G1\ V_{ZP} + V_{OFFSET}$

Thus $V_{2MIN} = G_T\ V_{ZP} + G2\ V_{OFFSET}$

Solving for G2, $G2 = (V_{2MIN} - G_T\ V_{ZP})/\ V_{OFFSET}$

numerically, G2 = (2V - (800x.0003V))/.335V

G2 = 5.2, and G1 = GT /G2 = 152

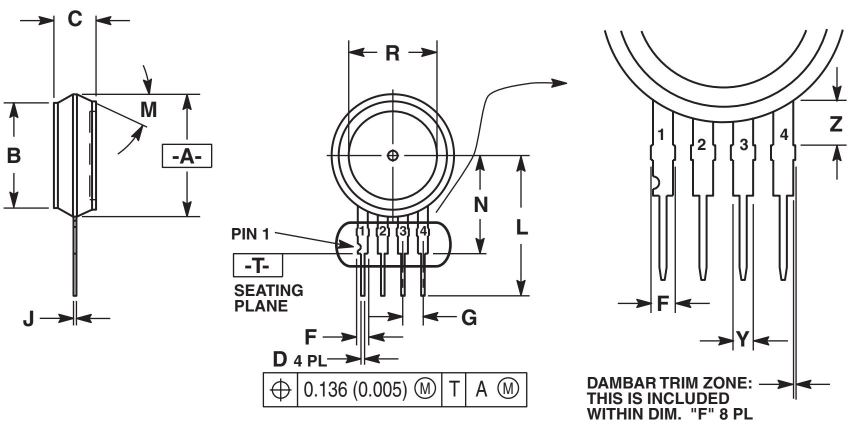
BOARD LAYOUT & CONTENT

The low-pressure evaluation board has been designed using standard components. The only item that requires careful selection is the operation amplifier IC. Because the selected gain may be relatively high as in the previous example, it is essential that this device have a low offset voltage. A device with a typical voltage offset of 35 mV has been selected. Even with a gain of 1500, this will result in a 52mV offset. Table 3 is a parts list for the board layout shown in Figure 1.

Table 3. Parts List

Ref.	Qty.	Description	Value	Vendor	Part No.
X1	1	Pressure Sensor	10 Kpa	Freescale	MPX2010 MPXC2011
C1	1	Vcc Cap	1 uF	Generic	
C2	1	Op-Amp Cap	0.1 uF	Generic	
C3	1	2nd stage cap	4700 pF	Generic	
D1	1	LED		Generic	
for U1	1	Op-Amp socket		Generic	
U1	1	Op-Amp		Analog Devices	OP496GP
R1, R4	2	1/4 W Resistor	100K	Generic	
R2,R3, R5,R6	4	1/4 W Resistor	1K	Generic	
R7	1	1/4 W Resistor	6.8K	Generic	
R8	1	1/4 W Resistor	510	Generic	
R9	1	Potentiometer	1K	Bourns	3386P-102
R10	1	1/4 W Resistor	51K	Generic	
R11	1	1/4 W Resistor	custom	Generic	
R12	1	1/4 W Resistor	2K	Generic	
R41	1	1/4 W Resistor	custom	Generic	
R51	1	1/4 W Resistor	custom	Generic	
JP1 - JP7	7	Jumper		Generic	
J1	1	3 Pos Connector		Phoenix	MKDS1

Package Dimensions



NOTES:
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION -A- IS INCLUSIVE OF THE MOLD STOP RING. MOLD STOP RING NOT TO EXCEED 16.00 (0.630).

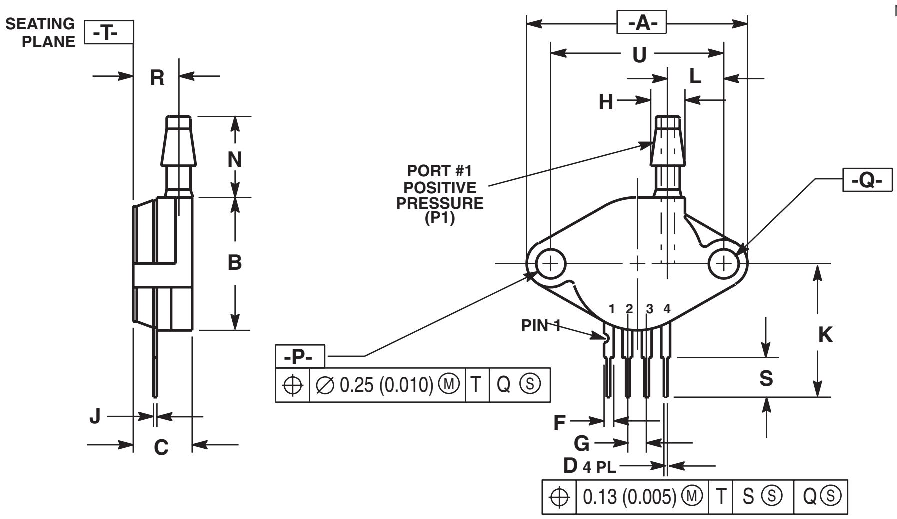
	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.595	0.630	15.11	16.00
B	0.514	0.534	13.06	13.56
C	0.200	0.220	5.08	5.59
D	0.016	0.020	0.41	0.51
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.40
L	0.695	0.725	17.65	18.42
M	30˚ NOM		30˚ NOM	
N	0.475	0.495	12.07	12.57
R	0.430	0.450	10.92	11.43
Y	0.048	0.052	1.22	1.32
Z	0.106	0.118	2.68	3.00

STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. - OUTPUT

STYLE 2:
PIN 1. V_{CC}
2. - SUPPLY
3. + SUPPLY
4. GROUND

STYLE 3:
PIN 1. GND
2. -VOUT
3. VS
4. +VOUT

CASE 344-15
ISSUE AA
SMALL OUTLINE PACKAGE



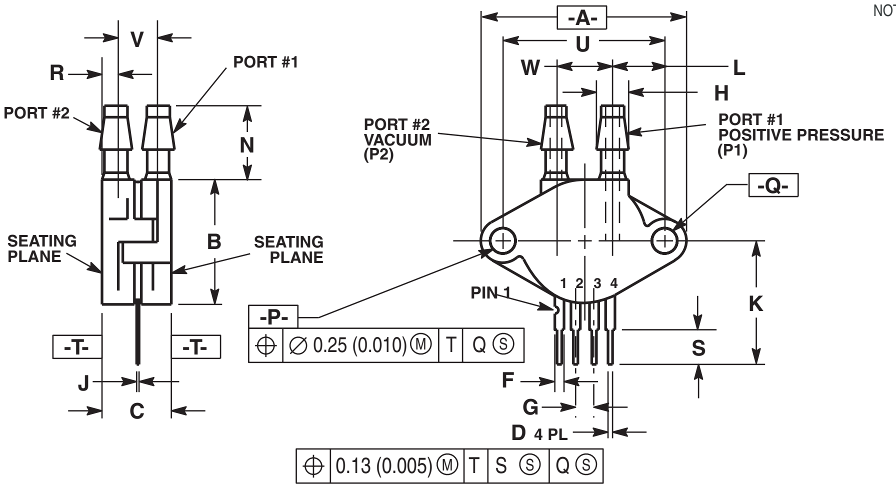
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	1.145	1.175	29.08	29.85
B	0.685	0.715	17.40	18.16
C	0.305	0.325	7.75	8.26
D	0.016	0.020	0.41	0.51
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
H	0.182	0.194	4.62	4.93
J	0.014	0.016	0.36	0.41
K	0.695	0.725	17.65	18.42
L	0.290	0.300	7.37	7.62
N	0.420	0.440	10.67	11.18
P	0.153	0.159	3.89	4.04
Q	0.153	0.159	3.89	4.04
R	0.230	0.250	5.84	6.35
S	0.220	0.240	5.59	6.10
U	0.910 BSC		23.11 BSC	

STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. - OUTPUT

CASE 344B-01
ISSUE B
SMALL OUTLINE PACKAGE

PACKAGE DIMENSIONS (CONTINUED)

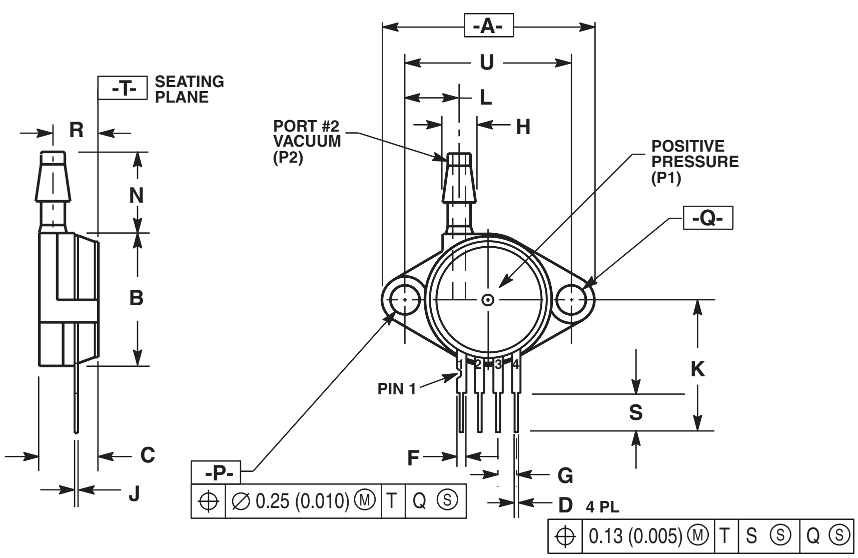


NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX
A	1.145	1.175	29.08	29.85
B	0.685	0.715	17.40	18.16
C	0.405	0.435	10.29	11.05
D	0.016	0.020	0.41	0.51
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
H	0.182	0.194	4.62	4.93
J	0.014	0.016	0.36	0.41
K	0.695	0.725	17.65	18.42
L	0.290	0.300	7.37	7.62
N	0.420	0.440	10.67	11.18
P	0.153	0.159	3.89	4.04
Q	0.153	0.159	3.89	4.04
R	0.063	0.083	1.60	2.11
S	0.220	0.240	5.59	6.10
U	0.910 BSC		23.11 BSC	
V	0.248	0.278	6.30	7.06
W	0.310	0.330	7.87	8.38

STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. - OUTPUT

CASE 344C-01
ISSUE B
SMALL OUTLINE PACKAGE



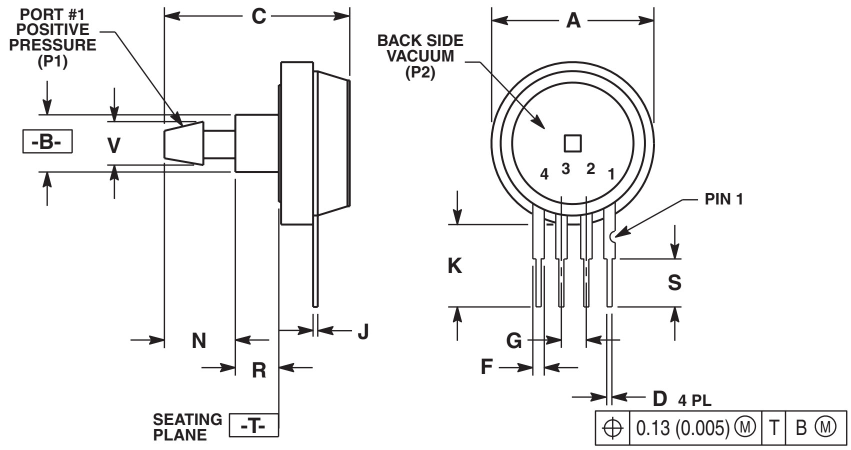
NOTES:
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
2. CONTROLLING DIMENSION: INCH.

DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX
A	1.145	1.175	29.08	29.85
B	0.685	0.715	17.40	18.16
C	0.305	0.325	7.75	8.26
D	0.016	0.020	0.41	0.51
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
H	0.182	0.194	4.62	4.93
J	0.014	0.016	0.36	0.41
K	0.695	0.725	17.65	18.42
L	0.290	0.300	7.37	7.62
N	0.420	0.440	10.67	11.18
P	0.153	0.159	3.89	4.04
Q	0.153	0.158	3.89	4.04
R	0.230	0.250	5.84	6.35
S	0.220	0.240	5.59	6.10
U	0.910 BSC		23.11 BSC	

STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. - OUTPUT

CASE 344D-01
ISSUE B
SMALL OUTLINE PACKAGE

PACKAGE DIMENSIONS (CONTINUED)

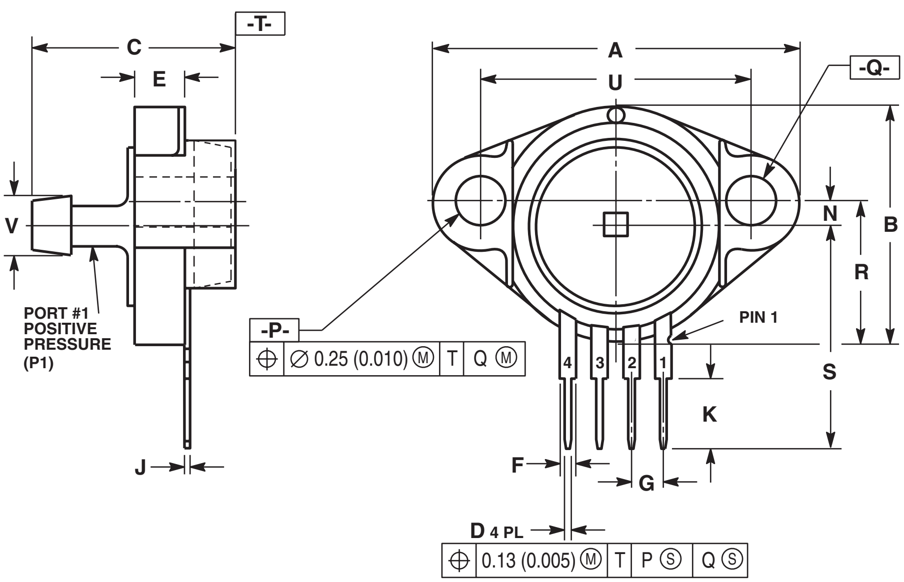


NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.690	0.720	17.53	18.28
B	0.245	0.255	6.22	6.48
C	0.780	0.820	19.81	20.82
D	0.016	0.020	0.41	0.51
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.41
K	0.345	0.375	8.76	9.53
N	0.300	0.310	7.62	7.87
R	0.178	0.186	4.52	4.72
S	0.220	0.240	5.59	6.10
V	0.182	0.194	4.62	4.93

STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. - OUTPUT

CASE 344E-01
ISSUE B
SMALL OUTLINE PACKAGE



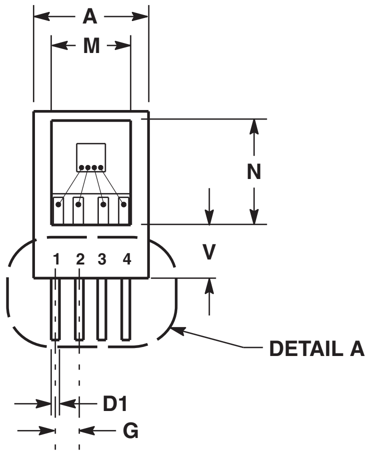
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	1.080	1.120	27.43	28.45
B	0.740	0.760	18.80	19.30
C	0.630	0.650	16.00	16.51
D	0.016	0.020	0.41	0.51
E	0.160	0.180	4.06	4.57
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.41
K	0.220	0.240	5.59	6.10
N	0.070	0.080	1.78	2.03
P	0.150	0.160	3.81	4.06
Q	0.150	0.160	3.81	4.06
R	0.440	0.460	11.18	11.68
S	0.695	0.725	17.65	18.42
U	0.840	0.860	21.34	21.84
V	0.182	0.194	4.62	4.92

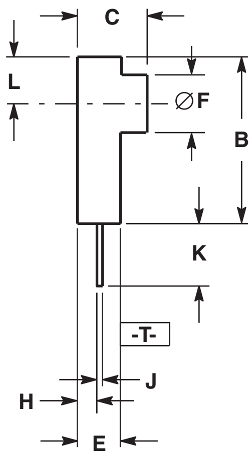
STYLE 1:
PIN 1. GROUND
2. V (+) OUT
3. V SUPPLY
4. V (-) OUT

CASE 344F-01
ISSUE B
SMALL OUTLINE PACKAGE

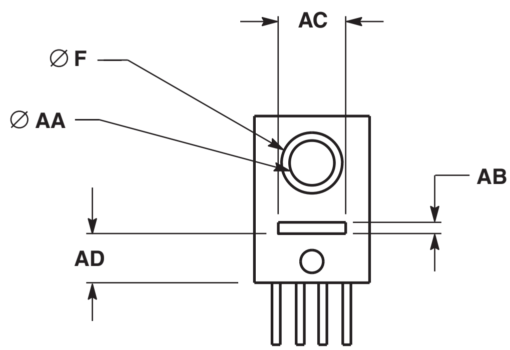
PACKAGE DIMENSIONS (CONTINUED)



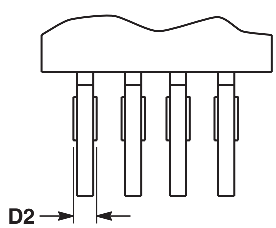
FRONT VIEW



END VIEW



BACK VIEW



DETAIL A

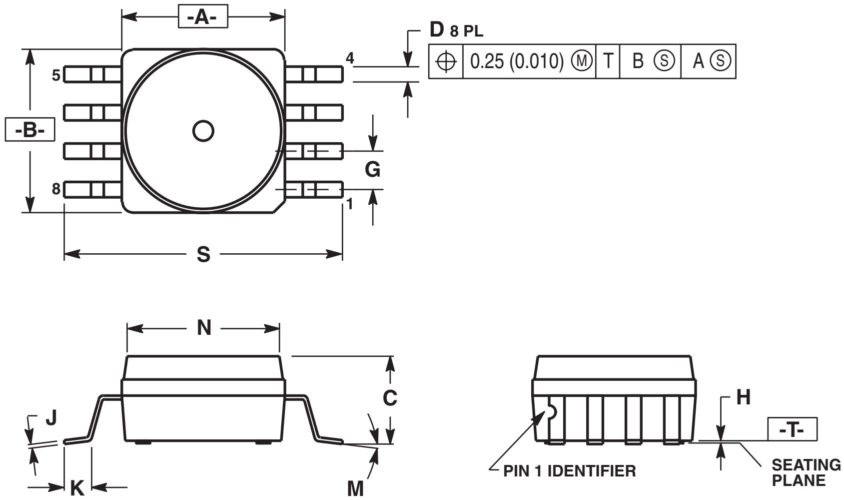
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

	INCHES		MILLIMETERS	
DIM	**MIN**	**MAX**	**MIN**	**MAX**
A	0.240	0.260	6.10	6.60
B	0.350	0.370	8.89	9.40
C	0.140	0.150	3.56	3.81
D1	0.012	0.020	0.30	0.51
D2	0.014	0.022	0.36	0.56
E	0.088	0.102	2.24	2.59
F	0.123	0.128	3.12	3.25
G	0.045	0.055	1.14	1.40
H	0.037	0.047	0.94	1.19
J	0.007	0.011	0.18	0.28
K	0.120	0.140	3.05	3.56
L	0.095	0.105	2.41	2.67
M	0.165	0.175	4.19	4.45
N	0.223	0.239	5.66	6.07
V	0.105	0.115	2.67	2.92
AA	0.095	0.107	2.41	2.72
AB	0.015	0.035	0.38	0.89
AC	0.120	0.175	3.05	4.45
AD	0.100	0.115	2.54	2.92

STYLE 1:
PIN 1. V_{CC}
2. +OUT
3. -OUT
4. GROUND

CASE 423A-03
ISSUE C
CHIP PAK PACKAGE

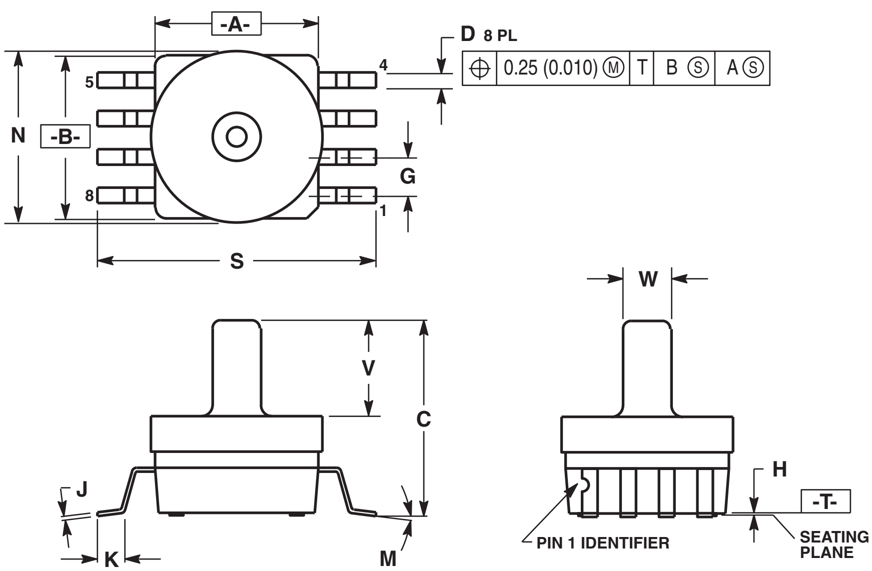
PACKAGE DIMENSIONS (CONTINUED)



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006).
5. ALL VERTICAL SURFACES 5˚ TYPICAL DRAFT.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.415	0.425	10.54	10.79
B	0.415	0.425	10.54	10.79
C	0.212	0.230	5.38	5.84
D	0.038	0.042	0.96	1.07
G	0.100 BSC		2.54 BSC	
H	0.002	0.010	0.05	0.25
J	0.009	0.011	0.23	0.28
K	0.061	0.071	1.55	1.80
M	0˚	7˚	0˚	7˚
N	0.405	0.415	10.29	10.54
S	0.709	0.725	18.01	18.41

CASE 482-01
ISSUE O
SMALL OUTLINE PACKAGE

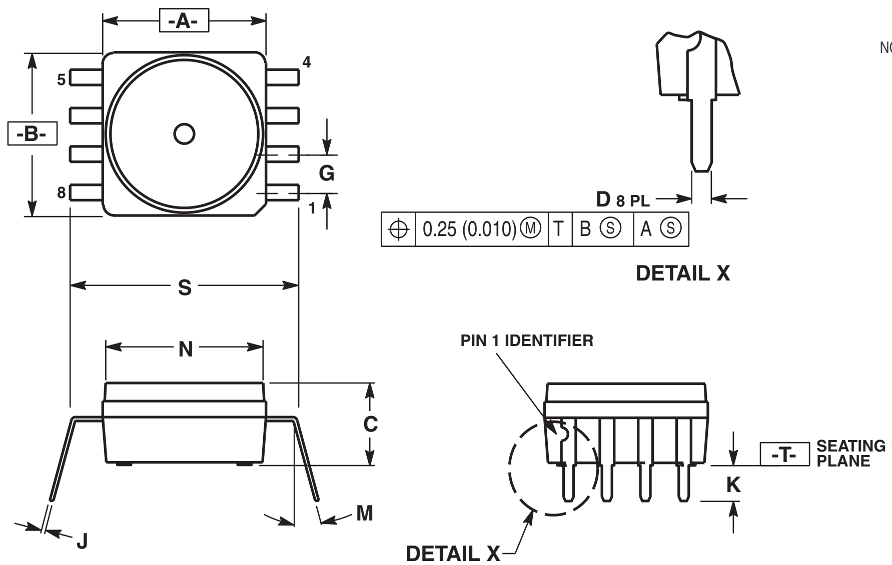


NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006).
5. ALL VERTICAL SURFACES 5˚ TYPICAL DRAFT.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.415	0.425	10.54	10.79
B	0.415	0.425	10.54	10.79
C	0.500	0.520	12.70	13.21
D	0.038	0.042	0.96	1.07
G	0.100 BSC		2.54 BSC	
H	0.002	0.010	0.05	0.25
J	0.009	0.011	0.23	0.28
K	0.061	0.071	1.55	1.80
M	0˚	7˚	0˚	7˚
N	0.444	0.448	11.28	11.38
S	0.709	0.725	18.01	18.41
V	0.245	0.255	6.22	6.48
W	0.115	0.125	2.92	3.17

CASE 482A-01
ISSUE A
SMALL OUTLINE PACKAGE

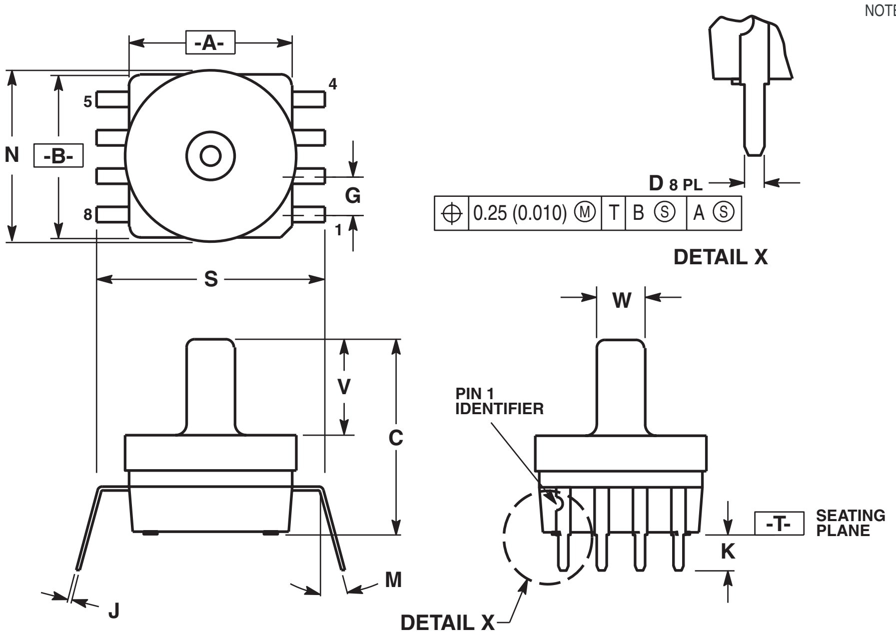
PACKAGE DIMENSIONS (CONTINUED)



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006).
5. ALL VERTICAL SURFACES 5° TYPICAL DRAFT.
6. DIMENSION S TO CENTER OF LEAD WHEN FORMED PARALLEL.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.415	0.425	10.54	10.79
B	0.415	0.425	10.54	10.79
C	0.210	0.220	5.33	5.59
D	0.026	0.034	0.66	0.864
G	0.100 BSC		2.54 BSC	
J	0.009	0.011	0.23	0.28
K	0.100	0.120	2.54	3.05
M	0°	15°	0°	15°
N	0.405	0.415	10.29	10.54
S	0.540	0.560	13.72	14.22

CASE 482B-03
ISSUE B
SMALL OUTLINE PACKAGE

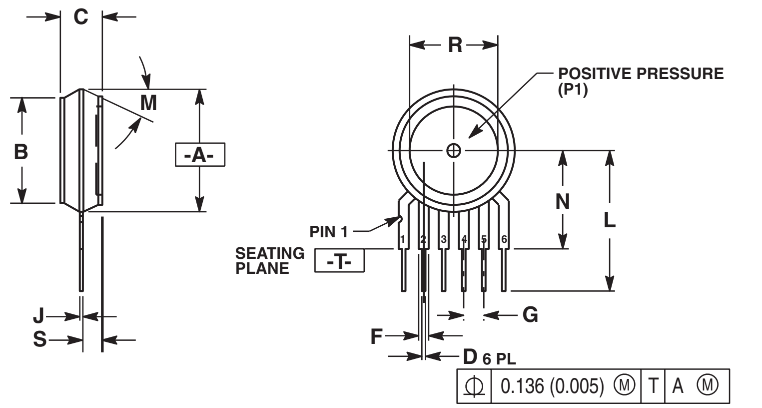


NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006).
5. ALL VERTICAL SURFACES 5° TYPICAL DRAFT.
6. DIMENSION S TO CENTER OF LEAD WHEN FORMED PARALLEL.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.415	0.425	10.54	10.79
B	0.415	0.425	10.54	10.79
C	0.500	0.520	12.70	13.21
D	0.026	0.034	0.66	0.864
G	0.100 BSC		2.54 BSC	
J	0.009	0.011	0.23	0.28
K	0.100	0.120	2.54	3.05
M	0°	15°	0°	15°
N	0.444	0.448	11.28	11.38
S	0.540	0.560	13.72	14.22
V	0.245	0.255	6.22	6.48
W	0.115	0.125	2.92	3.17

CASE 482C-03
ISSUE B
SMALL OUTLINE PACKAGE

PACKAGE DIMENSIONS (CONTINUED)



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION -A- IS INCLUSIVE OF THE MOLD STOP RING. MOLD STOP RING NOT TO EXCEED 16.00 (0.630).

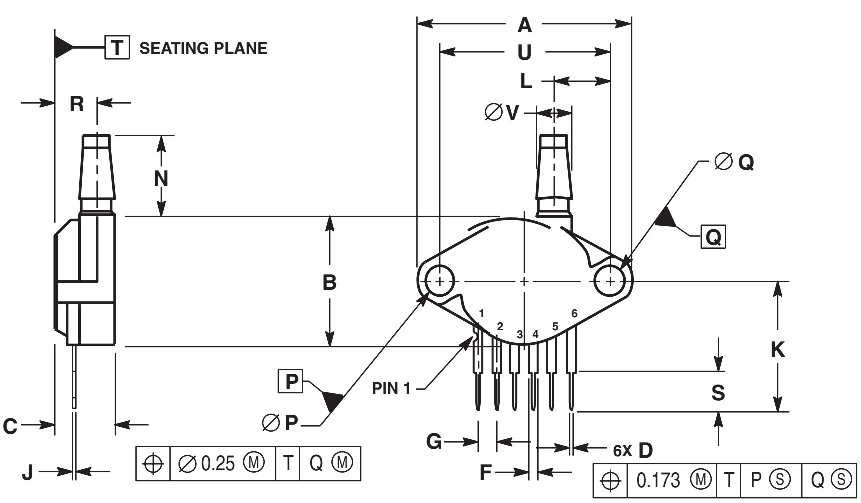
DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX
A	0.595	0.630	15.11	16.00
B	0.514	0.534	13.06	13.56
C	0.200	0.220	5.08	5.59
D	0.027	0.033	0.68	0.84
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.40
L	0.695	0.725	17.65	18.42
M	30° NOM		30° NOM	
N	0.475	0.495	12.07	12.57
R	0.430	0.450	10.92	11.43
S	0.090	0.105	2.29	2.66

STYLE 1:
PIN 1. VOUT
2. GROUND
3. VCC
4. V1
5. V2
6. VEX

STYLE 2:
PIN 1. OPEN
2. GROUND
3. -VOUT
4. VSUPPLY
5. +VOUT
6. OPEN

STYLE 3:
PIN 1. OPEN
2. GROUND
3. +VOUT
4. +VSUPPLY
5. -VOUT
6. OPEN

CASE 867-08
ISSUE N
UNIBODY PACKAGE



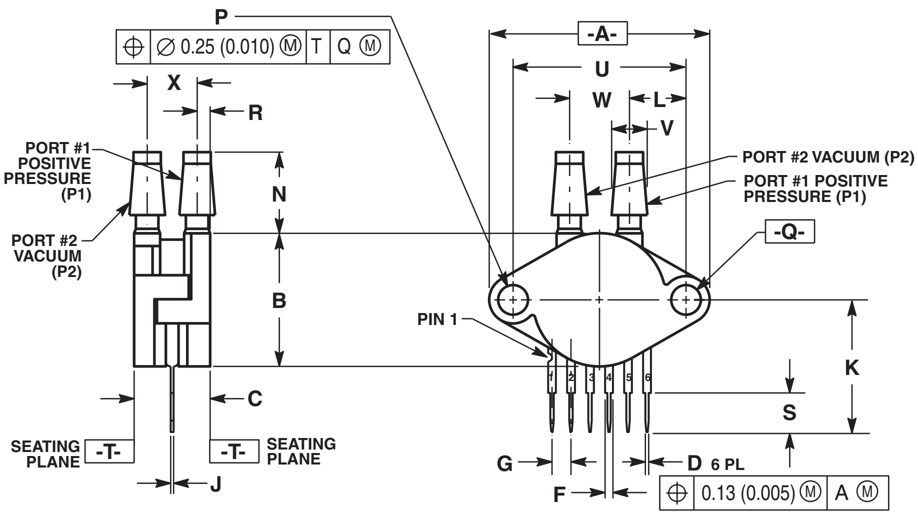
NOTES:
1. DIMENSIONS ARE IN MILLIMETERS.
2. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.

DIM	MILLIMETERS MIN	MILLIMETERS MAX
A	29.08	29.85
B	17.4	18.16
C	7.75	8.26
D	0.68	0.84
F	1.22	1.63
G	2.54 BSC	
J	0.36	0.41
K	17.65	18.42
L	7.37	7.62
N	10.67	11.18
P	3.89	4.04
Q	3.89	4.04
R	5.84	6.35
S	5.59	6.1
U	23.11 BSC	
V	4.62	4.93

STYLE 1:
PIN 1. V_{OUT}
2. GROUND
3. V_{CC}
4. V1
5. V2
6. V_{EX}

CASE 867B-04
ISSUE F
UNIBODY PACKAGE

PACKAGE DIMENSIONS (CONTINUED)

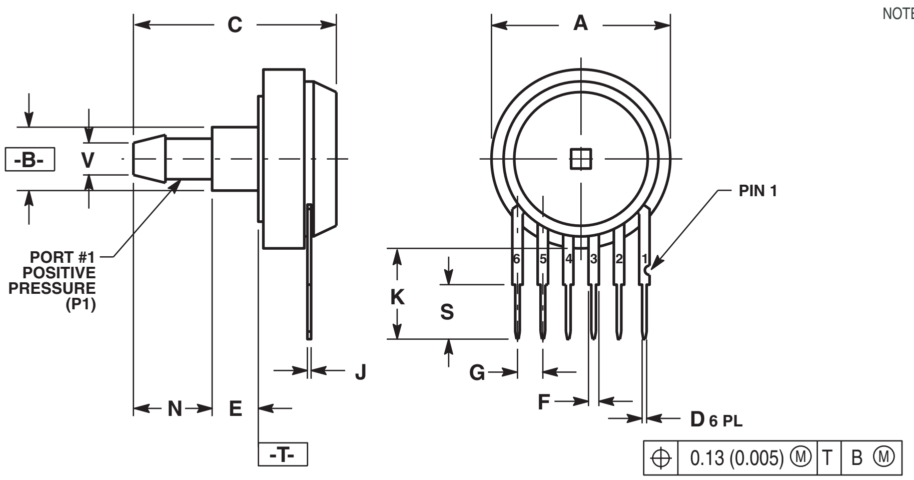


NOTES:
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
2. CONTROLLING DIMENSION: INCH.

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	1.145	1.175	29.08	29.85
B	0.685	0.715	17.40	18.16
C	0.405	0.435	10.29	11.05
D	0.027	0.033	0.68	0.84
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.41
K	0.695	0.725	17.65	18.42
L	0.290	0.300	7.37	7.62
N	0.420	0.440	10.67	11.18
P	0.153	0.159	3.89	4.04
Q	0.153	0.159	3.89	4.04
R	0.063	0.083	1.60	2.11
S	0.220	0.240	5.59	6.10
U	0.910 BSC		23.11 BSC	
V	0.182	0.194	4.62	4.93
W	0.310	0.330	7.87	8.38
X	0.248	0.278	6.30	7.06

STYLE 1:
PIN 1. V_{OUT}
2. GROUND
3. V_{CC}
4. V1
5. V2
6. V_{EX}

CASE 867C-05
ISSUE F
UNIBODY PACKAGE



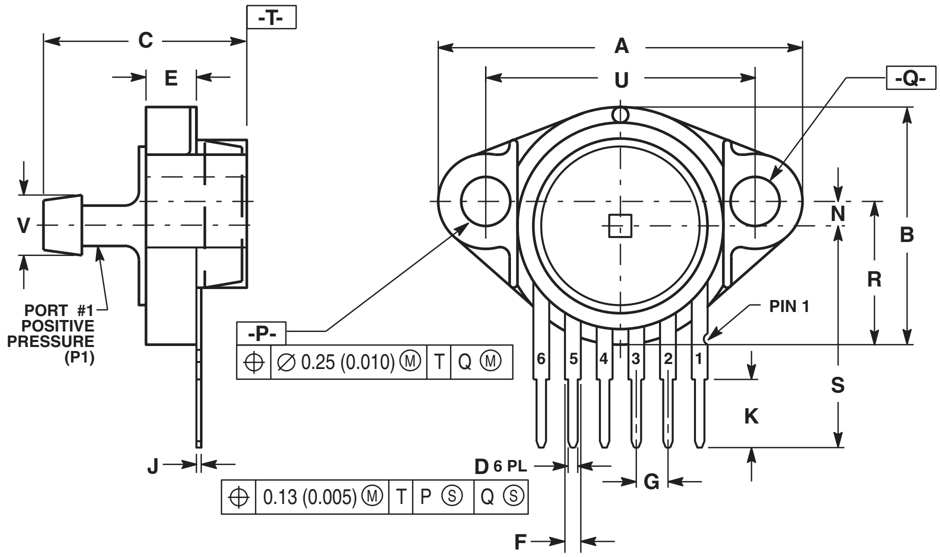
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.690	0.720	17.53	18.28
B	0.245	0.255	6.22	6.48
C	0.780	0.820	19.81	20.82
D	0.027	0.033	0.69	0.84
E	0.178	0.186	4.52	4.72
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.41
K	0.345	0.375	8.76	9.53
N	0.300	0.310	7.62	7.87
S	0.220	0.240	5.59	6.10
V	0.182	0.194	4.62	4.93

STYLE 1:
PIN 1. V_{OUT}
2. GROUND
3. V_{CC}
4. V1
5. V2
6. V_{EX}

CASE 867E-03
ISSUE D
UNIBODY PACKAGE

PACKAGE DIMENSIONS (CONTINUED)



NOTES:

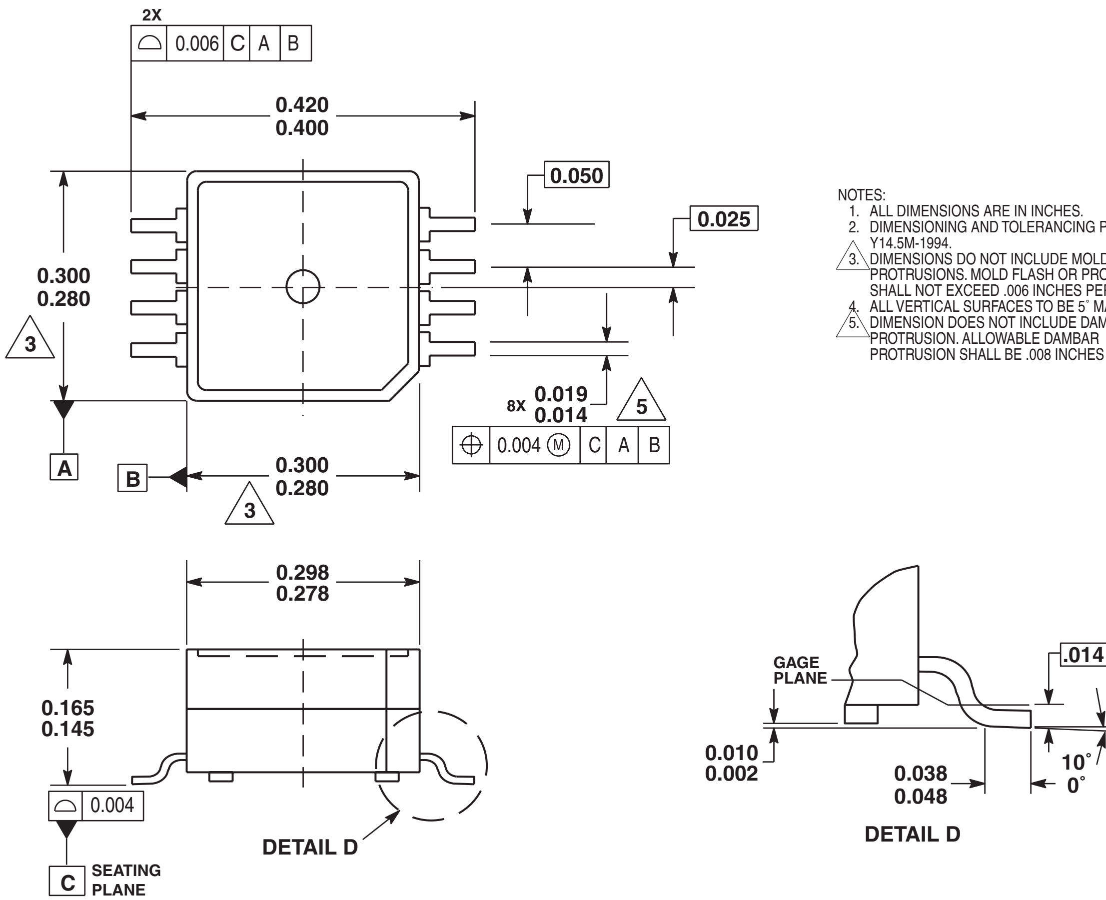
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	1.080	1.120	27.43	28.45
B	0.740	0.760	18.80	19.30
C	0.630	0.650	16.00	16.51
D	0.027	0.033	0.68	0.84
E	0.160	0.180	4.06	4.57
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.41
K	0.220	0.240	5.59	6.10
N	0.070	0.080	1.78	2.03
P	0.150	0.160	3.81	4.06
Q	0.150	0.160	3.81	4.06
R	0.440	0.460	11.18	11.68
S	0.695	0.725	17.65	18.42
U	0.840	0.860	21.34	21.84
V	0.182	0.194	4.62	4.93

STYLE 1:
PIN 1. V_{OUT}
2. GROUND
3. V_{CC}
4. V1
5. V2
6. V_{EX}

CASE 867F-03
ISSUE D
UNIBODY PACKAGE

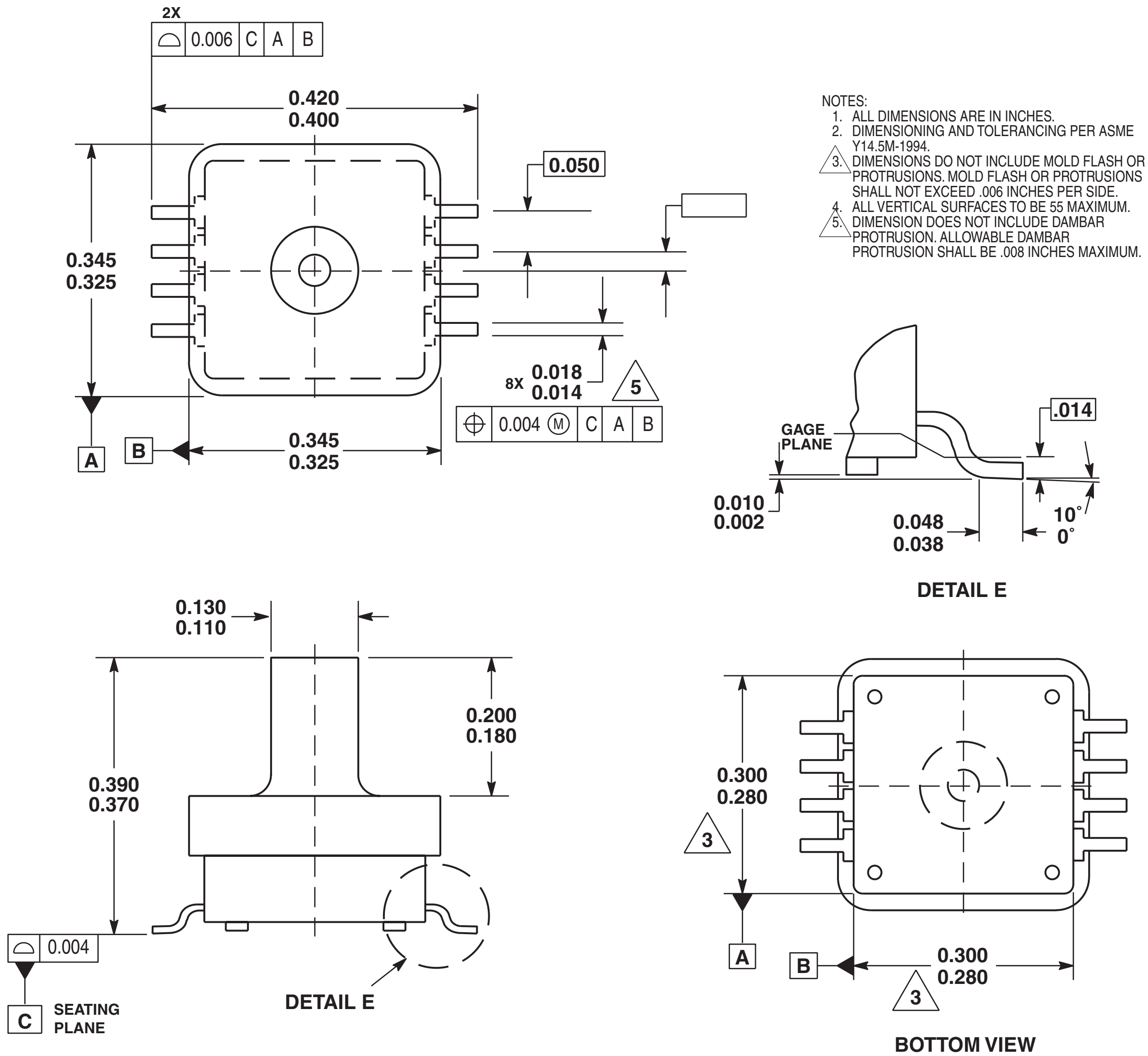
PACKAGE DIMENSIONS (CONTINUED)



NOTES:
1. ALL DIMENSIONS ARE IN INCHES.
2. DIMENSIONING AND TOLERANCING PER ASME Y14.5M-1994.
3. DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS. MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED .006 INCHES PER SIDE.
4. ALL VERTICAL SURFACES TO BE 5° MAXIMUM.
5. DIMENSION DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE .008 INCHES MAXIMUM.

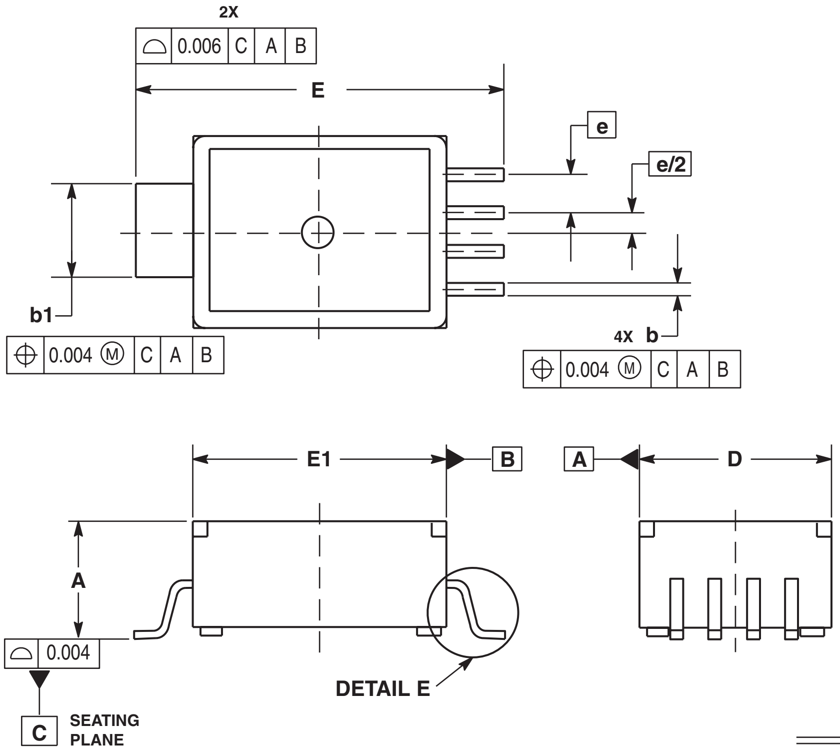
CASE 1317-04
ISSUE D
SUPER SMALL OUTLINE PACKAGE

PACKAGE DIMENSIONS (CONTINUED)



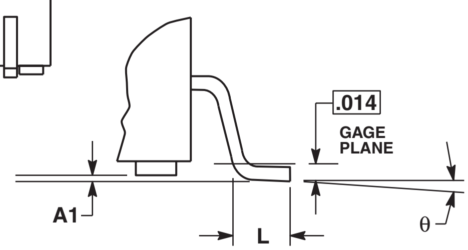
CASE 1317A-01
ISSUE A
SUPER SMALL OUTLINE PACKAGE

PACKAGE DIMENSIONS (CONTINUED)



NOTES:
1. DIMENSIONS ARE IN INCHES.
2. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
3. DIMENSIONS "D" AND "E1" DO NOT INCLUDE MOLD FLASH OR PROTRUSION. MOLD FLASH OR PROTRUSION SHALL NOT EXCEED .006" PER SIDE.
4. ALL VERTICAL SURFACES TO BE 5˚ MAXIMUM. DIMENSION "b" DOES NOT INCLUDE DAMBAR
5. PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE .008 MAXIMUM.

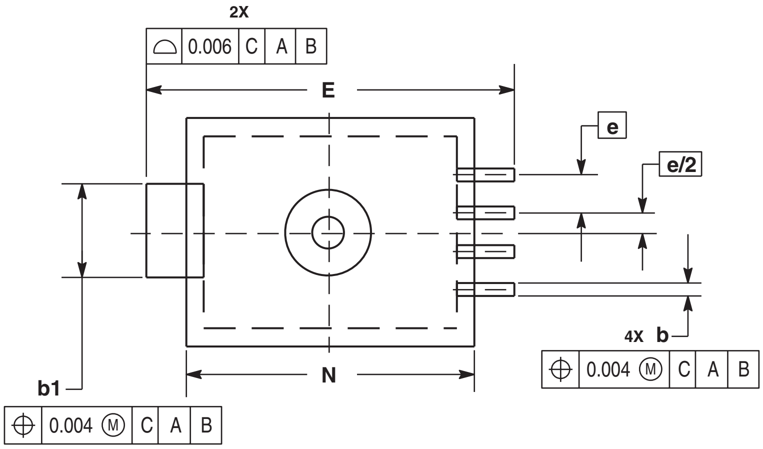
	INCHES	
DIM	MIN	MAX
A	.145	.155
A1	.002	.010
b	.014	.018
b1	.120	.130
D	.245	.255
E	.475	.485
E1	.325	.335
e	.050 BSC	
e/2	.025 BSC	
L	.038	.048
θ	0˚	7˚

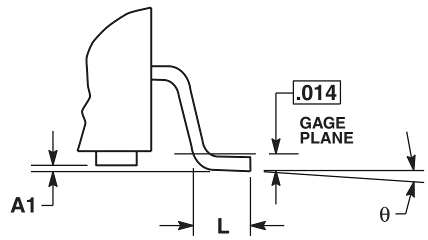


DETAIL E

CASE 1320-02
ISSUE A
MPAK PACKAGE

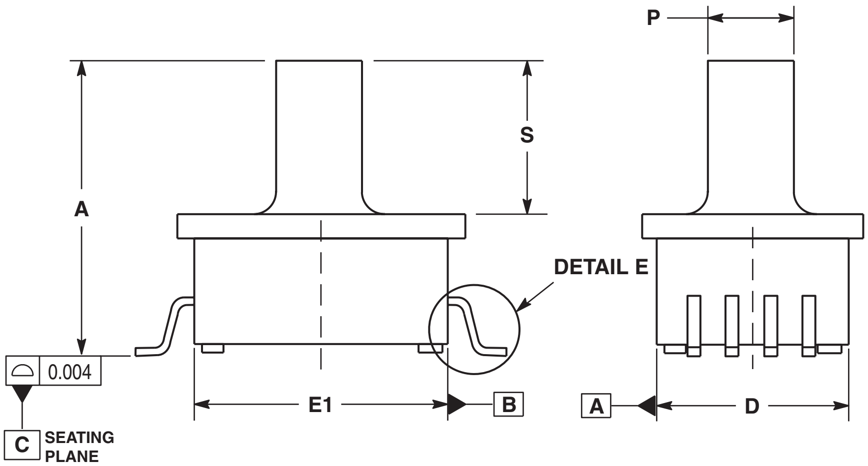
PACKAGE DIMENSIONS (CONTINUED)





DETAIL E

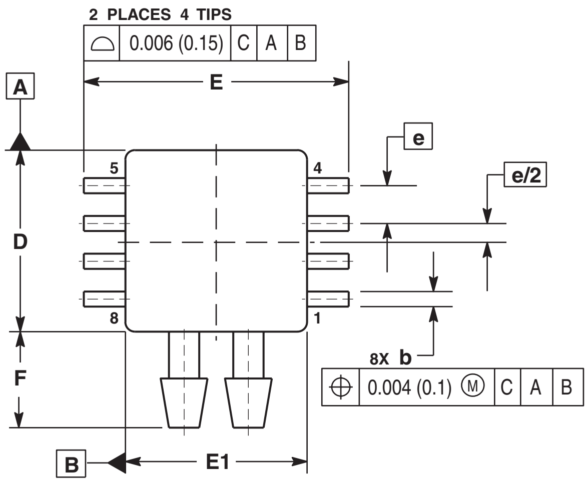
NOTES:
1. DIMENSIONS ARE IN INCHES.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS "D" AND "E1" DO NOT INCLUDE MOLD FLASH OR PROTRUSION. MOLD FLASH OR PROTRUSION SHALL NOT EXCEED .006" PER SIDE.
4. ALL VERTICAL SURFACES TO BE 55 MAXIMUM.
5. DIMENSIONS "b" DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE .008 MAXIMUM.

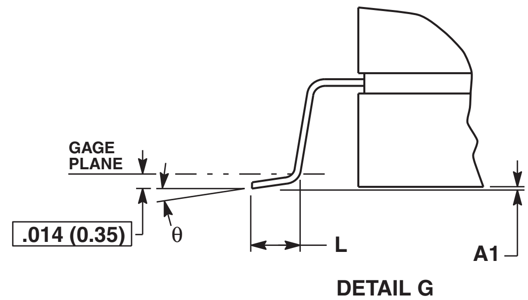


DIM	INCHES	
	MIN	MAX
A	.377	.397
A1	.002	.010
b	.014	.018
b1	.120	.130
D	.245	.255
E	.475	.485
E1	.325	.335
e	.050 BSC	
e/2	.025 BSC	
L	.013	.023
M	.283	.293
N	.363	.373
P	.107	.117
S	.192	.202
q	0°	7°

CASE 1320A-02
ISSUE O
MPAK PACKAGE

PACKAGE DIMENSIONS (CONTINUED)

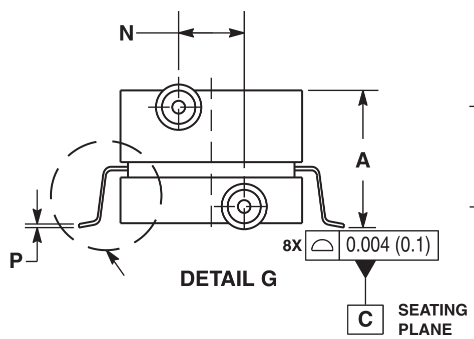


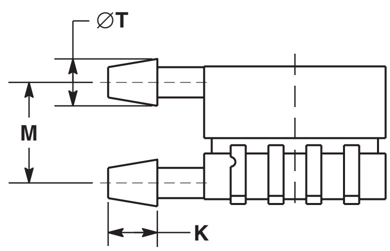


STYLE 1:
PIN 1. GND
2. +Vout
3. Vs
4. -Vout
5. N/C
6. N/C
7. N/C
8. N/C

STYLE 2:
PIN 1. N/C
2. Vs
3. GND
4. Vout
5. N/C
6. N/C
7. N/C
8. N/C

NOTES:
1. CONTROLLING DIMENSION: INCH.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M, 1994.
3. DIMENSIONS "D" AND "E1" DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS. MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.006 (0.152) PER SIDE.
4. DIMENSION "b" DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.008 (0.203) MAXIMUM.

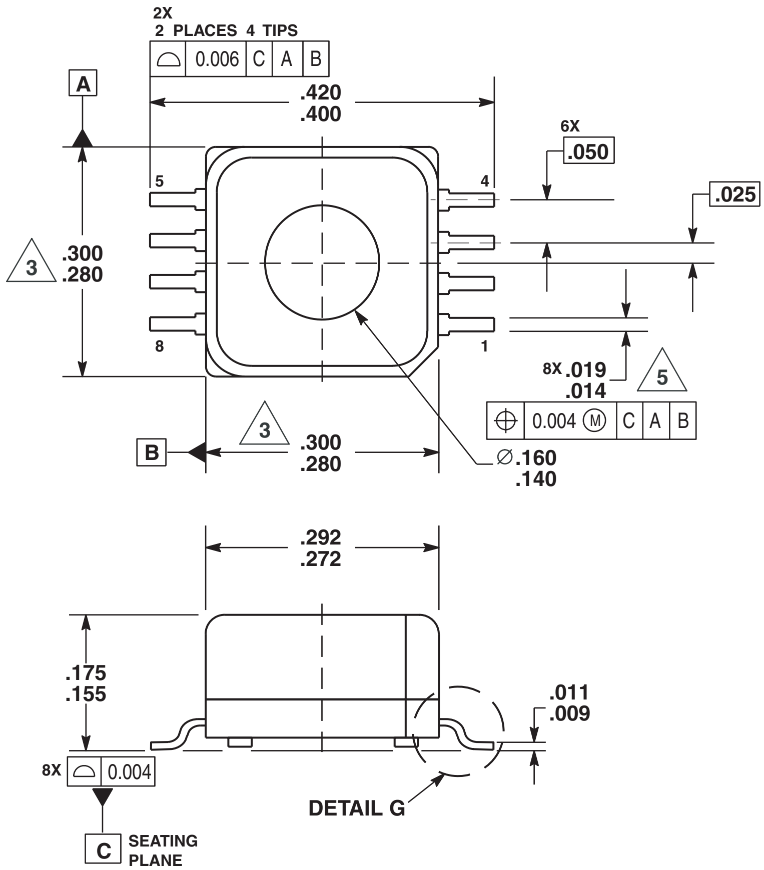




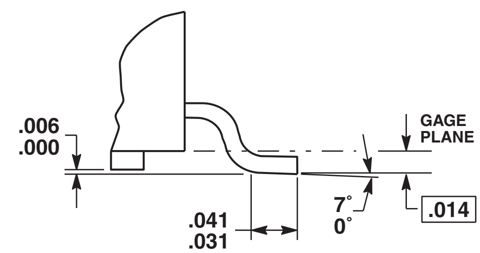
DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX
A	0.370	0.390	9.39	9.91
A1	0.002	0.010	0.05	0.25
b	0.038	0.042	0.96	1.07
D	0.465	0.485	11.81	12.32
E	0.680	0.700	17.27	17.78
E1	0.465	0.485	11.81	12.32
e	0.100 BSC		2.54 BSC	
F	0.240	0.260	6.10	6.60
K	0.115	0.135	2.92	3.43
L	0.040	0.060	1.02	1.52
M	0.270	0.290	6.86	7.37
N	0.160	0.180	4.06	4.57
P	0.009	0.011	0.23	0.28
T	0.110	0.130	2.79	3.30
θ	0°	7°	0°	7°

CASE1351-01
ISSUE O
SMALL OUTLINE PACKAGE

PACKAGE DIMENSIONS (CONTINUED)



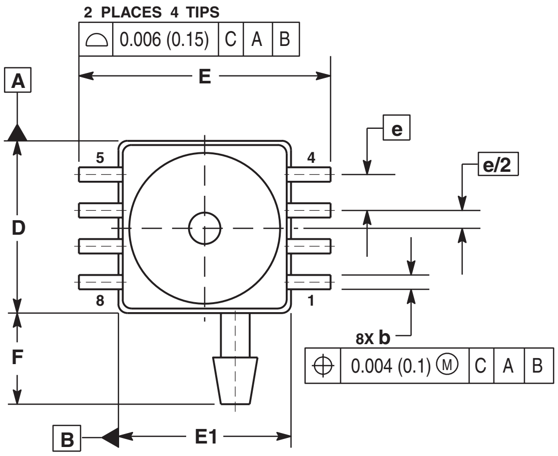
NOTES:
1. CONTROLLING DIMENSION: INCH.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS. MOLD FLASH AND PROTRUSIONS SHALL NOT EXCEED 0.006 PER SIDE.
4. ALL VERTICAL SURFACES TO BE 5˚ MAXIMUM.
5. DIMENSION DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.008 MAXIMUM.

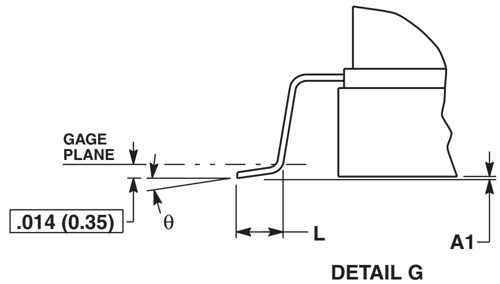


DETAIL G

CASE 1352-03
ISSUE B
SUPER SMALL OUTLINE PACKAGE

PACKAGE DIMENSIONS (CONTINUED)

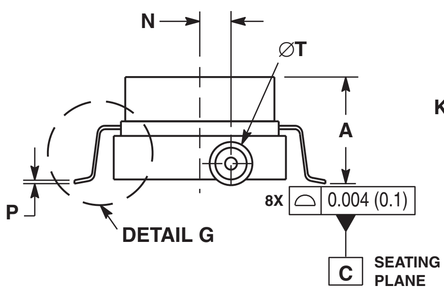


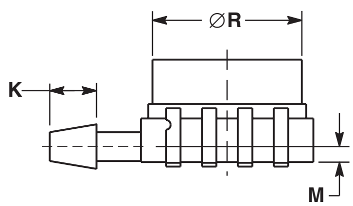


STYLE 1:
PIN 1. GND
2. +Vout
3. Vs
4. -Vout
5. N/C
6. N/C
7. N/C
8. N/C

STYLE 2:
PIN 1. N/C
2. Vs
3. GND
4. Vout
5. N/C
6. N/C
7. N/C
8. N/C

NOTES:
1. CONTROLLING DIMENSION: INCH.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS "D" AND "E1" DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS. MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.006 (0.152) PER SIDE.
4. DIMENSION "b" DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.008 (0.203) MAXIMUM.

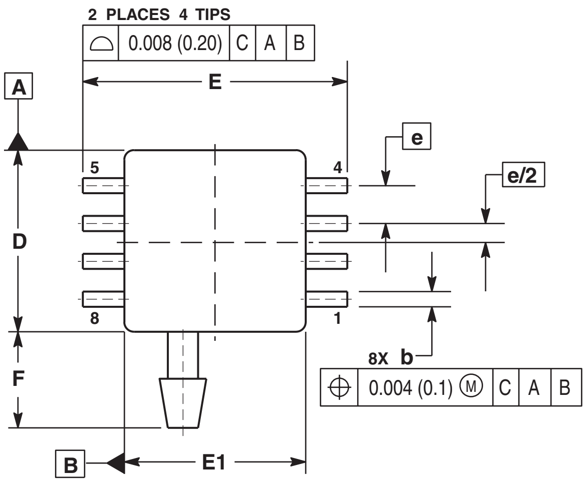


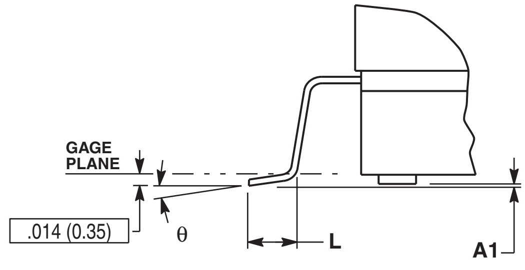


	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.280	0.300	7.11	7.62
A1	0.002	0.010	0.05	0.25
b	0.038	0.042	0.96	1.07
D	0.465	0.485	11.81	12.32
E	0.690 BSC		17.52 BSC	
E1	0.465	0.485	11.81	12.32
e	0.100 BSC		2.54 BSC	
F	0.240	0.260	6.10	6.60
K	0.115	0.135	2.92	3.43
L	0.040	0.060	1.02	1.52
M	0.035	0.055	1.90	2.41
N	0.075	0.095	0.89	1.39
P	0.009	0.011	0.23	0.28
T	0.110	0.130	2.79	3.30
R	0.405	0.415	10.28	10.54
θ	0°	7°	0°	7°

CASE 1368-01
ISSUE O
SMALL OUTLINE PACKAGE

PACKAGE DIMENSIONS (CONTINUED)

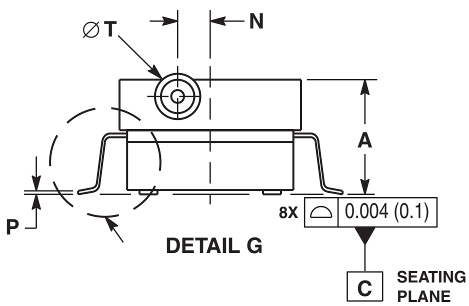




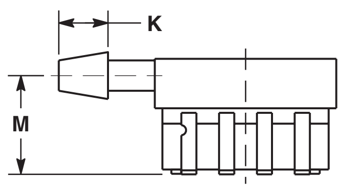
DETAIL G

NOTES:

1. CONTROLLING DIMENSION: INCH.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M, 1994.
3. DIMENSIONS "D" AND "E1" DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS. MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.006 (0.152) PER SIDE.
4. DIMENSION "b" DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.008 (0.203) MAXIMUM.



DETAIL G



	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.300	0.330	7.11	7.62
A1	0.002	0.010	0.05	0.25
b	0.038	0.042	0.96	1.07
D	0.465	0.485	11.81	12.32
E	0.717 BSC		18.21 BSC	
E1	0.465	0.485	11.81	12.32
e	0.100 BSC		2.54 BSC	
F	0.245	0.255	6.22	6.47
K	0.120	0.130	3.05	3.30
L	0.061	0.071	1.55	1.80
M	0.270	0.290	6.86	7.36
N	0.080	0.090	2.03	2.28
P	0.009	0.011	0.23	0.28
T	0.115	0.125	2.92	3.17
θ	0°	7°	0°	7°

CASE 1369-01
ISSUE O
SMALL OUTLINE PACKAGE

Reference Tables

FLOW EQUIVALENTS

1 Cu. Ft./Hr.		1 Cu. Ft./Min.		1 CC/Min.		1 CC/Hr.	
0.0166	Cu. Ft./Min	60	Cu. Ft./Min	60	CC/Hr.	0.0167	CC/Min.
0.4719	LPM	28.316	LPM	0.000035	Cu. Ft./Min	0.0000005	Cu. Ft./Min
28.316	LPH	1699	LPH	0.0021	Cu. Ft./Hr.	0.00003	Cu. Ft./Hr.
471.947	CC/Min.	28317	CC/Min.	0.001	LPM	0.000017	LPM
28317	CC/Hr.	1,699,011	CC/Hr.	0.06	LPH	0.001	LPH
0.1247	Gal/Min.	7.481	Gal/Min.	0.00026	Gal/Min.	0.000004	Gal/Min.
7.481	Gal/Hr.	448.831	Gal/Hr.	0.0159	Gal/Hr.	0.00026	Gal/Hr.
1 LPM		**1 LPH**		**1 Gal/Min.**		**1 Gal/Hr.**	
60	LPH	0.0166	LPH	60	Gal/Hr.	0.0167	Gal/Min.
0.035	Cu. Ft./Min.	0.00059	Cu. Ft./Min.	0.1337	Cu. Ft./Min.	0.002	Cu. Ft./Min.
2.1189	Cu. Ft./Hr.	0.035	Cu. Ft./Hr.	8.021	Cu. Ft./Hr.	0.1337	Cu. Ft./Hr.
1000	CC/Min.	16.667	CC/Min.	3.785	LPM	0.063	LPM
60,002	CC/Hr.	1000	CC/Hr.	227.118	LPH	3.785	LPH
0.264	Gal/Min.	0.004	Gal/Min.	3,785.412	CC/Min.	63.069	CC/Min.
15.851	Gal/Hr.	0.264	Gal/Hr.	227,125	CC/Hr.	3785	CC/Hr.

Airspeed

Knots	Inches of Mercury
60	0.1727
80	0.3075
100	0.4814
110	0.5832
120	0.6950
130	0.8168
140	0.9488
150	1.0910
175	1.4918
200	1.9589
225	2.4943
250	3.1002
275	3.7792
300	4.5343
325	5.3687
350	6.2859
375	7.2900

Knots	Inches of Mercury
400	8.3850
425	9.5758
450	10.8675
475	12.2654
500	13.7756
525	15.4045
550	17.1590
575	19.0465
600	21.0749
650	25.5893
700	30.7642
750	36.5662
800	42.9378
850	49.8423
900	57.2554
1,000	73.5454

Altitude (Feet)	Equivalent Pressure (Inches of Mercury)
-1,000	31.0185
-900	30.9073
0	29.9213
500	29.3846
1,000	28.8557
1,500	28.3345
2,000	27.8210
3,000	26.8167
4,000	25.8418
6,000	23.9782
8,000	22.2250
10,000	20.5770
12,000	19.0294

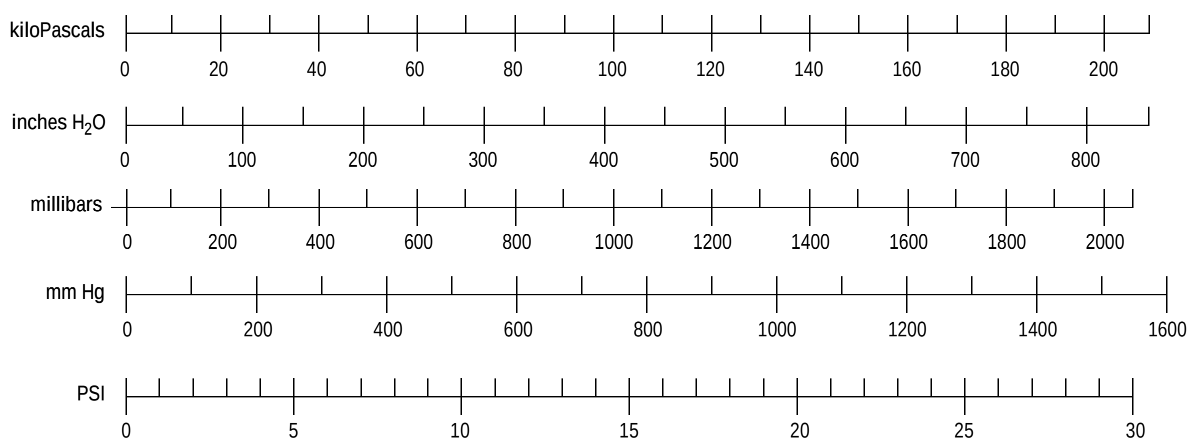
Altitude (Feet)	Equivalent Pressure (Inches of Mercury)
14,000	17.5774
16,000	16.2164
18,000	14.9421
20,000	13.7501
22,000	12.6363
25,000	11.1035
30,000	8.88544
35,000	7.04062
40,000	5.53802
45,000	4.35488
49,900	3.44112 (EST)
50,000	3.42466

Reference Tables (continued)

CONVERSION TABLE FOR COMMON UNITS OF PRESSURE

	kiloPascals	mm Hg	millibars	inches H_2O	PSI
1 atm	101.325	760.000	1013.25	406.795	14.6960
1 kiloPascal	1.00000	7.50062	10.0000	4.01475	0.145038
1 mm Hg	0.133322	1.00000	1.33322	0.535257	0.0193368
1 millibar	0.100000	0.750062	1.00000	0.401475	0.0145038
1 inch H_2O	0.249081	1.86826	2.49081	1.00000	0.0361
1 PSI	6.89473	51.7148	68.9473	27.6807	1.00000
1 hectoPascal	0.100000	0.75006	1.00000	0.401475	0.0145038
1 cm H_2O	0.09806	0.7355	9.8×10^{-7}	0.3937	0.014223

QUICK CONVERSION CHART FOR COMMON UNITS OF PRESSURE



Mounting and Handling Suggestions for the Unibody Pressure Sensor Package

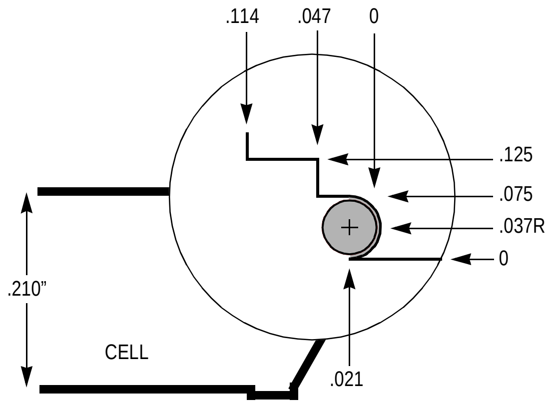


Figure 1. O-Ring to Sensor Cell Interface Dimensions

CUSTOM PORT ADAPTOR INSTALLATION TECHNIQUES

The Freescale Semiconductor MPX silicon pressure sensor is available in a basic chip carrier cell which is adaptable for attachment to customer specific housings/ports (Case 344 for 4-pin devices and Case 867 for 6-pin devices). The basic cell has chamfered shoulders on both sides which will accept an O-ring such as Parker Seal's silicone O-ring (p/n#2-015-S-469-40). Refer to Figure 1 for the recommended O-ring to sensor cell interface dimensions.

The sensor cell may also be glued directly to a custom housing or port using many commercial grade epoxies or RTV adhesives which adhere to grade Valox 420, reinforced polyester resin plastic polysulfone (MPX2040D only). The epoxy should be dispensed in a continuous bead around the cell-to-port interface shoulder. Refer to Figure 2. Care must be taken to avoid gaps or voids in the adhesive bead to help ensure that a complete seal is made when the cell is joined to the port. After cure, a simple test for gross leaks should be performed to ensure the integrity of the cell to port bond. Submerging the device in water for 5 seconds with full rated pressure applied to the port nozzle and checking for air bubbles will provide a good indication. Be sure device is thoroughly dried after this test.

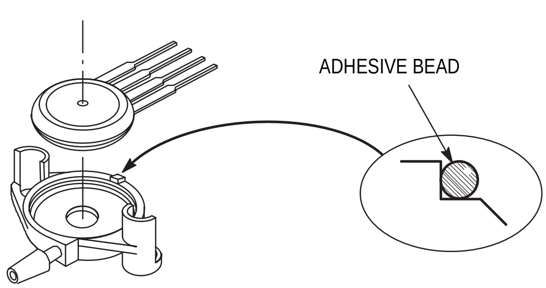


Figure 2. Glueing of Sensor Cell

STANDARD PORT ATTACH CONNECTION

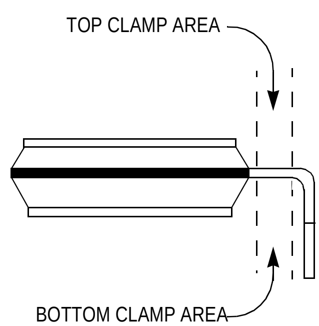
Freescale Semiconductor also offers standard port options designed to accept readily available silicone, vinyl, nylon or polyethylene tubing for the pressure connection. The inside dimension of the tubing selected should provide a snug fit over the port nozzle. Dimensions of the ports may be found in the case outline drawings. Installation and removal of tubing from the port nozzle must be parallel to the nozzle to avoid undue stress which may break the nozzle from the port base. Whether sensors are used with Freescale Semiconductor's standard ports or customer specific housings, care must be taken to ensure that force is uniformly distributed to the package or offset errors may be induced.

ELECTRICAL CONNECTION

The MPX series pressure sensor is designed to be installed on a printed circuit board (standard 0.100″ lead spacing) or to accept an appropriate connector if installed on a baseplate. The leads of the sensor may be formed at right angles for assembly to the circuit board, but one must ensure that proper leadform techniques and tools are employed. Hand or "needlenose" pliers should never be used for leadforming unless they are specifically designed for that purpose. Industrial leadform tooling is available from various companies including *Janesville Tool & Manufacturing* (608-868-4925). Refer to Figure 3 for the recommended leadform technique. It is also important that once the leads are formed, they should not be straightened and reformed without expecting reduced durability. The recommended connector for off-circuit board applications may be supplied by JST Corp. (1-800-292-4243) in Mount Prospect, IL.

The part numbers for the housing and pins are:

- 4 Pin Housing: SMP-04V-BC
- 6 Pin Housing: SMP-06V-BC
- Pin: SHF-01T-0.8SS
- The crimp tool part number is: YC12.



Leads should be securely clamped top and bottom in the area between the plastic body and the form being sure that no stress is being put on plastic body. The area between dotted lines represents surfaces to be clamped.

Figure 3. Leadforming

Standard Warranty Clause

Seller warrants that its products sold hereunder will at the time of shipment be free from defects in material and workmanship, and will conform to Seller's approved specifications. If products are not as warranted, Seller shall, at its option and as Buyer's exclusive remedy, either refund the purchase price, or repair, or replace the product, provided proof of purchase and written notice of nonconformance are received within the applicable periods noted below and provided said nonconforming products are, with Seller's written authorization, returned in protected shipping containers FOB Seller's plant within thirty (30) days after expiration of the warranty period unless otherwise specified herein. If product does not conform to this warranty, Seller will pay for the reasonable cost of transporting the goods to and from Seller's plant. This warranty shall not apply to any products Seller determines have been, by Buyer or otherwise, subjected to improper testing, or have been the subject of mishandling or misuse.

THIS WARRANTY EXTENDS TO BUYER ONLY AND MAY BE INVOKED BY BUYER ONLY FOR ITS CUSTOMERS. SELLER WILL NOT ACCEPT WARRANTY RETURNS DIRECTLY FROM BUYER'S CUSTOMERS OR USERS OF BUYER'S PRODUCTS. THIS WARRANTY IS IN LIEU OF ALL OTHER WARRANTIES WHETHER EXPRESS, IMPLIED OR STATUTORY INCLUDING IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE.

Seller's warranty shall not be enlarged, and no obligation or liability shall arise out of Seller's rendering of technical advice and/or assistance.

A Time periods, products, exceptions and other restrictions applicable to the above warranty are:

1. Unless otherwise stated herein, products are warranted for a period of one (1) year from date of shipment.
2. Device Chips/Wafers. Seller warrants that device chips or wafers have, at shipment, been subjected to electrical test/probe and visual inspection. Warranty shall apply to products returned to Seller within ninety (90) days from date of shipment. This warranty shall not apply to any chips or wafers improperly removed from their original shipping container and/or subjected to testing or operational procedures not approved by Seller in writing.

B Development products and Licensed Programs are licensed on an “AS IS” basis. IN NO EVENT SHALL SELLER BE LIABLE FOR ANY INCIDENTAL OR CONSEQUENTIAL DAMAGES.

Glossary of Terms

Absolute Pressure Sensor	A sensor which measures input pressure in relation to a zero pressure (a total vacuum on one side of the diaphragm) reference.
Analog Output	An electrical output from a sensor that changes proportionately with any change in input pressure.
Accuracy — also see Pressure Error	A comparison of the actual output signal of a device to the true value of the input pressure. The various errors (such as linearity, hysteresis, repeatability and temperature shift) attributing to the accuracy of a device are usually expressed as a percent of full scale output (FSO).
Altimetric Pressure Transducer	A barometric pressure transducer used to determine altitude from the pressure-altitude profile.
Barometric Pressure Transducer	An absolute pressure sensor that measures the local ambient atmospheric pressure.
Burst Pressure	The maximum pressure that can be applied to a transducer without rupture of either the sensing element or transducer case.
Calibration	A process of modifying sensor output to improve output accuracy.
Chip	A die (unpackaged semiconductor device) cut from a silicon wafer, incorporating semiconductor circuit elements such as resistors, diodes, transistors, and/or capacitors
Compensation	Added circuitry or materials designed to counteract known sources of error.
Diaphragm	The membrane of material that remains after etching a cavity into the silicon sensing chip. Changes in input pressure cause the diaphragm to deflect.
Differential Pressure Sensor	A sensor which is designed to accept simultaneously two independent pressure sources. The output is proportional to the pressure difference between the two sources.
Diffusion	A thermochemical process whereby controlled impurities are introduced into the silicon to define the piezoresistor. Compared to ion implantation, it has two major disadvantages: 1) the maximum impurity concentration occurs at the surface of the silicon rendering it subject to surface contamination, and making it nearly impossible to produce buried piezoresistors; 2) control over impurity concentrations and levels is about one thousand times poorer than obtained with ion implantation.
Drift	An undesired change in output over a period of time, with constant input pressure applied.
End Point Straight Line Fit	Freescale Semiconductor's method of defining linearity. The maximum deviation of any data point on a sensor output curve from a straight line drawn between the end data points on that output curve.
Error	The algebraic difference between the indicated value and the true value of the input pressure. Usually expressed in percent of full scale span, sometimes expressed in percent of the sensor output reading.
Error Band	The band of maximum deviations of the output values from a specified reference line or curve due to those causes attributable to the sensor. Usually expressed as "± % of full scale output." The error band should be specified as applicable over at least two calibration cycles, so as to include repeatability, and verified accordingly.
Excitation Voltage (Current) — see Supply Voltage (Current)	The external electrical voltage and/or current applied to a sensor for its proper operation (often referred to as the supply circuit or voltage). Freescale Semiconductor specifies constant voltage operation only.
Full Scale Output	The output at full scale pressure at a specified supply voltage. This signal is the sum of the offset signal plus the full scale span.
Full Scale Span	The change in output over the operating pressure range at a specified supply voltage. The SPAN of a device is the output voltage variation given between zero differential pressure and any given pressure. FULL SCALE SPAN is the output variation between zero differential pressure and when the maximum recommended operating pressure is applied.
Hysteresis — also see Pressure Hysteresis and Temperature Hysteresis	HYSTERESIS refers to a transducer's ability to reproduce the same output for the same input, regardless of whether the input is increasing or decreasing. PRESSURE HYSTERESIS is measured at a constant temperature while TEMPERATURE HYSTERESIS is measured at a constant pressure in the operating pressure range.
Input Impedance (Resistance)	The impedance (resistance) measured between the positive and negative (ground) input terminals at a specified frequency with the output terminals open. For Freescale Semiconductor X-ducer, this is a resistance measurement only.

Glossary of Terms (Continued)

Ion Implantation	A process whereby impurity ions are accelerated to a specific energy level and impinged upon the siliconwafer. The energy level determines the depth to which the impurity ions penetrate the silicon. Impingement time determines the impurity concentration. Thus, it is possible to independently control these parameters, and buried piezoresistors are easily produced. Ion implantation is increasingly usedthroughout the semiconductor industry to provide a variety of products with improved performance over those produced by diffusion.
Laser Trimming (Automated)	A method for adjusting the value of thin film resistors using a computer-controlled laser system.
Leakage Rate	The rate at which a fluid is permitted or determined to leak through a seal. The type of fluid, the differential pressure across the seal, the direction of leakage, and the location of the seal must be specified.
Linearity Error	The maximum deviation of the output from a straight line relationship with pressure over the operating pressure range, the type of straight line relationship (end point, least square approximation, etc.) should be specified.
Load Impedance	The impedance presented to the output terminals of a sensor by the associated external circuitry.
Null	The condition when the pressure on each side of the sensing diaphragm is equal.
Null Offset	The electrical output present, when the pressure sensor is at null.
Null Temperature Shift	The change in null output value due to a change in temperature.
Null Output	See ZERO PRESSURE OFFSET
Offset	See ZERO PRESSURE OFFSET
Operating Pressure Range	The range of pressures between minimum and maximum pressures at which the output will meet the specified operating characteristics.
Operating Temperature Range	The range of temperature between minimum and maximum temperature at which the output will meet the specified operating characteristics.
Output Impedance	The impedance measured between the positive and negative (ground) output terminals at a specified frequency with the input open.
Overpressure	The maximum specified pressure which may be applied to the sensing element of a sensor without causing a permanent change in the output characteristics.
Piezoresistance	A resistive element that changes resistance relative to the applied stress it experiences (e.g., strain gauge).
Pressure Error	The maximum difference between the true pressure and the pressure inferred from the output for any pressure in the operating pressure range.
Pressure Hysteresis	The difference in the output at any given pressure in the operating pressure range when this pressure is approached from the minimum operating pressure and when approached from the maximum operating pressure at room temperature.
Pressure Range — also see Operating Pressure Range	The pressure limits over which the pressure sensor is calibrated or specified.
Pressure Sensor	A device that converts an input pressure into an electrical output.
Proof Pressure	See OVERPRESSURE
Ratiometric	Ratiometricity refers to the ability of the transducer to maintain a constant sensitivity, at a constant pressure, over a range of supply voltage values.
Ratiometric (Ratiometricity Error)	At a given supply voltage, sensor output is a proportion of that supply voltage. Ratiometricity error is the change in this proportion resulting from any change to the supply voltage. Usually expressed as a percent of full scale output.
Range	See OPERATING PRESSURE RANGE
Repeatability	The maximum change in output under fixed operating conditions over a specified period of time.
Resolution	The maximum change in pressure required to give a specified change in the output.
Response Time	The time required for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
Room Conditions	Ambient environmental conditions under which sensors most commonly operate.
Sensing Element	That part of a sensor which responds directly to changes in input pressure.

Glossary of Terms (Continued)

Sensitivity	The change in output per unit change in pressure for a specified supply voltage or current.
Sensitivity Shift	A change in sensitivity resulting from an environmental change such as temperature.
Stability	The maximum difference in the output at any pressure in the operating pressure range when this pressure is applied consecutively under the same conditions and from the same direction.
Storage Temperature Range	The range of temperature between minimum and maximum which can be applied without causing the sensor to fail to meet the specified operating characteristics.
Strain Gauge	A sensing device providing a change in electrical resistance proportional to the level of applied stress.
Supply Voltage (Current)	The voltage (current) applied to the positive and negative (ground) input terminals.
Temperature Coefficient of Full Scale Span	The percent change in full scale span per unit change in temperature relative to the full scale span at a specified temperature.
Temperature Coefficient of Resistance	The percent change in the DC input impedance per unit change in temperature relative to the DC input impedance at a specified temperature.
Temperature Error	The maximum change in output at any pressure in the operating pressure range when the temperature is changed over a specified temperature range.
Temperature Hysteresis	The difference in output at any temperature in the operating temperature range when the temperature is approached from the minimum operating temperature and when approached from the maximum operating temperature with zero pressure applied.
Thermal Offset Shift	See TEMPERATURE COEFFICIENT OF OFFSET
Thermal Span Shift	See TEMPERATURE COEFFICIENT OF FULL SCALE SPAN
Thermal Zero Shift	See TEMPERATURE COEFFICIENT OF OFFSET
Thin Film	A technology using vacuum deposition of conductors and dielectric materials onto a substrate (frequently silicon) to form an electrical circuit.
Vacuum	A perfect vacuum is the absence of gaseous fluid.
Zero Pressure Offset	The output at zero pressure (absolute or differential, depending on the device type) for a specified supply voltage or current.

Symbols, Terms and Definitions

The following are the most commonly used letter symbols, terms and definitions associated with solid state silicon pressure sensors.

P_{burst}	Burst Pressure	The maximum pressure that can be applied to a transducer without rupture of either the sensing element or transducer case.
I_o	Supply Current	The current drawn by the sensor from the voltage source.
I_{o+}	Output Source Current	The current sourcing capability of the pressure sensor.
kPa	Kilopascals	Unit of pressure. 1 kPa = 0.145038 PSI.
—	Linearity	The maximum deviation of the output from a straight line relationship with pressure over the operating pressure range, the type of straight line relationship (end point, least square approximation, etc.) should be specified.
mm Hg	Millimeters of Mercury	Unit of pressure. 1 mmHg = 0.0193368 PSI.
P_{max}	Overpressure	The maximum specified pressure which may be applied to the sensing element without causing a permanent change in the output characteristics.
P_{OP}	Operating Pressure Range	The range of pressures between minimum and maximum temperature at which the output will meet the specified operating characteristics.
—	Pressure Hysteresis	The difference in the output at any given pressure in the operating pressure range when this pressure is approached from the minimum operating pressure and when approached from the maximum operating pressure at room temperature.
PSI	Pounds per Square Inch	Unit of pressure. 1 PSI = 6.89473 kPa.
—	Repeatability	The maximum change in output under fixed operating conditions over a specified period of time.
R_o	Input Resistance	The resistance measured between the positive and negative input terminals at a specified frequency with the output terminals open.
T_A	Operating Temperature	The temperature range over which the device may safely operate.
TCR	Temperature Coefficient of Resistance	The percent change in the DC input impedance per unit change in temperature relative to the DC input impedance at a specified temperature (typically +25°C).
TCV_{FSS}	Temperature Coefficient of Full Scale Span	The percent change in full scale span per unit change in temperature relative to the full scale span at a specified temperature (typically +25°C).
TCV_{off}	Temperature Coefficient of Offset	The percent change in offset per unit change in temperature relative to the offset at a specified temperature (typically +25°C).
T_{stg}	Storage Temperature	The temperature range at which the device, without any power applied, may be stored.
t_R	Response Time	The time required for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
—	Temperature Hysteresis	The difference in output at any temperature in the operating temperature range when the temperature is approached from the minimum operating temperature and when approached from the maximum operating temperature with zero pressure applied.
V_{FSS}	Full Scale Span Voltage	The change in output over the operating pressure range at a specified supply voltage.
V_{off}	Offset Voltage	The output with zero differential pressure applied for a specified supply voltage or current.
V_S	Supply Voltage DC	The dc excitation voltage applied to the sensor. For precise circuit operation, a regulated supply should be used.
$V_{S max}$	Maximum Supply Voltage	The maximum supply voltage that may be applied to a circuit or connected to the sensor.
Z_{in}	Input Impedance	The resistance measured between the positive and negative input terminals at a specified frequency with the output terminals open. For Freescale Semiconductor X-ducer, this is a resistance measurement only.
Z_{out}	Output Impedance	The resistance measured between the positive and negative output terminals at a specified frequency with the input terminals open.
$\Delta V/\Delta P$	Sensitivity	The change in output per unit change in pressure for a specified supply voltage.

Section Four

Safety and Alarm Integrated Circuits Overview

Freescale's Safety and Alarm Integrated Circuits (ICs) are low power, CMOS devices designed to meet a wide range of smoke detector applications at very competitive prices. Freescale has been producing both photoelectric and ionization safety and alarm ICs for more than 25 years. Found in consumer and commercial applications worldwide, these integrated circuits can be operated using a battery or AC power. In addition, these devices are designed to be used in stand-alone units or as an interconnected system of up to 40 units. All of Freescales's safety and alarm ICs have component recognition from Underwriter's Laboratories and the newest devices meet the NFPA's new temporal - new tone horn pattern.

Safety and alarm Integrated Circuits Products

Mini Selector Guide

Safety and Alarm Integrated Circuits

Smoke Ion

Product	Operating Voltage (V)	Horn Tone	Interconnectable	Primary Power Source	Ordering Suffix(1)
MC14467	6 to 12	Continuous - Old Tone - 4/6	No	DC	P1
MC14468	6 to 12	Continuous - Old Tone - 4/6	Yes	AC/DC	P
MC14568	6 to 12	Continuous - Old Tone - 4/6	Yes	AC/DC	P
MC145017	6 to 12	Temporal - New Tone - NFPA Tone	No	DC	P
MC145018	6 to 12	Temporal - New Tone - NFPA Tone	Yes	AC/DC	P

Smoke Photo

Product	Operating Voltage (V)	Horn Tone	Interconnectable	Primary Power Source	Ordering Suffix(1)
MC145010	6 to 12	Continuous - Old Tone - 4/6	Yes	AC/DC	P, DW, DWR2
MC145011	6 to 12	Continuous - Old Tone - 4/6	Yes	AC	P, DW, DWR2
MC145012	6 to 12	Temporal - New Tone - NFPA Tone	Yes	AC/DC	P, DW, DWR2

Comparator

Product	Operating Voltage (V)	Description	Horn Modulation	Primary Power Source	Ordering Suffix(1)
MC14578	3.5 to 14	Micro-Power Comparator Plus Voltage Follower	No Horn Driver	AC/DC	P

General Alarm

Product	Operating Voltage (V)	Description	Horn Tone(ms)	Primary Power Source	Ordering Suffix(1)
MC14600	6.0 to 12	Alarm Detection, Horn Driver, Low Battery Detection, LED Driver	Continuous - Old Tone - 4/6	AC/DC	P, DW, DWR2

NOTES:
1. P or P1 = 16-pin DIP, DW = SOIC 16-pin, DWR2 = SOIC 16-pin tape & reel

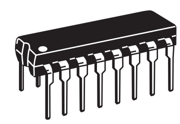
MC14467-1
Rev 4, 05/2005

MC14467-1

Low-Power CMOS Ionization Smoke Detector IC

The MC14467-1, when used with an ionization chamber and a small number of external components, will detect smoke. When smoke is sensed, an alarm is sounded via an external piezoelectric transducer and internal drivers. This circuit is designed to operate in smoke detector systems that comply with UL217 and UL268 specifications.

LOW-POWER CMOS IONIZATION SMOKE DETECTOR IC



P SUFFIX
16-LEAD PLASTIC DIP
CASE 648-08

Features

- Ionization Type with On-Chip FET Input Comparator
- Piezoelectric Horn Driver
- Guard Outputs on Both Sides of Detect Input
- Input-Production Diodes on the Detect Input
- Low-Battery Trip Point, Internally Set, can be Altered Via External Resistor
- Detect Threshold, Internally Set, can be Altered Via External Resistor
- Pulse Testing for Low Battery Uses LED for Battery Loading
- Comparator Outputs for Detect and Low Battery
- Internal Reverse Battery Protection

ORDERING INFORMATION		
Device	**Case No.**	**Package**
MC14467P1	648-08	Plastic Dip

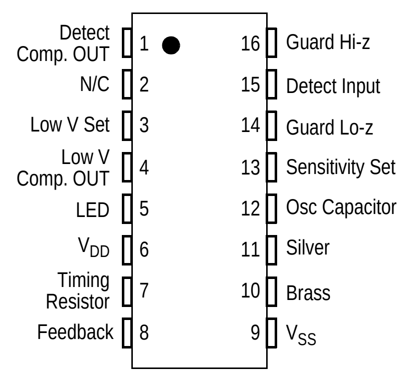


Figure 1. Pin Connections

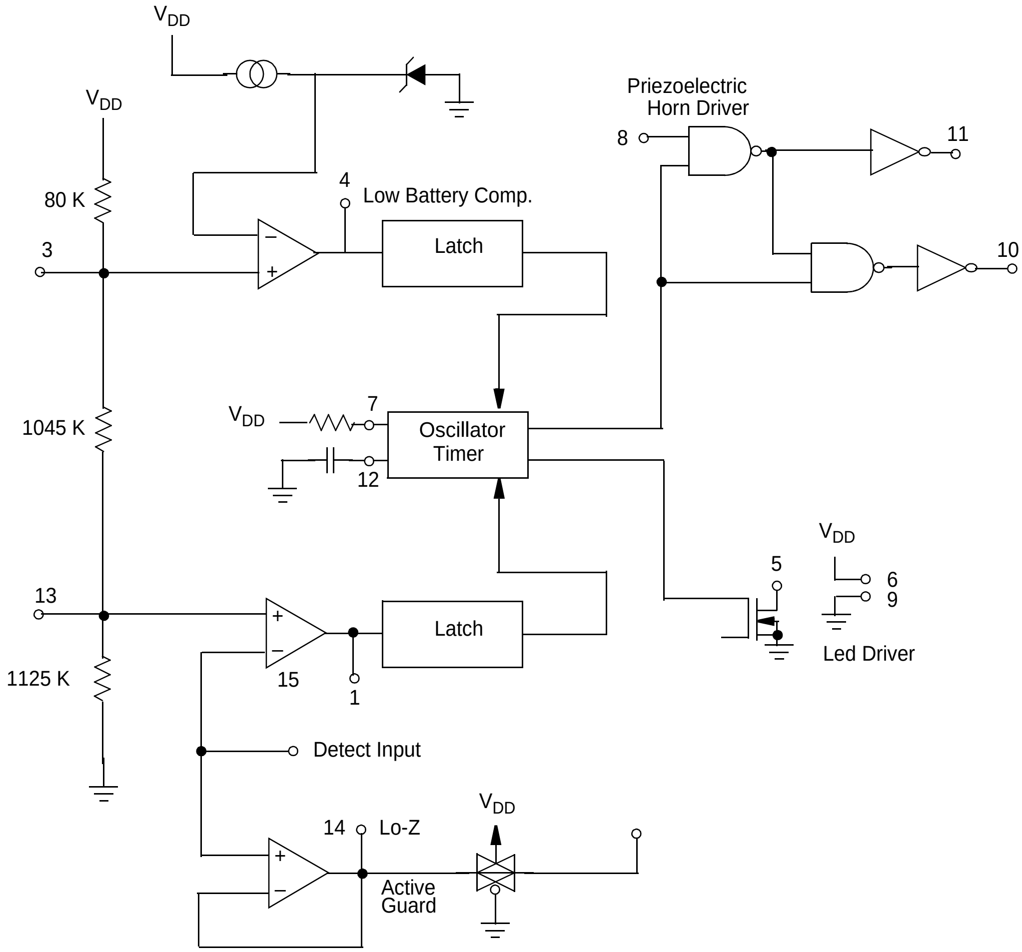


Figure 2. Block Diagram

Table 1. Maximum Ratings(1)
(Voltages referenced to V_{SS})

Rating	Symbol	Value	Unit
DC Supply Voltage	V_{DD}	–0.5 to + 15	V
Input Voltage, All Inputs Except Pin 8	V_{in}	–0.25 to V_{DD} + 0.25	V
DC Current Drain per Input Pin, Except Pin 15 = 1 mA	I	10	mA
DC Current Drain per Output Pin	I	30	mA
Operating Temperature Range	T_A	–10 to +60	°C
Storage Temperature Range	T_{stg}	–55 to + 125	°C
Reverse Battery Time	t_{RB}	5.0	s

1. Maximum Ratings are those values beyond which damage to the device may occur. This device contains circuitry to protect the inputs against damage due to high static voltages or electric fields; however, it is advised that normal precautions be taken to avoid application of any voltage higher than maximum rated voltages to this high impedance circuit. For proper operation it is recommended that except for pin 8, V_{in} and V_{out} be constrained to the range $V_{SS} \leq (V_{in}$ or $V_{out})$ V_{DD}. For pin 8, refer to the Electrical Characteristics.

Table 2. Recommended Operating Conditions
(Voltages referenced to V_{SS})

Parameter	Symbol	Value	Unit
Supply Voltage	V_{DD}	9.0	V
Timing Capacitor	—	0.1	μF
Timing Resistor	—	8.2	MΩ
Battery Load (Resistor or LED)	—	10	mA

Table 3. Electrical Characteristics
(Voltages referenced to V_{SS}, T_A = 25°C)

Characteristic	Symbol	V_{DD} V_{DC}	Min	Typ[1]	Max	Unit
Operating Voltage	V_{DD}	—	6.0	—	12	V
Output Voltage	V_{OH}					V
Piezoelectric Horn Drivers (I_{OH} = -16 mA)		7.2	6.3	—	—	
Comparators (I_{OH} = -30 μA)		9.0	8.5	8.8	—	
Piezoelectric Horn Drivers (I_{OL} = +16 mA)	V_{OL}	7.2	—	—	0.9	V
Comparators (I_{OL} = +30 μA)		9.0	—	0.1	0.5	
Output Voltage - LED Driver, I_{OL} = 10 mA	V_{OL}	7.2	—	—	3.0	V
Output Impedance, Active Guard						kΩ
Pin 14	Lo-Z	9.0	—	—	10	
Pin 16	Hi-Z	9.0	—	—	1000	
Operating Current (R_{bias} = 8.2 MΩ)	I_{DD}	9.0	—	5.0	9.0	μA
		12.0	—	—	12.0	
Input Current - Detect (40% R.H.)	I_{in}	9.0	—	—	±1.0	pA
Internal Set Voltage						
Low Battery	V_{low}	9.0	7.2	—	7.8	V
Sensitivity	V_{set}	—	47	50	53	%V_{DD}
Hysteresis	v_{hys}	9.0	75	100	150	mV
Offset Voltage (measured at Vin = VDD/2	V_{OS}					mV
Active Guard		9.0	—	—	±100	
Detect Comparator		9.0	—	—	±50	
Input Voltage Range, Pin 8	V_{in}	—	VSS - 10	—	VDD + 10	V
Input Capacitance	C_{in}	—	—	5.0	—	pF
Common Mode Voltage Range, Pin 15	V_{cm}	—	0.6	—	VDD - 2	V

1. Data labelled “Typ" is not to be used for design purposes but is intended as an indication of the IC's potential performance.

Table 4. Timing Parameters
(C = 0.1 μF, R_{bias} = 8.2 MΩ, V_{DD} = 9.0 V, T_A = 25°C, See Figure 7)

Characteristics		Symbol	Min	Typ[1]	Max	Units
Oscillator Period	No Smoke Smoke	t_{CI}	1.34 32	1.67 40	2.0 48	s ms
Oscillator Rise Time		t_r	8.0	10	12	ms
Horn Output (During Smoke)	On Time Off Time	PW_{on} PW_{off}	120 60	160 80	208 104	ms ms
LED Output	Between Pulses On Time	t_{LED} PW_{on}	32 8.0	40 10	48 12	s ms
Horn Output (During Low Battery)	On Time Between Pulses	t_{on} t_{off}	8.0 32	10 40	12 48	ms s

1. Data labelled "Typ" is not to be used for design purposes but is intended as an indication of the IC's potential performance.

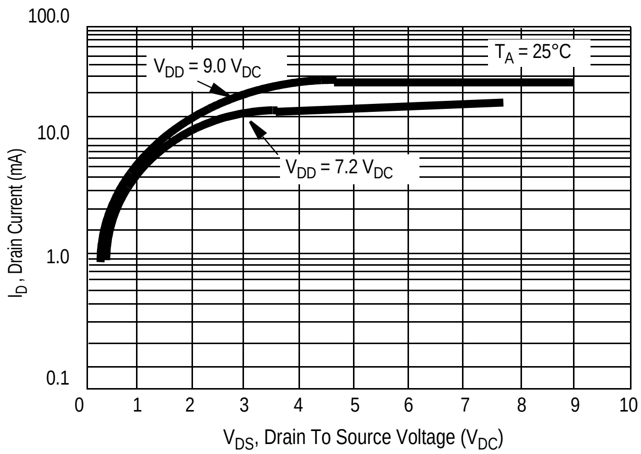


Figure 3. Typical LED Output I-V Characteristic

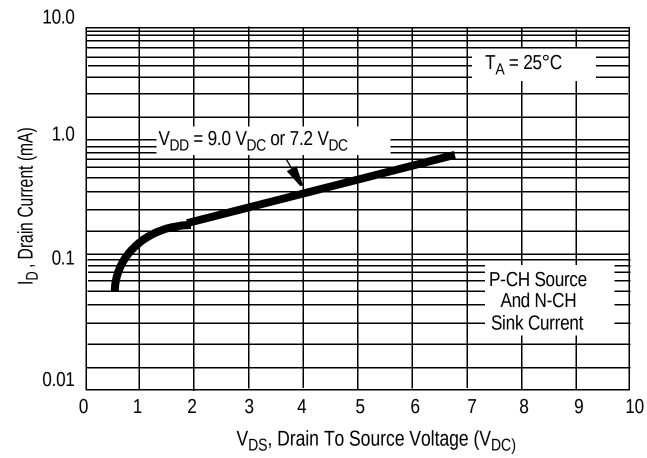


Figure 4. Typical Comparator Output I-V Characteristic

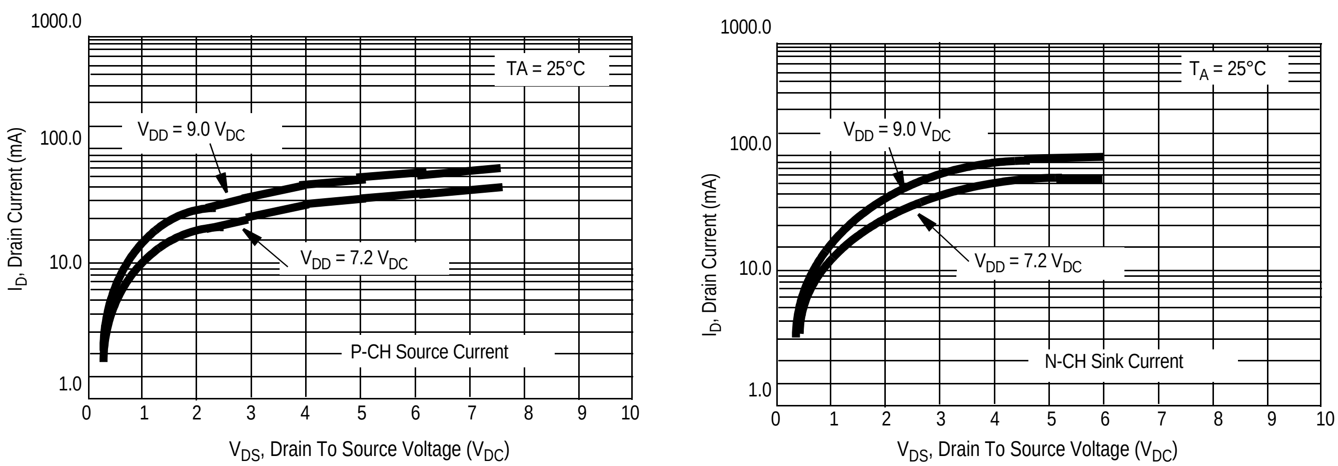


Figure 5. Typical P Horn Driver Output I-V Characteristic

DEVICE OPERATION

Timing

The internal oscillator of the MC14467-1 operates with a period of 1.67 seconds during no-smoke conditions. Each 1.67 seconds, internal power is applied to the entire IC and a check is made for smoke, except during LED pulse, Low Battery Alarm Chirp, or Horn Modulation (in smoke). Every 24 clock cycles a check is made for low battery by comparing V_{DD} to an internal zener voltage. Since very small currents are used in the oscillator, the oscillator capacitor should be of a low leakage type.

Detect Circuitry

If smoke is detected, the oscillator period becomes 40 ms and the piezoelectric horn oscillator circuit is enabled. The horn output is modulated 160 ms on, 80 ms off. During the off time, smoke is again checked and will inhibit further horn output if no smoke is sensed. During smoke conditions the low battery alarm is inhibited, but the LED pulses at a 1.0 Hz rate.

An active guard is provided on both pins adjacent to the detect input. The voltage at these pins will be within 100 mV of the input signal. This will keep surface leakage currents to a minimum and provide a method of measuring the input voltage without loading the ionization chamber. The active guard op amp is not power strobed and thus gives constant protection from surface leakage currents. Pin 15 (the Detect input) has internal diode protection against static damage.

Sensitivity/Low Battery Thresholds

Both the sensitivity threshold and the low battery voltage levels are set internally by a common voltage divider (please see Figure 2) connected between V_{DD} and V_{SS}. These voltages can be altered by external resistors connected from pins 3 or 13 to either V_{DD} or V_{SS}. There will be a slight interaction here due to the common voltage divider network. The sensitivity threshold can also be set by adjusting the smoke chamber ionization source.

Test Mode

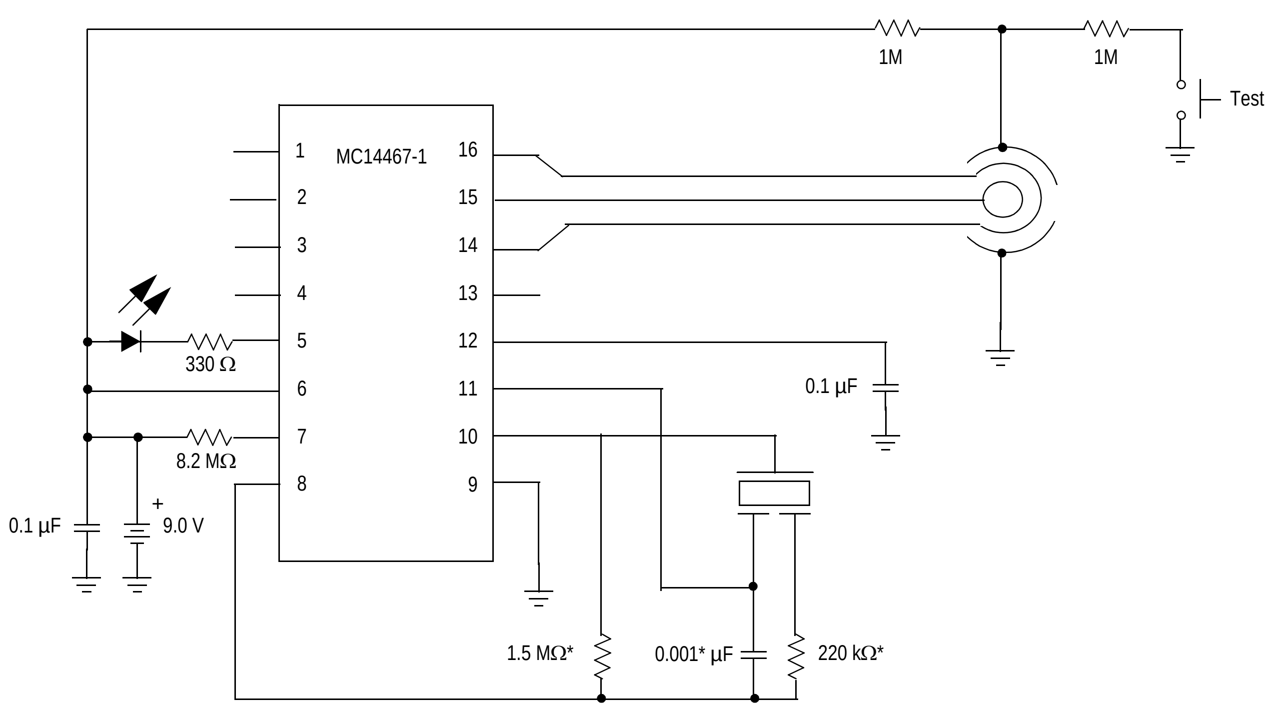
Since the internal op amps and comparators are power strobed, adjustments for sensitivity or low battery level could be difficult and/or time-consuming. By forcing Pin 12 to V_{SS}, the power strobing is bypassed and the outputs, Pins 1 and 4, constantly show smoke/no smoke and good battery/low battery, respectively. Pin 1 = V_{DD} for smoke and Pin 4 = V_{DD} for low battery. In this mode and during the 10 ms power strobe, chip current rises to approximately 50 μA.

LED Pulse

The 9-volt battery level is checked every 40 seconds during the LED pulse. The battery is loaded via a 10 mA pulse for 10 ms. If the LED is not used, it should be replaced with an equivalent resistor such that the battery loading remains at 10 mA.

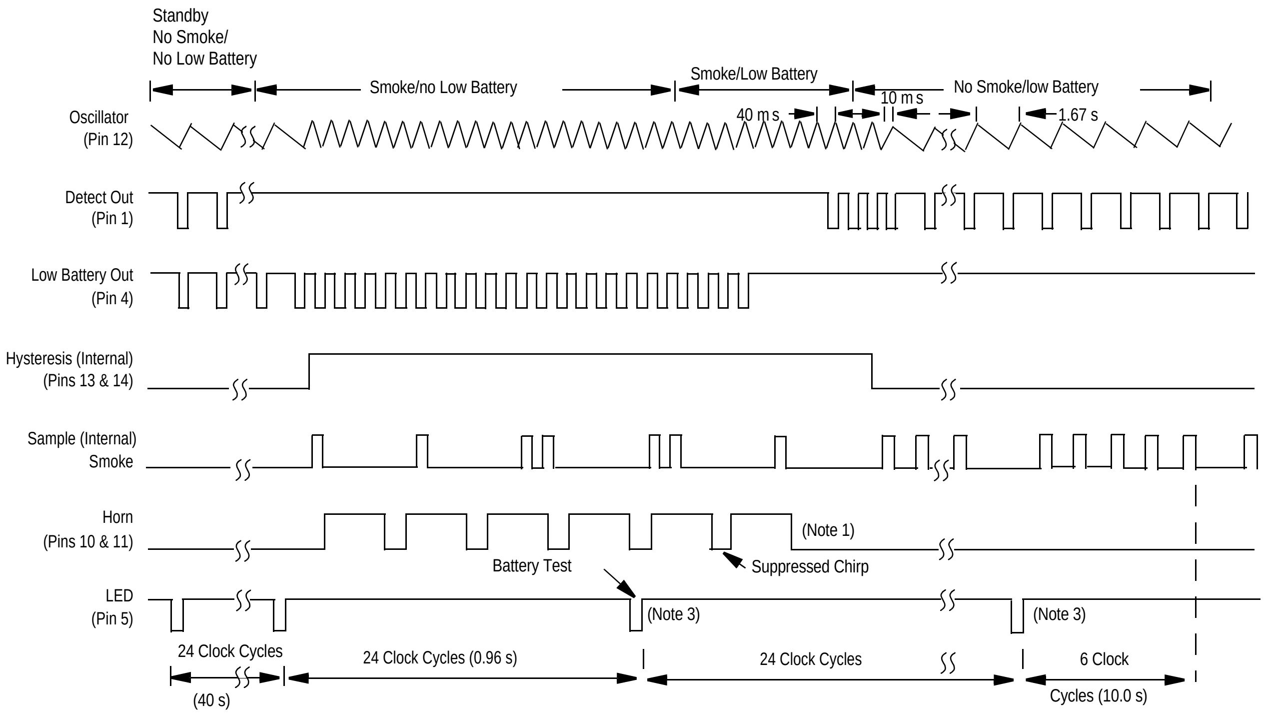
Hysteresis

When smoke is detected, the resistor/divider network that sets sensitivity is altered to increase sensitivity. This yields approximately 100 mV of hysteresis and reduces false triggering.



*NOTE: Component values may change depending on type of piezoelectric horn used.

Figure 6. Typical Application as Ionization Smoke Detector



Notes:
1. Horn modulation is self-completing. When going from smoke to no smoke, the alarm condition will terminate only when horn is off.
2. Comparators are strobed on once per clock cycle (1.67 s for no smoke, 40 ms for smoke).
3. Low battery comparator information is latched only during LED pulse.
4. ~ 100 mVp–p swing.

Figure 7. Timing Diagram

Freescale Semiconductor
Technical Data

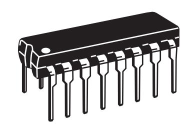
MC14468
Rev 4, 05/2005

MC14468

Low-Power CMOS Ionization Smoke Detector IC with Interconnect

LOW-POWER CMOS IONIZATION SMOKE DETECTOR IC WITH INTERCONNECT

The MC14468, when used with an ionization chamber and a small number of external components, will detect smoke. When smoke is sensed, an alarm is sounded via an external piezoelectric transducer and internal drivers. This circuit is designed to operate in smoke detector systems that comply with UL217 and UL268 specifications.



P SUFFIX
16-LEAD PLASTIC DIP
CASE 648-08

Features

- Ionization Type with On-Chip FET Input Comparator
- Piezoelectric Horn Driver
- Guard Outputs on Both Sides of Detect Input
- Input-Production Diodes on the Detect Input
- Low-Battery Trip Point, Internally Set, can be Altered Via External Resistor
- Detect Threshold, Internally Set, can be Altered Via External Resistor
- Pulse Testing for Low Battery Uses LED for Battery Loading
- Comparator Output for Detect
- Internal Reverse Battery Protection
- Strobe Output for External Trim Resistors
- I/O Pin Allows Up to 40 Units to be Connected for Common Signaling
- Power-On Reset Prevents False Alarms on Battery Change

ORDERING INFORMATION			
Device	**Temperature Range**	**Case No.**	**Package**
MC14468P	–10° to 60°C	648-08	Plastic Dip

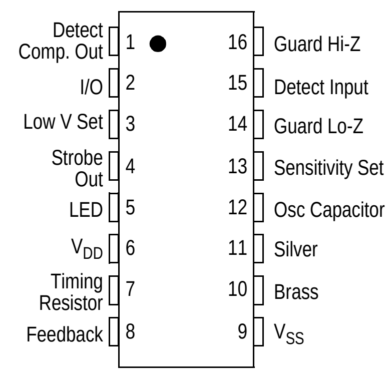


Figure 1. Pin Connections

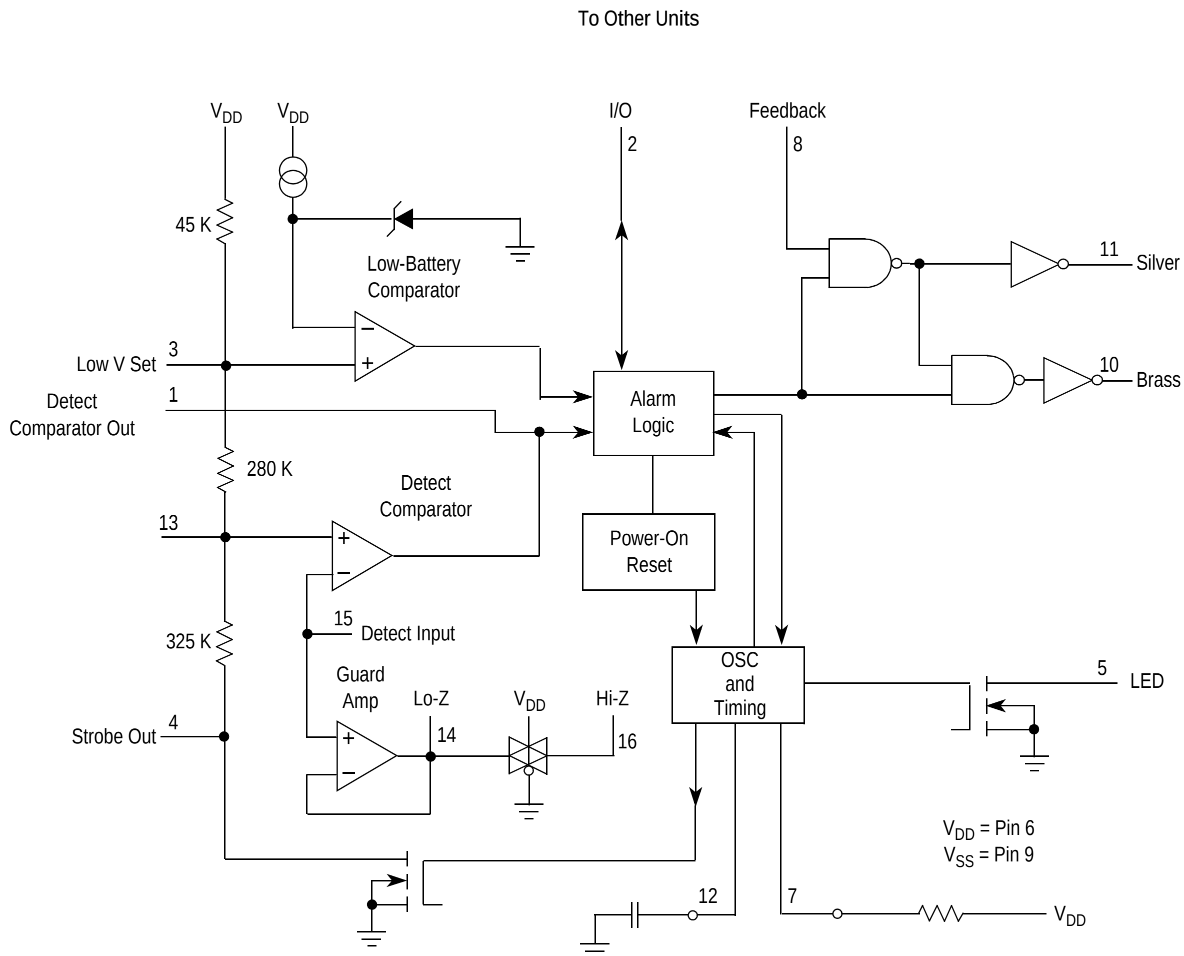


Figure 2. Block Diagram

Table 1. Maximum Ratings(1)
(Voltages referenced to VSS)

Rating	Symbol	Value	Unit
DC Supply Voltage	V_{DD}	–0.5 to +15	V
Input Voltage, All Inputs Except Pin 8	V_{in}	–0.25 to V_{DD} + 0.25	V
DC Current Drain per Input Pin, Except Pin 15 = 1 mA	I	10	mA
DC Current Drain per Output Pin	I	30	mA
Operating Temperature Range	T_A	–10 to +60	°C
Storage Temperature Range	T_{stg}	–55 to +125	°C
Reverse Battery Time	t_{RB}	5.0	s

1. Maximum Ratings are those values beyond which damage to the device may occur. This device contains circuitry to protect the inputs against damage due to high static voltages or electric fields; however, it is advised normal precautions be taken to avoid application of any voltage higher than maximum rated voltages to this high impedance circuit. For proper operation it is recommended V_{in} and V_{out} be constrained to the range $V_{SS} \leq (V_{in}$ or $V_{out}) \leq V_{DD}$.

Table 2. Recommended Operating Conditions
(Voltages Referenced to V_{SS})

Parameter	Symbol	Value	Unit
Supply Voltage	V_{DD}	9.0	V
Timing Capacitor	—	0.1	μF
Timing Resistor	—	8.2	MΩ
Battery Load (Resistor or LED)	—	10	mA

Table 3. Electrical Characteristics
(T_A = 25°C)

Characteristic	Symbol	V_{DD} V_{DC}	Min	Type[1]	Max	Unit
Operating Voltage	V_{DD}	—	6.0	—	12	V
Output Voltage Piezoelectric Horn Drivers (I_{OH} = –16 mA) Comparators (I_{OH} = –30 μA) Piezoelectric Horn Drivers (I_{OL} = +16 mA) Comparators (I_{OL} = +30 μA)	V_{OH} V_{OL} 	 7.2 9.0 7.2 9.0	 6.3 8.5 — —	 — 8.8 — 0.1	 — — 0.9 0.5	V V
Output Voltage — LED Driver, I_{OL} = 10 mA	V_{OL}	7.2	—	—	3.0	V
Output Impedance, Active Guard Pin 14 Pin 16	 Lo-Z Hi-Z	 9.0 9.0	 — —	 — —	 10 1000	kΩ
Operating Current (R_{bias} = 8.2 MΩ)	I_{DD}	9.0 12.0	— —	5.0 —	9.0 12.0	μA
Input Current — Detect (40% R.H.)	I_{in}	9.0	—	—	±1.0	pA
Input Current, Pin 8	I_{in}	9.0	—	—	±0.1	μA
Input Current @ 50°C, Pin 15	I_{in}	—	—	—	±6.0	pA
Internal Set Voltage Low Battery Sensitivity	 V_{low} V_{set}	 9.0 —	 7.2 47	 — 50	 7.8 53	 V %V_{DD}
Hysteresis	V_{hys}	9.0	75	100	150	mV
Offset Voltage (Measured at V_{in} = V_{DD}/2) Active Guard Detect Comparator	V_{OS}	 9.0 9.0	 — —	 — —	 ±100 ±50	mV
Input Voltage Range, Pin 8	V_{in}	—	V_{SS} – 10	—	V_{DD} + 10	V
Input Capacitance	C_{in}	—	—	5.0	—	pF
Common Mode Voltage Range, Pin 15	V_{cm}	—	0.6	—	V_{DD} – 2	V
I/O Current, Pin 2 Input, V_{IH} = V_{DD} –2 Output, V_{OH} = V_{DD} –2	 I_{IH} I_{OH}	 — —	 25 –4.0	 — —	 100 –16	 μA mA

1. Data labelled “Typ" is not to be used for design purposes, but is intended as an indication of the IC's potential performance.

Table 4. Timing Parameters
(C = 0.1 μF, R_{bias} = 8.2 MΩ, V_{DD} = 9.0 V, T_A = 25°C, See Figure 7)

Characteristics		Symbol	Min	Typ[1]	Max	Units
Oscillator Period	No Smoke Smoke	t_{CI}	1.34 32	1.67 40	20 48	s ms
Oscillator Rise Time		t_r	8.0	10	12	ms
Horn Output (During Smoke)	On Time Off Time	PW_{on} PW_{off}	120 60	160 80	208 104	ms ms
LED Output	Between Pulses On time	t_{LED} PW_{on}	32 8.0	40 10	48 12	s ms
Horn Output (During Low Battery)	On Time Between Pulses	t_{on} t_{off}	8.0 32	10 40	12 48	ms s

1. Data labelled "Typ" is not to be used for design purposes, but is intended as an indication of the IC's potential performance.

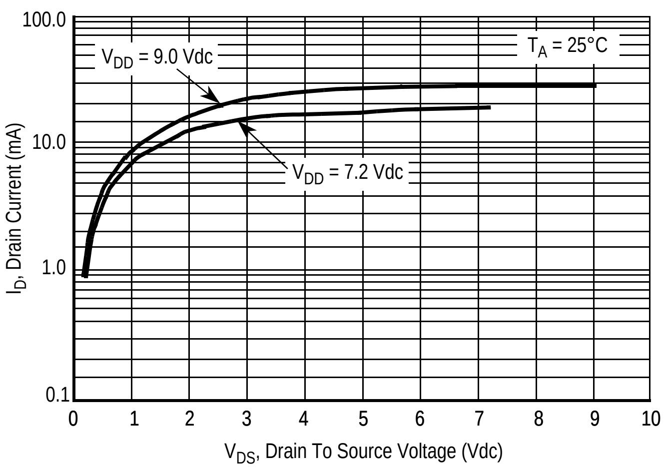


Figure 3. Typical LED Output I-V Characteristic

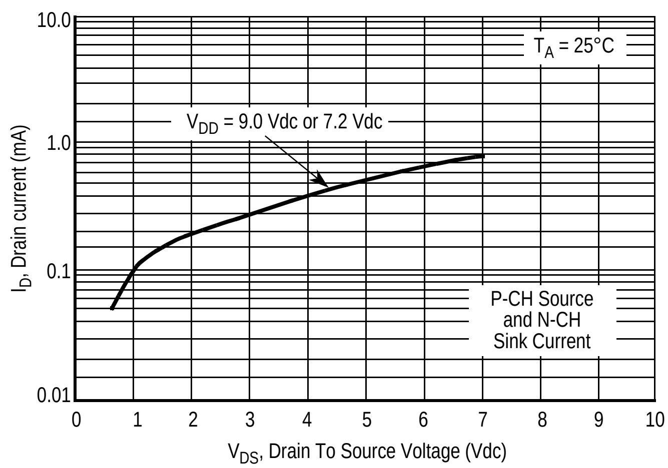


Figure 4. Typical Comparator Output I-V Characteristic

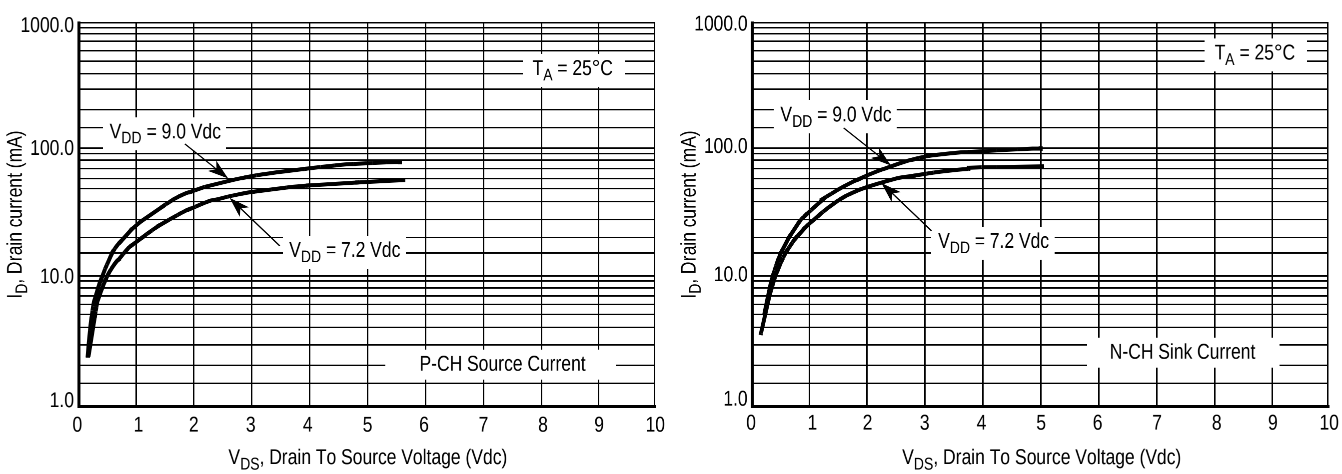


Figure 5. Typical P Horn Driver Output I-V Characteristic

Timing

The internal oscillator of the MC14468 operates with a period of 1.67 seconds during no-smoke conditions. Each 1.67 seconds, internal power is applied to the entire IC and a check is made for smoke, except during LED pulse, Low Battery Alarm Chirp, or Horn Modulation (in smoke). Every 24 clock cycles a check is made for low battery by comparing V_{DD} to an internal zener voltage. Since very small currents are used in the oscillator, the oscillator capacitor should be of a low leakage type.

Detect Circuitry

If smoke is detected, the oscillator period becomes 40 ms and the piezoelectric horn oscillator circuit is enabled. The horn output is modulated 160 ms on, 80 ms off. During the off time, smoke is again checked and will inhibit further horn output if no smoke is sensed. During local smoke conditions the low battery alarm is inhibited, but the LED pulses at a 1.0 Hz rate. In remote smoke, the LED is inhibited as well.

An active guard is provided on both pins adjacent to the detect input. The voltage at these pins will be within 100 mV of the input signal. This will keep surface leakage currents to a minimum and provide a method of measuring the input voltage without loading the ionization chamber. The active guard op amp is not power strobed and thus gives constant protection from surface leakage currents. Pin 15 (the Detect input) has internal diode protection against static damage.

Interconnect

The I/O (Pin 2), in combination with V_{SS}, is used to interconnect up to 40 remote units for common signaling. A Local Smoke condition activates a current limited output driver, thereby signaling Remote Smoke to interconnected units. A small current sink improves noise immunity during non-smoke conditions. Remote units at lower voltages do not draw excessive current from a sending unit at a higher voltage. The I/O is disabled for three oscillator cycles after power up, to eliminate false alarming of remote units when the battery is changed.

Sensitivity/Low Battery Thresholds

Both the sensitivity threshold and the low battery voltage levels are set internally by a common voltage divider (please see Figure 2) connected between V_{DD} and V_{SS}. These voltages can be altered by external resistors connected from pins 3 or 13 to either V_{DD} or V_{SS}. There will be a slight interaction here due to the common voltage divider network. The sensitivity threshold can also be set by adjusting the smoke chamber ionization source.

Test Mode

Since the internal op amps and comparators are power strobed, adjustments for sensitivity or low battery level could be difficult and/or time-consuming. By forcing Pin 12 to V_{SS}, the power strobing is bypassed and the output, Pin 1, constantly shows smoke/no smoke. Pin 1 = V_{DD} for smoke. In this mode and during the 10 ms power strobe, chip current rises to approximately 50 μA.

LED Pulse

The 9-volt battery level is checked every 40 seconds during the LED pulse. The battery is loaded via a 10 mA pulse for 10 ms. If the LED is not used, it should be replaced with an equivalent resistor such that the battery loading remains at 10 mA.

Hysteresis

When smoke is detected, the resistor/divider network that sets sensitivity is altered to increase sensitivity. This yields approximately 100 mV of hysteresis and reduces false triggering.

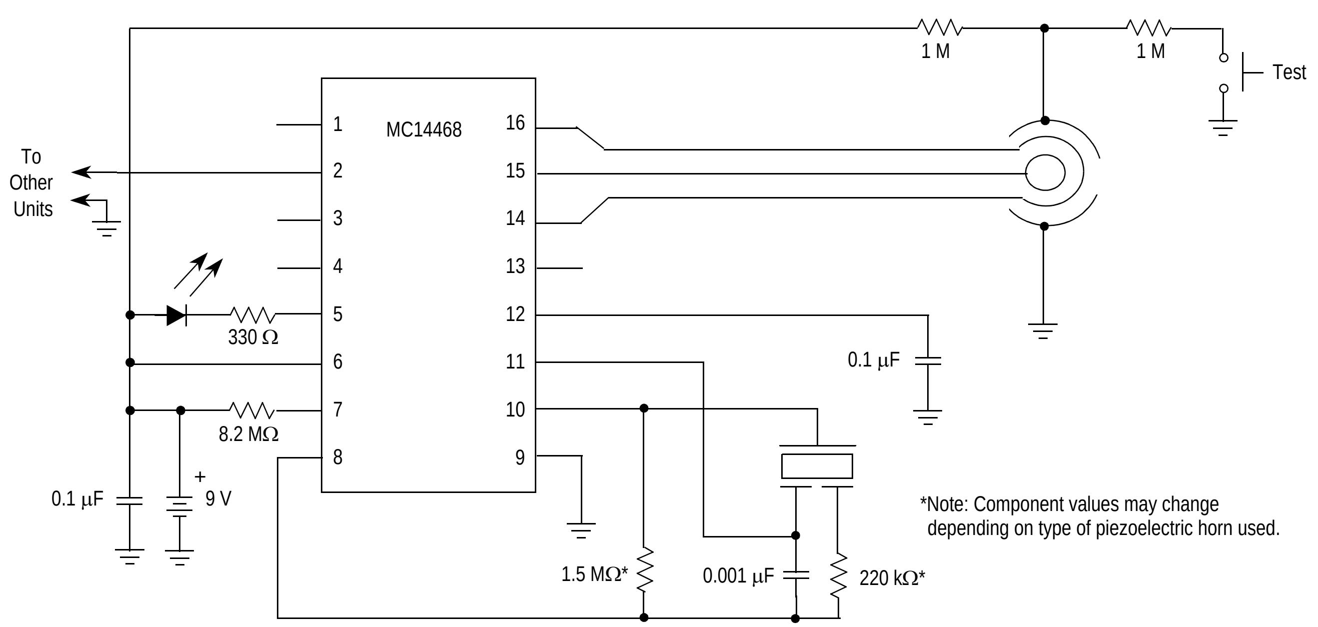
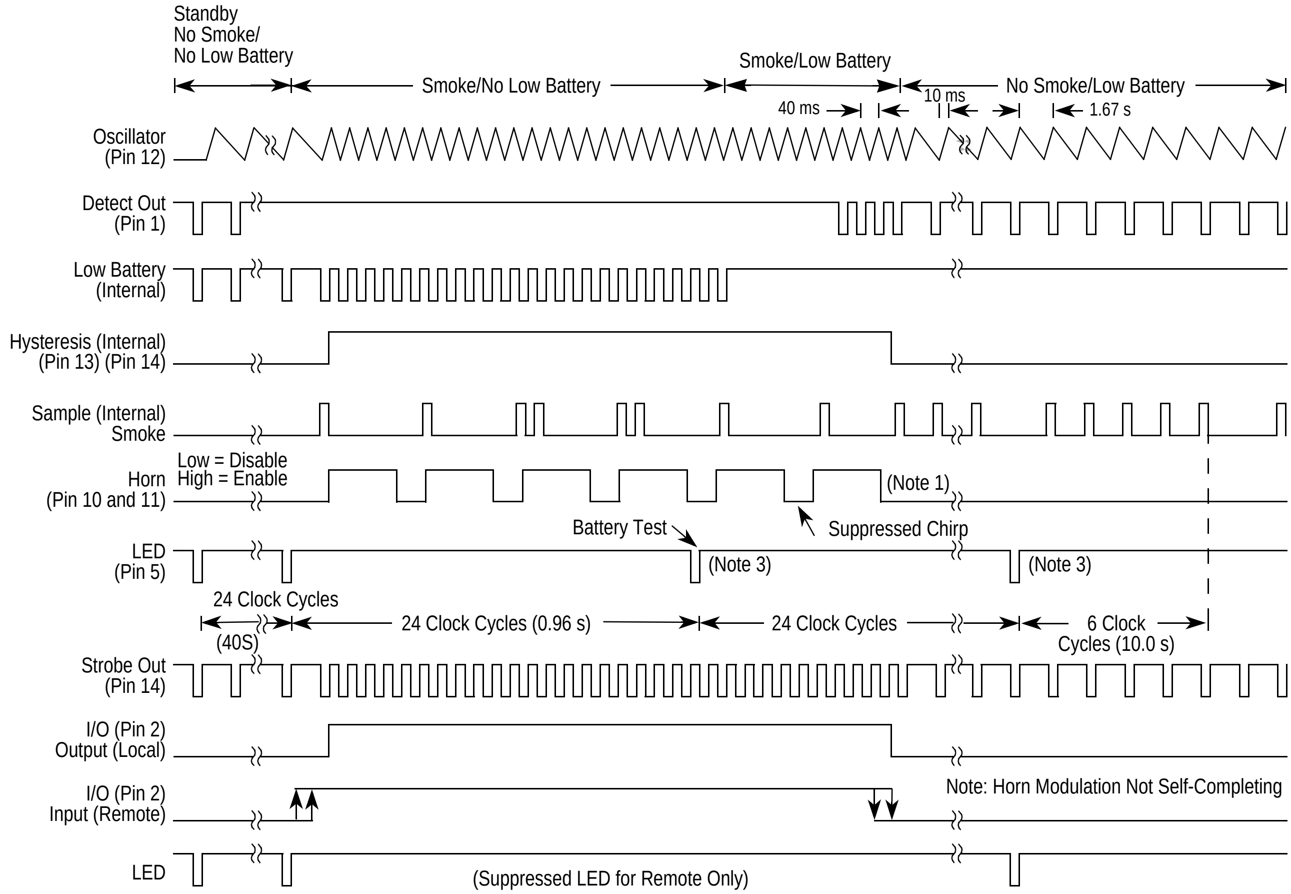


Figure 6. Typical Application as Ionization Smoke Detector



Notes:

1. Horn modulation is self-completing. When going from smoke to no smoke, the alarm condition will terminate only when horn is off.
2. Comparators are strobed on once per clock cycle (1.67 s for no smoke, 40 ms for smoke).
3. Low battery comparator information is latched only during LED pulse.
4. ~ 100 mV p-p swing.

Figure 7. Timing Diagram

MC14578

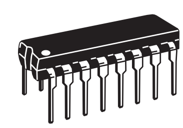
CMOS
Micro-Power Comparator plus Voltage Follower

CMOS
MICRO-POWER COMPARATOR
PLUS VOLTAGE FOLLOWER

The MC14578 is an analog building block consisting of a very-high input impedance comparator. The voltage follower allows monitoring the noninverting input of the comparator without loading.

Four enhancement-mode MOSFETs are also included on chip. These FETs can be externally configured as open-drain or totem-pole outputs. The drains have on-chip static-protecting diodes. Therefore, the output voltage must be maintained between V_{SS} and V_{DD}.

The chip requires one external component. A 3.9 MΩ ±10% resistor must be connected from the R_{bias} pin to V_{DD}. This circuit is designed to operate in smoke detector systems that comply with UL217 and UL268 specifications.



P SUFFIX
PLASTIC DIP
CASE 648-08

Features

- Applications:
  - Pulse Shapers
  - Threshold Detectors
  - Low-Battery Detectors
  - Line-Powered Smoke Detectors
  - Liquid/Moisture Sensors
  - CO Detector and Micro Interface
- Operating Voltage Range: 3.5 to 14 V
- Operating Temperature Range: -30° to 70°C
- Input Current (IN + Pin): ±1 pA @ 25°C (DIP Only)
- Quiescent Current: 10 µA @ 25°C
- Electrostatic Discharge (ESD) Protection Circuitry on All Pins

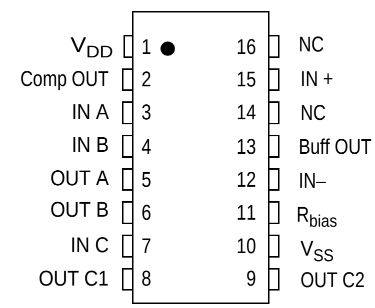


Figure 1. Pin Connections

ORDERING INFORMATION			
Device	**Temperature Range**	**Case No.**	**Package**
MC14578P	-30° to 70°C	648-08	Plastic Dip

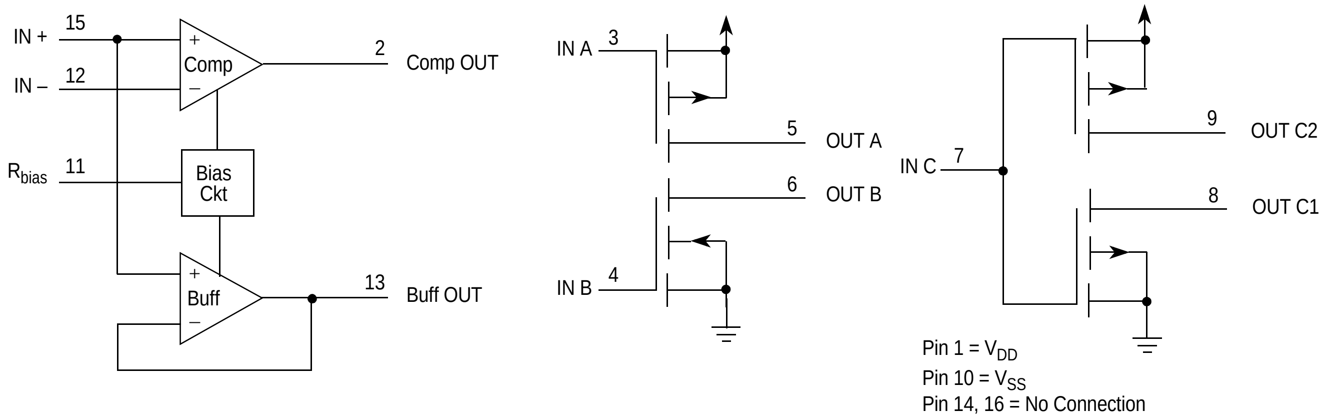


Figure 2. Block Diagram

Table 1. Maximum Ratings[1]
(Voltages Referenced to V_{SS})

Rating	Symbol	Value	Unit
DC Supply Voltage	V_{DD}	-0.5 to +14	V
DC Input Voltage	V_{in}	-0.5 to V_{DD} +0.5	V
DC Output Voltage	V_{out}	-0.5 to V_{DD} +0.5	V
DC Input Current, Except IN +	I_{in}	±10	mA
DC Output Current, IN +	I_{in}	±1.0	mA
DC Output Current, per Pin	I_{out}	±25	mA
DC Supply Current, V_{DD} and V_{SS} Pins	I_{DD}	±50	mA
Power Dissipation, per Package	P_D	500	mW
Storage Temperature	T_{stg}	-65 to + 150	°C
Lead Temperature (10-Second Soldering)	T_L	260	°C

1. Maximum Ratings are those values beyond which damage to the device may occur. This device contains protection circuitry to guard against damage due to high static voltages or electric fields. However, precautions must be taken to avoid applications of any voltage higher than maximum rated voltages to this high-impedance circuit. For proper operation, V_{in} and V_{out} should be constrained to the range $V_{SS} \leq (V_{in}$ or $V_{out}) \leq V_{DD}$. Unused inputs must always be tied to an appropriate logic voltage level (e.g., either V_{SS} or V_{DD}). Unused outputs must be left open.

Table 2. Electrical Characteristics
(Voltages Referenced to V_{SS}, R_{bias} = 3.9 MΩ to V_{DD}, T_A = -30° to 70°C Unless Otherwise Indicated)

Characteristic	Symbol	Test Condition	V_{DD} V_{DC}	Guaranteed Limit	Unit
Power Supply Voltage Range	V_{DD}		—	3.5 to 14.0	V
Maximum Low-Level Input Voltage, MOSFETs Wired as Inverters; i.e., IN A tied to IN B, OUT A to OUT B, OUT C1 to OUT C2	V_{IL}	V_{out} = 9.0 V, $\lvert I_{out}\rvert$ <1 μA	10.0	2.0	V
Minimum High-Level Input voltage, MOSFETs Wired as Inverters; i.e., IN A tied to IN B, OUT A to OUT B, OUT C1 to OUT C2	V_{IH}	V_{out} = 1.0 V, $\lvert I_{out}\rvert$ <1 μA	10.0	8.0	V
Comparator Input Offset Voltage	V_{IO}	T_A = 25°C, Over Common Mode Range	10.0	±50	mV
		T_A = 0° to 50°C, Over Common Mode Range	3.5 to 14.0	±75	
Comparator Common Mode Voltage Range	V_{CM}		3.5 to 14.0	0.7 to V_{DD} – 1.5	V
Maximum Low-Level Comparator Output Voltage	V_{OL}	IN +: V_{in} = V_{SS}, IN –: V_{in} = V_{DD}, I_{out} = 30 μA	10.0	0.5	V
Minimum High-Level Comparator Output Voltage	V_{OH}	IN +: V_{in} = V_{DD}, IN –: V_{in}= V_{SS}, I_{out} = -30 μA	10.0	9.5	V
Buffer Amp Output Offset Voltage	V_{OO}	R_{load} = 10 MΩ to V_{DD} or V_{SS}, Over Common Mode Range	—	±100	mV
Maximum Low-Level Input Voltage, MOSFETs Wired as Inverters; i.e., IN A tied to IN B, OUT A to OUT B, OUT C1 to OUT C2	V_{OL}	OUT C1, OUT C2, I_{out} = 1.1 mA	10.0	0.5	V
		OUT A, OUT B, I_{out} = 270 μA	10.0	0.5	V
Minimum High-Level Input Voltage, MOSFETs Wired as Inverters; i.e., IN A tied to IN B, OUT A to OUT B, OUT C1 to OUT C2	V_{OH}	OUT C1, OUT C2, I_{out} = -1.1 mA	10.0	9.5	V
		OUT A, OUT B, I_{out} = 270 μA	10.0	9.5	V
Maximum Input Leakage Current — IN + (DIP Only)	I_{in}	T_A = 25°C, 40% R.H., V_{in} = V_{SS} or V_{DD}	10.0	±1.0	pA
IN + (DIP Only)		T_A = 50°C, V_{in} = V_{SS} or V_{DD}	10.0	±6.0	
IN + (SOG), IN A, IN B, IN C, IN –		V_{in} = V_{SS} or V_{DD}	10.0	±40	nA
Maximum Off-State MOSFET Leakage Current	I_{OZ}	IN A, IN C: V_{in} = V_{DD}, OUT A, OUT C2: V_{out} = V_{SS} or V_{DD}	10.0	±100	nA
		IN B, IN C: V_{in} = V_{SS}, OUT B, OUT C1: V_{out} = V_{SS} or V_{DD}	10.0	±100	
Maximum Quiescent Current	I_{DD}	T_A = 25°C IN A, IN B, IN C: V_{in} = V_{SS} or V_{DD}, $\lvert V_{IN}+ - V_{IN}-\rvert$ = 100 mV I_{out} = 0 μA	10.0	10	μA
Maximum Input Capacitance — IN + / Other Inputs	C_{in}	f = 1 kHz	— / —	5.0 / 15	pF

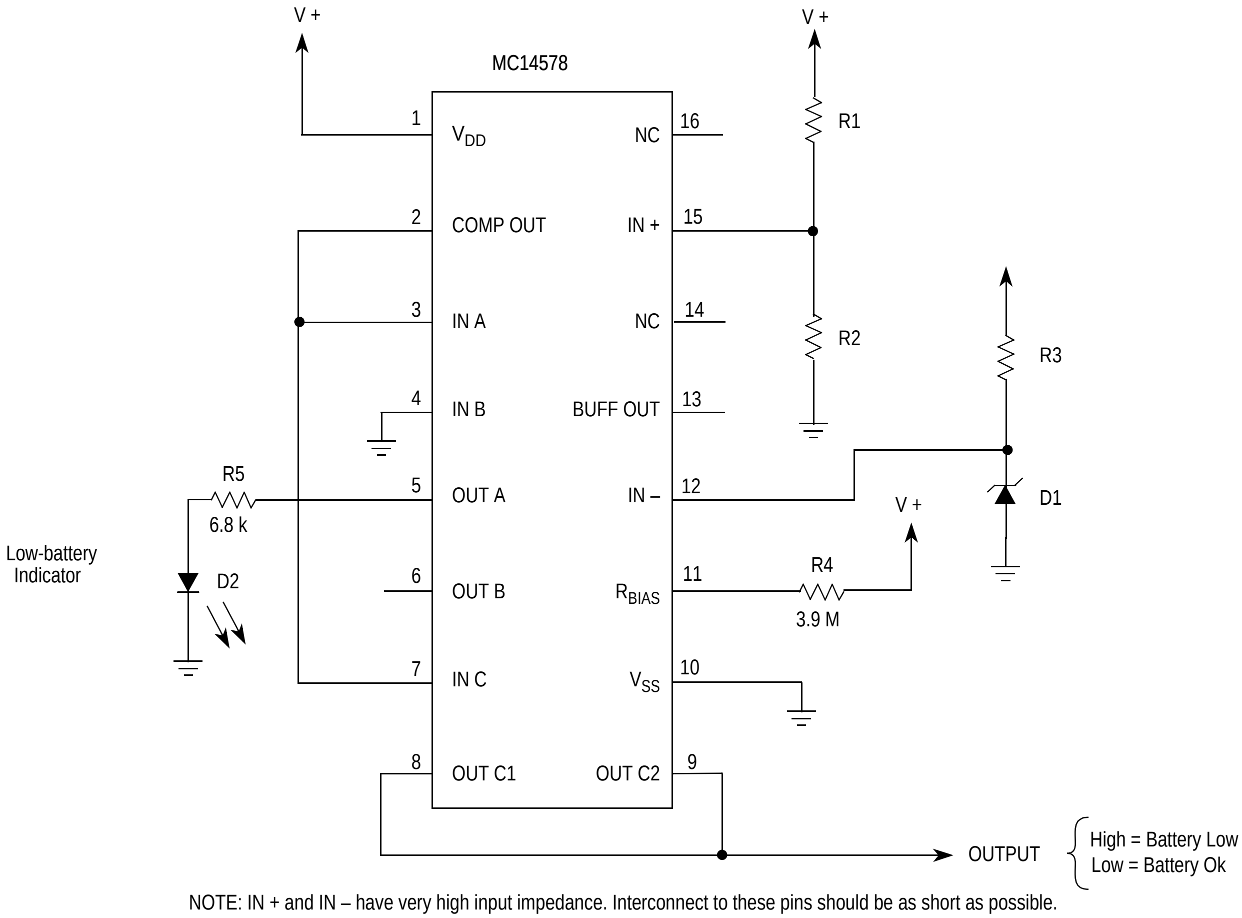


Figure 3. Low-Battery Detector

EXAMPLE VALUES

Near the switchpoint, the comparator output in the circuit of Figure 3. may chatter or oscillate. This oscillation appears on the signal labelled OUTPUT. In some cases, the oscillation in the transition region will not cause problems. For example, an MPU reading OUTPUT could sample the signal two or three times to ensure a solid level is attained. But, in a low battery detector, this probably is not necessary.

To eliminate comparator chatter, hysteresis can be added as shown in Figure 4.. The circuit of Figure 4. requires slightly more operating current than the Figure 3. arrangement.

R1	R2	R3	Nominal Tip Point
470 kΩ	1.3 MΩ	20 kΩ	4.08 V
820 kΩ	1.2 MΩ	39 kΩ	5.05 V
1.2 MΩ	1.2 MΩ	62 kΩ	6.00 V

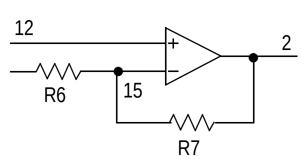


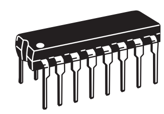
Figure 4. Adding Hysteresis

MC14600

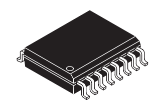
**LOW-POWER CMOS
ALARM IC
WITH HORN DRIVER**

Low-Power CMOS ALARM IC with Horn Driver

The MC14600 Alarm IC is designed to simplify the process of interfacing an alarm level voltage condition to a piezoelectric horn and/or LED. With an extremely low average current requirement and an integrated low battery detect feature, the part is ideally suited to battery operated applications. The MC14600 is easily configured with a minimum number of external components to serve a wide range of applications and circuit configurations. Typical applications include intrusion alarms, moisture or water ingress alarms, and personal safety devices.



**16-LEAD
PLASTIC DIP
CASE 648-08**



**16-LEAD
SOIC
CASE 751G-04**

Features

- High Impedance, FET Input Comparator
- Comparator Outputs for Low Battery and Alarm Detect
- Alarm Detect Threshold Easily Established with 2 Resistors
- Integrated Oscillator and Piezoelectric Horn Driver
- Low Battery Trip Point Set Internally (Altered Externally)
- Horn “Chirp" During Low Battery Condition
- Pulsed LED Drive Output
- Reverse Battery Protection
- Input Protection Diodes on the Detect Input
- Average Supply Current: 9 μA

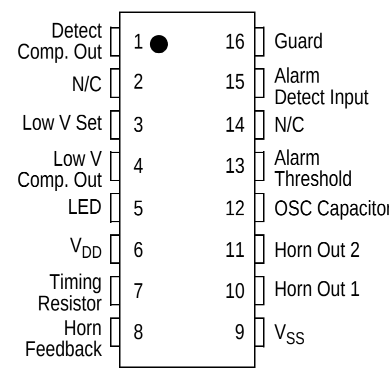


Figure 1. Pin Connections

ORDERING INFORMATION		
Device	**Case No.**	**Package**
MC14600P	648-08	Plastic Dip
MC14600DW	751G-04	SOIC
MC14600DWR2	751G-04	SOIC Tape & Reel

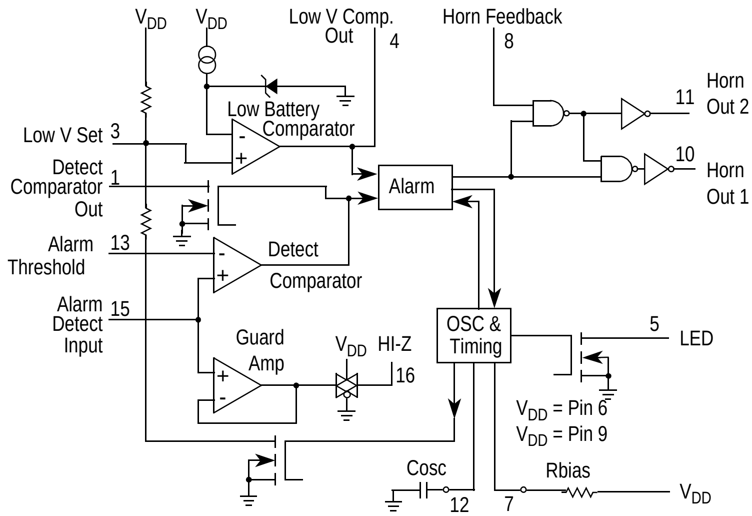


Figure 2. Block Diagram

Table 1. Maximum Ratings(1)
(Voltages referenced to V_{SS})

Rating	Symbol	Value	Unit
DC Supply Voltage	V_{DD}	-0.5 to +15	V
Input Voltage, All Inputs Except Pin 8	V_{IN}	-0.25 to VDD +0.25	V
DC Current Drain per Input Pin Except Pin 15 = 1 mA	I	10	mA
DC Current Drain per Output Pin	I	30	mA
Operating Temperature Range	T_A	-10 to +60°C	°C
Storage Temperature Range	T_{STG}	-55 to +125	°C
Reverse Battery Time	t_{RB}	5.0	s

1. Maximum Ratings are those values beyond which damage to the device may occur.
This device contains circuitry to protect the inputs against damage due to high static voltages or electric fields; however, it is advised normal precautions be taken to avoid application of any voltage higher than maximum rated voltages to this high impedance circuit. For proper operation, it is recommended V_{IN} and V_{OUT} be constrained to the range $V_{SS} \leq (V_{IN}$ or $V_{OUT}) \leq V_{DD}$.

Table 2. Recommended Operating Conditions
(Voltages referenced to V_{SS})

Parameter	Symbol	Value	Unit
Supply Voltage	V_{DD}	9.0	V
LED Load (Pin 5)	—	10	mA

Table 3. Electrical Characteristics
(Voltages referenced to V_{CC}, T_A = 25°C)

Characteristics	Symbol	V_{DD}/V_{DC}	Min	Typ[(1)]	Max	Unit
Output Voltage	V_{OH}					V
Piezoelectric Horm Drivers (I_{OH} = +16 mA), Pins 10, 11		7.4	6.5	—	—	
Comparators (I_{OH} = +30 μA), Pin 4		9.0	8.5	8.8	—	
Piezoelectric Horn Drivers (I_{OL} = -16 mA), Pins 10, 11	V_{OL}	7.4	—	—	0.9	V
Comparators (I_{OL} = -30 μA), Pin 4		9.0	—	0.1	0.5	
(I_{OL} = -200 μA), Pin 1		—	—	—	0.5	
Operating Voltage	V_{DD}	—	6.0	—	12	V
Output Voltage — LED Driver, I_{OL} = 10 mA, Pin 5	V_{OL}	7.2	—	—	2.0	V
Output Inpedance, Active Guard, Pin 16	HI-Z	9.0	—	—	1000	kΩ
Standby Current (R_{BIAS} = 8.2 MΩ)	I_{DD}	9.0 12.0	— —	5.0 —	9.0 12.0	μA
Input Leakage Current						
Pin 1	—	9.0	—	—	±30	nA
Pin 8	I_{IN}	9.0	—	—	±0.1	μA
Pin 13	—	9.0	—	—	±30	nA
Detect Comparator Out , Pin 1						
V = 3.0 V	—	—	2.50	—	—	mA
V = 9.0 V	—	—	—	—	8.00	mA
Low Battery Threshold Voltage (Pin 3 Open), Pin 6	V_{LOW}	9.0	7.2	—	7.8	V
Offset Voltage (Measured at V_{IN} = $V_{DD}/2$)	V_{OS}					mV
Active Guard		9.0	—	—	±100	
Detect Comparator		9.0	—	—	±50	
Input Voltage Range, Pin 8	V_{IN}	—	V_{SS} -10	—	V_{DD} +10	V
Input Capacities (to V_{SS} @ 1 khz), Pin 15	C_{IN}	—	—	5.0	—	pF
Common Mode Voltage Range, Pins 13, 15	V_{CM}	—	1.5	—	V_{DD} -2	V
Breakdown Voltage, All Pins Except 15	—	—	±500	—	—	V
Human Body Models/MIL–STD–883 Method 3015, Pin 15	—	—	±400	—	—	

1. Data labelled “Typ” is not to be used for design purposes, but is intended as an indication of the IC’s potential performance.

Table 4. Timing Parameters
(C_{OSC} = 0.1 μF, R_{BIAS} = 8.2 MΩ, V_{DD} = 9.0 V, T_A = 25°C, see Figure 3.)

Characteristic		Pin #	Symbol	Min	Max	Units
Oscillator Period (1 Clock Cycle = 1 Oscillator Period)	No Alarm Alarm	12	t_{CI} —	1.25 30	2.25 52	s ms
Oscillator Pulse Width (No Alarm and Alarm Condition)		3, 4, 5, 13	t_r	7.0	13	ms
LED Output Period	No Alarm Alarm	5	t_{LED} —	30 .71	52 1.25	s ms
Alarm Horn Output	Hi Time Low Time	10, 11	t_{ON} t_{OFF}	120 60	208 104	ms ms
Low Battery Horn OutpuT	Hi Time Between Pulses	10, 11	t_{ON} t_{OFF}	7.0 30	13 52	ms s

DEVICE OPERATION

Timing

The internal oscillator of the MC14600 operates with a period of 1.65 seconds during no-alarm conditions. Each 1.65 seconds, internal power is applied to the entire IC and a check is made for an alarm input level except during LED pulse, Low Battery Alarm Chirp, or Horn Modulation (in alarm). Every 24 clock cycles a check is made for low battery by comparing V_{DD} to an internal zener voltage. Since very small currents are used in the oscillator, the oscillator capacitor should be of a low leakage type.

Detect Circuitry

If an alarm condition is detected, the oscillator period becomes 41.67 ms and the piezoelectric horn oscillator circuit is enabled. The horn output is modulated 167 ms on, 83 ms off. During the off time, alarm detect input (Pin 15) is again checked and will inhibit further horn output if no alarm condition is sensed. During alarm conditions the low battery chirp is inhibited, and the LED pulses at a 1.0 Hz rate.

An active guard is provided on a pin adjacent to the detect input (Pin 16). The voltage at this pin will be within 100 mV of the input signal. Pin 16 will allow monitoring of the input signal at pin 15 through a buffer. The active guard op amp is not power strobed and thus gives constant protection from surface leakage currents. Pin 15 (the Detect input) has internal diode protection against static damage.

Low Battery Threshold

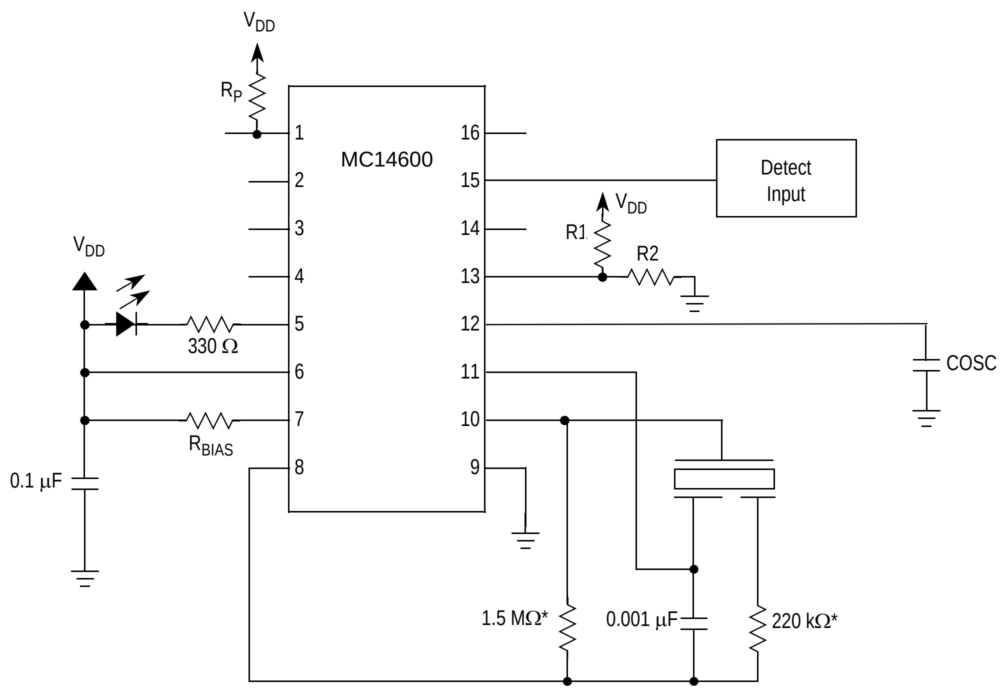
The low battery voltage level is set internally by a voltage divider connected between V_{DD} and V_{SS}. This voltage can be altered by external resistors connected from pin 3 to either V_{DD} or V_{SS}. A resistor to V_{DD} will decrease the threshold while a resistor to GND will increase it.

Alarm Threshold (Sensitivity)

The alarm condition voltage level is set externally through Pin 13. A voltage divider can be used to set the alarm trip point. Pin 13 is connected internally to the negative input of the detect comparator.

LED Pulse

The 9-volt battery level is checked every 40 seconds during the LED pulse. The battery is loaded via a 10 mA pulse for 10 ms. If the LED is not used, it should be replaced with an equivalent resistor so that the battery loading remains at 10 mA.



*Note: Component values may change depending on the type of piezoelectric horn used.

Figure 3. Typical Application Components

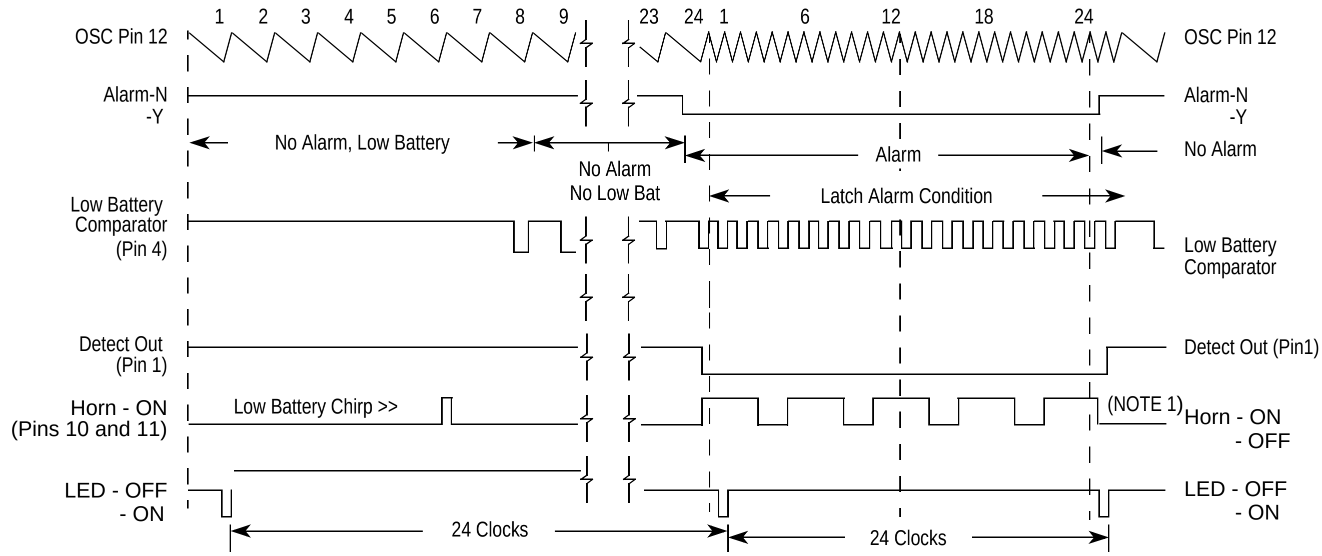


Figure 4. MC14600 Timing Diagram

NOTE:

1. Horn modulation is self-completing. When going from Alarm to No Alarm, the alarm condition will terminate only when horn is off.
2. Comparators are strobed once per cycle.
3. Low Battery comparator information is latched only during LED pulse.
4. Current source required into Pin 1.
5. Alarm Condition can initiate on any clock pulse except 1 and 7.

Photoelectric Smoke Detector IC with I/O

The CMOS MC145010 is an advanced smoke detector component containing sophisticated very-low-power analog and digital circuitry. The IC is used with an infrared photoelectric chamber. Detection is accomplished by sensing scattered light from minute smoke particles or other aerosols. When detection occurs, a pulsating alarm is sounded via on-chip push-pull drivers and an external piezoelectric transducer.

The variable-gain photo amplifier allows direct interface to IR detectors (photodiodes). Two external capacitors, C1 and C2, C1 being the larger, determine the gain settings. Low gain is selected by the IC during most of the standby state. Medium gain is selected during a local-smoke condition. High gain is used during push button test. During standby, the special monitor circuit which periodically checks for degraded chamber sensitivity uses high gain, also.

The I/O pin, in combination with V_{SS}, can be used to interconnect up to 40 units for common signaling. An on-chip current sink provides noise immunity when the I/O is an input. A local-smoke condition activates the short-circuit-protected I/O driver, thereby signaling remote smoke to the interconnected units. Additionally, the I/O pin can be used to activate escape lights, enable auxiliary or remote alarms, and/or initiate auto-dialers.

While in standby, the low-supply detection circuitry conducts periodic checks using a pulsed load current from the LED pin. The trip point is set using two external resistors. The supply for the MC145010 can be a 9 V battery.

A visible LED flash accompanying a pulsating audible alarm indicates a local-smoke condition. A pulsating audible alarm with no LED flash indicates a remote-smoke condition. A beep or chirp occurring virtually simultaneously with an LED flash indicates a low-supply condition. A beep occurring half-way between LED flashes indicates degraded chamber sensitivity. A low-supply condition does not affect the smoke detection capability if $V_{DD} \geq 6$ V. Therefore, the low-supply condition and degraded chamber sensitivity can be further distinguished by performing a push button (chamber) test.

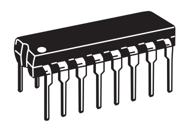
Features

- Circuit is designed to operate in smoke detector systems that comply with UL217 and UL268 Specifications
- Operating Voltage Range: 6 to 12 V
- Operating Temperature Range: - 10 to 60°C
- Average Supply Current: 12 μA
- Power-On Reset Places IC in Standby Mode (Non-Alarm State)
- Electrostatic Discharge (ESD) and Latch Up Protection Circuitry on All Pins
- Chip Complexity: 2000 FETs, 12 NPNs, 16 Resistors, and 10 Capacitors
- Ideal for battery powered applications.

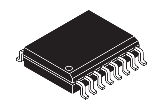
ORDERING INFORMATION			
Device	**Temp. Range**	**Case No.**	**Package**
MC145010P	-55 to +125°C	648-08	Plastic Dip
MC145010DW	-55 to +125°C	751G-04	SOIC

MC145010

PHOTOELECTRIC SMOKE DETECTOR IC WITH I/O



16-LEAD PLASTIC DIP CASE 648-08



16-LEAD SOIC CASE 751G-04

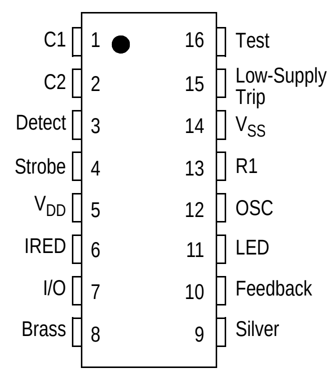


Figure 1. Pin Connections

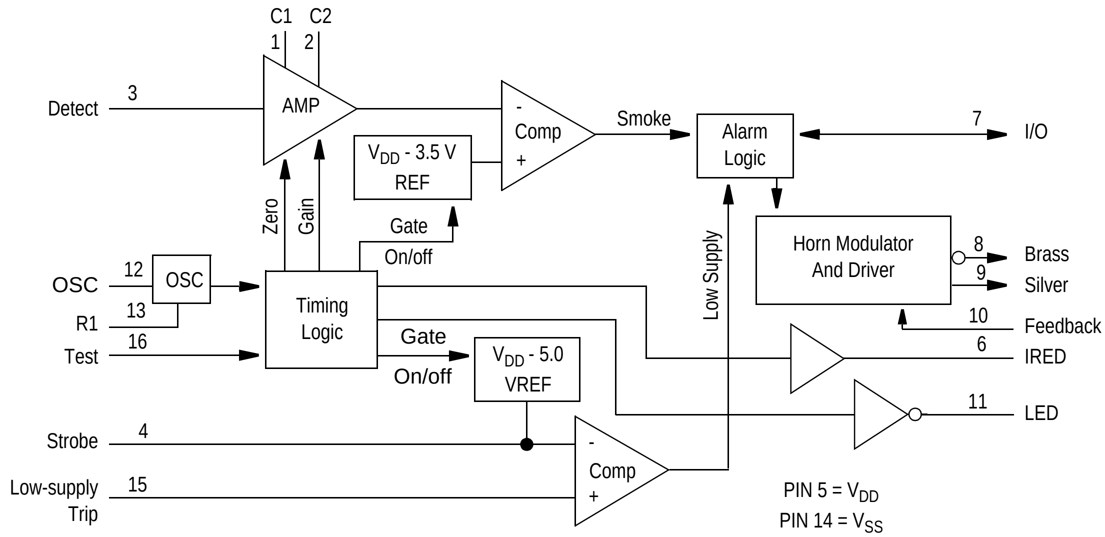


Figure 2. Block Diagram

Table 1. Maximum Ratings[1]
(Voltages referenced to V_{SS})

Rating	Symbol	Value	Unit
DC Supply Voltage	V_{DD}	-0.5 to +15	V
DC Input Voltage C1, C2, Detect OSC, Low-Supply Trip I/O Feedback Test	V_{IN}	 -0.25 to V_{DD} +0.25 -0.25 to V_{DD} +0.25 -0.25 to V_{DD} +10 -15 to +25 -1.0 to V_{DD} +0.25	V
DC Input Current per Pin	I_{IN}	±10	mA
DC Output Current per Pin	I_{OUT}	±25	mA
DC Supply Current, VDD and VSS Pins	I_{DD}	+25 / -150	mA
Power Dissipation in Still Air 5 Seconds Continuous	P_D	 1200[2] 350[3]	mW
Storage Temperature Range	T_{STG}	-55 to +125	°C
Lead Temperature, 1 mm From Case for 10 Seconds	T_L	5.0	°C

1. Maximum Ratings are those values beyond which damage to the device may occur. Functional operation should be restricted to the limits in the Electrical Characteristics tables.
2. Derating: -12 mW/°C from 25° to 60°C.
3. Derating -3.5 mW/°C from 25° to 60°C.
This device contains circuitry to protect the inputs against damage due to high static voltages or electric fields; however, it is advised normal precautions be taken to avoid application of any voltage higher than maximum rated voltages to this high impedance circuit. For proper operation, it is recommended V_{IN} and V_{OUT} be constrained to the range $V_{SS} \leq (V_{IN}$ or $V_{OUT}) \leq V_{DD}$.

Table 2. Electrical Characteristics
(T_A = -10 to 60°C unless otherwise indicated. Voltages referenced to V_{SS}.)

Characteristics	Symbol	V_{DD}/V_{DC}	Min	Typ	Max	Unit
Operating Voltage	V_{DD}	—	6.0	—	12.0	V
Supply Threshold voltage, Low-Supply Alarm Low-Supply Trip: VIN = VDD/3	V_{TH}	 —	 6.5	 —	 7.8	V
Average Operating Supply Current (per Package) Standby Configured per Figure 8	I_{DD}	12.0	—	—	12.0	µA
Peak Supply Current (per Package) During Strobe ON, IRED OFF Configured per Figure 8 During Strobe ON, IRED ON Configured per Figure 8	i_{DD}	 12.0 12.0	 — —	 — —	 2.0 3.0	mA
Low-Level Input Voltage I/O Feedback Test	V_{IL}	 9.0 9.0 9.0	 — — —	 — — —	 1.5 2.7 7.0	V
High-Level Input Voltage I/O Feedback Test	V_{IH}	 9.0 9.0 9.0	 3.2 6.3 8.5	 — — —	 — — —	V
Input Current OSC, Detect – V_{IN} = V_{SS} or V_{DD} Low-Supply Trip – V_{IN} = V_{SS} or V_{DD} Feedback – V_{IN} = V_{SS} or V_{DD}	I_{IN}	 12.0 12.0 12.0	 — — —	 — — —	 ±100 ±100 ±100	nA
Low -Level Input Current Test – V_{IN} = V_{SS} or V_{DD}	I_{IL}	12.0	—	—	-1.0	µA
Pull-Down Current Test – V_{IN} = V_{DD} I/O – No Local Smoke, V_{IN} = V_{DD} I/O – No Local Smoke, V_{IN} = 17 V	I_{IH}	 9.0 9.0 12.0	 0.5 25.0 —	 — — —	 10 100 140	µA
Low-Level Output Voltage LED – I_{OUT} = 10 mA Silver, Brass – I_{OUT} = 16 mA	V_{OL}	 6.5 6.5	 — —	 — —	 0.6 1.0	V
High-Level Output Voltage Silver, Brass – I_{OUT} = 16 mA	V_{OH}	 6.5	 5.5	 —	 —	V
Output Voltage (For Line Regulations, See Pin Descriptions) Strobe – Inactive, I_{OUT} = -1 µA Active, I_{OUT} = 100 µA to 500 µA (Load Regulation) IRED – Inactive, I_{OUT} = 1 µA Active, I_{OUT} = 6 µA (Load Regulation)	V_{OUT}	 — 9.0 — 9.0	 V_{DD} – 0.1 V_{DD} – 4.40 — 2.25[(1)]		 — V_{DD} – 5.30 0.1 3.75[1]	V
High-Level Output Current I/O – Local Smoke, V_{OUT} = 4.5 V I/O – Local Smoke, V_{OUT} = V_{SS} (Short Circuit Current)	I_{OH}	 6.5 12.0	 -4 —		 — -16	mA
Off-State Output Leakage Current LED – V_{OUT} = V_{SS} or V_{DD}	I_{OZ}	 12.0	 —	 —	 ±1.0	XA
Common Mode C1, C2, Detect, Voltage Range – Local Smoke, Push Button Test, or Chamber Sensitivity Test	V_{IC}	—	V_{DD} – 4	—	V_{DD} – 2	V
Smoke Comparator Internal Reference Voltage – Local Smoke, Push Button Test, or Chamber Sensitivity Test	V_{REF}	—	V_{DD} – 3.08	—	V_{DD} – 3.92	V

1. T_A = 25°C only.

Table 3. AC Electrical Characteristics

Reference Timing Diagram Figure 6 and Figure 7. (T_A = 25°C, V_{DD} = 9.0 V, Component values from Figure 8: R1 = 100.0 KΩ, C3 = 1500.0 pF, R2 = 10.0 MΩ.)

No.	Characteristics	Symbol	Clocks	Min	Max	Unit
1	Oscillator Period[(1)] Free-Running Sawtooth Measured at Pin 12	$1/f_{OSC}$	1	9.5	11.5	ms
 2 3 4	LED Pulse Period No Local Smoke, and No Remote Smoke Remote Smoke, but No Local Smoke Local Smoke or Push Button Test	t_{LED}	 4096 — 64	 38.9 — 0.60	 47.1 — 0.74	s
5	LED Pulse Width and Strobe Pulse Width	$t_{w(LED)}$, $t_{w(STB)}$	1	9.5	11.5	ms
 6 7 8	IRED Pulse Period Smoke Test Chamber Sensitivity Test without Local Smoke Push Button Test	t_{IRED}	 1024 4096 32	 9.67 38.9 0.302	 11.83 47.1 0.370	s
9	IRED Pulse Width	$t_{w(IRED)}$	T_f[1]	94	116	µs
10	IRED Rise Time IRED Fall Time	t_r t_f	— —	— —	30 200	µs
11	Silver and Brass Modulation Period Local or Remote Smoke	t_{MOD}	 —	 297	 363	ms
11 12	Silver and Brass Duty Cycle Local or Remote Smoke	t_{ON}/t_{MOD}	 —	 73	 77	%
13	Silver and Brass Chirp Pulse Period Low Supply or Degraded Chamber Sensitivity	t_{CH}	 4096	 38.9	 47.1	s
14	Silver and Brass Chirp Pulse Width Low Supply or Degraded Chamber Sensitivity	$tw_{(CH)}$	 1	 9.5	 11.5	ms
15	Rising Edge on I/O to Smoke Alarm Response Time Remote Smoke, No Local Smoke	t_{RR}	 —	 —	 800	ms
 16 17 18 19	Strobe Out Pulse Period Smoke Test Chamber Sensitivity Test without Local Smoke Low Supply Test without Local Smoke Push Button Test	t_{STB}	 1024 4096 4096 —	 9.67 38.9 38.9 0.302	 11.83 47.1 47.1 0.370	s

1. Oscillator Period T (= $T_r + T_f$) is determined by the external components R1, R2, and C3 where $T_r = (0.6931)\ R_2 \times C_3$ and $T_f = (0.6031)\ R_1 \times C_3$.
The other timing characteristics are some multiple of the oscillator timing shown in the table.

Table 4. Pin Description

Pin	Symbol	Description
1	C1	A capacitor connected to this pin, shown in Figure 8, determines the gain of the on-chip photo amplifier during push button test and chamber sensitivity test (high gain). The capacitor value is chosen such that the alarm is tripped from background reflections in the chamber during push button test. A_V ª 1 + (C1/10) where C1 is in pF. CAUTION: The value of the closed-loop gain should not exceed 10,000.
2	C2	A capacitor connected to this pin as shown in Figure 8 determines the gain of the on-chip photo amplifier except during push button or chamber sensitivity tests. $A_V \approx 1 + (C2/10)$ where C2 is in pF. This gain increases about 10% during the IRED pulse, after two consecutive local smoke detections. Resistor R14 must be installed in series with C2. $R14 \approx [1/(12\sqrt{C2)] - 680 \text{ where R14 is in ohms and C2 is in farads.}}$
3	DETECT	This input to the high-gain pulse amplifier is tied to the cathode of an external photodiodes. The photodiodes should have low capacitance and low dark leakage current. The diode must be shunted by a load resistor and is operated at zero bias. The Detect input must be ac/dc decoupled from all other signals, V_{DD}, and V_{SS}. Lead length and/or foil traces to this pin must be minimized, also. See Figure 9.
4	STROBE	This output provides a strobed, regulated voltage referenced to V_{DD}. The temperature coefficient of this voltage is ± 0.2%/°C maximum from - 10° to 60°C. The supply-voltage coefficient (line regulation) is ± 0.2%/V maximum from 6 to 12 V. Strobe is tied to external resistor string R8, R9, and R10.
5	V_{DD}	This pin is connected to the positive supply potential and may range from +6 to +12 V with respect to V_{SS}. CAUTION: In battery-powered applications, reverse-polarity protection must be provided externally.
6	IRED	This output provides pulsed base current for external NPN transistor Q1 used as the infrared emitter driver. Q1 must have $\beta \geq 100$. At 10 mA, the temperature coefficient of the output voltage is typically + 0.5%/°C from - 10° to 60°C. The supply-voltage coefficient (line regulation) is ± 0.2%/V maximum from 6 to 12 V. The IRED pulse width (active-high) is determined by external components R1 and C3. With a 100 kΩ/1500 pF combination, the nominal width is 105 µs. To minimize noise impact, IRED is not active when the visible LED and horn outputs are active. IRED is active near the end of Strobe pulses for Smoke Tests, Chamber Sensitivity Test, and Push button Test.
7	I/O	This pin can be used to connect up to 40 units together in a wired-OR configuration for common signaling. V_{SS} is used as the return. An on-chip current sink minimizes noise pick up during non-smoke conditions and eliminates the need for an external pull-down resistor to complete the wired-OR. Remote units at lower supply voltages do not draw excessive current from a sending unit at a higher supply voltage. I/O can also be used to activate escape lights, auxiliary alarms, remote alarms, and/or auto-dialers. As an input, this pin feeds a positive-edge-triggered flip-flop whose output is sampled nominally every 625 ms during standby (using the recommended component values). A local-smoke condition or the push button-test mode forces this current-limited output to source current. All input signals are ignored when I/O is sourcing current. I/O is disabled by the on-chip power-on reset to eliminate nuisance signaling during battery changes or system power-up. If unused, I/O must be left unconnected.
8	BRASS	This half of the push-pull driver output is connected to the metal support electrode of a piezoelectric audio transducer and to the horn-starting resistor. A continuous modulated tone from the transducer is a smoke alarm indicating either local or remote smoke. A short beep or chirp is a trouble alarm indicating a low supply or degraded chamber sensitivity.
9	SILVER	This half of the push-pull driver output is connected to the ceramic electrode of a piezoelectric transducer and to the horn-starting capacitor.
10	FEEDBACK	This input is connected to both the feedback electrode of a self-resonating piezoelectric transducer and the horn-starting resistor and capacitor through current-limiting resistor R4. If unused, this pin must be tied to V_{SS} or V_{DD}.
11	LED	This active-low open-drain output directly drives an external visible LED at the pulse rates indicated below. The pulse width is equal to the OSC period. The load for the low-supply test is applied by this output. This low-supply test is non-coincident with the smoke tests, chamber sensitivity test, push button test, or any alarm signals. The LED also provides a visual indication of the detector status as follows, assuming the component values shown in Figure 8: Standby (includes low-supply and chamber sensitivity tests) - Pulses every 43 seconds (nominal) Local Smoke - Pulses every 0.67 seconds (nominal) Remote Smoke - No pulses Push button Test - Pulses every 0.67 seconds (nominal)
12	OSC	This pin is used in conjunction with external resistor R2 (10 MΩ) to V_{DD} and external capacitor C3 (1500 pF) to V_{DD} to form an oscillator with a nominal period of 10.5 ms.
13	R1	This pin is used in conjunction with resistor R1 (100 kΩ) to pin 12 and C3 (1500 pF, see pin 12 description) to determine the IRED pulse width. With this RC combination, the nominal pulse width is 105 µs.
14	VSS	This pin is the negative supply potential and the return for the I/O pin. Pin 14 is usually tied to ground.
15	LOW-SUPPLY TRIP	This pin is connected to an external voltage which determines the low-supply alarm threshold. The trip voltage is obtained through a resistor divider connected between the V_{DD} and LED pins. The low-supply alarm threshold voltage (in volts) ≈ (5R7/R6) + 5 where R6 and R7 are in the same units.

Table 4. Pin Description (Continued)

Pin	Symbol	Description
16	TEST	This input has an on-chip pull-down device and is used to manually invoke a test mode. The *Push Button Test* mode is initiated by a high level at pin 16 (usually depression of a S.P.S.T. normally-open push button switch to V_{DD}). After one oscillator cycle, IRED pulses approximately every 336 ms, regardless of the presence of smoke. Additionally, the amplifier gain is increased by automatic selection of C1. Therefore, the background reflections in the smoke chamber may be interpreted as smoke, generating a simulated-smoke condition. After the second IRED pulse, a successful test activates the horn-driver and I/O circuits. The active I/O allows remote signaling for system testing. When the Push Button Test switch is released, the Test input returns to V_{SS} due to the on-chip pull-down device. After one oscillator cycle, the amplifier gain returns to normal, thereby removing the simulated-smoke condition. After two additional IRED pulses, less than a second, the IC exits the alarm mode and returns to standby timing.

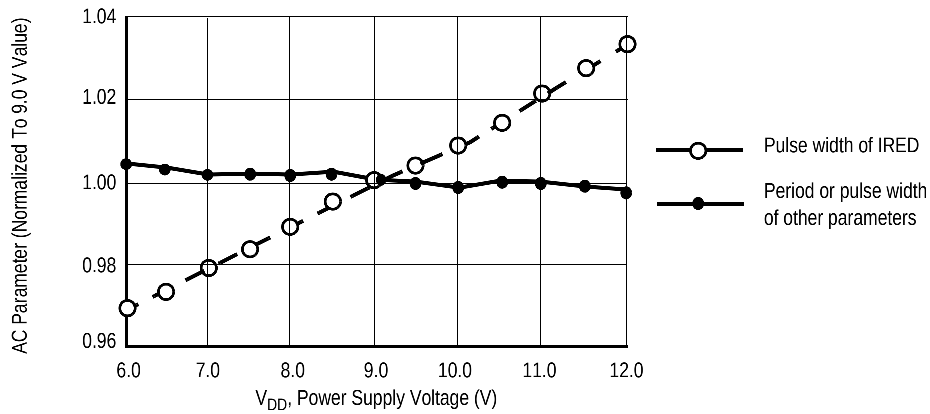


Figure 3. AC Characteristics vs. Supply

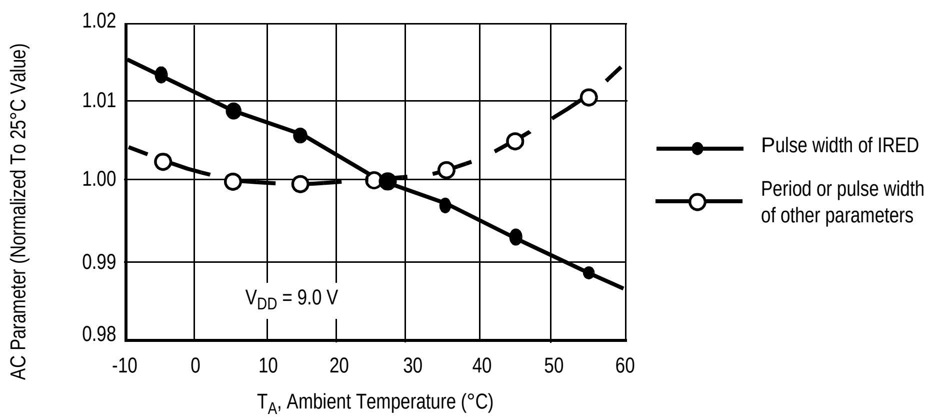
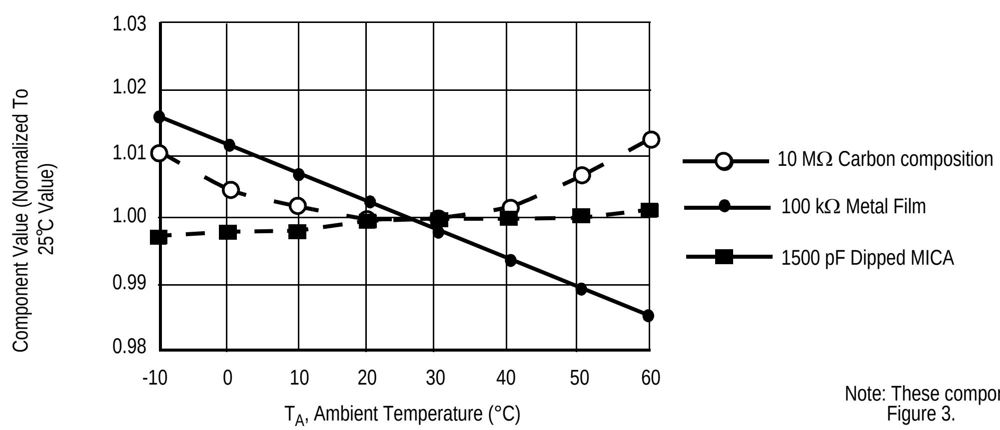


Figure 4. AC Characteristics vs. Temperature



Note: These components were used to generate Figure 3.

Figure 5. RC Component Variation Overtemperature

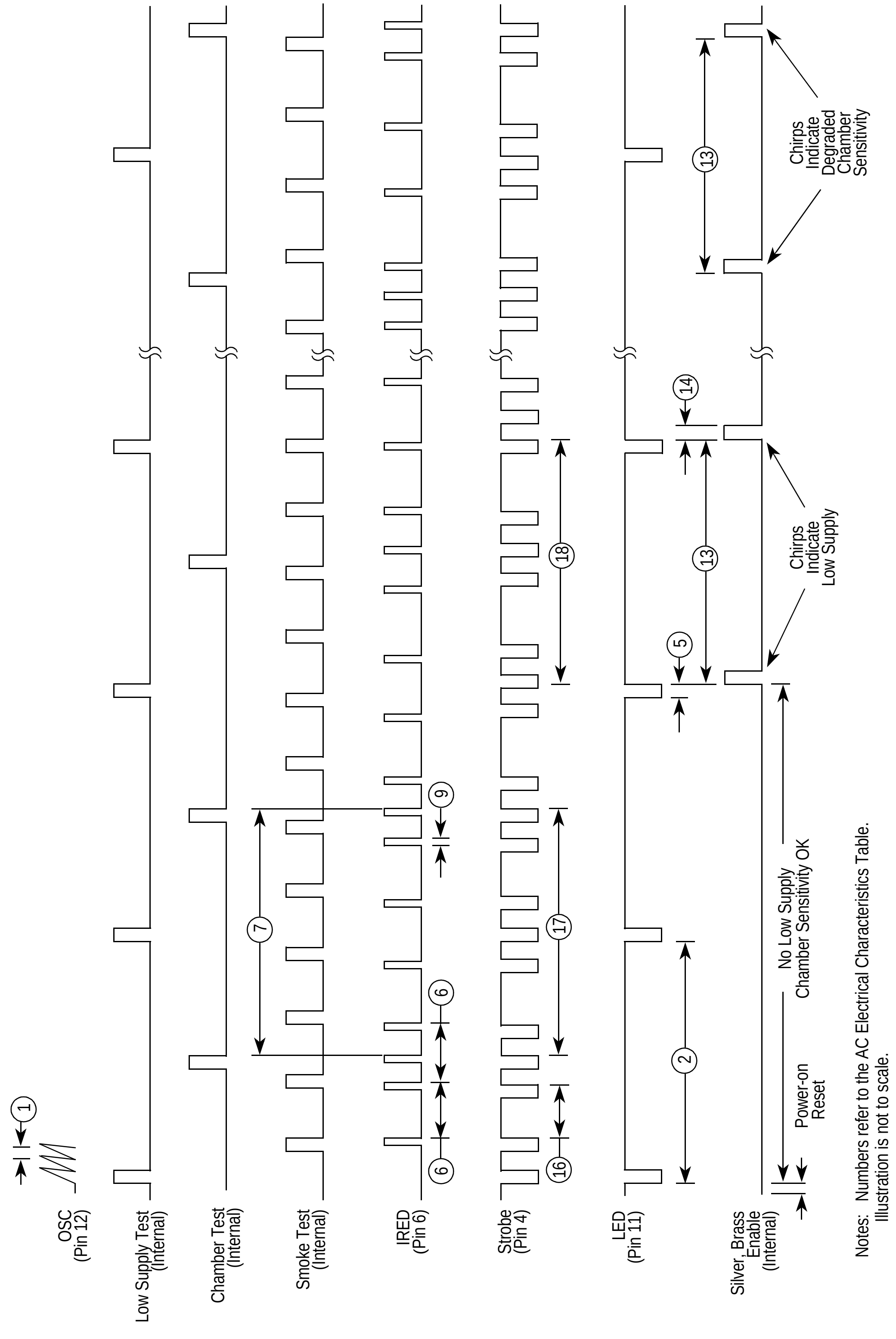


Figure 6. Standby Timing Diagram

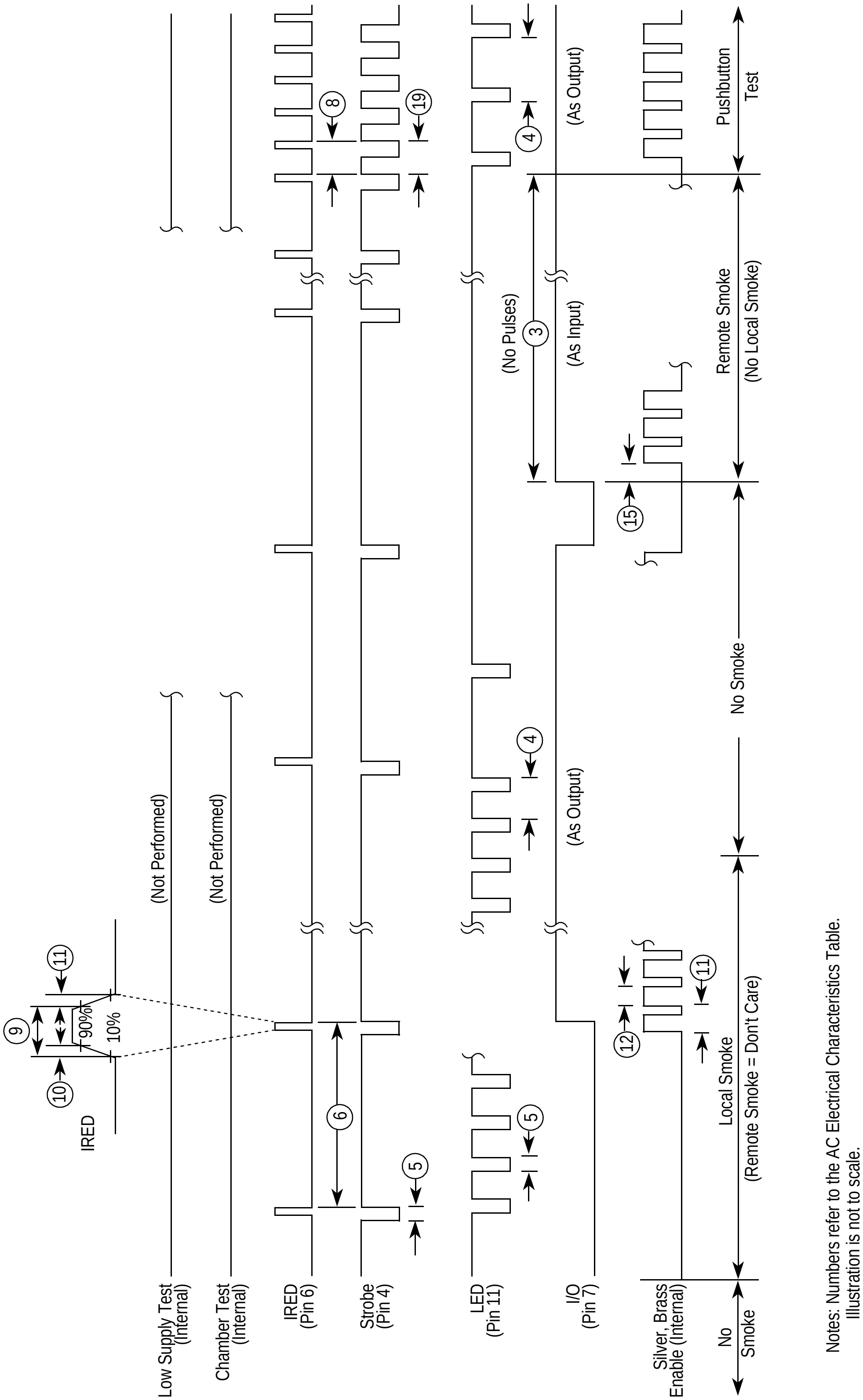
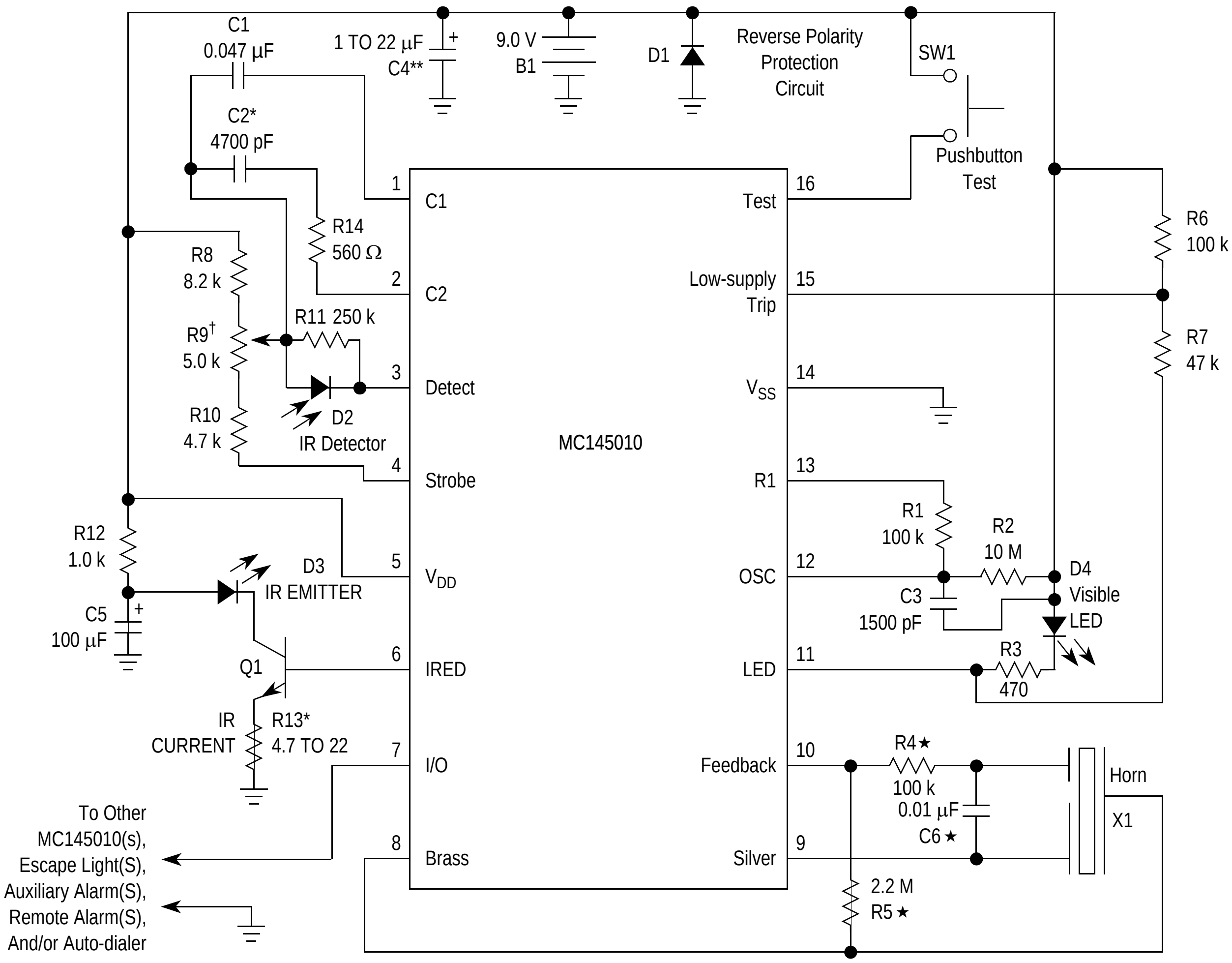


Figure 7. Smoke Timing Diagram



★Values for R4, R5, and C6 may differ depending on type of piezoelectric horn used.
* C2 and R13 are used for coarse sensitivity adjustment. Typical values are shown.
† R9 is for fine sensitivity adjustment (optional). If fixed resistors are used, R8 = 12 k, R10 is 5.6 k to 10 k, and R9 is eliminated. When R9 is used, noise pickup is increased due to antenna effects. Shielding may be required.
**C4 should be 22 µF if B1 is a carbon battery. C4 could be reduced to 1 µF when an alkaline battery is used.

Figure 8. Typical Battery-Powered Application

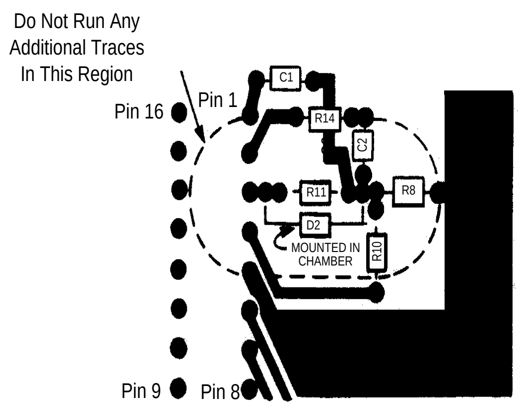
CALIBRATION

To facilitate checking the sensitivity and calibrating smoke detectors, the MC145010 can be placed in a calibration mode. In this mode, certain device pins are controlled/reconfigured as shown in Table 5. To place the part in the calibration mode, pin 16 (Test) must be pulled below the V_{SS} pin with 100 µA continuously drawn out of the pin for at least one cycle on the OSC pin. To exit this mode, the Test pin is floated for at least one OSC cycle.

In the calibration mode, the IRED pulse happens at every clock cycle and strobe is always on (active low). Also, Low Battery and supervisory tests are disabled in this mode.

Table 5. Configuration of Pins in the Calibration Mode

Description	Pin	Comment
I/O	7	Disabled as an output. Forcing this pin high places the photo amp output on pin 1 or 2, as determined by Low-Supply Trip. The amp's output appears as pulses and is referenced to V_{DD}.
Low-Supply Trip	15	If the I/O pin is high, pin 15 controls which gain capacitor is used. Low: normal gain, amp output on pin 1. High: supervisory gain, amp output on pin 2.
Feedback	10	Driving this input high enables hysteresis (10% gain increase) in the photo amp; pin 15 must be low.
OSC	12	Driving this input high brings the internal clock high. Driving the input low brings the internal clock low. If desired, the RC network for the oscillator may be left intact; this allows the oscillator to run similar to the normal mode of operation.
Silver	9	This pin becomes the smoke comparator output. When the OSC pin is toggling, positive pulses indicate that smoke has been detected. A static low level indicates no smoke.
Brass	8	This pin becomes the smoke integrator output. That is, two consecutive smoke detections are required for ON (static high level) and two consecutive no-detections for “off” (static low level).



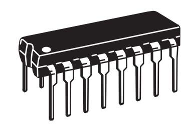
NOTES:
Illustration is bottom view of layout using a Dip. Top view for SOIC layout is mirror image. Optional potentionmeter R9 is not illustrated.
Drawing is not to scale.
Leads on D2, R11, R8, and R10 and their associated traces must be kept as short as possible. This practice minimizes noise pick-up.
Pin 3 must be decoupled from all other traces.

Figure 9. Recommended PCB Layout

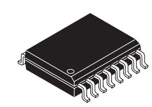
Photoelectric Smoke Detector IC with I/O For Line-Powered Applications

MC145011

PHOTOELECTRIC SMOKE DETECTOR IC WITH I/O FOR LINE-POWERED APPLICATIONS



P SUFFIX
PLASTIC DIP
CASE 648-08



DW SUFFIX
PLASTIC SOIC
CASE 751G-04

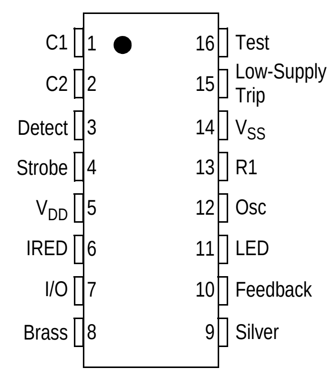


Figure 1. Pin Connections

The CMOS MC145011 is an advanced smoke detector component containing sophisticated very-low-power analog and digital circuitry. The IC is used with an infrared photoelectric chamber. Detection is accomplished by sensing scattered light from minute smoke particles or other aerosols. When detection occurs, a pulsating alarm is sounded via on-chip push-pull drivers and an external piezoelectric transducer.

The variable-gain photo amplifier allows direct interface to IR detectors (photo-diodes). Two external capacitors C1 and C2, C1 being the larger, determine the gain settings. Low gain is selected by the IC during most of the standby state. Medium gain is selected during a local-smoke condition. High gain is used during pushbutton test. During standby, the special monitor circuit which periodically checks for degraded chamber sensitivity uses high gain, also.

The I/O pin, in combination with V_{SS}, can be used to interconnect up to 40 units for common signaling. An on-chip current sink provides noise immunity when the I/O is an input. A local-smoke condition activates the short-circuit-protected I/O driver, thereby signaling remote smoke to the interconnected units. Additionally, the I/O pin can be used to activate escape lights, enable auxiliary or remote alarms, and/or initiate auto-dialers.

While in standby, the low-supply detection circuitry conducts periodic checks using a load current from the LED pin. The trip point is set using two external resistors. The supply for the MC145011 must be a dc power source capable of supplying 35 mA continuously and 45 mA peak. When the MC145011 is in standby, an external LED is continuously illuminated to indicate that the device is receiving power.

An extinguished LED accompanied by a pulsating audible alarm indicates a local-smoke condition. A pulsating audible alarm with the LED illuminated indicates a remote-smoke condition. A beep or chirp indicates a low-supply condition or degraded chamber sensitivity. A low-supply condition does not affect the smoke detection capability if $V_{DD} \geq 6$ V. Therefore, the low-supply condition and degraded chamber sensitivity can be distinguished by performing a pushbutton (chamber) test. This circuit is designed to operate in smoke detector systems that comply with UL217 and UL268 specifications.

Features

- Operating Voltage Range: 6 to 12 V
- Operating Temperature Range: -10 to 60°C
- Average Standby Supply Current (Visible LED Illuminated): 20 mA
- Power-On Reset Places IC in Standby Mode (Non-Alarm State)
- Electrostatic Discharge (ESD) and Latch Up Protection Circuitry on All Pins
- Chip Complexity: 2000 FETs, 12 NPNs, 16 Resistors, and 10 Capacitors

ORDERING INFORMATION	
Device	**Package**
MC145011P	Plastic Dip
MC145011DW	Soic Package

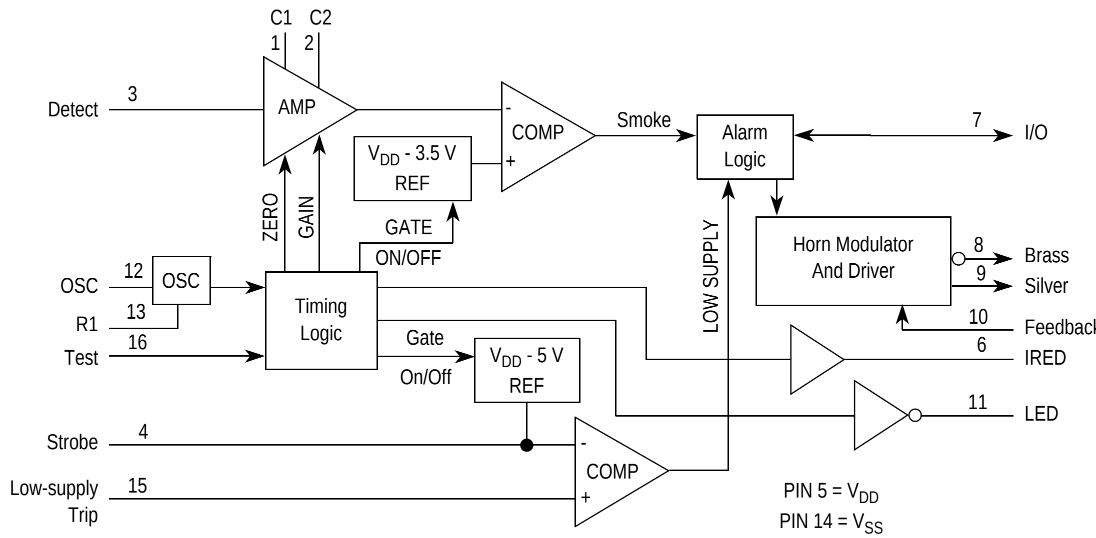


Figure 2. Block Diagram

Table 1. Maximum Ratings[1]
(Voltages referenced to V_{SS})

Parameter		Symbol	Value	Unit
DC Supply Voltage		V_{DD}	-0.5 to +12	V
DC Input Voltage	C1, C2, Detect Osc, Low-Supply Trip I/O Feedback Test	V_{in}	-0.25 to V_{DD} +0.25 -0.25 to V_{DD} +0.25 -0.25 to V_{DD} +10 -15 to +25 -1.0 to V_{DD} +0.25	V
DC Input Current, per Pin		I_{in}	±10	mA
DC Output Current, per Pin		I_{out}	±25	mA
DC Supply Current, V_{DD} and V_{SS} Pins		I_{DD}	+25 / -150	mA
Power Dissipation in Still Air	5 Seconds Continuous	P_D	1200[2] 350[3]	mW
Storage Temperature		T_{stg}	-55 to +125	°C
Lead Temperature, 1 mm from Case for 10 Seconds		T_L	260	°C

1. Maximum Ratings are those values beyond which damage to the device may occur. Functional operation should be restricted to the limits in the Electrical Characteristics tables.
2. Derating: -12 mW/°C from 25° to 60°C.
3. Derating: - 3.5 mW/°C from 25° to 60°C.

This device contains protection circuitry to guard against damage due to high static voltages or electric fields. However, precautions must be taken to avoid applications of any voltage higher than maximum rated voltages to this high-impedance circuit. For proper operation, V_{in} and V_{out} should be constrained to the range $V_{SS} \leq (V_{in}$ or $V_{out}) \leq V_{DD}$ except for the I/O, which can exceed V_{DD}, and the Test input, which can go below V_{SS}.

Unused inputs must always be tied to an appropriate logic voltage level (e.g., either V_{SS} or V_{DD}). Unused outputs and/or an unused I/O must be left open.

Table 2. Electrical Characteristics
(T_A = -10 to 60°C Unless Otherwise Indicated, Voltages Referenced to V_{SS})

Characteristic		Symbol	Test Condition	V_{DD}/V_{DC}	Min	Max	Unit
Power Supply Voltage Range		V_{DD}		—	6.0	12	V
Supply Threshold Voltage, Low-Supply Alarm		V_{TH}	Low-Supply Trip: $V_{in} = V_{DD}/3$	—	6.5	7.8	V
Average Operating Supply Current, Excluding the Visible LED Current (per Package)		I_{DD}	Standby Configured per Figure 8	12.0	—	12	µA
Peak Supply Current, Excluding the Visible LED Current (per Package)		i_{DD}	During Strobe On, IRED Off Configured per Figure 8	12.0	—	2.0	mA
			During Strobe On, IRED On Configured per Figure 8	12.0	—	3.0	
Low-Level Input Voltage	I/O Feedback Test	V_{IL}		9.0 9.0 9.0	— — —	1.5 2.7 7.0	V
High-Level Input Voltage	I/O Feedback Test	V_{IH}		9.0 9.0 9.0	3.2 6.3 8.5	— — —	V
Input Current	Osc, Detect Low-Supply Trip Feedback	I_{in}	$V_{in} = V_{SS}$ or V_{DD} $V_{in} = V_{SS}$ or V_{DD} $V_{in} = V_{SS}$ or V_{DD}	12.0 12.0 12.0	— — —	±100 ±100 ± 00	nA
Low-Level Input Current	Test	I_{IL}	$V_{in} = V_{SS}$	12.0	—	-1	µA
Pull-Down Current	Test I/O	I_{IH}	$V_{in} = V_{DD}$ No Local Smoke, $V_{in} = V_{DD}$ No Local Smoke, V_{in} = 17 V	9.0 9.0 12.0	0.5 25 —	10 100 140	µA
Low-Level Output Voltage	LED Silver, Brass	V_{OL}	I_{out} = 10 mA I_{out} = 16 mA	6.5 6.5	— —	0.6 1.0	V
High-Level Output Voltage	Silver, Brass	V_{OH}	I_{out} = -16 mA	6.5	5.5	—	V
Output Voltage (For Line Regulation, see Pin Descriptions)	Strobe	V_{out}	Inactive, I_{out} = -1 µA Active, I_{out} = 100 µA to 500 µA (Load Regulation)	— 9.0	V_{DD} - 0.1 V_{DD} - 4.4	— V_{DD} - 5.6	V
	IRED		Inactive, I_{out} = 1 µA Active, I_{out} = 6 mA (Load Regulation)	— 9.0	— 2.25(1)	0.1 3.75(1)	
High-Level Output Current	I/O	I_{OH}	Local Smoke, V_{out} = 4.5 V	6.5	-4	—	mA
			Local Smoke, $V_{out} = V_{SS}$ (Short Circuit Current)	12.0	—	-16	
Off-State Output Leakage Current	LED	I_{OZ}	$V_{out} = V_{SS}$ or V_{DD}	12.0	—	±1	µA
Common Mode Voltage Range	C1, C2, Detect	V_{IC}	Local Smoke, Pushbutton Test, or Chamber Sensitivity Test	—	V_{DD} - 4	V_{DD} - 2	V
Smoke Comparator Reference Voltage	Internal	V_{ref}	Local Smoke, Pushbutton Test, or Chamber Sensitivity Test	—	V_{DD} - 3.08	V_{DD} - 3.92	V

1. T_A = 25°C only.

Table 3. AC Electrical Characteristics
(Reference Timing Diagram Figure 6 and Figure 7) (T_A = 25°C, V_{DD} = 9.0 V, Component Values from Figure 8: R1 = 100.0 KΩ, C3 = 1500.0 pF, R2 = 10.0 MΩ)

No.	Characteristic	Symbol	Test Condition	Min	Max	Unit
1	Oscillator Period[(1)]	$1/f_{osc}$	Free-Running Sawtooth Measured at Pin 12	9.5	11.5	ms
2	LED Status	t_{LED}	No Local Smoke, and No Remote Smoke	Illuminated		
3			Remote Smoke, but No Local Smoke	Illuminated		
4			Local Smoke or Pushbutton Test	Extinguished		
5	Strobe Pulse Width	$t_{w(stb)}$		9.5	11.5	ms
6	IRED Pulse Period	t_{IRED}	Smoke Test	9.67	11.83	s
7			Chamber Sensitivity Test, without Local Smoke	38.9	47.1	
8			Pushbutton Test	0.302	0.370	
9	IRED Pulse Width	$t_{w(IRED)}$		94	116	µs
10	IRED Rise Time	t_r		—	30	µs
	IRED Fall Time	t_f		—	200	
11	Silver and Brass Modulation Period	t_{mod}	Local or Remote Smoke	297	363	ms
11, 12	Silver and Brass Duty Cycle	t_{on}/t_{mod}	Local or Remote Smoke	73	77	%
13	Silver and Brass Chirp Pulse Period	t_{CH}	Low Supply or Degraded Chamber Sensitivity	38.9	47.1	s
14	Silver and Brass Chirp Pulse Width	$t_{w(CH)}$	Low Supply or Degraded Chamber Sensitivity	9.5	11.5	ms
15	Rising Edge on I/O to Smoke Alarm Response Time	t_{RR}	Remote Smoke, No Local Smoke	—	800	ms
16	Strobe Pulse Period	t_{stb}	Smoke Test	9.67	11.83	s
17			Chamber Sensitivity Test, without Local Smoke	38.9	47.1	
18			Low Supply Test, without Local Smoke	38.9	47.1	
19			Pushbutton Test	0.302	0.370	

1. Oscillator period T (= $T_r + T_f$) is determined by the external components R1, R2, and C3 where T_r = (0.6931) R2 C3 and T_f = (0.6931) R1 C3. The other timing characteristics are some multiple of the oscillator timing as shown in the table.

Table 4. Pin Description

Pin No.	Pin Name	Description
1	C1	A capacitor connected to this pin as shown in Figure 8. determines the gain of the on-chip photo amplifier during pushbutton test and chamber sensitivity test (high gain). The capacitor value is chosen such that the alarm is tripped from background reflections in the chamber during pushbutton test. **$A_v \approx 1 + (C1/10)$ where C1 is in pF. CAUTION: The value of the closed-loop gain should not exceed 10,000.**
2	C2	A capacitor connected to this pin as shown in Figure 8. determines the gain of the on-chip photo amplifier except during pushbutton or chamber sensitivity tests. $A_v \approx 1 + (C2/10)$ where C2 is in pF. This gain increases about 10% during the IRED pulse, after two consecutive local smoke detections. Resistor R14 must be installed in series with C2. R14 ≈ $[1/(12\sqrt{C2})] - 680$ where R14 is in ohms and C2 is in farads.
3	DETECT	This input to the high-gain pulse amplifier is tied to the cathode of an external photodiode. The photodiode should have low capacitance and low dark leakage current. The diode must be shunted by a load resistor and is operated at zero bias. The Detect input must be ac/dc decoupled from all other signals, V_{DD}, and V_{SS}. Lead length and/or foil traces to this pin must be minimized, also. See Figure 9.

Table 4. Pin Description (Continued)

Pin No.	Pin Name	Description
4	STROBE	This output provides a strobed, regulated voltage referenced to V_{DD}. The temperature coefficient of this voltage is ± 0.2% °C maximum from - 10° to 60°C. The supply-voltage coefficient (line regulation) is ± 0.2%/V maximum from 6 to 12 V. Strobe is tied to external resistor string R8, R9, and R10.
5	VDD	This pin is connected to the positive supply potential and may range from + 6 to + 12 V with respect to V_{SS}.
6	IRED	This output provides pulsed base current for external NPN transistor Q1 used as the infrared emitter driver. Q1 must have $\beta \geq 100$. At 10 mA, the temperature coefficient of the output voltage is typically + 0.5%/°C from - 10° to 60°C. The supply-voltage coefficient (line regulation) is ± 0.2%/V maximum from 6 to 12 V. The IRED pulse width (active-high) is determined by external components R1 and C3. With a 100 kΩ/1500 pF combination, the nominal width is 105 µs. To minimize noise impact, IRED is not active when the visible LED and horn outputs are active. IRED is active near the end of Strobe pulses for Smoke Tests, Chamber Sensitivity Test, and Pushbutton Test.
7	I/O	This pin can be used to connect up to 40 units together in a wired-OR configuration for common signaling. V_{SS} is used as the return. An on-chip current sink minimizes noise pick up during non-smoke conditions and eliminates the need for an external pull-down resistor to complete the wired-OR. Remote units at lower supply voltages do not draw excessive current from a sending unit at a higher supply voltage. I/O can also be used to activate escape lights, auxiliary alarms, remote alarms, and/or auto-dialers. As an input, this pin feeds a positive-edge-triggered flip-flop whose output is sampled nominally every 625 ms during standby (using the recommended component values). A local-smoke condition or the pushbutton-test mode forces this current-limited output to source current. All input signals are ignored when I/O is sourcing current. If unused, I/O must be left unconnected.
8	BRASS	This half of the push-pull driver output is connected to the metal support electrode of a piezoelectric audio transducer and to the horn-starting resistor. A continuous modulated tone from the transducer is a smoke alarm indicating either local or remote smoke. A short beep or chirp is a trouble alarm indicating a low supply or degraded chamber sensitivity.
9	SILVER	This half of the push-pull driver output is connected to the ceramic electrode of a piezoelectric transducer and to the horn-starting capacitor.
10	FEEDBACK	This input is connected to both the feedback electrode of a self-resonating piezoelectric transducer and the horn-starting resistor and capacitor through current-limiting resistor R4. If unused, this pin must be tied to V_{SS} or V_{DD}.
11	LED	This active-low open-drain output directly drives an external visible LED. The load for the low-supply test is applied by this output. This low-supply test is non-coincident with the smoke tests, chamber sensitivity test, pushbutton test, or any alarm signals. The LED also provides a visual indication of the detector status as follows, assuming the component values shown in Figure 8: Standby (includes low-supply and chamber sensitivity tests) - constantly illuminated Local Smoke - constantly extinguished Remote Smoke - constantly illuminated Pushbutton Test - constantly extinguished (system OK); constantly illuminated (system problem)
12	OSC	This pin is used in conjunction with external resistor R2 (10 MΩ) to V_{DD} and external capacitor C3 (1500 pF) to V_{DD} to form an oscillator with a nominal period of 10.5 ms.
13	R1	This pin is used in conjunction with resistor R1 (100 kΩ) to pin 12 and C3 (1500 pF, see pin 12 description) to determine the IRED pulse width. With this RC combination, the nominal pulse width is 105 µs.
14	VSS	This pin is the negative supply potential and the return for the I/O pin. Pin 14 is usually tied to ground.
15	LOW-SUPPLY TRIP	This pin is connected to an external voltage which determines the low-supply alarm threshold. The trip voltage is obtained through a resistor divider connected between the V_{DD} and LED pins. The low-supply alarm threshold voltage (in volts) ≈ (5R7/R6) + 5 where R6 and R7 are in the same units.
16	TEST	This input has an on-chip pull-down device and is used to manually invoke a test mode. The *Pushbutton Test* mode is initiated by a high level at pin 16 (usually depression of a S.P.S.T. normally-open pushbutton switch to V_{DD}). After one oscillator cycle, IRED pulses approximately every 336 ms, regardless of the presence of smoke. Additionally, the amplifier gain is increased by automatic selection of C1. Therefore, the background reflections in the smoke chamber may be interpreted as smoke, generating a simulated-smoke condition. After the second IRED pulse, a successful test activates the horn-driver and I/O circuits. The active I/O allows remote signaling for system testing. When the Pushbutton Test switch is released, the Test input returns to V_{SS} due to the on-chip pull-down device. After one oscillator cycle, the amplifier gain returns to normal, thereby removing the simulated-smoke condition. After two additional IRED pulses, less than a second, the IC exits the alarm mode and returns to standby timing.

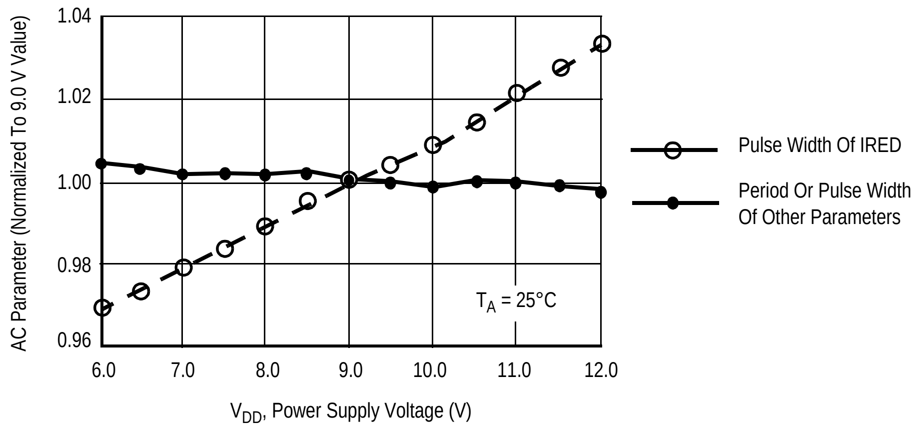
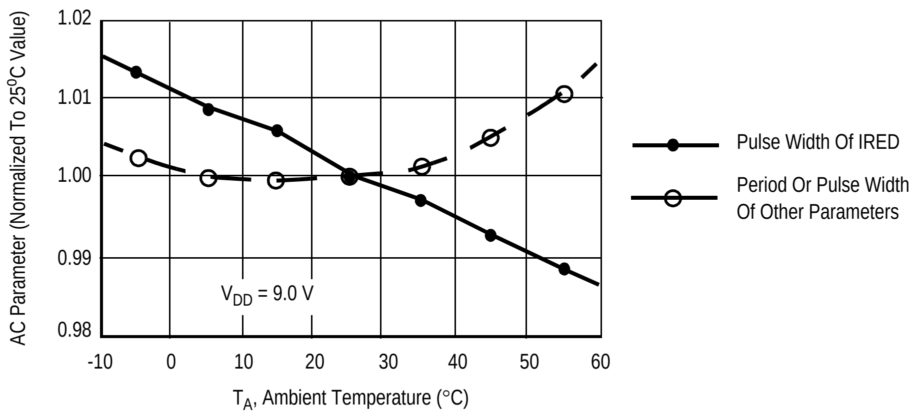
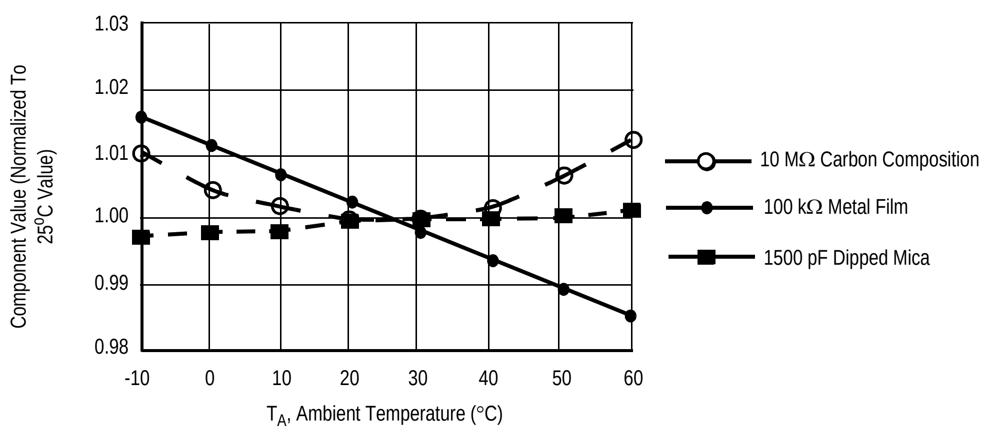


Figure 3. AC Characteristics versus Supply



NOTE: Includes external component variations. See Figure 5.

Figure 4. AC Characteristics versus Temperature



NOTE: These components were used to generate Figure 4.

Figure 5. RC Component Variation Over Temperature

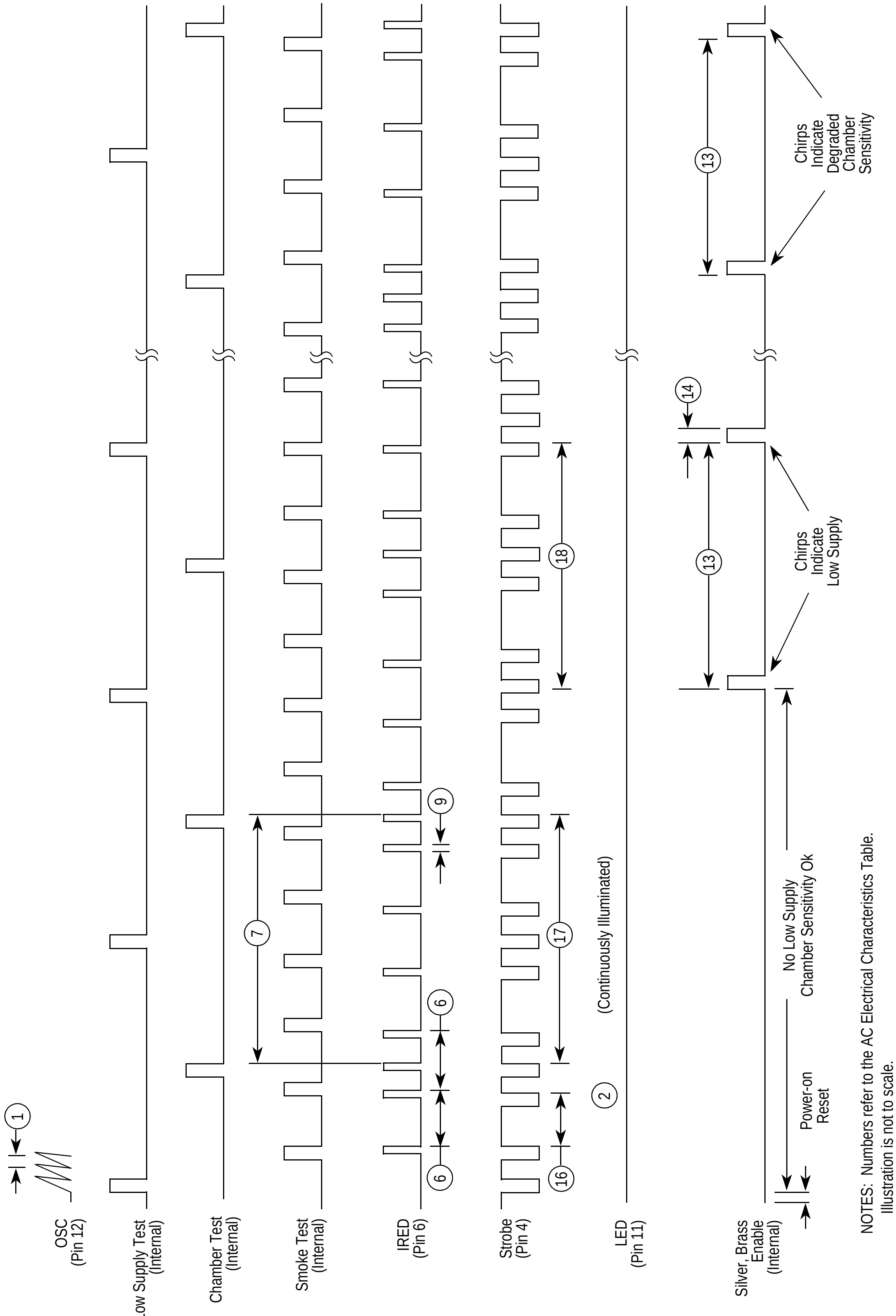


Figure 6. Standby Timing Diagram

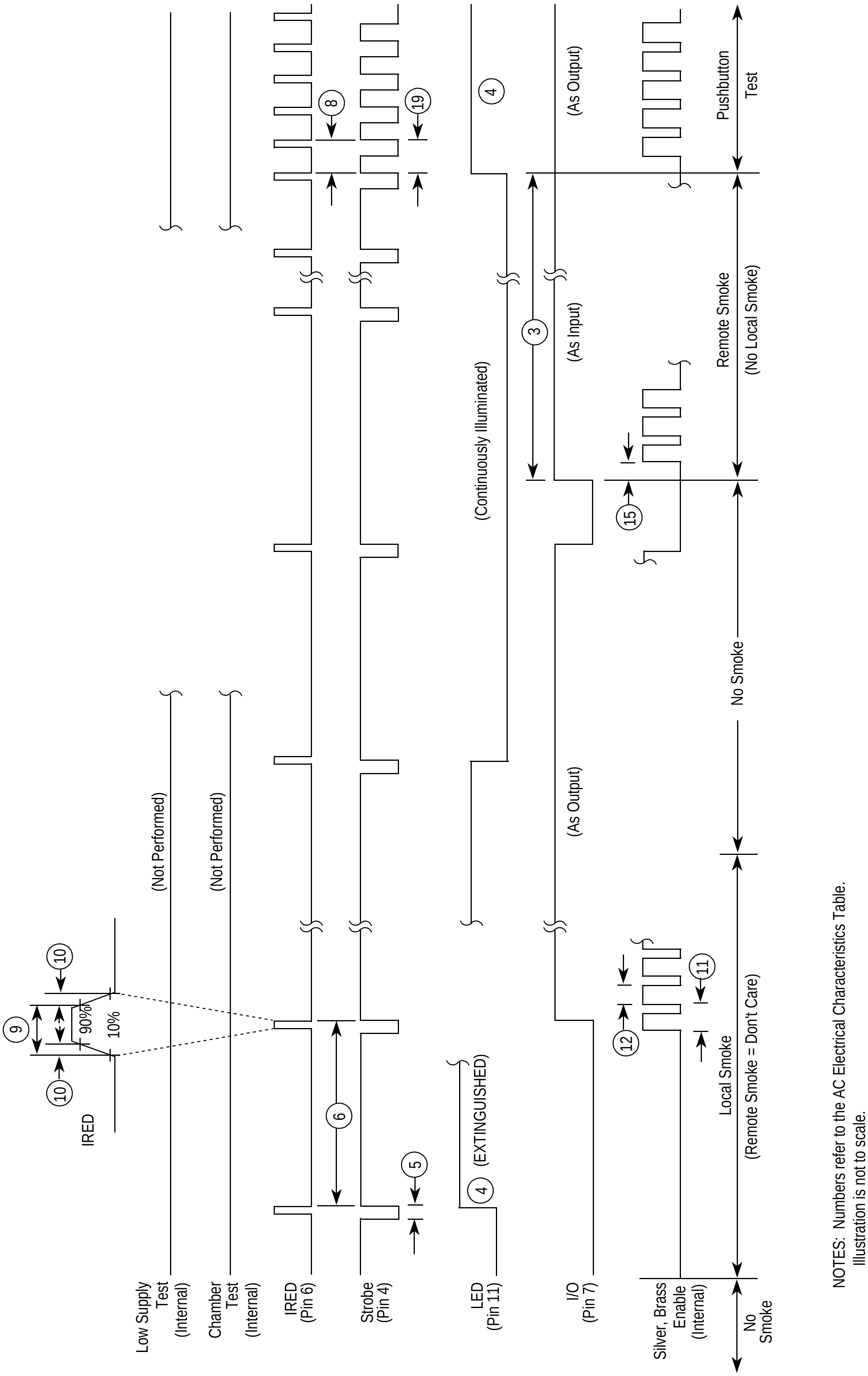
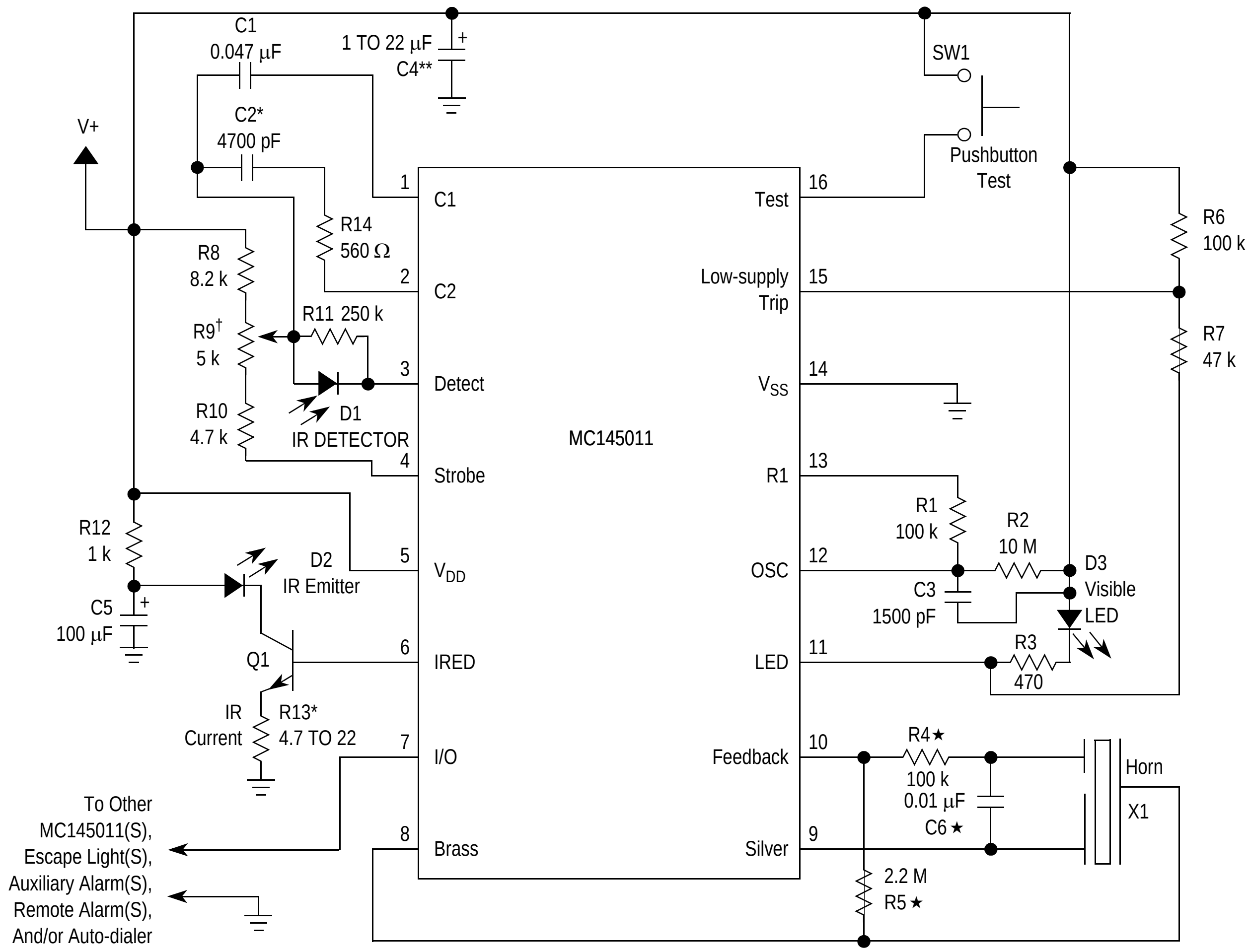


Figure 7. Smoke Timing Diagram



★ Values for R4, R5, and C6 may differ depending on type of piezoelectric horn used.

* C2 and R13 are used for coarse sensitivity adjustment. Typical values are shown.

† R9 is for fine sensitivity adjustment (optional). If fixed resistors are used, R8 = 12 k, R10 is 5.6 k to 10 k, and R9 is eliminated. When R9 is used, noise pickup is increased due to antenna effects. Shielding may be required.

** C4 should be 22 μF if B1 is a carbon battery. C4 could be reduced to 1 μF when an alkaline battery is used.

Figure 8. Typical Application

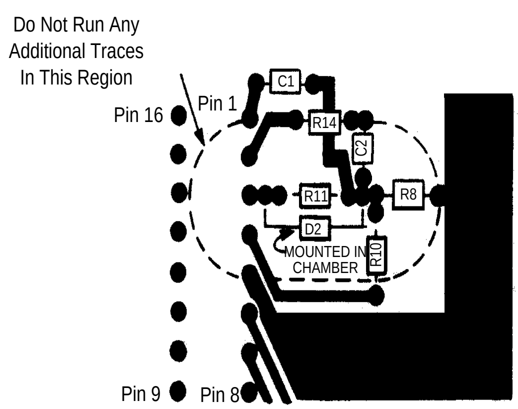
CALIBRATION

To facilitate checking the sensitivity and calibrating smoke detectors, the MC145011 can be placed in a calibration mode. In this mode, certain device pins are controlled/ reconfigured as shown in Table 5. To place the part in the calibration mode, Pin 16 (Test) must be pulled below the V_{SS} pin with 100 μA continuously drawn out of the pin for at least one cycle on the OSC pin. To exit this mode, the Test pin is floated for at least one OSC cycle.

In the calibration mode, the IRED pulse rate is increased to one for every OSC cycle. Also, Strobe is always active low.

Table 5. Configuration of Pins in the Calibration Mode

Pin	Description	Comment
7	I/O	Disabled as an output. Forcing this pin high places the photo amp output on pin 1 or 2, as determined by Low-Supply Trip. The amp's output appears as pulses and is referenced to V_{DD}.
15	Low-Supply Trip	If the I/O pin is high, pin 15 controls which gain capacitor is used. Low: normal gain, amp output on pin 1. High: supervisory gain, amp output on pin 2.
10	Feedback	Driving this input high enables hysteresis (10% gain increase) in the photo amp; pin 15 must be low.
12	Osc	Driving this input high brings the internal clock high. Driving the input low brings the internal clock low. If desired, the RC network for the oscillator may be left intact; this allows the oscillator to run similar to the normal mode of operation.
9	Silver	This pin becomes the smoke comparator output. When the OSC pin is toggling, positive pulses indicate that smoke has been detected. A static low level indicates no smoke.
8	Brass	This pin becomes the smoke integrator output. That is, 2 consecutive smoke detections are required for “on” (static high level) and 2 consecutive no-detections for “off” (static low level).



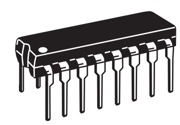
NOTES: Illustration is bottom view of layout using a DIP. Top view for SOIC layout is mirror image.
Optional potentiometer R9 is not included.
Drawing is not to scale.
Leads on D1, R11, R8, and R10 and their associated traces must be kept as short as possible. This practice minimizes noise pick up.
Pin 3 must be decoupled from all other traces.

Figure 9. Recommended PCB Layout

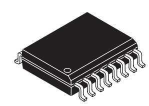
Photoelectric Smoke Detector IC with I/O and Temporal Pattern Horn Driver

MC145012

PHOTOELECTRIC SMOKE DETECTOR IC WITH I/O AND TEMPORAL PATTERN HORN DRIVER



P SUFFIX
PLASTIC DIP
CASE 648-08



DW SUFFIX
SOIC PACKAGE
CASE 751G-04

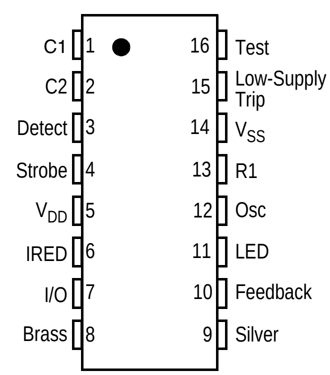


Figure 1. Pin Connections

The CMOS MC145012 is an advanced smoke detector component containing sophisticated very-low-power analog and digital circuitry. The IC is used with an infrared photoelectric chamber. Detection is accomplished by sensing scattered light from minute smoke particles or other aerosols. When detection occurs, a pulsating alarm is sounded via on-chip push-pull drivers and an external piezoelectric transducer.

The variable-gain photo amplifier allows direct interface to IR detectors (photodiodes). Two external capacitors, C1 and C2, C1 being the larger, determine the gain settings. Low gain is selected by the IC during most of the standby state. Medium gain is selected during a local-smoke condition. High gain is used during push-button test. During standby, the special monitor circuit which periodically checks for degraded chamber sensitivity uses high gain also.

The I/O pin, in combination with V_{SS}, can be used to interconnect up to 40 units for common signaling. An on-chip current sink provides noise immunity when the I/O is an input. A local-smoke condition activates the short-circuit-protected I/O driver, thereby signaling remote smoke to the interconnected units. Additionally, the I/O pin can be used to activate escape lights, enable auxiliary or remote alarms, and/or initiate auto-dialers.

While in standby, the low-supply detection circuitry conducts periodic checks using a pulsed load current from the LED pin. The trip point is set using two external resistors. The supply for the MC145012 can be a 9.0 V battery.

A visible LED flash accompanying a pulsating audible alarm indicates a local-smoke condition. A pulsating audible alarm with no LED flash indicates a remote-smoke condition. A beep or chirp occurring virtually simultaneously with an LED flash indicates a low-supply condition. A beep or chirp occurring halfway between LED flashes indicates degraded chamber sensitivity. A low-supply condition does not affect the smoke detection capability if $V_{DD} \geq 6.0$ V. Therefore, the low-supply condition and degraded chamber sensitivity can be further distinguished by performing a push-button (chamber) test.

Features

- Circuit is designed to operate in smoke detector systems that comply with UL217 and UL268 Specifications
- Operating Voltage Range: 6.0 V to 12 V
- Operating Temperature Range: - 10 to 60°C
- Average Supply Current: 8 μA
- I/O Pin Allows Units to be Interconnected for Common Signalling
- Power-On Reset Places IC in Standby Mode (Non-Alarm State)
- Electrostatic Discharge (ESD) and Latch Up Protection Circuitry on All Pins
- Chip Complexity: 2000 FETs, 12 NPNs, 16 Resistors, and 10 Capacitors
- Supports NFPA 72, ANSI S3.41, and ISO 8201 Audible Emergency Evacuation Signals
- Ideal for battery-powered applications

ORDERING INFORMATION	
Device	**Package**
MC145012P	PLASTIC DIP
MC145012DW	SOIC

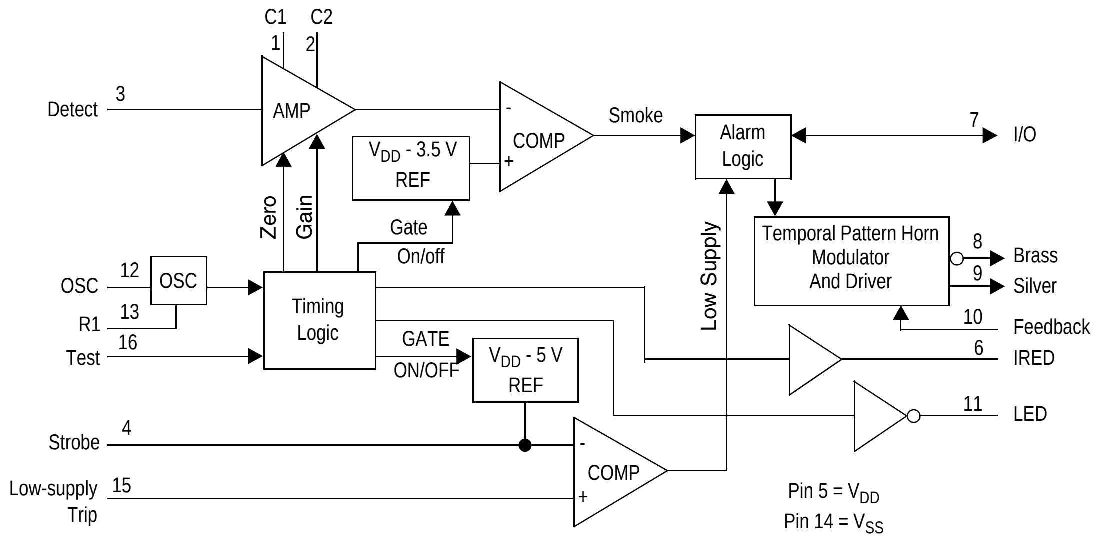


Figure 2. Block Diagram

Table 1. Maximum ratings(1)

(Voltages referenced to V_{SS})

Rating	Symbol	Value	Unit
DC Supply Voltage	V_{DD}	-0.5 to +12	V
DC Input Voltage C1, C2, Detect Osc, Low-Supply Trip I/O Feedback Test	V_{in}	 -0.25 to V_{DD} +0.25 -0.25 to V_{DD} +0.25 -0.25 to V_{DD} +10 -15 to +25 -1.0 to V_{DD} +0.25	V
DC Input Current, per Pin	I_{in}	±10	mA
DC Output Current, per Pin	I_{out}	±25	mA
DC Supply Current, V_{DD} and V_{SS} Pins	I_{DD}	+25 / -150	mA
Power Dissipation in Still Air 5 Seconds Continuous	P_D	 1200(2) 350(3)	mW
Storage Temperature	T_{stg}	-55 to +125	°C
Lead Temperature, 1 mm from Case for 10 Seconds	T_L	260	°C

1. Maximum Ratings are those values beyond which damage to the device may occur. Functional operation should be restricted to the limits in the Electrical Characteristics tables.
2. Derating: -12 mW/°C from 25° to 60°C.
3. Derating: -3.5 mW/°C from 25° to 60°C.

This device contains protection circuitry to guard against damage due to high static voltages or electric fields. However, precautions must be taken to avoid applications of any voltage higher than maximum rated voltages to this high-impedance circuit. For proper operation, V_{in} and V_{out} should be constrained to the range $V_{SS} \le (V_{in}$ or $V_{out}) \le V_{DD}$ except for the I/O, which can exceed V_{DD}, and the Test input, which can go below V_{SS}.

Unused inputs must always be tied to an appropriate logic voltage level (e.g., either V_{SS} or V_{DD}). Unused outputs and/or an unused I/O must be left open.

Table 2. Electrical Characteristics
(Voltages Referenced to V_{SS}, T_A = - 10 to 60°C Unless Otherwise Indicated).

Characteristic		Symbol	Test Condition	V_{DD} V	Min	Max	Unit
Power Supply Voltage Range		V_{DD}		—	6.0	12	V
Supply Threshold Voltage, Low-Supply Alarm		V_{TH}	Low-Supply Trip: $V_{in} = V_{DD}/3$	—	6.5	7.8	V
Average Operating Supply Current (per Package) (Does Not Include Current through D3-IR Emitter)		I_{DD}	Standby Configured per Figure 8	12.0	—	8.0	µA
Peak Supply Current (per Package) (Does Not Include IRED Current into Base of Q1)		i_{DD}	During Strobe On, IRED Off Configured per Figure 8	12.0	—	2.0	mA
			During Strobe On, IRED On Configured per Figure 8	12.0	—	3.0	
Low-Level Input Voltage	I/O Feedback Test	V_{IL}		9.0 9.0 9.0	— — —	1.5 2.7 7.0	V
High-Level Input Voltage	I/O Feedback Test	V_{IH}		9.0 9.0 9.0	3.2 6.3 8.5	— — —	V
Input Current	OSC, Detect Low-Supply Trip Feedback	I_{in}	$V_{in} = V_{SS}$ or V_{DD} $V_{in} = V_{SS}$ or V_{DD} $V_{in} = V_{SS}$ or V_{DD}	12.0 12.0 12.0	— — —	± 100 ± 100 ± 100	nA
Low-Level Input Current	Test	I_{IL}	$V_{in} = V_{SS}$	12.0	- 100	- 1.0	µA
Pull-Down Current	Test I/O	I_{IH}	$V_{in} = V_{DD}$ No Local Smoke, $V_{in} = V_{DD}$ No Local Smoke, V_{in} = 17 V	9.0 9.0 12.0	0.5 25 —	10 100 140	µA
Low-Level Output Voltage	LED Silver, Brass	V_{OL}	I_{out} = 10 mA I_{out} = 16 mA	6.5 6.5	— —	0.6 1.0	V
High-Level Output Voltage	Silver, Brass	V_{OH}	I_{out} = - 16 mA	6.5	5.5	—	V
Output Voltage (For Line Regulation, See Pin Descriptions)	Strobe	V_{out}	Inactive, I_{out} = 1 µA Active, I_{out} = 100 µA to 500 µA (Load Regulation)	— 9.0	V_{DD} - 0.1 V_{DD} - 4.40	— V_{DD} - 5.30	V
	IRED		Inactive, I_{out} = 1 µA Active, I_{out} = 6 mA (Load Regulation)	— 9.0	— 2.25[(1)]	0.1 3.75[(1)]	
High-Level Output Current	I/O	I_{OH}	Local Smoke, V_{out} = 4.5 V	6.5	-4.0	—	mA
			Local Smoke, $V_{out} = V_{SS}$ (Short Circuit Current)	12.0	—	-16	
Off-State Output Leakage Current	LED	I_{OZ}	$V_{out} = V_{SS}$ or V_{DD}	12.0	—	±1.0	µA
Common Mode Voltage Range	C1, C2, Detect	V_{IC}	Local Smoke, Push-button Test, or Chamber Sensitivity Test	—	V_{DD} - 4.0	V_{DD} - 2.0	V
Smoke Comparator Reference Voltage	Internal	V_{ref}	Local Smoke, Push-button Test, or Chamber Sensitivity Test	—	V_{DD} - 3.08	V_{DD} - 3.92	V

1. T_A = 25°C only.

Table 3. AC Electrical Characteristics
(Reference Timing Diagram Figure 6 and Figure 7)
(T_A = 25°C, V_{DD} = 9.0 V, Component Values from Figure 8: R1 = 100.0 KΩ, C3 = 1500.0 pF, R2 = 7.5 MΩ).

No.	Parameter	Symbol	Test Condition	Clocks	Min(1)	Typ(2)	Max(1)	Unit
1	Oscillator Period	$1/f_{osc}$	Free-Running Sawtooth Measured at Pin 12	1.0	7.0	7.9	8.6	ms
2	LED Pulse Period	t_{LED}	No Local Smoke, and No Remote Smoke	4096	28.8	32.4	35.2	s
3			Remote Smoke, but No Local Smoke	—	Extinguished			
4			Local Smoke	64	0.45	—	—	
5			Push-button Test	64	0.45	—	—	
6	LED Pulse Width and Strobe Pulse Width	$t_{w(LED)}$, $t_{w(stb)}$		1.0	7.0	—	8.6	ms
7	IRED Pulse Period	t_{IRED}	Smoke Test	1024	7.2	8.1	8.8	s
8	IRED Pulse Period	t_{IRED}	Chamber Sensitivity Test, without Local Smoke	4096	28.8	32.4	35.2	s
9			Push-button Test	128	0.9	1.0	1.1	
10	IRED Pulse Width	$t_{w(IRED)}$		T_f*	94	—	116	µs
11	IRED Rise Time	t_r		—	—	—	30	
12	IRED Fall Time	t_f		—	—	—	200	µs
13	Silver and Brass Temporal Modulation Pulse Width	t_{on}		64	0.45	0.5	0.55	s
14		t_{off}			0.45	0.5	0.55	
15		t_{offd}		192	1.35	1.52	1.65	
16	Silver and Brass Chirp Pulse Period	t_{CH}	Low Supply or Degraded Chamber Sensitivity	4096	28.8	32.4	35.2	s
17	Silver and Brass Chirp Pulse Width	t_{wCH}		1	7.0	7.9	8.6	ms
18	Rising Edge on I/O to Smoke Alarm Response Time	t_{RR}	Remote Smoke, No Local Smoke	—	—	2.0(3)	—	s
19	Strobe Out Pulse Period	t_{stb}	Smoke Test	1024	7.2	8.1	8.8	s
20			Chamber Sensitivity Test, without Local Smoke	4096	28.8	32.4	35.2	
21			Low Supply Test, without Local Smoke	4096	28.8	32.4	35.2	
22			Push-button Test	—	—	1.0	—	

1. Oscillator period T (= T_r + T_f) is determined by the external components R1, R2, and C3 where T_r = (0.6931) R_2 C_3 and T_f = (0.6931) R_1 * C_3. The other timing characteristics are some multiple of the oscillator timing as shown in the table. The timing shown should accommodate the NFPA 72, ANSI S3.41, and ISO 8201 audible emergency evacuation signals.
2. Typicals are not guaranteed.
3. Time is typical - depends on what point in cycle signal is applied.

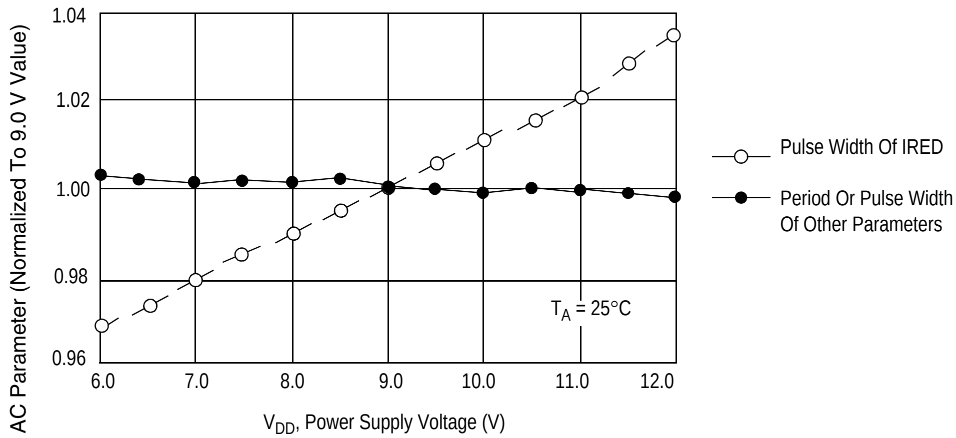
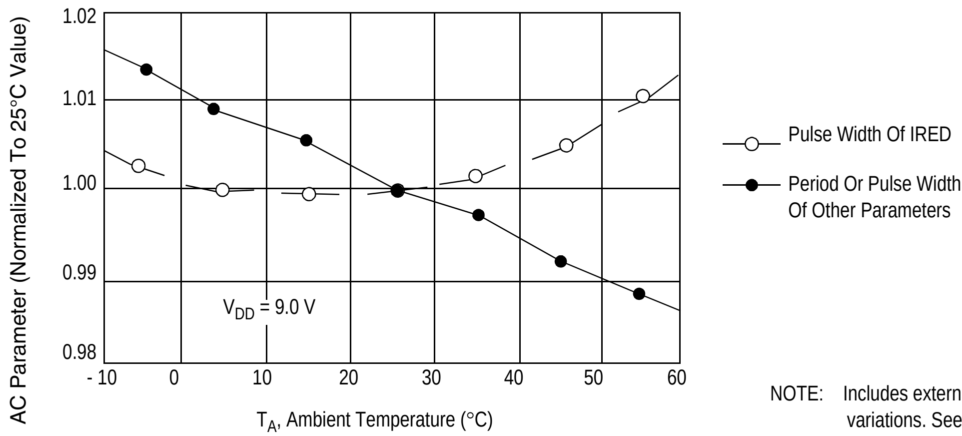
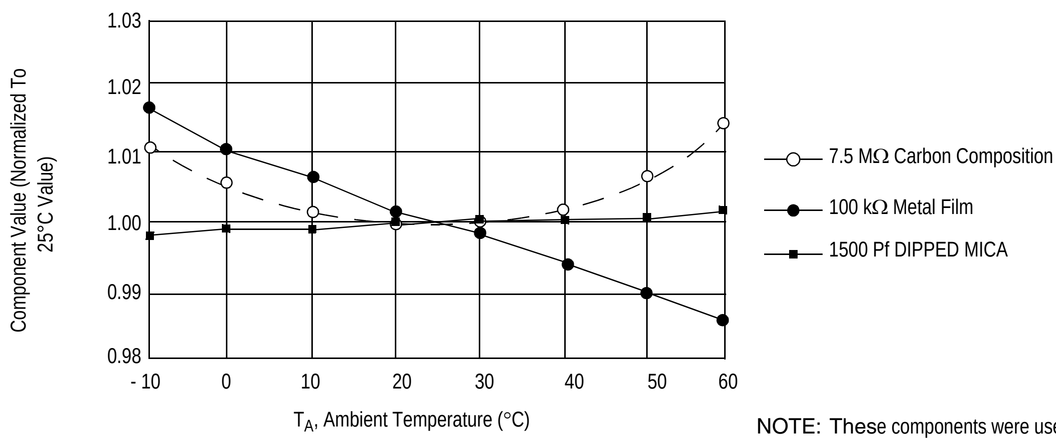


Figure 3. AC Characteristics versus Supply



NOTE: Includes external component variations. See Figure 5.

Figure 4. AC Characteristics versus Temperature



NOTE: These components were used to generate Figure 4.

Figure 5. RC Component Variation Over Temperature

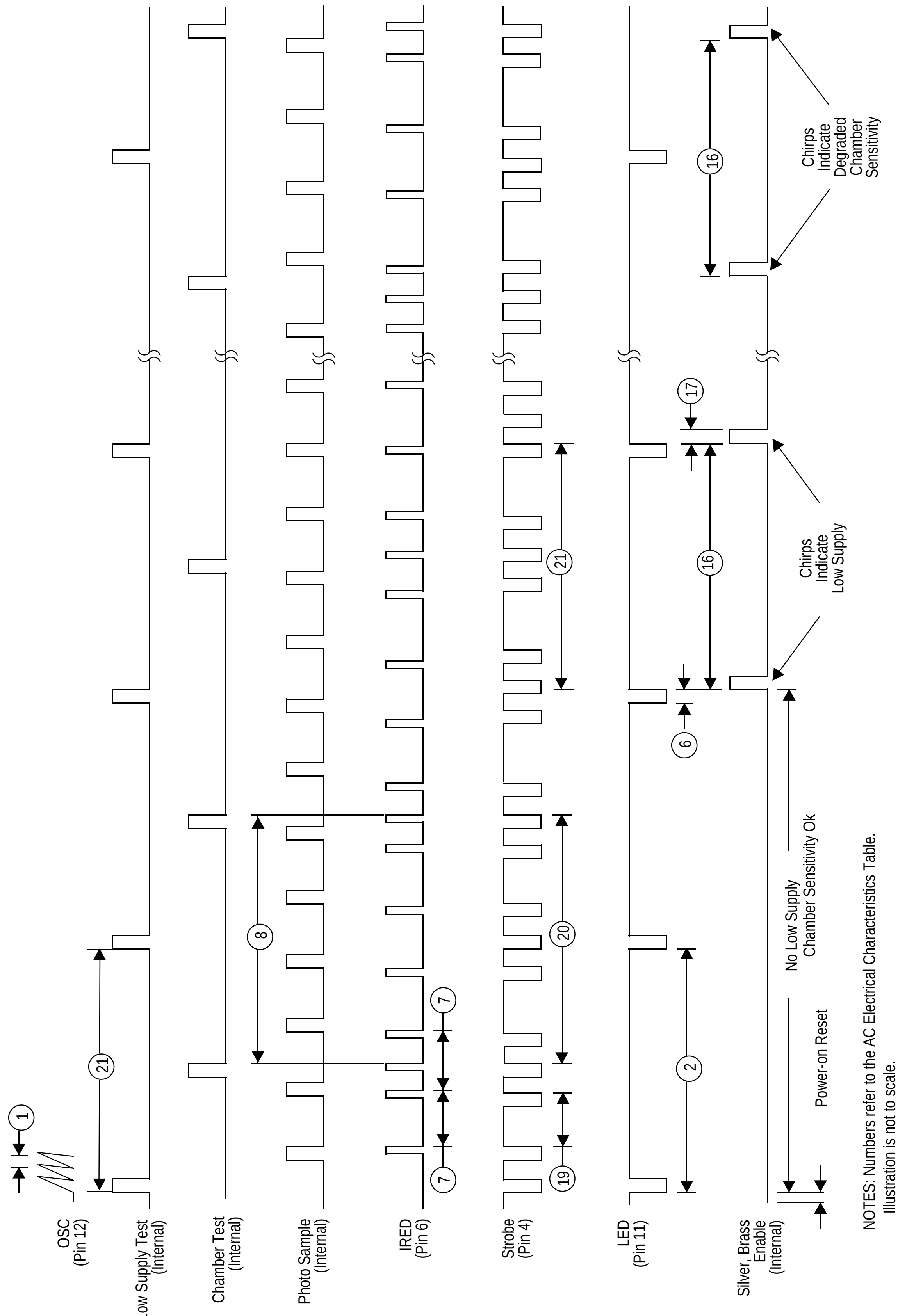


Figure 6. Typical Standby Timing

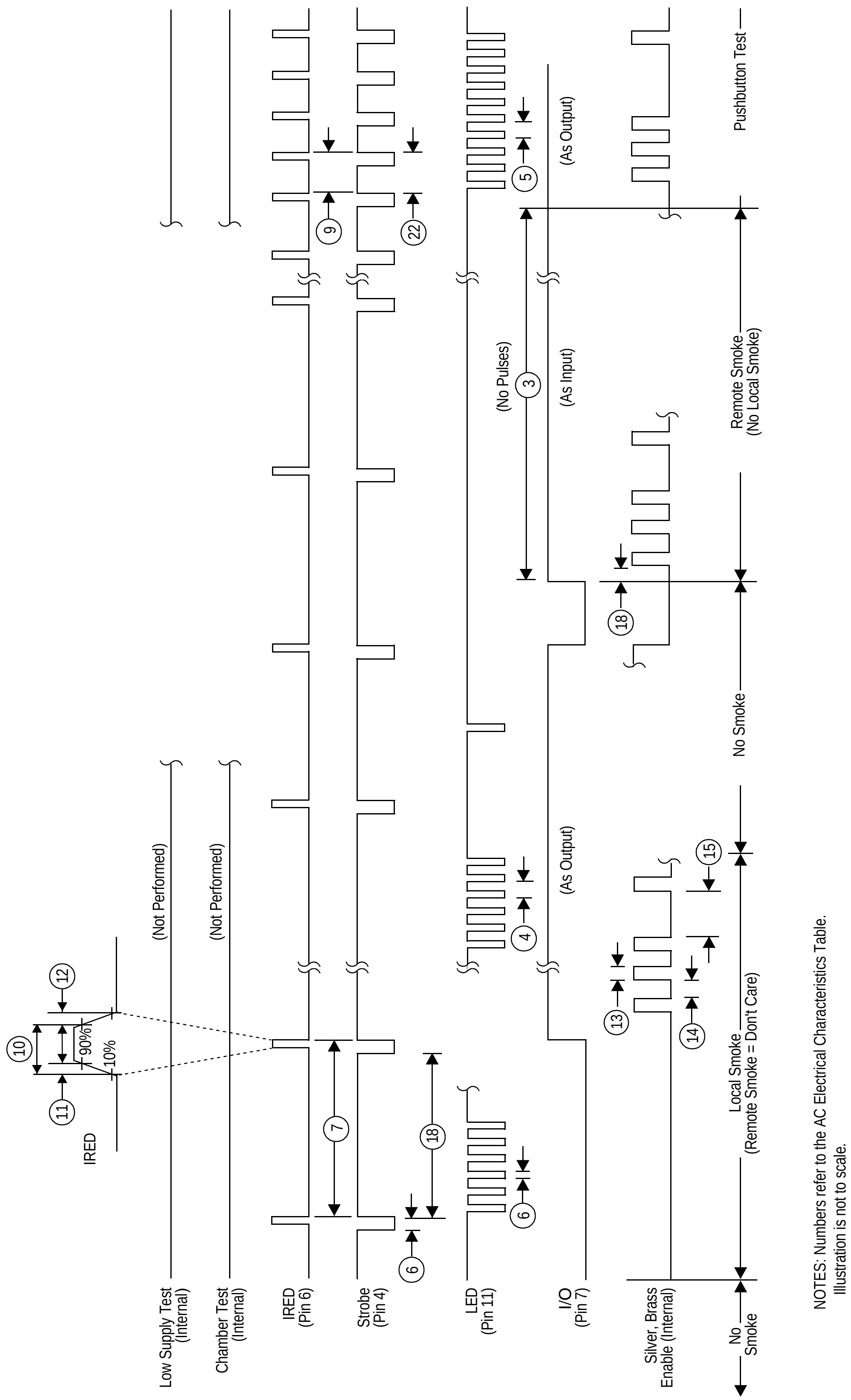
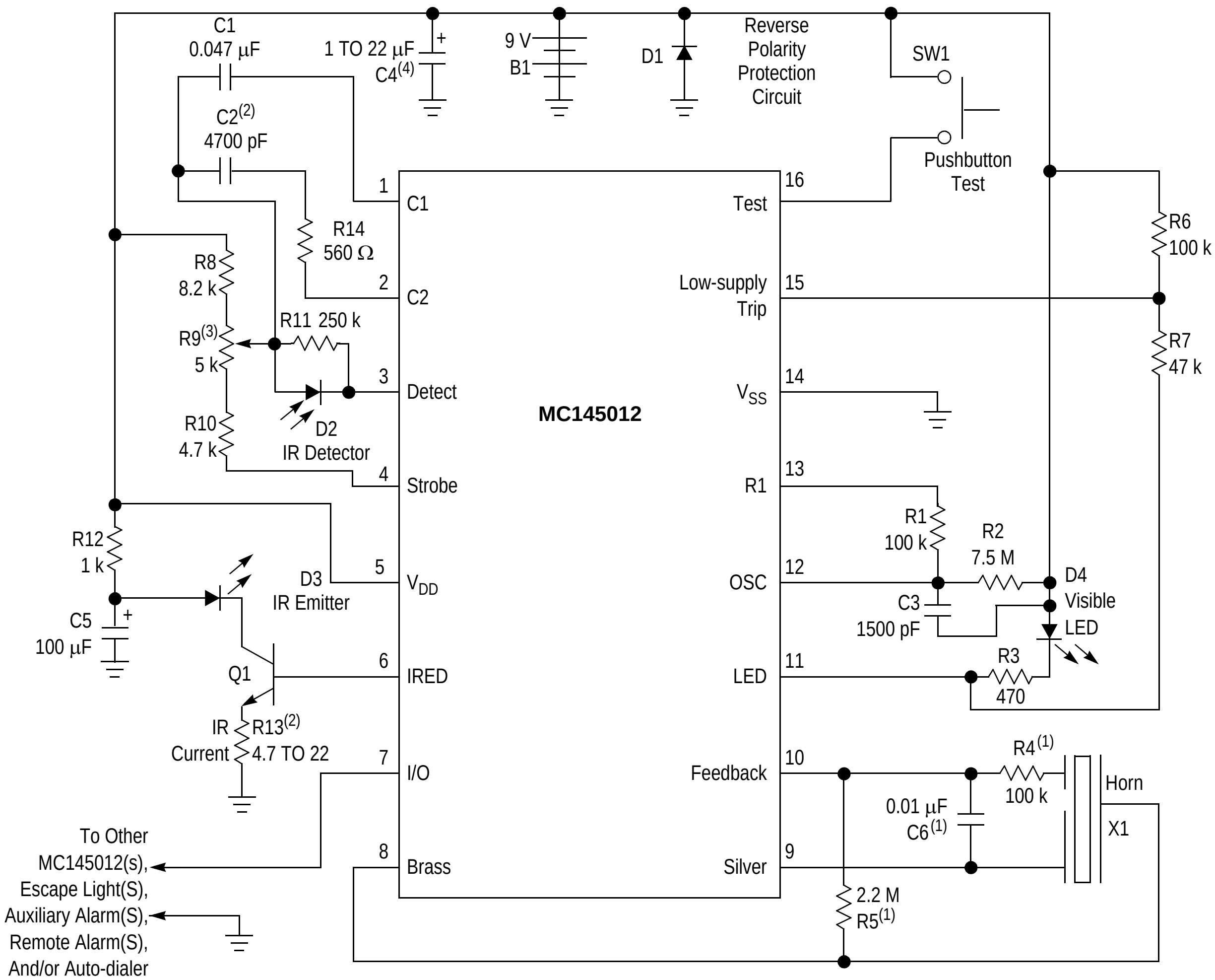


Figure 7. Typical Local Smoke Timing



1. Values for R4, R5, and C6 may differ depending on type of piezoelectric horn used.
2. C2 and R13 are used for coarse sensitivity adjustment. Typical values are shown.
3. R9 is for fine sensitivity adjustment (optional). If fixed resistors are used, R8 = 12 k, R10 is 5.6 k to 10 k, and R9 is eliminated. When R9 is used, noise pickup is increased due to antenna effects. Shielding may be required.
4. C4 should be 22 μF if B1 is a carbon battery. C4 could be reduced to 1 μF when an alkaline battery is used.

Figure 8. Typical Battery-Powered Application

Table 4. Pin Description

Pin No.	Pin Name	Description
1	C1	A capacitor connected to this pin as shown in Figure 8 determines the gain of the on-chip photo amplifier during push-button test and chamber sensitivity test (high gain). The capacitor value is chosen such that the alarm is tripped from background reflections in the chamber during push-button test. $A_v \approx 1 + (C1/10)$ where C1 is in pF. CAUTION: The value of the closed-loop gain should not exceed 10,000.
2	C2	A capacitor connected to this pin as shown in Figure 8 determines the gain of the on-chip photo amplifier except during push-button or chamber sensitivity tests. $A_v \approx 1 + (C2/10)$ where C2 is in pF. This gain increases about 10% during the IRED pulse, after two consecutive local smoke detections. Resistor R14 must be installed in series with C2. $R14 \approx [1/(12\sqrt{C2})] - 680$ where R14 is in ohms and C2 is in farads.
3	Detect	This input to the high-gain pulse amplifier is tied to the cathode of an external photodiode. The photodiode should have low capacitance and low dark leakage current. The diode must be shunted by a load resistor and is operated at zero bias. The Detect input must be AC/DC decoupled from all other signals, V_{DD}, and V_{SS}. Lead length and/or foil traces to this pin must be minimized, also. See Figure 9.

Table 4. Pin Description (Continued)

Pin No.	Pin Name	Description
4	STROBE	This output provides a strobed, regulated voltage referenced to V_{DD}. The temperature coefficient of this voltage is ± 0.2%/°C maximum from - 10° to 60°C. The supply-voltage coefficient (line regulation) is ± 0.2%/V maximum from 6.0 V to 12 V. Strobe is tied to external resistor string R8, R9, and R10.
5	VDD	This pin is connected to the positive supply potential and may range from + 6.0 V to + 12 V with respect to V_{SS} **CAUTION:** In battery-powered applications, reverse-polarity protection must be provided externally.
6	IRED	This output provides pulsed base current for external NPN transistor Q1 used as the infrared emitter driver. Q1 must have $\beta \geq 100$. At 10 mA, the temperature coefficient of the output voltage is typically + 0.5%/°C from - 10° to 60°C. The supply-voltage coefficient (line regulation) is ± 0.2%/V maximum from 6.0 V to 12 V. The IRED pulse width (active-high) is determined by external components R1 and C3. With a 100 kΩ/1500 pF combination, the nominal width is 105 µs. To minimize noise impact, IRED is not active when the visible LED and horn outputs are active. IRED is active near the end of strobe pulses for smoke tests, chamber sensitivity test, and push-button test.
7	I/O	This pin can be used to connect up to 40 units together in a wired-OR configuration for common signaling. V_{SS} is used as the return. An on-chip current sink minimizes noise pick up during non-smoke conditions and eliminates the need for an external pull-down resistor to complete the wired-OR. Remote units at lower supply voltages do not draw excessive current from a sending unit at a higher supply voltage. I/O can also be used to activate escape lights, auxiliary alarms, remote alarms, and/or auto-dialers. As an input, this pin feeds a positive-edge-triggered flip-flop whose output is sampled nominally every 1 second during standby (using the recommended component values). A local-smoke condition or the push-button-test mode forces this current-limited output to source current. All input signals are ignored when I/O is sourcing current. I/O is disabled by the on-chip power-on reset to eliminate nuisance signaling during battery changes or system power-up. If unused, I/O must be left unconnected.
8	BRASS	This half of the push-pull driver output is connected to the metal support electrode of a piezoelectric audio transducer and to the horn-starting resistor. A continuous modulated tone from the transducer is a smoke alarm indicating either local or remote smoke. A short beep or chirp is a trouble alarm indicating a low supply or degraded chamber sensitivity.
9	SILVER	This half of the push-pull driver output is connected to the metal support electrode of a piezoelectric audio transducer and to the horn-starting resistor. A continuous modulated tone from the transducer is a smoke alarm indicating either local or remote smoke. A short beep or chirp is a trouble alarm indicating a low supply or degraded chamber sensitivity.
10	FEEDBACK	This input is connected to both the feedback electrode of a self-resonating piezoelectric transducer and the horn-starting resistor and capacitor through current-limiting resistor R4. If unused, this pin must be tied to V_{SS} or V_{DD}.
11	LED	This active-low open-drain output directly drives an external visible LED at the pulse rates indicated below. The pulse width is equal to the OSC period. The load for the low-supply test is applied by this output. This low-supply test is non-coincident with the smoke tests, chamber sensitivity test, push-button test, or any alarm signals. The LED also provides a visual indication of the detector status as follows, assuming the component values shown in Figure 8: Standby (includes low-supply and chamber sensitivity tests) — Pulses every 32.4 seconds (typical) Standby (includes low-supply and chamber sensitivity tests) — Pulses every 32.4 seconds (typical) Local Smoke — Pulses every 0.51 seconds (typical) Remote Smoke — No pulses Push-button Test — Pulses every 0.51 seconds (typical)
12	OSC	This pin is used in conjunction with external resistor R2 (7.5 MΩ) to V_{DD} and external capacitor C3 (1500 pF) to V_{DD} to form an oscillator with a nominal period of 7.9 ms (typical).
13	R1	This pin is used in conjunction with resistor R1 (100 kΩ) to Pin 12 and C3 (1500 pF, see Pin 12 description) to determine the IRED pulse width. With this RC combination, the nominal pulse width is 105 µs.
14	VSS	This pin is the negative supply potential and the return for the I/O pin. Pin 14 is usually tied to ground.
15	LOW-SUPPLY TRIP	This pin is connected to an external voltage which determines the low-supply alarm threshold. The trip voltage is obtained through a resistor divider connected between the V_{DD} and LED pins. The low-supply alarm threshold voltage (in volts) ≈ (5R7/R6) + 5 where R6 and R7 are in the same units.
16	TEST	This input has an on-chip pull-down device and is used to manually invoke a test mode. The *Push-button Test* mode is initiated by a high level at Pin 16 (usually depression of a S.P.S.T. normally-open push-button switch to V_{DD}). After one oscillator cycle, IRED pulses approximately every 1.0 second, regardless of the presence of smoke. Additionally, the amplifier gain is increased by automatic selection of C1. Therefore, the background reflections in the smoke chamber may be interpreted as smoke, generating a simulated-smoke condition. After the second IRED pulse, a successful test activates the horn-driver and I/O circuits. The active I/O allows remote signaling for system testing. When the Push-button Test switch is released, the Test input returns to V_{SS} due to the on-chip pull-down device. After one oscillator cycle, the amplifier gain returns to normal, thereby removing the simulated-smoke condition. After two additional IRED pulses, less than three seconds, the IC exits the alarm mode and returns to standby timing.

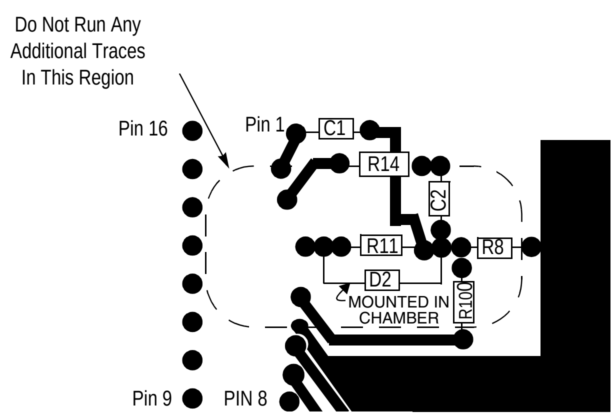
CALIBRATION

To facilitate checking the sensitivity and calibrating smoke detectors, the MC145012 can be placed in a calibration mode. In this mode, certain device pins are controlled/ reconfigured as shown in Table 5. To place the part in the calibration mode, Pin 16 (Test) must be pulled below the V_{SS} pin with 100 μA continuously drawn out of the pin for at least one cycle on the OSC pin. To exit this mode, the Test pin is floated for at least one OSC cycle.

In the calibration mode, the IRED pulse rate is increased to one for every OSC cycle. Also, Strobe is always active low.

Table 5. Configuration of Pins in the Calibration Mode

Description	Pin	Comment
I/O	7	Disabled as an output. Forcing this pin high places the photo amp output on Pin 1 or 2, as determined by Low-Supply Trip. The amp's output appears as pulses and is referenced to V_{DD} etc.
Low-Supply Trip	15	If the I/O pin is high, Pin 15 controls which gain capacitor is used. Low: normal gain, amp output on Pin 1. High: supervisory gain, amp output on Pin 2.
Feedback	10	Driving this input high enables hysteresis (10% gain increase) in the photo amp; Pin 15 must be low.
OSC	12	Driving this input high brings the internal clock high. Driving the input low brings the internal clock low. If desired, the RC network for the oscillator may be left intact; this allows the oscillator to run similar to the normal mode of operation.
Silver	9	This pin becomes the smoke comparator output. When the OSC pin is toggling, positive pulses indicate that smoke has been detected. A static low level indicates no smoke.
Brass	8	This pin becomes the smoke integrator output. That is, 2 consecutive smoke detections are required for “on” (static high level) and 2 consecutive no-detections for “off” (static low level).



NOTES: Illustration is bottom view of layout using a DIP. Top view for SOIC layout is mirror image.
Optional potentiometer R9 is not included.
Drawing is not to scale.
Leads on D2, R11, R8, and R10 and their associated traces must be kept as short as possible. This practice minimizes noise pick up.
Pin 3 must be decoupled from all other traces.

Figure 9. Recommended PCB Layout

MC145017
Rev 5, 05/2005

Low-Power CMOS Ionization Smoke Detector IC with Temporal Pattern Horn Driver

The MC145017, when used with an ionization chamber and a small number of external components, will detect smoke. When smoke is sensed, an alarm is sounded via an external piezoelectric transducer and internal drivers. This circuit is designed to operate in smoke detector systems that comply with UL217 and UL268 specifications.

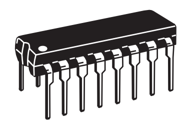
Features

- Ionization Type with On-Chip FET Input Comparator
- Piezoelectric Horn Driver
- Guard Outputs on Both Sides of Detect Input
- Input-Production Diodes on the Detect Input
- Low-Battery Trip Point, Internally Set, can be Altered Via External Resistor
- Detect Threshold, Internally Set, can be Altered Via External Resistor
- Pulse Testing for Low Battery Uses LED for Battery Loading
- Comparator Outputs for Detect and Low Battery
- Internal Reverse Battery Protection
- Supports NFPA 72, ANSi 53.41, and ISO 8201 Audible Emergency Evacuation Signals

ORDERING INFORMATION		
Device	**Case No.**	**Package**
MC145017P	648-08	Plastic Dip

MC145017

LOW-POWER CMOS IONIZATION SMOKE DETECTOR IC WITH TEMPORAL PATTERN HORN DRIVER



P SUFFIX
PLASTIC DIP
CASE 648-08

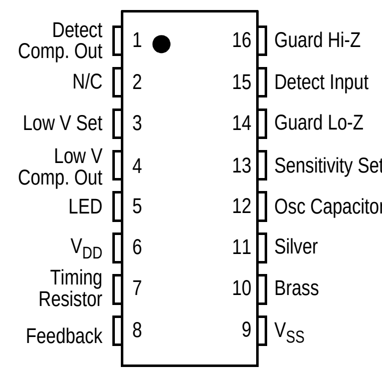


Figure 1. . Pin Connections

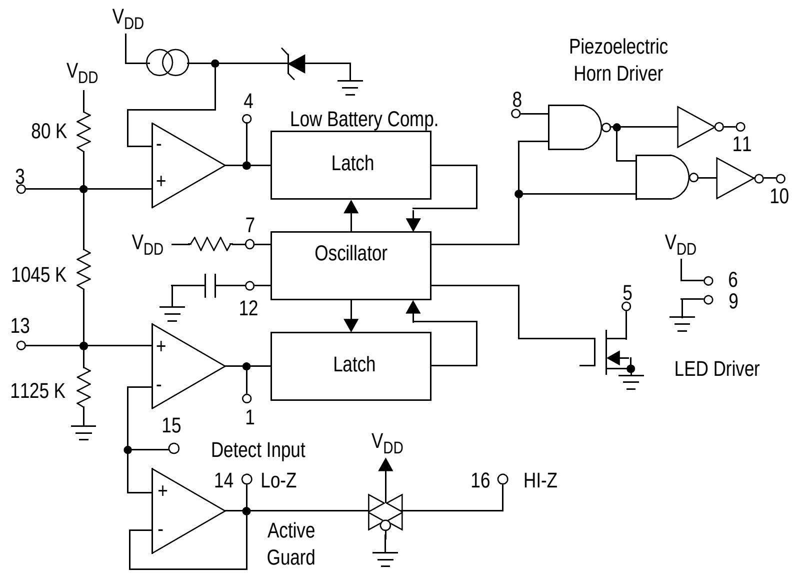


Figure 2. Block Diagram

Table 1. Maximum Ratings[1]
(Voltages referenced to V_{SS})

Rating	Symbol	Value	Unit
DC Supply Voltage	V_{DD}	-0.5 to + 15	V
Input Voltage, All Inputs Except Pin 8	V_{in}	-0.25 to V_{DD} +0.25	V
DC Current Drain per Input Pin, Except Pin 15 = 1 mA	I	10	mA
DC Current Drain per Output Pin	I	30	mA
Operating Temperature Range	T_A	-10 to +60	°C
Storage Temperature Range	T_{stg}	-55 to +125	°C
Reverse Battery Time	t_{RB}	5.0	s

1. Maximum Ratings are those values beyond which damage to the device may occur.

This device contains circuitry to protect the inputs against damage due to high static voltages or electric fields; however, it is advised that normal precautions be taken to avoid application of any voltage higher than maximum rated voltages to this high impedance circuit. For proper operation it is recommended that V_{in} and V_{out} be constrained to the range $V_{SS} \leq (V_{in}$ or $V_{out}) \leq V_{DD}$.

Table 2. Recommended Operating Conditions
(Voltages referenced to V_{SS})

Parameter	Symbol	Value	Unit
Supply Voltage	V_{DD}	9.0	V
Timing Capacitor	—	0.1	µF
Timing Resistor	—	8.2	MΩ
Battery Load (Resistor or LED)	—	10	mA

Table 3. Electrical Characteristics[1]
(Voltages referenced to V_{SS}, T_A = 25°C)

Characteristic	Symbol	V_{DD} V_{DC}	Min	Typ	Max	Unit
Operating Voltage	V_{DD}	—	6.0	—	12	V
Output Voltage Piezoelectric Horn Drivers (I_{OH} = -16 mA) Comparators (I_{OH} = -30 μA) Piezoelectric Horn Drivers (I_{OL} = +16 mA) Comparators (I_{OL} = +30 μA)	V_{OH} V_{OL}	 7.2 9.0 7.2 9.0	 6.3 8.5 — —	 — 8.8 — 0.1	 — — 0.9 0.5	V V
Output Voltage — LED Driver, I_{OL} = 10 mA	V_{OL}	7.2	—	—	3.0	V
Output Impedance, Active Guard Pin 14 Pin 16	 Lo-Z Hi-Z	 9.0 9.0	 — —	 — —	 10 1000	kΩ
Operating Current (R_{bias} = 8.2 MΩ)	I_{DD}	9.0 12.0	— —	3.2 —	7.0 10.0	μA
Input Current — Detect (40% R.H.)	I_{in}	9.0	—	—	±1.0	pA
Input Current, Pin 8	I_{in}	9.0	—	—	±0.1	μA
Input Current @ 50°C, Pin 15	I_{in}	—	—	—	±6.0	pA
Internal Set Voltage Low Battery Sensitivity	 V_{low} V_{set}	 9.0 —	 7.2 47	 — 50	 7.8 53	 V %V_{DD}
Hysteresis	v_{hys}	9.0	75	100	150	mV
Offset Voltage (measured at V_{in} = V_{DD}/2 Active Guard Detect Comparator	V_{OS}	 9.0 9.0	 — —	 — —	 ±100 ±50	mV
Input Voltage Range, Pin 8	V_{in}	—	V_{SS} -10	—	V_{DD} + 10	V
Input Capacitance	C_{in}	—	—	5.0	—	pF
Common Mode Voltage Range, Pin 15	V_{cm}	—	0.6	—	V_{DD} - 2	V

1. Data labelled “Typ” is not to be used for design purposes but is intended as an indication of the IC’s potential performance.

Table 4. Timing Parameters
(C = 0.1 μF, R_{bias} = 8.2 MΩ, V_{DD} = 9.0 V, T_A = 25°C, See Figure 7)

Characteristics		Symbol	Min	Max	Units
Oscillator Period	No Smoke Smoke	t_{CI}	1.46 37.5	1.85 45.8	s ms
Oscillator Rise Time		t_r	10.1	12.3	ms
Horn Output (During Smoke)	On Time Off Time	PW_{on} PW_{off}	450 450	550 550	ms ms
LED Output	Between Pulses On Time	t_{LED} PW_{on}	35.0 10.1	44.5 12.3	s ms
Horn Output (During Low Battery)	On Time Between Pulses	t_{on} t_{off}	10.1 35.0	12.3 44.5	ms s

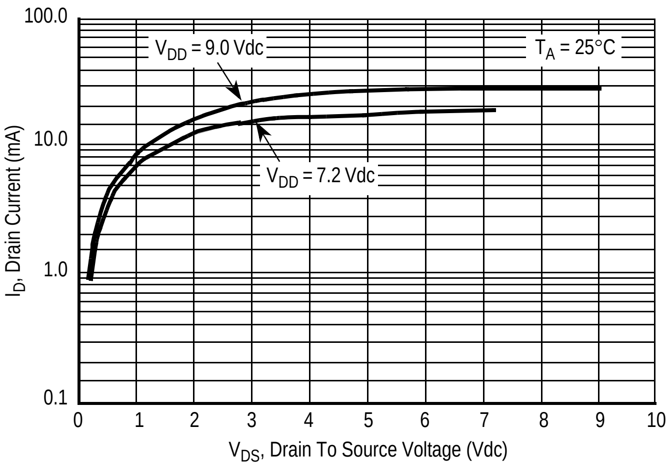


Figure 3. Typical LED Output I–V Characteristic

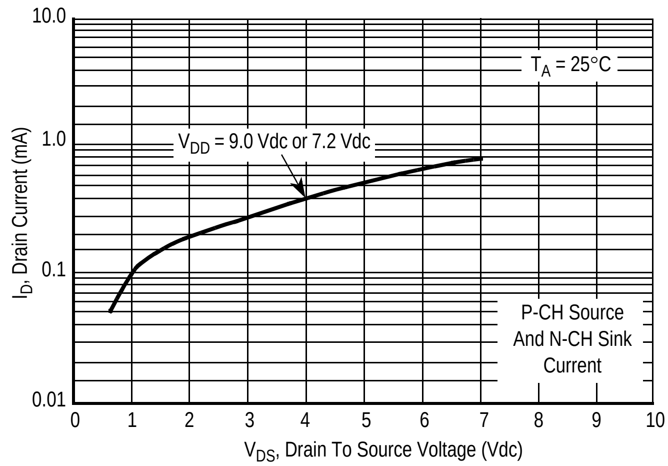


Figure 4. Typical Comparator Output I–V Characteristic

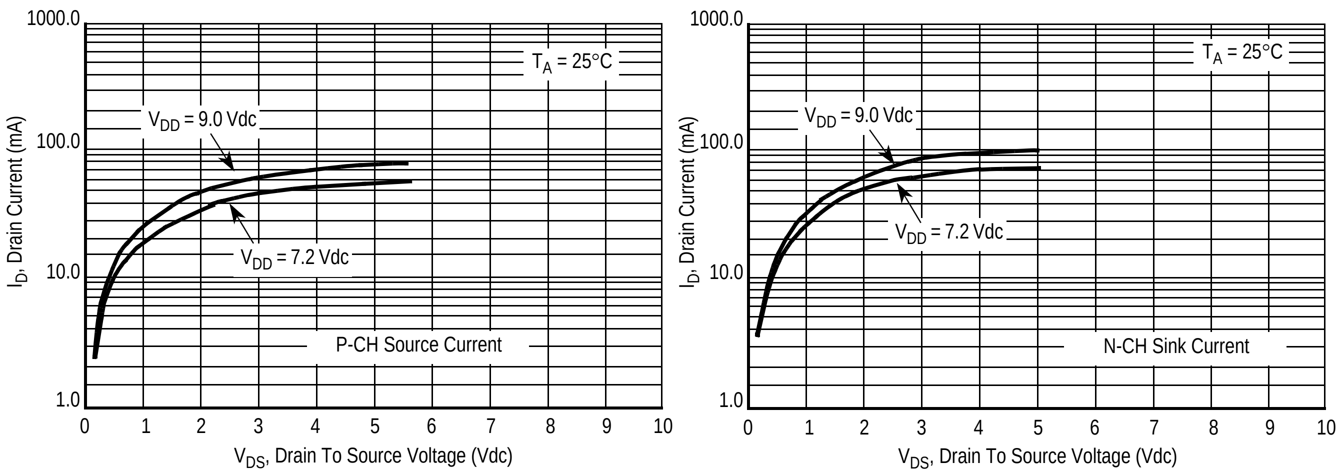


Figure 5. Typical P Horn Driver Output I–V Characteristic

DEVICE OPERATION

Timing

The internal oscillator of the MC145017 operates with a period of 1.65 seconds during no-smoke conditions. Each 1.65 seconds, internal power is applied to the entire IC and a check is made for smoke, except during LED pulse, Low Battery Alarm Chirp, or Horn Modulation (in smoke). Every 24 clock cycles a check is made for low battery by comparing V_{DD} to an internal zener voltage. Since very small currents are used in the oscillator, the oscillator capacitor should be of a low leakage type.

Detect Circuitry

If smoke is detected, the oscillator period becomes 41.67 ms and the piezoelectric horn oscillator circuit is enabled. The horn output is modulated 500 ms on, 500 ms off. During the off time, smoke is again checked and will inhibit further horn output if no smoke is sensed. During smoke conditions the low battery alarm is inhibited, but the LED pulses at a 1.0 Hz rate.

An active guard is provided on both pins adjacent to the detect input. The voltage at these pins will be within 100 mV of the input signal. This will keep surface leakage currents to a minimum and provide a method of measuring the input voltage without loading the ionization chamber. The active guard op amp is not power strobed and thus gives constant protection from surface leakage currents. Pin 15 (the Detect input) has internal diode protection against static damage.

Sensitivity/Low Battery Thresholds

Both the sensitivity threshold and the low battery voltage levels are set internally by a common voltage divider (please see Figure 2) connected between V_{DD} and V_{SS}. These voltages can be altered by external resistors connected from pins 3 or 13 to either V_{DD} or V_{SS}. There will be a slight interaction here due to the common voltage divider network. The sensitivity threshold can also be set by adjusting the smoke chamber ionization source.

Test Mode

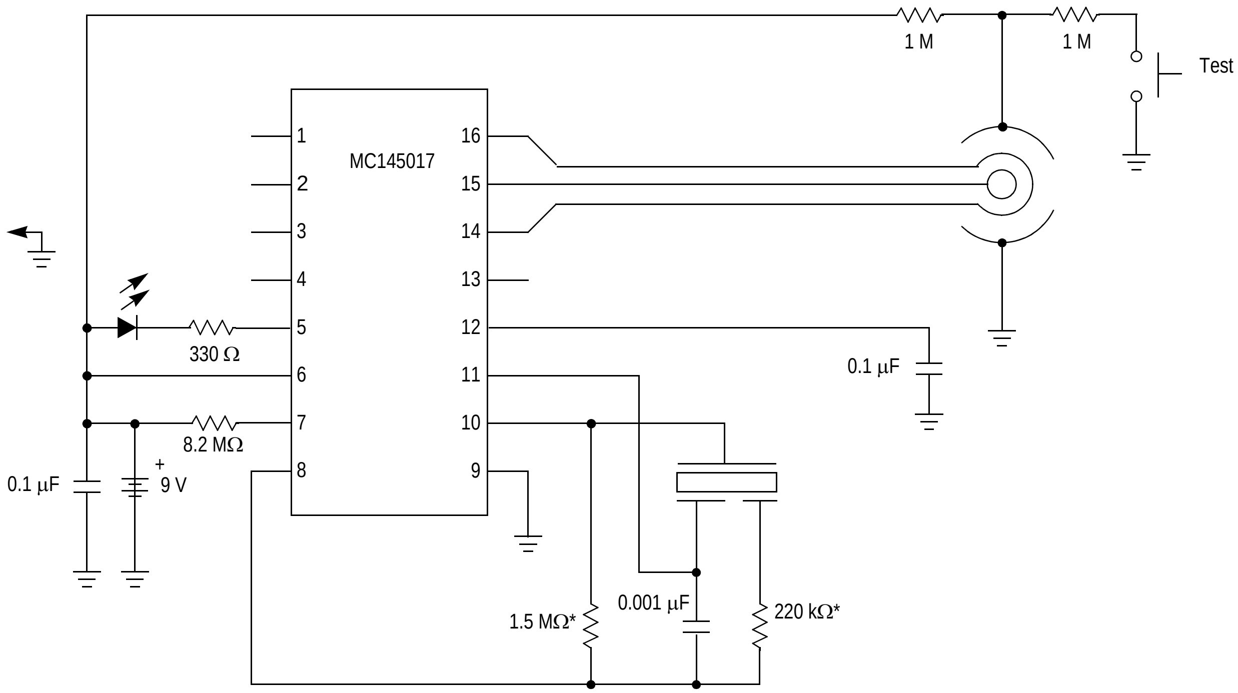
Since the internal op amps and comparators are power strobed, adjustments for sensitivity or low battery level could be difficult and/or time-consuming. By forcing Pin 12 to V_{SS}, the power strobing is bypassed and the outputs, Pins 1 and 4, constantly show smoke/no smoke and good battery/low battery, respectively. Pin 1 = V_{DD} for smoke and Pin 4 = V_{DD} for low battery. In this mode and during the 10 ms power strobe, chip current rises to approximately 50 μA.

Led Pulse

The 9-volt battery level is checked every 40 seconds during the LED pulse. The battery is loaded via a 10 mA pulse for 11.6 ms. If the LED is not used, it should be replaced with an equivalent resistor such that the battery loading remains at 10 mA.

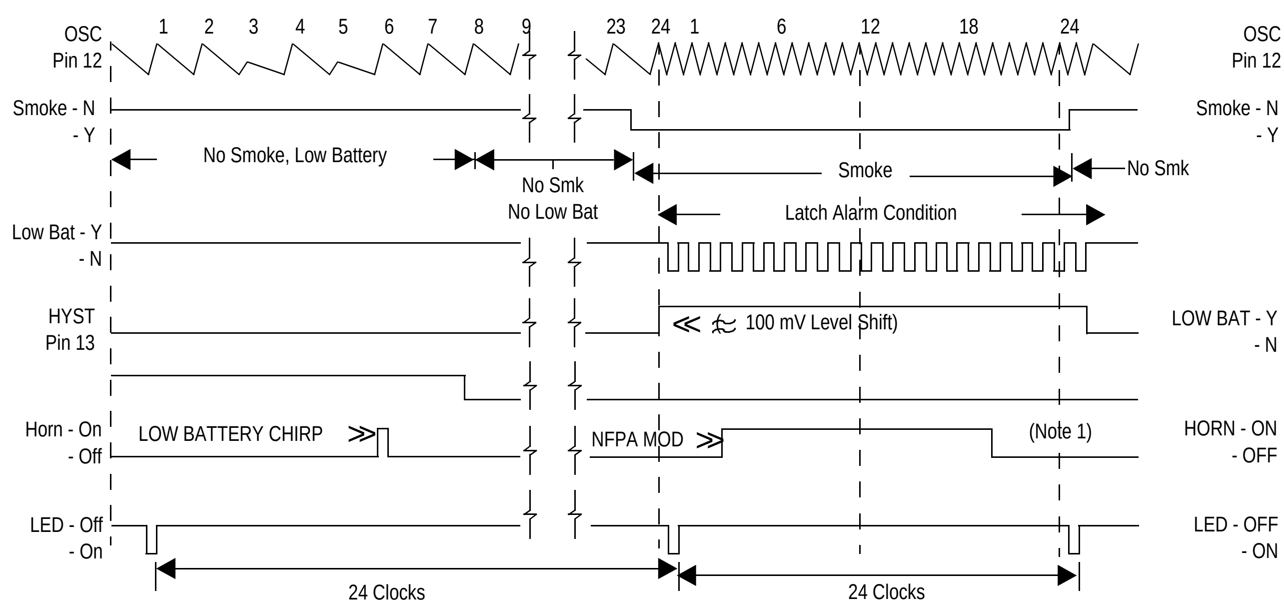
Hysteresis

When smoke is detected, the resistor/divider network that sets sensitivity is altered to increase sensitivity. This yields approximately 100 mV of hysteresis and reduces false triggering.



*NOTE: Component values may change depending on type of piezoelectric horn used.

Figure 6. Typical Application as Ionization Smoke Detector



NOTES:

1. Horn modulation is self-completing. When going from smoke to no smoke, the alarm condition will terminate only when horn is off.
2. Comparators are strobed once per cycle (1.65 sec for no smoke, 40 msec for smoke).

Figure 7. MC145017 Timing Diagram

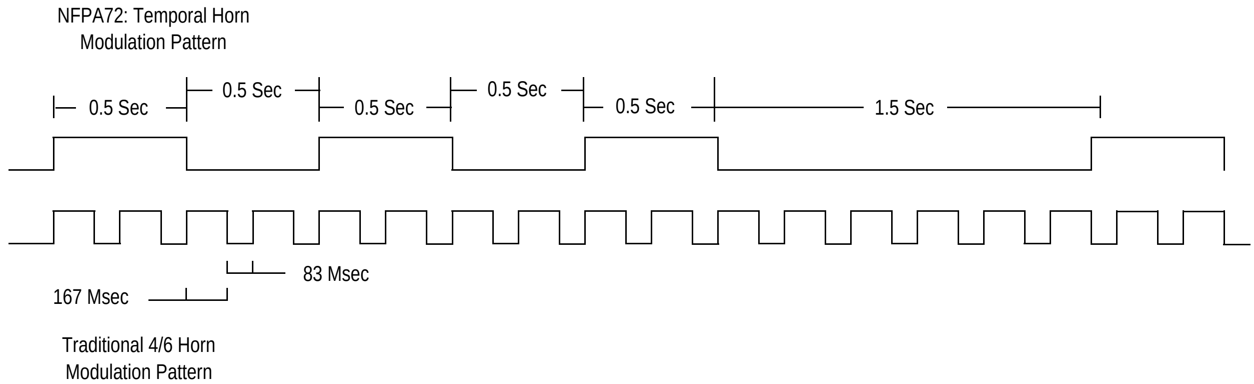


Figure 8. Horn Modulation

Freescale Semiconductor
Technical Data

MC145018
Rev 4, 05/2005

Low-Power CMOS Ionization Smoke Detector IC with Interconnect and Temporal Horn Driver

The MC145018, when used with an ionization chamber and a small number of external components, will detect smoke. When smoke is sensed, an alarm is sounded via an external piezoelectric transducer and internal drivers. This circuit is designed to operate in smoke detector systems that comply with UL217 and UL268 specifications.

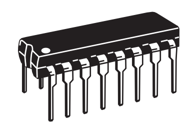
Features

- Ionization Type with On-Chip FET Input Comparator
- Piezoelectric Horn Driver
- Guard Outputs on Both Sides of Detect Input
- Input-Protection Diodes on the Detect Input
- Low-Battery Trip Point, Internally Set, can be Altered Via External Resistor
- Detect Threshold, Internally Set, can be Altered Via External Resistor
- Pulse Testing for Low Battery Uses LED for Battery Loading
- Comparator Output for Detect
- Internal Reverse Battery Protection
- Strobe Output for External Trim Resistors
- I/O Pin Allows Up to 40 Units to be Connected for Common Signaling
- Supports NFPA 72, ANSi 53.41, and ISO 8201
  Audible Emergency Evacuation Signals
- Power-On Reset Places IC in Standby Mode

ORDERING INFORMATION		
Device	**Case No.**	**Package**
MC145018P	648-08	Plastic Dip

MC145018

IONIZATION SMOKE DETECTOR IC WITH INTERCONNECT AND TEMPORAL HORN DRIVER



P SUFFIX
PLASTIC DIP
CASE 648-08

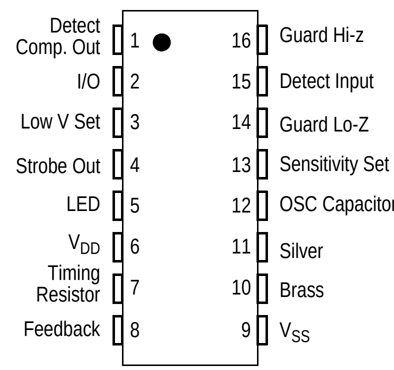


Figure 1. Pin Assignment

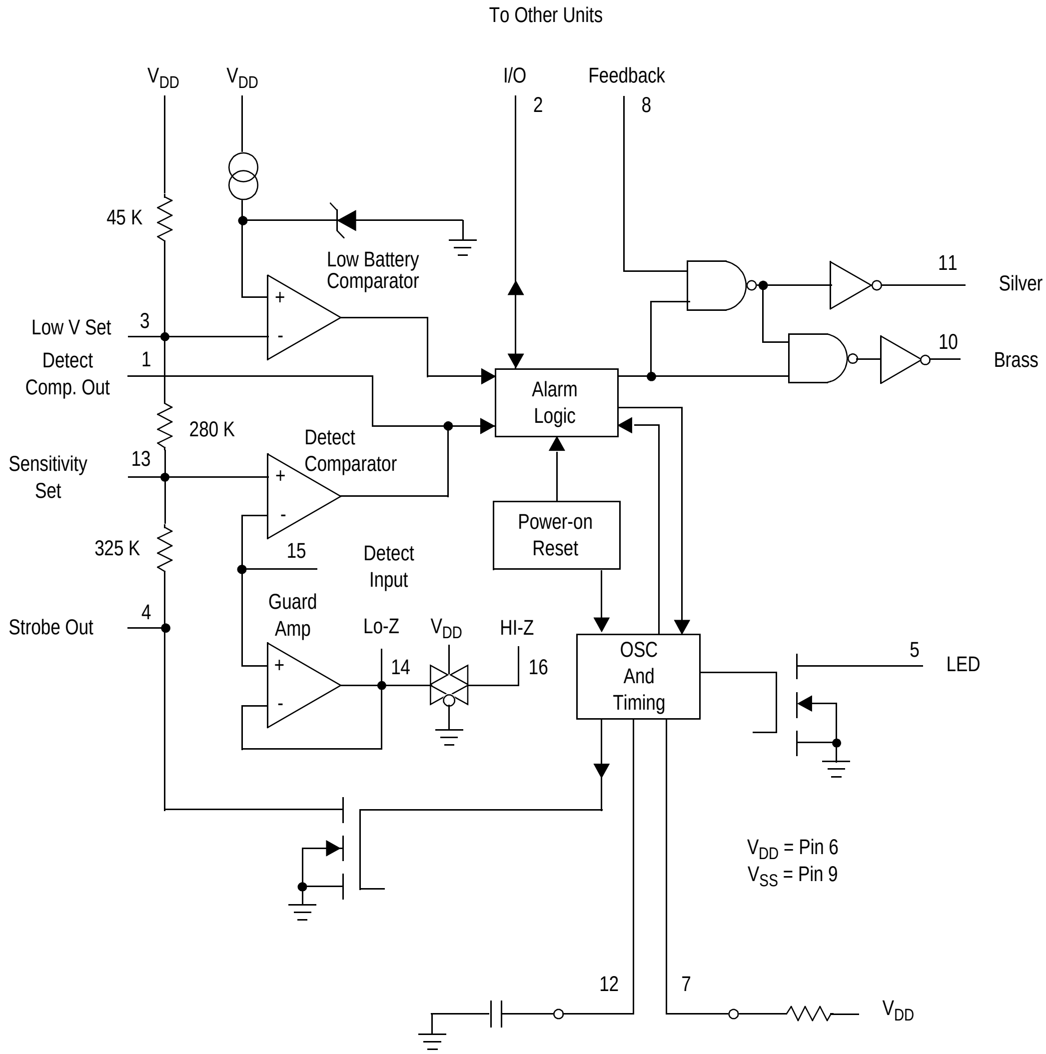


Figure 2. Block Diagram

Table 1. Maximum Ratings[(1)]
(Voltages referenced to V_{SS})

Rating	Symbol	Value	Unit
DC Supply Voltage	V_{DD}	–0.5 to + 15	V
Input Voltage, All Inputs Except Pin 8	V_{in}	–0.25 to V_{DD} + 0.25	V
DC Current Drain per Input Pin, Except Pin 15 = 1 mA	I	10	mA
DC Current Drain per Output Pin	I	30	mA
Operating Temperature Range	T_A	–10 to + 60	°C
Storage Temperature Range	T_{stg}	–55 to + 125	°C
Reverse Battery Time	t_{RB}	5.0	s

1. Maximum Ratings are those values beyond which damage to the device may occur.
   This device contains circuitry to protect the inputs against damage due to high static voltages or electric fields; however, it is advised that normal precautions be taken to avoid application of any voltage higher than maximum rated voltages to this high impedance circuit. For proper operation it is recommended that V_{in} and V_{out} be constrained to the range $V_{SS} \leq (V_{in} \text{ or } V_{out}) \leq V_{DD}$.

Table 2. Recommended Operating Conditions
(Voltages referenced to V_{SS})

Parameter	Symbol	Value	Unit
Supply Voltage	V_{DD}	9.0	V
Timing Capacitor	—	0.1	μF
Timing Resistor	—	8.2	MΩ
Battery Load (Resistor or LED)	—	10	mA

Table 3. Electrical Characteristics
(Voltages referenced to V_{SS}, TA = 25°C)

Characteristic	Symbol	V_{DD} V_{DC}	Min	Typ[1]	Max	Unit
Operating Voltage	V_{DD}	—	6.0	—	12	V
Output Voltage Piezoelectric Horn Drivers (I_{OH} = –16 mA) Comparators (I_{OH} = –30 μA) Piezoelectric Horn Drivers (I_{OL} = + 16 mA) Comparators (I_{OL} = +30 μA)	V_{OH} V_{OL}	 7.2 9.0 7.2 9.0	 6.3 8.5 — —	 — 8.8 — 0.1	 — — 0.9 0.5	V V
Output Voltage - LED Driver, I_{OL} = 10 mA	V_{OL}	7.2	—	—	3.0	V
Output Impedance, Active Guard Pin 14 Pin 16	 Lo-Z Hi-Z	 9.0 9.0	 — —	 — —	 10 1000	 kΩ
Operating Current (R_{bias} = 8.2 MΩ)	I_{DD}	9.0 12.0	— —	5.0 —	9.0 12.0	μA
Input Current - Detect (40% R.H.)	I_{in}	9.0	—	—	±1.0	pA
Input Current, Pin 8	I_{in}	9.0	—	—	±0.1	μA
Input Current @ 50°C, Pin 15	I_{in}	—	—	—	±6.0	pA
Internal Set Voltage Low Battery Sensitivity	 V_{low} V_{set}	 9.0 —	 7.2 47	 — 50	 7.8 53	 V %V_{DD}
Hysteresis	v_{hys}	9.0	75	100	150	mV
Offset Voltage (measured at Vin = VDD/2) Active Guard Detect Comparator	V_{OS}	 9.0 9.0	 — —	 — —	 ±100 ±50	mV
Input Voltage Range, Pin 8	V_{in}	—	VSS –10	—	VDD + 10	V
Input Capacitance	C_{in}	—	—	5.0	—	pF
Common Mode Voltage Range, Pin 15	V_{cm}	—	0.6	—	VDD –2	V
I/O Current, Pin 2 Input, V_{IH} = VDD –2 Output, V_{OH} = VDD –2	 I_{IH} I_{OH}	 — —	 25 –4.0	 — —	 100 —16	 μA mA

1. Data labelled “Typ" is not to be used for design purposes but is intended as an indication of the IC's potential performance.

Table 4. Timing Parameters
(C = 0.1 μF, R_{bias} = 8.2 MΩ, V_{DD} = 9.0 V, T_A = 25°C, See Figure 7)

Characteristics		Symbol	Min	Max	Units
Oscillator Period	No Smoke Smoke	t_{CI}	1.46 37.5	1.85 45.8	s ms
Oscillator Rise Time		t_r	10.1	12.3	ms
Horn Output (During Smoke)	On Time Off Time	PW_{on} PW_{off}	450 450	550 550	ms ms
LED Output	Between Pulses On Time	t_{LED} PW_{on}	35.0 10.1	44.5 12.3	s ms
Horn Output (During Low Battery)	On Time Between Pulses	t_{on} t_{off}	10.1 35.0	12.3 44.5	ms s

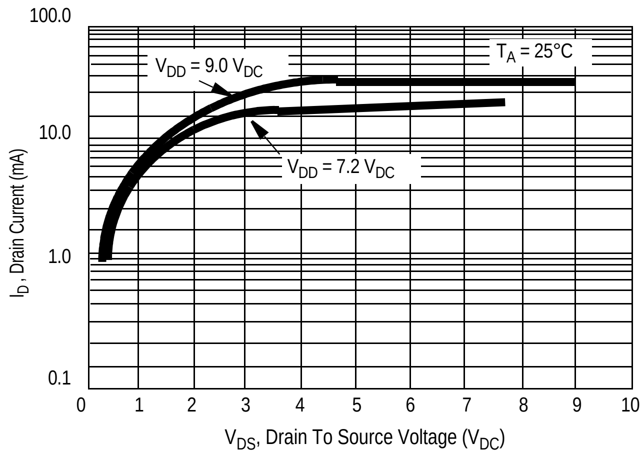


Figure 3. Typical LED Output I-V Characteristic

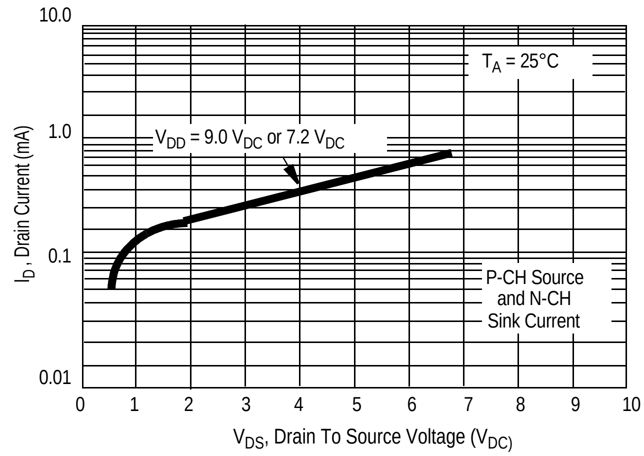


Figure 4. Typical Comparator Output I-V Characteristic

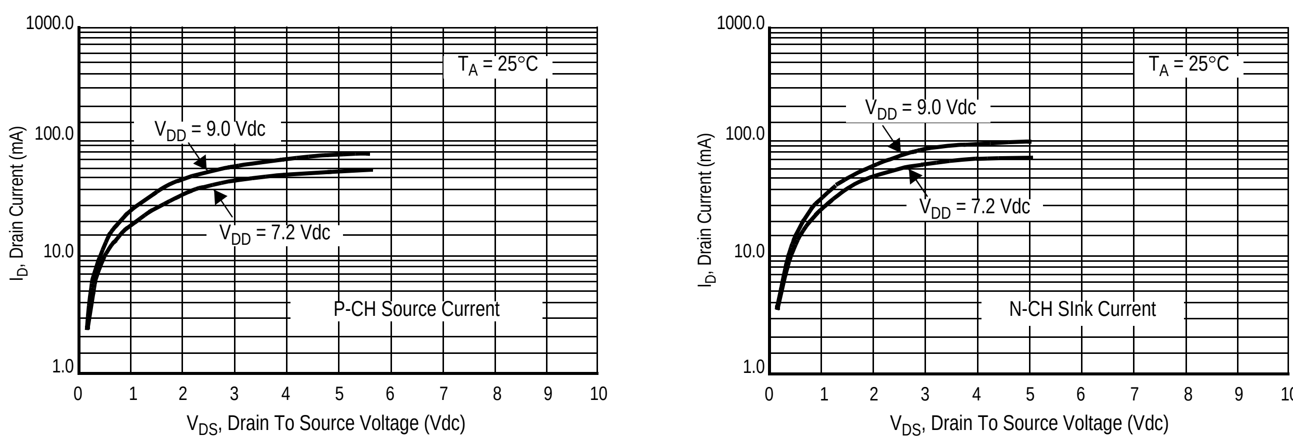


Figure 5. Typical P Horn Driver Output I-V Characteristic

DEVICE OPERATION

Timing

The internal oscillator of the MC145018 operates with a period of 1.65 seconds during no-smoke conditions. Each 1.65 seconds, internal power is applied to the entire IC and a check is made for smoke, except during LED pulse, Low Battery Alarm Chirp, or Horn Modulation (in smoke). Every 24 clock cycles a check is made for low battery by comparing V_{DD} to an internal zener voltage. Since very small currents are used in the oscillator, the oscillator capacitor should be of a low leakage type.

Detect Circuitry

If smoke is detected, the oscillator period becomes 41.67 ms and the piezoelectric horn oscillator circuit is enabled. The horn output is modulated 500 ms on, 500 ms off. During the off time, smoke is again checked and will inhibit further horn output if no smoke is sensed. During local smoke conditions the low battery alarm is inhibited, but the LED pulses at a 1.0 Hz rate. In remote smoke, the LED is inhibited as well.

An active guard is provided on both pins adjacent to the detect input. The voltage at these pins will be within 100 mV of the input signal. This will keep surface leakage currents to a minimum and provide a method of measuring the input voltage without loading the ionization chamber. The active guard op amp is not power strobed and thus gives constant protection from surface leakage currents. Pin 15 (the Detect input) has internal diode protection against static damage.

Interconnect

The I/O (Pin 2), in combination with V_{SS}, is used to interconnect up to 40 remote units for common signaling. A Local Smoke condition activates a current limited output driver, thereby signaling Remote Smoke to interconnected units. A small current sink improves noise immunity during non-smoke conditions. Remote units at lower voltages do not draw excessive current from a sending unit at a higher voltage. The I/O is disabled for three oscillator cycles after power up, to eliminate false alarming of remote units when the battery is changed.

Sensitivity/Low Battery Thresholds

Both the sensitivity threshold and the low battery voltage levels are set internally by a common voltage divider (see Figure 2) connected between V_{DD} and V_{SS}. These voltages can be altered by external resistors connected from pins 3 or 13 to either V_{DD} or V_{SS}. There will be a slight interaction here due to the common voltage divider network. The sensitivity threshold can also be set by adjusting the smoke chamber ionization source.

Test Mode

Since the internal op amps and comparators are power strobed, adjustments for sensitivity or low battery level could be difficult and/or time-consuming. By forcing Pin 12 to V_{SS}, the power strobing is bypassed and the output, Pin 1, constantly shows smoke/no smoke. Pin 1 = V_{DD} for smoke. In this mode and during the 10 ms power strobe, chip current rises to approximately 50 μA.

LED Pulse

The 9-volt battery level is checked every 40 seconds during the LED pulse. The battery is loaded via a 10 mA pulse for 11.6 ms. If the LED is not used, it should be replaced with an equivalent resistor such that the battery loading remains at 10 mA.

Hysteresis

When smoke is detected, the resistor/divider network that sets sensitivity is altered to increase sensitivity. This yields approximately 100 mV of hysteresis and reduces false triggering.

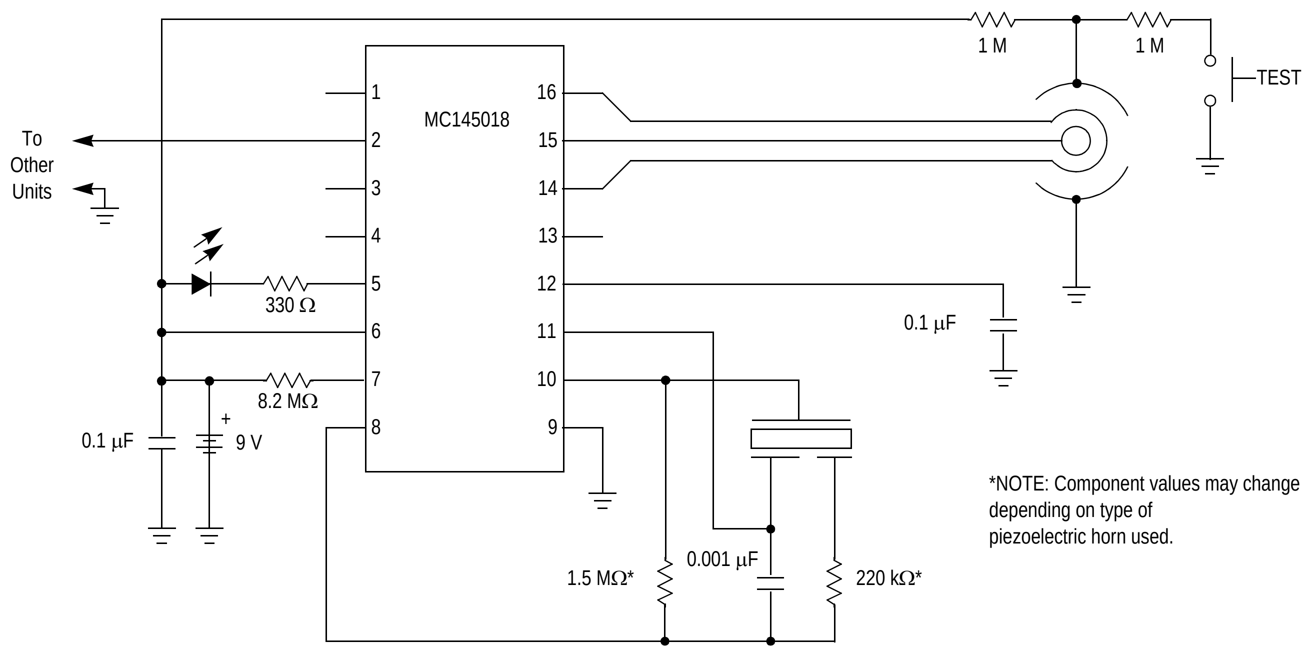


Figure 6. Typical Application as Ionization Smoke Detector

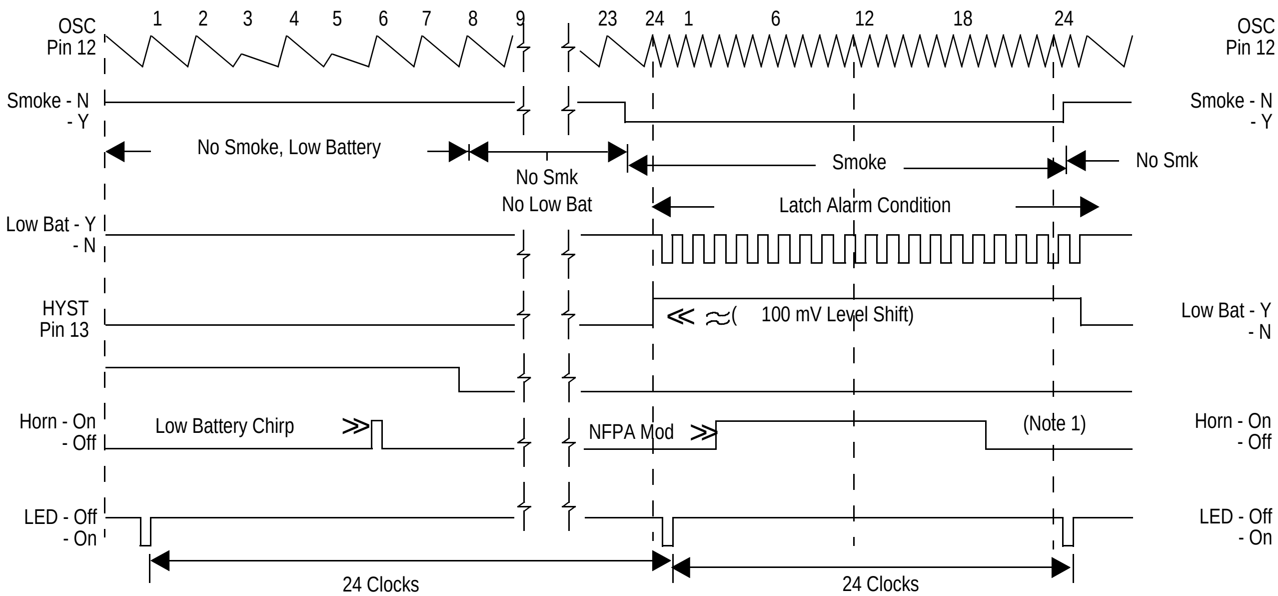


Figure 7. MC145017 Timing Diagram

NOTE:

1. Horn modulation is self-completing. When going from smoke to no smoke, the alarm condition will terminate only when horn is off.
   Comparators are strobed once per cycle (1.65 sec for no smoke, 40 msec for smoke).
   For timing under remote conditions, refer to MC14468 data sheet.

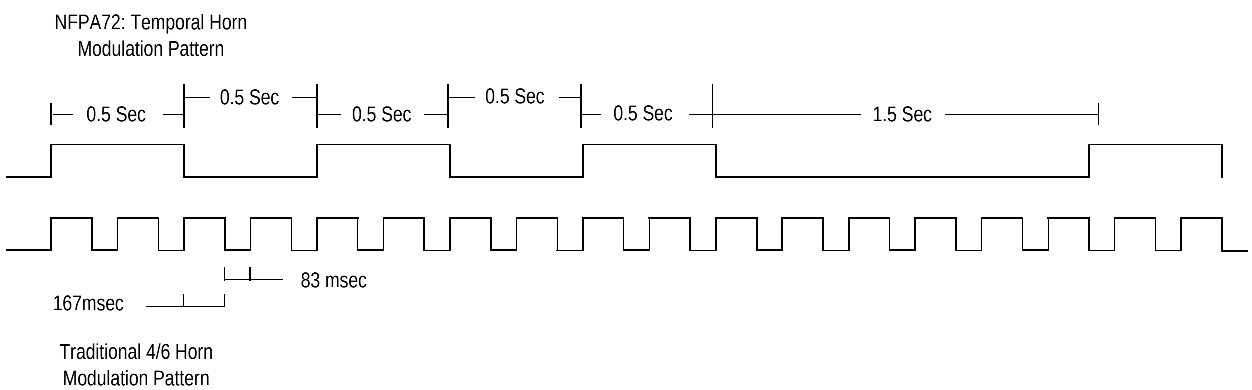


Figure 8. Horn Modulation

AN1690
Rev 4, 05/2005

Alarm IC General Applications Overview

by: Leticia Gomez and Diana Pelletier, Sensor Applications Engineering
Sensor Products, Systems and Applications Engineering

INTRODUCTION

The MC14600, an IC designed for alarm applications, is a versatile part that can easily be configured with a minimum number of external components to serve a wide range of alarm applications and circuit configurations. For example, the MC14600 can be used in systems that detect pressure and temperature change, liquid levels, motion or intrusion. This application note presents considerations in interfacing external components to the MC14600 and an approach for configuring it with a latch.

The MC14600 Alarm IC can be simply described as a comparator that determines whether an alarm condition exists and in response drives a piezo horn. As illustrated in Figure 1 the MC14600 is more than a comparator and a horn driver. It drives an LED to indicate the device is working and has internal low battery detection circuitry. In the event of a low battery the MC14600 provides the signal to chirp the piezo horn. It also has a logical output that can be used to drive other outputs such as an LED. The MC14600 alarm threshold and oscillator speed are set externally providing system design flexibility. Figure 2 is a detailed block diagram of the MC14600 that includes the pin numbers referenced in this document.

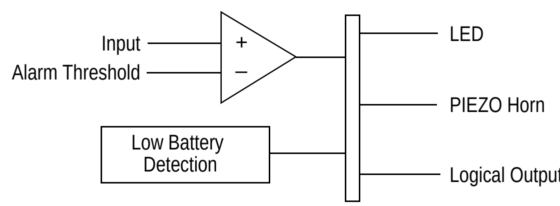


Figure 1. Alarm IC Concept

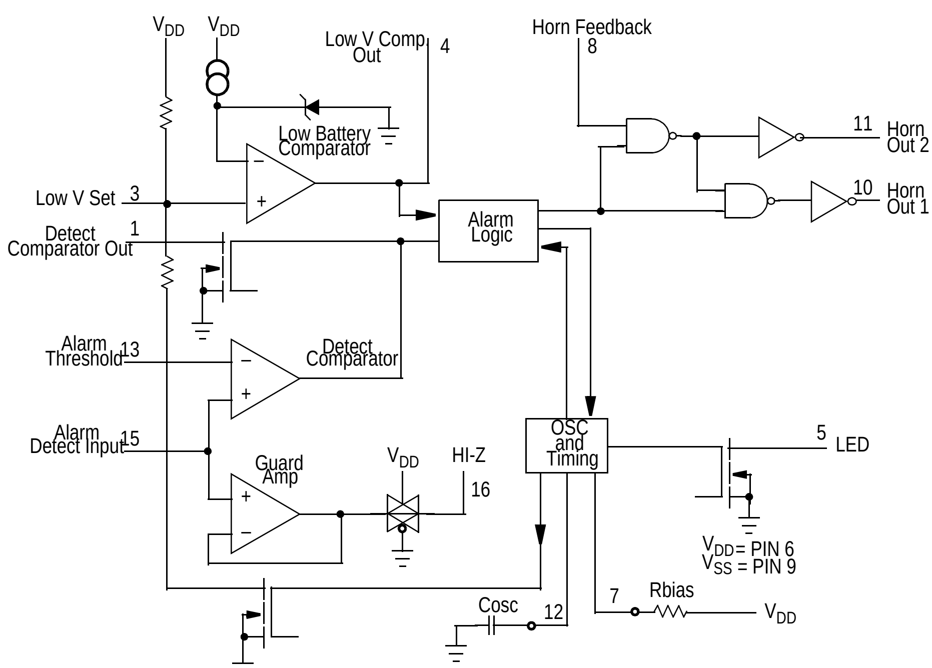


Figure 2. MC14600 Block Diagram

ALARM THRESHOLD ADJUSTMENTS

The alarm trigger point (alarm threshold) is set externally to any voltage level with a simple voltage divider connected to pin 13. For instance, to connect the Alarm IC to a sensor that has an output of 1.0 V during a no alarm condition and 4.0 V during an alarm condition, the alarm threshold voltage could be set to 3.0 V using a 2 MΩ and a 1 MΩ resistor connected between V_{DD} and ground (See Figure 3). Pin 13 connects internally to the negative input of the Detect Comparator. Based on the input impedance of the Detect Comparator the maximum suggested total resistance for the threshold voltage divider is 10 MΩ.

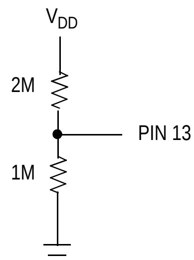


Figure 3. Alarm Threshold Voltage Divider

OSCILLATOR

The master clock frequency for the MC14600 is determined by the external components Rbias (pin 7) and Cosc (pin 12). This RC network provides the timing for the various functions conducted by the IC. The oscillator timing affects the period between LED pulses, alarm signal sampling, and the horn output pulses and power consumption. A standard RC network for the MC14600 oscillator uses an 8.2 M resistor (Rbias) connected from V_{DD} to pin 7 and a 0.1 µF capacitor (Cosc) connected from pin 12 to ground. This configuration will provide a period of approximately 1.65 sec in standby and 41.67 msec in alarm. A change in oscillator speed is accomplished by changing the resistor and capacitor values previously stated. Changing the oscillator timing will not change the horn pattern but it will change the speed at which it's delivered. The table below lists examples of RC values and measured sampling periods achieved with those values (deviation from theoretical values are due to tolerance in components).

Table 1. Oscillator Period vs. R_{bias} and C_{osc} Value

R_{bias}	C_{osc}	Period (no Alarm)	Period (Alarm)
5.6 MΩ	0.01 µF	93 ms	2.3 ms
8.2 MΩ	0.01 µF	142 ms	3.4 ms
10 MΩ	0.01 µF	172 ms	3.9 ms
5.6 MΩ	0.1 µF	1.4 s	32 ms
8.2 MΩ	0.1 µF	2.2 s	50 ms
10 MΩ	0.1 µF	2.7 s	60 ms
8.2 MΩ	1.0 µF	20.1 s	456 ms

PIEZO HORN INTERFACE

The MC14600 contains on-board horn driver circuitry to drive three leaded piezo horns. A three leaded horn is considered self-driven, having a feedback pin that is connected to a closed loop oscillation circuit. The MC14600 uses pin 8 (Horn Feedback), pin 10 (Horn Out 1) and pin 11 (Horn Out 2) to interface to a piezo horn and achieve the drive circuit. Pin 10 and pin 11 alternate their output providing the oscillation for the horn. Three external components are required to interface a piezo horn to the Alarm IC: R1, C1 and R2 (Figure 4). R1 is usually around 1.5 MΩ and is the least critical component as it only biases the horn. R2 and C1 are critical to achieve maximum horn output. The two components must be set so that the value of 1/(R2*C1) is close to the resonant frequency of the horn being used. Table 2 lists a common horn frequency and potential external components that can be used for R2 and C1.

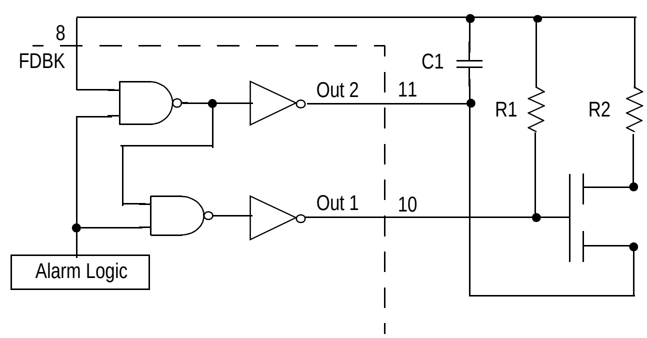


Figure 4. Piezo Horn Interface to MC14600

Table 2. External Components for a 3.4 kHz Three Leaded Piezo Horn

Horn OSC Frequency	R1	R2	C1	1/(R2*C1)
3.4 ± 0.4 kHz	1.5 MΩ 820 kΩ 1.5 MΩ 1.5 MΩ	200 kΩ 200 kΩ 120 kΩ 100 kΩ	1.5 nF 1.5 nF 2.2 nF 2.2 nF	3.33 kHz 3.33 kHz 3.79 kHz 4.55 kHz

LOW BATTERY THRESHOLD ADJUSTMENTS

The Alarm IC has a typical internal low battery reference voltage of 6 V. An internal resistor divider string provides a voltage of 80% of V_{DD} which is compared to the 6 V reference voltage (See Figure 5). This results in a low battery condition and horn chirp if the V_{DD} level is decreased to approximately 7.5 V. The percentage of V_{DD} that is compared can be changed by adding a resistor to pin 3. A resistor from pin 3 to V_{DD} will lower the percentage while a resistor from pin 3 to GND will increase the percentage. The low battery comparator information will be latched only during the LED pulse. Testing of the voltage at pin 3 should be done during the LED pulse for confirmation. It should also be measured through a high impedance buffer to avoid altering the voltage level.

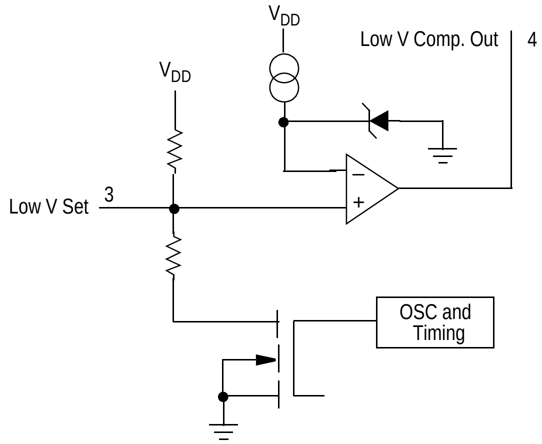


Figure 5. Low Battery Detection Circuitry

ALARM LATCHING APPROACHES

There are detection applications where the event that triggers the alarm can be instantaneous, such as shock or motion. In this case the Alarm IC would alarm for the brief moment that the event occurred and then stop. This is not always desirable, in particular during events where safety is of concern.

A latch can be implemented using the concept of **hysteresis** to alter the alarm threshold level and therefore remain in an alarm condition. It is very simple as it requires only one resistor, R3, connected to pin 1 (Detect Comp. Out.) and added in series to the alarm threshold voltage divider, R1 and R2, on pin 13 (See Figure 6). During a no alarm condition pin 1 is high which makes the alarm threshold voltage divider look like it would without R3 connected, keeping the alarm threshold at the initial desired point. When an alarm condition occurs pin 1 goes low, which in turn dramatically lowers the threshold voltage into the alarm comparator. When the alarm signal ends and the input voltage into pin 15 decreases, the alarm condition does not end because the alarm threshold has been lowered to below a standby voltage level. The MC14600 will continue in an alarm condition until the unit is RESET or pin 15 receives a signal below this alarming threshold. A RESET is implemented by connecting a switch to pin 1 that will toggle to V_{DD} through a resistor. This solution has the possibility that it will not latch on to the alarm condition indefinitely. As described above it is essentially just lowering the alarm threshold voltage so if the output from the sensor during a no alarm condition is below this threshold the latch will not work.

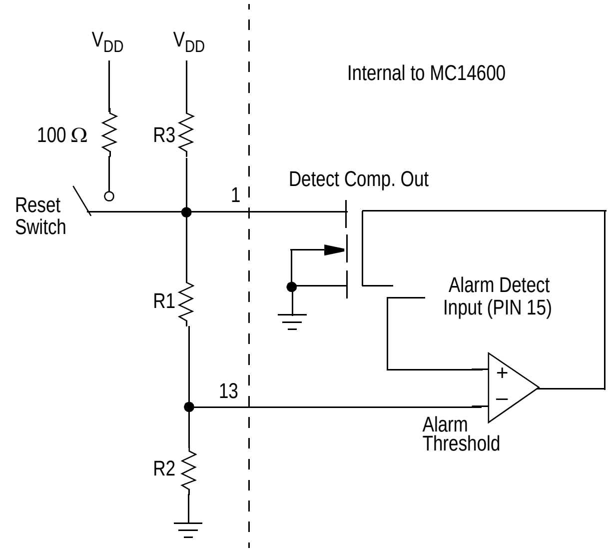


Figure 6. Latch Using Resistor in Series with Threshold Divider

SAMPLE DETECTION INPUTS

The MC14600 is a versatile device because its high impedance input pin allows it to be connected to a variety of systems and input signals. All that is required for an input is a device or circuit that will produce a change in voltage that corresponds to an environmental change. For example, a simple circuit around a thermistor could cause the MC14600 to alarm when the temperature gets too high. A photo transistor could be connected to cause an alarm for either the absence or existence of light.

Freescale also has sensors, specifically accelerometers and pressure sensors, that could be used as the input to the MC14600. An accelerometer, such as the MMA1201P, could be used to sense a shock or vibration. A possible solution is shown in Figure 7. The MC7805 is a voltage regulator that provides the 5 V supply required by the MMA1201P. Since the output of the MMA1201P resulting from a shock or vibration is very short some simple peak detection circuitry is required to keep the signal high long enough for the MC14600 to latch onto the alarm condition.

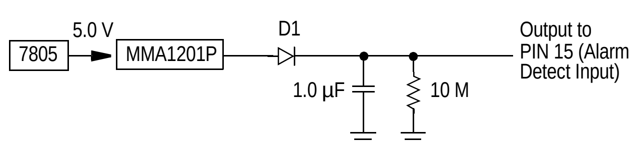


Figure 7. Shock and Vibration Detection Circuit

Freescale's pressure sensors can also provide the input to the MC14600. The MPX5000 series includes a wide variety of compensated and integrated pressure sensors with different pressure ranges, packaging and measurement options. One possible sensor is the MPXV5010. The output of the MPXV5010 can be fed directly into the input of the MC14600 (pin 15). If the latch described above is used with a pressure sensor resistors may be required at the output of the MPXV5010 to scale the output voltage (See Figure 8). This is because the output voltage for pressure sensors in the MPX5000 series under no pressure is 0.2 V, which may be below the lowered alarm threshold. (See previous section.)

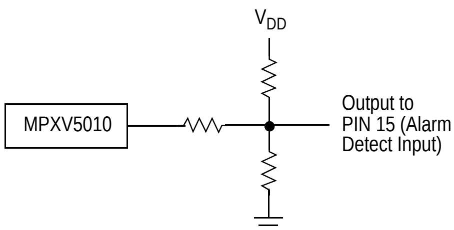


Figure 8. Pressure Detection Circuit

CONCLUSION

The MC14600 offers a simple solution for use in a wide variety of alarm applications. With a high impedance input pin it can be connected to many types of sensor devices. For sensor inputs that require a latched alarm condition there are several simple ways to add this option to the MC14600. It has the feature of not having a predetermined alarm threshold which gives it the flexibility of being set to any level as required by the application. The MC14600 has an internal horn driver that can drive a three leaded piezo horn with the addition of two resistors and one capacitor. The MC14600 integrates the features desired in alarm devices into a small and simple package that is still flexible enough for all types of alarm applications.

Alarm IC Sample Applications

by: Rudi Lenzen
Applications Engineer, Toulouse France

INTRODUCTION

The MC14600 is an integrated circuit (IC) designed for low-cost applications requiring an alarm to be triggered and heard. This device affords the designer a low-cost, easy-to-integrate solution, where board space and design time are at a premium. The Alarm IC can be used in multiple applications, such as personal, home and auto safety/security devices; door, gate and pool alarms; and even toys, where lasers and motion are employed, for example. However, this paper's purpose is to introduce you to just a few applications for which the MC14600 is a perfect fit.

GAS SENSOR APPLICATION

The MC14600, used with a flammable gas sensor and a few added components, provides a reliable solution for gas detection.

When gas leakage is detected, the sensing resistor decreases typically by a factor 3 or 4 as the gas concentration reaches 10 percent of the lower explosive limit. During the calibration sequence (test under gas), a variable resistor is used to set the trigger level of the Alarm IC comparator which, in response, drives a piezo horn.

By adding a thermistor—with negative temperature coefficient (NTC) in this case—in the detection circuit, the variation of the sensor resistance with temperature is easily compensated, avoiding false alarms when the room temperature increases.

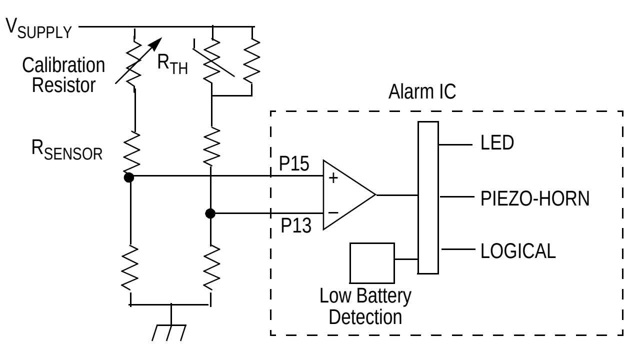


Figure 1. Gas Detection Example

The logical output is useful to signal a remote control station that a gas leakage has been detected.

When using a low power sensor, the circuit is fully compliant with a portable solution enhanced by the integrated low battery comparator indicating the state of the power supply.

TEMPERATURE LEVEL DETECTOR

When connected to a simple network of thermistor and resistors, the Alarm IC provides a portable solution for temperature control and supervision. The example hereafter uses an NTC thermistor.

An audible alarm will sound when the threshold value at the comparator input is reached. A logic output is usable for starting either a fan or a heater depending upon the required temperature.

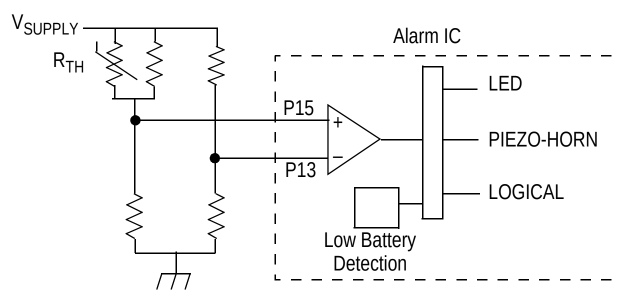


Figure 2. Temperature Level Example

WATER LEVEL DETECTOR

A single probe connected directly on the detection pin of the Alarm IC provides a portable solution for water level detection.

When liquid enters in contact with the probe, the resistor between the detection pin and the supply drops from an open circuit to a measurable value. With an appropriate choice of bridge resistors, the presence of liquid will trigger the comparator. The logic level can be connected to any monitoring system allowing pump starting, floodgate closing and others. This simple system is useful for numerous applications, such as swimming pool water level alarms, defrosting water level detectors, and in-house flood alarms.

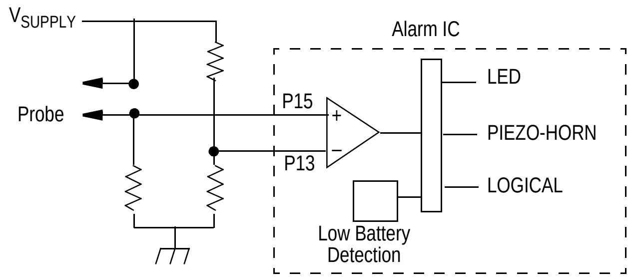


Figure 3. Water-Level Detection Example

MOTION INDICATOR

The Alarm IC can be used to detect motion and can be integrated into products, such as an ordinary clothes iron, where this is critical. Used with a low G accelerometer and a few logic components, the device can signal the user that there is a risk of clothes burning during use and that the iron must be shut off from the AC power after use. At the output of the accelerometer, a simple peak detection circuit is required to keep the signal active long enough.

When no movement is detected, the output comparator is low and the counter starts. A first "beep" is heard after a few seconds to advise that there is a risk of clothes burning. If no movement is detected, the counting continues and drives a flip-flop connected to pin 15 of the Alarm IC. The alarm is triggered and will continue on until a new movement is detected, resetting the counter.

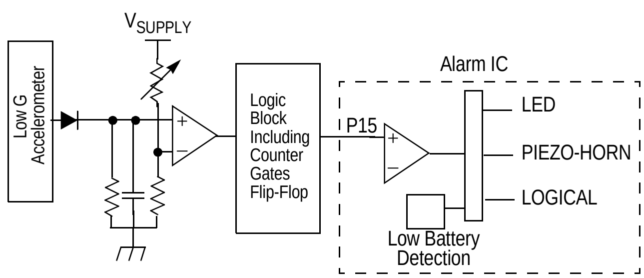


Figure 4. Motion Indicator Example

FILTER MONITOR

An ideal solution for air cleanliness control is provided when the Alarm IC is directly connected to an MPX5000 series pressure sensor. This sensor family is compensated in temperature and has its output signal directly exploitable (internally amplified). Therefore, the sensor can be connected to the detection pin of the circuit without any additional component. When a certain level of dust affects the efficiency of the filter, a differential pressure is measured and the Alarm IC comparator is triggered.

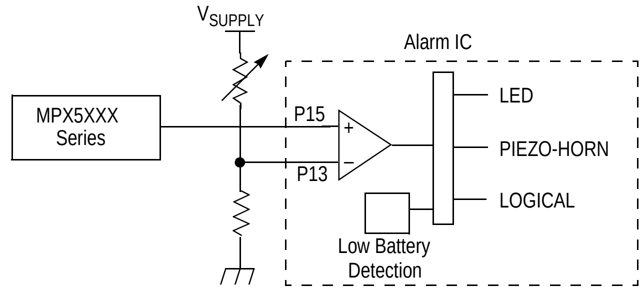
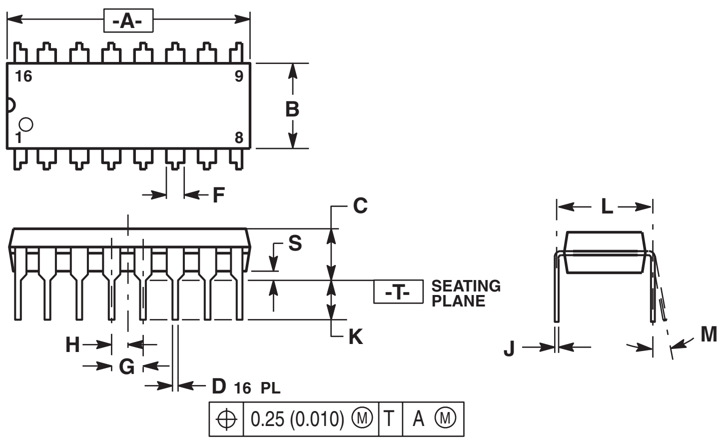


Figure 5. Pressure Change (Filter) Example

Package Dimensions



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
4. DIMENSION B DOES NOT INCLUDE MOLD FLASH.
5. ROUNDED CORNERS OPTIONAL.

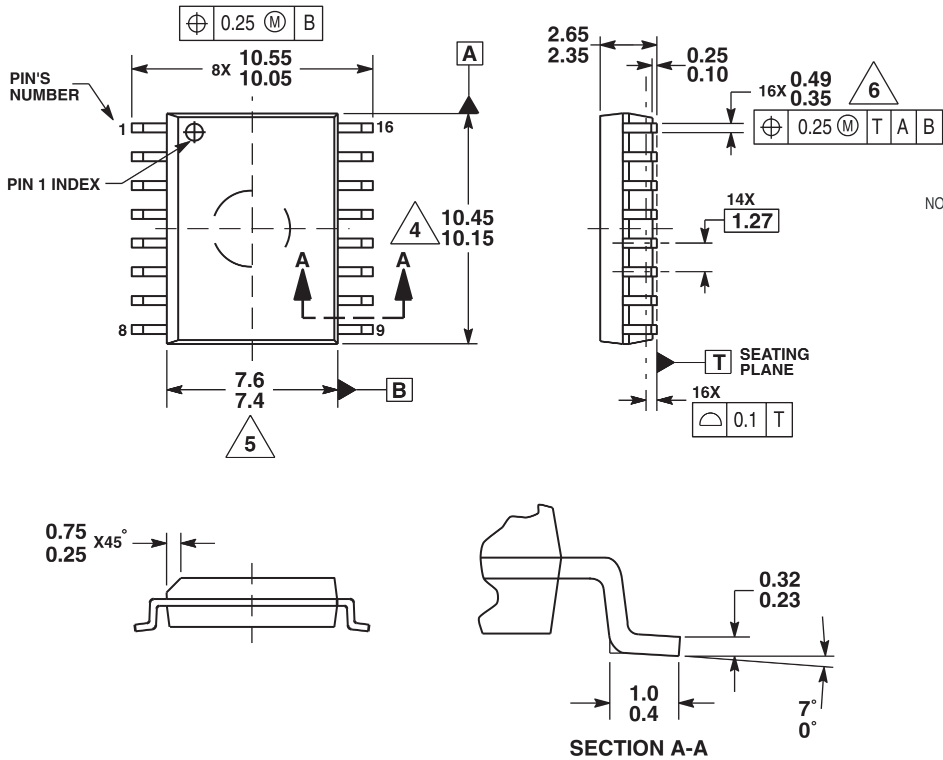
	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.740	0.770	18.80	19.55
B	0.250	0.270	6.35	6.85
C	0.145	0.175	3.69	4.44
D	0.015	0.021	0.39	0.53
F	0.040	0.70	1.02	1.77
G	0.100 BSC		2.54 BSC	
H	0.050 BSC		1.27 BSC	
J	0.008	0.015	0.21	0.38
K	0.110	0.130	2.80	3.30
L	0.295	0.305	7.50	7.74
M	0	10	0	10
S	0.020	0.040	0.51	1.01

STYLE 1:
PIN 1. CATHODE
2. CATHODE
3. CATHODE
4. CATHODE
5. CATHODE
6. CATHODE
7. CATHODE
8. CATHODE
9. ANODE
10. ANODE
11. ANODE
12. ANODE
13. ANODE
14. ANODE
15. ANODE
16. ANODE

STYLE 2:
PIN 1. COMMON DRAIN
2. COMMON DRAIN
3. COMMON DRAIN
4. COMMON DRAIN
5. COMMON DRAIN
6. COMMON DRAIN
7. COMMON DRAIN
8. COMMON DRAIN
9. GATE
10. SOURCE
11. GATE
12. SOURCE
13. GATE
14. SOURCE
15. GATE
16. SOURCE

CASE 648-08
ISSUE R
16-LEAD PLASTIC DIP

PACKAGE DIMENSIONS (CONTINUED)



NOTES:
1. DIMENSIONS ARE IN MILLIMETERS.
2. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
3. DATUMS A AND B TO BE DETERMINED AT THE PLANE WHERE THE BOTTOM OF THE LEADS EXIT THE PLASTIC BODY.
4. THIS DIMENSION DOES NOT INCLUDE MOLD FLASH, PROTRUSION OR GATE BURRS. MOLD FLASH, PROTRUSTION OR GATE BURRS SHALL NOT EXCEED 0.15mm PER SIDE. THIS DIMENSION IS DETERMINED AT THE PLANE WHERE THE BOTTOM OF THE LEADS EXIT THE PLASTIC BODY.
5. THIS DIMENSION DOES NOT INCLUDE INTER-LEAD FLASH OR PROTRUSIONS. INTER-LEAD FLASH AND PROTRUSIONS SHALL NOT EXCEED 0.25mm PER SIDE. THIS DIMENSION IS DETERMINED AT THE PLANE WHERE THE BOTTOM OF THE LEADS EXIT THE PLASTIC BODY.
6. THIS DIMENSION DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL NOT CAUSE THE LEAD WIDTH TO EXCEED 0.62mm.

CASE 751G-04
ISSUE D
16-LEAD SOIC

Section Five

Electric Field Sensor Overview

Freescale's electric field (E-field) sensor is intended for applications where non-contact sensing of objects is desired. It contains circuitry necessary to generate a low level electric field and measure the field loading caused by objects moved into the field. The sensor is intended for use in detecting objects in an electric field associated with an electrode. When connected to external electrodes, an electric field is created. The IC generates a low frequency sine wave. The frequency is adjustable by using an external resistor and is optimized for 125 kHz. The sine wave has very low harmonic content to avoid the generation of harmonic interference. The internal generator produces a nominal 5.0 V peak-to-peak output which is passed through an internal resistor of about 22 kOhm. The sensor contains support circuits for an MCU to allow the construction of a 2 chip E-field system.

Freescale's electric field sensor is economical and can be used for touch panel applications, liquid sensing and proximity detection

Electric Field Sensor Products

Mini Selector Guide

E-Field Sensing

Device	Description	Main Characteristics	No. of Channels	Current Limit (mA)	Max Voltage	Communications	Packaging	Status
MC33794	Electric Field Imaging Devices	125 kHz generator, shield drive, 9 electrodes + 2 V_{REF} outputs, detector, 5 V regulator, MCU support	11	75	40	ISO-9141	44-pin HSOP 54-pin SOICW	Production EVB

Electric Field Imaging Device

The 33794 is intended for applications where noncontact sensing of objects is desired. When connected to external electrodes, an electric field is created.

The 33794 is intended for use in detecting objects in this electric field. The IC generates a low-frequency sine wave. The frequency is adjustable by using an external resistor and is optimized for 120 kHz. The sine wave has very low harmonic content to reduce harmonic interference.

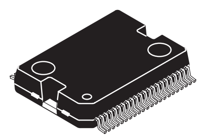
The 33794 also contains support circuits for a microcontroller unit (MCU) to allow the construction of a two-chip E-field system.

Features

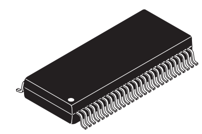
- Supports up to 9 Electrodes and 2 References or Electrodes
- Shield Driver for Driving Remote Electrodes Through Coaxial Cables
- +5.0 V Regulator to Power External Circuit
- ISO-9141 Physical Layer Interface
- Lamp Driver Output
- Watchdog and Power-ON Reset Timer
- Critical Internal Nodes Scaled and Selectable for Measurement
- High-Purity Sine Wave Generator Tunable with External Resistor

33794

ELECTRIC FIELD IMAGING DEVICE



DH SUFFIX
98ARH98330A
44-LEAD HSOP



DWB SUFFIX
98ASA10506D
54-LEAD SOICW-EP

ORDERING INFORMATION

Device	Temperature Range (T_A)	Package
MC33794DH/R2	-40°C to 85°C	44 HSOP
MC33794DWB/R2		54 SOICW-EP

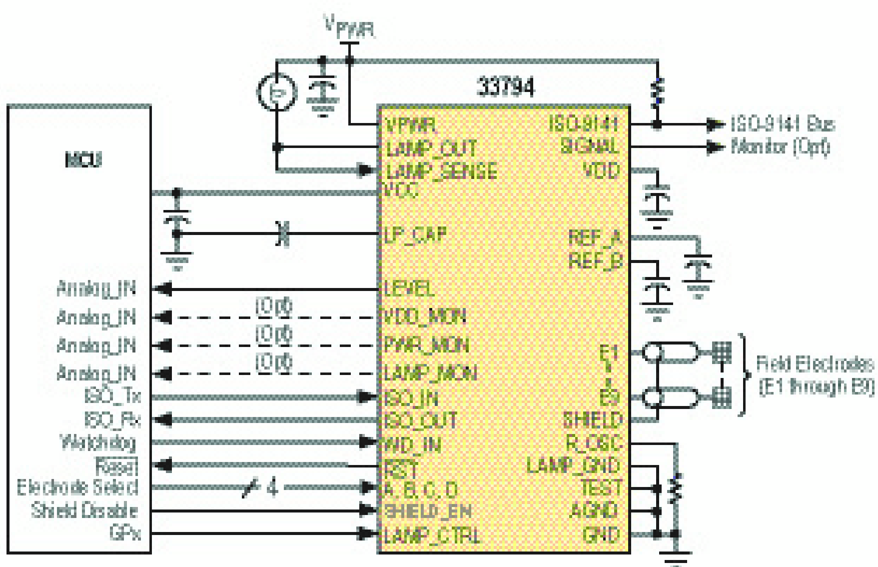
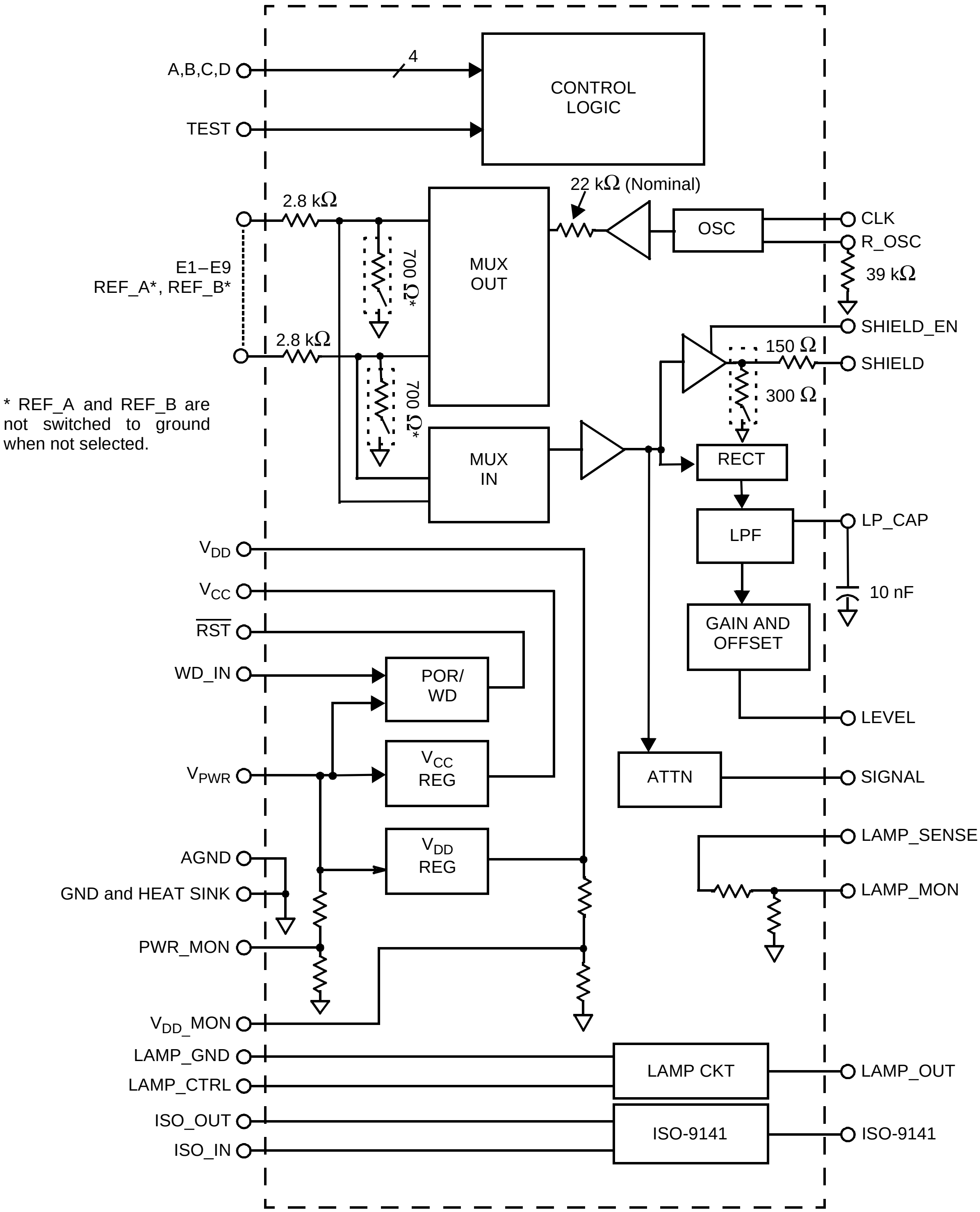


Figure 1. 33794 Simplified Application Diagram

INTERNAL BLOCK DIAGRAM



(Note: All Resistor Values are Nominal)

Figure 2. 33794 Simplified Internal Block Diagram

HSOP TERMINAL CONNECTIONS

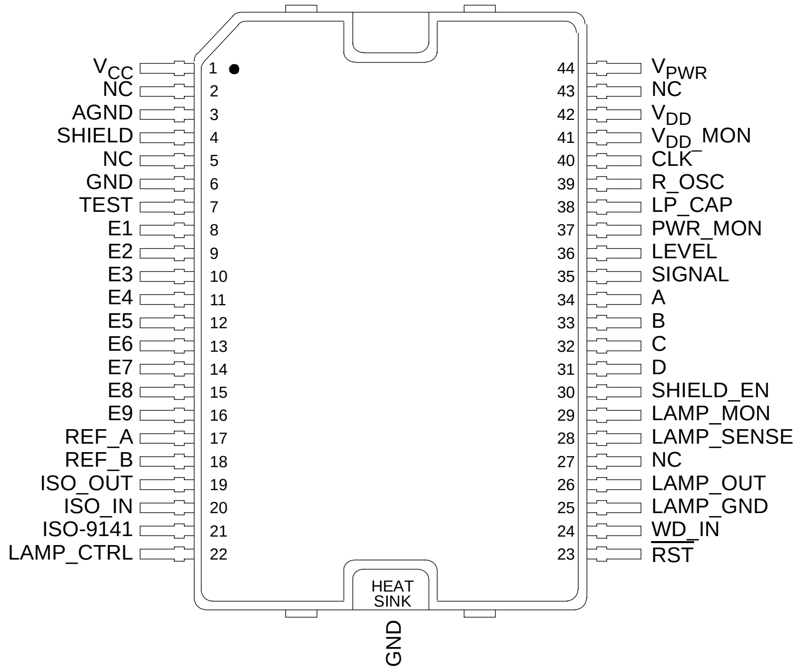


Figure 3. HSOP Terminal Connections

Table 1. HSOP Terminal Definitions

Terminal	Terminal Name	Formal Name	Definition
1	V_{CC}	5.0 V Regulator Output	This output terminal requires a 47 µF capacitor and provides a regulated 5.0 V for the MCU and for internal needs of the 33794.
2, 5, 27, 43	NC	No connect	These terminals may be used at some future date and should be left open.
3	AGND	Analog Ground	This terminal is connected to the ground return of the analog circuitry. This ground should be kept free of transient electrical noise like that from logic switching. Its path to the electrical current return point should be kept separate from the return for GND.
4	SHIELD	Shield Driver	This terminal connects to cable shields to cancel cable capacitance.
6, Heat Sink	GND	Ground	This terminal and metal backing is the IC power return and thermal radiator/ conductor.
7	TEST	Test Mode Control	This terminal is normally connected to circuit ground. There are special operating modes associated with this terminal when it is not at ground.
8–16	E1–E9	Electrode Connections	These are the electrode terminals. They are connected either directly or through coaxial cables to the electrodes for measurements. When not selected, these outputs are grounded through the internal resistance.
17, 18	REF_A, REF_B (E10, E11)	Reference Connections (Or as additional electrodes)	These terminals can be individually selected to measure a known capacitance value. Unlike E1-E9, these two inputs are not grounded when not selected.
19	ISO_OUT	ISO-9141 Output	This terminal translates ISO-9141 receive levels to 5.0 V logic levels for the MCU.

Table 1. HSOP Terminal Definitions(continued)

Terminal	Terminal Name	Formal Name	Definition
20	ISO_IN	ISO-9141 Input	This terminal accepts data from the MCU to be sent over the ISO-9141 communications interface. It translates the 5.0 V logic levels from the MCU to transmit levels on the ISO-9141 bus.
21	ISO-9141	ISO-9141 Bus	This terminal connects to the ISO-9141 bus. It provides the drive and detects signaling on the bus and translates it from the bus level to logic levels for the MCU.
22	LAMP_CTRL	Lamp Control	This signal is used to control the lamp driver. A high logic level turns on the lamp
23	$\overline{RST}$	Reset	This output is intended to generate the reset function of a typical MCU. It has a delay for Power-ON Reset, level detectors to force a reset when V_{CC} is out-of-range high or low, and a watchdog timer that will force a reset if WD_IN is not asserted at regular intervals. Timing is derived from the oscillator and will change with changes in the resistor attached to R_OSC.
24	WD_IN	Watchdog Input	This terminal must be asserted and deasserted at regular interval in order to prevent $\overline{RST}$ from being asserted. By having the MCU program perform this operation more often the allowed time, a check that the MCU is running and executing its program is assured. If this doesn't occur, the MCU will be reset. If the watchdog function is not desired, this terminal may be connected to CLK to prevent a reset from being issued.
25	LAMP_GND	Lamp Ground	This is the ground for the current from the lamp. The current into LAMP_OUT flows out through this terminal.
26	LAMP_OUT	Lamp Driver	This is an active low output capable of sinking current of a typical indicator lamp. One end of the lamp should be connected to a positive supply (for example, battery voltage) and the other side to this terminal. The current is limited to prevent damage to the IC in the case of a short or surge during lamp turn-on or burn-out.
28	LAMP_SENSE	Lamp Sense	This terminal is normally connected to the LAMP_OUT terminal. The voltage at this terminal is reduced and sent to LAMP_MON so the voltage at the lamp terminal is brought into the range of the analog-to-digital converter (ADC) in the MCU.
29	LAMP_MON	Lamp Monitor	This terminal is connected through a voltage divider to the LAMP_SENSE terminal. The voltage divider scales the voltage at this terminal so that battery voltage present when the lamp is off is scaled to the range of the MCU ADC. With the lamp off, this terminal will be very close to battery voltage if the lamp is not burned out and the terminal is not shorted to ground. This is useful as a lamp check.
30	SHIELD_EN	Shield Driver Disable	This terminal is used to enable the shield signal. The shield is disabled when SHIELD_EN is at a logic low (ground).
34–31	A, B, C, D	Selector Inputs	These input terminals control which electrode or reference is active. Selection values are shown in Table 1, Electrode Selection, page 15. These are logic level inputs.
35	SIGNAL	Undetected Signal	This is the undetected signal being applied to the detector. It has a DC level with the low radio frequency signal superimposed on it. Care must be taken to minimize DC loading of this signal. A shift of DC will change the center point of the signal and adversely affect the detection of the signal.
36	LEVEL	Detected Level	This is the detected, amplified, and offset representation of the signal voltage on the selected electrode. Filtering of the rectified signal is performed by a capacitor attached to LP_CAP.

Table 1. HSOP Terminal Definitions(continued)

Terminal	Terminal Name	Formal Name	Definition
37	PWR_MON	Power Monitor	This is connected through a voltage divider to V_{PWR}. It allows reduction of the voltage so it will fall within the range of the ADC on the MCU.
38	LP_CAP	Low-Pass Filter Capacitor	A capacitor on this terminal forms a low pass filter with the internal series resistance from the detector to this terminal. This terminal can be used to determine the detected level before amplification or offset is applied. A 10 nF capacitor connected to this terminal will smooth the rectified signal. More capacitance will increase the response time.
39	R_OSC	Oscillator Resistor	A resistor from this terminal to circuit ground determines the operating frequency of the oscillator. The 33794 is optimized for operation around 120 kHz.
40	CLK	Clock	This terminal provides a square wave output at the same frequency as the internal oscillator. The edges of the square wave coincide with the peaks (positive and negative) of the sine wave.
41	V_{DD}_MON	V_{DD} Monitor	This is connected through a voltage divider to V_{DD}. It allows reduction of the voltage so it will fall within the range of the ADC on the MCU.
42	V_{DD}	V_{DD} Capacitor	A capacitor is connected to this terminal to filter the internal analog regulated supply. This supply is derived from V_{PWR}.
44	V_{PWR}	Positive Power Supply Input	12 V power applied to this terminal will be converted to the regulated voltages needed to operate the part. It is also converted to 5.0 V (V_{CC}) and 8.5 V (V_{DD}) to power the MCU and external devices.

SOICW-EP TERMINAL CONNECTIONS

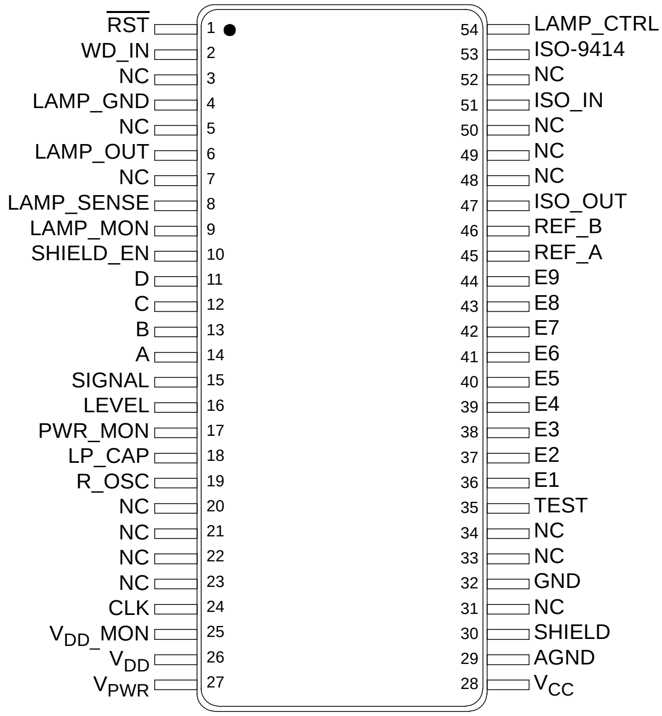


Figure 4. SOICW-EP Terminal Connections

Table 2. SOICW-EP TERMINAL FUNCTION DESCRIPTION

Terminal	Terminal Name	Formal Name	Definition
1	$\overline{RST}$	Reset	This output is intended to generate the reset function of a typical MCU. It has a delay for Power-ON Reset, level detectors to force a reset when V_{CC} is out-of-range high or low, and a watchdog timer that will force a reset if WD_IN is not asserted at regular intervals. Timing is derived from the oscillator and will change with changes in the resistor attached to R_OSC.
2	WD_IN	Watchdog In	This terminal must be asserted and deasserted at regular interval in order to prevent $\overline{RST}$ from being asserted. By having the MCU program perform this operation more often the allowed time, a check that the MCU is running and executing its program is assured. If this doesn't occur, the MCU will be reset. If the watchdog function is not desired, this terminal may be connected to CLK to prevent a reset from being issued.
3, 5, 7, 20–23, 31, 33, 34, 48–50, 52	NC	No connect	These terminals may be used at some future date and should be left open.
4	LAMP_GND	Lamp Ground	This is the ground for the current from the lamp. The current into LAMP_OUT flows out through this terminal.
6	LAMP_OUT	Lamp Driver	This is an active low output capable of sinking current of a typical indicator lamp. One end of the lamp should be connected to a positive supply (for example, battery voltage) and the other side to this terminal. The current is limited to prevent damage to the IC in the case of a short or surge during lamp turn-on or burn-out.

Table 2. SOICW-EP TERMINAL FUNCTION DESCRIPTION (continued)

Terminal	Terminal Name	Formal Name	Definition
8	LAMP_SENSE	Lamp Sense	This terminal is normally connected to the LAMP_OUT terminal. The voltage at this terminal is reduced and sent to LAMP_MON so the voltage at the lamp terminal is brought into the range of the analog-to-digital converter (ADC) in the MCU.
9	LAMP_MON	Lamp Monitor	This terminal is connected through a voltage divider to the LAMP_SENSE terminal. The voltage divider scales the voltage at this terminal so that battery voltage present when the lamp is off is scaled to the range of the MCU ADC. With the lamp off, this terminal will be very close to battery voltage if the lamp is not burned out and the terminal is not shorted to ground. This is useful as a lamp check.
10	SHIELD_EN	Shield Driver	This terminal is used to enable the shield signal. The shield is disabled when SHIELD_EN is a logic low (ground)
14–11	A, B, C, D	Selector Inputs	These input terminals control which electrode or reference is active. Selection values are shown in Table 1, Electrode Selection, page 15. These are logic level inputs.
15	SIGNAL	Undetected Signal	This is the undetected signal being applied to the detector. It has a DC level with the low radio frequency signal superimposed on it. Care must be taken to minimize DC loading of this signal. A shift of DC will change the center point of the signal and adversely affect the detection of the signal.
16	LEVEL	Detected Level	This is the detected, amplified, and offset representation of the signal voltage on the selected electrode. Filtering of the rectified signal is performed by a capacitor attached to LP_CAP.
17	PWR_MON	Power Monitor	This is connected through a voltage divider to V_{PWR}. It allows reduction of the voltage so it will fall within the range of the ADC on the MCU.
18	LP_CAP	Low-Pass Filter Capacitor	A capacitor on this terminal forms a low pass filter with the internal series resistance from the detector to this terminal. This terminal can be used to determine the detected level before amplification or offset is applied. A 10 nF capacitor connected to this terminal will smooth the rectified signal. More capacitance will increase the response time .
19	R_OSC	Oscillator Resistor	A resistor from this terminal to circuit ground determines the operating frequency of the oscillator. The 33794 is optimized for operation around 120 kHz.
24	CLK	Clock	This terminal provides a square wave output at the same frequency as the internal oscillator. The edges of the square wave coincide with the peaks (positive and negative) of the sine wave.
25	V_{DD}_MON	V_{DD} Monitor	This is connected through a voltage divider to V_{DD}. It allows reduction of the voltage so it will fall within the range of the ADC on the MCU.
26	V_{DD}	V_{DD} Capacitor	A capacitor is connected to this terminal to filter the internal analog regulated supply. This supply is derived from V_{PWR}.
27	V_{PWR}	Positive Power Supply	12 V power applied to this terminal will be converted to the regulated voltages needed to operate the part. It is also converted to 5.0 V (V_{CC}) and 8.5 V (V_{DD}) to power the MCU and external devices.
28	V_{CC}	5.0 V Regulator Output	This output terminal requires a 47 μF capacitor and provides a regulated 5.0 V for the MCU and for internal needs of the 33794.
29	AGND	Analog Ground	This terminal is connected to the ground return of the analog circuitry. This ground should be kept free of transient electrical noise like that from logic switching. Its path to the electrical current return point should be kept separate from the return for GND.
30	SHIELD	Shield Driver	This terminal connects to cable shields to cancel cable capacitance.
32	GND	Ground	This terminal and metal backing is the IC power return and thermal radiator/ conductor.

Table 2. SOICW-EP TERMINAL FUNCTION DESCRIPTION (continued)

Terminal	Terminal Name	Formal Name	Definition
35	TEST	Test Mode Control	This terminal is normally connected to circuit ground. There are special operating modes associated with this terminal when it is not at ground.
36 – 44	E1 – E9	Electrode Connections	These are the electrode terminals. They are connected either directly or through coaxial cables to the electrodes for measurements. When not selected, these outputs are grounded through the internal resistance.
45, 46	REF_A, REF_B (E10, E11)	Reference Connections (Or as additional electrodes)	These terminals can be individually selected to measure a known capacitance value. Unlike E1-E9, these two inputs are not grounded when not selected.
47	ISO_OUT	ISO-9141 Output	This terminal translates ISO-9141 receive levels to 5.0 V logic levels for the MCU.
51	ISO_IN	ISO-9141 Input	This terminal accepts data from the MCU to be sent over the ISO-9141 communications interface. It translates the 5.0 V logic levels from the MCU to transmit levels on the ISO-9141 bus.
53	ISO-9141	ISO-9141 Bus	This terminal connects to the ISO-9141 bus. It provides the drive and detects signaling on the bus and translates it from the bus level to logic levels for the MCU.
54	LAMP_CTRL	Lamp Control	This signal is used to control the lamp driver. A high logic level turns on the lamp.

MAXIMUM RATINGS

Table 3. Maximum Ratings

All voltages are with respect to ground unless otherwise noted.

Rating	Symbol	Value	Unit
Peak VPWR Voltage	V_{PWRPK}	40	V
Double Battery 1 Minute Maximum T_A = 30°C	V_{DBLBAT}	26.5	V
ESD Voltage Human Body Model [(1)] Machine Model [(2)]	V_{ESD1} V_{ESD2}	±2000 ±200	V
Storage Temperature	T_{STG}	-55 to 150	°C
Operating Ambient Temperature	T_A	-40 to 85	°C
Operating Junction Temperature	T_J	-40 to 125	°C
Thermal Resistance Junction-to-Ambient [(3)] Junction-to-Case [(4)] Junction-to-Board [(5)]	$R_{\theta JA}$ $R_{\theta JC}$ $R_{\theta JB}$	41 0.2 3.0	°C/W
Lead Soldering Temperature (for 10 Seconds)	T_{SOLDER}	260	°C

Notes

1. ESD1 performed in accordance with the Human Body Model (C_{ZAP} = 100 pF, R_{ZAP} = 1500 Ω).
2. ESD2 performed in accordance with the Machine Model (C_{ZAP} = 200 pF, R_{ZAP} = 0 Ω).
3. Junction temperature is a function of on-chip power dissipation, package thermal resistance, mounting site (board) temperature, ambient temperature, air flow, power dissipation of other components on the board, and board thermal resistance. In accordance with SEMI G38-87 and JEDEC JESD51-2 with the single layer board horizontal.
4. Indicates the average thermal resistance between the die and the case top surface as measured by the cold plate method (MILSPEC 883 Method 1012.1) with the cold plate temperature used for the case temperature.
5. Thermal resistance between the die and the printed circuit board per JEDEC JESD51-8. Board temperature is measured on the top surface of the board near the package.

STATIC ELECRTICAL CHARACTERISTICS

Table 4. Static Electrical Caracteristics

Characteristics noted under condition -40°C ≤ T_J ≤ 125°C. Voltages are relative to GND unless otherwise noted.

Characteristic	Symbol	Min	Typ	Max	Unit
Voltage Regulators					
5.0 V Regulator Voltage 7.0 V ≤ V_{PWR} ≤ 18 V, 1.0 mA ≤ I_L ≤ 75 mA, C_{FILT} = 47 µF	V_{CC}	4.75	5.0	5.25	V
Analog Regulator Voltage 9.0 V ≤ V_{PWR} ≤ 18 V, C_{FILT} = 47 µF	V_{ANALOG}	8.075	8.5	8.925	V
VCC Out-of-Range Voltage Detector					
5.0 V Low Voltage Detector	V_{LV5}	4.0	4.52	4.72	V
5.0 V High Voltage Detector	V_{HV5}	5.26	5.55	5.83	V
5.0 V Out-of-Range Voltage Detector Hysteresis	V_{HYS5}	–	0.05	–	V
ISO-9141 Communications Interface					
Input Low Level (6)	VIF_{INLO}	0.30	0.33	–	V/V
Input High Level (6)	VIF_{INHI}	–	0.53	0.7	V/V
Input Hysteresis (6)	VIF_{INHYS}	–	0.2	–	V/V
Output Low (6)	VIF_{OLO}	–	–	0.2	V/V
Output High (6)	VIF_{OHI}	0.8	–	–	V/V
Output Breakdown I_{OUT} = 20 mA	VIF_Z	40	–	–	V
Output Resistance I_{OUT} = 40 mA	RIF_{ON}	–	58	–	Ω
Current Limit Sinking Current with V_{OUT} < 0.3 $V_{PWR\ IN}$	IIF_{LIM}	60	90	120	mA
Output Propagation Delay Out to ISO-9141, C_{LOAD} = 20 pF	TIF_{DLY}	–	–	8.0	µs
ISO In					
Logic Output Low I_{SINK} = 1.0 mA	VIF_{OLO}	–	–	1.0	V
Logic Output Pull-Up Current V_{OUT} = 0 V	IIF_{PU}	100	–	–	µA
Input to Output Propagation Delay ISO-9141 to ISO_IN, R_L = 10 kΩ, C_L = 470 pF, 7.0 V ≤ V_{PWR} ≤ 18 V	TIF_{DLY}	–	–	5.4	µs

Notes

6. Ratio to V_{PWR}

Table 4. Static Electrical Caracteristics (continued)

Characteristics noted under condition -40°C ≤ T_J ≤ 125°C. Voltages are relative to GND unless otherwise noted.

Characteristic	Symbol	Min	Typ	Max	Unit
Electrode Signals					
Total Variance Between Electrode Measurements [7] All C_{LOAD} = 15 pF	ELV_{VAR}	–	–	3.0	%
Electrode Maximum Harmonic Level Below Fundamental [8] 5.0 pF ≤ C_{LOAD} ≤ 100 pF	EL_{HARM}	–	-20	–	dB
Electrode Transmit Output Range 5.0 pF ≤ C_{LOAD} ≤ 100 pF	EL_{TXV}	1.0	–	8.0	V
Receive Input Voltage Range	RX_V	0	–	9.0	V
Grounding Switch on Voltage I_{SW} = 1.0 mA	SW_{VON}	–	–	5.0	V
Shield Driver					
Shield Driver Output Level 0 pF ≤ C_{LOAD} ≤ 500 pF	SD_{TXV}	1.0	–	8.0	V
Shield Driver Input Range	SD_{IN}	0	–	9.0	V
Grounding Switch on Voltage [9]	SW_{VON}	–	–	1.5	V
Logic I/O					
CMOS Logic Input Low Threshold	V_{THL}	0.3	–	–	V_{CC}
Logic Input High Threshold	V_{THH}	–	–	0.7	V_{CC}
Voltage Hysteresis	V_{HYS}	–	0.06	–	V_{CC}
Input Current V_{IN} = V_{CC} V_{IN} = 0 V	I_{IN}	 10 -5.0	 – –	 50 5.0	µA
Signal Detector					
Detector Output Resistance	DET_{RO}	–	50	–	kΩ
LP_CAP to LEVEL Gain	A_{REC}	3.6	4.0	4.4	A_V
LP_CAP to LEVEL Offset	V_{RECOFF}	-3.3	-3.0	-2.7	V

Notes

7. Verified by design. Not tested in production.
8. Verified by design and characterization. Not tested in production.
9. Current into grounded terminal under test = 1.0 mA.

Table 4. Static Electrical Caracteristics (continued)

Characteristics noted under condition -40°C ≤ T_J ≤ 125°C. Voltages are relative to GND unless otherwise noted.

Characteristic	Symbol	Min	Typ	Max	Unit
LAMP DRIVER					
On Resistance I_{IN} = 400 mA	RLD_{DSON}	–	1.75	3.5	Ω
Current Limit V_{OUT} = 1.0 V	ILD_{LIM}	0.7	–	1.7	A
On-Voltage I_{OUT} = 400 mA	VLD_{ON}	–	–	1.4	V
Breakdown Voltage I_{OUT} = 100 µA, Lamp Off	VLD_Z	40	–	–	V
VOLTAGE MONITORS					
LAMP_MON to LAMP_SENSE Ratio	LMP_{MON}	0.1950	0.20524	0.2155	V/V
PWR_MON to V_{PWR} Ratio	PWR_{MON}	0.2200	0.2444	0.2688	V/V
V_{DD}_MON to V_{DD} Ratio	V_{DDMON}	0.45	0.5	0.55	V/V
SUPPLY					
I_{DD} (V_{PWR} = 14 V)[(10)] (Quiescent supply current measured over temperature. Assumes that no external devices connected to internal voltage regulators)	I_{DD}	6.0	7.0	8.0	mA

DYNAMIC ELECTRICAL CHARACTERISTICS

Table 5. Dynamic Electrical Characteristics

Characteristics noted under condition -40°C ≤ T_J ≤ 125°C. Voltages are relative to GND unless otherwise noted.

Characteristic	Symbol	Min	Typ	Max	Unit
OSC					
OSC Frequency Stability [(10), (11)]	f_{STAB}	–	–	10	%
OSC Center Frequency R_OSC = 39 kΩ	f_{OSC}	–	120	–	kHz
Harmonic Content [(10)] 2nd through 4th Harmonic Level 5th and Higher	$OSCH_{ARM}$	 – –	 – –	 -20 -60	dB
Shield Driver					
Shield Driver Maximum Harmonic level below Fundamental [(10)] 10 pF ≤ C_{LOAD} ≤ 500 pF	SD_{HARM}	–	-20	–	dB
Shield Driver Gain Bandwidth Product [(10)] Measured at 120 kHz	SD_{GBW}	–	4.5	–	MHz
POR					
POR Time-Out Period	t_{PER}	9.0	–	50	ms
WATCHDOG					
Watchdog Time-Out Period	t_{WDPER}	50	68	250	ms
Watchdog Reset Hold Time	t_{WDHLD}	9.0	–	50	ms
Lamp Driver					
Short Circuit to Battery Survival Time	t_{SCB}	3.0	–	–	ms

Notes

10. Verified by design and characterization. Not tested in production.
11. Does not include errors in external reference parts.

ELECTRODE SELECTION

Table 6. Electrode Selection

TERMINAL/SIGNAL	D	C	B	A
Source (internal)	0	0	0	0
E1	0	0	0	1
E2	0	0	1	0
E3	0	0	1	1
E4	0	1	0	0
E5	0	1	0	1
E6	0	1	1	0
E7	0	1	1	1

Table 6. Electrode Selection (continued)

TERMINAL/SIGNAL	D	C	B	A
E8	1	0	0	0
E9	1	0	0	1
REF_A	1	0	1	0
REF_B	1	0	1	1
Internal OSC	1	1	0	0
Internal OSC after 22 kΩ	1	1	0	1
Internal Ground	1	1	1	0
Reserved	1	1	1	1

SYSTEM/APPLICATION INFORMATION

INTRODUCTION

The 33794 is intended for use in detecting objects using an electric field. The IC generates a low radio frequency sine wave. The frequency is set by an external resistor and is optimized for 120 kHz. The sine wave has very low harmonic content to reduce potential interference at higher harmonically related frequencies. The internal generator produces a nominal 5.0 V peak-to-peak output that is passed through an internal resistor of about 22 kΩ. An internal multiplexer routes the signal to one of 11 terminals under control of the ABCD input terminals. A receiver multiplexer simultaneously connected to the selected electrode routes its signal to a detector, which converts the sine wave to a DC level. This DC level is filtered by an external capacitor and is multiplied and offset to increase sensitivity. All of the unselected electrode outputs are grounded by the device. The current flowing between the selected electrode and the other grounded electrodes plus other grounded objects around the electrode causes a voltage drop across the internal resistance. Objects brought into or out of the electric field change the current and resulting voltage at the IC terminal, which in turn reduces the voltage at LP_CAP and LEVEL.

A shield driver is included to minimize the effect of capacitance caused by using coaxial cables to connect to remote electrodes. By driving the coax shield with this signal, the shield voltage follows that of the center conductor, significantly reducing the effective capacitance of the coax and maintaining sensitivity to the capacitance at the electrode.

The 33794 is made to work with and support a microcontroller. It provides two voltage regulators, a Power-ON-reset/out-of-range voltage detector, watchdog circuit, lamp driver and sense circuit, and a physical layer ISO-9141 communications interface.

BLOCK DIAGRAM COMPONENTS

Refer to Figure 2, 33794 Internal Block Diagram, page 4, for a graphic representation of the block diagram information in this section.

OSC

This section generates a high purity sine wave. The center frequency is controlled by a resistor attached to R_OSC. The normal operating frequency is around 120 kHz. A square wave version of the frequency output is available at CLK. Timing for the Power-ON Reset and watchdog (POR/WD) circuit are derived from this oscillator’s frequency.

MUX OUT

This circuit directs the output of the sine wave to one of nine possible electrode outputs or two reference terminals. All unused terminals are automatically grounded (except the two reference terminals). The selected output is controlled by the ABCD inputs.

ELECTRODES E1-E9

These are the electrode terminals. They are connected either directly or through coaxial cables to the electrodes for measurements. Every electrode has a 2.8K (± 20%) resistor in series with the external pad and the internal electronics. Only one of these electrodes can be selected at a time for capacitance measurement. All of the other unselected electrodes are switched to ground by an internal switch that has an internal on-resistance of approximately 700 Ω. The signal at the selected electrode terminal is routed to the shield driver amplifier by an internal switch. All of the coaxial cable shields should be isolated from ground and connected SHIELD.

REF_A & REF_B ELECTRODES

These terminals can be individually selected like E1 through E9. Unlike E1 through E9, these terminals are not grounded when not selected. Both terminals have a 2.8K (± 20%) resistor in series with the external pad and the internal electronics. The purpose of these terminals is to allow known capacitors to be measured. By using capacitors at the low and high end of the expected range, absolute values for the capacitance on the electrodes can be computed. These terminals can be used for electrodes E10 and E11 with the only difference is that these two electrodes will not be grounded when not selected.

SHIELD DRIVE

This circuit connects provides a buffered version of the returned AC signal from the electrode. Since it nearly has the same amplitude and phase as the electrode signal, there is little or no potential difference between the two signals thereby cancelling out any electric field. In effect, the shield drive and isolate the electrode signal from external virtual grounds. A common application is to connect the Shield Drive to the shield of a coax cable used to connect an electrode to the corresponding electrode terminal. Another typical use is to drive a ground plane that is used behind an array of touch senors electrodes in order to cancel out any virtual grounds that could attenuate the AC signal.

MUX IN

This circuit connects the selected electrode, reference, or one of two internal nodes to an amplifier/detector. The selection is controlled by the ABCD inputs and follows the driven electrode/reference when one is selected.

RECT

The rectifier circuit detects the level from MUX IN by offsetting the midpoint of the sine wave to zero volts and inverting the waveform when it is below the midpoint. It is important to avoid DC loading of the signal, which would cause a shift in the midpoint voltage of the signal.

LPF

The rectified sine wave is filtered by a low pass function formed by an internal resistance and an external capacitance attached to LP_CAP. The nominal value of the internal resistance is 50 kΩ. The value of the external capacitor is selected to provide filtering of noise while still allowing the desired settling time for the detector output. A 10 nF capacitor would allow 99% settling in less than 5.0 ms. In practice, it is recommended you wait at least 1.5 ms after selecting an electrode before reading LEVEL.

GAIN AND OFFSET

This circuit multiplies the detected and filtered signal by a gain and offsets the result by a DC level. This results in an output range that covers 1.0 V to 4.0 V for capacitive loading of the field in the range of 10 pF to 100 pF. This allows higher sensitivity for a digital-to-analog converter with a 0 V-to-5.0 V input range.

ATTN

This circuit passes the undetected signal to SIGNAL for external use.

SHIELD_EN

A logic low on this input disables the shield drive. The purpose of doing this is to be able to detect that the shield signal is not working or the connection to the coax shields is broken. If either of these conditions exists, there will be little or no change in the capacitance measured when the SHIELD_EN is changed. If the SHIELD output is working and properly connected, the capacitance of the coax will not be cancelled when this terminal is asserted and the measured capacitance will appear to change by approximately the capacitance between the center conductor and the shield in the coax.

LAMP CKT

This section controls the operation of the LAMP_OUT terminal. When LAMP_CTRL is asserted, LAMP_OUT is pulled to LAMP_GND. If one side of an indicator lamp or LED (with appropriate current setting resistor) is connected to a positive voltage source and the other is connected to LAMP_OUT, and LAMP_GND is connected to ground, the lamp will light. This circuit provides current limiting to prevent damage to itself in the case of a shorted lamp or during a high-surge condition typical of an incandescent lamp burnout.

LAMP_GND should always be connected to ground even if the lamp circuit is not used.

ISO-9141

This circuit connects to an ISO-9141 bus to allow remote communications. ISO_IN is data from the bus to the MCU and ISO_OUT is data to drive onto the bus from the MCU.

POR/WD

This circuit is a combined Power-ON Reset and watchdog timer. The $\overline{RST}$ output is held low until a certain amount of time after the V_{CC} output has remained above a minimum operating threshold. If V_{CC} falls below the level at any time, $\overline{RST}$ is pulled low again and held until the required time after V_{CC} has returned high. An over voltage circuit is also included, which will force a reset if V_{CC} rises above a maximum voltage. The watchdog function also can force $\overline{RST}$ low if too long an interval is allowed to pass between positive transitions on WD_IN.

V_{CC} REG

This circuit converts an unregulated voltage from VIN to a regulated 5.0 V source, which is used internally and available for other components requiring a regulated voltage source.

V_{DD} REG

This is a regulator for analog devices that require more than 5.0 V. This is used by the device and some current is available to operate op-amps and other devices. By having this higher voltage available, some applications can avoid the need for a rail-to-rail output amplifier and still achieve the 0 V-to-5.0 V output for a digital-to-analog converter input. V_{DDMON} is a divided output from V_{DD}, which allows a 0 V-to-5.0 V ADC to measure V_{DD}. Normal value for V_{DD} is 8.5 Volts.

CONTROL LOGIC

This contains the logic that decodes and controls the MUXes and some of the test modes

APPLICATION INFORMATION

The 33794 is intended to be used where an object's size and proximity are to be determined. This is done by placing electrodes in the area where the object will be. The proximity of an object to an electrode can be determined by the increase in effective capacitance as the object gets closer to the electrode and modifies the electric field between the electrode and surrounding electrically common objects. The shape and size of an object can be determined by using multiple electrodes over an area and observing the capacitance change on each of the electrodes. Those that don't change have nothing near them, and those that do change have part of the object near them.

A “capacitor” can be formed between the driving electrode and the object, each forming a “plate” that holds the electric charge. Capacitance is directly proportional to the area of the electrode plates. Doubling the area doubles the capacitance. Capacitance is also directly proportional to the *dielectric constant* of the material between the plates. Air typically has a dielectric constant of 1 (unity) whereas water can have a dielectic constant of 80 (which means the capacitance is roughly 80 times larger). Plastics and glass that are commonly used in touch panel applications have dielectric constants greater than unity. A third consideration is that capacitance is *inversely proportional* to the distance between the plates. Doubling the distance between the two plates will reduce capacitance by four. This property can be exploited in cases where small distances need to be measured.

Form the above, it can be seen that increased detection sensitivity is a function of the plate size, the dielectric constant of the material between the plates, and the distance between them.

The voltage measured at LEVEL is an inverse function of the capacitance between the electrode being measured and the surrounding electrodes and other objects in the electric field surrounding the electrode. Increasing capacitance results in decreasing voltage. The value of series resistance (22 kΩ) was chosen to provide a nearly linear relationship at 120 kHz over a range of 10 pF to 100 pF.

The measured value may change with any change in frequency, series resistance, driving voltage, the dielectric constant of the capacitor, or detector sensitivity. These can change with temperature and time. There are several ways to compensate for these changes. One method uses the REF_A and REF_B capacitors. Another method may use long term averages to set a baseline value.

Using REF_A and REF_B, a typical measurement algorithm would start by measuring the voltage for two known value capacitors (attached to REF_A and REF_B). The value of these capacitors would be chosen to be near the minimum and maximum values of capacitance expected to be seen at the electrodes. These reference voltages and the known capacitance values are then used with the electrode measurement voltage to determine the capacitance seen by the electrode. This method can be used to detect short- and long-term changes due to objects in the electric field and significantly reduce the effect of temperature-and time-induced changes.

Another approach is to run long term averaging of the electrode values. Long term, in this case, may mean several seconds. These long term averages are then used as a set point so that short term changes in the field intensity can be reliably determined. This is typically the method used for touch panel applications.

The 33794 does not contain an ADC. It is intended to be used with an MCU that contains one. Offset and gain have been added to the 33794 to maximize the sensitivity over the range of 0 pF to 100 pF. An 8-bit ADC can resolve around 0.4 pF of change and a 10-bit converter around 0.1 pF. Higher resolution results in more distant detection of smaller objects. Due to the relatively slow data access resquirements (approximately 2 ms per electrode), digitial over-sampling techniques can be used to extend the resolution of 8- or 10-bit converters by 2 or 3 bits.

DC loading on the electrodes should be avoided. A typical situation where this might occur is if moisture gets in direct contact between electrodes, or between an electrode and ground or shield drive. The signal is generated with a DC offset that is more than half the peak-to-peak level. This keeps the signal positive above ground at all times. The detector uses this voltage level as the midpoint for detection. All signals below this level are inverted and added to all signals above this level. Loading of the DC level will cause some of the positive half of the signal to be inverted and added and will change the measurement.

If it is not possible to assure that the electrodes will always have a high DC resistance to ground source, a series capacitor of about 10 nF should be connected between the IC electrode terminals and the electrodes. This capacitor will block an DC bias voltages to the detector. Note that it is also advisable to add a DC blocking capacitor in series with the Shield Driver output as well.

EXAMPLE APPLICATION DIAGRAM

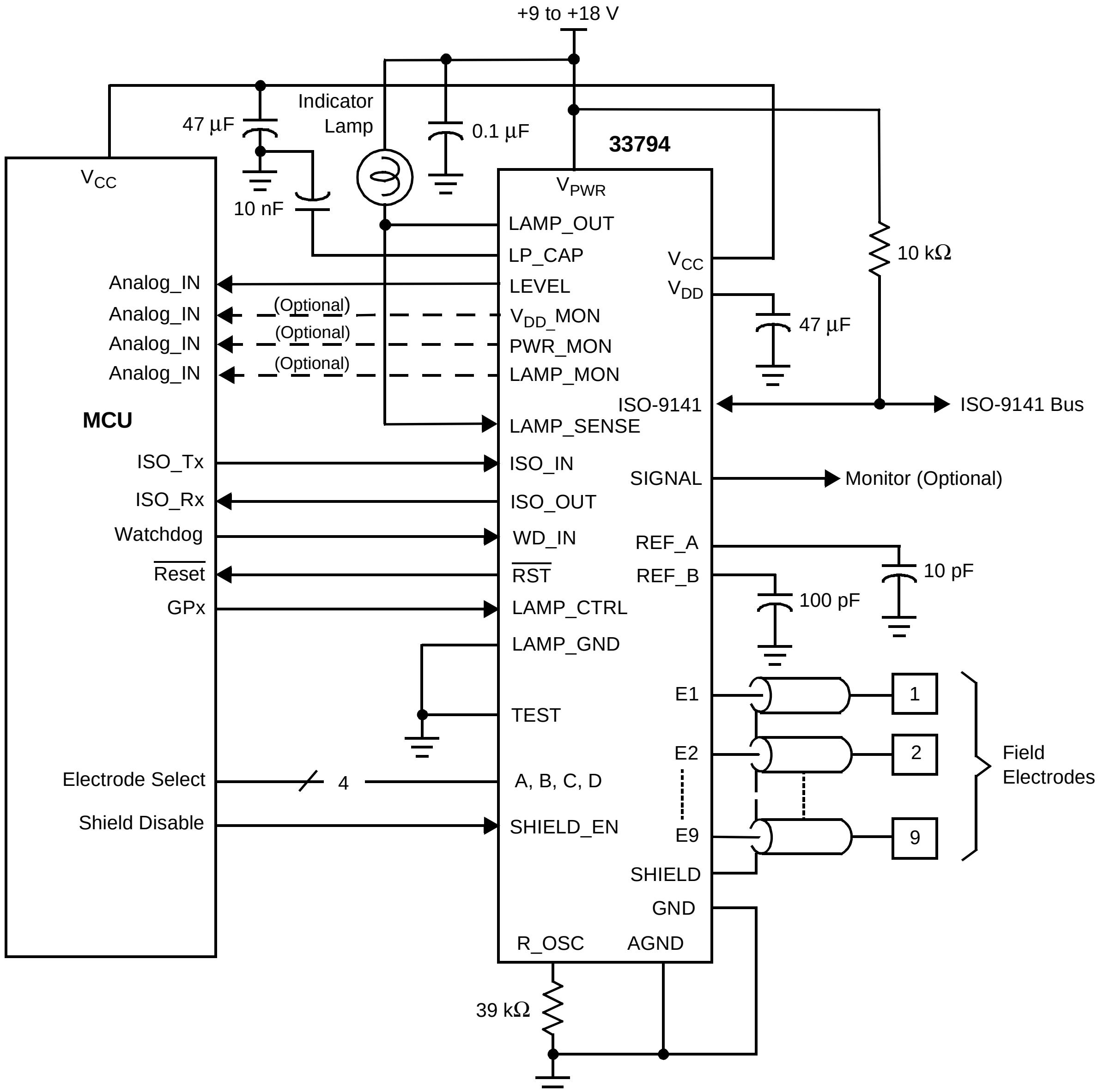


Figure 5. Example Application Diagram

Touch Panel Applications Using the MC33794 E-Field IC

E-FIELD SENSING: AN ALTERNATIVE SOLUTION TO CONTROL PANEL APPLICATIONS

Human touch can be a useful tool. Control panels, appliances, heavy machinery, toys, lighting controls, and anything that has a mechanical switch or push button requires some sort of human interaction to operate. Traditionally, pushbuttons are made out of mechanical switches and/or multilayer resistive touchpads that can deteriorate and become less dependable over time. This is because most of these switches require physical displacement and pressure which are susceptible to wear-out, contact bounce, corrosion and arcing.

The MC33794 Electric Field Imaging device from Freescale Semiconductor, Inc. offers an alternative to mechanical pushbuttons for control panel applications. The MC33794 Integrated Circuit (IC) contains the circuitry necessary to generate a low level electric field and measure the field loading caused by objects moving into or out of the field. It is ideal for applications that desire non-contact sensing, proximity detection, and three-dimensional E-field imaging. The IC integrates support for a microcontroller and up to nine electrodes, which can be used independently to determine the size or location of an object in a weak electric field.

With the MC33794, membrane switches and resistive touchpads can be replaced with an array of touchpads consisting of conductive electrodes embedded beneath an insulating surface. Since it has the capability of sensing touch and proximity through the insulating surface, without direct electrical contact with the electrode metal, problems of wear, contamination, and corrosion are eliminated. This capability is also important for sophisticated touch control applications, including a user interface panel that is sensitive to different degrees of proximity - enabling the system to go from standby to active mode as a finger approaches the panel.

Further, one of the MC33794 key features that surpass simple capacitive based sensors is its on-board shield driver. Touchpads do not have to be combined and located at one centralized location. With proper shielding, coaxial cables or PCB layers can be used to connect remote touchpads up to a few meters away, while obtaining measurements as accurately as if the touchpads were directly connected to the IC. The MC33794 does this by driving a signal on the shield of the coax or a PCB trace which closely follows the signal conductor voltage. The current which flows through the electric field between two conductors is proportional to the voltage difference between them. With little or no voltage difference between them, there is little or no current flow between the electrode conductor and the shielding trace or coax shield. In a cook top application, for example, this capability allows the activation touchpad for an individual burner to be in different places, rather than at the usual centralized location, without requiring a separate IC at each location. The same IC could be used to activate the down-draft vent and oven with their touch control near what they are controlling.

The potential for the chip goes well beyond touch panel applications. Target applications of the IC includes appliances, machine tools, security systems, and automotive safety systems. From liquid level sensing, to occupant classification, to theft detection, the applications list for the MC33794 is growing.

HOW THE MC33794 E-FIELD SENSOR WORKS

The MC33794 electric field is derived by the oscillator circuitry within the IC which generates a high purity, low frequency, 5 V peak-to-peak sine wave. This frequency is tunable by an external resistor and is optimized for 120 kHz. This AC signal is fed through an internal 22 kΩ resistor, to a multiplexer which directs the signal to the selected electrode or reference pin or to an internal measurement node. Unselected electrodes are automatically connected to the circuit ground by the IC.

These deselected electrodes can act as the return path needed to create the electric field current, since in order to create current flow, the current must follow a complete path: out of the electrode pin and back to the common ground of the IC GND pin. Thus, an electric field will cause a current to flow between the active electrode and any object with an electrical path to the IC ground, including deselected electrodes.

The current flowing between the electrode and its surrounding grounds will result in a voltage drop across the internal resistance. This, in turn, results in a voltage change at the pin. An on-board detector in the IC converts the AC signal to DC level. The DC level is then low-pass filtered using an internal series resistor and an external parallel capacitor. This DC voltage is multiplied, offset and sent to the LEVEL pin of the IC.

To help reduce application development cycle times, Freescale offers an evaluation module for the MC33794, called a KIT33794DWB. The kit includes an MC33794DWB, a preprogrammed 68HC908QY4CDW 8-bit microcontroller, an RS-232 communication IC, and other passive supporting components on a Printed Circuit Board. The 8-bit microcontroller converts the analog signal from the MC33794 into an 8-bit byte. The MCU transmits this value to a computer via its COM port. A Windows type program called EFLD is included in the kit. This program displays the measured A-to-D value in real time along with its corresponding analog bar graph. The program can be made to scan all of the electrodes, references and internal nodes of the MC33794 or any combination of them.

USING THE MC33794 FOR TOUCH CONTROL APPLICATIONS

The MC33794 can detect anything that is either conductive or has different dielectric properties than the electrodes' surroundings. Human beings are well suited for E-field imaging. This is because the human body is composed mainly of water that has a high dielectric constant and contains ionic matter which gives it good conductivity. The body also provides good electrical coupling to earth ground which can be connected to the ground return of the IC. Thus, when a finger is brought close to a metal electrode, an electrical path is formed, producing a change in electric field current that is detected by the MC33794 and translated to a different output voltage.

The things which need to be determined in the development of an MC33794 touch panel application are:

1. Touch pad electrode layout and design.
2. The different dielectric materials for the surface of the panel.
3. The effect on E-field measurements of various environmental conditions.

The above matters were investigated using the available KIT33794DWB evaluation module. Figure 1 displays the general setup using the kit.

Throughout the tests, all the generated data was obtained using a "calibrated" artificial finger equivalent to medium pressure applied by a finger based on actual tests and data. The artificial finger was designed to make the pressure applied to the panel consistent. The artificial finger was connected to ground and made from a copper rod with a surface area of 0.26 in^2 and mass of 62 grams.

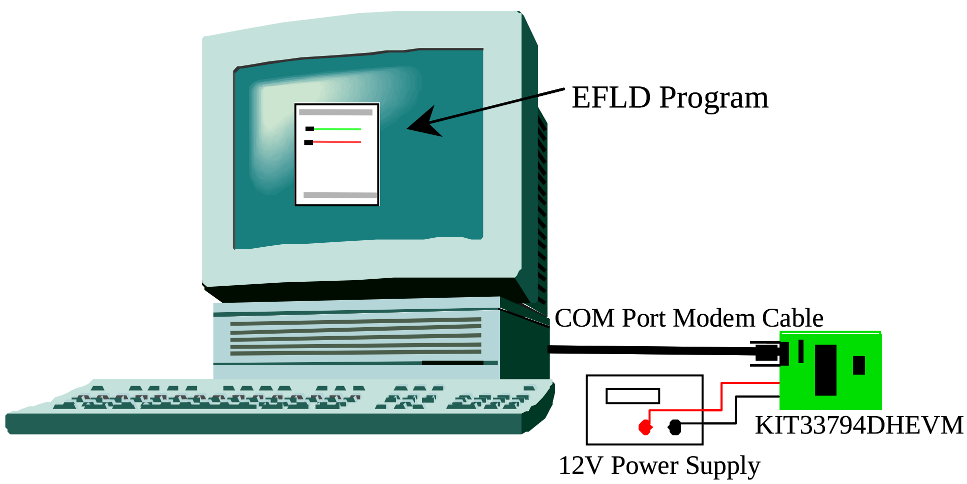


Figure 1. E-Field Evaluation Module Setup

Electrode Design

To understand how electrode designs effect the IC's capabilities, it is important to understand the basic definition of a capacitor. A common capacitor uses an electric field and an insulating dielectric to allow current conduction to occur. It can be made by placing two metal plates in parallel with each other. If the plates are separated by a distance "d" with each plate having an area of "A."

The capacitance of the capacitor can be calculated using the formula:

$$C = (kA\varepsilon)/d$$

where:

C is the capacitance of the capacitor in Farads

A is the area of the plates in meter^2

d is the distance between the plates in meters

k is the dielectric constant of the material between the plates

ε is the permittivity (8.85×10^{-12} F/m)

From the above equation, it can be seen that area (*A*), distance/spacing (*d*) , and the dielectric constant (*k*) are the three factors that affect the magnitude of the capacitance. At a given frequency and voltage of an applied signal, the capacitance controls the resulting electric field current flow. The output of the MC33794 responds to variations in this current.

Size Matters

An electrode can be anything that is electrically conductive. When designing the electrodes for any application, one must take into account the physical size of the conductive electrode. The larger the electrode, the more range and sensitivity will be obtained. However, as the electrode size is increased, so is its susceptibility to interference, electrical noise, and "stray" electric-field paths in its surroundings. One of the key practices regarding electrode design is for the electrode's area to correspond the surface area of the object being detected. Touchpads for touch panel applications, for example, would only require a size that suits the surface area of a finger.

Spacing

The area of the touchpad only needs to accommodate the contact area of the finger. This limits its useable size. Therefore, the distance or spacing factor will play a significant role on how the electrode should be laid out. Another factor which needs to be considered is how the fringing between the patterns adds to electric field current.

Some of the electric field current will flow in the fringing field between a pair of electrodes. Figure 2 shows the direct field path between two conductors which are end-to-end and a few of the fringing field paths between the electrodes. If the ratio of the fringing field path to the direct path is held constant, the height of the fringing field relative to the plane of the electrodes increases in direct proportion with the spacing. Figure 2 shows pictorially how the height of the fringing field relative to the electrodes becomes greater as the two electrodes are moved further away from each other.

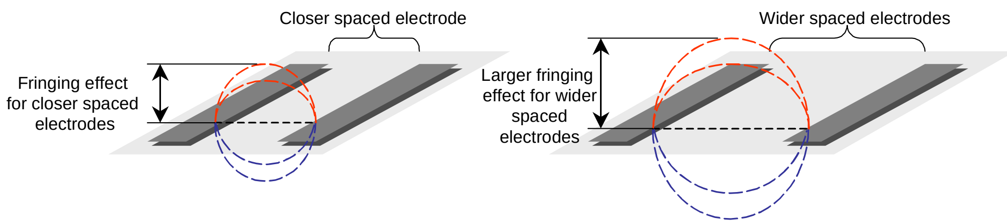


Figure 2. Fringing Fields and the Effects of Spacing

This fringing field allows an ungrounded object to be sensed in the "third" dimension above the essentially two dimensional array of electrodes, and the relative sensitivity for a given height above the plane of the electrodes increases with electrode spacing. It is important to note that the total current flow decreases with increased spacing. The point of this is that there is interaction between electrode size and spacing and their ability to sense objects in the third dimension. In the case of a grounded object, the fringing field will not play as much of a role since some of the current will flow directly to the grounded object from the electrode, but good electrode design should keep both of these effects in mind.

The MC33794 works best when the total capacitance between an electrode and ground or another electrode close to 50 pF, when the finger is in the "activate" range. The total system capacitance should be below 100 pF and preferably below 75 pF for best sensitivity. This includes the IC pin, PWB trace, wire, and any other stray capacitance. Large electrodes should be used when distances are great, and small electrodes when distances are small.

Significance of Ground—Single Electrode Sensing

The placement of ground is important. As mentioned earlier, electric field currents can exist between the active electrode and any grounded object. By intertwining the electrode with ground, the essential ground source needed to create an E -field is directly accessible to the electrode. This path is less variable than the path through a body and earth and provides a more predictable and less noisy path.

To investigate how variables in ground can effect the E-field measurement, we tested the ground phenomena with a two electrode design, a spiral and an inter-digitated layout. In addition, the width of the ground electrode intertwined with a signal electrode was varied to determine how much ground area affects the readings. One electrode-ground test configuration was designed with ground having the same width as the electrode, and another with the ground electrode thinner than the signal electrode. We designed a touchpad which had an area large enough to accommodate a typical finger in a square shape with a length and width of 0.6 in. The dimensions of the electrodes are displayed in Figure 3.

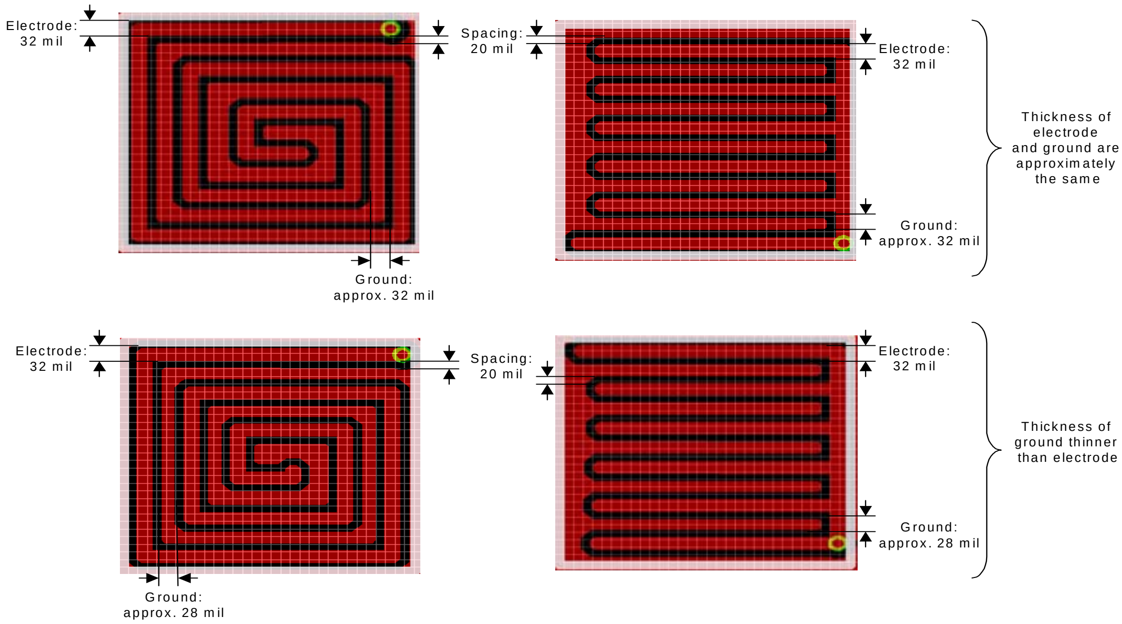


Figure 3. Intertwined Electrode and Ground Designs and Dimensions

The E-field loading for each touch pad is displayed in Figure 4. This figure shows the difference in measurement, not the absolute reading of the electrodes. A 4.5 mil (".0045) thick vinyl film was used as an insulator over the patterns. The 2 top bars show the readings for a ground with the same width as the electrodes. The bottom 2 are for the electrodes where the grounded electrode is thinner than the signal electrode. The bar graph shows that the layout with the narrower ground electrode provided a slightly greater amount of difference in comparison to the design with ground having the same width.

The practice of intertwining electrodes with ground is more important when the electrodes connected to the IC's pins are at a distance from each other. When electrodes are close to each other, the adjacent electrodes could act as the ground source needed to create the field current. This is due to the IC connecting the deselected electrodes to ground; making the deselected electrode often act as the ground return path needed to allow an electric field current to flow.

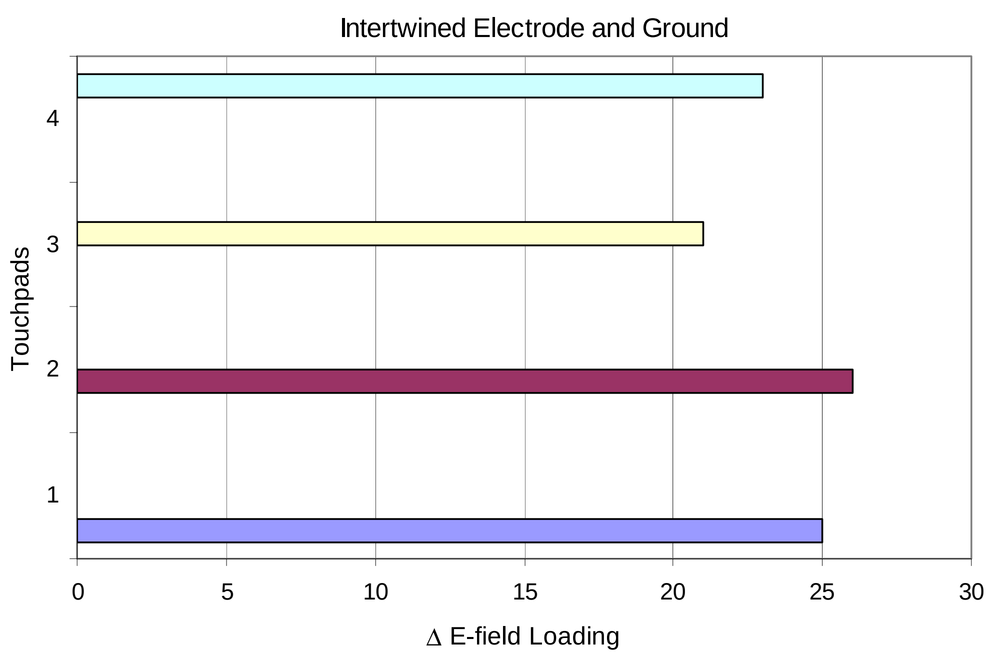


Figure 4. Results of Electrode-Ground Configuration Multiplexed Electrodes

Multiplexed Electrodes

A single MC33794 can support as many as 9 electrodes which can be used independently to map the location and area of an object. By employing multiple electrodes, it is possible to get an idea about the size and shape of an object influencing the MC33794's electric field depending on which electrodes indicate a change in their electric field current.

A panel that requires only a few push buttons could use a single electrode for each touchpad. Doing this would limit an application using a single MC33794 to a maximum of nine simple single element electrode buttons, corresponding to the nine available electrode pins in the IC. By intertwining multiple electrodes in each touchpad, many more touchpads could be supported by a single MC33794.

To determine the best method to maximize the use of the available electrode connections on the IC, a number of design layouts were analyzed. For this investigation, we designed touchpads that had two, three, and four intertwined electrodes.

When integrating multiple electrodes in one touchpad, the electrode was laid out so that when a finger is over a touchpad, there is an even distribution of the finger's surface area over each of the electrodes. Numerous geometric arrangements and shapes were investigated to determine the best way to construct the electrodes in a square area. The Inter-digitated configuration like the two right side drawings in Figure 4 were found to be the best layout for intertwining two electrodes. This pattern had two comb-like patterns with the teeth of the combs meshed with each other but not touching each other. An Inter-digitated configuration allows for an exact distribution of each electrode and allows the system to detect the same loading from each electrode when in the presence of a finger.

Further extending this idea, two electrodes in a single touchpad could be organized by multiplexing the electrode following a column-row configuration. Increasing the number of rows and/or columns in the array will provide more electrode combinations. With this configuration, a single IC could detect as many as 20 individual push buttons. Figure 5 highlights the column-row configurations.

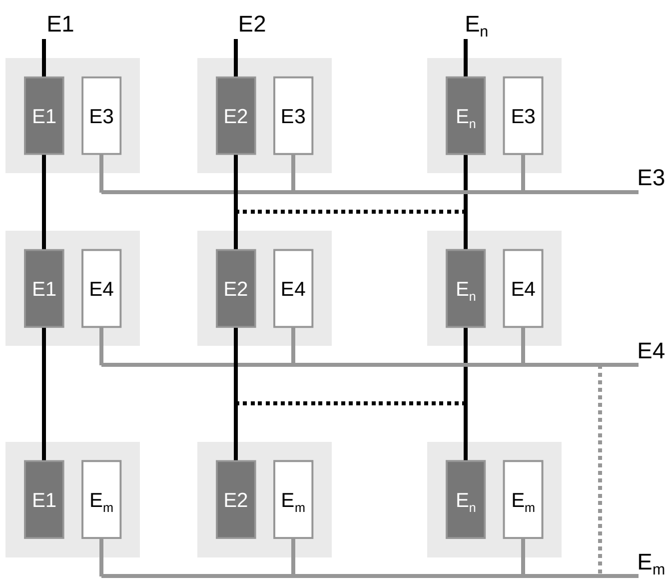


Figure 5. Multiplexed Electrodes Following a Column-Row Configuration

The electrode layout gets more complex as the number of electrodes in each touchpad increases. For three intertwined electrodes, a spiral like geometry is suitable as shown in . Although the exposed electrode surface areas are not exactly equal to each other, when a finger is placed over the center of the pad, the currents will be reasonably close to the same. For four intertwined electrodes, the layout design had electrodes following an 'S' shape. Again, when a finger is over the center of the pad, it would be able to cover the majority of each electrode's exposed area.

When intertwining five or more electrodes, the design gets more complex. One must take into account the size of the available area for the touchpad when determining the maximum number of electrodes in a touchpad. The number of electrodes is limited by the width and spacing requirements of the electrodes and the minimum area of each electrode for the required sensitivity.

Earlier, we discussed electrodes which were intertwined with ground in order to form a path for the field current. In a multiplexing configuration, a separate ground does not have to be intertwined because the IC automatically connects the unselected electrodes to ground. For example, in the case of the two intertwined electrodes following an inter-digitated configuration and connected to *E1* and *E2,* when *E1* is selected, *E2* (the deselected electrode) acts as the ground return to produce the field current between the two electrodes. After the system has gone through the measurement process for *E1,* the role of the two electrodes are then reversed (e.g., *E2* is selected for measurement while *E1* is connected to ground). The same phenomenon is present for touchpads with three and four intertwined electrodes.

These layouts were tested using a 4.5 mil vinyl covering.
The difference in loading can be seen in the graph of Figure 6.

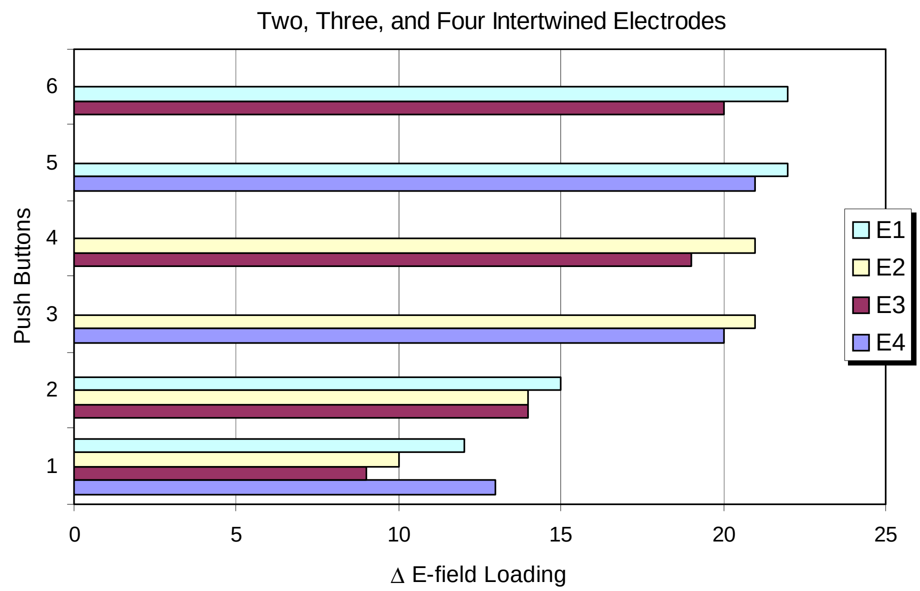


Figure 6. Difference in E-Field Loading Resulting from 2, 3, and 4 Intertwined Electrodes in a Push Button

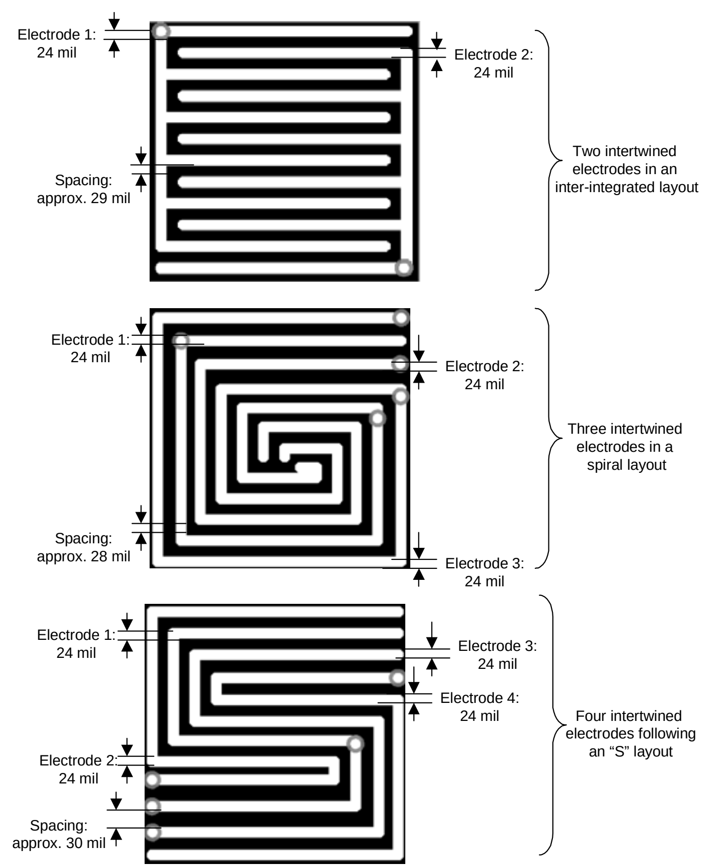


Figure 7. Two, Three, and Four Electrodes Ideally Intertwined to Form a Touchpad

The top four bar pairs of the graph display the value obtained having two intertwined electrodes (like Figure 3). The measurements are very similar to each other. For the three intertwined electrodes, the difference in measurement is still visible, having about a third less magnitude than the ones with two intertwined electrodes. The reading from a touchpad with four intertwined electrodes shows even lower sensitivity. The reduction in sensitivity as the number of intertwined electrodes is increased is due to the reduction of area in of each of the electrodes.

The reduction of sensitivity as the number of intertwined electrodes is increased can be offset by a thinner or higher dielectric constant cover over the touchpads. Conversely, the thickness and dielectric constant of the covering may limit the number of inter-twined electrodes.

The electrode layout and design used to measure the data in Figure 6 is displayed in . Where 2 bars are together in Figure 6, the bars are showing the difference measurements for each electrode when using 2 intertwined electrodes in the touchpad. Three bars together are for 3 inter-twined electrodes and the group of four are for 4 intertwined electrodes in a touchpad.

The number of touchpads supported by the available electrode connections is more than a simple multiplexing scheme might appear to indicate. Touchpads made of 1, 2, 3, 4 or more electrodes can all be used in the same system. For instance *E1* could be intertwined with a circuit ground electrode to form a touchpad which would show only *E1* being affected when it is selected by a finger. In the same application *E1* and *E2* can be intertwined to form a touchpad so that a finger selecting it would affect both electrodes. Since both electrodes are affected in this touchpad and only *E1* was affected in the other touchpad, the one being selected can be determined.

Table 1 shows the 45 touchpad electrode combinations possible using 1 and 2 electrodes per touchpad with the 9 electrodes available on the MC33794. This gives some idea of the power of electric field multiplexing. If combinations of 1, 2 and 3 electrodes were used per touchpad, the number of possible unique touchpads a single MC33794 could support grows to 126!

Table 1. 1 and 2 Electrode Touch Pad Combinations

Electrode=>	A	B	C	D	E	F	G	H	I	Electrodes
TouchPad										TouchPad
↓										↓
1	X									1
2		X								1
3			X							1
4				X						1
5					X					1
6						X				1
7							X			1
8								X		1
9									X	1
10	X	X								2
11	X		X							2
12	X			X						2
13	X				X					2
14	X					X				2
15	X						X			2
16	X							X		2
17	X								X	2
18		X	X							2
19		X		X						2
20		X			X					2
21		X				X				2
22		X					X			2
23		X						X		2
24		X							X	2
25			X	X						2
26			X		X					2
27			X			X				2
28			X				X			2
29			X					X		2
30			X						X	2

Table 1. 1 and 2 Electrode Touch Pad Combinations (Continued)

Electrode=>	A	B	C	D	E	F	G	H	I	Electrodes
31				X	X					2
32				X		X				2
33				X			X			2
34				X				X		2
35				X					X	2
36					X	X				2
37					X		X			2
38					X			X		2
39					X				X	2
40						X	X			2
41						X		X		2
42						X			X	2
43							X	X		2
44							X		X	2
45								X	X	2

Electrode—Isolated or a unit?

Electrically conductive electrodes can be attached directly to the MC33794 electrode pins via wire or coax cable. The IC SHIELD pin allows coaxial cable to be used without reducing sensitivity or adding variations due to changes in the coax capacitance. The signal from the SHIELD pin is a buffered version of the signal driving the selected electrode. It has the same amplitude and phase. This reduces amplitude of the electric field between the center conductor and the shield of the coax to nearly 0. This results in nearly zero field current between them and doesn't add to the field current at the electrodes.

The electrodes of a touchpad can be formed directly on Printed Circuit Boards (PCB) using copper circuit traces. We formed the electrodes used in Figure 3 (electrode intertwined with ground) and Figure 6 (two, three, four intertwined electrodes) this way. The field current of the wires used to connect the IC pins to the electrodes was reduced by placing a copper layer connected to the shield pin over the signal traces. This is shown in Figure 8. This practice also hides the exposed wires from the plate to be contacted by the user. This prevents false indications of a touch when a finger touches as area above the routing traces.

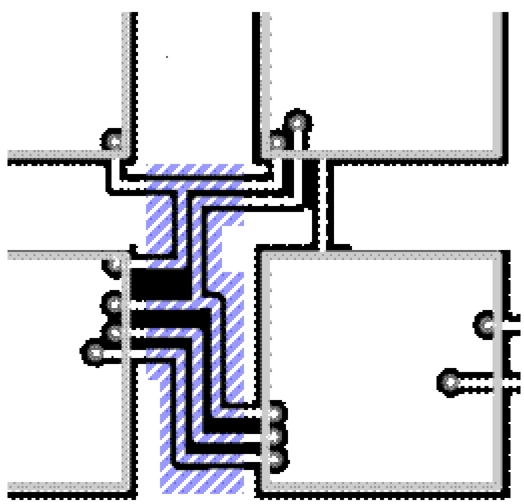


Figure 8. Wires Covered with Conductive Plate Connected to the SHIELD Pin to Minimize Effective Capacitance of Wire

Further, an electric current could flow in the field created from the touchpad to an object above or below it. Since we want the field to only propagate on top of the touchpad, Figure 9 shows how we eliminated the effective capacitance on the back side of the touchpad by placing a conductive layer under all of the touchpads and connected it to the shield driver pin of the IC.

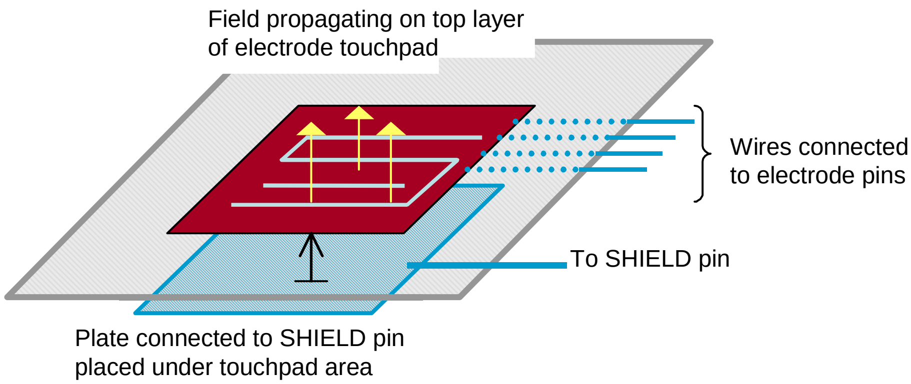


Figure 9. Shielded Conductive Plate Placed Under Touchpad to Remove Bottom Fringing Path

When touchpads are close together, it is possible that a finger could be over more than one touchpad at a time In this case, the analog levels from the IC can be used to determine which of the electrodes has more coverage. In a column-row configuration, for example, when a finger with its surface area distributed between buttons A and B (as in Figure 10), *E1* will attain a great amount of loading, while *E3* and *E4* will also detect some difference in measurements. Software can determine which of the electrodes (*E3* or *E4*) will have a higher amount of loading difference. The higher reading of *E3* or *E4*, when combined with *E1* would then be chosen to perform whatever particular task was intended.

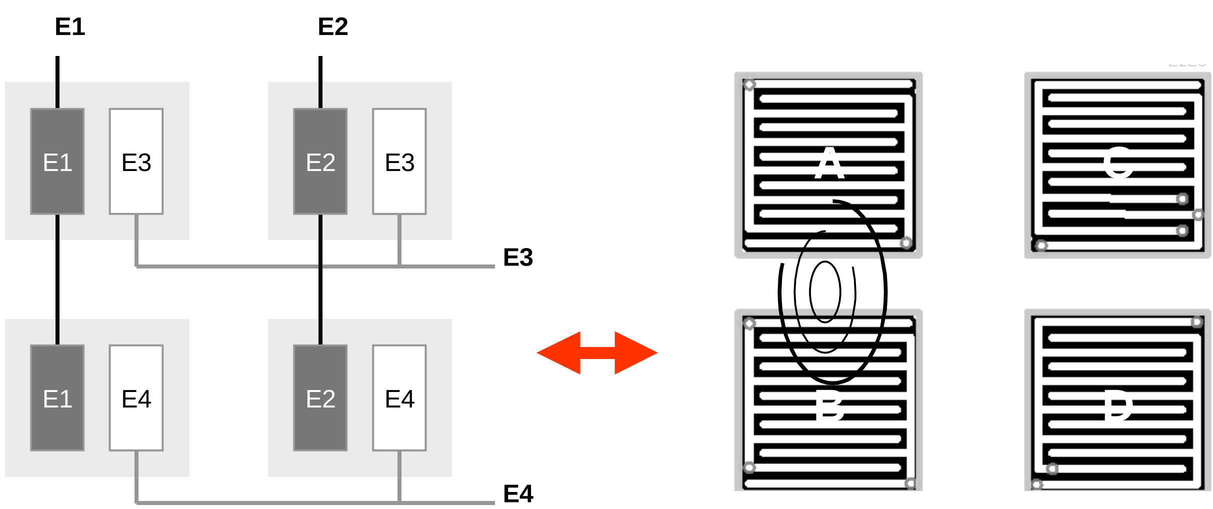


Figure 10. An Array of 2x2 Inter-Integrated Electrodes Following a Column-Row Configuration

Dielectric Material for Panel Coverings

In order to have a non-direct electrical connection, electrodes must be covered with an insulator. When selecting the proper material for the surface of the touch panel, one must take into consideration the thickness and the composition of the material. The thickness and the dielectric constant of the insulator both play a significant role in the sensitivity of the system.

To determine how the E-field is affected by the insulator's thickness and composition, we tested the touch panel setup with the different materials and thicknesses listed in Table 2.

Table 2. Dielectric Materials With Different Thicknesses and Dielectric Constants

Dielectric Material	Thickness (mil)	*k*
Acrylic	84.5	2.7-4.5
Glass	74.5	7.5
Nylon Plastic	68.0	3.0-5.0
Polycarbonate	61.0	2.9-3
PVC (Polyvinyl chloride)	59.5	3.18
Polystyrene	43.0	2.4-2.6
Soft Neoprene Rubber	38.0	5
Polypropylene	14.0	1.5
Polyester Film	10.0	3.2
Flexible Vinyl Film	9.0	2.8-4.5

Data for Figure 11 through Figure 15 was obtained using an inter-digitated touchpad configuration with the same dimensions as in Figure 3. Note that throughout the experiment, the existence of air (k = 1) was minimized between the cover and the electrode in order to obtain the best results.

Dielectric Constant

A material with high dielectric constant (k) will help propagate the field through to the front of the panel better than a low dielectric constant material, enabling the system to better detect an object at the surface.

As seen in Figure 11, the difference in E-field measurements was quite noticeable between polypropylene, polyester film, and flexible vinyl film. Also notice that despite the greater thickness of the flexible neoprene rubber, a very large difference in loading was noted. This is due to its high dielectric constant and, perhaps, its pliable nature. Neoprene (k = 5) allows the field to propagate through it with around 3 times the magnitude of polypropylene plastic (k =1.5).

In general, the results show what we would expect. Increasing thickness reduces sensitivity. Increasing dielectric constant increases sensitivity. A good example is the comparison between glass and nylon. The glass is thicker than the nylon but shows a larger change because of its higher dielectric constant.

Insulation Thickness

An interesting exception to this generalization is Soft Neoprene Rubber. Its dielectric constant is, at best only twice that of flexible vinyl film but its thickness is more than 4 times as much. The sensitivity is around twice as much. It would be expected to be half as sensitive. One possible explanation for this is the compliance of the rubber and its porosity. As the rubber is compressed, the small internal air pockets get squeezed such that more of the path is through the solid part of the rubber which has a much higher dielectric constant. If this theory is correct, the dielectric constant effectively increases as pressure is put on it. Further, the thickness is reduced as pressure is put on the rubber which would also increase the amount of change. The bottom line is that Soft Neoprene Rubber would make a great covering for the electrodes.

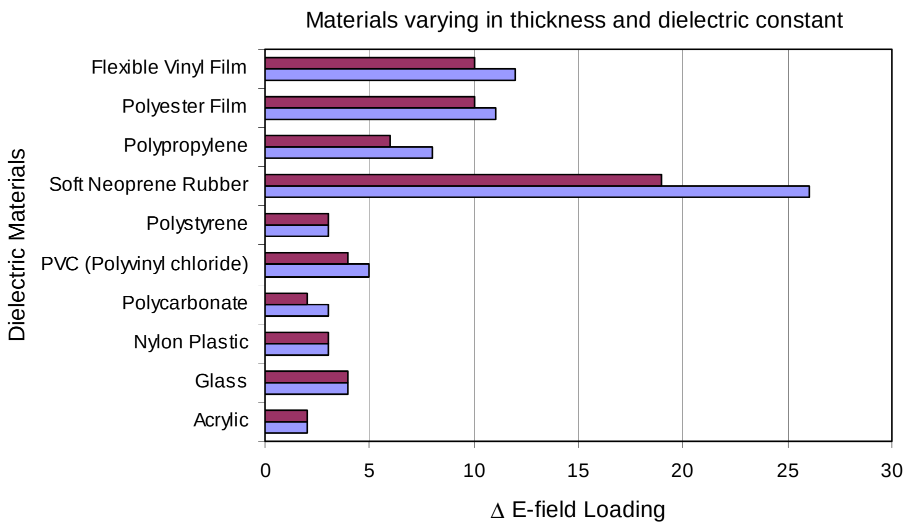


Figure 11. Difference in E-Field Loading With Varying Materials as Panel

In general, the thinner the insulation, the more sensitive the touchpads are to touch. In order to investigate this more thoroughly, the same test was applied for polyester film (k = 3.2 with thicknesses that varied from 1 mil to 10 mils. The tests where done using 2 inter-digitated electrodes. The results are shown inFigure 12. The strong relationship between thickness and sensitivity is quite visible in this curve.

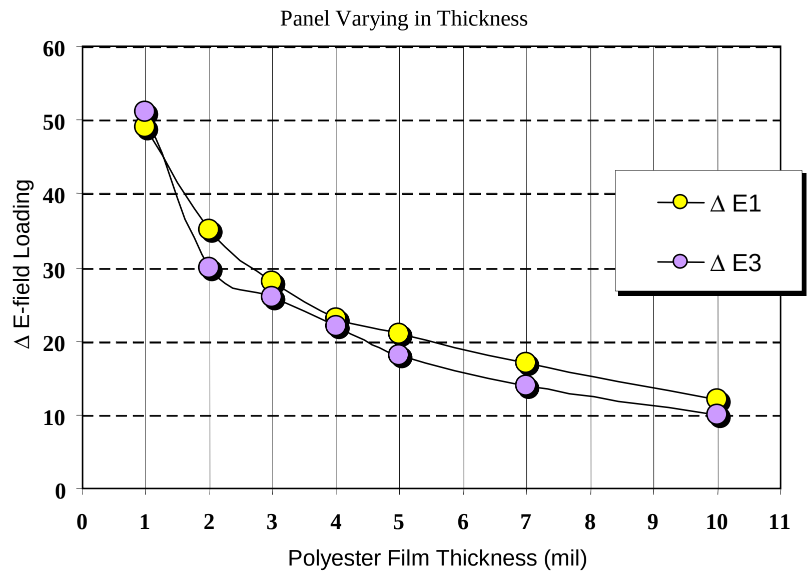


Figure 12. Data With Polyester Film (k = 3.2) Varying in Thickness

Environment Effects

The different dielectric materials from Table 1 were tested under various conditions to determine the effect of moisture or oil on the surface and for the effect of gloves. This was done to measure how naturally occurring conditions might affect an application using this technology. Moisture is often encountered in outdoor applications, and oils can build up when people touch the panel.

Influence of Oil and Moisture

Figure 13, shows the results obtained with oil on the surface. The oil did not significantly affect the readings, due to the low dielectric constant of oil (vegetable oil, k = 3). Comparing the results with that of Figure 11, it can be seen that the oil film on top of the material actually improved the detection of the finger. This is due to the oil filling the airgaps in the finger print. Its higher dielectric constant increased the amount of current created by the field.

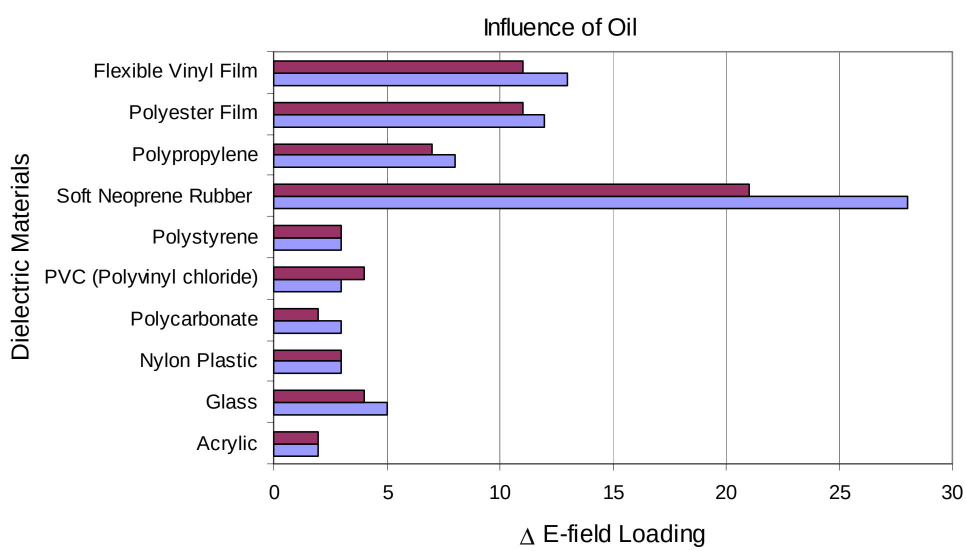


Figure 13. Difference in E-Field Loading Under Influence of Oil (k = 3)

Water was put on the surface of the panel and the data in Figure 14 was obtained. The amount of change in the output was better than when using oil. It was noticed that there was more effect on the adjacent touchpads. This is probably due to the higher current path provided by the high dielectric constant water from the finger to the other electrodes. This could be problem requiring some change in the physical design of the panel. Wider separation of the touchpads reduces the effect. The slope of the panel to make water run off it would help. A material which "sheds" water might also be beneficial.

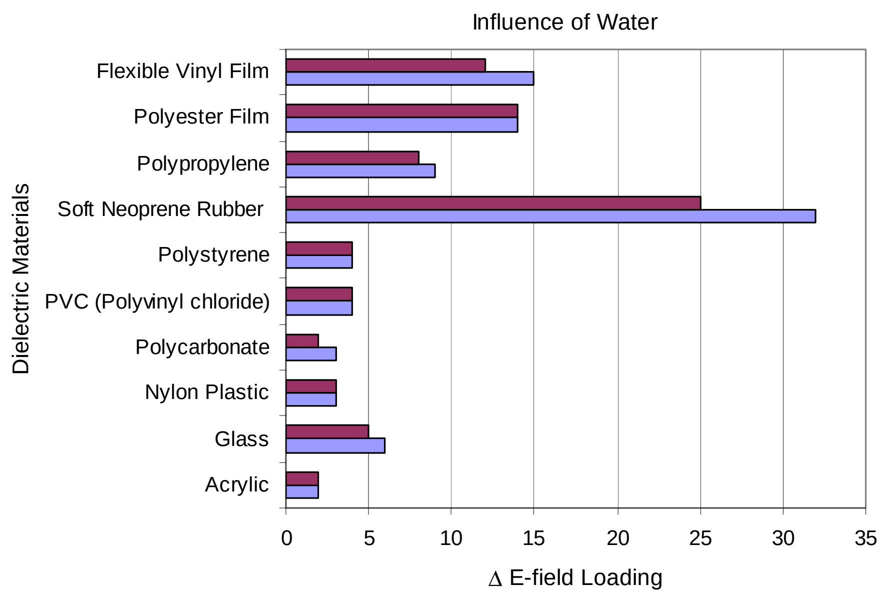


Figure 14. Difference in E-Field Loading Under the Influence of Water (k = 80)

Effect of Gloves

Another test applied to the system that of using a gloved finger. The data shows that a gloved finger is difficult to detect. The gloves add distance between the surface of the panel and the finger. The glove used in the experiment was rather thick and was made of cotton materials with dielectric constant close to air (k = 1.3-1.4). The data is shown inFigure 15.

For this application an electrode that is responsive to a degree of pressure would be more suitable. Instead of depending on the finger's capacitance, a conductive membrane could be embedded behind a flexible panel and would alter the reading based on the applied pressure.

Another option is based on the large amount of change that was detected from the soft neoprene rubber. This gave rise to another experiment. A piece of neoprene was placed on above the electrode in such a way that there was a gap of air between the electrode and the rubber. When pressure was placed on top of the rubber by a finger, the air between the rubber and the electrode was eliminated and a great amount of difference (almost a count of 40) was detected. This was because the field current is primarily limited by the low dielectric constant of air in the gap between the neoprene and the touchpad. When pressure was applied by the finger, the rubber closed this air-gap providing a lower impedance to the field current between the interwoven ground and sense electrodes.[1]

1. All the generated data was obtained using a "calibrated" artificial finger equivalent to a medium pressure applied by a finger based on actual tests and data. The rod finger is designed in an effort to keep the pressure controlled. The artificial finger is connected to ground and is made out of copper rod with a surface area of 0.26 in^2 and mass of 61900.76 mg.

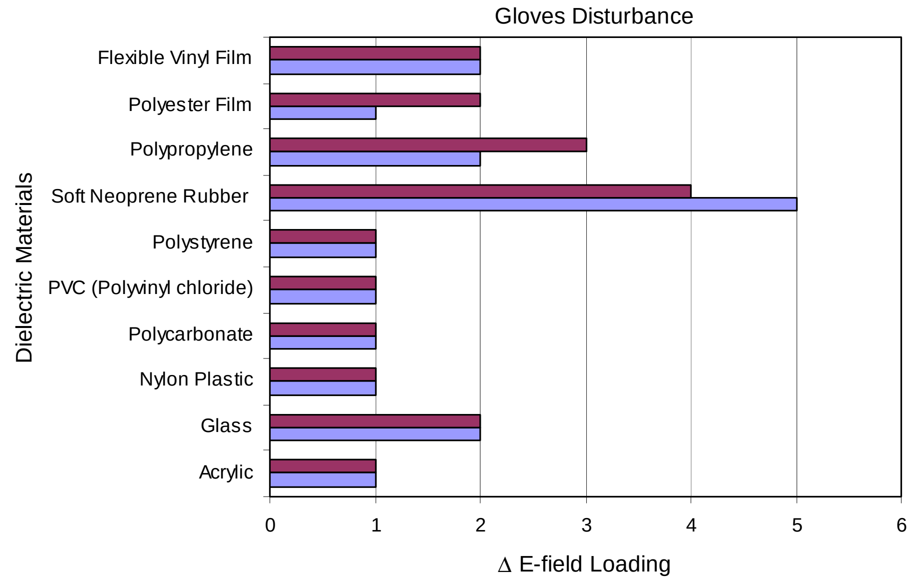


Figure 15. Difference in E-Field Loading Measured With the Presence of a Gloved Finger

Effects of Temperature

Another test that was conducted was observing how the MC33794 system was affected by heat and frost.

The first occurrence observed was how the references reach a particular value for every given temperature, as shown in Table 3.

Frequency and other component values may change over time or be affected by environmental variables such as temperature and humidity. To compensate for this, the MC33794 relies on two reference inputs, Ref A and Ref B, that would be connected to temperature stable capacitors. One capacitor is chosen with a capacitance near the expected minimum capacitance, while the other is chosen with a capacitance near the maximum capacitance to be expected at the electrodes. These reference capacitances and their corresponding measured voltages provide a pair of value that can be used to correct errors in the electrode measurements caused by temperature, aging or other component related changes.

The curves in Figure 16 display the occurrence of increasing reference A and B values with decreasing temperature.

Table 3. Ref A and B versus Temperature Table

deg. Fahrenheit	-5	0	10	20	30	40	50	60	70	80	90	100	110
deg. Celcius	-20	-18	-12	-7	-1	4	10	16	21	27	32	38	43
Ref A	179	178	178	177	176	175	174	173	173	172	171	170	169
Ref B	75	74	72	69	66	64	61	58	55	52	50	47	45

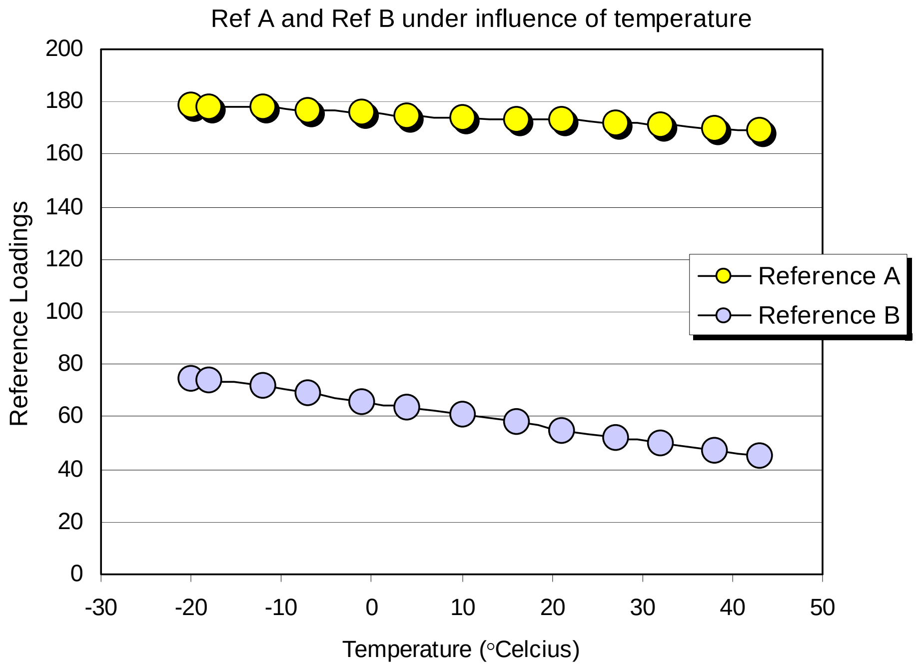


Figure 16. A-to-D Value of Ref A and Ref B Based on Varying Temperatures

From the above lists of materials, neoprene, polypropylene, polyester and vinyl film were also tested to determine the effect on E-field measurements with variations in temperature (43°C to -20°C).

Figure 17 highlights the difference in loading for a touchpad with inter-digitated electrodes for different insulation materials over varying temperature. Note that the curves in Figure 16 and Figure 17 have opposite temperature coefficients. This is how the correction can be done. Since the capacitors don't change their capacitance over temperature, the current through them would be expected to stay the same. Since the readings do change, it can be assumed that the measurements of the unknown field currents would change a proportionate amount. The correction method is to subtract the change in the reference capacitor from the readings taken. In other words, if the reference readings go up by 3 counts, subtract 3 counts from the electrode values to obtain a "corrected" value. The best correction would use a "normalization" technique using the 2 reference values to correct for both offset and gain drift.

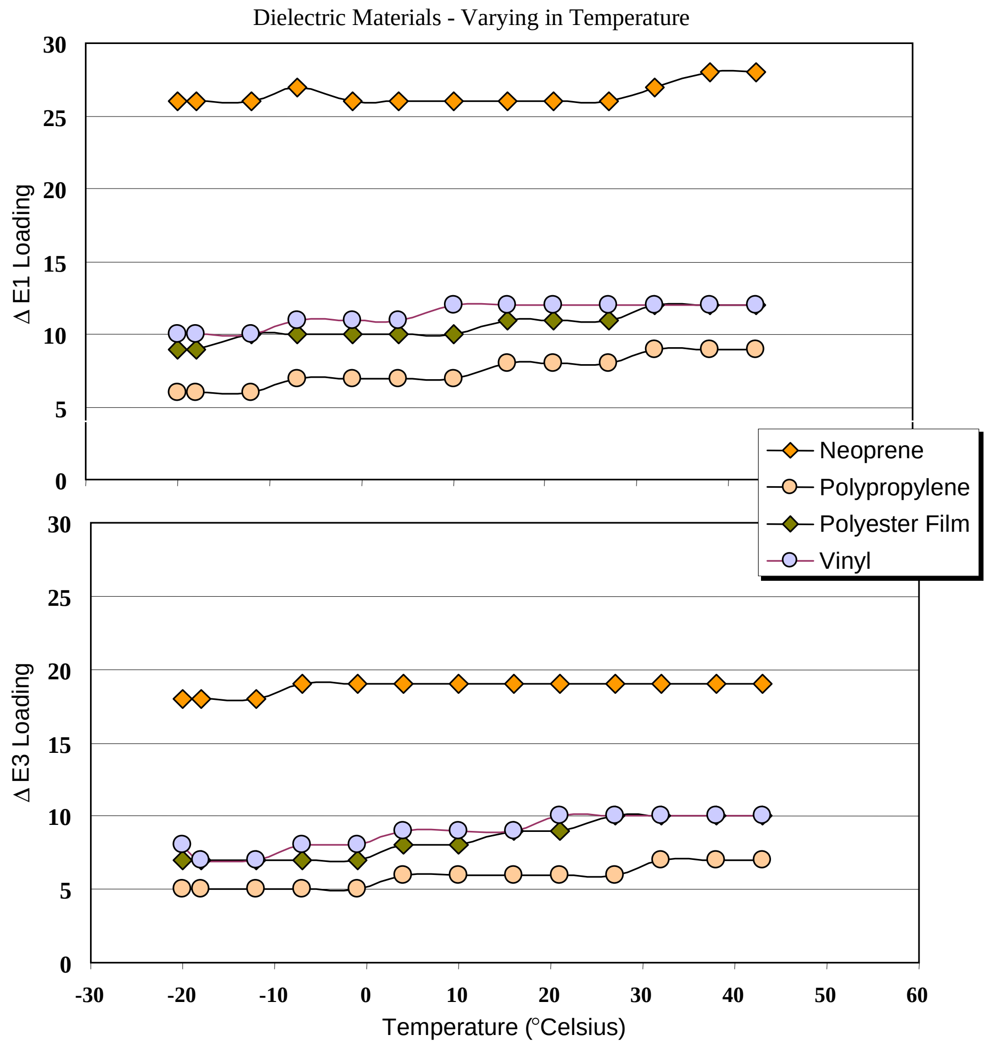


Figure 17. Difference in E-Field Loading With System Under the Influence of Varying Temperature

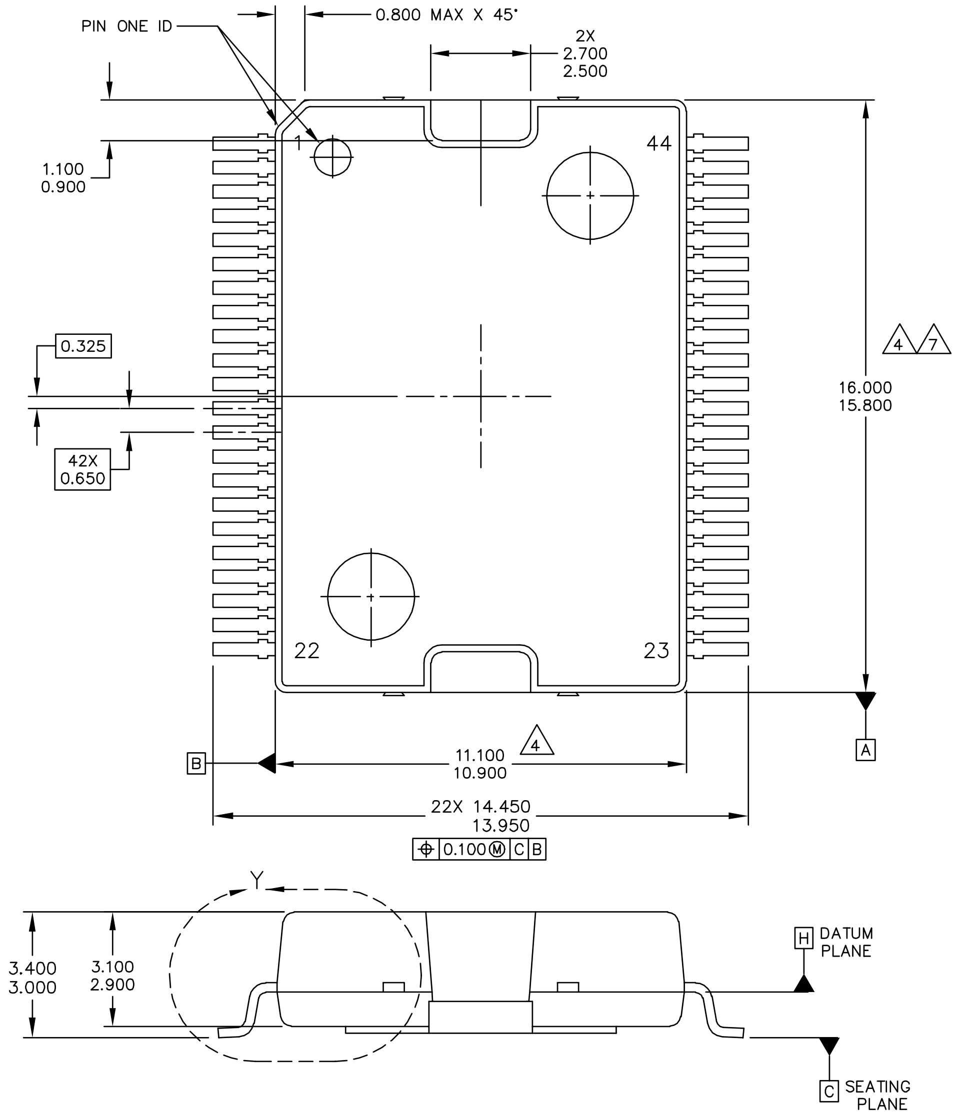
SUMMARY

When developing a touch panel using the MC33794 IC the following key points should be kept in mind:

- The size of the electrode should correspond to the size of the object operating the panel, such as a finger or palm. The area of the electrodes should be made as large as possible within this constraint.
- The insulator over the touchpads should be as thin as possible with as high a dielectric constant as possible.
- Multiplexing can dramatically increase the number of touchpads supported by a single IC.
- If you anticipate that the device will be affected by excessive moisture make sure the panel is mounted at an angle to aid in water run-off.
- The reference correction method should be used to offset the effects of temperature and component drift.

The MC33794 can support many other things than touch controls. When using it for other things, maximize your use of it by adding touch control to the same object using any left over electrodes.

PACKAGE DIMENSION - DH SUFFIX



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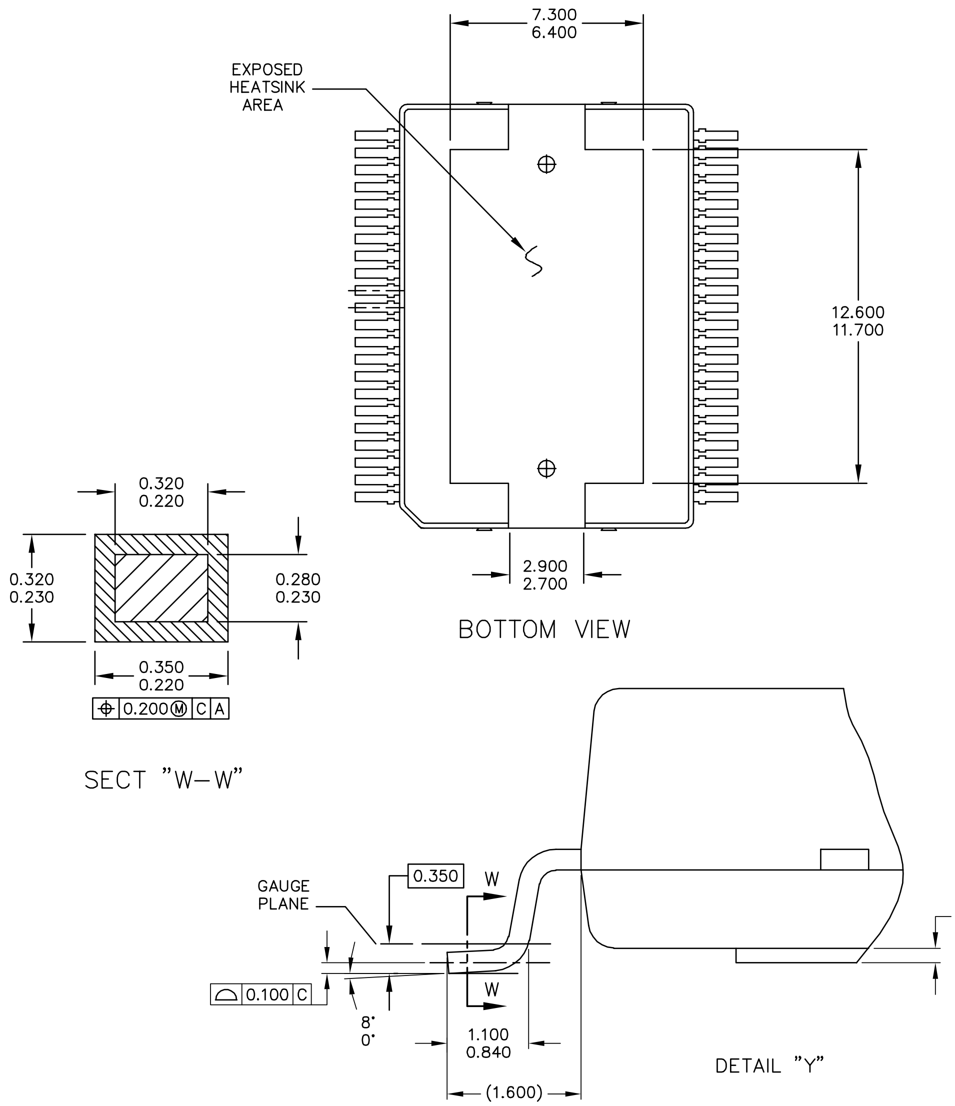
TITLE: 44 LEAD HSOP W/PROTRUDING HEATSINK		DOCUMENT NO: 98ARH98330A	REV: B
		CASE NUMBER: 1291–02	16 MAR 2005
		STANDARD: NON–JEDEC	

PACKAGE DIMENSION - DH SUFFIX (CONTINUED)



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TITLE: 44 LEAD HSOP W/PROTRUDING HEATSINK	DOCUMENT NO: 98ARH98330A		REV: B
	CASE NUMBER: 1291–02		16 MAR 2005
	STANDARD: NON–JEDEC		

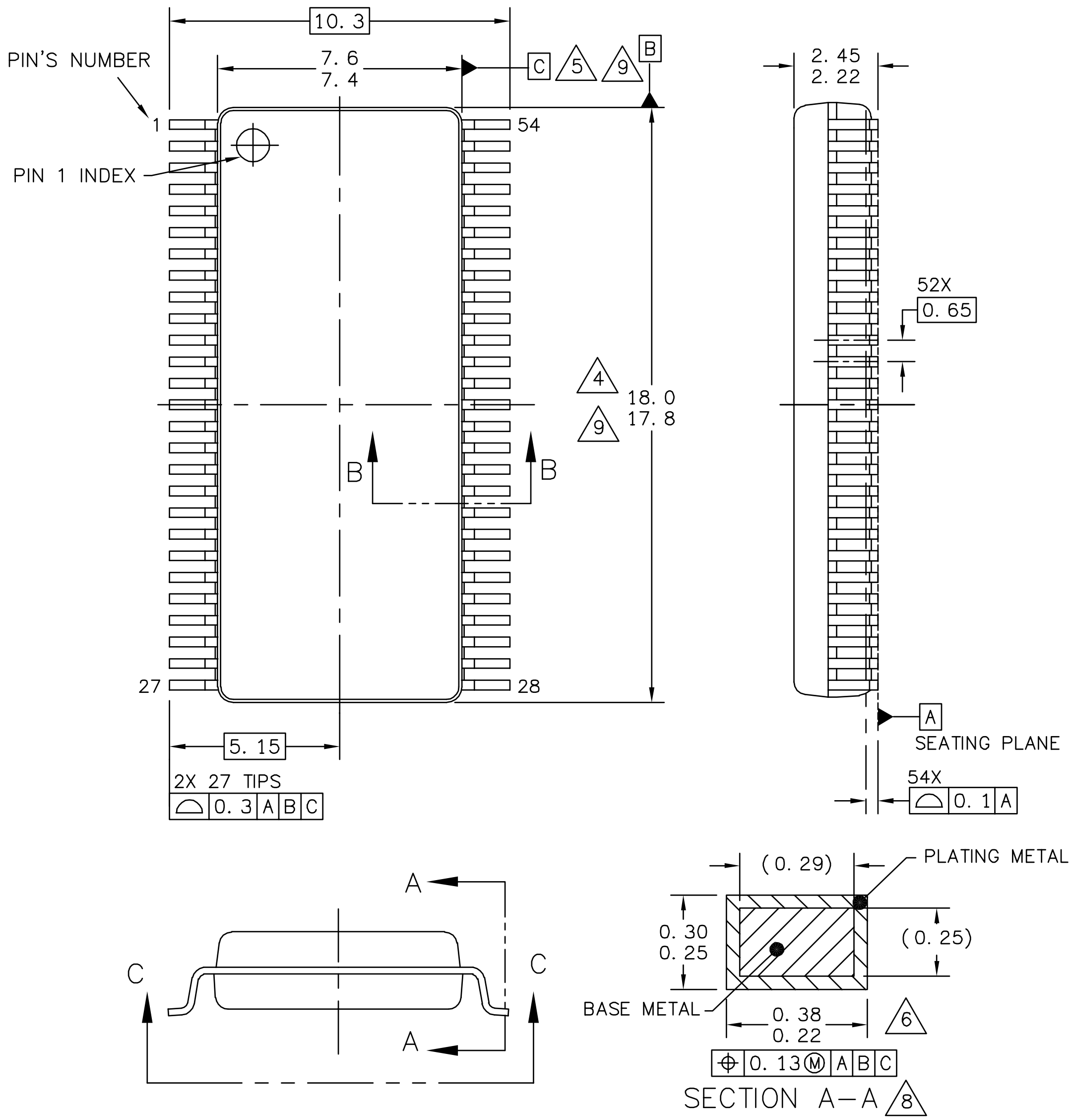
PACKAGE DIMENSION - DH SUFFIX (CONTINUED)

NOTES:

1. CONTROLLING DIMENSION: MILLIMETER
2. DIMENSIONS AND TOLERANCES PER ASME Y14.5M–1994.
3. DATUM PLANE H IS LOCATED AT BOTTOM OF LEAD AND IS COINCIDENT WITH THE LEAD WHERE THE LEAD EXITS THE PLASTIC BODY AT THE BOTTOM OF THE PARTING LINE.
4. THIS DIMENSIONS DO NOT INCLUDE MOLD PROTRUSION. ALLOWABLE PROTRUSION IS 0.15 PER SIDE. THIS DIMENSIONS DO INCLUDE MOLD MISMATCH AND ARE DETERMINED AT DATUM PLANE H.
5. THIS DIMENSION DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.127 TOTAL IN EXCESS OF THE DIMENSION AT MAXIMUM MATERIAL CONDITION.
6. DATUMS A AND B TO BE DETERMINED AT DATUM PLANE H.
7. THIS DIMENSIONS DOES NOT INCLUDE TIEBAR PROTRUSIONS. ALLOWABLE TIEBAR PROTRUSIONS ARE 0.15 PER SIDE.

	MECHANICAL OUTLINE	PRINT VERSION NOT TO SCALE
TITLE: 44 LEAD HSOP W/PROTRUDING HEATSINK	DOCUMENT NO: 98ARH98330A	REV: B
	CASE NUMBER: 1291–02	16 MAR 2005
	STANDARD: NON–JEDEC	

PACKAGE DIMENSION - DWB SUFFIX



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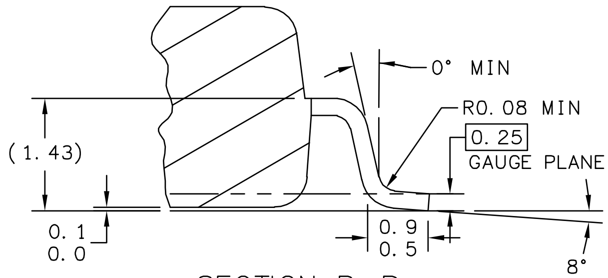
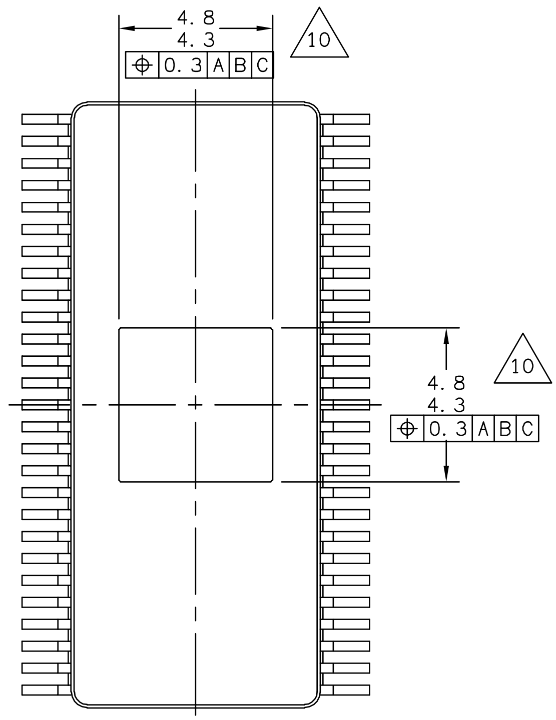
TITLE: 54LD SOIC W/B, 0.65 PITCH 4.6 X 4.6 EXPOSED PAD, CASE-OUTLINE	DOCUMENT NO: 98ASA10506D	REV: C
	CASE NUMBER: 1390-02	11 MAR 2005
	STANDARD: NON-JEDEC	

PACKAGE DIMENSION - DWB SUFFIX (CONTINUED)



SECTION B–B



VIEW C–C

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TITLE: 54LD SOIC W/B, 0.65 PITCH 4.6 X 4.6 EXPOSED PAD, CASE-OUTLINE		DOCUMENT NO: 98ASA10506D	REV: C
		CASE NUMBER: 1390–02	11 MAR 2005
		STANDARD: NON-JEDEC	

PACKAGE DIMENSION - DWB SUFFIX (CONTINUED)

NOTES:

1. DIMENSIONS ARE IN MILLIMETERS.
2. DIMENSIONING AND TOLERANCING PER ASME Y14.5M–1994.
3. DATUMS B AND C TO BE DETERMINED AT THE PLANE WHERE THE BOTTOM OF THE LEADS EXIT THE PLASTIC BODY.

△4. THIS DIMENSION DOES NOT INCLUDE MOLD FLASH, PROTRUSION OR GATE BURRS. MOLD FLASH, PROTRUSION OR GATE BURRS SHALL NOT EXCEED 0.15 MM PER SIDE. THIS DIMENSION IS DETERMINED AT THE PLANE WHERE THE BOTTOM OF THE LEADS EXIT THE PLASTIC BODY.

△5. THIS DIMENSION DOES NOT INCLUDE INTER–LEAD FLASH OR PROTRUSIONS. INTER–LEAD FLASH AND PROTRUSIONS SHALL NOT EXCEED 0.25 MM PER SIDE. THIS DIMENSION IS DETERMINED AT THE PLANE WHERE THE BOTTOM OF THE LEADS EXIT THE PLASTIC BODY.

△6. THIS DIMENSION DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL NOT CAUSE THE LEAD WIDTH TO EXCEED 0.46 mm. DAMBAR CANNOT BE LOCATED ON THE LOWER RADIUS OR THE FOOT. MINIMUM SPACE BETWEEN PROTRUSION AND ADJACENT LEAD SHALL NOT BE LESS THAN 0.07 mm.

△7. EXACT SHAPE OF EACH CORNER IS OPTIONAL.

△8. THESE DIMENSIONS APPLY TO THE FLAT SECTION OF THE LEAD BETWEEN 0.1 mm AND 0.3 mm FROM THE LEAD TIP.

△9. THE PACKAGE TOP MAY BE SMALLER THAN THE PACKAGE BOTTOM. THIS DIMENSION IS DETERMINED AT THE OUTERMOST EXTREMES OF THE PLASTIC BODY EXCLUSIVE OF MOLD FLASH, TIE BAR BURRS, GATE BURRS AND INTER–LEAD FLASH, BUT INCLUDING ANY MISMATCH BETWEEN THE TOP AND BOTTOM OF THE PLASTIC BODY.

△10. THESE DIMENSIONS DEFINE THE PRIMARY SOLDERABLE SURFACE AREA.

	MECHANICAL OUTLINE	PRINT VERSION NOT TO SCALE	
TITLE: 54LD SOIC W/B, 0.65 PITCH 4.6 X 4.6 EXPOSED PAD, CASE–OUTLINE	DOCUMENT NO: 98ASA10506D		REV: C
	CASE NUMBER: 1390–02		11 MAR 2005
	STANDARD: NON–JEDEC		

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STATISTICAL METHODS FOR ASSESSING AGREEMENT BETWEEN TWO METHODS OF CLINICAL MEASUREMENT

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SUMMARY

In clinical measurement comparison of a new measurement technique with an established one is often needed to see whether they agree sufficiently for the new to replace the old. Such investigations are often analysed inappropriately, notably by using correlation coefficients. The use of correlation is misleading. An alternative approach, based on graphical techniques and simple calculations, is described, together with the relation between this analysis and the assessment of repeatability.

(*Lancet*, 1986; **i:** 307-310)

INTRODUCTION

Clinicians often wish to have data on, for example, cardiac stroke volume or blood pressure where direct measurement without adverse effects is difficult or impossible. The true values remain unknown. Instead indirect methods are used, and a new method has to be evaluated by comparison with an established technique rather than with the true quantity. If the new method agrees sufficiently well with the old, the old may be replaced. This is very different from calibration, where known quantities are measured by a new method and the result compared with the true value or with measurements made by a highly accurate method. When two methods are compared neither provides an unequivocally correct measurement, so we try to assess the degree of agreement. But how?

The correct statistical approach is not obvious. Many studies give the product-moment correlation coefficient (*r*) between the results of the two measurement methods as an indicator of agreement. It is no such thing. In a statistical journal we have proposed an alternative analysis, [1] and clinical colleagues have suggested that we describe it for a medical readership.

Most of the analysis will be illustrated by a set of data (Table 1) collected to compare two methods of measuring peak expiratory flow rate (PEFR).

SAMPLE DATA

The sample comprised colleagues and family of J.M.B. chosen to give a wide range of PEFR but in no way representative of any defined population. Two measurements were made with a Wright peak flow meter and two with a mini Wright meter, in random order. All measurements were taken by J.M.B., using the same two instruments. (These data were collected to demonstrate the statistical method and provide no evidence on the comparability of these two instruments.) We did not repeat suspect readings and took a single reading as our measurement of PEFR. Only the first measurement by each method is used to illustrate the comparison of methods, the second measurement being used in the study of repeatability.

PLOTTING DATA

The first step is to plot the data and draw the line of equality on which all points would lie if the two meters gave exactly the same reading every time (fig 1). This helps the eye in gauging the degree of agreement between measurements, though, as we shall show, another type of plot is more informative.

PEFR MEASURED WITH WRIGHT PEAK FLOW AND MINI WRIGHT PEAK FLOW METER

	Wright peak flow meter		Mini Wright peak flow meter	
	First PEFR	Second PEFR	First PEFR	Second PEFR
Subject	(l/min)	(l/mi)	(l/min)	(l/min)
1	494	490	512	525
2	395	397	430	415
3	516	512	520	508
4	434	401	428	444
5	476	470	500	500
6	557	611	600	625
7	413	415	364	460
8	442	431	380	390
9	650	638	658	642
10	433	429	445	432
11	417	420	432	420
12	656	633	626	605
13	267	275	260	227
14	478	492	477	467
15	178	165	259	268
16	423	372	350	370
17	427	421	451	443

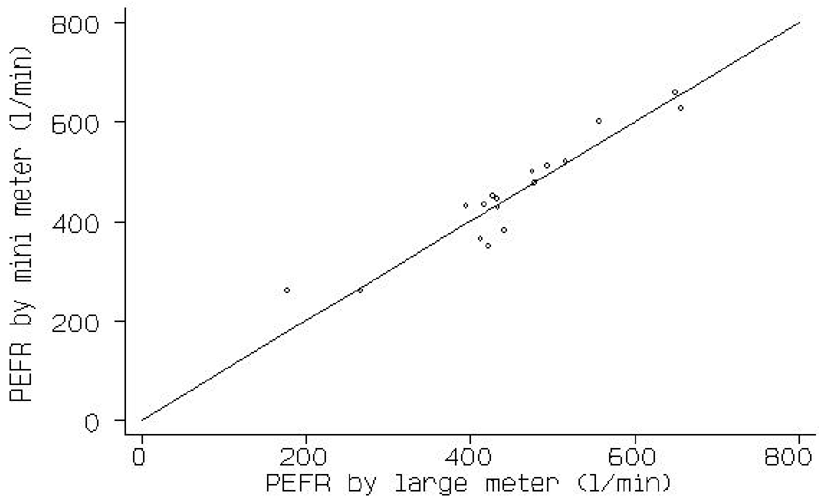

Fig 1. PEFR measured with large Wright peak flow meter and mini Wright peak flow meter, with line of equality.

INAPPROPRIATE USE OF CORRELATION COEFFICIENT

The second step is usually to calculate the correlation coefficient (*r*) between the two methods. For the data in fig 1, $r = 0.94$ ($p < 0.001$). The null hypothesis here is that the measurements by the two methods are not linearly related. The probability is very small and we can safely conclude that PEFR measurements by the mini and large meters are related. However, this high correlation does not mean that the two methods agree:

(1) *r* measures the strength of a relation between two variables, not the agreement between them. We have perfect agreement only if the points in fig 1 lie along the line of equality, but we will have perfect correlation if the points lie along any straight line.

(2) A change in scale of measurement does not affect the correlation, but it certainly affects the agreement. For example, we can measure subcutaneous fat by skinfold calipers. The calipers will measure two thicknesses of fat. If we were to plot calipers measurement against half-calipers measurement, in the style of fig 1, we should get a perfect straight line with slope 2.0. The correlation would be 1.0, but the two measurements would not agree — we could not mix fat thicknesses obtained by the two methods, since one is twice the other.

(3) Correlation depends on the range of the true quantity in the sample. If this is wide, the correlation will be greater than if it is narrow. For those subjects whose PEFR (by peak flow meter) is less than 500 l/min, r is 0.88 while for those with greater PEFRs r is 0.90. Both are less than the overall correlation of 0.94, but it would be absurd to argue that agreement is worse below 500 l/min and worse above 500 l/min than it is for everybody. Since investigators usually try to compare two methods over the whole range of values typically encountered, a high correlation is almost guaranteed.

(4) The test of significance may show that the two methods are related, but it would be amazing if two methods designed to measure the same quantity were not related. The test of significance is irrelevant to the question of agreement.

(5) Data which seem to be in poor agreement can produce quite high correlations. For example, Serfontein and Jaroszewicz [2] compared two methods of measuring gestational age. Babies with a gestational age of 35 weeks by one method had gestations between 34 and 39.5 weeks by the other, but r was high (0.85). On the other hand, Oldham et al. [3] compared the mini and large Wright peak flow meters and found a correlation of 0.992. They then connected the meters in series, so that both measured the same flow, and obtained a "material improvement" (0.996). If a correlation coefficient of 0.99 can be materially improved upon, we need to rethink our ideas of what a high correlation is in this context. As we show below, the high correlation of 0.94 for our own data conceals considerable lack of agreement between the two instruments.

MEASURING AGREEMENT

It is most unlikely that different methods will agree exactly, by giving the identical result for all individuals. We want to know by how much the new method is likely to differ from the old: if this is not enough to cause problems in clinical interpretation we can replace the old method by the new or use the two interchangeably. If the two PEFR meters were unlikely to give readings which differed by more than, say, 10 l/min, we could replace the large meter by the mini meter because so small a difference would not affect decisions on patient management. On the other hand, if the meters could differ by 100 l/min, the mini meter would be unlikely to be satisfactory. How far apart measurements can be without causing difficulties will be a question of judgment. Ideally, it should be defined in advance to help in the interpretation of the method comparison and to choose the sample size.

The first step is to examine the data. A simple plot of the results of one method against those of the other (fig 1) though without a regression line is a useful start but usually the data points will be clustered near the line and it will be difficult to assess between-method differences. A plot of the difference between the methods against their mean may be more informative. Fig 2 displays considerable lack of agreement between the large and mini meters, with discrepancies of up to 80 l/min, these differences are not obvious from fig 1. The plot of difference against mean also allows us to investigate any possible relationship between the measurement error and the true value. We do not know the true value, and the mean of the two measurements is the best estimate we have. It would be a mistake to plot the difference against either value separately because the difference will be related to each, a well-known statistical artefact. [4]

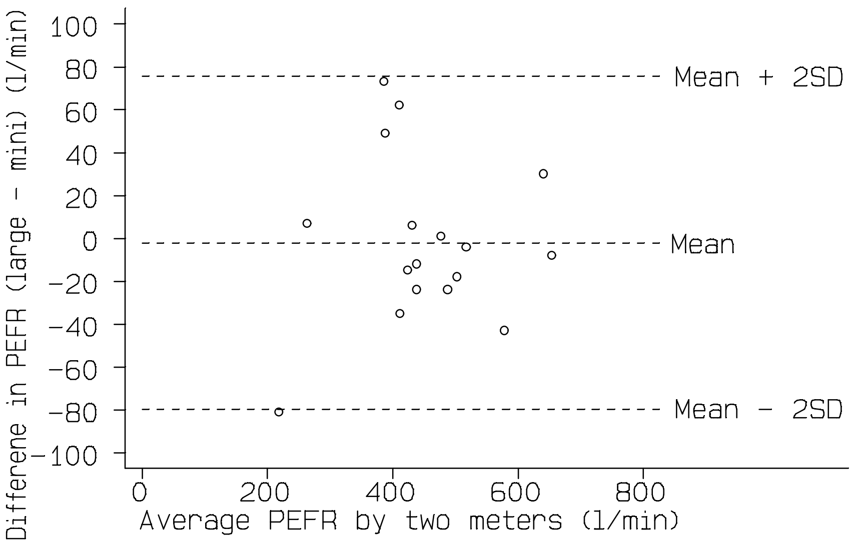

Fig 2. Difference against mean for PEFR data.

For the PEFR data, there is no obvious relation between the difference and the mean. Under these circumstances we can summarise the lack of agreement by calculating the bias, estimated by the mean difference $\bar{d}$ and the standard deviation of the differences (s). If there is a consistent bias we can adjust for it by subtracting $\bar{d}$ from the new method. For the PEFR data the mean difference (large meter minus small meter) is -2.1 l/min and s is 38.8 l/min. We would expect most of the differences to lie between $\bar{d} - 2s$ and $\bar{d} + 2s$ (fig 2). If the differences are Normally distributed (Gaussian), 95% of differences will lie between these limits (or, more precisely, between $\bar{d} - 1.96s$ and $\bar{d} + 1.96s$). Such differences are likely to follow a Normal distribution because we have removed a lot of the variation between subjects and are left with the measurement error. The measurements themselves do not have to follow a Normal distribution, and often they will not. We can check the distribution of the differences by drawing a histogram. If this is skewed or has very long tails the assumption of Normality may not be valid (see below).

Provided differences within $\bar{d} \pm 2s$ would not be clinically important, we could use the two measurement methods interchangeably. We shall refer to these as the "limits of agreement". For the PEFR data we get:

$$\bar{d} - 2s = -2.1 - (2 \times 38.8) = -79.7 \text{ l/min}$$

$$\bar{d} + 2s = -2.1 + (2 \times 38.8) = -75.5 \text{ l/min}$$

Thus, the mini meter may be 80 l/min below or 76 l/min above the large meter, which would be unacceptable for clinical purposes. This lack of agreement is by no means obvious in fig 1.

PRECISION OF ESTIMATED LIMITS OF AGREEMENT

The limits of agreement are only estimates of the values which apply to the whole population. A second sample would give different limits. We might sometimes wish to use standard errors and confidence intervals to see how precise our estimates are, provided the differences follow a distribution which is approximately Normal. The standard error of $\bar{d}$ is $\sqrt{s^2/n}$, where n is the sample size, and the standard error of $\bar{d} - 2s$ and $\bar{d} + 2s$ is about $\sqrt{3s^2/n}$. 95% confidence intervals can be calculated by finding the appropriate point of the t distribution with $n-1$ degrees of freedom, on most tables the columns marked 5% or 0.05, and then the confidence interval will be from the observed value minus t standard errors to the observed value plus t standard errors.

For the PEFR data s = 38.8. The standard error of $\bar{d}$ is thus 9.4, For the 95% confidence interval we have 16 degrees of freedom and t = 2.12. Hence the 95% confidence interval for the bias is $-2.1-(2.12\times 9.4)$ to $-2.1+(2.12\times 9.4)$, giving -22.0 to 17.8 l/min. The standard error of the limit $\bar{d}-2s$ is 16.3 l/min. The 95% confidence interval for the lower limit of agreement is $-79.7-(2.12\times 16.3)$ to $-79.7+(2.12\times 16.3)$, giving -114.3 to -45.1 l/min. For the upper limit of agreement the 95% confidence interval is 40.9 to 110.1 l/min. These intervals are wide, reflecting the small sample size and the great variation of the differences. They show, however, that even on the most optimistic interpretation there can be considerable discrepancies between the two meters and that the degree of agreement is not acceptable.

EXAMPLE SHOWING GOOD AGREEMENT

Fig 3 shows a comparison of oxygen saturation measured by an oxygen saturation monitor and pulsed oximeter saturation, a new non-invasive technique. [5] Here the mean difference is 0.42 percentage points with 95% confidence interval 0.13 to 0.70. Thus pulsed oximeter saturation tends to give a lower reading, by between 0.13 and 0.70. Despite this, the limits of agreement (-2.0 and 2.8) are small enough for us to be confident that the new method can be used in place of the old for clinical purposes.

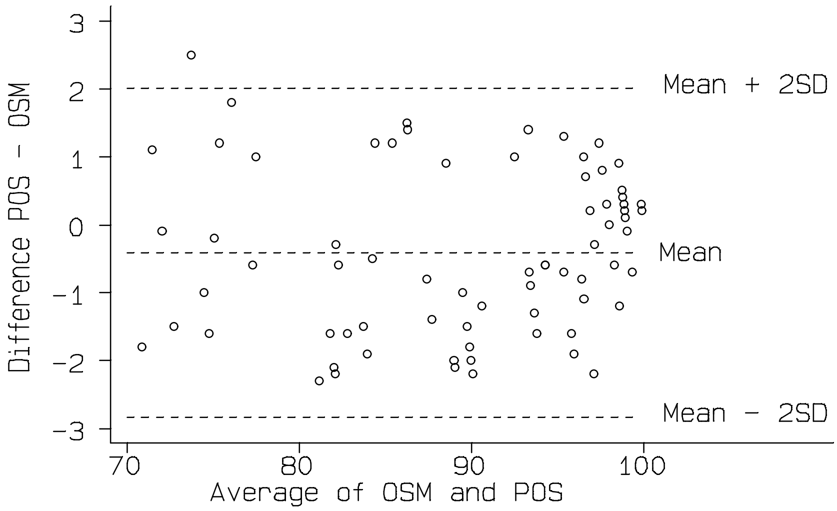

Fig 3. Oxygen saturation monitor and pulsed saturation oximeter

RELATION BETWEEN DIFFERENCE AND MEAN

In the preceding analysis it was assumed that the differences did not vary in any systematic way over the range of measurement. This may not be so. Fig 4 compares the measurement of mean velocity of circumferential fibre shortening (VCF) by the long axis and short axis in M-mode echocardiography. [6] The scatter of the differences increases as the VCF increases. We could ignore this, but the limits of agreement would be wider apart than necessary for small VCF and narrower than they should be for large VCF. If the differences are proportional to the mean, a logarithmic transformation should yield a picture more like that of figs 2 and 4, and we can then apply the analysis described above to the transformed data.

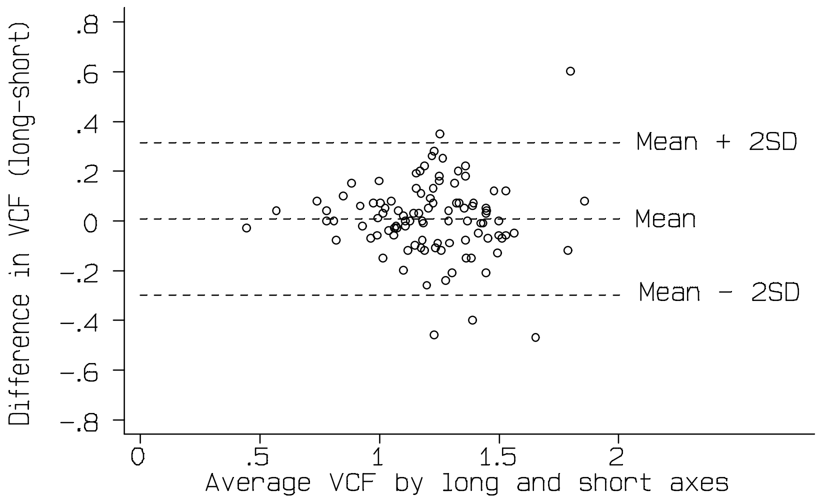

Fig 4. Mean VCF by long and short axis measurements.

Fig 5 shows the log-transformed data of fig 4. This still shows a relation between the difference and the mean VCF, but there is some improvement. The mean difference is 0.003 † on the log scale and the limits of agreement are -0.098 † and 0.106.† However, although there is only negligible bias, the limits of agreement have somehow to be related to the original scale of measurement. If we take the antilogs of these limits, we get 0.80 and 1.27. However, the antilog of the difference between two values on a log scale is a dimensionless ratio. The limits tell us that for about 95% of cases the short axis measurement of VCF will be between 0.80 and 1.27 times the long axis VCF. Thus the short axis measurement may differ from the long axis measurement by 20% below to 27% above. (The log transformation is the only transformation giving back-transformed differences which are easy to interpret, and we do not recommend the use of any other in this context.)

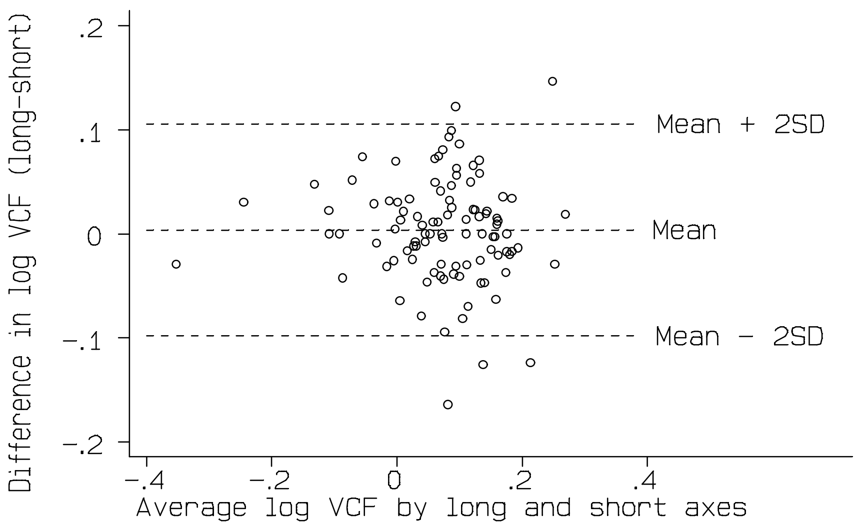

Fig 5. Data of fig 4 after logarithmic transformation.

† These numbers were incorrectly printed as 0.008, -0.226, and 0.243 in the *Lancet*. This mistake arose because when revising the paper we dithered over whether to use natural logs or logs to base 10 and got hopelessly confused.

Sometimes the relation between difference and mean is more complex than that shown in fig 4 and log transformation does not work. Here a plot in the style of fig 2 is very helpful in comparing the methods. Formal analysis, as described above, will tend to give limits of agreement which are too far apart rather than too close, and so should not lead to the acceptance of poor methods of measurement.

REPEATABILITY

Repeatability is relevant to the study of method comparison because the repeatabilities of the two methods of measurement limit the amount of agreement which is possible. If one method has poor repeatability — i.e. there is considerable variation in repeated measurements on the same subject — the agreement between the two methods is bound to be poor too. When the old method is the more variable one, even a new method which is perfect will not agree with it. If both methods have poor repeatability, the problem is even worse.

The best way to examine repeatability is to take repeated measurements on a series of subjects. The table shows paired data for PEFR. We can then plot a figure similar to fig 2, showing differences against mean for each subject. If the differences are related to the mean, we can apply a log transformation. We then calculate the mean and standard deviation of the differences as before. The mean difference should here be zero since the same method was used. (If the mean difference is significantly different from zero, we will not be able to use the data to assess repeatability because either knowledge of the first measurement is affecting the second or the process of measurement is altering the quantity.) We expect 95% of differences to be less than two standard deviations. This is the definition of a repeatability coefficient adopted by the British Standards Institution. [7] If we can assume the main difference to be zero this coefficient is very simple to estimate: we square all the differences, add them up, divide by n, and take the square root, to get the standard deviation of the differences.

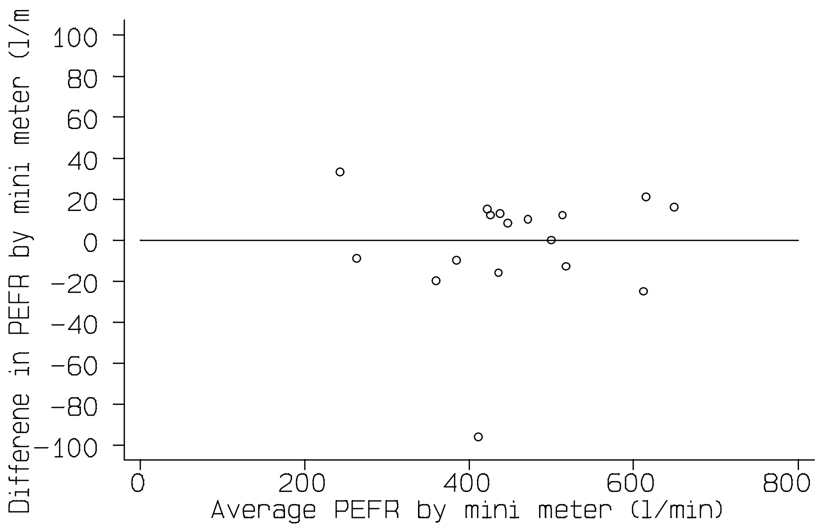

Fig 6. Repeated measures of PEFR using mini Wright peak flow meter.

Fig 6 shows the plot for pairs of measurements made with the mini Wright peak flow meter. There does not appear to be any relation between the difference and the size of the PEFR. There is, however, a clear outlier. We have retained this measurement for the analysis, although we suspect that it was technically unsatisfactory. (In practice, one could omit this subject.) The sum of the differences squared is 13479 so the standard deviation of differences between the 17 pairs of repeated measurements is 28.2 l/min. The coefficient of repeatability is twice this, or 56.4 l/min for the mini meter. For the large meter the coefficient is 43.2 l/min.

If we have more than two repeated measurements the calculations are more complex. We plot the standard deviation of the several measurements for that subject against their mean and then use one-way analysis of variance, [8] which is beyond the scope of this article.

MEASURING AGREEMENT USING REPEATED MEASUREMENTS

If we have repeated measurements by each of the two methods on the same subjects we can calculate the mean for each method on each subject and use these pairs of means to compare the two methods using the analysis for assessing agreement described above. The estimate of bias will be unaffected, but the estimate of the standard deviation of the differences will be too small, because some of the effect of repeated measurement error has been removed. We can correct for this. Suppose we have two measurements obtained by each method, as in the table. We find the standard deviation of differences between repeated measurements for each method separately, s_1 and s_2, and the standard deviation of the differences between the means for each method, s_D. The corrected standard deviation of differences, s_c, is $\sqrt{s_D^2 + \frac{1}{4}s_1^2 + \frac{1}{4}s_2^2}$. This is approximately $\sqrt{2s_D^2}$, but if there are differences between the two methods not explicable by repeatability errors alone (i.e. interaction between subject and measurement method) this approximation may produce an overestimate. For the PEFR, we have $s_D = 33.2$, $s_1 = 21.6$, $s_2 = 28.2$ ‡ l/min. s_c is thus $\sqrt{33.2^2 + 1/4 \times 21.6^2 + 1/4 \times 28.2^2}$ or 37.7 l/min. Compare this with the estimate 38.8 l/min which was obtained using a single measurement. On the other hand, the approximation $\sqrt{2s_D^2}$ gives an overestimate (47.0 l/min).

DISCUSSION

In the analysis of measurement method comparison data, neither the correlation coefficient (as we show here) nor techniques such as regression analysis [1] are appropriate. We suggest replacing these misleading analyses by a method that is simple both to do and to interpret. Further, the same method may be use to analyse the repeatability of a single measurement method or to compare measurements by two observers.

Why has a totally inappropriate method, the correlation coefficient, become almost universally used for this purpose?. Two processes may be at work here --- namely, pattern recognition and imitation. A likely first step in the analysis of such data is to plot a scatter diagram (fig 1). A glance through almost any statistical textbook for a similar picture will lead to the correlation coefficient as a method of analysis of such a plot, together with a test of the null hypothesis of no relationship. Some texts even use pairs of measurements by two different methods to illustrate the calculation of r. Once the correlation approach has been published, others will read of a statistical problem similar to their own being solved in this way and will use the same technique with their own data. Medical statisticians who ask "why did you use this statistical method?" will often be told "because this published paper used it". Journals could help to rectify this error by returning for reanalysis papers which use incorrect statistical techniques. This may be a slow process. Referees, inspecting papers in which two methods of measurement have been compared, sometimes complain if no correlation coefficients are provided, even when the reasons for not doing so are given.

‡ This was incorrectly printed as s_c in the *Lancet* and in *Biochimica Clinica*.

We thank of our colleagues for their interest and assistance, including Dr David Robson who first brought the problem to us, Dr P. D'Arbela and Dr H. Seeley for the use of their data; and Mrs S Stevens for typing the manuscript.

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TONOPORT V

Ambulatory Blood Pressure Monitor
Firmware Version 1.4

Operator's Manual

2001589-007 ENG Revision E

GE Medical Systems
Information Technologies

Revision History

This manual is subject to the *GE Medical Systems Information Technologies* change order service. The revision code, a letter that follows the document part number, changes with every update of the manual.

Part No./Revision	Date	Comment
2001589-007 A	2000-01	Initial Release
2001589-007 B	2001-01	ECO 066338
2001589-007 C	2001-07	ECO 067092
2001589-007 D	2001-12	ECO 068207
2001589-007 E	2002-07	ECO 071404

General Information

- The product TONOPORT V bears the CE mark
  CE-0482
  indicating its conformity with the provisions of the Council Directive 93/42/EEC concerning medical devices and fulfills the essential requirements of Annex I of this directive.
  It has an internal power source and is an MDD class IIa device.
- The product has a BF-type applied part.
- The product complies with the requirements of standard EN 60601-1 "Medical Electrical Equipment, Part 1: General Requirements for Safety" as well as with the interference protection requirements of standard EN 60601-1-2 "Electromagnetic Compatibility – Medical Electrical Devices".
- The radio-interference emitted by this device is within the limits specified in CISPR11/EN 55011, class B.
- The CE mark covers only the accessories listed in the chapter "Order Information".
- This manual reflects firmware version 1.4.
- This manual is an integral part of the product and describes its intended use. It should always be kept close to the equipment. Observance of the manual is a prerequisite for proper product performance and correct operation and ensures patient and operator safety. **Please note that information pertinent to several chapters is given only once. Therefore, carefully read the manual once in its entirety.**
- The symbol ⚠ means: Consult accompanying documents. It indicates points which are of particular importance in the operation of the device.
- This manual conforms with the product specifications and applicable IEC publications on safety and essential performance of electromedical equipment valid at the time of printing. All rights are reserved for devices, circuits, techniques, software programs, and names appearing in this manual.
- On request *GE Medical Systems Information Technologies* will provide a service manual.
- The *GE Medical Systems Information Technologies* quality management system complies with the international standards DIN EN ISO 9001 and EN 46001.
- The safety information given in this manual is classified as follows:

Danger
indicates an imminent hazard. If not avoided, the hazard will result in death or serious injury.

Warning
indicates a hazard. If not avoided, the hazard can result in death or serious injury.

Caution
indicates a potential hazard. If not avoided, this hazard may result in minor personal injury and/or product/property damage.

- To ensure patient safety, the specified measuring accuracy, and interference-free operation, we recommend to use only original *GE Medical Systems Information Technologies* components. The user is responsible for application of accessories from other manufacturers.
- The warranty does not cover damage resulting from the use of unsuitable accessories and consumables from other manufacturers.
- *GE Medical Systems Information Technologies* is responsible for the effects on safety, reliability, and performance of the device, only if
  - assembly operations, extensions, readjustments, modifications, or repairs are carried out by *GE Medical Systems Information Technologies* or by persons authorized by *GE Medical Systems Information Technologies*,
  - the device is used in accordance with the instructions given in this operator's manual.

Manufacturer: PAR Medizintechnik GmbH, Berlin

Postfach 600265
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Telephone +49 761 45 43-0

1 Introduction to TONOPORT V, Safety Information

1.1 TONOPORT V Features

Intended Use

TONOPORT V is a small-size, patient-borne blood-pressure monitor for long-term, non-invasive measurement of the patient's blood pressure. It can be used to measure the blood pressure of adults, children and small children, but it **cannot** be used on neonates. Also, it is **not** suitable for use in intensive care medicine.

For periods of up to 30 hours it records the patient's blood pressure at predefined intervals and saves the results. There is a choice of 3 different measurement protocols. The stored data can be documented via a printer.

Furthermore, TONOPORT V can be operated in conjunction with CardioSys and with the CardioSoft DFT data evaluation software package that comes with TONOPORT V. CardioSys / CardioSoft supports the configuration of patient-specific measurement protocols and on-screen review of the measured results in tabular and graphic form.
(All instructions given in this manual that describe the operation in conjunction with CardioSys / CardioSoft apply to V4.14 and later versions of CardioSys / CardioSoft.)

Biocompatibility

The parts of the product described in this operator manual, including all accessories that come in contact with the patient during the intended use, fulfill the biocompatibility requirements of the applicable standards. If you have questions in this matter, please contact GE Medical Systems Information Technologies or its representatives.

Oscillometric Measuring Method

The blood pressure is measured by the oscillometric method. The criteria for this method are the pressure pulsations superimposed with every systole on the air pressure in the cuff.

The blood pressure cuff is wrapped around the upper arm and inflated to a pressure which must be clearly above the expected systolic pressure. A pressure transducer measures the cuff pressure as well as the superimposed pressure pulsations. During blood pressure measurements the cuff must be level with the heart. If this is not ensured, the hydrostatic pressure of the liquid column in the blood vessels will falsify the measurement results.

When the patient is sitting or standing during measurements, the cuff is automatically at the correct level.

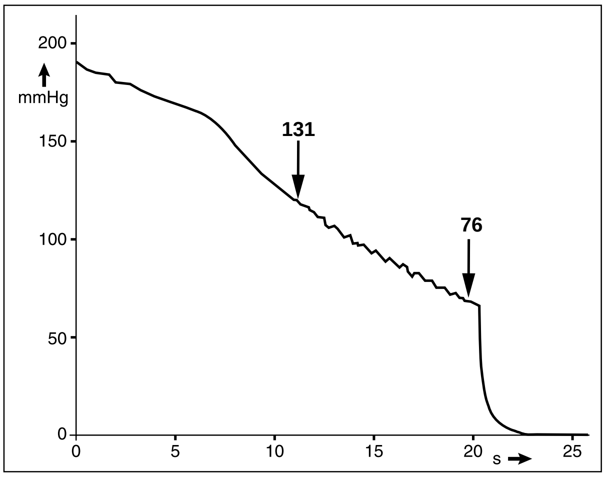

Figure 1-1. Waveform representing the cuff pressure decrease during a measurement; systolic pressure at 131 mmHg diastolic pressure at 76 mmHg

1.2 Functional Description

The TONOPORT V BP monitor houses the blood-pressure measuring system and a microprocessor for system control and data processing. The BP monitor is powered from two AA size batteries (alkaline batteries or rechargeable NiMH batteries).

1.3 Safety Information

Danger

- ***The devices are not designed for use in areas where an explosion hazard may occur. An explosion hazard may result from the use of flammable anesthetics, skin cleansing agents and disinfectants.***
- ***Devices may be connected to other devices or to parts of systems only when it has been made certain that there is no danger to the patient, the operators, or the environment as a result. In those instances where there is any element of doubt concerning the safety of connected devices, the user must contact the manufacturers concerned or other informed experts as to whether there is any possible danger to the patient, the operator, or the environment as a result of the proposed combination of devices. Compliance with the IEC standard 60601-1-1 must be ensured in each case.***
  TONOPORT V may be connected to CardioSys, to a PC with the CardioSoft program, and to a printer. While connected to any of these devices, TONOPORT V must be disconnected from the patient.
- ***Chemicals required for the maintenance of the device for instance, must under all circumstances be stored, prepared, and kept at hand in their specific containers. Failure to observe this instruction may result in severe consequences for the patient.***
- ***Liquids must not be allowed to enter the devices. Devices into which liquids have penetrated must be immediately cleaned and checked by a service technician, before they can be reused.***
- ***Before cleaning TONOPORT V BP monitors, disconnect them from other devices (CardioSys, PC, printer).***
- ***Dispose of the packaging material, observing the applicable waste-control regulations. Keep the packaging material out of children's reach.***

Warning

- ***Magnetic and electrical fields are capable of interfering with the proper performance of the device. For this reason make sure that all external devices operated in the vicinity of the defibrillator comply with the relevant EMC requirements. X-ray equipment, MRI devices and radio systems are a possible source of interference as they may emit higher levels of electromagnetic radiation.***
- ***Only use accessories the application of which has been approved by GE Medical Systems Information Technologies. The user is responsible for application of accessories from other manufacturers.***

Caution

- ***Before using the device, the operator must ascertain that it is in correct working order and operating condition.***
- ***The operator must be trained in the use of the device.***
- ***Only persons who are trained in the use of such medical electrical equipment and are capable of applying it properly are authorized to handle such equipment.***
- ***Check the device performance at regular intervals (once a month).***
  The technical safety inspections must be carried out on an annual basis, the inspections of the measuring system every two years (see chapter 7 "Cleaning, Maintenance").
- ***There are no user-replaceable components inside the device. Do not open the device housing (notify service).***

Literature

Medical Device Directive of August 2, 1994

EN 60601-1: 1990 + A 1: 1993 + A 2: 1995
Medical electrical equipment. General requirements for safety.

EN 60601-1-1: 9/1994 + A1: General requirements for safety. Requirements for the safety of medical electrical systems.

IEC-Publication 513/1994: Fundamental aspects of safety standards for medical equipment.

2 Controls and Indicators

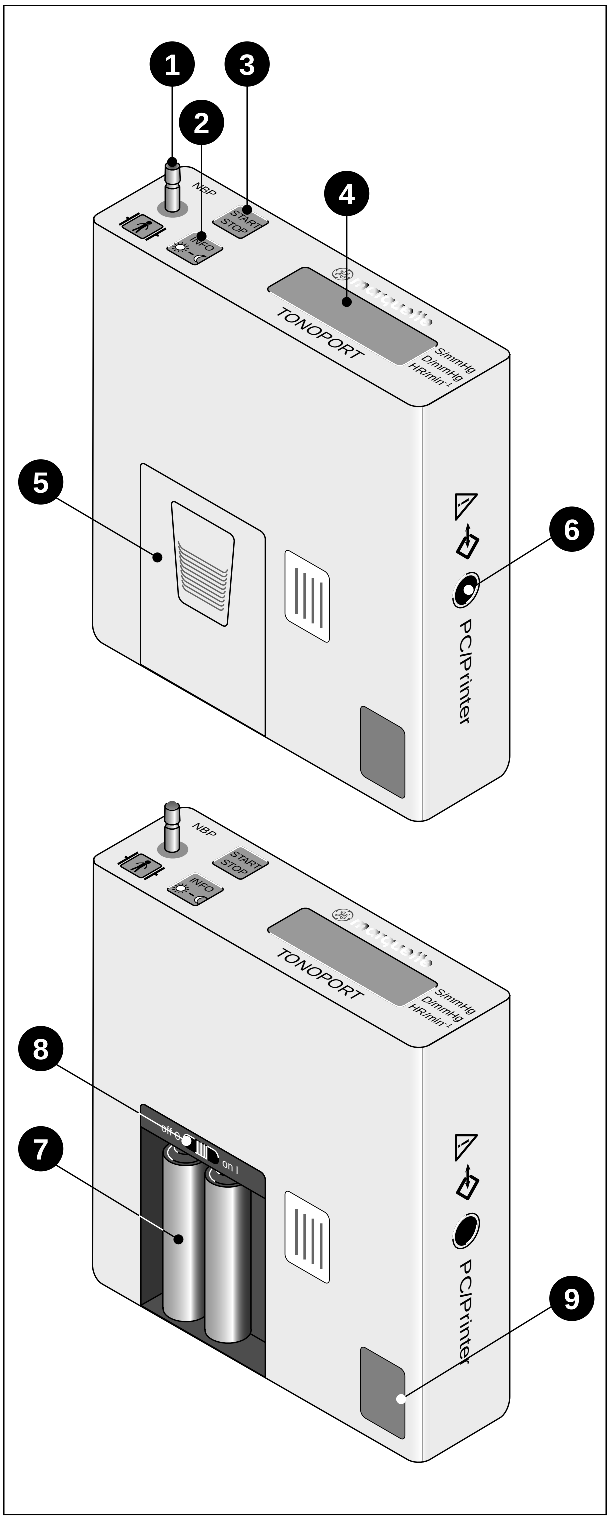

Figure 2-1. Controls and indicators of the TONOPORT V blood pressure monitor

1 *Connection for the blood pressure cuff*

2 *Button* INFO *to display the most recent parameter readings. Readings appear in the following order:*

- *systolic value "S/mmHg"*
- *diastolic value "D/mmHg"*
- *pulse rate "HR/min^{-1}".*

The same button is used

- *to switch from the day to the night phase (chapter 4, section "Toggle Manually Between Day and Night Phase) and*
- *to program the BP monitor (chapter 3 "Set Up the TONOPORT V BP Monitor")*

3 *Button* START STOP *to start and stop a measurement, or to confirm entries*

4 *Liquid crystal display (LCD)*

5 *Lid covering battery compartment*

6 *PC / printer port*

7 *(Rechargeable) batteries*

8 *Power switch*

9 *Calibration mark*

Explanation of Signs and Symbols

Symbols used on the BP monitor

⚠ Attention, refer to Operator's Manual

Data input / output

BF-type applied part (defibrillator-proof)

Symbols used on the display

M blinks with each detected oscillation
is continuously lit to indicate that BP data is stored in memory

blinks when batteries are almost discharged,
is continuously displayed when batteries are discharged and BP measurements cannot be taken

☀ day period selected

☾ night period selected

3 Set Up the TONOPORT V BP Monitor

Some Basic Facts on Battery Power

TONOPORT V is either powered from two alkaline batteries, or from two rechargeable Nickel Metal Hydride (NiMH) batteries. The BP monitor must be set to the power source used (see section "Insert Batteries" below). The BP monitor also contains a Lithium cell which powers the clock and which can only be replaced by a service technician. The Lithium cell has a minimum service life of 10 years.

The capacity of two new alkaline batteries or of two fully charged NiMH batteries is sufficient for a minimum of 30 hours of operation or 200 measurements.

The capacity of rechargeable batteries decreases with age. If the capacity of fully charged batteries drops considerably below 24 hours of operation, the batteries have to be replaced.

Caution

- ***Use only the original NiMH batteries (>1500 mAh HR-3U Sanyo) or alkaline batteries.***
- ***Recharge NiMH batteries immediately after use and do not leave batteries uncharged.***
- ***Use only the original charging unit to recharge the NiMH batteries.***

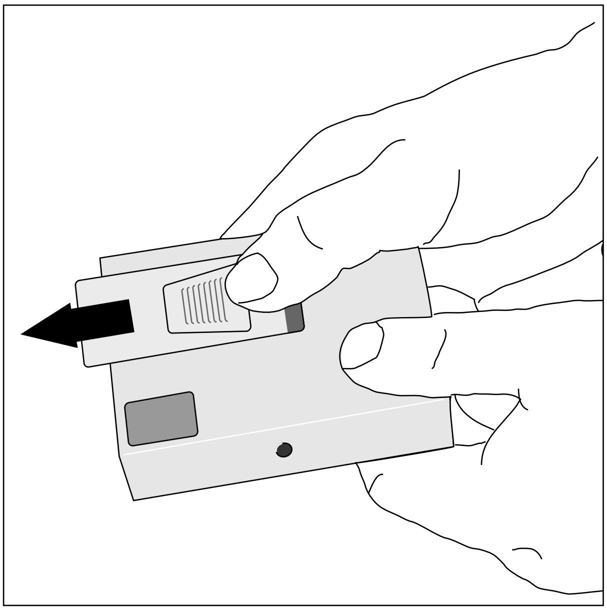

Figure 3-1. Opening the battery compartment

Insert Batteries

- Hold the TONOPORT V BP monitor in your hands as shown in Figure 3-1 and slide the lid of the battery compartment open (approx. 1 cm).

It is not possible to open the lid more than approx. 1 cm; this is just enough to permit access to the power switch under the lid. When replacing batteries, lift the lid upward to remove it.

- Place the two batteries into the compartment as indicated by the symbols.

Select the Energy Source

- Turn on the BP monitor (the power switch is located in the battery compartment).
- Wait until the display shows the time.
- Press [INFO] six times: The display shows "H 6".
- Press [START STOP]: The display will show "bbbb" when the BP monitor is set up for disposable alkaline batteries. If the monitor is set up for rechargeable NiMH batteries (default setup upon delivery), the display will read "AAAA".
- Confirm the displayed information with [START STOP] or change the selection with [INFO] and confirm the new selection with [START STOP].
- Next the BP monitor will briefly display the capacity of the inserted batteries. "b 50" means the alkaline batteries are half depleted (50% capacity), "A 100" means the NiHM batteries are fully charged (100% capacity).
- Place the lid on the battery compartment and slide it towards the back to close the compartment.

Note

The energy source needs to be selected only when the BP monitor is put into service for the first time or when you change from disposable to rechargeable batteries and vice versa.

Charge NiMH Batteries

If TONOPORT V is operated with rechargeable NiHM batteries (four batteries are supplied with the BP monitor), they should be recharged immediately after each use (24 hours). Use only the original charging unit supplied with the BP monitor.

- Check whether the voltage ratings on the nameplate of the charging unit are those of your local power line.
- If necessary, replace the connector to match the installed wall outlet type as follows (the charging unit is supplied with the Euro connector inserted):
  - push the slide below the connector in the direction indicated by the arrow (Figure 3-2),
  - remove the connector and insert the suitable type,
  - ensure that the new connector clicks into place.
- Plug the charging unit into the wall outlet.
- Insert the two rechargeable batteries into the charging unit, observing the correct polarity.

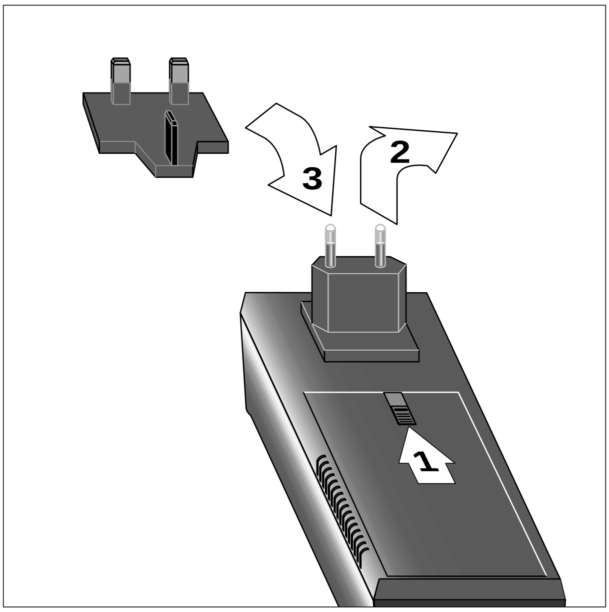

Figure 3-2. Exchanging the connector

The batteries take up to 3 hours to recharge. The red LED indicates the charge cycle. Each of the green LEDs corresponds to one of the charger compartments (Figure 3-3). During the charge cycle, the corresponding green LED blinks approx. once per second. Note: If the green LED does not light up, the battery may be inserted the wrong way round. When the battery is full, the LED is solid green and the charger trickle-charges the battery to compensate for self-discharging.

To extend the useful life of NiMH batteries, we recommend to run a full discharge/charge cycle once a month as described below:

- Insert the batteries in the charger.
- Push the yellow button labeled PRESS for approx. 2 seconds.

Figure 3-3. Green charger LEDs

> **Caution**
>
> ***Observe the user instructions that come with your charging unit.***

The batteries are now first fully discharged (the discharge cycle is signaled by the green LEDs lighting up consecutively from right to left). The batteries may take up to 8 hours to discharge. Once discharged, they will automatically be recharged.

If a green LED blinks at a fast rate (approx. 4 times per second), the charger has identified a battery problem. The charging current to this compartment will be cut off. Remove the battery and discard it as appropriate.

Performance Check

When turned on, TONOPORT V runs a self-test which includes all symbols and segments on the LCD (Figure 3-4). Then the BP monitor checks the batteries and indicates the remaining capacity. When the display indicates "b 50", this means the alkaline batteries are half depleted (50% capacity), "A 100" means the NiHM batteries are fully charged (100% capacity).
The minimum battery capacity for a 24-hour measurement is 90%. If the capacity is below 90%, insert either fresh or fully charged batteries.

BP monitors which have passed the self-test and completed the battery test will indicate the following information
– the time of day,
– the measuring phase (day ☀ / night ☾), and
– whether or not BP data are stored in the monitor (**M**) (Figure 3-5).

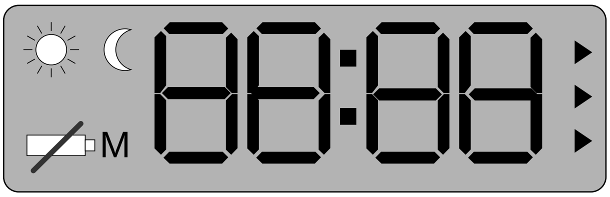

Figure 3-4. Test display on the LCD

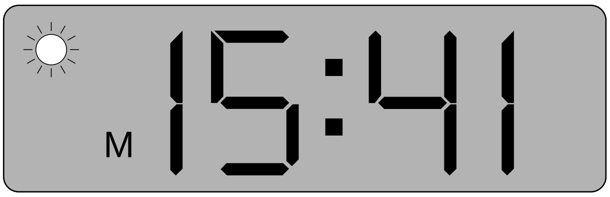

Figure 3-5. Example of a display when the BP monitor has passed the self-test (M = BP data in memory, ☀ = measuring phase: day)

Before using TONOPORT V on a patient
– delete old data stored in memory,
– check time and date and correct, if necessary,
– select the appropriate measurement protocol, if necessary.

Functions of the [INFO] Button

The different setup functions, such as deleting data, setting date and time, are activated with the [INFO] button.

[INFO] button	Message on display	Function
Push once	H 1	delete data
Push twice	H 2	adjust date and time
Push 3 times	H 3	select measurement protocol
Push 4 times	H 4	calibration mode
Push 5 times	H 5	display firmware version and select language
Push 6 times	H 6	select energy source

Delete BP Data

The "M" on the LCD indicates that BP data is stored in memory. If you intend to use this data for evaluation, refer to chapter 5 "Data Output" for instructions. If you do not need the data any more, you can delete it as follows:

- Briefly switch the TONOPORT V BP monitor off, then switch it on again and wait until the time of day displays.
- Press [INFO] : the display indicates "H 1".
- Press [START STOP] : the display indicates "LLLL".
- Press [START STOP] again to delete the data. The display indicates "0000", then it shows the time of day (if you do not intend to delete the data, turn off the patient monitor instead of pressing [START STOP]).

The CardioSys system and the CardioSoft program have a special function which allows you to delete the TONOPORT data.

Time and Date

Usually the BP monitors are set to the correct time and date before delivery. The internal clock is powered from a Lithium cell with a minimum service life of 10 years. For this reason, it is only necessary to correct the time when changing between Daylight Saving Time and Standard Time.
If using TONOPORT V in conjunction with CardioSys or CardioSoft, it is possible to adapt the time to the system time when TONOPORT V is connected to CardioSys or to the PC.

Set Time and Date

- Briefly switch the TONOPORT V BP monitor off, then switch it on again and wait until the time of day displays.
- Press [INFO ☼–☾] twice: the display indicates "H 2".
- Press [START STOP] . The year will be displayed, e.g. 2002.
- If the displayed year is correct, press [START STOP] or correct the year with [INFO ☼–☾] and confirm the new value with [START STOP].
- The month will be displayed, e.g. 08.
- If the displayed month is correct, press [START STOP] or correct the month with [INFO ☼–☾] and confirm the new value with [START STOP].
- In the same manner, correct day, hours and minutes.
- In the end, the time of day will be displayed again.

Measurement Protocols

In conjunction with CardioSys / CardioSoft, patient-specific measurement protocols can be configured and the maximum inflation pressure can be adjusted in the range between 200 mmHg and 280 mmHg (see also chapter 5 "Data Output" and the CardioSys / CardioSoft Operator's Manual).

If you do not have this option, you can choose among three preconfigured protocols.

Protocol	**Day Phase** (7 a.m. to 10 p.m.)	**Night Phase** (10 p.m. to 7 a.m.)
P1	every 15 minutes	every 30 minutes
P2	every 20 minutes	every 40 minutes
P3	every 30 minutes	every 60 minutes

Max. inflation pressure: day phase – 250 mmHg
night phase – 220 mmHg

Select a Measurement Protocol

- Briefly switch the TONOPORT V BP monitor off, then switch it on again and wait until the time of day displays.
- Press [INFO ☼–☾] three times: the display indicates "H 3".
- Press [START STOP] : the display indicates "LLLL" (Selecting a protocol automatically deletes old data. If you do not want to delete the data, turn off the BP monitor.)
- Press [START STOP] : the display indicates "P1" (protocol 1).
- Either select protocol 2 or 3 with [INFO ☼–☾] or
- Confirm the selected protocol with [START STOP].

4 Application

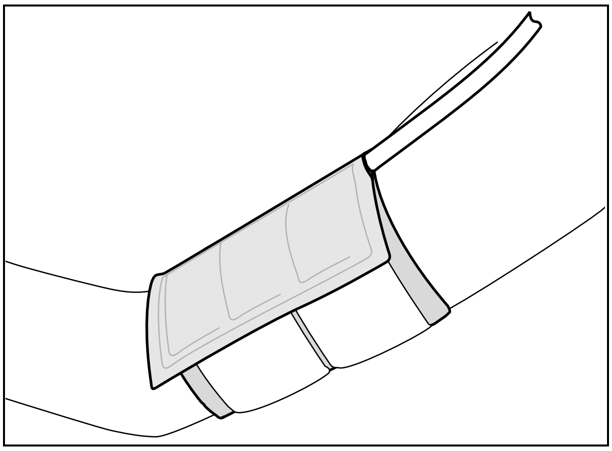

Figure 4-1. Applying the cuff

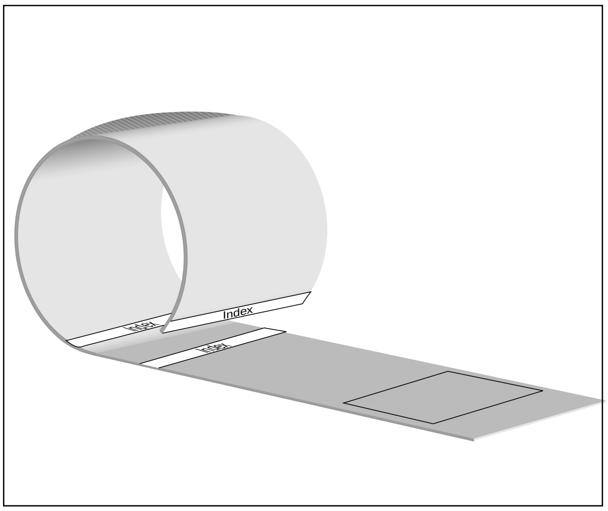

Figure 4-2. Applying the cuff

Danger

Disconnect TONOPORT V from any other device (CardioSys, PC, printer) before connecting it to the patient.

- Always insert two new Alkaline batteries or two fully charged NiMH batteries into the BP monitor before starting a measurement.
- Check that old data has been deleted (page 11 "Delete BP Data").
- First of all, select the appropriate cuff size (refer to cuff label). **When the cuff is too small the BP values will be overrated, when it is too big, the measured values will be too low.**

Caution

– ***Use only the cuffs listed in chapter 9 "Order Information".***
– ***Replace cuffs at regular intervals. Damaged Velcro fasteners may prevent correct BP measurements.***

- Place the cuff on that arm of the patient which is used less frequently during normal daily activities: on adults about 2 fingers' breadth above the bend of the elbow, on children a little closer. Bending the arm must not alter the cuff level.
- Verify that
  - the cuff tubing points upward towards the shoulder (Figure 4-1),
  - the side with the "Patient" label is on the skin,
  - the arrow is located above the brachial or femoral artery,
  - the white index line at the end of the cuff is located between the two index lines when you close the cuff (Figure 4-2, if this is not the case, select another cuff size),
  - the cuff fits snugly around the arm, but does not occlude blood vessels.

Initiate a Trial Measurement

- Turn on TONOPORT V and place it in the carrying pouch. There is an aperture in the pouch to accommodate the cuff connection tube.
- Attach the pouch to the patient (shoulder strap, belt). For reasons of hygiene, it is not advised to carry the pouch on the bare skin.
- Guide the pressure hose around the patient's neck as a strain relief and connect it to the BP monitor. Advise the patient to avoid kinking the tubing during the procedure.
- Check that the time of day is displayed.

  If the patient monitor contains BP data, the letter "M" will appear on the display when you turn the monitor on. If you still try to initiate a measurement, the message "LLLL" prompts you to clear the memory. Press START STOP twice to delete the stored data. If you do not want to delete the BP data, do not push the START STOP button, and turn the monitor off instead.
- To prevent erroneous measurements, ensure that the patient does not move during the trial measurement. The patient may stand or sit.
- Press START STOP to initiate the first measurement.

After a short waiting period, the monitor starts inflating the cuff. When the inflation pressure has been reached, the cuff is gradually deflated. The cuff pressure is continuously indicated and the letter **M** displays with each detected oscillation. At the end of the measurement, the following information appears in that order

– the systolic reading (S/mmHg),
– the diastolic reading (D/mmHg), and
– the pulse rate (HR/min^{-1}).

If the error code **E 29** (insufficient number of oscillations detected) appears after the measurement, tighten the cuff a little and press START STOP again (see also chapter 6 "Error Codes").

If the trial measurement has been successfully completed, the monitor is ready to take automatic blood-pressure measurements.

Patient Information

Advise your patient

– not to move while a measurement is being taken, because motion artifact may lead to erroneous readings,
– that at night it is recommended to place the TONOPORT V BP monitor on the night stand,
– how to switch the monitor manually to the day or night phase (see page 15),
– that events deemed important should be noted down in a little diary and that intermediate measurements, if necessary, can be initiated with the START STOP button,
– that the measurement can be aborted at any time with the START STOP button (the cuff will be deflated),
– not to open the battery compartment.

Warning

Instruct your patient

– ***to terminate the measurement with the START STOP button, whenever the cuff is not deflated within about 2 minutes,***

– ***to remove the cuff if it is not deflated after activation of the START STOP button. In this case, the cuff tubing may be kinked. The cuff must be reapplied as described earlier before additional measurements can be taken.***

General Information on Ambulatory BP Measurements

These are the buttons on the monitor which are used in the course of an ambulatory BP measurement:

START STOP starts and stops a measurement

INFO ☼–☾ calls up the values of the last measurement or the last error code, toggles between day and night phase (see below)

For the first measurement, the cuff is inflated to a pressure of 170 mmHg (initial pressure). For subsequent measurements, the monitor inflates the cuff to a pressure which is 30 mmHg above the systolic value of the previous measurement (minimum inflation pressure: 120 mmHg).

If the measuring value is above the inflation pressure, the monitor will increase the cuff pressure another 50 mmHg.

A manual measurement can be initiated at any time between the automatic measurements. Manual measurements are identified with the symbol + in the tabular BP data.

The monitor will repeat an unsuccessful measurement after 2 minutes. An error code referring to this situation is generated only if three consecutive measurements were unsuccessful.

Error codes E02 (battery depleted), E06 (inflation time over) and E08 (200 pressure measurements taken) do not lead to a second measurement. After the error code E06, the next measurement will take place in the selected rhythm.

After the error codes E02 and E08, the monitor enters a power saving mode to prevent over discharging of the rechargeable batteries. This mode can only be terminated by turning the monitor off and on again.

Toggle Manually Between Day and Night Phase

In the three measurement protocols, the day and night phases last from 7 a.m. to 10 p.m. and from 10 p.m. to 7 a.m., respectively; on the display they are represented by the symbols ☀ (day) and ☾ (night).

Patients whose day and night phases are different from these predefined periods can press the INFO ☼–☾ button twice to change from one phase to the other.

If the measurement protocol used was programmed with CardioSys / CardioSoft, pressing the INFO ☼–☾ button twice will have the following effect (with CardioSys / CardioSoft V4.14 and later):

1 BP period (manual switchover is not possible): beginning of night or day phase is annotated in the report.

2 BP periods: manual switchover from period 1 to period 2 and vice versa.

3 BP periods or more: manual switchover is not possible.

5 Data Output

Danger

Disconnect TONOPORT V from the patient, before connecting it to any peripheral device (CardioSys, PC, printer).

Note

If you do not click the "Download data" button to initiate data transfer within 10 minutes of connecting the TONOPORT V monitor to CardioSys / CardioSoft, TONOPORT V will enter the power save mode and the message "Error initializing interface" appears.

Follow these steps in this situation:

- ***turn the TONOPORT V off and on again***
- ***reactivate the ambulatory blood pressure mode***
- ***initiate data transfer within 10 minutes by clicking the "Download data" button.***

Note

TONOPORT V was designed for use with CardioSys / CardioSoft V4.14 and later versions. When operating TONOPORT V in conjunction with older version of CardioSys / CardioSoft, wait about 10 seconds before clicking the "Download data" button. Otherwise the message "Difference between number of expected and transferred data!" may appear.

When you see the message, acknowledge it with "OK" and click "Download data" again.

Data Output via CardioSys / CardioSoft

When operating TONOPORT V in conjunction with CardioSys / CardioSoft, the procedure data can be reviewed on screen in tabular and graphic form (see CardioSys / CardioSoft Operator's Manual).

- Turn the TONOPORT V monitor off.
- Using the supplied cable, connect the TONOPORT V monitor to the PC (Figure 5-1).
- Turn the TONOPORT V monitor on.

The determination of the statistics intervals depends on the number of configured BP periods (CardioSys / CardioSoft V4.14 and later):

1 BP period:

The "Statistics Intervals" button on the "Test Summary" screen is disabled. BP data for the night phase are available only when the patient has manually switched to the night phase. Otherwise there is no night phase and no wake-up time. The wake-up time begins 2 hours before the day time.

Measurements taken during the night phase are identified with an asterisk * in the tabular BP data and with a short dash above the time scale in the graphic data. Manual measurements are identified with the symbol + in the tabular BP data.

2 BP periods:

As above. If the patient does not switch manually to the night phase, the BP monitor will automatically switch to the night phase (2^{nd} BP period).

3 or 4 BP periods:

The patient cannot switch manually to the next period. Nocturnal data are not available. The day and night phases can be defined as usual in the Statistics Intervals dialog. There is no special identification for measurements taken during the night phase or for manual measurements.

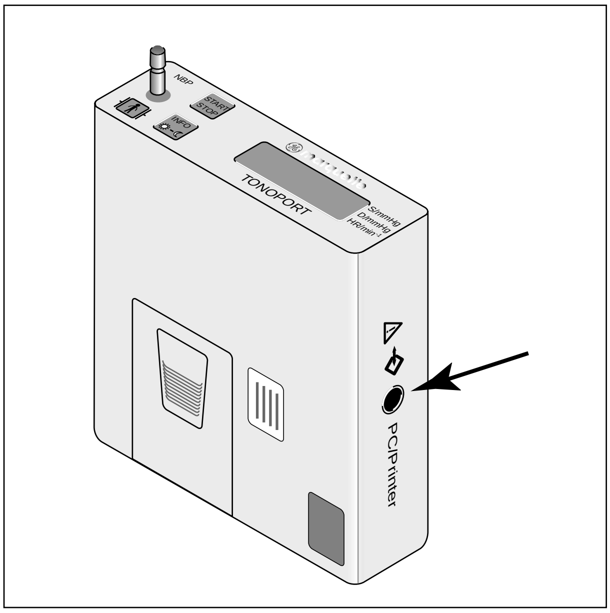

Figure 5-1. Connection for printer or PC cable

Direct Data Output to Printer

If you do not operate the BP monitor in conjunction with CardioSys / CardioSoft, the ambulatory blood-pressure report can be generated on a 9-needle dot-matrix printer with serial interface (EPSON LX-300+). Before printing the report, set up the printer as follows (observe the printer's user manual):

– character table PC 437
– baud rate 9600
– parity none
– word length 8 bit

In addition, you can select the language for the printed report (see section “Select Language for Direct Data Output to Printer” below). The language can be changed at any time. Stored data will not be deleted. If your printed report is in German, for instance, and you would rather have an English, just change the language to English and print the report again.

- Turn off TONOPORT V.
- Using the cable supplied with the printer, connect TONOPORT V to the printer (Figure 5-1).
- Turn on the printer.
- Turn on TONOPORT V.

The display indicates "0000".

- Press START STOP to initiate the report printout.

Refer to the Appendix for a sample printout.

Select Language for Direct Data Output to Printer

- Briefly turn TONOPORT V off and on again and wait for the time to be displayed (TONOPORT V is not connected to the printer at this point).
- Push INFO five times: the display indicates "**H 5**".
- Push START STOP : the display indicates the firmware version and the language, e.g. „14:01“ (factory setting).
  – the number preceding the colon indicates the firmware version (14 = V1.4),
  – the number following the colon indicates the language (01 = German, 02 = English, 03 = French, 04 = Italian, 05 = Spanish).
- Either confirm the set language with START STOP or select another language with INFO (sequencing key) and confirm the selection with START STOP.

Note
The language you select remains active.

6 Error Codes

E 02 Batteries depleted. Code appears when the battery capacity is insufficient for new BP measurements. The monitor differentiates between two states: the memory has just been cleared (i.e., the battery test is performed with a higher drain to ensure that fresh batteries will be inserted at the beginning of the measurement) or measurements have already been taken.

E 03 Measurement time over. Code is displayed when a measurement is not completed within 60 seconds (excluding cuff inflation time).

E 06 Inflation time over. The maximum inflation time of 60 seconds has elapsed. This condition indicates a leak in the cuff or tubing, or a defective gasket.

E 07 This code appears
– when the monitor could not determine a systolic value although the cuff pressure was already increased twice
– when the current cuff pressure would exceed the maximum permitted inflation pressure of 280 mmHg
The monitor will not inflate the cuff to a pressure which is above the selected maximum pressure, and waits until the next measurement is due.

E 08 200 pressure measurements taken; storage capacity exhausted.

E 14 Diastolic reading below 40 mmHg. Code appears when the cuff pressure has dropped to 40 mmHg and no diastolic pressure could be identified (TONOPORT V does not measure diastolic pressures below 40 mmHg).

E 15 Motion artifact during diastole detection.

E 17 Internal hardware error (notify Service).

E 18 Systolic reading outside measuring range.
E 19 Diastolic reading outside measuring range. (These codes are displayed when the systolic and diastolic values are outside the range in which oscillations have been detected.)

E 21 Difference between systolic and diastolic pressure too small (10 mmHg or less).

E 22 Motion artifact during systole detection.

E 24 No systole detected in the provided time frame.

E 26 Systolic reading below measuring range.

E 27 Systolic reading above measuring range.

E 29 Insufficient number of oscillations detected: For a correct measurement, the system must detect at least 8 oscillations. Tighten the cuff so that one finger, but not two, can be inserted between the patient's arm and the cuff. At the same time the device switches to a deflation rate of 4 mmHg/s. When it detects more than 13 oscillations later on, the rate changes to 6 mmHg/s.

7 Cleaning, Maintenance

7.1 Cleaning, Disinfection

Monitor Surface

Danger

Before cleaning TONOPORT V, disconnect it from the PC or printer.

- Turn off TONOPORT V.
- Wipe the monitor clean with a moist cloth. Do not let liquid enter the monitor.
  All hospital-grade cleaning agents and disinfectants can be used.

Caution

Do not disinfect the device surface with phenol-based disinfectants or peroxide compounds.

Danger

Devices into which liquids have penetrated must be immediately cleaned and checked by a service technician, before they can be reused.

Cuffs

- Use a moist cloth to wipe clean slightly soiled cuffs.
- Remove heavy soiling by washing the cuff with soap water or a suitable cleaning agent that contains a disinfectant (do not machine-wash). Ensure that no liquid penetrates into the cuff bladder or the pressure hose (for this reason, remove the bladder from the cuff before cleaning it).
- After cleaning, rinse the cuff thoroughly with water and let it dry at room temperature for about 15 hours.

– The cuffs can be disinfected with isopropyl alcohol 70%, ethanol 70%, Microzid, Buraton liquid, Sporicidin or Cidex. After disinfection, rinse the cuff thoroughly with tap water and air-dry.

– The cuffs may be gas-sterilized with ethylene oxide. Strictly observe the manufacturer's instructions.

Cables

- Disconnect cables from the device before cleaning them.
- Use a cloth moistened with soap water to wipe the cables clean. Do not immerse the cable in liquid.

7.2 Maintenance

Checks before each use

- Before each use visually check the device and the cables for signs of mechanical damage.

If you detect damages or impaired functions which may result in a hazard to the patient or the operator, the device must be repaired before it can be used again.

Technical Safety Inspections

For safety, the devices require regular maintenance. To ensure functional and operational safety of the TONOPORT V, Technical Safety Inspections should be carried out on an annual basis.

These checks should be performed by persons with adequate training and experience.

The checks can be carried out by *GE Medical Systems Information Technologies* within the framework of a service agreement.

The nature and scope of these checks are explained in the corresponding sections of the Service Manual.

The device does not require any other maintenance.

Technical Inspections of the Measuring System

The non-invasive pressure measurement system must be inspected every 2 years.

These checks should be performed by persons with adequate training and experience.

The checks can be carried out by *GE Medical Systems Information Technologies* within the framework of a service contract.

The nature and scope of these checks are explained in the corresponding sections of the Service Manual.

> **Caution**
> ***At the end of their service life, the device described in this manual and its accessories must be disposed of in compliance with the applicable local waste control regulations. If you have questions regarding the disposal of the product or of the accessories, please contact GE Medical Systems Information Technologies or its representatives.***

Calibration Mode

(e.g. to check the pneumatic system for leaks)

- Connect a rubber bulb between pressure hose and cuff, using a T-adapter.
- Roll up cuff tight.
- Switch off device and switch it on again after a few seconds.
- Wait until the display shows the time.
- Press the [INFO] button 4 times: the display indicates "H 4".
- Press the [START STOP] button: the display indicates an internal value which must be between 25 and 100. If the displayed value is outside this range, the TONOPORT V monitor must be returned to *GE Medical Systems Information Technologies* for repair.
- Press the [START STOP] button again: display indicates "0" (the display now indicates the pressure in mmHg).
- Generate a test pressure of 200 mmHg and measure the pressure decrease after waiting at least 30 seconds. (Pressure decreases between 3 and 5 mmHg are typical; if the pressure decrease exceeds 6 mmHg, there must be a leak and the system needs to be repaired.)
- Press [START STOP] to exit the calibration mode.

View Firmware Version and System Language

- Switch on device and wait for display to indicate the time.
- Press [INFO] 5 times: the display indicates "**H 5**".
- [START STOP]: the firmware version will be indicated, e.g.
  "14:01" = firmware version 1.4, German
  "14:02" = firmware version 1.4, English
  "14:03" = firmware version 1.4, French
  "14:04" = firmware version 1.4, Italian
  "14:05" = firmware version 1.4, Spanish
- Press [START STOP] to end the display.

8 Technical Specifications

Microprocessor

– P80C558EFB

Storage Capacity

– 128 x 8 bit (= 1 Megabit) EEPROM
– 512 x 8 bit (= 4 Megabit) EEPROM

Measuring Range

– systolic pressure	60 to 260 mmHg
– diastolic pressure	40 to 220 mmHg
– mean pressure:	50 to 260 mmHg
– pulse rate (HR):	35 to 240 min^{-1}

Acquisition Period

– up to 30 hours or 200 measurements

Battery

– 2 AA size rechargeable NiMH batteries, 1.2 V, ≥ 1500 mAh or
– 2 AA size alkaline batteries

Battery Charging Period

– 2 to 3 hours

Max. Cuff Pressure

– 300 mmHg

Measuring Method

– oscillometric

Environment

Operation

– temperature +10 to + 40° C / 32 to 104° F
– relative humidity 30 to 75 %, no condensation
– atmospheric pressure 700 to 1060 hPa

Transport and Storage

– temperature -10 to 70° C / 14 to 158° F
– relative humidity 10 to 90 %, no condensation
– atmospheric pressure 500 to 1060 hPa

Dimensions and Weight

– height 99 mm
– width 80 mm
– depth 27 mm
– weight 199 g, incl. batteries

9 Order Information

Subject to change. Always refer to latest list of accessories.

2001762-002 **TONOPORT V** Ambulatory Blood Pressure System

- TONOPORT V Blood-Pressure Monitor
- TONOPORT V – PC connection cable
- 4 (four) Alkaline batteries
- Carrying pouch
- Belt for carrying pouch
- Blood-pressure cuff for adults, standard, width 14 cm, for circumference between 24 and 32 cm, plug-in connection
- TONOPORT V Operator's Manual
- CardioSoft DFT data analysis program (Windows 9x, Windows NT)
- CardioSoft Operator's Manual

Accessories

2001589-007	TONOPORT V Operator's Manual
2001589-013	Battery charger
2001589-014	Rechargeable NiMH battery (monitor requires 2)
737 000 08	Alkaline battery, 1.5 V (monitor requires 2)
2001589-015	Carrying pouch
2001589-016	Belt for carrying pouch
2001589-011	TONOPORT V – PC connection cable
2001589-018	Blood-pressure cuff for adults, standard, width 14 cm, for circumference between 24 and 32 cm, plug-in connection
2001589-017	Blood-pressure cuff for adults, small, width 10.5 cm, for circumference between 17 and 26 cm, plug-in connection
2001589-019	Blood-pressure cuff for adults, large, width 17.3 cm, for circumference between 32 and 42 cm, plug-in connection
701 217 18	Printer, EPSON LX-300+ (incl. connection cable)
2001589-012	TONOPORT V – printer connection cable
2006303-001	CardioSoft DFT data analysis program (Windows 9x, Windows NT)
2005907-002	CardioSoft Operator's Manual

EU Declaration of Conformity

PAR Medizintechnik GmbH, Einemstr. 9, 10787 Berlin

We declare that the medical device

TONOPORT V, Hardware-Version **HW 1.2,** Firmware-Version **FW 1.4**
(including system-components and accessories, UMDNS-code: 12 – 386)

is in conformity with the following standards and normative documents:

1. Council Directive 93/42/EEG of June 14, 1993

2. EN 60601-1:1990 + A1:1993 + A2:1995
   EN 60601-1-4:1996
   EN 60601-1-2:1993
   EN 60601-2-30:2000
   EN 55011:1998, Class B
   EN 1060-1:1995
   EN 1060-3:1997
   DIN 58130:1996

The medical device is defined as class IIa devices in accordance to annex IX of the Council Directive 93/42/EEG. It is marked with

CE - 0482

The medical device is designed, produced and verified under control of a quality system in accordance to EN ISO 9001, EN 46001 and annex II of the Council Directive 93/42/EEG. The conformity of the quality system is certificated by:

MEDCERT Zertifizierungs- und Prüfungsgesellschaft für die Medizin GmbH

Berlin, August, 1, 2002

PAR Medizintechnik GmbH

H.-P. Steffens
Managing Director

TONOPORT V	GE Medical Systems IT	D-79111 Freiburg
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PROCEDURE REPORT Ambulatory BP Measurement

Patient : ______________ ID: ______________

Date : ______________ Indication: ______________

Physician : ______________ Unit: ______________

Interpretation: ______________

P R O C E D U R E O V E R V I E W

Begin of record : 20.09.2001/ 8:00

End of record : 21.09.2001/ 8:02

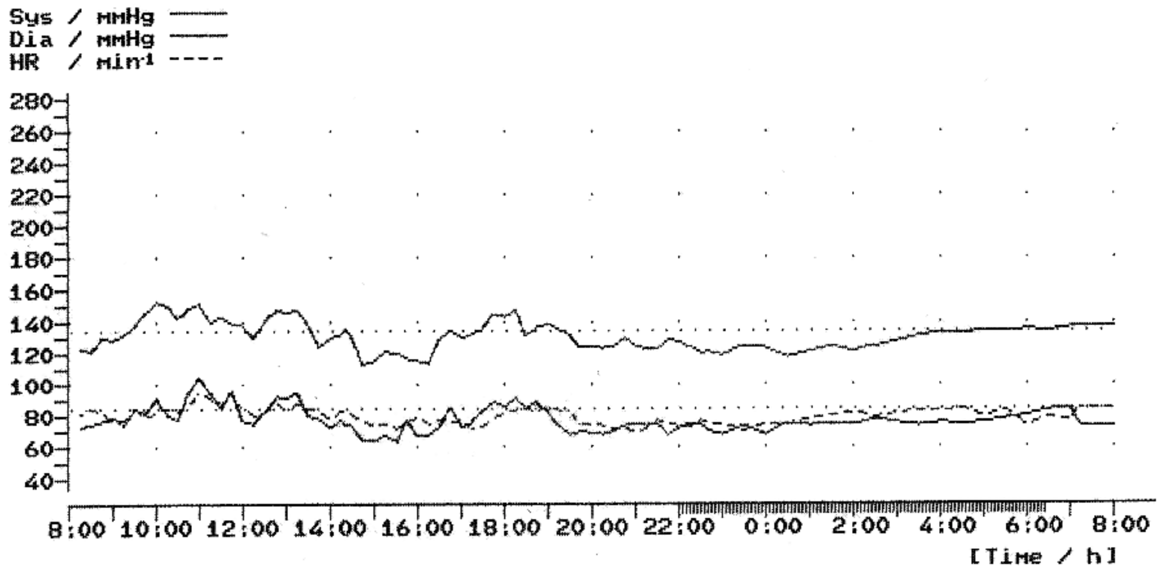
Duration of record : 24 hours 2 minutes

Number of measurements : 81

Systole > 135 mmHg : 29 is equ. to 36 %
Diastole > 85 mmHg : 12 is equ. to 15 %

n = 80	MIN	MEAN	MAX
Systole	112	132	152
Diastole	63	77	104
mean BP	76	94	122
HR	69	80	94

Minimum systolic pressure : 112 mmHg at 14:45/20.09.2001
Maximum systolic pressure : 152 mmHg at 10:00/20.09.2001
Minimum diastolic pressure : 63 mmHg at 15:33/20.09.2001
Maximum diastolic pressure : 104 mmHg at 11:00/20.09.2001



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PROCEDURE REPORT Ambulatory BP Measurement

Time	HR	SYS	DIA	MAP
8:00	83	121	75	90
8:15	81	123	72	87
8:30	84	121	75	90
8:45	82	130	77	96
9:00	76	129	79	96
9:15	78	132	74	86
9:31	84	138	84	108
9:45	79	146	81	99
10:00	82	152	91	111
10:17	85	150	80	103
10:30	83	142	77	97
10:45	86	149	95	113
11:00	94	151	104	121
11:15	91	140	95	110
11:31	88	143	85	104
11:45	91	139	96	107
12:00	85	138	77	97
12:15	80	130	75	93
12:30	82	140	82	101
12:48	88	148	92	114
13:00	83	146	91	113
13:15	88	148	95	113
13:30	85	138	80	99
13:45	82	125	78	94
14:01	78	130	72	91
14:15	83	132	78	96
14:21+	83	136	74	89
14:30	80	130	73	92
14:45	77	112	65	81
15:00	73	116	64	81
15:15	75	121	68	82
15:33	71	120	63	77
15:45	76	117	77	89
16:00	79	116	67	76
16:15	75	113	68	83
16:29	78	129	72	91
16:45	76	134	85	109
17:02	78	130	72	93
17:15	71	132	76	91
17:30	73	136	83	110
17:45	79	145	89	122
18:00	81	143	86	108
18:15	83	148	91	109
18:30	84	131	85	95
18:46	82	137	89	102
19:00	86	139	82	92
19:15	83	135	73	94
19:30	82	131	68	89
19:45	75	124	70	85
20:15	73	123	68	89
20:30	71	125	70	85
20:45	72	130	73	94
21:00	69	125	74	89
21:16	71	122	73	85
21:30	77	123	74	94
21:45	75	129	68	89
22:02*	72	127	72	85
22:30*	77	120	74	83
22:40*+	76	121	70	83
23:00*	74	119	68	83
23:29*	70	125	73	86
0:00*	74	123	68	87
0:31*	75	118	75	85
1:00*	78	121	73	84

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PROCEDURE REPORT Ambulatory BP Measurement

Time	HR	SYS	DIA	MAP
1:29*	80	124	74	89
2:00*	82	121	74	85
2:30*	79	125	78	91
3:01*	81	128	76	89
3:30*	83	131	73	91
4:00*	82	133	76	89
4:30*	84	132	75	85
5:01*	79	134	76	90
5:30*	83	134	78	89
6:00*	74	136	80	85
6:30*	79	135	83	84
7:01	77	137	84	86
7:16	85	138	73	94
7:32	85	138	73	94
7:46	85	138	73	94
8:02	85	138	73	94

Legend:
* - night phase
+ - manual measurement

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PROCEDURE REPORT   Ambulatory BP Measurement

Date : 20:09.2001

Error List

Time	Error Code
20:05	Error : 22

Error Code

Error 22: Too many motion artifacts during systole

Index

T

W

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Special Invited Articles

What's New in Childhood Hypertension?

MJ ***DILLON***

Abstract The pattern of childhood hypertension is changing with a significant increase in the numbers of children with primary hypertension occurring in conjunction with childhood obesity. The phasing out of mercury sphygmomanometry, the problems of identifying an alternative method of blood pressure measurement, the increasing use of ambulatory blood pressure monitoring, the emphasis on systolic hypertension and the recognition of white coat hypertension are modifying the views of what is and what is not hypertension in childhood. Newer investigative techniques and more sophisticated therapeutic manoeuvres, including interventional radiology, are influencing the handling of secondary hypertension and there is an increasing recognition that monogenic forms of hypertension affect children. Anti-hypertensive drug trials are now including children with hopefully in future the availability of newer therapeutic agents for paediatric use.

Key words Blood pressure; Childhood; Hypertension; Mercury; Obesity

Introduction

In recent years it has been accepted that 1-3% of the childhood population have a blood pressure consistently above the upper end of the normal range and that approximately 10% of these have severe hypertension, usually secondary, with renal disease as the most common cause.[1-3] However, although, these figures are probably still relevant there is overwhelming evidence that there is a significant increase in the numbers of children with primary hypertension, a hitherto predominantly adult disorder, and this is closely associated with childhood obesity.[4-7] The pattern is therefore beginning to change and this has also been associated with other factors that have impinged on the identification of high blood pressure in children namely the phasing out of mercury sphygmomanometry,[8,9] the problems of the accuracy and validation of alternative blood pressure measuring devices,[10] the increasing use of ambulatory blood pressure monitoring,[11,12] the need to establish new device specific blood pressure nomograms,[13] the emphasis on systolic rather than diastolic hypertension[14] and the recognition of "white coat hypertension" even though what it means remains uncertain.[15] Of course, secondary hypertension as a cause of severe treatment requiring increases in blood pressure remains a problem for paediatricians but newer investigational tools and better therapeutic options have improved the accuracy of diagnosis and the outcomes in affected children.[1,16] In addition the identification of monogenic forms of hypertension is beginning to help in the understanding of the genetic factors that influence blood pressure[17,18] and the increasing awareness of the importance of providing newer more effective antihypertensive drugs for children has resulted in attempts to undertake trials of agents in children as well as adults so younger patients will not be denied the latest therapy as has been the case in the past.[19-21] An attempt will be made to address some of these issues in this review.

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Received September 12, 2003

Phasing Out of Mercury Sphygmomanometry

Concerns regarding potential toxic effects of mercury from sphygmomanometers, inspite of the fact that these must be minimal compared to environmental pollution, have resulted in recommendations to phase out mercury sphygmomanometry.[8,9] The problem, however, that arises is what are we going to do without mercury? The alternatives are to utilise aneroid devices or oscillometric devices. Aneroid manometry involves pressure being registered by a bellows and lever system that is initially accurate but becomes inaccurate with use and underestimates blood pressure.[22,23] Hence, aneroid devices require very regular calibration and maintenance, and are particularly vulnerable to the day to day trauma of routine clinical use.[24]

Most aneroid manometers are not recommended for adults let alone children on the basis of their accuracy and reliability. However, some devices have recently been shown to fulfill validation criteria allowing recommendation for use in adults and perhaps there is an opportunity for these to be further studied to see if they will also be acceptable for paediatric practice.[25]

Oscillometry, on the other hand, utilises the arterial wall oscillation at the time of pulsatile blood flow through the vessel transmitted to a cuff encircling the extremity to measure blood pressure. Systolic blood pressure is recorded at the point where a rapid increase in oscillation amplitude occurs (the equivalent of K1). Diastolic blood pressure is recorded at a point where a sudden decrease in oscillation amplitude occurs (the equivalent of K5). Early devices tended to overestimate blood pressure in children.[13,24] The ESH (European Society of Hypertension) utilising the AAMI (Association for the Advancement of Medical Instrumentation) and the BHS (British Hypertension Society) validation procedures recommended 2 instruments: the Datascope Accutor Plus and the CAS model 9010 (that had also been tested in neonates).[26] More recently the Welsh Allyn "Vital Signs" monitor also passed AAMI and BHS validation procedures in adults and was strongly recommended for hospital use. It's noteworthy that the Dinamap 8100, often used in paediatric departments, failed and was not recommended.[27]

Inspite of these findings no alternative device to mercury sphygmomanometry has been securely validated for use in children. Furthermore it has to be remembered that all non mercury devices need to be calibrated against mercury and elimination of all mercury sphygmomanometers is a foolhardy step until satisfactory alternatives have been identified and satisfactory non mercury means of calibration have been developed. Two important publications, one from North America and one from Europe, strongly recommend that mercury sphygmomanometers should not be abandoned until satisfactory alternatives have been found.[8,9]

Ambulatory Blood Pressure Monitoring

In recent years ambulatory blood pressure monitoring (ABPM) has become an important additional tool in identifying hypertension and monitoring treatment for it. The advantages are that it allows multiple measurements utilising a consistent device for the purpose, it provides a "truer" picture of blood pressure trends, it provides better blood pressure correlation with cardiac outcome, it identifies "white coat hypertension" and identifies nocturnal hypertension (non dippers).[28] A number of important publications have appeared describing ABPM in paediatric practice and providing blood pressure nomograms, at least for certain devices.[11,12,29,30]

However, there are problems with ABPM monitors and surprisingly some of the most commonly used worldwide have failed the vigorous validation procedures to which they have been subjected.

The ESH have examined 24 devices utilising AAMI and BHS criteria and amongst these 5 have been evaluated in childhood.[26] The oscillometric Space Labs 9027 passed the AAMI test for systolic BP but failed the diastolic test. It received a C for systolic and a D for diastolic using BHS criteria and was therefore not recommended. The Takoda TM-2421 (also oscillometric) received a C for both systolic and diastolic BP utilising the BHS procedure and was also not recommended. However, the Tycos Quiet Track (Welch Allyn) oscillometric device passed both AAMI and BHS criteria and was recommended.

One of the issues that has arisen in relation to ABPM is the question of the standards used to define population normal blood pressures. Since devices differ in a number of ways and are not necessarily directly comparable, unlike mercury sphygmomanometry, should standards be device specific?[13] This matter remains unresolved at present but will need to be addressed especially as there are a number of devices in paediatric use worldwide but only nomograms prepared utilising one or perhaps two devices available.

Systolic Hypertension

Historically there has been an emphasis on diastolic blood pressure and diastolic hypertension. There has also been a view that systolic blood pressure and systolic hypertension has been benign and less clinically important. Diagnosis of hypertension used to be based on diastolic blood pressure thresholds but there has been a change of emphasis. There is evidence that systolic hypertension is a clear cardiovascular risk factor in adults.[31] From systolic hypertension treatment trials also in adults, there is clear benefit compared to placebo in terms of myocardial infarction, heart failure and stroke.[32,33]

From a paediatric perspective systolic hypertension is more common than diastolic hypertension in children,[14,34] systolic blood pressure is more closely related than diastolic blood pressure to left ventricular mass (LVM) and left ventricular mass index (LVMI) in normotensive and hypertensive children[35,36] and the risk of left ventricular hypertrophy (LVH) in children is influenced to a greater extent by systolic blood pressure elevation than by diastolic blood pressure elevation.[37] Therefore, systolic hypertension in children should be considered of importance in terms of prognostic influence, trials of anti-hypertensive medication in children should focus on systolic hypertension and therapy for paediatric hypertension should be directed at normalisation of systolic blood pressure even when diastolic blood pressure is within the normal range.[14]

White Coat Hypertension

Is white coat hypertension common and does it matter? The former question is fairly easily answered. Yes it is common as has been shown in a number of studies and has been identified in 53%, 45% and 22% of 115 children referred for evaluation of elevated casual blood pressure who underwent 24 hour ABPM if compared to Task Force criteria, mean BP or BP load respectively.[15] Is it innocuous? This is another matter and the answer presently is not clear. However, it may not be a benign entity and could indicate an early stage of cardiovascular dysfunction.[13,38,39] This might justify individuals classified as manifesting this phenomenon being followed up in the longer term to define whether they eventually develop sustained hypertension.

Primary Hypertension

Hitherto, as mentioned previously, primary hypertension in childhood, compared to adults, contributed a small proportion of the overall hypertensive population where secondary hypertension predominated. However, there is a changing pattern emerging and this is particularly linked to obesity. The prevalence of overweight children in the USA. increased from 5% in the 1960's to 11% in the 1990's[7] and is likely to be 30% or so at the present time if Canadian data are considered.[40] In the USA, the number of overweight children has doubled in the past 2-3 years and in the world it is estimated that there are 22 million children <5 years of age who are overweight.[5]

Obese children are at approximately a 3-fold higher risk for hypertension than non obese children and this is probably the major factor in the increasing numbers of children with primary hypertension.[7]

The mechanisms of hypertension in obese children and adolescents is multi-factorial. The following are considered to play some part:- excess renal sodium reabsorption; insulin resistance; renal structural changes; altered vascular structure and function; renin-angiotensin-aldosterone activity; sympathetic nervous system overactivity and alterations in the hypothalamic-pituitary-adrenal axis.[41]

In addition there are pre-natal influences that appear to be linked to post-natal growth that almost certainly play a part.[42,43] Twenty-five percent of children with low birth weight but high body mass index (BMI) at 12 years have been shown to subsequently develop a high blood pressure compared to 9% of those with a high birth weight and a low BMI.[43] Evidence also supports the view that hypertension originates in slow foetal growth followed by rapid compensatory growth in childhood.[42] It has also been shown that this path of growth has a greater effect on the risk of disease among children who live in poor social conditions.[43] From these studies the primary prevention of hypertension may depend on strategies that promote foetal growth and reduce childhood obesity.

Secondary Hypertension

As has been mentioned already secondary hypertension in childhood is the main type of hypertension that requires treatment and renal disease predominates as the cause. Inspite of the increasing prevalence of primary disease it still remains important to exclude a secondary aetiology before assuming that the hypertension is primary in nature.

There are many transient causes of hypertension in the young and amongst these renal pathology predominates in the form of various types of glomerulonephritis or conditions leading to renal impairment. However, neurological disorders, drug therapy and various states of salt and water overload, some iatrogenic, contribute to this group of factors.[3] Sustained hypertension, on the other hand, can be considered under a number of headings as shown in Table 1 with again renal causes predominating. The commonest cause of secondary hypertension is some form of parenchymal renal disorder with the coarsely scarred kidneys of reflux nephropathy topping the list followed closely by various glomerulonephritic disorders. Renovascular hypertension contributes approximately 10% of cases but is important since it has the potential for cure by some form of intervention, either transluminal angioplasty or revascularisation surgery. Catecholamine excess hypertension and various corticosteroid excess states or low renin hypertensive states are extremely rare.[44]

Recent advances in terms of imaging have improved the diagnostic skill in identifying the underlying cause of increased blood pressure in childhood including the use of Doppler and computed duplex sonography, colour Doppler sonography and ACE inhibitor renography especially for renovascular disease.[45] However, the sensitivity and specificity of these techniques still remains less than might be hoped for and the gold standard diagnostically for renovascular hypertension is still renal angiography to which might be added renal vein renin sampling to localise sources of excess renin release.[46] Magnetic resonance and CT angiography are utilised at times but the former is still relatively insensitive in picking up intra renal vascular pathology and the latter exposes the child to unacceptably excessive radiation.[47,48]

Table 1 Causes of sustained hypertension in children

Coarctation of aorta
Chronic or end stage renal failure
Parenchymal renal disease
Reflux nephropathy
Chronic glomerulonephritis
Congenital or inherited renal disease
Other acquired renal disease e.g. following HUS
Renovascular disease
Renal tumours
Catecholamine excess
Phaeochromocytoma
Paraganglioma
Corticosteroid excess/low renin states
Some congenital adrenal hyperplasias
Cushing's disease/syndrome
Conn's syndrome
Liddle's syndrome
Apparent mineralocorticoid excess
Essential hypertension

MIBG scanning, labeled somatostatin scanning, caval catecholamine sampling as well as CT and MRI scanning all have roles in identifying the site of a catecholamine secreting tumour[3,49,50] and newer molecular genetic studies are revolutionising the understanding of some of the rare low renin hypertensive states.[17]

Therapeutically, apart from anti-hypertensive medication that will be dealt with subsequently, what has played a major part in changing the management of renovascular disease has been the development of transluminal angioplasty for amenable renal artery stenosis[51,52] as well as the more sophisticated revascularisation surgical techniques including not only by-pass surgery but also auto transplantation and major vascular reconstruction including the aorta.[53,54] Stenting and embolisation have occasional roles and, of course, nephrectomy still remains a necessity at times. The possibility of gene therapy is also on the agenda especially in the light of knowledge of the various mechanisms involved in angiogenesis and preliminary data from treatment of coronary artery disease.[55] This, however, is not as yet a serious option.

Monogenic Hypertension

Amongst the many secondary causes of hypertension some monogenic disorders have been identified[17] including Liddle's syndrome (sodium channel defect), apparent mineralo corticoid excess (11-beta-hydroxy-steroid dehydrogenase defect) and glucocorticoid suppressible aldosteronism (aldosterone synthase defect) that present with hypokalaemic low renin hypertension and require specific therapeutic approaches. These conditions can be suspected by a number of investigative procedures but now specific confirmation is possible by molecular genetic studies.[3,56-58] These findings might throw some light on genetic influences in the aetiology of adult essential hypertension but at present the latter would appear to be a multifactorial and polygenic disorder.

Anti-hypertensive Medication

Paediatricians have in the past been severely handicapped in the management of their patients by the lack of easily available data on hypotensive agents in comparison to their adult medical colleagues. The result of this has been that children have usually been treated by less modern agents since the pharmaceutical companies have not, in the development of the agents, undertaken trials in children and usually market the product with a "not for use in children" recommendation. Paediatricians have, as a result, undertaken studies themselves or by use developed protocols that have provided dose schedules for their patients, although these have often not been so rigorous as those available in adult medicine. Recently, however, in an attempt to overcome this handicap, new regulations have been introduced by the FDA in the United States in the hope of encouraging pharmaceutical companies to focus on the paediatric end of the age spectrum when developing and marketing their products.[19-21] Needless to say this has involved a financial carrot to the companies by extending the deadline for the discontinuation of their patent rights if they embrace the paediatric age range in controlled trials. This has led to some hastily put together and poorly thought out studies being launched but inspite of this it is a step in the right direction. Hopefully paediatricians will have greater opportunities in the future to prescribe with confidence newer and more focussed therapeutic agents rather than relying on drugs that adult physicians had discarded a decade or so ago.

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Summary Report

NATIONAL HIGH BLOOD PRESSURE EDUCATION PROGRAM (NHBPEP)/NATIONAL HEART, LUNG, AND BLOOD INSTITUTE (NHLBI) AND AMERICAN HEART ASSOCIATION (AHA) WORKING MEETING ON BLOOD PRESSURE MEASUREMENT

Natcher Conference Center
National Institutes of Health (NIH)
Bethesda, Maryland
April 19, 2002

Contents

National High Blood Pressure Education Program (NHBPEP)/
National Heart, Lung, and Blood Institute (NHLBI) and
American Heart Association (AHA)
Working Meeting on Blood Pressure Measurement

April 19, 2002
Natcher Conference Center
National Institutes of Health (NIH)
Bethesda, Maryland

Participants: Dr. Daniel W. Jones, M.D., Cochair, Dr. Claude Lenfant, M.D., Cochair, Dr. Lawrence J. Appel, M.D., M.P.H., Ms. Vicki Burt, R.N., Sc.M., Ms. Jean Charleston, R.N., Dr. Jeffrey A. Cutler, M.D., M.P.H., Dr. Rosalie A. Dunn, Ph.D., Dr. Bruce Friedman, D. Eng., Dr. John Graves, M.D., Ms. Carlene Grim, R.N., B.S.N., M.S.N., Dr. Clarence E. Grim, M.D., M.S., Joanne Karimbakas, M.S., Dr. Janice Meck, Ph.D., Mr. Thomas Murray, Dr. Bruce Z. Morgenstern, M.D., Dr. Ami Ostchega, Ph.D., R.N., Dr. Thomas Pickering, M.D., Dr. Edward J. Roccella, Ph.D., M.P.H., Dr. Sheldon G. Sheps, M.D., Ms. Sue Shero, R.N., M.S., Dr. Paul D. Sorlie, Ph.D., Dr. Sandy F.C. Stewart, Ph.D., Mr. Michael Wolz

INTRODUCTION

Welcome and Meeting Goals [Dr. Daniel Jones]

Dr. Jones welcomed the group to this joint meeting, sponsored by the NHBPEP/NHLBI and the AHA, and asked participants to introduce themselves and their particular interest in the topic of blood pressure (BP) measurement. The group included representatives from Government agencies, academia, and industry.

Dr. Jones stated the need for original thinking on how to improve BP measurement. He noted that the participants recognize the challenges and clinical problems that result from inadequate measurement, though they all come with their own biases about which type of measurement they prefer (e.g., mercury manometers, aneroid instruments, etc.).

Reviewing the reasons for the meeting, Dr. Jones said that the AHA convened a Writing Group to provide recommendations for BP measurement in the United States. A central issue was the dependence on the mercury manometer as the “gold standard” for BP measurement; the instrument is no longer available in some health care settings. This is creating a problem. One solution is to ask people to slow down the removal of mercury manometers in health care settings until there is a better understanding of the principles of BP measurement and alternatives. Another is to ask for a new set of standards.

The goals of the meeting are to examine the science that supports current BP measurement policies and to identify additional research needed to strengthen policies. This may lead to changes in standards by which BP is measured and how instruments are regulated, thereby leading to changes in policies to improve measurement. The Working Meeting will make recommendations to the director of the NHLBI, who suggested the meeting.

Dr. Jones listed the following questions to be addressed:

- Is the accurate measurement of BP important?
- Are mercury manometers dangerous?
- Is the use of mercury manometers forbidden?
- Are currently available aneroid and electronic instruments a reliable substitute for mercury manometers?
- Are current standards of validation of aneroid and electronic instruments adequate, or do we need new standards?
- Is there a sufficient knowledge base for establishing standards and guidelines regarding the validation of BP measurement instruments?
- Are current programs for calibration adequate, or do we need new standards and guidelines?

Possible meeting outcomes will include the following:

- Publication of a paper in the journal *Hypertension* next summer. The paper will be written by a small group and then reviewed by the entire group.
- Identification of research questions, which may lead to a Special Emphasis Panel that will further refine the research questions, leading to funding for research.
- Suggestions to manufacturers through the Association for the Advancement of Medical Instrumentation (AAMI) and other mechanisms.

History and Overview of Blood Pressure Measurement Policy Development [Dr. Sheldon Sheps]

Dr. Sheps reviewed highlights in the history of sphygmomanometry and policy development, beginning with the development of the mercury manometer and aneroid manometer in Europe in 1896 and 1897, respectively, and Korotkoff's presentation on the auscultation of arterial sounds in 1905. Janeway's book, *The Clinical Study of Blood Pressure* (1906), influenced the Northwestern Mutual Life Insurance Company to include BP measurements in physical examinations. By 1918, most life insurance companies required readings of systolic and diastolic BPs using Phase V (in Europe, Phase IV was preferred). Life insurance data for 700,000 persons were pooled, and in 1925 the Joint Committee on Mortality of the Association of Life Insurance Medical Directors and the Actuarial Society of America reported average BP by gender, age, and body build and related increased BP to mortality. Subsequent reports were provided through 1979.

The American Bureau of Standards published reports to improve BP measurement in 1917, 1921, and 1927, recognizing the need for standardization of both equipment and measurement. In 1938, Dr. Irving Wright reported on a survey of measurement errors and also conducted a survey of medical schools and life insurance examiners, finding great variation in every aspect of measurement. In the late 1930s, the U.S. Bureau of Standards started a nationwide study of BP apparatus, and the Taylor Instrument Company developed a standard device for checking manometer accuracy.

The proliferation of coin-operated BP measurement devices 50 years later led to an NHLBI-sponsored AAMI report on manometers and the establishment of the Sphygmomanometer Committee. Specifications for manometers were developed and were promoted by the American National Standards Group. The Food and Drug Administration (FDA) delegated regulation of sphygmomanometers to the AAMI, generally accepting the manufacturers' certification that their equipment meets AAMI standards. In addition, the British Standards Institution (BSI) and the European Union produce specifications for mercury and aneroid manometers.

Dr. Sheps described the following six reports that included recommendations for human BP determinations by sphygmomanometry and summarized their changing recommendations for cuff size and technique for measuring diastolic BP (DBP).

1. The 1939 *Joint Recommendations of the AHA and the Cardiac Society of Great Britain and Ireland* recommends annual calibration, especially for aneroids, and offers recommendations for cuff size and placement, patient positioning, palpation, and specifications for taking systolic BP (SBP) and DBP. Some recommendations differed from those in the United States.

2. In 1951, the AHA asked Dr. Carl Wiggers to produce "Recommendations for Human Blood Pressure Determinations by Sphygmomanometers." This report recommends a cuff 20 percent wider than arm diameter and preferred cessation of sound for DBP. It includes a discussion of thigh cuffs, training, and literature abstracts.

3. In 1967, the AHA's Professional Education Committee (chaired by Dr. Walter Kirkendall) updated the previous report for practicing health care providers. The update includes further recommendations for cuff placement, suggests a seated position for patients, and includes sections on epidemiology, basal BP, and clinical conditions. The report describes the five phases of Korotkoff (K) sounds, the auscultatory gap, and specifications for SBP and DBP. The report regards muffling as the best index of DBP.

4. The AHA's Post Graduate Education Committee requested a report, chaired by Dr. Kirkendall and published in 1980, that includes recommendations for cuff circumference, length, and sizes by age, as well as details on care and calibration of devices, the use of the stethoscope bell, and a measurement section detailing observer/patient preparation, equipment, and technique. This report defines DBP as disappearance of sound, based on clinical trials and NHBPEP reports, but does not define high BP, or hypertension (HTN). The report dismisses kilopascals (kPa) as the unit of measurement.

5. The 1988 "Recommendations for Human Blood Pressure Determinations by Sphygmomanometers," chaired by Dr. Edward Frohlich, emphasizes standardization of cuff size and recommends marking the cuffs to indicate the circumferences for which they can be used. It disparages the use of electronic devices and ambulatory BP in clinical care and refers to AAMI for standards. Measurement technique is detailed, with a recommendation for two or more sitting BPs at each visit and three visits to diagnose HTN. This report prompted discussion because of inconsistencies in the text and tables.

6. The sixth and current report, "Human Blood Pressure Determination by Sphygmomanometry," published in 1993 and chaired by Dr. Dorothy Perloff, was intended "for everyone who measures BP." This report discusses epidemiology and cuff size and placement. It disapproves of the use of the large cuff (12.5 by 35 cm) for all adults recommended by the British Hypertension Society (BHS) because use of such a cuff could lead to systematic underestimation or overestimation of blood pressure. It recommends that the width of the bladder be 40 percent of the arm circumference, and the length of the bladder be long enough to encircle at least 80 percent of the adult's arm. The report suggests that aneroid manometers can provide accurate measurements if properly calibrated. This report underscores concern about mercury toxicity and vets automated devices, except for those used on the finger and wrist. It includes greater detail on observer and subject technique, describes errors, and includes an appendix with the classification of BP as set forth in "The Fifth Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure" (JNC V).

Dr. Sheps also mentioned similar efforts in Europe, including those of the World Health Organization's Expert Committee on Cardiovascular Disease and Hypertension (1959), the BHS (1986–1999), the European Society of Hypertension (2001), and four papers on BP measurement published in 2001 in the *British Medical Journal*.

Dr. Sheps then listed current issues and efforts. Issues include the following:

- "Standard" cuff sizes are often inconsistent and inappropriate. They are device-specific and cannot be interchanged in the electronic manometers.
- Should K5 be defined as the last sound heard or the onset of silence? This is a 2 mmHg difference.
- Environmental concerns about mercury are real; do we have reliable substitute manometers for medical environments as well as for self-use?
- If we don't have mercury, should we revisit kPa?

Current efforts include development of new devices to simulate mercury and enhanced aneroids, automated devices to obtain multiple readings at a single office visit, self-measurement devices that store many readings and print and send data to a server, and a more universal cuff.

Importance of Accuracy: The Costs of Errors [Dr. Clarence Grim]

Dr. Grim stressed that the key to BP control is good BP measurement. If BP measurements are not done accurately and reliably, there is a potential for great harm and great cost. Patients with truly high BP who are measured as normal are denied the proven benefits of treatment, and they will suffer premature disability and death from undiagnosed HTN.

Describing the “chain of community blood pressure control,” Dr. Grim said that if measured BP is “high,” the reading must be recognized as high, the patient must be informed, the provider must decide to treat, the patient must decide this is important, the patient must be given a goal, feedback must be given on progress, and problems must be solved to achieve the goal. In addition, the physician must make decisions based on the BP measurement—in terms of making a diagnosis, starting therapy, and increasing or decreasing treatment. In 1996, BP was measured in about half of the 734 million outpatient visits that year (about 1 million BP measurements per day). Hypertension is the major reason to see a physician for a chronic condition (31 million visits per year).

Dr. Grim observed that the life insurance industry benefits when an insured person lives a long time. Recognizing that lower BP extends life, the industry was doing palpated BPs before osculatory techniques were available. The “Build and Blood Pressure Study: 1935–1954” and the Metropolitan Life Insurance Company in 1991 looked at the natural history of a 35-year-old white male with untreated HTN. This study showed that each 1 mm rise in DBP in this population shortened lifespan about 1 year.

Dr. Grim also pointed out the implications of small reductions in DBP for primary prevention, citing several studies that found an association between such reductions and lower risk of coronary heart disease (CHD) and stroke. For example, Cook et al. (1995) showed that a 5–6 mmHg reduction would reduce CHD by 16 percent and stroke by 38 percent. More recent analysis of longer term therapy showed reductions of 20 percent and 40 percent, respectively.

Data from the Hypertension Detection and Followup Program (HDFP) indicate that the definition of DBP determines the number of people diagnosed. For illustration purposes, if 50 million people have high DBP when the cutoff is ≥ 90 mmHg, moving the cutoff to ≥ 85 mmHg would add 27 million people to this total. The cutoff of ≥ 120 mmHg would diagnose only 1 million people with high BP.

Dr. Grim noted that many people think that an error of 5 mmHg is insignificant, but this error at the 90–95 mmHg range would miss the 21 million U.S. hypertensives. Over the next 6 years, those 21 million would have a coronary artery disease (CAD) death rate of 5 per 1,000, or 125,000 CAD deaths (Kannel, 1986). Treating BP in this group would be expected to decrease the CAD death rate by 20 percent, saving 25,000 lives (McMahon, 1990), and prevent a similar number of fatal strokes. Conversely, measuring blood pressure 5 mmHg too high would falsely classify 27 million persons as having HTN. At the cost of $1,000 per year to treat a patient, this would add $27 billion to the Nation’s health care bill to treat a nondisease.

Accurate BP measurement can save money—for example, by delaying renal failure. HTN (with or without diabetes) causes 80 percent of renal failure. The annual cost of treating renal failure will soon exceed $19 billion. Because BP control can delay the onset of renal failure by 4.5 years and each year of dialysis costs about $50,000, controlling BP in one person potentially could save $225,000.

Dr. Grim said that retrospective analysis has revealed serious BP measurement errors in national surveys in Finland, Norway, the United States, Australia, and England. The errors include terminal-digit bias, direction bias (a tendency to read too high or too low), falsification of data, and failure to follow the protocol for calibration and technique.

Dr. Grim then discussed problems with aneroid instruments. Five studies (from 1970 to 1997) found inaccuracies in an average of 35 percent of aneroids, suggesting that no quality assurance (QA) measures have been implemented. He described a calibration check in 86 practices in Green Bay, Wisconsin, in which no mercury manometers were used. When the aneroids were checked against a mercury manometer (using a Y tube), 35 percent were off by at least 6 mmHg; the average error was –10 mmHg; and 2 percent leaked excessively. Only 7 of 13 clinics had an equipment maintenance schedule, and none of the nursing homes or health care services knew that aneroid manometers should be inspected every 6 months. Correcting the problem would require calibrating all aneroid devices and removing all those that are off >1 mmHg. Regular annual quality control (QC) could detect 2,500 errors, while daily QC could detect 10 errors.

Dr. Grim said that an alternative is to use a mercury manometer. He noted that environmental assessments of hospital mercury waste loads have presented no evidence that manometers contribute significantly to combustion waste. He suggested that the Environmental Protection Agency (EPA) has tried to draft simple, broad laws against all persistent bioaccumulative toxins and has lost its ability to discriminate between categories of risk. Dr. Grim stated that it would appear that mercury manometers do not constitute a risk to the population and, as the absolute primary standard, they are essential to the accurate measurement and treatment of HTN.

Dr. Grim also made the following recommendations to address the lack of mandated inspection of BP measurement equipment or training for equipment operators.

- Routine inspection and calibration of office BP manometers should be implemented. How often, by whom, and at what cost remain to be decided.
- Careful training of those who use BP devices must be done and kept current.
- Legislation may be needed to assure compliance (as it does for glucose-monitoring equipment).
- Ongoing QA must be implemented.

VALIDATION

Review of Current Validation Standards and the Regulatory Process

Food and Drug Administration: Consensus Standards for Blood Pressure Monitors [Dr. Sandy Stewart]

Dr. Stewart, who is with the FDA's Office of Science and Technology, Center for Devices and Radiological Health (CDRH), reviewed the current standards for several types of BP monitors:

- **Manual blood pressure cuffs—**ANSI/AAMI SP9 (1994)

- **Automated noninvasive blood pressure (NIBP) monitors—**ANSI/AAMI SP10: 1992 for electronic or automated sphygmomanometers; IEC 60601-2-30 (1999-2012) for automatic cycling NIBP monitoring equipment

- **Invasive blood pressure transducers—**ANSI/AAMI BP22: 1994 (R) 2001 for blood pressure transducers; IEC 60610-2-34 (2000-10) for particular requirements for safety, including essential performance of invasive BP monitoring equipment

Dr. Stewart also listed future standards being developed for manual, electronic, or automated manometers. A new version of AAMI/SP10, designated AAMI/CVD-2 SP10, is just coming up for a vote. This standard will cover manual, electronic, or automated manometers and will combine the old SP9 and SP10 standards. The new version will cover all BP measurement using a cuff; update clinical validation studies to include infants and the pediatric population; and include requirements for software verification and validation as well as electromagnetic compatibility (EMC) testing.

Dr. Stewart noted that well-written consensus standards provide a solid scientific basis for objective reviews of applications, help focus on important issues and thus streamline the review process, and provide a level playing field for manufacturers. Certain standards have been formally recognized by CDRH so that they can be used in the abbreviated 510(k) process. The CDRH uses those standards as the basis for approving new devices. For example, ANSI/AAMI SP10:1992 is a standard that is recognized by the CDRH and can be used in preparing an abbreviated 510(k). However, this standard does not include EMC testing or software validation and verification, which are important components of medical device safety. Thus, a supplemental data sheet points to CDRH's National Information Policy Board (NIPB) guidance, which specifies that the manufacturer must submit EMC test data and software verification and validation along with the Certificate of Conformance to SP10: 1992. The supplemental data sheets and guidance are used even if a standard already exists because the standards may be out of date.

Dr. Stewart noted that sphygmomanometers and noninvasive blood pressure monitors (NIBPs) are pre-amendment 510(k) devices and, as such, can be approved by one of three methods: recognized standards such as SP10, substantial equivalence to a predicate device, or other standards. For NIBP monitors, SP10 is the preferred standard because it includes statistically based clinical trial protocols as well as electrical safety, environmental, and other testing. For manual sphygmomanometers, SP9 is the preferred standard because it includes requirements for testing the cuff and includes accuracy requirements for the pressure-measuring device. In the future, the new version of SP10 will probably be the standard of choice for both manual sphygmomanometers and automated NIBP monitors.

During the question period, it was noted that some blood pressure cuffs are marketed without the FDA's approval. Dr. Stewart said that there is not enough enforcement and that companies that play by the rules should complain. It was also noted that British and U.S. standards differ and that the BHS does not look at engineering aspects of a device. Dr. Stewart pointed out that there is an effort under way to base the standards on science as well as consensus.

Association for the Advancement of Medical Instrumentation: Oscillometric Blood Pressure Measurement [Dr. Bruce Friedman]

Dr. Friedman, interim cochair of the AAMI committee, discussed several aspects of the performance of oscillometry for BP measurement. The basis of oscillometry is that the pressure volume curve changes the volume pulse. Although oscillometry assumes that blood pressure is constant over the period of measurement, that is not always the case.

Dr. Friedman described the ratio method and the deflation method. The ratio method is determined by the mean arterial pressure (MAP), based on the maximum oscillation measured by the monitor in the cuff. The largest oscillation occurs near mean pressure. Specific ratios are used to determine SBP and DBP where oscillations occur at those ratios relative to the maximum. The deflation method uses either linear or step deflation, both of which determine MAP from maximum oscillation by looking at change in slope of the oscillations' inflection point and using ratios to determine SBP and DBP. Inflection points are used in linear but not step deflation. The devices interpolate between steps.

Two artifact rejection methods are used: one uses the characteristics of the oscillometric signal (normal sinus rhythm is assumed); the other, electrocardiogram (ECG) gating, is more applicable in ambulatory monitors or in hospital settings.

Dr. Friedman listed the following limitations of oscillometric instruments:

- Motion can increase cuff pressure, which will alter the result. Motion can also produce noise that can be interpreted as pressure oscillations.
- Arrythmias can distort the reading. Variations in pulse pressure "distort" the oscillometric envelope.
- The monitors have not been tested in all patient populations (by age and disease). Manufacturers should state which patients and cuffs have been tested. The AAMI does not address this issue specifically.
- Manufacturers test only using their own cuffs.

Dr. Friedman noted the importance of knowing the instrument's model and serial number and its type of software (and software revision, if applicable), but he also noted that this information is sometimes not available. "Secrecy" has become less of a problem. Manufacturers should be willing to provide accuracy information (an abstract of the clinical study used for the device). Dr. Friedman added that blood pressure simulators are useful in testing, but clinical testing is needed.

Memorandum of Understanding Between the Environmental Protection Agency (EPA) and the American Hospital Association [Mr. Thomas Murray]

Mr. Murray said that one concern of the EPA's Office of Prevention, Pesticides, and Toxic Substances is the problem of chemicals that are persistent, bioaccumulative, and toxic (PBTs). Top priorities are dioxins/furans, and mercury and mercury compounds. He noted that the EPA started out as a highly regulatory agency but now increasingly focuses on prevention.

Mr. Murray reviewed the risks of mercury, stating that it is well known for its toxic effects, especially those of methyl mercury (MeHg). Long-term exposure can damage the brain, kidneys, and the developing fetus. Groups at highest risk are pregnant women, nursing infants, young children, and fish eaters (particularly among tribal nations). Efforts by the EPA and States to control mercury have led to an 85 percent reduction in its use in the United States. New controls for incinerators are expected to reduce emissions by 90 percent, and fish consumption advisories and thermometer/barometer take-back programs are designed to decrease mercury exposure. However, data from the National Health and Nutrition Examination Survey (NHANES) suggest that 10 percent of women of childbearing age have unsafe mercury levels, and an estimated 400,000 newborns per year are at risk of developmental problems from exposure to MeHg. Mr. Murray stressed the need for techniques to rid the biosystem of mercury, noting that some current efforts are only storing or recycling it. Most mercury is mined internationally and is used in many devices and consumer products. Sphygmomanometers are only one medical use of mercury, which is also used in thermometers, esophageal dilators, feeding tubes, batteries, preservatives, lab chemicals, fluorescent lights, etc.

PBTs are a global priority, and a number of international efforts and treaties have been established to deal with organic pollutants. EPA priorities include reducing the use of mercury (especially with respect to mercury-containing devices used in the medical area), reducing anthropogenic releases of mercury (e.g., through coal-fired power plants), reducing exposures through improved risk communication, ensuring safe storage and disposal of mercury waste and nonwaste elemental Hg, and investigating life cycle issues for mercury as a global commodity.

The EPA works with hospitals because hospitals generate about 2 million tons of solid waste annually, and medical waste incinerators are the fourth-largest known source of mercury emissions to the environment. Importantly, health care facilities are willing pollution-prevention partners; their benefits from involvement include reducing costs and liability and promoting community trust.

Mr. Murray described the EPA/American Hospital Association Memorandum of Understanding (MOU) that was signed in 1998. This MOU created Hospitals for a Healthy Environment (H2E), a project that asks all hospitals to pledge to virtually eliminate mercury waste by 2005; to reduce total waste volume by 33 percent by year 2005 and by 50 percent by 2010; and to identify hazardous substances in hospitals for P2 and waste-reduction opportunities.

Other organizations participating in H2E are Health Care Without Harm (HCWH), the American Nurses Association, and the "H2E community"—more than 250 partners (hospitals, clinics, and nursing homes) representing 330 facilities. Approximately 1,000 partners are expected by the end of the year. In addition, more than 30 health care organizations, such as Kaiser Permanente, champion H2E.

H2E is a voluntary program. Patient care comes first, and change is encouraged. H2E provides tools and resources, encourages the development of effective and reliable substitutes, and gives awards to health care facilities that are leading the way to reducing mercury in their facilities. Consultants help set up new policies and procedures for no fee (a fee may be charged later). Mr. Murray stressed that full involvement is needed to ensure the success of the program, which focuses on pollution prevention and behavioral change. He provided the Web site for the H2E program, http://www.h2e-online.org. A listserv is also available, and a video describes the program.

Physics of Measurement and Review of Literature on Accuracy of BP Measuring Devices [Dr. Thomas Pickering]

Dr. Pickering reviewed basic principles of noninvasive BP measurement. He noted that small differences in BP are increasingly important, BP variability is high, and human factors (such as the white coat effect and poor technique) lead to unrepresentative readings and the need for automated measurements.

Dr. Pickering cited data indicating the need for multiple BP measurements. One study found that 10 readings were more accurate than just 1 or 2. Another indicated that automated BP readings taken in an office setting were closer to the ambulatory average than were readings taken by physicians or nurses.

An ideal technique should be noninvasive, accurate in all conditions (e.g., obesity or pregnancy), and automatic (to eliminate observer error). It should also provide multiple readings and be cheap and easy to use. Dr. Pickering said that aneroid and oscillometric devices are the leading contenders for replacing mercury manometers; other possibilities are a hybrid sphygmomanometer and a device based on the wideband K2 method. He mentioned the following findings about the various techniques:

- A study of wideband recording of K signals (Blank et al., 1998)—based on a filtering technique developed in collaboration with Bell Labs—found it to be more accurate than the ausculatory method. Two studies (Blank et al., 1995; Fang et al., 1995) found that the K2 method gave a closer approximation of true intra-arterial pressure than the ausculatory method, which tends to overestimate DBP and underestimate SBP. Although potentially more accurate than other noninvasive methods, the K2 method has not been developed commercially.

- A study examining the physiological basis of the ausculatory gap found that it is due to fluctuations in blood pressure. Patients with the gap are older and have more peripheral artery disease.

- A study of DBP measurement during pregnancy found that Phase IV (muffling) overestimates DBP in pregnancy. As in nonpregnancy, ausculatory SBP is lower than the K2 method. In contrast to nonpregnancy, ausculatory (Phase V) DBP is the same by both methods.

- Reports on the accuracy of aneroid devices vary and may be manufacturer-dependent. The error rate among five studies ranged from 1 percent to 44 percent.

- The oscillometric technique measures mean pressure accurately. Limitations include the fact that estimation of SBP and DBP are indirect and depend on individual algorithms. Furthermore, there may be a consistent error in substantial numbers of subjects, and error is greater in older subjects, those with stiffer arteries, and those with isolated systolic hypertension.

- A potential advantage of the hybrid sphygmomanometer is that it is based on the mercury ausculatory method but does not use mercury. (The mercury column is replaced with a transducer.) The hybrid should be acceptable to clinicians accustomed to using mercury, and the readings are equivalent to mercury readings. The device eliminates observer bias (the operator presses a button to get the results), it can be programmed to prevent excessive cuff deflation rate, and it can provide electronic output.

Dr. Pickering noted that existing BHS and AAMI validation protocols tend to lump people together as a population, but what we need to know is whether a device will work in individual patients. BHS and AAMI standards both recommend 3 readings on each of 85 individuals pooled for analysis. The mean error should be within ±5 mmHg, and the standard deviation within 8 mmHg. A problem is that if we take three readings on one person, we expect that they will be grouped more closely together than those taken on different subjects. However, raw data from a validity study (O'Brien) of an ambulatory monitor shows a huge scatter of readings. Analysis of the data indicates a consistent error in the percentage of persons within 5 mmHg. The new protocol will try to report on individual subjects.

In summary, Dr. Pickering listed the advantages and disadvantages of different types of sphygmomanometers:

	Mercury	**Aneroid**	**Oscillometric**	**Hybrid**
Cuff pressure reading	Accurate	Questionable	Accurate	Accurate
SBP/DBP reading	Accurate	Accurate	Questionable	Accurate
Terminal digit preference	Yes	Yes	No	No
Individual validation needed	No	No	Yes	Yes

He concluded that there is an urgent need to find a replacement for the mercury sphygmomanometer and that the limitations of the various alternative devices will need to be addressed.

Review of Literature on Out-of-Office Devices [Dr. Lawrence Appel]

Dr. Appel presented results from an evidence-based report prepared for the Agency for Healthcare Research and Quality (AHRQ) and the NHLBI. The pre-2001 literature on ambulatory BP (ABP) and self-measured blood pressure (SMBP) was reviewed for risk prediction and treatment. The review included electronic searches of three databases and hand searches of major references, recent issues of key journals, and symposia of recent major meetings. The review looked at approximately 6,000 abstracts for eligibility and 600 potentially eligible papers. Data were abstracted from about 100 articles, and evidence tables and the report were prepared. Main eligibility criteria for including a paper were English language, sample size (from 20 to 50, depending on the research question), and the involvement of at least 2 clinic BP visits. Most of the eligible papers were in specialty journals, and there were few large-scale, multicenter studies. The quality of clinic BP measurements was poor or uncertain in most studies.

The evidence-based review included four research questions:

1. What is the distribution of BP differences between ABP, SMBP, and clinic BP, and the reproducibility of these differences?

2. What is the prevalence and reproducibility of white coat hypertension (WCH)?

3. What are the relationships of ABP, SMBP, clinic BP, and WCH with (a) subclinical outcomes in cross-sectional studies and (b) clinical outcomes in prospective studies?

4. What are the effects of treatment guided by ABP or SMBP on BP control, BP-related clinical outcomes, and other outcomes?

Dr. Appel listed some of the conclusions of the review:

- Mean clinical BP exceeded SMBP and ABP (day, night, and 24-hour).

- Mean daytime ABP and SMBP appeared similar, but few studies included these data.

- Few studies assessed the reproducibility of WCH and the reproducibility of differences between clinic BP and either ABP or SMBP. The prevalence of WCH based on ABP is approximately 20 percent among hypertensives but is highly dependent on its definition and the study population (it is more common in women than men).

- There is insufficient literature to determine associations of SMBP with target organ damage. Cross-sectional and prospective studies showed an association between ABP and left ventricular (LV) mass or albuminuria. Prospective evidence supported the idea that at least one dimension of ABP (the BP level or pattern) predicted outcome.

- WCH was associated with reduced risk of cardiovascular disease (CVD) events compared with nondipping BP, which was associated with increased risk in most cases.

The review's major findings include the following:

- **Risk Prediction:** ABP levels and patterns predict clinical outcomes. Corresponding evidence for SMBP is unavailable. Comparison of risk prediction based on ABP and clinic BP is limited, in part because of poor or uncertain quality of clinic measurements.

- **Treatment:** SMBP may improve BP control, but further trials that test interventions with contemporary devices are needed. There was insufficient literature to determine whether treatment guided by ABP reduced BP or clinical outcomes.

Dr. Appel also identified the need for research in the following areas:

- Prospective observational studies that address reproducibility of WCH, risks associated with WCH, risks associated with nondipping BP, and incremental gain from use of ABP.

- Clinical trials that determine whether treatment guided by SMBP can improve BP control and outcomes.

- Decision analyses that determine the costs and effects of strategies that integrate clinic BP, SMBP, and ABP.

Human BP Measurement Accuracy With Nonelectronic and Electronic Devices [Ms. Carlene Grim]

Ms. Grim reviewed the literature and approaches to standardized BP measurement and discussed barriers to accurate measurement. She noted that many health care providers are not aware of the existence of guidelines for BP measurement, including the latest AHA guidelines with updates on measurement in the pediatric population and pregnancy.

In a year 2000 survey of 150 physicians, 27 responded. Fifty percent of the responders said they were not familiar with AHA recommendations for BP measurement; 45 percent were aware of them but had not read them; and only 5 percent had read them cover to cover. The amount of time spent when they first learned to measure BP varied from 2 to 4 hours and as little as 10 minutes. Less than 10 percent reported the use of a standardized training videotape or audiotape, and less than 20 percent had an instructor listen with them.

Other barriers to accurate BP measurement are a belief that technology will eliminate human error, lack of standardized equipment, and debated aspects of technique such as the cutoffs for cuff bladder size and arm circumference and uncertainties about the danger of mercury in this setting.

Ms. Grim reviewed training, testing, and certification methods. She noted that in a pretest of knowledge, 2 of 3 health care providers scored less than 50 percent on a 16-question test on BP measurement, and one-quarter of M.D.s scored greater than 80 percent. On the triple stethoscope practical exercise (in which two participants listen with an instructor), 8 percent of M.D.s and 19 percent of others needed to repeat the test. Errors of interpretation included measuring SBP (the first loud, distinct, strong sound) and DBP (K4 or K5—the last sound or disappearance of sound that is 2 mmHg below the last sound). Normal variations are an absent Phase V and an ausculatory gap. Ms. Grim said that standardized BP readings force response to sounds and allow repeating the exact readings. The usual error is 10 mmHg. There is a tendency to prefer one side of the manometer, as well as problems reading "backwards" down the manometer.

To detect and correct errors, Ms. Grim recommends practice testing with stethoscopes and videotapes, comparing readings using a dual stethoscope, identifying observers who read high or low and determining the cause, checking for observer bias and differences between the readings recorded, and checking for digit bias and cutoff bias in hospital records. In one study of terminal digit bias among medical students just learning to take BPs, 53 percent had a bias to the digit 0.

Ms. Grim made the following points:

- Patient-related errors correctable by automated devices include K sound variation, arrhythmia, and patient/provider interaction. Automated devices also correct for poor eyesight, hearing, and hand-eye coordination.

- Technique-related errors include cuff selection, positioning, and preparation. Preparation and training result in optimal readings. The Children's Heart Study showed that providers who pass a test based on videotape training measure BP well in the field.

- Equipment-related errors can be prevented by making several cuff sizes available and by making regular cuffs and automated-device cuffs interchangeable. Mercury hazard and human error are also related to equipment.

- QA in the practice setting must become routine, and steps to standardize aneroid instrument should be widely implemented.

Ancillary Issue—Cuff Size [Dr. John Graves]

Dr. Graves began by pointing out that "standard" adult cuffs are not standard—there are variations by manufacturer. He referred to the following studies of arm circumference and cuff size:

- Beavers et al. (1987) found that an arm circumference >33 cm was seen about 7 percent of the time in a general population and in 15.7 percent of 209 hypertensives in a hospital-based clinic.

- O'Brien (1993) found a mean arm circumference of 30.2 ±4 cm among Irish men and women. Use of a BHS standard cuff (12 by 35 cm) would result in 6 percent being correctly cuffed and 94 percent being overcuffed.

- Rastam et al. (1990) analyzed arm circumference in family participants in the Minneapolis Children's Blood Pressure Study and found that 38 percent of men and 18 percent of women had circumferences greater than 32 cm (considered a big arm).

- Dr. Graves' paper in *Blood Pressure Monitoring* (2001) was based on 430 consecutive hypertensives seen at the Mayo Clinic's Division of Hypertension in 1999; 61 percent (mostly of Northern European background) had arm circumferences >33 cm.

- Mayo Clinic data (2001) on out-of-office BP measurement found that 20 of 190 people had purchased the wrong cuff, even though they received direction about which cuff to buy.

- A study of nurse BP measurement by Devenhorn et al. (2001) found that only 9 of 21 nurses used the correct cuff.

Dr. Graves then reported a study he conducted with Ms.Vicki Burt, using the NHANES III Population Survey database to compare the distribution of arm circumferences in the U.S. population between the Survey's Phase 1 (1988–91) and Phase II (1991–94). This was the first study to identify the distribution of arm circumferences in a national population. The study found that mean arm circumference is increasing in the U.S. population—both in normotensives and hypertensives—paralleling the increase in obesity. Estimates of the percentages of all Americans by ethnicity fit by six standard cuffs indicated that certain cuffs would be best for persons with larger circumferences. There were also variations using the "large adult" cuff, indicating that the solution is not just to pick a bigger cuff.

Dr. Graves concluded that accurate blood pressure measurement in the United States increasingly will require the use of "large adult" and thigh cuffs. Manufacturers of BP measuring devices should use knowledge of arm circumference distributions to manufacture "standard arm" cuffs that better fit the U.S. population. The cuffs should be given new, nonpejorative designations to encourage the use of the appropriately sized cuff in each patient.

EQUIPMENT CALIBRATION [Dr. Bruce Morgenstern]

Dr. Morgenstern said that the issue isn't the device—it's getting people to use the devices correctly. First he addressed the blind faith that mercury manometers are accurate. He cited a study in the *Journal of Human Hypertension* (Mion et al., 1998) that cited the percentage of inaccurate mercury manometers in Brazil (21 percent) and Canada (12.6 percent), with more than half having a nonfunctioning component. In a study of office practices in the United Kingdom (UK), all failed on at least one British standard, and 86 percent did not meet all health and safety standards. In an inner-city study in the UK, only 2.3 percent were inaccurate, and a higher percentage of aneroids were inaccurate.

Dr. Morgenstern said that mercury is toxic, persistent, and bioaccumulable. He noted that the real cost is not toxicity but what happens when there is a mercury spill. At the Mayo Clinic, which owns its own medical waste incinerator, there were 50 spills from sphygmomanometers over a 2-year period, resulting in $26,000 in cleanup costs (spills on carpets would cost much more to clean up). The Mayo Clinic got rid of thermometers in 1992 because of state laws, and it has also replaced all mercury manometers with commercially available aneroid devices. These devices are calibrated every 6 months at three sites, using a Digimano digital gauge from Netech Corporation and a mercury column for QA. At each site, 2–3 people have been trained to test each device at 0 mmHg and 10 points between 60 and 240 mmHg. It takes 5 to 20 minutes to test each unit and 6 months to cycle through each site. The cost per site is about $7,000 each year. Failure of the device occurs if the zero is off, the readings are ≥ 4 mmHg off the standard, or the needle does not move smoothly. Device failure rates were 1.6 percent over 3 years and 4 percent over 6 months. According to a paper by Canzenello et al. (2001), the accuracy of the aneroid devices at Mayo Clinic is within the 4-mmHg range recommended by the AAMI.

Dr. Morgenstern cited several sources on the toxicity of Hg, including a study by Markandu et al. (2000) suggesting that mercury manometers should be abandoned and a statement by the British Medical Device Agency recommending that consideration be given to the selection of mercury-free devices where appropriate. Furthermore, an AHA article states that most mercury instruments have not been adequately validated over a wide range of BP, ages, and clinical conditions to warrant routine use in hospitals and outpatient settings. It encourages the general use of mercury manometers until other instruments are better validated through the AAMI or similar organization.

Additional concerns are that automated devices may work accurately in populations but not in individuals and that automated oscillometric devices might not work in every setting for every patient. Another concern is secrecy about the algorithms.

Dr. Morgenstern noted that the draft revision of the SP10 standard for mercury manometers includes concern about leaking from the top of instrument or from the reservoir during shipment, which would affect performance and may also be a hazard. The standard gives companies the opportunity to use devices other than a mercury column for calibration. He also called attention to Sustainable Hospitals Web site, http://www.sustainablehospitals.org, which includes a table comparing aneroid, electronic, and mercury devices and rated electronic monitors as most reliable.

In conclusion, Dr. Morgenstern said there is no reason to fear replacing mercury manometers with manual aneroid devices. The issue is ensuring validation, calibration, and regular maintenance.

DISCUSSION OF ISSUES AND DECISIONS [Dr. Jones and Dr. Edward Roccella]

Dr. Jones thanked the presenters and said that he sensed more common ground than he had expected. He asked them to send him their slides and abstracts, noting that the paper to be written would use these materials.

The group was asked to give preliminary votes on the questions listed earlier (see page 1). The following additional questions were raised:

- How great is the risk and environmental impact of mercury manometers? Should we encourage the development of electronic (not oscillometric) manometers as a substitute for mercury manometers?
- Should the use of mercury manometers be terminated in a short period of time or within 5 or 10 years? Should this group suggest to the EPA and the American Hospital Association that they take more time to phase out mercury devices?
- Is our current approach to BP measurement, validation, and calibration of mercury, aneroid, and electronic instruments adequate, or should we encourage stronger standards based on the science?
- Is there a sufficient knowledge base for establishing standards and guidelines regarding the validation of BP measurement instruments?
- Would national guidelines for equipment calibration resolve BP measurement issues? Would calibration overcome equipment problems associated with oscillometric devices?
- How many false positives should be acceptable with multiple readings for an individual patient: > 5 percent, > 20 percent?

Possible Recommendations

During the discussion, there was a consensus on the following recommendations (captured by Mr. Wolz on flip charts):

- Blood pressure devices should not be sold without appropriate regulatory approval.
- Blood pressure measurement devices must be manufactured with the ability to accept cuffs interchangeably from a standard set of cuff sizes.
  - The interchangeability need not extend to other brands, only within one machine.
  - Instructions must be included with the devices to allow users to match body type with appropriate cuff type.

- A system of standard cuff sizes should be developed.

- A standard system of training, certification, and recertification—perhaps linked to licenses—should be implemented and enforced.

- Send a message to the EPA (and other agencies, including state governments).

  – We support elimination of mercury from the environment.

  – We recommend a period of research to devise an adequate replacement for the mercury manometer.

- Promote calibration and maintenance programs with the NHLBI, AHA, and Joint Commission on Accreditation of Healthcare Organizations (JCAHO) as partners.

- Develop methods to determine the accuracy of a given device when tested against a standard sample or measure.

- Develop standards based not only on group numbers but also on individual numbers—e.g., the percent of individuals whose blood pressure reading error falls outside a given multiple of the standard deviation.

- Recommend a regulated informational package insert for devices.

- Recommend that auxiliary health providers be certified to take blood pressures, perhaps with automated devices, at every visit.

Recommendations Regarding Research

- Determine the feasibility of implementing a system of standardized mercury manometers for calibration purposes.

- Find other standard measures for device calibration and testing.

- Develop methods of calibrating and standardizing oscillometric devices.

- Look at the relationships between cuff size, body size and type, and measurement error.

- Develop the standardization of cuff size.

The following issue was not decided:

- Should we encourage the development of electronic manometers as a substitute for mercury manometers?

Other Discussion Points

During the course of the discussion, participants made the following additional suggestions and comments:

- Allow limited use of mercury until research on non-mercury instruments is completed. Participants suggested allowing as much as 10–25 years or as little as 2 years. Dr. Jones suggested allowing 1.5 to 2 years for funding, followed by a period for research.

- Ask the EPA not to eliminate mercury but to allow research and hospital groups to make this decision. Develop a robust mercury manometer for calibration purposes. Calibration should look at moving columns rather than static ones. The upcoming AHA report should focus on specific calibration programs.

- Recommend that calibration be a measure for the Health Plan Employer Data and Information Set (HEDIS) and a requirement for all NIH clinical studies.

- Encourage the enforcement of current FDA standards for BP measurement devices.

- Clarify the frequency of BP measurement and who needs repeat measures. The JNC VI states that BP should be measured once every 2 years if the initial blood pressure readings are normal. Some participants suggested that the JNC should advocate measurements "at each health care encounter."

- Report results for individuals as well as populations. Look at replicate measure by the same device and the standard. Increase the number of samples for each patient.

- Conduct research on the validity of quick BP measurements in clinics and hospitals. Determine the false negative rate.

- Conduct research to construct a model for validation standards. (The AAMI standards are a compromise.) Report validation results for both arterial and oscillatory measures.

- Report variability for individuals as well as groups. The percent error should be reported for individuals with error greater than 4 mmHg.

- Develop recommendations for a broader range of patients, such as older adults. Specify the range of clinical circumstances in which the device was tested, the subjects' weights, and whether there were arm size requirements. Specify age >50 or end-stage renal disease. Require that people with stiff arteries be given special consideration.

- Take measurement out of the physicians' hands; use trained observers or nurses. There should be observer training, certification, recertification, and licensing for BP measurement. Take advantage of new technologies for education and certification that are available on the Internet. Use training tapes.

- Encourage insurance companies to reimburse for BP measurement devices. They should be available by prescription only (this is required by third-party payers) and should be purchased only through a blood pressure store. A regulated package insert should provide information about cuff size, etc.

- Suggest that hospitals offer free maintenance checks for measurement devices during National High Blood Pressure Education Month.

WRAP-UP

Dr. Jones thanked the participants for their efforts, which have begun to identify research questions. He said that a draft paper based on the meeting will be circulated for comment, and agencies will be contacted for their recommendations. This will result in a report to the NHLBI as well as recommendations for a Special Emphasis Panel that will lead to research. Participants may be called on to contribute to groups that would embellish the report.

Dr. Roccella added that the effort does not end here. This is an ongoing process that will lead to possibly several papers and sets of actions.

It was suggested that the group submit a short editorial or letter to *Hypertension* or another journal. Dr. Jones said that he would look into this.

ADJOURNMENT

Dr. Jones adjourned the meeting.

Attachment A

Participants

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Attachment B

National Heart, Lung, and Blood Institute
National High Blood Pressure Education Program
and the American Heart Association
Working Meeting on Blood Pressure Measurement

Natcher Conference Center
NIH Campus
Bethesda, MD
Friday, April 19, 2002
8:00 a.m. to 3:00 p.m.

Agenda

8:00 a.m.	**INTRODUCTION**	
	Greetings and Introductions	Dr. Claude Lenfant Dr. Daniel Jones
8:15	**Goals of Meeting** • Examine the science that supports the current measurement policies • Identify additional research needed to strengthen policies	Dr. Jones
8:30	**History and Overview of Blood Pressure Measurement Policy Development**	Dr. Sheldon Sheps
8:50	**Importance of Accuracy: The Costs of Errors**	Dr. Clarence Grim
	VALIDATION	
	Review of Current Validation Standards and the Regulatory Process	
9:10	Food and Drug Administration	Dr. Sandy Stewart
9:30	Association for the Advancement of Medical Instrumentation • Algorithms for electronic instruments: secrecy in science	Dr. Bruce Friedman
9:50	**Memorandum of Understanding Between the Environmental Protection Agency and the American Hospital Association**	Mr. Thomas Murray
10:10	**Physics of Measurement and Review of Literature on Accuracy of BP Measuring Devices**	Dr. Thomas Pickering

10:45	**Midmorning Break**	
11:00	**Review of Literature on Out-of-Office Devices**	Dr. Lawrence Appel
11:20	**Human Accuracy With Nonelectronic and Electronic Devices**	Ms. Carlene Grim
11:40	**Ancillary Issue—Cuff Size** • Increasing arm size • Interchangeability between manufacturers	Dr. John Graves
12:00 p.m.	**EQUIPMENT CALIBRATION** • Status of availability of mercury instruments • Current standards and practices • The Mayo model	Dr. Bruce Morgenstern
12:20	**Lunch**	
	DISCUSSION OF ISSUES AND DECISIONS **Questions:** • Is the accurate measurement of blood pressure important? • Are mercury manometers dangerous? • Is the use of mercury manometers forbidden? • Are currently available aneroid and electronic instruments a reliable substitute for mercury manometers? • Are current standards of validation adequate, or do we need new standards? • Is there a sufficient knowledge base for establishing standards and guidelines regarding the validation of blood pressure measurement instruments? • Are current programs of calibration adequate, or do we need new standards/guidelines?	Moderators: Drs. Jones and Edward Roccella
	OUTCOMES • Workshop proceedings published • Identified research questions • Suggestions to manufacturers	Drs. Jones and Roccella
3:00	**Adjournment**	

Attachment C

Abstracts

BACKGROUND SCIENCE THAT SUPPORTS THE CURRENT MEASUREMENT POLICIES

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Europe and the United States are phasing out hospital equipment and devices containing mercury. Many institutions have removed the mercury sphygmomanometer, replacing it with various aneroid and automated devices. With the phasing out of mercury, important issues regarding blood pressure measurement have emerged.

Misdiagnosing hypertensive patients is a real possibility if blood pressure measuring devices are used without adequate attention to validation and calibration. The aneroid devices, while accurate, need to be recalibrated regularly and, without proper maintenance, will provide erroneous measures. In addition, these devices still allow for the potential of human error by requiring expertise in auscultation. Automated devices may reduce the possibility of human error, but they use different algorithms to calculate systolic and diastolic pressure, and these algorithms are usually proprietary, making it difficult to determine the accuracy of the devices. Recently it was reported one automated device was producing a zero bias. Automated devices have difficulty in providing accurate blood pressure readings as arterial stiffness increases. These devices need to be independently validated and properly maintained to provide accurate readings.

Regardless of the type of device used to measure blood pressure, selecting appropriate-sized cuffs is critical. The appropriate cuff must be used, based not only on arm size but it should also be one designed for use with the particular blood pressure measurement device chosen. Recent data from NHANES 1999 show that 61 percent of Americans are either overweight or obese. The need to select an appropriate-sized cuff becomes important every time the patient's weight significantly changes. With the increasing weight of so many Americans, data should be evaluated to determine the ideal length and width of the blood pressure cuff. Efforts should be undertaken to collaborate with industry to promote the use of proper-sized cuffs and provide information regarding the inter-changeability of cuffs produced by different manufacturers. Inaccuracies due to inappropriate cuff size or inadequate attention to validation and calibration of blood pressure measuring need to be addressed.

Because of the clear public health implications of blood pressure measurement inaccuracies, and the importance of building consensus among different groups to accept and implement a national standard, the National Heart, Lung, and Blood Institute, and the American Heart Association, will convene a Working Group on Blood Pressure Measurement. The Working Group will be charged with evaluating the current state-of-the-science that supports measurement policies and will make recommendations for additional research needed to strengthen these policies.

HISTORY OF POLICY DEVELOPMENT IN BLOOD PRESSURE (BP) MEASUREMENT—SUMMARY

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Indirect BP measurement came into general use about 100 years ago following the development of the mercury manometer by Riva-Rocci in 1896 and the aneroid manometer by Hill and Bernard in 1897. Janeway published an important monograph in 1904. Systolic blood pressure (SBP) was the only measure for several decades but estimates of diastolic pressure (DBP) evolved in the early 20th century. Korotkoff described the auscultation of arterial sounds (phases) in 1905. All the methods [auscultation, oscillometric, ultrasound, photoplethysmographic (finapres, etc.)] are derived from physiological phenomena that are mainly but not exclusively related to BP. BP estimates then are method-dependent.

Dr. J. W. Fisher, medical director of the Northwestern Mutual Life Insurance Co. was influenced by Janeway's book "the Clinical Study of Blood-Pressure" among other developments. In 1906 he initiated the inclusion of a blood pressure reading in every routine examination by their examiners. By 1918 most companies were taking blood pressures. In 1925 the first report was published of the Joint Committee on Mortality of the Association of Life Insurance Medical Directors and the Actuarial Society of America. They used 5th phase for DBP. Average BPs for gender, age and build were established. It was clear that if your pressure was less than average, you had less mortality and vice versa.

Korotkoff's presentation was rapidly disseminated. In Europe, for DBP the 4th phase was advocated while in America it was the 5th. This controversy in and outside of America was to last until the latter part of the 20th century, resolved at last in Korotkoff's favor (5th). The cuff bladder initially encircled the upper arm. The width and length remain somewhat controversial. Soon the commonly used manometers were mercury, aneroid and oscillometric.

The American Bureau of standards [aeronautic instruments section] published reports to improve blood pressure measurement standards in 1917, 1921 and a comprehensive one in 1927. Some 50 years later, the NHLBI contracted with AAMI, the Association for the Advancement of Medical Instrumentation. AAMI initiated a sphygmomanometer committee, which is composed of representatives from industry and users, mostly academics. The FDA has delegated the regulation of BP equipment to AAMI and accepts the manufacturers' certification that their equipment meets AAMI standards.

By the 1930s, it became clear to early leaders such as Irving S. Wright that standardization was necessary both for equipment and measurement. He reported on a survey of these errors in 1938. "Time does not permit a review of the volumes of literature written on the sources of error in blood pressure determinations". There was great variation in every aspect. The medical profession had little idea or influence on what was being done.

In 1939, Dr. Wright chaired a committee for the AHA on the Standardization of Blood Pressure Readings in cooperation with a similar committee of the Cardiac Society of Great Britain and Ireland chaired by Dr. Maurice Campbell. 5 subsequent US reports have been published. Until 1980, there was controversy about diastolic pressure; whether K4 or K5 was the best phase to use. This was resolved in 1980 in favor of K5 for adults and more recently for children as well. At present bladder width is recommended to be 40% of the circumference of the limb at the point of measurement and length, sufficient to encircle at least 80% of the limb. For all who measure blood pressure, these documents describe in detail the technique, observer and subject preparation, manometers available, epidemiology and special circumstances. Recommendations have been presented by European organizations as well, notably the British Hypertension Society.

Issues remain to be resolved and will be addressed by subsequent speakers.

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THE COST OF INACCURATE BLOOD PRESSURE MEASUREMENT

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Unless blood pressure (BP) is measured accurately, the proven benefits of diagnosing and treating an unhealthy blood pressure will not be transferred to the population. Although the assessment of BP is the most cost-effective procedure in medicine, it is rarely performed according to guidelines. Measurement is cost-effective because the capital cost of equipment is low ($250), the skills can be mastered and practiced by all health professionals (and patients) and it is the only way to detect and manage the asymptomatic, most common risk factor for premature death and disability-high blood pressure. The standards for obtaining an accurate BP are intermittently updated by the American Heart Association Council for High BP Research and published by the AHA yet most who measure blood pressure have never read these recommendations and few current training programs teach to these standards. Failure to follow these guidelines has been proven to result in errors of up to 100 mmHg. However, even errors as small as 2-5 mmHg can have astounding costs to the individual patient, to the health care system, to a research project, for government planning and for society. The cost of errors will be discussed in the terms of reading blood pressure systematically too low, systematically too high or reading imprecisely (sometimes too low and sometimes too high or reading with bias).

Patients with truly high BP, but measured as normal, are denied the proven benefits of treatment and will suffer premature disability and death because of untreated high blood pressure. An error of “only” minus 5 mmHg at the 90-95 mmHg range will miss the 21 million hypertensives in the US in this range (42% of all with HTN). Over the next 6 years these 21 million untreated HTN will experience 125,000 CAD deaths[1] of which at least 20% would be prevented by treatment[2]. About the same number of fatal strokes would have also been prevented. Thus a -5 mm error will cause about 50,000 preventable deaths not to mention preventing perhaps twice this many non-fatal CADs and CVAs. Aneroid devices out of calibration most often read too low.

Measuring BP falsely high increases costs by treating those who do not truly have high BP. Thus an error of +5 mmHg would move 27 million people from 85-89 into the high BP range. As the estimated cost of treating one person for high BP is $1000/yr., this will cost at $27 billion/yr. to treat a “non-disease.” In those with HTN, a false high reading will result in more medications being used to get the BP to “goal.” Even a 2 mmHg error will misclassify about 6 million persons into the 90–95 range. Current standards permit devices ±3 mm of the mercury standard. This seems too lenient.

Observers or machines that measure sometimes high and sometimes low confuse the provider and patient and no or sporadic treatment may result. In clinical trials, this added error increases the number of subjects to be studied to see “effects” of treatments or genes. Effective drugs may be abandoned and clues to genetic causes of hypertension missed. Indecision in diagnosing hypertension in pregnancy may result.[3]

National and international surveys and trials have frequently[4,5,6] had problems with quality control of BP measurement due to observers and/or devices (electronic[7] and nonelectronic). This has required dropping sites, diluting the power of studies estimating the burden of disease in populations and testing hypotheses.[8]

Practice surveys around the world report serious problems in the accuracy of sphygmomanometers (aneroids, mercury and electronic) and poor adherence to proper technique. It has been suggested that clinicians using equipment that has not been maintained and calibrated may be medically negligent.[9] It appears that the most common error in the practice of medicine occurs when BP is measured. The potential for great harm to the public is clear. Efforts to improve the practice of BP measurement will likely have a major impact on the health of the population.[10]

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CONSENSUS STANDARDS FOR BLOOD PRESSURE MONITORS

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Many standards exist for blood pressure measurement, including the ANSI/AAMI SP9[1] standard for manual blood pressure cuffs, the ANSI/AAMI SP10[2] and IEC 60601-2-30[3] standards for automated non-invasive blood pressure (NIBP) monitors, and the ANSI/AAMI BP20[4] and IEC 60601–2–34[5] standards for intra-arterial blood pressure transducers. Standards continue to be revised and improved to reflect the current state of the art. For example, the new version of SP10, now being finalized, will combine elements of the old SP9 and SP10. The new version will cover both manual and automated blood pressure monitors that work with a cuff, thus providing a single reference for cuff-related issues. It will also update requirements for NIBPs, providing specifications for the clinical verification studies for infants and pediatric patients (including improved statistics for these studies), and specifying testing requirements for software verification/validation and electromagnetic compatibility.

Consensus standards are an important tool in the review process at the Center for Devices and Radiological Health (CDRH). Well-written standards provide a solid scientific basis for reviewers to make decisions on new applications, thus streamlining the review process and providing a more level playing field. Certain standards have been formally recognized by CDRH, so that they can be used in the abbreviated 510(k) process. In this case, the manufacturer still performs all the required testing specified by the standard, but submits only a declaration of conformance to the standard. SP10 and IEC 60601–2–30 are two such standards. In some cases, CDRH has recognized a standard, but limits the extent of the recognition as specified in a "supplementary information sheet." The extent of recognition may recognize or exclude part of the standard. Often the information sheet refers the manufacturer to a guidance written to provide additional details required by CDRH. Software verification/validation of NIBPs is an example of testing not included in the current SP10 that is requested to be included along with the declaration of conformance. This process of recognizing a standard but requiring additional information allows CDRH to rely on standards without being limited by the typical one-to-five year lag in scientific and technological advance that standards typically experience.

Although manufacturers may qualify NIBPs using any relevant standard, or by comparison to a predicate device, from CDRH's standpoint the SP10 standard appears to be the most comprehensive, in that it includes protocols for clinical verification studies. The new version will include protocols for neonates, infants, pediatrics, and adults. Once the new version is adopted, the NIBP guidance and supplementary data sheets for SP10 will be revisited.

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ALGORITHMS FOR ELECTRONIC INSTRUMENTS

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The oscillometric method was developed in the late 1800's, but practical automated devices based on the oscillometric method were not available until 1976. A number of factors affect the performance of automated oscillometric monitors including: pressure control method (linear vs. stepped deflation), systolic/diastolic determination (ratios or inflection points), artifact rejection methods, and the reference standard used for accuracy testing.

Operations manuals should include any limitations for use of the device. These may include performance during arrhythmias, performance during patient motion, appropriate patient population (adult, pediatric, neonatal), cuffs approved for use.

Performance may also be affected by the hardware and software used in the monitors. Manufacturers track their products using model number, serial number, and software revision level. On most products, users can easily obtain this information. The manufacturer should then be able to supply a summary of accuracy test data.

PHYSICS OF MEASUREMENT AND REVIEW OF LITERATURE ON ACCURACY OF BP MEASURING DEVICES

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Although hypertension can only be identified by measuring the blood pressure (BP), the conventionally used methods for its detection are notoriously unreliable. There are three main reasons for this: inaccuracies in the methods, some of which are avoidable; the inherent variability of BP; and the tendency for BP to increase in the presence of a physician (the so-called white coat effect). For clinical practice, the gold standard is measurements made with the Korotkoff sound technique by a physician using a mercury sphygmomanometer, but mercury is likely to be banned in the near future. This raises the issue of what will replace it. The two most widely used methods in clinical practice continue to be the auscultatory and oscillometric techniques.

The Auscultatory Technique. The Korotkoff sound method tends to give values for systolic pressure (SBP) that are lower than the intra-arterial pressure, and diastolic values that are higher, but there is no obvious superiority for phase 5 over phase 4. When both low and high frequency signals are recorded under a cuff (the K2 method) the appearance and disappearance of the high frequency component (K2) corresponds to intra-arterial SBP and diastolic pressure (DBP) (1). In people with high DBP but normal SBP when measured by the auscultatory method (known to be at low risk) the K2 method usually shows a normal DBP (2). Although potentially more accurate than other noninvasive methods, the K2 method has not been developed commercially.

The Oscillometric Technique. When the oscillations of pressure in a sphygmomanometer cuff are recorded during gradual deflation, the point of maximal oscillation corresponds to the mean intra-arterial pressure. The oscillations begin at approximately SBP and continue below DBP, so that SBP and DBP can only be estimated indirectly according to some empirically derived algorithm. One advantage of the method is that no transducer need be placed over the brachial artery, so that placement of the cuff is not critical. Other potential advantages of the oscillometric method for ambulatory monitoring are that it is less susceptible to external noise (but not to low frequency mechanical vibration). The oscillometric technique has become standard for clinical electronic blood recorders.

Alternatives to mercury. The two most popular alternatives to mercury are aneroid sphygmomanometers, and electronic oscillometric devices. The former are often inaccurate after prolonged use, and the latter may be consistently inaccurate in some patients, even though they have satisfied validation criteria. Ideally, they need to be checked on every patient. An alternative is a hybrid device which functions like a mercury sphygmomanometer but uses an electronic transducer to record the cuff pressure (3).

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AN EVIDENCE-BASED REPORT ON THE CLINICAL UTILITY OF AMBULATORY AND SELF-MEASURED BLOOD PRESSURE

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Background: The optimum technique to measure blood pressure (BP) remains uncertain, in part because clinic BP may not be representative of usual BP. Ambulatory BP (ABP) and self-measured BP (SMBP) monitoring are two techniques that record BP outside of the clinic setting and that might be satisfactory alternatives to clinic measurements.

Methods: We conducted a systematic review of the published literature on the clinical utility of ABP and SMBP. Specific goals were to synthesize evidence on:

- distributions of the differences between ABP, SMBP and clinic BP, and the reproducibility of these differences,
- the prevalence and reproducibility of white coat hypertension (WCH),
- the relationships of ABP, SMBP, clinic BP and WCH with subclinical outcomes in cross-sectional studies and clinical outcomes in prospective studies, and
- the effects of treatment guided by SMBP or ABP.

Three electronic databases were searched. Over 6,000 abstracts were reviewed. Nearly 100 articles met our inclusion criteria. Pairs of reviewers extracted data and assessed study quality.

Findings: For both systolic and diastolic BP, clinic measurements exceeded SMBP, daytime ABP, nighttime ABP and 24 hour ABP. In the few studies that compared SMBP and ABP, daytime ABP and SMBP appeared similar. The prevalence of WCH based on ABP varied considerably by definition; overall, WCH prevalence was approximately 20 percent among hypertensives. Few studies assessed the reproducibility of WCH and the reproducibility of differences between clinic BP and either ABP or SMBP. In cross-sectional studies, left ventricular mass and albuminuria were both associated with absolute ABP levels; in most studies, left ventricular mass was less in individuals with WCH than those with sustained hypertension. In each of ten prospective studies, at least one dimension of ABP predicted clinical outcomes. In two of these studies, WCH predicted a reduced risk of CVD events compared to sustained hypertension. No prospective study adequately compared the risk associated with WCH to the risk associated with normotension. In four of five studies, a non-dipping or inverse dipping pattern predicted an increased risk of clinical outcomes. The literature was insufficient to determine whether absolute SMBP levels or WCH based on SMBP was associated with left ventricular mass or proteinuria or whether SMBP measurements predicted subsequent CVD. In both cross-sectional and prospective studies, the poor or uncertain quality of clinic BP measurements precluded a satisfactory comparison of SMBP and ABP with clinic BP. In six of 12 trials, including two trials that tested contemporary devices, use of SMBP was associated with reduced BP. The availability of just two ABP trials limited

inferences about the utility of ABP to guide BP management. The vast majority of studies included both men and women, but few studies reported results stratified by gender. Few studies reported enrollment African-Americans, and race-stratified data were rarely presented. The only notable subgroup finding was a higher prevalence of WCH in women than men.

Conclusions: In cross-sectional studies, ABP levels and ABP patterns were associated with BP-related target organ damage. Likewise, in prospective studies, higher ABP, sustained BP and a non-dipping ABP pattern were associated with an increased risk of subsequent CVD events. Few studies examined corresponding relationships for SMBP. The poor or uncertain quality of clinic BP measurements precluded satisfactory comparisons of risk prediction based on ABP or SMBP with risk prediction based on clinic BP. In aggregate, these findings provide some evidence that ABP monitoring is useful in evaluating prognosis. However, evidence was insufficient to determine whether the risks associated with WCH are sufficiently low to consider withholding drug therapy in this large subgroup of hypertensive patients. For SMBP, available evidence from several trials suggested that use of SMBP can improve BP control; however, further trials are needed.

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HUMAN ACCURACY WITH NONELECTRONIC AND ELECTRONIC DEVICES

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Research designed to explore and document human blood pressure (BP) error has amassed a considerable body of literature over the past seventy years. Though much of the error can be traced to a lack of awareness of standard technique and recognized guidelines, comparatively little effort has gone into correcting the deficit in basic professional education.[1,2,3] The literature documenting the need for repeated training until mastery is extensive and ways to monitor and identify those who measure inaccurately (observers and devices) have been published.[4,5,6] Human measurement errors are commonly identified in epidemiological studies by looking for last digit preference (terminal digit bias), occurrence of identical readings, sign difference between first and second readings, and occurrence of odd numbers.

Instrument-related human errors are frequent and easily observed in the clinical setting. They include failure to select the appropriate cuff bladder size, improperly positioning the measurement device and the subject's limb, failure to rapidly inflate the cuff above the palpated systolic, too rapid deflation rate, and failure to examine or notice when equipment is not operating properly. A popular approach to the elimination of human measurement error has been to seek an automatic device that will result in foolproof and effortless assessments.

The reality is that human BP measurement errors persist regardless of the device used to obtain the reading.[7,8] Most professionals were never taught that small details in the way BP is measured can result in big differences in reading outcomes. BP measurement education should incorporate proven training methods[1,2] now used primarily for epidemiological studies. With a move to electronic data records quality monitoring methods used by epidemiological studies should become standard to easily identify observers and devices that are not reading accurately and reliably.

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THE CHANGING PREVALENCE ARM CIRCUMFERENCES FROM NHANES III AND ITS IMPACT ON BLOOD PRESSURE CUFF MANUFACTURE AND PURCHASE

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Accurate measurement of blood pressure is dependent upon a number of factors including the relationship between arm circumference and the length and width of the blood pressure cuff used. Blood pressure measurement using too small a cuff for the patient's arm circumference will over-estimate blood pressure while use of too large a cuff under-estimates blood pressure. JNC VI guidelines recommend that "the appropriate cuff size must be used to ensure accurate measurement. The bladder (cuff length) should encircle at least 80% of the arm. Many adults will require a large adult cuff." Two epidemiologic studies of arm circumference exist. The Minneapolis Children's Blood Pressure study found that in 1484 women the mean arm circumference was 28.5 ± 4.6 cm and amongst 940 men it was 31.6 ± 3.3 cm. More importantly, 38.1% men and 17.7% of women had arm circumferences > 32 cm.[1] O'Brien found that the mean arm circumference in a population of 1300 Irish men and women was 30.2 ± 4cm (R-17.5–46 cm).[2] In clinical practice settings, Beavers[3] found that 15.7% of 209 hypertensives in a hospital based clinic had arm circumfernece > 33cm, while Graves[4] found that 61% of 430 consecutive hypertensive patients seen in tertiary care clinic had arm circumfernece of > 33cm.

We evaluated the changes in arm circumference that were seen in NHANES III between period one (1988–1991) and period 2 (1991–1994). The mean arm circumference increased from 31.5 cm in period one to 31.8 cm in period two (P < 0.001). For the hypertensive population a smaller but statistically significant change from 32.1 in period one to 32.2 (P < 0.03) in period two was found. The percentage of arm circumference that were 35.1 cm or greater increased from 20.1% to 23.6% (P<0.001). A multivariate analysis correcting for age, sex, weight, height and period showed that the increase in arm circumference was due to the increase in weight seen between the two periods. Each 10 kg increase in weight was associated with a 2.7 cm increase in arm circumference.

The NHANES III data allows one to predict the clinical utility of different manufacturers blood pressure cuffs in the adult US population. Estimations of the numbers of adults and hypertensive adults correctly cuffed with for six major standard adult blood pressure cuffs are seen in Table 1. This information should allow manufacturers of blood pressure cuffs to optimize their product to fit the adult US population.

Table 1.

Cuff Type	Cuffed Correctly			
	All (177 million)		Htn (29.55 million)	
	M	%	M	%
Welch-Allyn	135	76.3	24.2	82
Mabis	109	63.2	14.9	50.3
Baumanometer	128.4	72.5	19.25	65
Omron	142.6	80.5	24.7	83.5
Graham-Field	82.7	46.7	10.5	35
Datascope	143.4	80.9	21.5	72.9

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MERCURY MANOMETERS, EQUIPMENT CALIBRATION, ONE INSTITUTION'S RESPONSE

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Mercury as an element used in many settings has come under increasing criticism. It has been noted to be "toxic, persistent and bioaccumable."[1] It's use for medical devices has been eliminated in Sweden and the Netherlands. The British Medical Device Agency has recommended use of alternative devices. Several large medical groups in the United States have moved to aneroid and/or electronic devices. Despite what seems to be an inexorable move away from mercury manometers, the American Heart Association has taken a more assertive position in favor of continuing the use of mercury in manometers.[2] The European position is more accommodating to the loss of mercury.[3,4] Evidence is also accumulating that mercury manometers in clinical practices are not nearly as accurate as many believe.[3, 5]

The American Heart Association and the Association for the Advancement of Medical Instrumentation (AAMI) are continuing to either advocate or allow for mercury manometers. In the proposed SP10 standard for manual sphygmomanometers, only one sentence comments on the potential toxicity of mercury. The document does not discuss the steps required to clean up a mercury spill or the proper way to discard an old and poorly functioning manometer. The immediate medical toxicities from mercury manometers are rare, but potentially quite morbid. The major hazard would appear to be the long-term environmental impact.

However, both the US and British agree that care must be taken in the transition away from mercury. Electronic sphygmomanometers have not been subjected to validated regular use in the variety of clinical circumstances in hospitals.[4] Even though automated devices have been successfully validated, oscillometric techniques cannot measure blood pressure in all situations.[4] The algorithms which determine how the devices report pressures are proprietary. Oscillometric devices have been the subjects of increased scrutiny.[6] Aneroid devices are also felt to be of questionable accuracy and reliability.

The Mayo Clinic has migrated from mercury to aneroid devices in its hospitals and outpatient locations in Rochester, MN. Data have already demonstrated that aneroid devices, when properly maintained and calibrated remain quite accurate.[7] For two of the 3 sites in Rochester, there are >1100 aneroid manometers per site that are regularly assessed for function and accuracy, using visual inspection as well as a digital pressure gauge. Over the past three years, accuracy within 4 mmHg across a range of pressure measurements has been demonstrated repeatedly (every 6 months) for >98% of the devices. In fact, only 2.7% have been rejected for all reasons (including non-zeroing and poor needle movement). Replacement of manual mercury devices by manual aneroid devices is realistic, practical and will not adversely affect measurement of blood pressure.

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NATIONAL HEALTH AND NUTRITION EXAMINATION SURVEY (NHANES) 1999–2000: TRAINING OF OBSERVERS AND STANDARDIZATION OF MEASUREMENTS TO DECREASE ERROR IN BLOOD PRESSURE READINGS

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Abstract

The NHANES certification program and observer training are presented. The program resulted in a major reduction in the variability of blood pressure (BP) measurement commonly due to observer and technical error. Given specific training and protocol, instruction the effects on measured blood pressure by cuff width/circumference ratio, end-digit preference, were analyzed in detail. The participants were persons aged 8 years and older who had their BP taken in the mobile examination center (N=7,416) during NHANES 1999-2000. In stepwise principal components multiple regression analysis, CW/AC ratio accounted for less than 2% of variability R^2 in all readings. With the exception of end-digit "2" for diastolic (17.6%), all other end digits were close to 20% ("0" end digit = 21% systolic and 23% diastolic). No overall observer effect was present for mean systolic BP readings. A significant observer effect ($p<.0001$) was detected for mean diastolic BP readings of <90 mmHg. However, for readings of $\geq$ 90 mmHg there was no significant observer effect ($p=.06$). The analysis shows that standardization and training can reduce observers' errors.