PONTIFICIA UNIVERSIDAD CATÓLICA DEL PERÚ

FACULTAD DE CIENCIAS E INGENIERÍA

ROBOT PARA SUPERVISIÓN DE EQUIPAMIENTO EN SUBESTACIONES ELÉCTRICAS

Tesis para optar el Título de **INGENIERO MECATRÓNICO,** que presenta el bachiller:

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CRONOGRAMA DE ACTIVIDADES PARA EL DISEÑO DEL ROBOT PARA SUPERVISIÓN DE EQUIPAMIENTO EN SUBESTACIONES ELÉCTRICAS																			
Actividades	*Semanas desde el 18/08 al 12/12 del 2016*																		**Duración (días)**
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
	15-Ago	22-Ago	29-Ago	5-Set	12-Set	19-Set	26-Set	3-Oct	10-Oct	17-Oct	24-Oct	31-Oct	7-Nov	14-Nov	21-Nov	28-Nov	5-Dic	12-Dic	
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Total de días trabajados																			**90**

Figura 1 Cronograma de actividades. Fuente: Elaboración propia

ANEXO B. ESTÁNDARES DE CALIDAD AMBIENTAL PARA RADIACIONES NO IONIZANTES

Rango de Frecuencias (f)	Intensidad de Campo Eléctrico (E) (V/m)	Intensidad de Campo Magnético (H) (A/m)	Densidad de Flujo Magnético (B) (µT)	Densidad de Potencia (S_{eq}) (W/m^2)	Principales aplicaciones (no restrictiva)
Hasta 1 Hz	-	$3,2 \times 10^4$	4×10^4	-	Líneas de energía para trenes eléctricos, resonancia magnética
1 - 8 Hz	10 000	$3,2 \times 10^4 / f^2$	$4 \times 10^4 / f^2$	-	
8 - 25 Hz	10 000	$4\,000 / f$	$5\,000 / f$	-	Líneas de energía para trenes eléctricos
0,025 - 0,8 kHz	$250 / f$	$4 / f$	$5 / f$	-	Redes de energía eléctrica, líneas de energía para trenes, monitores de video
0,8 - 3 kHz	$250 / f$	5	6,25	-	Monitores de video
3 - 150 kHz	87	5	6,25	-	Monitores de video
0,15 - 1 MHz	87	$0,73 / f$	$0,92 / f$	-	Radio AM
1 - 10 MHz	$87 / f^{0.5}$	$0,73 / f$	$0,92 / f$	-	Radio AM, diatermia
10 - 400 MHz	28	0,073	0,092	2	Radio FM, TV VHF, Sistemas móviles y de radionavegación aeronáutica, teléfonos inalámbricos, resonancia magnética, diatermia
400 - 2000 MHz	$1,375\, f^{0.5}$	$0,0037\, f^{0.5}$	$0,0046\, f^{0.5}$	$f / 200$	TV UHF, telefonía móvil celular, servicio troncalizado, servicio móvil satelital, teléfonos inalámbricos, sistemas de comunicación personal
2 - 300 GHz	61	0,16	0,20	10	Redes de telefonía inalámbrica, comunicaciones por microondas y vía satélite, radares, hornos microondas

1. f está en la frecuencia que se indica en la columna Rango de Frecuencias

2. Para frecuencias entre 100 kHz y 10 GHz, S_{eq}, E^2, H^2, y B^2, deben ser promediados sobre cualquier período de 6 minutos.

3. Para frecuencias por encima de 10 GHz, S_{eq}, E^2, H^2, y B^2, deben ser promediados sobre cualquier período de $68 / f^{1.05}$ minutos (f en GHz).

Figura 2 Estándares de calidad ambiental para radiaciones no ionizantes [4]

ANEXO C. LISTA DE REQUERIMIENTOS

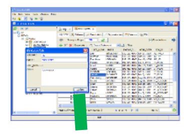
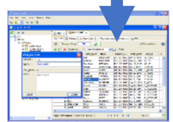
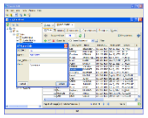
Tabla 1 Lista de exigencias y deseos del sistema. Fuente: Elaboración propia

Lista de Requerimientos	
Exigencias	
Características	**Descripción**
Función principal	El sistema deberá realizar la supervisión co-asistida del equipamiento en una subestación eléctrica.
Función principal	El sistema determinará los equipos más propensos a fallar en la subestación usando análisis termográfico.
Función	Análisis de las imágenes térmicas obtenidas de la supervisión para determinar temperatura del equipo
Función	Almacenamiento y generación de archivo con mapeo de los equipos críticos en memoria para ser extraídos posteriormente por el operario.
Geometría	Las dimensiones del sistema no serán mayores a 30x30x50cm
Cinemática	El sistema podrá desplazarse sobre superficies de tierra y pequeñas rocas, con capacidad de avanzar, retroceder y girar hacia ambos lados (velocidad mínima de 1km/h)
Energía	Energía suficiente para realizar una supervisión de equipamiento por un máximo de 2 horas.
Energía	Detección de batería necesaria para volver a la posición más cercana de seguridad, ya que su zona de trabajo es de alto riesgo eléctrico.
Fuerzas	Dos personas podrán levantar el sistema completo. Deberá tener un peso menor a 30 kilos.
Ergonomía	Se podrá levantar el sistema mediante dos asas de plástico removibles ubicadas a los costados.
Señales	Los parámetros de entrada del sistema serán la posición inicial y las posiciones de seguridad en la subestación.
Señales	Se dispondrá de alarmas de batería baja y de falla de sistema.

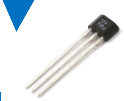
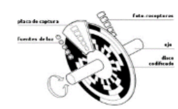
Seguridad	El sistema contará con aislamiento y protección en sus componentes electrónicos.
Seguridad	Se dispondrá de alarmas en caso de detección de altos niveles de radiación.
Seguridad	El sistema debe mantener estabilidad y no poseer bordes punzocortantes para su manipulación.
Fabricación	El sistema debe poseer materiales mecánicos resistentes y aislamientos para componentes electrónicos.
Montaje	El sistema debe ser de fácil montaje y desmontaje.
Mantenimiento	El mantenimiento deberá realizarse después de una exposición no mayor a 2 horas de campo magnético.
Transporte	Fácil disposición de las piezas para transporte de todo el sistema en una maleta de viaje.
Calidad	Se ejecutará el calibrado automático de sensores antes de realizar cada supervisión.
Calidad	Detección de zonas con mayor intensidad de campo magnético.
Costo	El costo de todo el sistema no será mayor a 20,000 nuevos soles
Deseos	
Características	**Descripción**
Función principal	Realizar medición de corriente y voltaje de cada elemento supervisado.
Energía	Energía suficiente para realizar una supervisión de equipamiento por un máximo de 4 horas.
Ergonomía	Capaz de ser levantado por una persona. El peso no mayor 20 kilos.
Señales	Control remoto desde centro de control por el operario.
Señales	Transmisión del espectro de calor de los equipos en tiempo real a una computadora en el centro de control
Fabricación	Obtención de repuestos en el mercado local

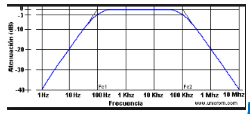
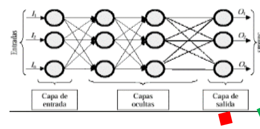
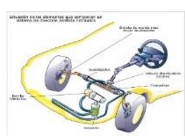
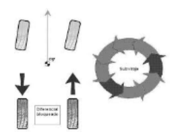
ANEXO D. MATRIZ MORFOLÓGICA

Tabla 2 Matriz Morfológica. Fuente: Elaboración propia

Función	S1	S2	S3	S4
Enviar comandos	Mando remoto	Interfaz gráfica (GUI)	Autónomo	Aplicación para celular
				
Mostrar datos	Interfaz gráfica (GUI)	Archivo	Aplicación para celular	HMI
				
Medio de comunicación	Wifi	Puerto USB	Bluetooth	Ethernet
				
Indicar alarmas (batería baja, proceso terminado)	Leds	HMI	Parlante pequeño	Interfaz gráfica (GUI)
				

Almacenar información del proceso	Base de datos	Memoria SD	Archivo	
				
Controlador	PLC	Raspberry PI	Arduino Mega	
				
Protección para campo magnético	Revestimiento conforme	Jaula de Faraday	Mu metal	
				
Capturar espectro térmico	Sensor infrarrojo	Flir ONE	FLIR C2 (cámara)	
				
Almacenar energía eléctrica	Batería Ion litio	Batería Ácido plomo	Batería Li-po	
				

Girar sensor infrarrojo	Motor a paso	Servomotor		
				
Avanzar y girar vehículo	Motor a paso	Motor DC	Servomotor	Omni wheel
				
Medir campo magnético	Sensor EMDEX - II	Sensor de efecto Hall	Aplicación para celular	
				
Definir posición	GPS	Cámara USB	Encoder incremental	Encoder absoluto
				
Medir temperatura interna	Termistor	Termopar	RTD	
				

Detectar equipos	Filtrado de imagen	Redes neuronales		
				
Detectar obstáculos	Control manual	Sensor Capacitivo	Sensor de ultrasonido	
				
Mecanismo de movimiento	Llantas de caucho (amortiguamiento propio)	Tren de rodajes	Llantas con amortiguadores	
				
Configuración giro de vehículo	Caja de dirección	Giro sobre su propio eje		
				

SOLUCIÓN 1	SOLUCIÓN 2	SOLUCIÓN 3

ANEXO E. ESTIMACIÓN DEL PESO

Tabla 3 Peso de los componentes del sistema. Fuente: Elaboración propia

Componentes	Cantidad	Peso [kg/unid.]	Peso total [kg]
Servomotor	1	0.017	0.017
Driver Roboclaw	2	0.017	0.034
Motor con encoder	4	0.104	0.416
Raspberry pi	1	0.045	0.045
Arduino Mega	1	0.037	0.037
Cámara web	1	0.076	0.076
Adaptador wifi	1	0.03	0.03
Módulo GY-283 (x5)	1	0.002	0.002
Sensor termográfico	1	0	0
Batería 8Ah	1	0.2	0.2
Batería 10Ah	1	0.75	0.75
Botón LED	1	0	0
Base y ventilador Pi B	1	0	0
Carcasa	1	0.579	0.579
Base de componentes	1	0.667	0.667
Base	1	4.856	4.856
Soporte inferior servomotor	1	0.015	0.015
Soporte superior servormotor	1	0.007	0.007
Malla de G iron	1	0	0
Perfil	2	0.257	0.514
Sistema de amortiguación	4	0.27	1.08
Llantas(X2)	2	0.264	0.528
Base de motores	1	2.944	2.944
Soporte de motor	4	0.085	0.34
			13.137

La Tabla 3 pretende dar una estimación del peso del sistema. Se asume que el peso total de los componentes faltantes no es mayor a 1 kg. Peso total = 15 kg.

ANEXO F. CÁLCULOS MECÁNICOS

Para la selección del motor a emplear para desplazarse a través de la subestación, se realizará el análisis dinámico para subir a una superficie ubicada a una altura no mayor a 4.5 cm. En la Figura 3(medidas en cm) se presenta un escenario donde la llanta está en contacto con la losa. Se realiza un análisis geométrico para hallar el ángulo que genera la línea de tangencia con el suelo, dato que será necesario para ver la aplicación de las reacciones sobre la llanta.

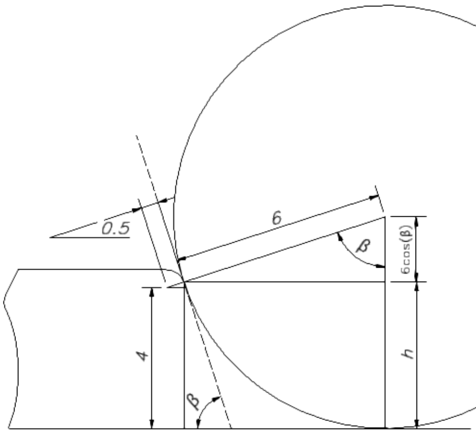


Figura 3 Análisis geométrico de la llanta con la losa. Fuente: Elaboración propia

$$\circ\ h = 4 + 0.5\cos(\beta)$$
$$\circ\ 6 = 6\cos(\beta) + h$$
$$\beta = \cos^{-1}\left(\frac{2}{6.5}\right) \approx 72.1^{\circ}$$

Con los cálculos geométricos realizados se puede dibujar el siguiente DCL (diagrama de cuerpo libre) de una llanta del vehículo (ver Figura 4). Siendo "M" la masa total, la fuerza normal "N_l" que ejerce la losa sobre la llanta, "f_l" la fuerza de rozamiento entre la losa y la llanta, la fuerza normal "N_s" que ejerce el suelo sobre la llanta, "f_s" la fuerza de rozamiento entre el suelo y la llanta, y finalmente "T" es el torque que aplica el motor.

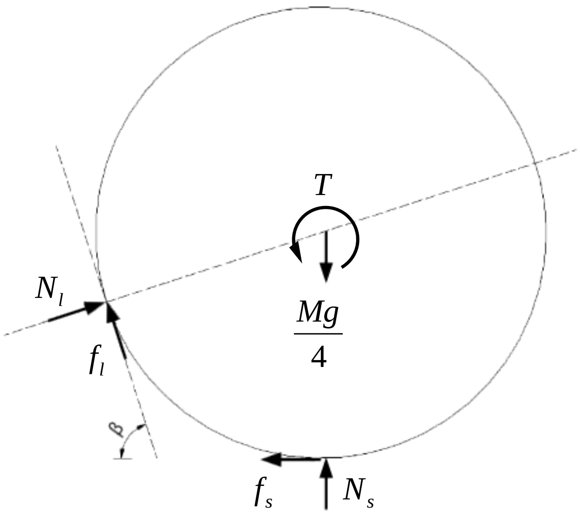


Figura 4 Diagrama de cuerpo libre de una llanta. Fuente: Elaboración propia

$$\sum F_y = 0 : N_l = (\frac{Mg}{4} - N_s)\cos\beta - f_s sen\beta \tag{3.1}$$

$$\sum F_x = 0 : \frac{M}{4} * a_{centro} = f_l - (\frac{Mg}{4} - N_s) sen\beta + f_s \cos\beta \tag{3.2}$$

Cuando la llanta deja de estar en contacto con el suelo, la fuerza normal “ N_s ” y la fuerza de fricción “ f_s ” se vuelven nulas. Por lo tanto, el análisis se reduce a analizar el movimiento en una pendiente sin deslizar. Modificamos las ecuaciones (3.1) y (3.2) y agregamos las condiciones necesarias para el desplazamiento.

$$N_l = \frac{Mg}{4}\cos\beta \tag{3.3}$$

$$\frac{M}{4} * a_{centro} = f_l - \frac{Mg}{4} sen\beta \tag{3.4}$$

$$Condición \text{ para subir : } f_l \geq \frac{Mg}{4} sen\beta$$

$$Condición \text{ para no deslizar : } \mu_e N_l \geq f_l \tag{3.5}$$

$$\mu_e \frac{Mg}{4}\cos\beta \geq f_l \tag{3.6}$$

Adicionalmente se tiene la siguiente relación:

$$\sum M_{centro} = I * \alpha_{centro} \tag{3.7}$$

Realizando la sumatoria de momentos en el centro de la llanta y conocido su momento de inercia “ I ” se obtiene la ecuación (3.8).

$$T - f_l * R = \frac{1}{2} * \frac{MR^2}{4} * \alpha_{centro} \qquad (3.8)$$

Se tendrán en cuenta las siguientes relaciones por ser un movimiento de rodadura sin deslizamiento:

$$V = w * R$$
$$a_{centro} = \alpha_{centro} * R$$

Reemplazando en la ecuación 3.8, simplificando y ordenando:

$$T - f_l * R = \frac{R}{2} * (\frac{M}{4} * a_{centro}) \qquad (3.9)$$

Se procede a reemplazar la ecuación (3.4) en (3.9):

$$T - f_l * R = \frac{R}{2} * (f_l - \frac{Mg}{4} sen\beta) \qquad (3.10)$$

Ordenando una vez más:

$$\frac{T}{R} = f_l + \frac{1}{2} (f_l - \frac{Mg}{4} sen\beta) \qquad (3.11)$$

$$\frac{T}{R} = \frac{3}{2} f_l - \frac{Mg}{8} sen\beta \qquad (3.12)$$

Ahora se agrupan las condiciones de las ecuaciones (3.5) y (3.6)

$$\frac{Mg}{4} sen\beta \leq f_l \leq \mu_e \frac{Mg}{4} \cos\beta$$

Y reemplazando la ecuación 3.12 en el intervalo anterior:

$$\frac{Mg}{4} sen\beta \leq \frac{T}{R} \leq \frac{Mg}{8} (3\mu_e \cos\beta - sen\beta) \qquad (3.13)$$

Este intervalo depende del ángulo “ β ”, y analizando los límites mínimo y máximo se halla que el ángulo máximo que se puede subir sin deslizar es aproximadamente $\beta = 41^{\circ}$. Por lo tanto, se propone la estructura (ver Figura 5) para poder cruzar la losa de pavimento, la cual deberá ir a ambos lados de la losa que se quiera cruzar. Con estas condiciones se puede continuar con el desplazamiento del vehículo.

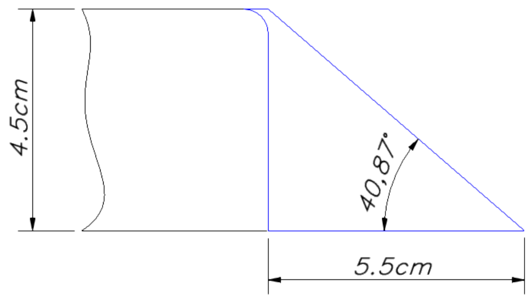


Figura 5 Rampa para subir a la losa. Fuente: Elaboración propia

Ahora se pueden evaluar los siguientes datos:

$M = 15kg$
$\beta = 41^{\circ}$
$g = 9.81 m/s^{2}$
$\mu_{e} = 0.9$(coeficiente entre caucho y pavimento)
$R = 0.06m$

$$24.13N \leq \frac{T}{R} \leq 25.41N$$

Por tal motivo, el torque requerido se encontraría en el siguiente intervalo:

$$1.45N.m \leq T \leq 1.52N.m$$

Adicionalmente la velocidad mínima deseada es $1km/h \cong 0.3m/s$:

$$w = \frac{V}{R} = \frac{0.3}{0.06} = 5rad/s = 47.75rpm$$

Se cambian las unidades del torque para encontrar seleccionar el motor

$$205.34oz - in \leq T \leq 215.25oz - in$$

Con los valores de torque y velocidad angular se busca el motor apropiado.

ANEXO G. CÁLCULOS ELECTRÓNICOS

Los cálculos electrónicos se dividirán en sección de control y sección de potencia para verificar si es necesario el empleo de baterías por separado o será suficiente el empleo de una sola.

- Sección de control

Tabla 4 Consumo de los componentes de la sección de control. Fuente: Elaboración propia

Componente	Consumo de corriente
Raspberry pi 2	0.7 A
Arduino Mega 2560 (20 mA por pin)	0.4 A
Módulo GY-283 (x3)	900 uA
Cámara web	0.5 A
Módulo Flir	0.11 A
Adaptador inalámbrico USB	0.5 A
Driver Roboclaw (x2)	0.18A

En la Tabla 4 se observa que el Raspberry pi es el componente que mayor corriente consume, sin embargo, falta aclarar que este controlador alimenta a los siguientes componentes: Cámara web, Módulo Flir, Adaptador inalámbrico USB. Y la carga máxima que puede circular por el mismo es de 2A (solo se llega hasta 1.81A). Sumando todos los demás consumos de corriente y tomando en cuenta la consideración anterior se obtiene un consumo total: 2 + 0.4 + 0.18 =2.58 A

- Sección de potencia

Se realizan los cálculos de potencia para los actuadores: motor DC y servomotor. En ambos casos se utiliza un factor de eficiencia de 0.8 en la conversión entre potencia eléctrica a mecánica: $T * w = 0.8 * V * I$.

- Motor DC (T=1.11 Nm, w=5 rad/s, V=12 V)

$$1.11 * 5 = 0.8 * 12 * I$$
$$I = 0.58A$$

- Servomotor (T=0.00469 Nm, w=1.047 rad/ 0.12s=8.725rad/s, V=4.8 V)

$$0.00469*8.725 = 0.8*4.8*I$$
$$I = 0.01A$$

En total se tienen 4 motores DC y un servomotor, entonces el consumo total de la sección de potencia sería: 4*0.58+0.01=2.33 A.

- Corriente total del sistema: 2.58+2.33=4.91 A

Dado que el consumo del servomotor es bajo, este será conectado al Arduino Mega y teniendo presentes los voltajes y corrientes que se deben tener, se muestra la siguiente tabla que divide a los componentes respecto a la batería a emplear.

Tabla 5 Consumo total del sistema con designación de baterías. Fuente: Elaboración propia

Componente	Consumo total	Batería	Duración estimada
Raspberry pi	2 A, 5 V	8000 mAh 5V	4h
Cámara web			
Módulo Flir			
Antena USB			
Arduino Mega 2560	2.91 A, 12V	10000 mAh 12V	3.44h
Módulo GY-283 (x3)			
Driver Roboclaw (x2)			
Mini servo			
Motor DC (x4)			

Como se puede observar en la Tabla 5 se decidió dividir los componentes para no sobrecargar los controladores. Además, se cumplen con los requerimientos deseados de duración del equipo. Se busca una duración más prolongada de la autonomía del sistema para evitar que no se pueda volver a una posición segura después de haber realizado una supervisión de 2 horas.

❖ Sistema de carga

Una vez terminada la tarea de supervisión se necesita recargar las baterías para asegurar otra supervisión de 2 horas. En la siguiente tabla (ver Tabla 6) se indican los requerimientos para poder cargar cada batería.

Tabla 6 Sistema de carga de las baterías del sistema. Fuente: Elaboración propia

Batería	Sistema de carga
Li-Polímero (8000mAh)	DC 5V/1.5A
Li-ion (10000mAh)	DC 12,6V/3A

La primera batería mencionada en la Tabla 6 posee una entrada micro USB y viene con un cable con puerto USB y micro USB (ver Figura 6) para poder cargar la batería utilizando un cargador de celular convencional que presente la salida de DC 5V/1.5A.

En el caso de la segunda batería se necesita un cargador exclusivo de baterías Li-ion por recomendación del fabricante. Este cargador (ver Figura 7)ya viene incluido con el equipo y ofrece una salida de DC 12,6V/3A.

Figura 6 Cable de batería Li-Polímero (8000mAh) [2]

Figura 7 Cargador de batería Li-ion (10000mAh) [1]

ANEXO H. TABLA DE VISCOSIDADES

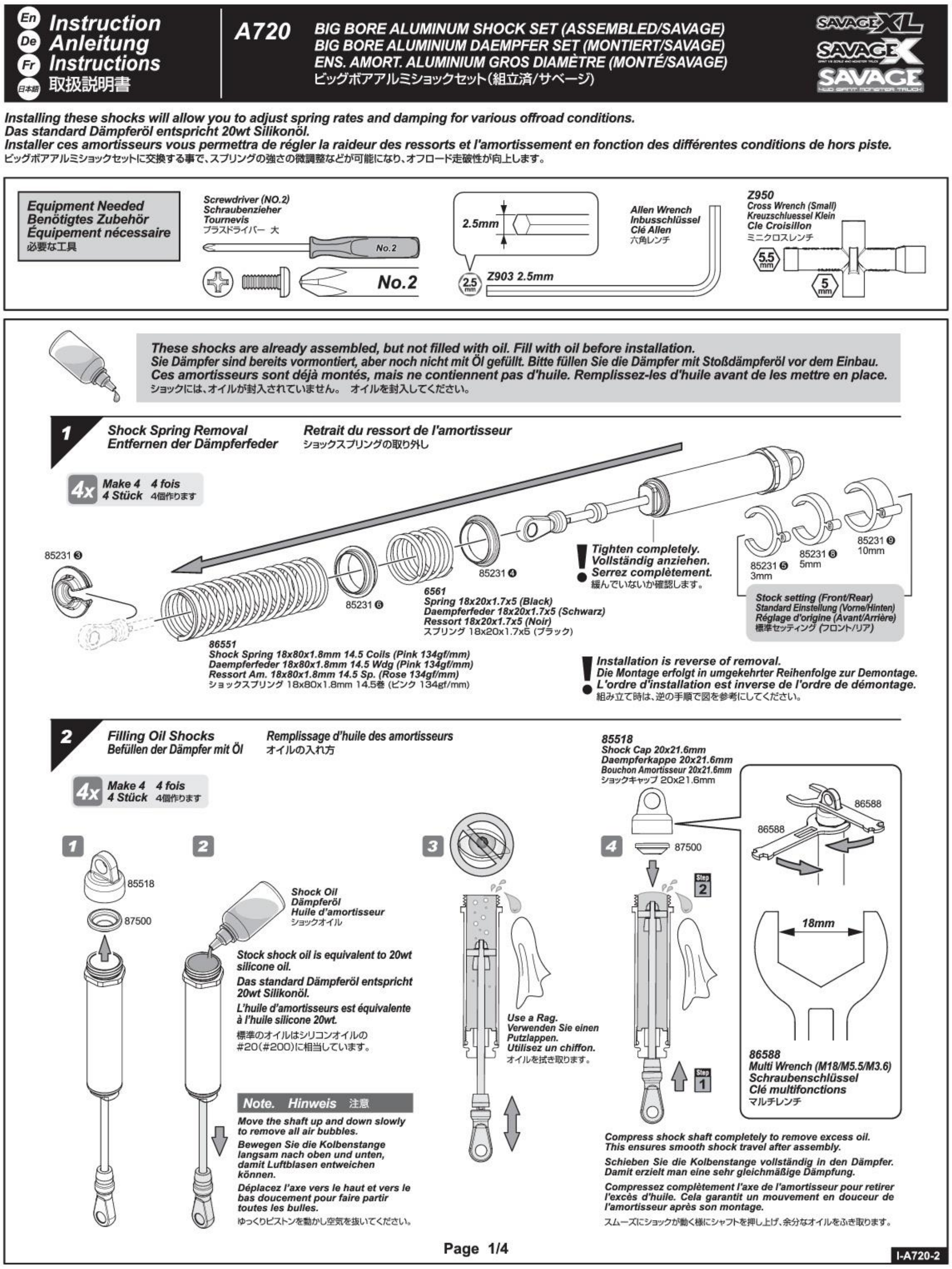
Tabla 7 Tabla de viscosidades de la distribuidora Team Durango [3]

shock oil comparison chart

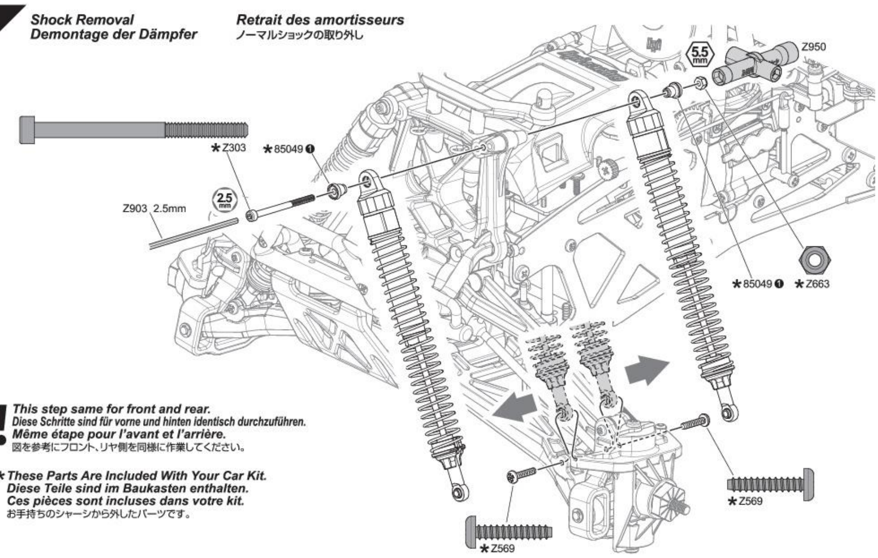
	Durango	LOSI	AE	XRAY	KYOSHO	TRINITY
	cSt	wt (cts)	wt (cts)	cst	cts	cts
cSt	100	15 (110)	10 (108)	106		
	150	17.5 (158)	15 (154)	179		
	200		20 (208)	248		
	250	20 (243)		292	244	
	300	25 (294)	25 (286)	354	302	
	350	27.5 (345)	30 (373)	381	351	30 (337)
	400	30 (381)		441	411	35 (376)
	450	35 (459)	35 (454)	475		
	500	37.5 (477)	40 (525)	542	506	40 (505)
	550	40 (546)				
	600			625		45 (597)
	650	45 (657)				50 (658)
	700		50 (707)	702		

ANEXO I. HOJAS TÉCNICAS

I.1 Hoja técnica de ensamblaje del sistema de suspensión. Fuente: SAVAGEXL



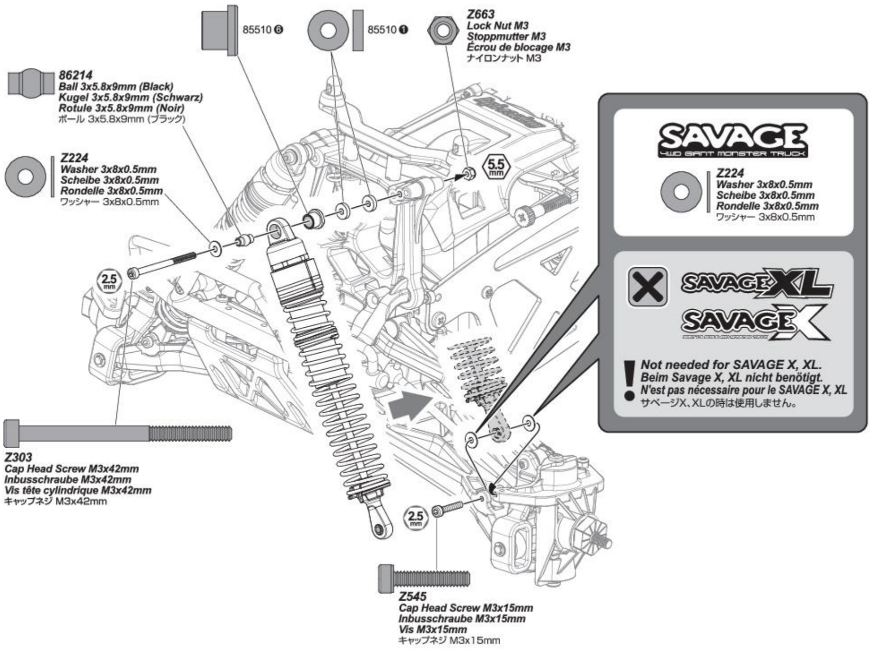
3 Shock Removal / Demontage der Dämpfer / Retrait des amortisseurs / ノーマルショックの取り外し



This step same for front and rear.
Diese Schritte sind für vorne und hinten identisch durchzuführen.
Même étape pour l'avant et l'arrière.
図を参考にフロント、リヤ側を同様に作業してください。

*** These Parts Are Included With Your Car Kit.**
Diese Teile sind im Baukasten enthalten.
Ces pièces sont incluses dans votre kit.
お手持ちのシャーシから外したパーツです。

4 BIG BORE ALUMINUM SHOCK installation / Montage der Big Bore Aluminium Dämpfer / Mise En Place Des Amortisseurs Aluminium Gros Diamètre / アルミショックの取り付け



Shock Maintenance / Dämpferwartung / Entretien des amortisseurs / ショックのメンテナンス

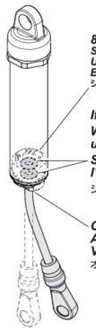
Look for any damaged parts.
Schauen Sie nach defekten Teilen.
Vérifiez qu'il n'y ait pas de pièces endommagées.
各部が傷んでいないか確認してください。

If shock is damaged, shaft is bent, or oil is leaking, you can rebuild the shocks as seen below.

Falls der Dämpfer beschädigt oder die Kolbenstange verbogen ist oder der Dämpfer Öl verliert, können Sie ihn wie unten gezeigt reparieren.

Si l'amortisseur est endommagé, que son axe est tordu ou que de l'huile fuit, vous pouvez les réparer comme cela est indiqué ci-dessous.

各部の傷み、シャフトの曲がり、オイルの漏れなどが合った場合は、下図を参考にメンテナンスしてください。



87500
Bladder 16x5mm (Flat Type)
Daempfermembran 16x5mm (Flach)
Reservoir Souple 16x5mm (Type Plat)
ブラダー 16x5mm (フラットタイプ)

87524
Rubber Bump Stop
Einfederwegbegrenzer Aus Gummi
Butee Caoutchouc
バンプストップラバー

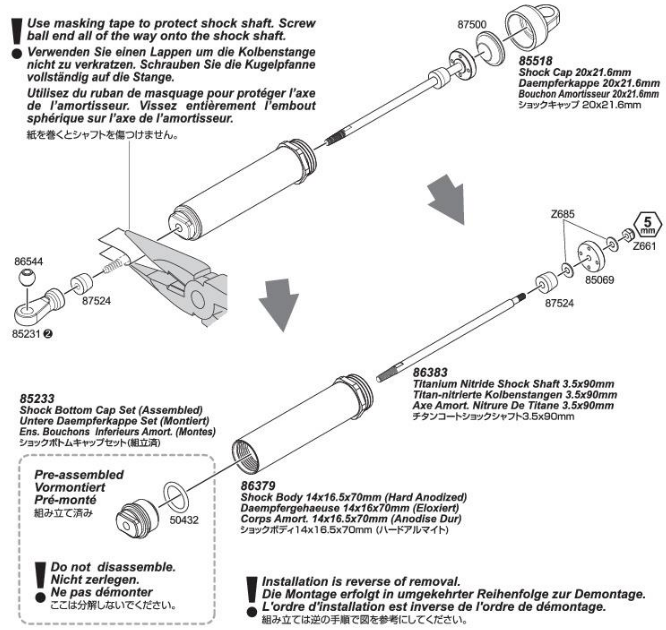
86544
Ball 7x6mm
Kugelkopf 7x6mm
Rotule 7x6mm
ボール 7x6mm

Z661
Lock Nut M2.6
Stoppmutter M2.6
EÉcrou de blocage M2.6
ナイロンナット M2.6

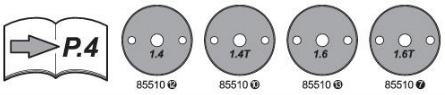
Z685
Washer 2.7x6.7x0.5mm
Scheibe 2.7x6.7x0.5mm
Rondelle 2.7x6.7x0.5mm
ワッシャー 2.7x6.7x0.5mm

85069
Precision Piston 1.5x4 Holes (White)
Kolbenplatte 1.5x4 Loecher (Weiss)
Piston Précision 1.5x4 Trous (Blanc)
プレシジョンピストン 1.5x4穴(ホワイト)

50432
O-Ring S-12 (Black)
O-RING S-12 (SCHWARZ)
JOINT TORIQUE S-12 (NOIR)
Oリング S-12 (ブラック)



Installation is reverse of removal.
Die Montage erfolgt in umgekehrter Reihenfolge zur Demontage.
L'ordre d'installation est inverse de l'ordre de démontage.
組み立ては逆の手順で図を参考にしてください。



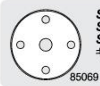
Refer to page 4 for optional piston information.
Schauen Sie auf Seite 4 für weitere Informationen zu den Kolbenplatten.
Reportez-vous à la page 4 pour y trouver des informations supplémentaires sur les pistons.
オプションピストン(黒)を使用するときはP4を参考にしてください。

Shock Piston setting / Réglage du piston de l'amortisseur
Auswahl der Kolbenplatten / ダンパーピストンセッティング

See below for shock piston information. Stock (White) piston is recommended for most applications.
Untenstehend finden Sie Informationen zu den Kolbenplatten. Die standard-Kolbenplatte (weiß) wird für die meisten Strecken empfohlen.
Vous trouverez ci-dessous des informations sur le piston de l'amortisseur. Le piston d'origine (blanc) est conseillé pour la plupart des utilisations.
下図を参考にセッティングしてください。キット標準ピストンの使用をお勧めします。

Stock setting / Réglage d'origine
Standard Einstellung / 標準セッティング

Good for most surfaces
Passend für die meisten Untergründe
Convient à la plupart des surfaces
滑りやすい路面、悪路、ジャンプ、すべての路面に適しています。



Oil weight
Öl-Vistkosität
Viscosité de l'huile
オイルの硬さ

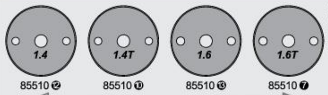
#10(86951) ***#20**(86953) **#30**(86955) **#40**(86957) **#50**(86959)

You can use #10(thin) to #50(thick) oil.
Sie können #10 (dünnflüssig) bis #50 (dickflüssig) Öl verwenden.
Vous pouvez utiliser de l'huile de viscosité allant de 10 (fluide) à 50 (épaisse).
オイルは、#10(やわらかめ)から#50(固めの)の間でセッティングしてください。

***Stock shock oil is equivalent to 20wt silicone oil.**
Das Dämpferöl entspricht 20wt Silikonöl.
L'huile d'origine des amortisseurs est équivalente à l'huile silicone 20wt.
標準のオイルはシリコンオイルの#20(#200)に相当しています。

High traction surface setting / Réglage pour une surface à forte accroche
Einstellung für griffigen Untergrund / ハイグリップ路面セッティング

Stiff setting for high traction surfaces (Good forward traction)
Harte Abstimmung für griffigen Untergrund (gute Beschleunigung)
Réglage raide pour les surfaces à forte accroche (bonne traction vers l'avant)
ハイグリップ路面でサスペンションをあまり動かさないセッティング(車が前に進むセッティング)。



Option piston set (Black)
Optionale Kolbenplatten (schwarz)
Ensemble de pistons optionnels (noirs)
オプションピストンセット(黒)

Stiff damping
Harte Dämpfung
Amortissement plus raide
ダンパーが効く

Soft damping
Weiche Dämpfung
Amortissement plus souple
ダンパー効果が少ない

!
Using thin oil makes the truck bottom out easily.
Bei zu dünnem Öl kann der Truck leicht durchschlagen.
Avec de l'huile fluide, les amortisseurs peuvent facilement arriver en butée basse.
ピストンに対してオイルがやわらかいとフルボトムしてしまいます。

#30 oil is recommended.
#30 Öl wird empfohlen.
L'huile de viscosité 30 est conseillée.
オイルは#30をお勧めします。

Spare Parts / Pièces détachées
Ersatzteile / スペアパーツ

Number Artikel# Référence 品番	Bag qty. Anzahl Quantité 入数	Description Bezeichnung Description 品名	Number Artikel# Référence 品番	Bag qty. Anzahl Quantité 入数	Description Bezeichnung Description 品名	Number Artikel# Référence 品番	Bag qty. Anzahl Quantité 入数	Description Bezeichnung Description 品名
6561	x2	SPRING 18x20x1.7x5 (BLACK) DAEMPFERFEDER 18x20x1.7x5 (SCHWARZ) RESSORT 18x20x1.7x5 (NOIR) スプリング 18x20x1.7x5 (ブラック)	85518	x2	SHOCK CAP 20x21.6mm DAEMPFERKAPPE 20x21.6mm BOUCHON AMORTISSEUR 20x21.6mm ショックキャップ 20x21.6mm	87524	x4	RUBBER BUMP STOP EINFEDERWEGBEGRENZER AUS GUMMI BUTÉE CAOUTCHOUC バンプストップラバー
50432	x5	O-Ring S-12 (BLACK) O-RING S-12 (SCHWARZ) JOINT TORIQUE S-12 (NOIR) Oリング S-12 (ブラック)	86214	x4	BALL 3x5.8x9mm (BLACK) KUGEL 3x5.8x9mm (SCHWARZ) ROTULE 3x5.8x9mm (NOIR) ボール 3x5.8x9mm (ブラック)	Z224	x10	WASHER M3x8mm UNTERLAGSCHEIBE M3x8mm RONDELLE M3x8mm NOIR ワッシャーM3x8mm
75075	x12	SILICONE O-RING S4 (3.5x2mm) SILIKON O-RING S4 (3.5x2mm) JOINT TORIQUE SILICONE S4 (3.5x2mm) シリコン O-リング S4 (3.5x2mm)	86379	x2	SHOCK BODY 14x16.5x70mm (HARD ANODIZED) DAEMPFERGEHAEUSE 14x16x70mm (ELOXIERT) CORPS AMORT. 14x16.5x70mm ((ANODISÉ)) ショックボディ14x16.5x70mm (ハードアルマイト)	Z303	x6	CAP HEAD SCREW M3x42mm INBUSSCHRAUBE M3x42mm VIS TÊTE CYLINDRIQUE M3x42mm キャップネジ M3x42mm
85069	x2	PRECISION PISTON 1.5x4 HOLES (WHITE) KOLBENPLATTE 1.5x4 LOECHER (WEISS) PISTON PRÉCISION 1.5X4 TROUS (BLANC) プレシジョンピストン 1.5x4穴(ホワイト)	86383	x2	TITANIUM NITRIDE SHOCK SHAFT 3.5x90mm TITAN-NITRIERTE KOLBENSTANGEN 3.5x90mm AXE AMORT. NITRURE DE TITANE 3.5x90mm チタンコートショックシャフト3.5x90mm	Z545	x6	CAP HEAD SCREW M3x15mm INBUSSCHRAUBE M3x15mm VIS TÊTE CYLINDRIQUE M3x15mm キャップネジ M3x15mm
85231	x1	SHOCK SPACER PARTS SET DAEMPFER SPACER SET JEU PIÈCES ENTRETOISE AMORTISSEUR ショックスペーサーパーツセット	86544	x4	BALL 7x6mm KUGELKOPF 7x6mm ROTULE 7x6mm ボール 7x6mm	Z661	x4	LOCK NUT M2.6 STOPPMUTTER M2.6 ECROU NYLON M2.6 ナイロンナット M2.6
85233	x2	SHOCK BOTTOM CAP SET (ASSEMBLED) UNTERE DAEMPFERKAPPE SET (MONTIERT) ENS. BOUCHONS INFÉRIEURS AMORT. (MONTÉS) ショックボトムキャップセット(組立済)	86551	x2	SHOCK SPRING 18x80x1.8mm 14.5 COILS (PINK 134gF/mm) DAEMPFERFEDER 18x80x1.8mm 14.5 WDG (PINK 134gF/mm) RESSORT AM. 18x80x1.8mm 14.5 SP. (ROSE 134gF/mm) ショックスプリング 18X80X1.8mm 14.5巻 (ピンク 134gF/mm)	Z663	x6	LOCK NUT M3 STOPPMUTTER M3 ÉCROU DE BLOCAGE M3 ナイロンナットM3
85510	x1	SHOCK PARTS SET DAEMPFER TEILE SET JEU PIECES AMORTISSEUR ショックパーツセット	87500	x4	BLADDER 16x5mm (FLAT TYPE) DAEMPFERMEMBRAN 16x5mm (FLACH) RÉSERVOIR SOUPLE 16x5mm (TYPE PLAT) ブラダー 16x5mm (フラットタイプ)	Z685	x10	WASHER 2.7x6.7x0.5mm UNTERLAGSCHEIBE 2.7x6.7x0.5mm RONDELLE 2.7x6.7x0.5mm ワッシャー 2.7x6.7x0.5mm

Optional Parts / Pièces optionnelles
Tuningteile / オプションパーツ

Number Artikel# Référence 品番	Bag qty. Anzahl Quantité 入数	Description Bezeichnung Description 品名	Number Artikel# Référence 品番	Bag qty. Anzahl Quantité 入数	Description Bezeichnung Description 品名	Number Artikel# Référence 品番	Bag qty. Anzahl Quantité 入数	Description Bezeichnung Description 品名
86549	x2	SHOCK SPRING 18x80x1.5mm 12.5 COILS (BLUE 71gF/mm) DAEMPFERFEDER 18x80x1.8mm 12.5 WDG (BLAU 71gF/mm) RESSORT AM. 18x80x1.5mm 12.5 SP. (BLEU 71gF/mm) ショックスプリング 18X80X1.5mm 12.5巻 (ブルー 71gF/mm)	86555	x2	SHOCK SPRING 18x80x1.8mm 10.5 COILS (RED 196gF/mm) DAEMPFERFEDER 18x80x1.8mm 10.5 WDG (ROT 196gF/mm) RESSORT AM. 18x80x1.8mm 10.5 SP. (ROUGE 196gF/mm) ショックスプリング 18X80X1.8mm 10.5巻 (レッド 196gF/mm)	86957	x1	PRO SILICONE SHOCK OIL 40wt (60cc) SILIKON-DAEMPFER-OEL 40wt (60ccm) HUILE AMORTISSEURS PRO 40wt (60ml) PRO シリコンショックオイル 40wt (60cc)
86550	x2	SHOCK SPRING 18x80x1.5mm 10.5 COILS (SILVER 89gF/mm) DAEMPFERFEDER 18x80x1.5mm 10.5 WDG(SILBER 89gF/mm) RESSORT AM. 18x80x1.5mm 10.5 SP. (ARGENT 89gF/mm) ショックスプリング 18X80X1.5mm 10.5巻 (シルバー 89gF/mm)	86951	x1	PRO SILICONE SHOCK OIL 10wt (60cc) SILIKON-DAEMPFER-OEL 10wt (60ccm) HUILE AMORTISSEURS PRO 10wt (60ml) PRO シリコンショックオイル 10wt (60cc)	86959	x1	PRO SILICONE SHOCK OIL 50wt (60cc) SILIKON-DAEMPFER-OEL 50wt (60ccm) HUILE AMORTISSEURS PRO 50wt (60ml) PRO シリコンショックオイル 50wt (60cc)
86553	x2	SHOCK SPRING 18x80x1.8mm 12.5 COILS (WHITE 159gF/mm) DAEMPFERFEDER 18x80x1.8mm 12.5 WDG(WEISS 159gF/mm) RESSORT AM. 18x80x1.8mm 12.5 SP. (BLANC 159gF/mm) ショックスプリング 18X80X1.8mm 12.5巻 (ホワイト 159gF/mm)	86953	x1	PRO SILICONE SHOCK OIL 20wt (60cc) SILIKON-DAEMPFER-OEL 20wt (60ccm) HUILE AMORTISSEURS PRO 20wt (60ml) PRO シリコンショックオイル 20wt (60cc)			
86554	x2	SHOCK SPRING 18x80x1.8mm 11.5 COILS (YELLOW 177gF/mm) DAEMPFERFEDER 18x80x1.8mm 11.5 WDG (GELB 177gF/mm) RESSORT AM. 18x80x1.8mm 11.5 SP. (JAUNE 177gF/mm) ショックスプリング 18X80X1.8mm 11.5巻 (イエロー 177gF/mm)	86955	x1	PRO SILICONE SHOCK OIL 30wt (60cc) SILIKON-DAEMPFER-OEL 30wt (60ccm) HUILE AMORTISSEURS PRO 30wt (60ml) PRO シリコンショックオイル 30wt (60cc)			

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HPI Europe
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Derbyshire, DE11 0BB, UK
(44) 01283 229400

I.2 Hojas técnicas sensor Flir. Fuente: FLIR

FLIR LEPTON® Long Wave Infrared (LWIR) Datasheet

General Description

Lepton® is a complete long-wave infrared (LWIR) camera module designed to interface easily into native mobile-device interfaces and other consumer electronics. It captures infrared radiation input in its nominal response wavelength band (from 8 to 14 microns) and outputs a uniform thermal image.

Features

- Dimensions:

  8.5 x 11.7 x 5.6 mm (without socket),
  10.6 x 11.7 x 5.9 mm (including socket)

- 51-deg HFOV, 63.5-deg diagonal (f/1.1 silicon doublet)
- LWIR sensor, wavelength 8 to 14 µm
- 80 (h) × 60 (v) active pixels
- Thermal sensitivity <50 mK
- Integrated digital thermal image processing functions, including automatic thermal environment compensation, noise filters, non-uniformity correction, and gain control
- Optional temperature-stable output to support radiometric processing
- Export compliant frame rate (< 9 Hz)
- MIPI and SPI video interfaces
- Two-wire I2C-like serial-control interface
- Uses standard cell-phone-compatible power supplies: 2.8V to sensor, 1.2V to digital core, and flexible IO from 2.5V to 3.1V
- Fast time to image (< 0.5 sec)
- Low operating power, nominally 150 mW (< 160 mW over full temperature range)
- Low power standby mode
- RoHS compliant
- 32-pin socket interface to standard Molex or similar side-contact connector

Applications

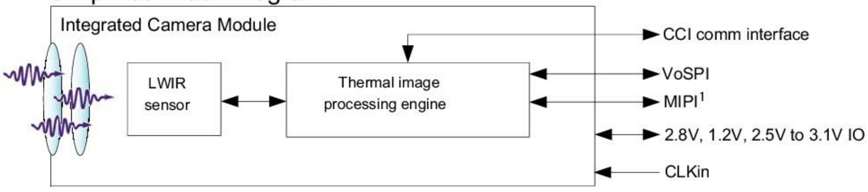
- Mobile phones
- Gesture recognition
- Building automation
- Thermal imaging
- Night vision

Information on this page is subject to change without notice. Shipping: CIP per INCOTERMS 2010.

FLIR® | The World's Sixth Sense™

FLIR LEPTON® Long Wave Infrared (LWIR) Datasheet

Simplified Block Diagram



1. Feature anticipated in a future product release

Note: All specifications subject to change without notice

FLIR LEPTON® Long Wave Infrared (LWIR) Datasheet

Contents

FLIR LEPTON® Long Wave Infrared (LWIR) Datasheet

Revision History

Revision	Date	Description of Change
1.0	5/1/2014	Initial release
1.1	7/7/2014	Updated to cover new features of the Lepton 2.0 release.
1.2	9/23/2014	Minor corrections
1.2.3	10/15/2014	Formatting and minor corrections
1.2.5	1/21/2015	Fixed an error in Table 7

Contact Us

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http://www.FLIR.com

References

Lepton Software Interface Description Document (IDD) - Public. Document #110-0144-03.

FLIR LEPTON® Long Wave Infrared (LWIR) Datasheet

1.0 Device Overview

Lepton is an infrared camera system that integrates a fixed-focus lens assembly, an 80x60 long-wave infrared (LWIR) microbolometer sensor array, and signal-processing electronics. Easy to integrate and operate, Lepton is intended for mobile devices as well as any other application requiring very small footprint, very low power, and instant-on operation. Lepton can be operated in its default mode or configured into other modes through a command and control interface (CCI).

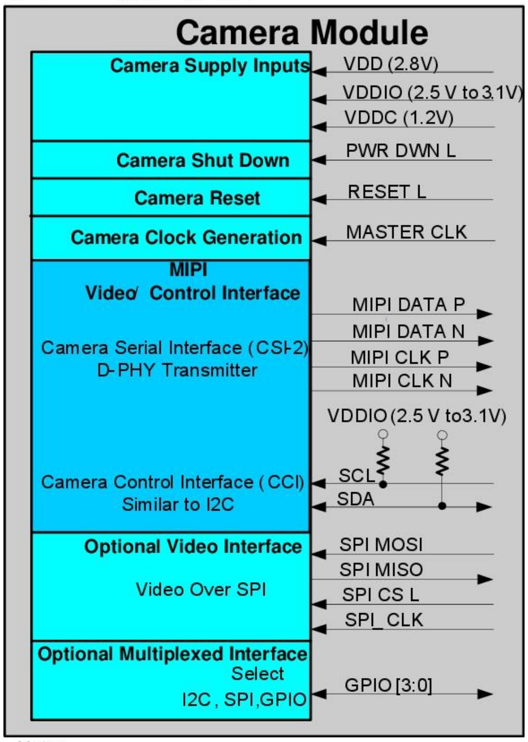
Figure 1 shows a view of the Lepton camera, both as standalone and mounted in a socket.

Figure 1 Lepton Camera (with and without socket)

2.0 Applications

A typical application using the Lepton camera module is shown in *Figure 2*.

Figure 2 Typical Application



Note:

(1) The CCI pullup resistors are required and must be handled outside the camera module by a host controller

(2) MIPI is not currently supported

3.0 Key Specifications

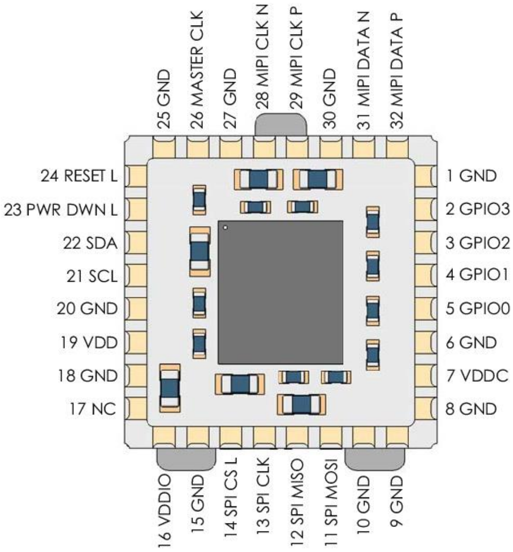
The key specifications of the Lepton camera module are listed in *Table 1*. See *Figure 3 on page 8* for the corresponding package pinout diagram.

Table 1 Key Specifications

Specification	Description
Overview	
Function	Passive thermal imaging module for mobile equipment
Sensor technology	Uncooled VOx microbolometer
Spectral range	Longwave infrared, 8 µm to 14 µm
Array format	80 × 60, progressive scan
Pixel size	17 µm
Effective frame rate	8.6 Hz (exportable)
Thermal sensitivity	<50 mK (0.050° C)
Temperature compensation	Automatic. Output image independent of camera temperature (optional mode - see *Radiometry Modes, page 22*).
Non-uniformity corrections	Automatic (with scene motion)
FOV - horizontal	51°
FOV - diagonal	63.5°
Depth of field	10 cm to infinity
Lens type	f/1.1 silicon doublet
Output format	User-selectable 14-bit, 8-bit (AGC applied)
Solar protection	Integral
Electrical	
Input clock	25-MHz nominal, CMOS IO Voltage Levels (see *Operating States and Modes, page 13*)
Video data interface	Video over SPI (see *VoSPI Channel, page 28*)
Control port	CCI (I2C-like), CMOS IO Voltage Levels (see *Command and Control Interface, page 27*)
Input supply voltage (nominal)	2.8 V, 1.2 V, 2.5 V to 3.1 V IO (see *DC and Logic Level Specifications, page 45*)
Power dissipation	Nominally 150 mW at room temperature (operating), 4 mW (standby)
Mechanical	
Package dimensions – socket version	8.5 × 11.7 × 5.6 mm (w × l × h)
Weight	0.55 grams (typ)
Environmental	
Optimum operating temperature range	-10 °C to +65 °C
Non-operating temperature range	-40 °C to +80 °C
Shock	1500 G @ 0.4 ms

4.0 Lepton Camera Module Pinout Diagram

Figure 3 Pinout Diagram (viewed from back of camera module)



5.0 Pin Descriptions

The Lepton camera module pin descriptions are shown in *Table 2*.

Table 2 Lepton Camera Module Pin Descriptions

Pin #	Pin Name	Signal Type	Signal Level	Description
1, 6, 8, 9, 10, 15, 18, 20, 25, 27, 30	GND	Power	GND	Common Ground
2	GPIO3	IN/OUT	VDDIO	The GPIO multiplexed functions are optional and configurable. The GPIO pins are unused in the current release.
3	GPIO2	IN/OUT	VDDIO	
4	GPIO1	IN/OUT	VDDIO	
5	GPIO0	IN/OUT	VDDIO	
7	VDDC	Power	1.2V	Supply for MIPI Core, PLL, ASIC Core (1.2V +/- 5%)
11	SPI_MOSI	IN	VDDIO	Video Over SPI Slave Data In (see *VoSPI Channel, page 28*)
12	SPI_MISO	OUT	VDDIO	Video Over SPI Slave Data Out (see *VoSPI Channel, page 28*)
13	SPI_CLK	IN	VDDIO	Video Over SPI Slave Clock (see *VoSPI Channel, page 28*)
14	SPI_CS_L	IN	VDDIO	Video Over SPI Slave Chip Select, active low (see *VoSPI Channel, page 28*)
16	VDDIO	Power	2.5 V — 3.1 V	Supply used for System IO
17	No connection	—	—	—
19	VDD	Power	2.8V	Supply for Sensor (2.8V +/- 3%).
21	SCL	IN	VDDIO	Camera Control Interface Clock, I2C compatible
22	SDA	IN/OUT	VDDIO	Camera Control Interface Data, I2C compatible

Table 2 Lepton Camera Module Pin Descriptions *(continued)*

Pin #	Pin Name	Signal Type	Signal Level	Description
23	PWR_DWN_L	IN	VDDIO	This active low signal shuts down the camera
24	RESET_L	IN	VDDIO	This active low signal resets the camera
26	MASTER_CLK	IN	VDDIO	ASIC Master Clock Input (see ***Operating States and Modes, page 13***)
28	MIPI_CLK_N	OUT	Diff Pair	MIPI Digital Video Clock Negative[1]
29	MIPI_CLK_P	OUT	Diff Pair	MIPI Digital Video Clock Positive[1]
31	MIPI_DATA_N	OUT	Diff Pair	MIPI Digital Video Data Negative[1]
32	MIPI_DATA_P	OUT	Diff Pair	MIPI Digital Video Data Positive[1]

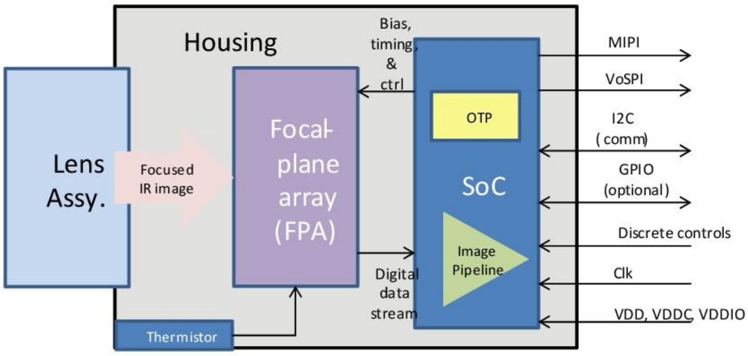
Note(s)

1. MIPI is not currently supported. Let the MIPI pins float.

6.0 System Architecture

A simplified architectural diagram of the Lepton camera module is shown in ***Figure 4***.

Figure 4 Lepton Architecture



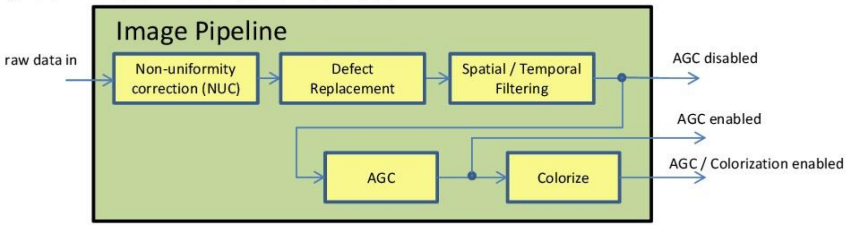
The lens assembly focuses infrared radiation from the scene onto an 80x60 array of thermal detectors with 17-micron pitch. Each detector element is a vanadium-oxide (VOx) microbolometer whose temperature fluctuates in response to incident flux. The change in temperature causes a proportional change in each microbolometer's resistance. VOx provides a high temperature coefficient of resistance (TCR) and low 1/f noise, resulting in excellent thermal sensitivity and stable uniformity. The microbolometer array is grown monolithically on top of a readout integrated circuit (ROIC) to comprise the complete focal plane array (FPA). Once per frame, the ROIC senses the resistance of each detector by applying a bias voltage and integrating the resulting current for a finite period of time called the integration period.

The serial stream from the FPA is received by a system on a chip (SoC) device, which provides signal processing and output formatting. The image pipeline is defined in ***Video Pipeline, page 12***.

7.0 Video Pipeline

A block diagram of the video pipeline is shown in *Figure 5*.

Figure 5 Lepton Video Pipeline Block Diagram



The video pipeline includes non-uniformity correction (NUC), defect replacement, spatial and temporal filtering, automatic gain correction (AGC), and colorization.

7.1 NUC

The non-uniformity correction (NUC) block applies correction terms to ensure that the camera produces a uniform output for each pixel when imaging a uniform thermal scene. Factory-calibrated terms are applied to compensate for temperature effects, pixel response variations, and lens-illumination roll-off. To compensate for temporal drift, the NUC block also applies an offset term that can be periodically updated at runtime via a process called flat-field correction (FFC). The FFC process is further described in ***FFC States, page 17***.

7.2 Defect Replacement

The defect-replacement block substitutes for any pixels identified as defective during factory calibration or during runtime. The replacement algorithm assesses the values of neighboring pixels and calculates an optimum replacement value. The typical number of defective pixels is ≤1.

7.3 Spatial / Temporal Filtering

The image pipeline includes a number of sophisticated image filters designed to enhance signal-to-noise ratio (SNR) by eliminating temporal noise and residual non-uniformity. The filtering suite includes a scene-based non-uniformity correction (SBNUC) algorithm which relies on motion within the scene to isolate fixed pattern noise (FPN) from image content.

7.4 AGC

The AGC algorithm for converting the full-resolution (14-bit) thermal image into a contrast-enhanced image suitable for display is a histogram-based non-linear mapping function. See ***AGC Modes, page 25***.

7.5 Colorize

The colorize block takes the contrast-enhanced thermal image as input and generates a 24-bit RGB color output. This feature is anticipated in a future release and is not currently accessible.

8.0 Operating States and Modes

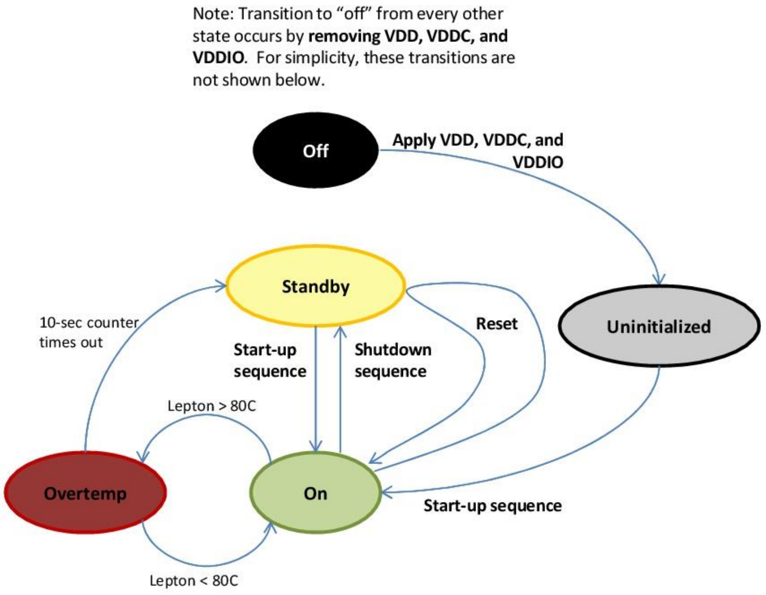
Lepton provides a number of operating states and modes, more completely defined in the sections that follow:

- *Power States, page 13*
- *FFC States, page 17*
- *Telemetry Modes, page 19*
- *Radiometry Modes, page 22*
- *AGC Modes, page 25*
- *Interface Descriptions, page 27*

8.1 Power States

Lepton currently provides five power states. As depicted in the state diagram shown in ***Figure 6***, most of the transitions among the power states are the result of explicit action from the host. The automatic transition to and from the overtemp state is an exception. In the figure, transitions that require specific host-side action are shown in bold. Automatic transitions are not bolded.

Figure 6 State Diagram Showing Transitions among the Five Power States

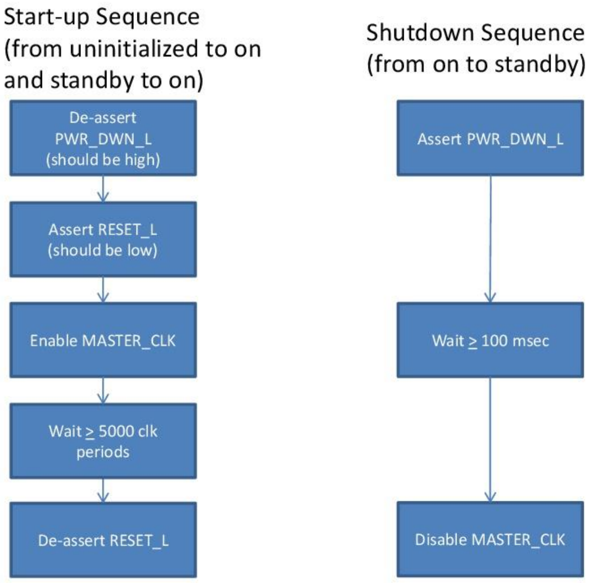


The power states are listed here:

- **Off**: When no voltage is applied, Lepton is in the off state. In the off state, no camera functions are available.
- **Uninitialized**: In the uninitialized state, all voltage forms are applied, but Lepton has not yet been booted and is in an indeterminate state. It is not recommended to leave Lepton in this state as power is not optimized; it should instead be booted to the on-state (and then transitioned back to standby if imaging is not required).
- **On**: In the on state, all functions and interfaces are fully available.
- **Standby**: In the standby state, all voltage forms are applied, but power consumption is approximately 4 mW. In the standby state, no functions are available, but it is possible to transition to the on state via the start-up sequence defined in *Figure 7 on page 16*. The shutdown sequence shown in *Figure 7 on page 16* is the recommended transition back to the standby state. It is also possible to transition between standby and on states via software commands, as further defined in the software IDD.
- **Overtemp**: The overtemp state is automatically entered when the Lepton senses that its temperature has exceeded approximately 80 °C. Upon entering the overtemp state, Lepton enables a “shutdown imminent” status bit in the telemetry line and starts a 10-second counter. If the temperature of the Lepton falls below 80 °C before the counter times out, the “shutdown imminent” bit is cleared and the system transitions back to the on state. If the counter does time out, Lepton automatically transitions to the standby state.

Power sequencing is as shown in *Figure 7*.

Figure 7 Power Sequencing

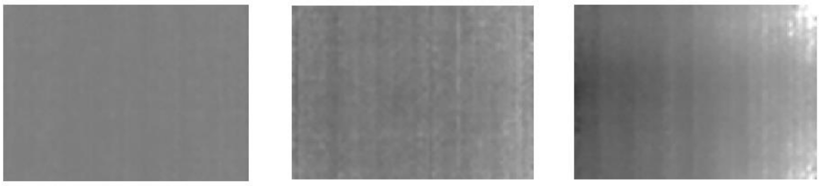


8.2 FFC States

Lepton is factory calibrated to produce an output image that is highly uniform, such as shown in *Figure 8* (a), when viewing a uniform-temperature scene. However, drift effects over long periods of time degrade uniformity, resulting in imagery which appears more grainy (*Figure 8* (b)) and/or blotchy (*Figure 8* (c)). Operation over a wide temperature range (for example, powering on at -10 °C and heating to 65 °C) will also have a detrimental effect on image quality.

For scenarios in which there is ample scene movement, such as most handheld applications, Lepton is capable of automatically compensating for drift effects using an internal algorithm called scene-based non-uniformity correction (scene-based NUC or SBNUC). However, for use cases in which the scene is essentially stationary, such as fixed-mount applications, scene-based NUC is less effective. In those applications, it is recommended to periodically perform a flat-field correction (FFC). FFC is a process whereby the NUC terms applied by the camera's signal processing engine are automatically recalibrated to produce the most optimal image quality. The sensor is briefly exposed to a uniform thermal scene, and the camera updates the NUC terms to ensure uniform output. The entire FFC process takes less than a second.

Figure 8 Examples of Good Uniformity, Graininess, and Blotchiness



(a) Highly uniform image

(b) Grainy image (high-spatial frequency noise)

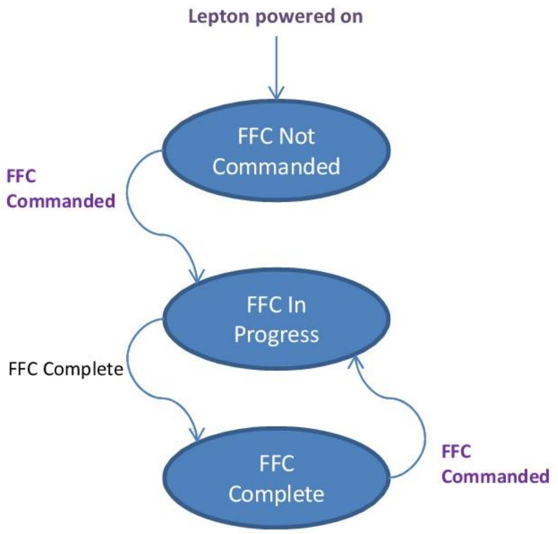
(c) Blotchy image (low-spatial frequency noise)

The current FFC state is provided through the telemetry line. There are three FFC states, as illustrated in *Figure 9 on page 18*:

1. **FFC not commanded** (default): In this state, Lepton applies by default a set of factory-generated FFC terms.
2. **FFC in progress**: Lepton enters this state when FFC is commanded. The default FFC duration is nominally 23 frames.
3. **FFC complete**: Lepton automatically enters this state whenever FFC is completed.

Lepton also provides an "FFC desired" flag in the telemetry line. The "FFC desired" flag is asserted at start-up, when a specified period (default = 3 minutes) has elapsed since the last FFC, or when the sensor temperature has changed by a specified value (default = 3 Celsius degrees) since the last FFC. The "FFC desired" flag is intended to indicate to the host to command an FFC at the next possible opportunity.

Figure 9 FFC States



8.3 Telemetry Modes

There are three telemetry modes that affect the video output signal:

- **Telemetry disabled** (default)
- **Telemetry as header**
- **Telemetry as footer**

Explicit commands over the CCI select each mode. The contents and encoding of the telemetry data are shown in *Table 3*. Note that the second and third lines (line B and line C) are reserved for future growth and contain no information at this time.

Table 3 Telemetry Data Content and Encoding

Telemetry Row	Word start	Word End	Number of 16-bit Words	Name	Notes
A	0	0	1	Telemetry Revision	Format = major (byte 1), minor rev (byte 0).
A	1	2	2	Time Counter	32 bit counter in units of msec elapsed since boot-up
A	3	4	2	Status Bits	See *Table 4 on page 21*
A	5	12	8	Module serial #	
A	13	16	4	Software revision	
A	17	19	4	Reserved	
A	20	21	2	Frame Counter	32-bit counter of output frames
A	22	22	1	Frame Mean	
A	23	23	1	FPA Temp	In counts (prior to conversion to Kelvin)
A	24	24	1	FPA Temp	In Kelvin x 100
A	25	25	1	Housing Temp	In counts (prior to conversion to Kelvin)

Table 3 Telemetry Data Content and Encoding ***(continued)***

Telemetry Row	Word start	Word End	Number of 16-bit Words	Name	Notes
A	26	26	1	Housing Temp	In Kelvin x 100
A	27	28	2	Reserved	
A	29	29	1	FPA Temp at last FFC	Updated every FFC. Units are Kelvin x100
A	30	31	2	Time Counter at last FFC	Updated every FFC. Units are msec
A	32	32	1	Housing temp at last FFC	Updated every FFC. Units are Kelvin x100
A	33	33	1	Reserved	
A	34	37	4	AGC ROI	(top, left, bottom, right)
A	38	38	1	AGC Clip-Limit High	See ***AGC, page 12***
A	39	39	1	AGC Clip-Limit Low	
A	40	73	34	Reserved	
A	74	74	1	Log2 of FFC frames	See ***FFC States, page 17***
A	75	79	5	Reserved	
B	0	79	80	Reserved	
C	0	78	79	Reserved	

Table 4 shows the encoding of the status bits (Telemetry Row A, Words 3 and 4).

Table 4 Status Bit Encoding (Telemetry Row A, words 3 and 4)

Bit start	Bit end	Number of Bits	Name	Notes
0			Reserved	
3	3	1	FFC Desired[1]	0 = FFC not desired 1 = FFC desired
4	5	2	FFC State[1]	Telemetry Revision 8: 00 = FFC never commanded 01 = FFC in progress 10 = FFC complete 11 = undefined Telemetry Revision 9: 00 = FFC never commanded 01 = Reserved 10 = FFC in progress 11 = FFC complete
6	11	6	Reserved	
12	12	1	AGC State	0=Disabled 1=Enabled
13	19	7	Reserved	
20	20	1	Overtemp shut down imminent	Goes true 10 seconds before shutdown (see *Power States, page 13*)
21	31	11	Reserved	

Note(s)

1. See *FFC States, page 17*.

8.4 Radiometry Modes

There are two radiometry modes that affect the video output signal:

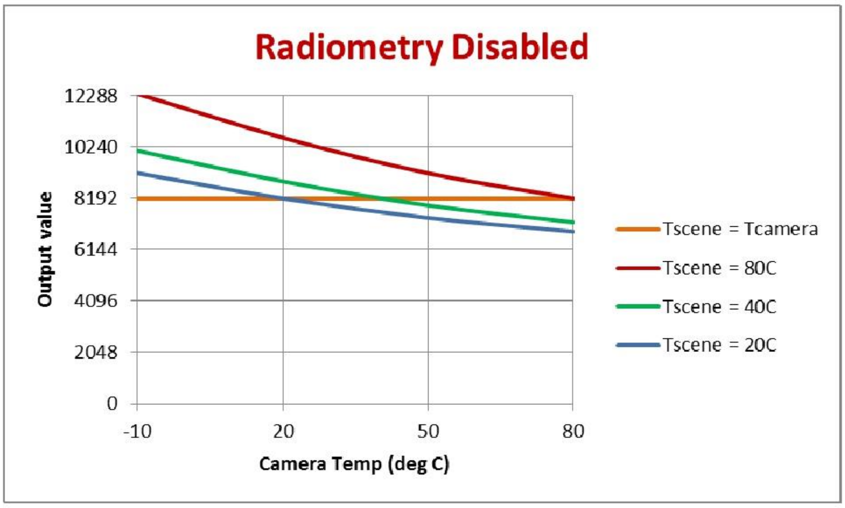
- **Radiometry disabled (default)**
- **Radiometry enabled**

The radiometric modes affect the transfer function between incident flux (scene temperature) and pixel output. From an image-quality standpoint, both radiometry modes produce nearly identical performance (no change in NEDT), and either mode is appropriate for strict imaging applications. However, for applications in which it is intended to convert the Lepton output signal to one proportional to scene temperature, the radiometry-enabled mode is preferred because the conversion is constant over the full operating temperature range of the camera. Note that the following discussion assumes AGC is disabled (see ***AGC Modes, page 25***). If AGC is enabled, the differences between the two radiometry modes are completely obscured by the AGC algorithm. In other words, with AGC enabled, any differences in signal output between radiometry-disabled and radiometry-enabled modes are negligible.

8.4.1 Radiometry Disabled

With radiometry disabled, the output of a given pixel is intended to be near the middle of the 14-bit range (~8192) when viewing a scene with a temperature equal to the temperature of the camera. Furthermore, the responsivity, which is defined as the change in pixel output value for a change in scene temperature, varies over the camera's operating temperature range. The resulting output for three different scene temperatures is illustrated hypothetically in ***Figure 10*** (note that the figure is for illustration purposes and not perfectly representative).

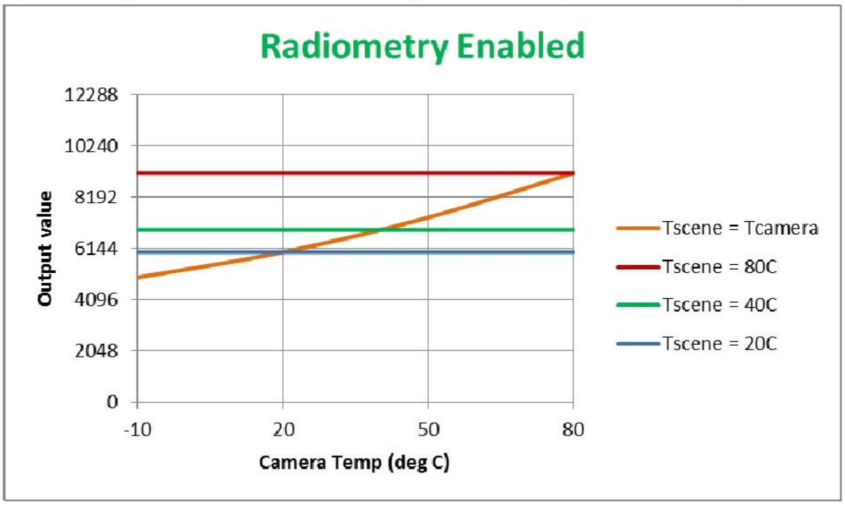
Figure 10 Hypothetical Illustration of Camera Output vs. Camera Temperature in Radiometry-disabled Mode



8.4.2 Radiometry Enabled

With radiometry enabled, Lepton performs internal adjustments to the signal level such that in principle the output is independent of the camera's own temperature. The resulting output for three different scene temperatures is illustrated hypothetically in *Figure 11*. Notice in *Figure 11* that the output is only a function of scene temperature, not camera temperature (again, the figure is for illustration purposes only and not perfectly representative. In practice, there is slight output variation as camera temperature changes, particularly when the temperature change is rapid). Also notice that responsivity is also independent of camera temperature; that is, the difference in output between two different scene temperatures is a constant, as opposed to in *Figure 10 on page 23*, where it decreases with increasing camera temperature.

Figure 11 Hypothetical Illustration of Camera Output vs. Camera Temperature in Radiometry-enabled Mode



8.5 AGC Modes

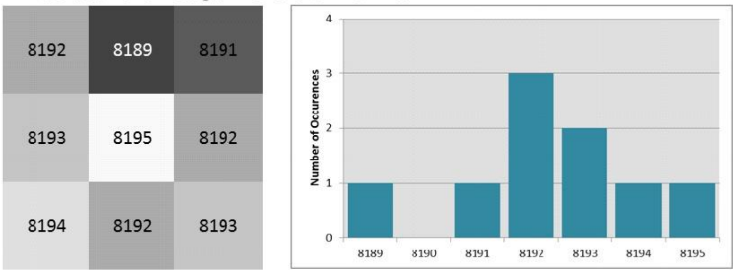
There are two AGC modes:

- **AGC disabled** (default)
- **AGC enabled**

AGC is a process whereby the large dynamic range of the infrared sensor is collapsed to a range more appropriate for a display system. For Lepton, this is a 14-bit to 8-bit conversion. In its most simplistic form, AGC can be a linear mapping from 14-bit to 8-bit; however, a simple linear AGC is generally incapable of providing pleasing imagery in all imaging conditions. For example, when a scene includes both cold and hot regions (for example, a hot object in front of a cold background as illustrated in *Figure 13 on page 26*), linear AGC can produce an output image in which most pixels are mapped to either full black or full white with very little use of the grayshades (8-bit values) in between. Because of this limitation of linear AGC, a more sophisticated algorithm is preferred.

Similar to most AGC algorithms that optimize the use of grayshades, Lepton's is histogram-based. Essentially a histogram counts the number of pixels in each frame that have a given 14-bit value. *Figure 12 on page 25* illustrates the concept for a 3x3 pixel area.

Figure 12 Illustration of a Histogram for a 3x3 Pixel Area



Classic histogram equalization uses the cumulative histogram as a mapping function between 14-bit and 8-bit. The intent is to devote the most grayshades to those portions of the input range occupied by the most pixels. For example, an image consisting of 60% sky devotes 60% of the available grayshades to the sky, leaving only 40% for the remainder of the image. By comparison, linear AGC “wastes” grayshades when there are gaps in the histogram, whereas classic histogram equalization allocates no grayshades to the gaps. This behavior is in principle an efficient use of the available grayshades, but there are a few drawbacks:

- The resulting contrast between an object and a much colder (or hotter) background can be rendered poor by the fact the algorithm “collapses” the separation between such that the object is only 1 grayshade above the background. This phenomenon is illustrated in *Figure 13*.

- Too much emphasis can be placed on background clutter, particularly when a mostly isothermal background comprises a large fraction of the total image area. This is also illustrated in *Figure 13*.

The Lepton AGC algorithm is a modified version of classic histogram equalization that mitigates these shortcomings. One such modification is a parameter called “clip limit high.” It clips the maximum population of any single bin, limiting the influence of heavily populated bins on the mapping function. Another parameter utilized by the Lepton algorithm is called “clip limit low.” It adds a constant value to every non-zero bin in the histogram, resulting in additional contrast between portions of the histogram separated by gaps. *Figure 13* is an example showing the benefit of the Lepton clip parameters.

Figure 13 Comparison of Linear AGC and Classic/Lepton Variant of Histogram Equalization

(a) Linear AGC | (b) Classic Histogram Equalization | (c) Lepton’s Variant of Histogram Equalization

A high value of clip limit high results in a mapping more like classic histogram equalization, whereas a low value results in mapping more like linear AGC. For clip limit low, the opposite is true: a high value results in a mapping more like linear AGC, whereas a low value results in a mapping more like classic histogram equalization. The default values of both parameters produce a good compromise between the two; however, because optimum AGC is highly subjective and often application dependent, customers are encouraged to experiment to find settings most appropriate for the target application.

By default, the histogram used to generate Lepton's 14-bit to 8-bit mapping function is collected from the full array. In some applications, it is desirable to have the AGC algorithm ignore a portion of the scene when collecting the histogram. For example, in some applications it may be beneficial to optimize the display to a region of interest (ROI) in the central portion of the image. When the AGC ROI is set to a subset of the full image, any scene content located outside of the ROI is not included in the histogram and therefore does not affect the mapping function (note: this does not mean the portion outside of the ROI is not displayed or that AGC is not applied there, only that those portions outside the AGC ROI do not influence the mapping function).

9.0 Interface Descriptions

9.1 Command and Control Interface

Lepton provides a command and control interface (CCI) via a two-wire interface similar to I2C (the only difference relative to the true I2C standard is that all Lepton registers are 16 bits wide and consequently, only 16-bit transfers are allowed). The CCI address is 0x2A. The interface is described in detail in a separate document, the Lepton Software Interface Description Document (IDD), FLIR document #110-0144-03. Generally speaking, all commands issued through the CCI take the form of a “get” (reading data), a “set” (writing data), or a “run” (executing a function). *Table 5* shows a partial list of parameters / features controllable through the CCI.

Table 5 Partial List of Parameters Controllable through the CCI

Parameter	Power-On Default	Section in this document	Telemetry Line Location
AGC Mode	Disabled	*AGC Modes, page 25*	A3-4
AGC ROI	(0,0,79,59)	*AGC Modes, page 25*	A34-A37
AGC Dampening Factor	64	*AGC Modes, page 25*	A42
AGC Clip Limit High	4800	*AGC Modes, page 25*	A38
AGC Clip Limit Low	512	*AGC Modes, page 25*	A39
SYS Telemetry Mode	Disabled	*Telemetry Modes, page 19*	n/a
SYS Telemetry Location	Footer	*Telemetry Modes, page 19*	n/a
SYS Number of Frames to Average	8	*FFC States, page 17*	A74
VID Color LUT Select	Fusion	*Interface Descriptions, page 27*	n/a
VID User Color LUT Upload/Download	n/a	*Interface Descriptions, page 27*	n/a

9.2 VoSPI Channel

The Lepton VoSPI protocol allows efficient and verifiable transfer of video over a SPI channel. The protocol is packet-based with no embedded timing signals and no requirement for flow control. The host (master) initiates all transactions and controls the clock speed. Data can be pulled from the Lepton (the slave) at a flexible rate. This flexibility is depicted in ***Figure 14***, which shows the use of a relatively slow clock utilizing most of the available frame period as well as the use of a fast clock that bursts frame data. Once all data for a given frame is read, the master has the option to stop the clock and/or deassert the chip select until the next available frame. Alternatively, the master can simply leave the clock and chip select enabled, in which case Lepton transmits discard packets until the next valid video data is available.

Figure 14 VoSPI Flexible Clock Rate

(a) F_{SCLK} ~2.2 MHz

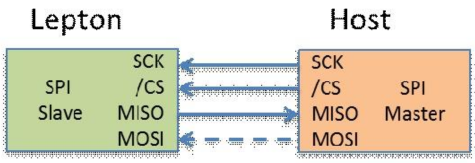
(a) F_{SCLK} ~20 MHz

9.2.1 VoSPI Physical Interface

As illustrated in ***Figure 15***, VoSPI utilizes 3 of the 4 lines of a typical SPI channel:

- SCK (Serial Clock)
- /CS (Chip Select, active low),
- MISO (Master In/Slave Out).

Figure 15 VoSPI I/O



The MOSI (Master Out/Slave In) signal is not currently employed and should be grounded. Implementations are restricted to a single master and single slave. The Lepton uses SPI Mode 3 (CPOL=1, CPHA=1); SCK is HIGH when idle. Data is set up by the Lepton on the falling edge of SCK and should be sampled by the host controller on the rising edge. See ***Figure 16***. Data is transferred most-significant byte first and in big-endian order. ***Figure 17*** provides an example of the transmission of the value 0x8C08.

Figure 16 SPI Mode 3 (CPOL=1, CPHA=1)

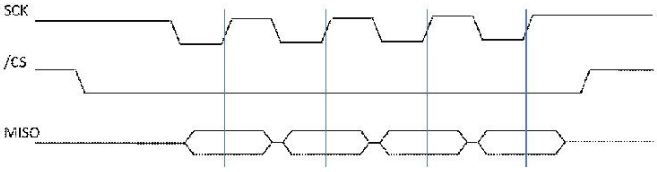
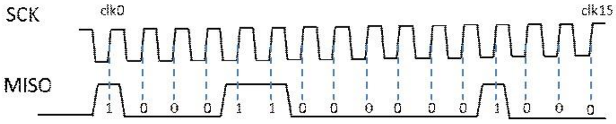


Figure 17 SPI Bit Order (transmission of 0x8C08)



The maximum clock rate is 20 MHz. The minimum clock rate is a function of the number of bits of data per frame that need to be retrieved. As described in the sections that follow, the number of bits of data varies depending upon user settings (video format mode, telemetry mode). For default conditions (Raw14 mode, telemetry disabled), there are 60 video packets per frame, each 1312 bits long, at approximately 25.9 frames per second. Therefore, the minimum rate is on the order of 2 MHz.

9.2.2 VoSPI Protocol

VoSPI is built on a collection of object types as defined hierarchically below.

- **VoSPI Packet**: The Lepton VoSPI protocol is based on a single standardized VoSPI packet, the minimum “transaction” between master and slave. Each video packet contains data for a single video line or telemetry line. In addition to video packets, the VoSPI protocol includes discard packets that are provided when no video packets are available.
- **VoSPI Frame**: A VoSPI frame is defined as a continuous sequence of VoSPI packets consisting of a full frame's worth of pixel data.
- **VoSPI Stream**: A VoSPI stream is defined as a continuous sequence of VoSPI frames.

As summarized in *Table 6 on page 30*, the number of packets per frame varies depending upon telemetry mode.

Table 6 Packet Length and Number of Video Packets per Frame as a Function of User Settings

Video Format Mode	Telemetry Mode	
	Telemetry Disabled	Telemetry Enabled
Raw14	Video packets per frame: 60	Video packets per frame: 63

9.2.2.1 VoSPI Packets

As depicted in *Figure 18*, each packet contains a 4-byte header followed by a 160-byte payload.

Figure 18 Generic VoSPI Packet

ID	CRC	Payload
4 bytes		160 bytes

For video packets, the header includes a 2-byte ID and a 2-byte CRC. The ID field is a 12-bit packet number as shown in *Figure 19* (the leading 4 bits of the ID field are reserved and are not part of the packet number). Note that packet numbering restarts at zero on each new frame. The CRC portion of the packet header contains a 16-bit cyclic redundancy check (CRC), computed using the following polynomial:

$$x^{16} + x^{12} + x^{5} + x^{0}$$

The CRC is calculated over the entire packet, including the ID and CRC fields. However, the four most-significant bits of the ID and all sixteen bits of the CRC are set to zero for calculation of the CRC. There is no requirement for the host to verify the CRC. However, if the host does find a CRC mismatch, it is recommended to re-synchronize the VoSPI stream to prevent potential misalignment.

Figure 19 Video Packet

ID	CRC	Payload
xNNN (16 bits)	CRC (16 bits)	Video pixels for one video line

At the beginning of SPI video transmission until synchronization is achieved (see *VoSPI Stream, page 33*) and also in the idle period between frames, Lepton transmits discard packets until it has a new frame from its imaging pipeline. As shown in *Figure 20*, the 2-byte ID field for discard packets is always xFxx (where 'x' signifies a “don't care” condition). Note that VoSPI-enabled cameras do not have vertical resolution approaching 3840 lines (0xF00), and therefore it is never possible for the ID field in a discard packet to be mistaken for a video line.

Figure 20 Discard Packet

ID	CRC	Payload
xFxx	xxxx	Discard data (same number of bytes as video packets)

The payload is 160 bytes long. Excluding telemetry lines[1], each packet contains pixel data for all 80 pixels in a single video line (with AGC disabled, the first two bits of each pixel's two-byte word are always set to 0; if AGC is enabled, the first eight bits are set to 0).

This is illustrated in the following payload encoding figures.

Figure 21 Raw14 Mode: 1 video line per 160-byte payload

Byte 0	Byte 1	Byte 2	Byte 3	…	Byte 158	Byte 159
Line m		Line m		…	Line m	
Pixel 0		Pixel 1			Pixel 79	

9.2.2.2 VoSPI Frames

A single Lepton frame contains data from all 60 rows of the sensor. However, the total number of video packets is not necessarily 60; the exact number depends upon user settings, specifically the telemetry mode (disabled, as header, or as footer). *Table 7* shows the number of packets per frame and the contents of each packet for all of the various combinations.

Table 7 Video Packet Contents Per Frame as a Function of Video Format and Telemetry-mode Settings

	Configuration		
Telemetry Mode	As header	As footer	Disabled
Packet 0	Telemetry line A	FPA Row 0	FPA Row 0
Packet 1	Telemetry line B	FPA Row 1	FPA Row 1
Packet 2	Telemetry line C	FPA Row 2	FPA Row 2
Packet 3	FPA Row 0	FPA Row 3	FPA Row 3
…	…	…	…
Packet 29	FPA Row 26	FPA Row 29	FPA Row 29
Packet 30	FPA Row 27	FPA Row 30	FPA Row 30
Packet 31	FPA Row 28	FPA Row 31	FPA Row 31
Packet 32	FPA Row 29	FPA Row 32	FPA Row 32

Note(s)

1. See *Telemetry Modes, page 19* for payload contents of the telemetry lines

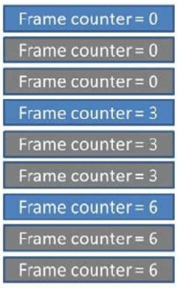
Table 7 Video Packet Contents Per Frame as a Function of Video Format and Telemetry-mode Settings

	Configuration		
…	…	…	…
Packet 59	FPA Row 56	FPA Row 59	FPA Row 59
Packet 60	FPA Row 57	Telemetry line A	n/a
Packet 61	FPA Row 58	Telemetry line B	n/a
Packet 62	FPA Row 59	Telemetry line C	n/a

9.2.2.3 VoSPI Stream

A VoSPI stream is simply a continuous sequence of VoSPI frames following a synchronization event. Provided that synchronization is maintained, a VoSPI stream can continue indefinitely. Note that the frame rate of the stream is nominally just below 27 Hz, allowing easy interface to a display system without the need for host-side frame buffering. However, the rate of *unique* frames is just below 9 Hz to comply with US export restrictions. For each unique frame, two duplicates follow in the VoSPI stream. This pattern is illustrated in ***Figure 22***, with unique frames shown in blue and duplicates shown in gray. In some applications, it might be beneficial to identify the first of the three identical frames (the frame with the least latency). The 32-bit frame counter provided in the telemetry lines (see ***Telemetry Modes, page 19***) can be used for this purpose. It only increments on new frames, which is also illustrated in ***Figure 22***.

Figure 22 Frame Counter for Successive Frames



NOTE: Blue frames are different than the previous frames, gray frames are identical to the previous blue frame.

9.2.2.3.1Establishing/Re-Establishing Sync

The basic process for establishing synchronization is listed below:

- Deassert /CS and idle SCK for at least 5 frame periods (>185 msec). This step ensures a timeout of the VoSPI interface, which puts the Lepton in the proper state to establish (or re-establish) synchronization.
- Assert /CS and enable SCLK. This action causes the Lepton to start transmission of a first packet.
- Examine the ID field of the packet, identifying a discard packet. Read out the entire packet.
- Continue reading packets. When a new frame is available (should be less than 39 msec after asserting /CS and reading the first packet), the first video packet will be transmitted. The master and slave are now synchronized.

9.2.2.3.2Maintaining Sync

There are three main violations that can result in a loss of synchronization:

- Intra-packet timeout. Once a packet starts, it must be completely clocked out within 3 line periods. Provided that VoSPI clock rate is appropriately selected and that /CS is not de-asserted (or SCLK disrupted) in the midst of the packet transfer, an intra-packet timeout is an unexpected event.
- Failing to read out all packets for a given frame before the next frame is available. Two examples of this violation are shown in ***Figure 24*** and ***Figure 25 on page 35***. Note that the vertical blue line shown in the illustrations represents an internal frame-sync signal that indicates a new frame is ready for read-out.
- Failing to read out all available frames. This violation is depicted in ***Figure 26 on page 35***. Note that the requirement to read out all frames applies to both the unique and the duplicate frames.

A CRC error does not result in an automatic loss of synchronization. However, as mentioned previously, it is recommended to intentionally re-synchronize (de-assert /CS for >185 msec) following a CRC error.

The following figures are examples of violations that result in a loss of synchronization.

Figure 23 Valid Frame Timing (no loss of synchronization)

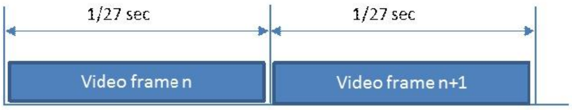


Figure 24 Clock Too Slow - Failure to Read an Entire Frame Within the Frame Period

Figure 25 Intra-frame Delay Too Long - Failure to Read Out an Entire Frame Before the Next is Available

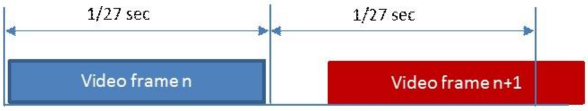
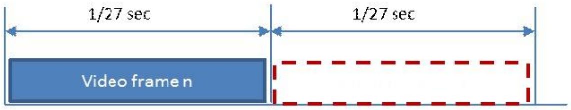


Figure 26 Failure to Read Out an Available Frame



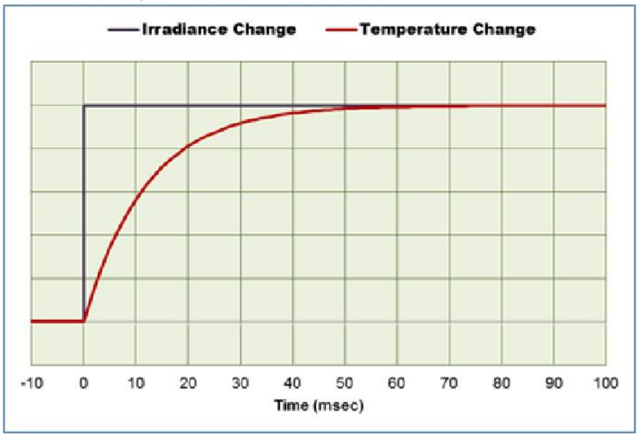
9.3 MIPI Interface

An optional MIPI interface will be supplied in a later release of Lepton.

10.0 Thermal Camera Basics

It is noteworthy that the integration period for a thermal detector does not have the same impact on image formation as it does for a photon detector, such as a typical CMOS array. A photon detector converts incoming photons to electrons with near-instantaneous response time but only collects information from the scene during the integration period. In other words, high-speed phenomena (such as a strobed signal) can be missed entirely if the resulting photons are incident at a point in time when the detector is not integrating. A thermal detector, on the other hand, is always changing temperature in response to incident radiation. That is to say, it is always "active" regardless of whether or not it is being actively integrated. The integration period only refers to the time that resistance is being sensed by integration of current, not the time the sensor is actively responding to irradiance from the scene. The ability to detect high-speed phenomena is more a function of the detector's thermal time constant, which governs the rate of temperature change. For Lepton, the detector time constant is on the order of 12 msec, which means that an instantaneous irradiance change will result in a temperature change of the detector as shown in *Figure 27*.

Figure 27 Illustration of Lepton Detector Time Constant

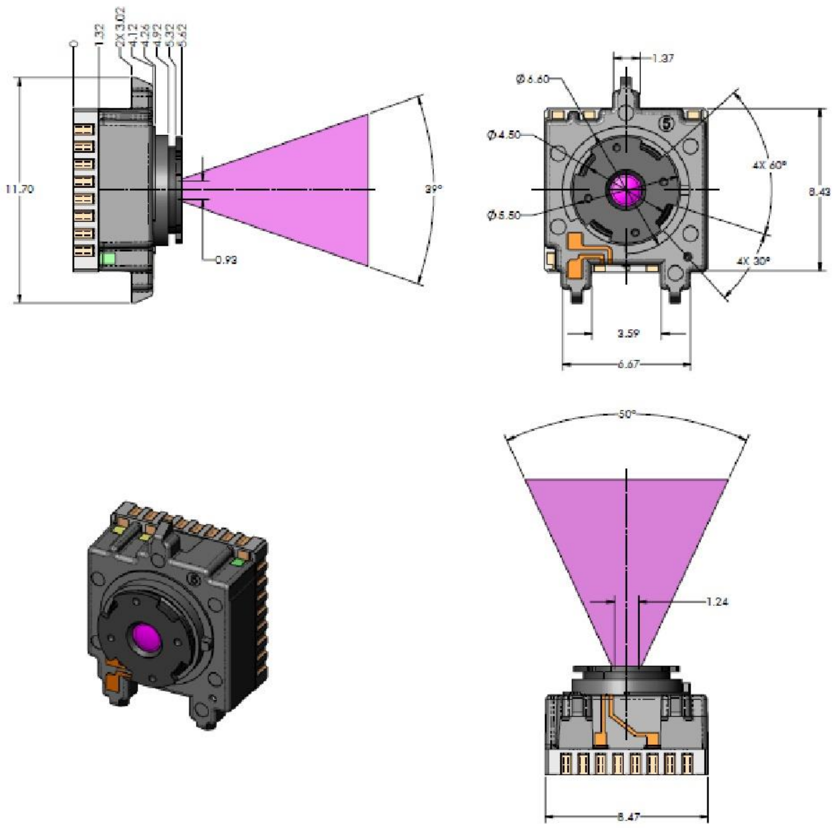


In addition to integrating signal current, the ROIC also digitizes and multiplexes the signal from each detector into a serial stream. And the Lepton ROIC digitizes data from an on-chip temperature sensor as well as a thermistor attached to the camera housing. An anti-reflection (AR) coated window is bonded above the sensor array via a wafer-level packaging (WLP) process, encapsulating the array in a vacuum. The purpose of the vacuum is to provide high thermal resistance between the microbolometer elements and the ROIC substrate, allowing for maximum temperature change in response to incident radiation.

11.0 Mounting Specifications

The Lepton camera mounting dimensions are shown in ***Figure 28***.

Figure 28 Lepton Camera Mounting Dimensions

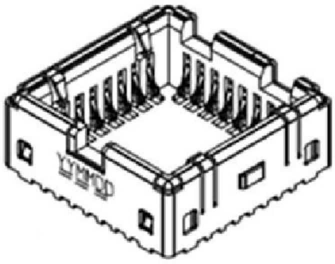


11.1 Socket Information

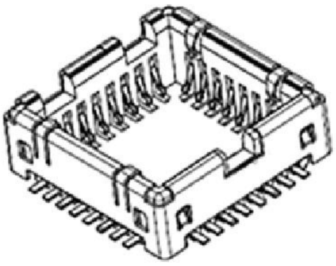
The Lepton module is compatible with two commercially-available sockets, Molex 1052028-1001 and Molex 105028-2031, illustrated in *Figure 29* below. The former makes electrical contact on the upper surface of a printed circuit board, the latter to the lower surface (with a cutout in the board that allows the socket to pass through). *Figure 30* depicts both socket configurations mounted on a PCB.

To order sockets, visit **www.parts.arrow.com**.

Figure 29 Two Commercially-available Sockets (both from Molex) Compatible with Lepton

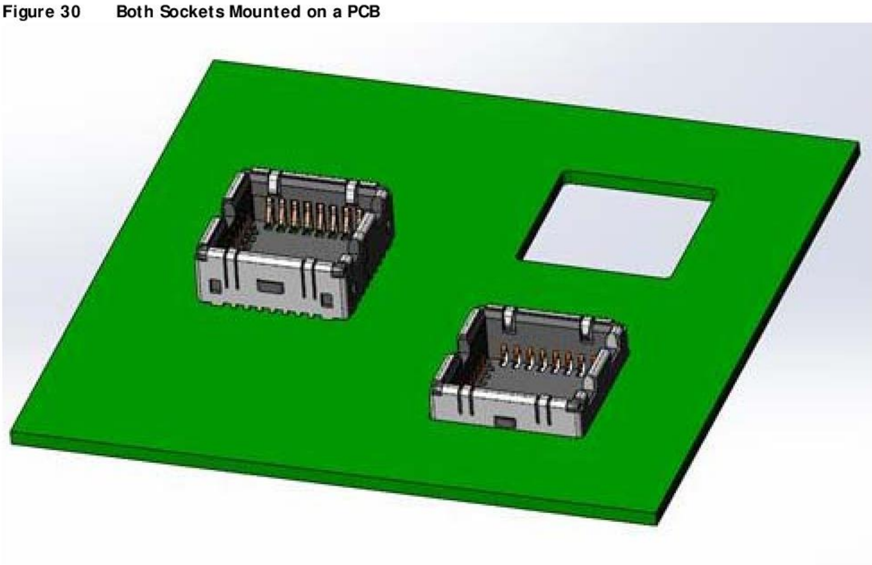


105028-1001



105028-2031

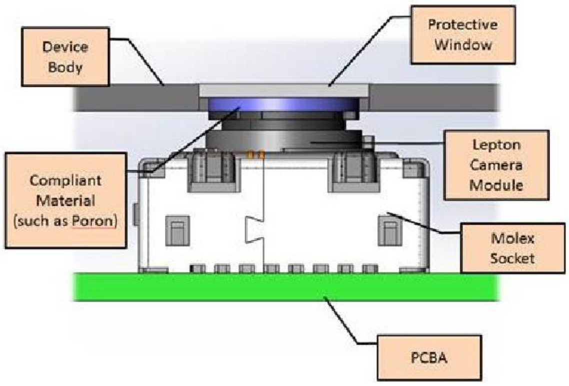
Figure 30 Both Sockets Mounted on a PCB



11.2 Mechanical Considerations

The socket is not intended to retain the Lepton assembly under high-shock conditions. It is recommended to incorporate front-side retention such as illustrated in *Figure 31*.

Figure 31 Recommended Approach to Retaining Lepton in the end Application



The Lepton camera is not a sealed assembly. Consequently, for most applications it is recommended to locate the assembly behind a sealed protective window. Common materials for LWIR windows include silicon, germanium, and zinc selenide (LWIR absorption in silicon is on the order of 15%/mm, which means NEDT is adversely affected using a silicon window. Bulk absorption in germanium and zinc selenide is negligible, and performance is essentially unchanged provided both surfaces of the window are anti-reflection (AR) coated.) Note that the window should be sized large enough to avoid encroaching upon the optical keepout zone (see *Optical Considerations, page 41*).

11.3 Thermal Considerations

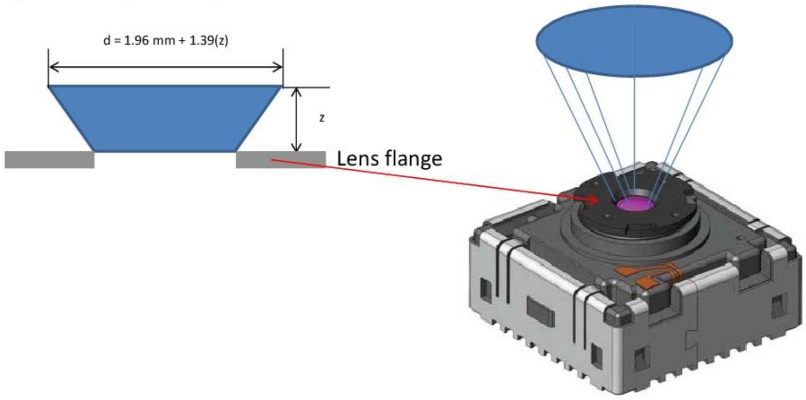
It is important to minimize any temperature gradient across the camera. The sensor should be mounted in such a fashion so as to isolate it from heat loads such as electronics, heaters, and non-symmetric external heating.

The surrounding area must be able to support and withstand the dissipation of up to 160 mW of heat by the camera.

11.4 Optical Considerations

The optical keepout zone is shown in ***Figure 32***. To avoid mechanical vignetting, do not impinge upon the keepout zone.

Figure 32 Optical Keepout Zone



12.0 Image Characteristics

The information given in *Table 8* applies across the full operating temperature range.

Table 8 Image Characteristics

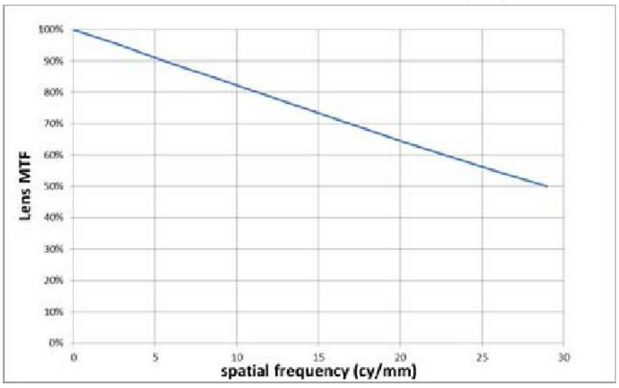
Parameter	Description	Value
NETD	Noise Equivalent Temperature Difference (random temporal noise)	<50 mK (20 mK typical)
Intrascene Range	Minimum and maximum scene temperature	0 K to >400 K
Operability	Number of non-defective pixels	>99.0% (<1 defect typical)
Clusters	Number of adjacent defective pixels "Adjacent" means any of the 8 nearest neighbors (or nearest 5 for an edge pixel, nearest 3 for a corner).	Unallowed[1]

Note(s)

1. : Only single-pixel defects are allowed (no clusters)

The nominal curve of on-axis modulation transfer function (MTF) for the Lepton lens assembly is shown for reference in *Figure 33*.

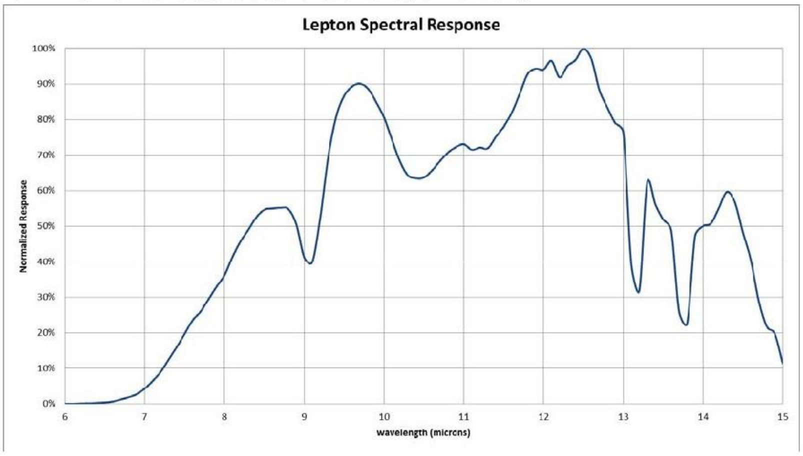
Figure 33 Nominal Curve of On-axis Modulation Transfer Function (MTF)



13.0 Spectral Response

For reference, *Figure 34* depicts the spectral response of the Lepton camera

Figure 34 Normalized Response as a Function of Signal Wavelength



14.0 Electrical Specifications

14.1 DC and Logic Level Specifications

Table 9 DC and Logic Levels

Symbol	Parameter	Min	Typ	Max	Units
VDDC	Core Voltage (primary power for the Lepton internal ASIC)	1.14	1.20	1.26	Volts
VDD	Sensor Voltage (primary power for the Lepton internal sensor chip)	2.72	2.80	2.88	Volts
VDDIO	I/O Voltage (primary power for the Lepton I/O ring)	2.5	—	3.1	Volts
I_DDC	Supply current for core (VDDC)	76	84	110	mA
I_DD	Supply current for sensor (VDD)	12	14	16[1]	mA
I_DDIO	Supply current for I/O ring (VDDIO)	1	2	4	mA

Note(s)

1. Maximum at 65 degrees C

14.2 AC Electrical Characteristics

Table 10 AC Electrical Characteristics

Parameter	Min	Typ	Max	Units
MASTER_CLK, F_{clk}	TBD	25 MHz	TBD	Master clock rate
MASTER_CLK, $F_{clk\ duty}$	45%	50%	55%	Master clock duty cycle
MASTER_CLK, t_r	–	–	TBD	Clock rise time (10% to 90%)
MASTER_CLK, t_f	–	–	TBD	Clock fall time (90% to 10%)
SPI_CLK, F_{clk}	See note[1]		20 MHz	VoSPI clock rate
SPI_CLK, $F_{clk\ duty}$	45%	50%	55%	SPI-clock duty cycle

Table 10 AC Electrical Characteristics *(continued)*

Parameter	Min	Typ	Max	Units
SPI_CLK, t_r	–	–	TBD	SPI clock rise time (10% to 90%)
SPI_CLK, t_f	–	–	TBD	SPI clock fall time (90% to 10%)
SCL, F_{clk}			1 MHz	I2C clock rate
SCL, $F_{clk\ duty}$	45%	50%	55%	I2C-clock duty cycle
SCL_CLK, t_r	–	–	TBD	I2C clock rise time (10% to 90%)
SCL_CLK, t_f	–	–	TBD	I2C clock fall time (90% to 10%)

Note(s)

1. As described in ***VoSPI Protocol, page 30***, the minimum VoSPI clock frequency is dependent upon the requirement to read out all video packets for a given frame within the frame period. The size and number of video packets vary with user settings.

15.0 Absolute Maximum Ratings

Electrical stresses beyond those listed in ***Table 11*** may cause permanent damage to the device. These are stress rating only, and functional operation of the device at these or any other conditions beyond those indicated under the recommended operating conditions listed in ***Table 9 on page 45*** is not implied. Exposure to absolute-maximum-rated conditions for extended periods of time may affect device reliability.

Table 11 Absolute Maximum Ratings

Parameter	Absolute Maximum Rating
Core Voltage (VDDC)	1.5 V
Sensor Voltage (VDD)	4.8 V
I/O Voltage (VDDIO)	4.8 V
Voltage on any I/O pin	4.8 V

16.0 Environmental Specifications

Environmental stresses beyond those listed may cause permanent damage to the device. Exposure to absolute-maximum-rated conditions for extended periods of time may affect device reliability.

Table 12 Environmental Specifications

Stress	Maximum Rating
Operating Temperature Range	-10° C to 65° C (-20° C to 75° C with some possible performance degradation)
Maximum Operating Temperature	80 °C[1]
Storage Temperature	-40° C to 80° C
Altitude (pressure)	12 km altitude equivalent
Relative Humidity	95%
Thermal Shock	Air-to-air across operating temp. extremes (-10° C to 65° C, 65° C to -10° C)
Mechanical Shock	1500 g, 0.4 msec
Vibration	Transportation profile, 4.3 grms
ESD	Human Body Model (HBM), 2kV Charged Device Model (CDM), 500V

Note(s)

1. Lepton contains an automatic shutdown feature when its internal temperature exceeds the maximum safe operating value. See *Power States, page 13*.

16.1 Compliance with Environmental Directives

Lepton complies with the following directives and regulations:

- Directive 2002/95/EC, "Restriction of the use of certain Hazardous Substances in electrical and electronic equipment (RoHS)"
- Directive 2002/96/ EC, "Waste Electrical and Electronic Equipment (WEEE)".
- Regulation (EC) 1907/2006, "Registration, Evaluation, Authorization and Restriction of Chemicals (REACH)"

17.0 Abbreviations and Acronyms

Abbreviation	Description
AGC	Automatic Gain Control
AR	Anti-reflection
CCI	Command and Control Interface
CRC	Cyclic Redundancy Check
DSP	Digital Signal Processor
EMC	Electromagnetic Compatibility
FFC	Flat Field Correction
FOV	Field of View
FPA	Focal Plane Array
FPN	Fixed Pattern Noise
GPIO	General Purpose IO
HFOV	Horizontal Field of View
I2C	Inter-Integrated Circuit
IDD	Interface Description Document
LWIR	Long Wave Infrared
MIPI	Mobile Industry Processor Interface
MISO	Maser In/Slave Out
MOSI	Master Out/Slave In
NEDT	Noise Equivalent Differential Temperature
NUC	Non-Uniformity Correction
OTP	One-Time Programmable
PLL	Phase-Lock Loop
REACH	Registration, Evaluation, Authorization, and Restriction of Chemicals
RoHS	Reduction of Hazardous Substances

FLIR LEPTON® Long Wave Infrared (LWIR) Datasheet

ROIC	Readout Integrated Circuit
SBNUC	Scene-based Non-uniformity Correction
SNR	Signal to Noise Ratio
SoC	System on a Chip
SPI	Serial Peripheral Interface
SVP	Software-based Video Processing
TCR	Temperature Coefficient of Resistance
TWI	Two-wire Interface
VoSPI	Video Over SPI
VOx	Vanadium-oxide
WEEE	Waste Electrical and Electronic Equipment
WLP	Wafer-level Packaging

FLIR LEPTON® Long Wave Infrared (LWIR) Datasheet

If you have questions that are not covered in this manual, or need service, contact FLIR Commercial Systems Customer Support at 805.964.9797 for additional information prior to returning a camera.

This documentation and the requirements specified herein are subject to change without notice.

This equipment must be disposed of as electronic waste.
Contact your nearest FLIR Commercial Systems, Inc. representative for instructions on how to return the product to FLIR for proper disposal.

FCC Notice. This device is a subassembly designed for incorporation into other products in order to provide an infrared camera function. It is not an end-product fit fo1r consumer use. When incorporated into a host device, the end-product will generate, use, and radiate radio frequency energy that may cause radio interference. As such, the end-product incorporating this subassembly must be tested and approved under the rules of the Federal Communications Commission (FCC) before the end-product may be offered for sale or lease, advertised, imported, sold, or leased in the United States. The FCC regulations are designed to provide reasonable protection against interference to radio communications. See 47 C.F.R. §§ 2.803 and 15.1 et seq.

Industry Canada Notice. This device is a subassembly designed for incorporation into other products in order to provide an infrared camera function. It is not an end-product fit for consumer use. When incorporated into a host device, the end-product will generate, use, and radiate radio frequency energy that may cause radio interference. As such, the end-product incorporating this subassembly must be tested for compliance with the Interference-Causing Equipment Standard, Digital Apparatus, ICES-003, of Industry Canada before the product incorporating this device may be: manufactured or offered for sale or lease, imported, distributed, sold, or leased in Canada.

Avis d'Industrie Canada. Cet appareil est un sous-ensemble conçu pour être intégré à un autre produit afin de fournir une fonction de caméra infrarouge. Ce n'est pas un produit final destiné aux consommateurs. Une fois intégré à un dispositif hôte, le produit final va générer, utiliser et émettre de l'énergie radiofréquence qui pourrait provoquer de l'interférence radio. En tant que tel, le produit final intégrant ce sous-ensemble doit être testé pour en vérifier la conformité avec la Norme sur le matériel brouilleur pour les appareils numériques (NMB-003) d'Industrie Canada avant que le produit intégrant ce dispositif puisse être fabriqué, mis en vente ou en location, importé, distribué, vendu ou loué au Canada.

EU Notice. This device is a subassembly or component intended only for product evaluation, development or incorporation into other products in order to provide an infrared camera function. It is not a finished end-product fit for general consumer use. Persons handling this device must have appropriate electronics training and observe good engineering practice standards. As such, this product does not fall within the scope of the European Union (EU) directives regarding electromagnetic compatibility (EMC). Any end-product intended for general consumer use that incorporates this device must be tested in accordance and comply with all applicable EU EMC and other relevant directives.

Information on this page is subject to change without notice. Shipping: CIP per INCOTERMS 2010.

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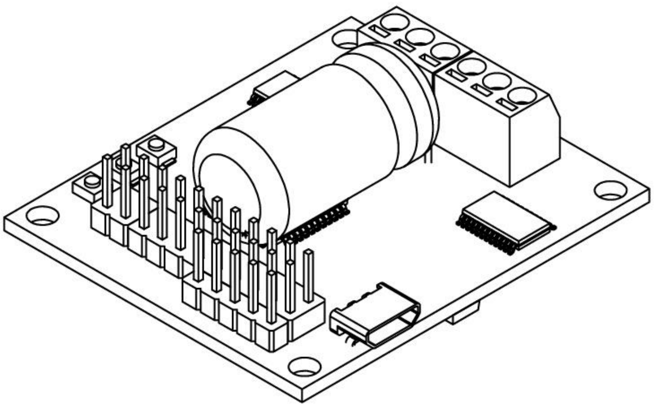
I.3 Hojas técnicas driver Roboclaw. Fuente: ION MOTION CONTROL

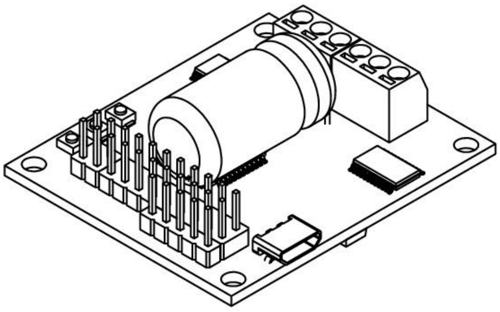
ION MOTION CONTROL



RoboClaw 2x7A, 34VDC Dual Channel
Brushed DC Motor Controller

Feature Overview:

- 15 Amps Peak Per Channel
- Channel Bridging Supported
- Dual Quadrature Decoding
- 19.6 million PPS Decoding
- Multimode Interface
- TTL Serial
- USB Port
- Analog Interface
- R/C Input Control
- Up to 34VDC Operation
- Air Cooled
- 3.3v Compliant Control Outputs
- 5v Tolerant Control Inputs
- Programmable Current Limiting
- Closed and Open Loop Operation
- Auto Tuning PID Feature
- Mixed Control Modes
- Data Logging
- Diagnostic LEDs
- Field Firmware Updates
- Regulated 5VDC, 1A User Available Output
- Over Voltage and Under Voltage Protection
- Easy Tuning, Monitor and Setup with PC utility



Device Overview
The RoboClaw motor controller series by Ion Motion Control, is a high power, high performance rugged DC brushed motor controller. It is built to withstand the most demanding applications. With its multi mode interface it can be controlled from USB, R/C radio, serial devices, analog and or microcontrollers such as an Arduino or Raspberry Pi.

Closed and open loop modes are supported. Closed loop mode supports dual quadrature encoders with up to 19.6 million QPPS for precision motion control. RoboClaw's closed loop functionality creates absolute control over speed, velocity and direction regardless of loading changes. In addition, a wide range of sensor inputs including potentiometers and absolute encoders are supported.

At the heart of RoboClaw is a high performance motion control intelligence which achieves precision control and optimum motor performance in open or closed loop modes. RoboClaw utilizes precision sensing to detect and monitor parameters such as current, voltage and temperature enabling safe and reliable operation.

RoboClaw is a synchronous regenerative motor controller. During slow down or breaking the regenerative power can charge the main battery. RoboClaw can also be configured to redirect the regenerative power for use with switching power supplies. With it's advance circuitry it can also change direction during full throttle without damage! In addition a lithium voltage cutoff circuit is incorporated to protect batteries from damage.

Multimode Interface
The RoboClaw can be controlled by USB, TTL, R/C Pulse and Analog. The RoboClaw works with E-stops, limit and home switches.

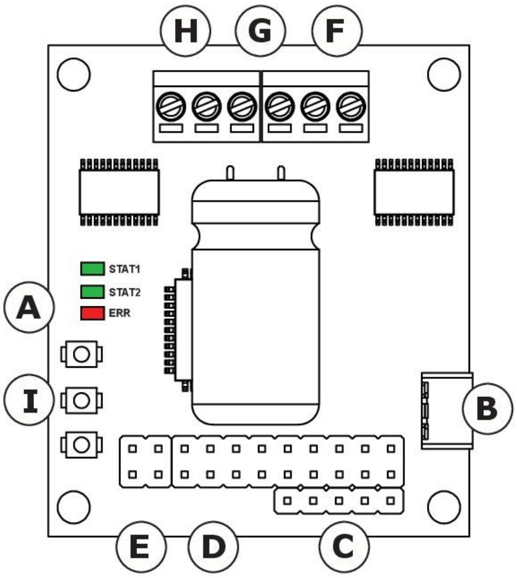
Regulated User Power
The RoboClaw utilizes a high efficiency switching regulator which can supply 5VDC at up to 1.2Amps or up to 3Amps depending on model. This voltage can be used to supply external sensors, encoders, MCU and other electronics.

Main Input Voltage
The peak operational voltage depending on model can be 34VDC, 60VDC or 80VDC. RoboClaw is a regenerative motor controller. During regeneration, voltages can peak over the maximum rated voltage. RoboClaw is designed to handle over voltage spikes and is not rated to its absolute maximum operating specifications which allows for a safe and reliable margin of operation.

Software
IonMotion is a free PC configuration utility used to setup, configure and monitor RoboClaw. The software can be used during run time to monitor and control several operational parameters.

User Manual
Basic wiring and usage are covered in this data sheet. For more information on specific modes and wiring diagrams refer to the RoboClaw user manual.

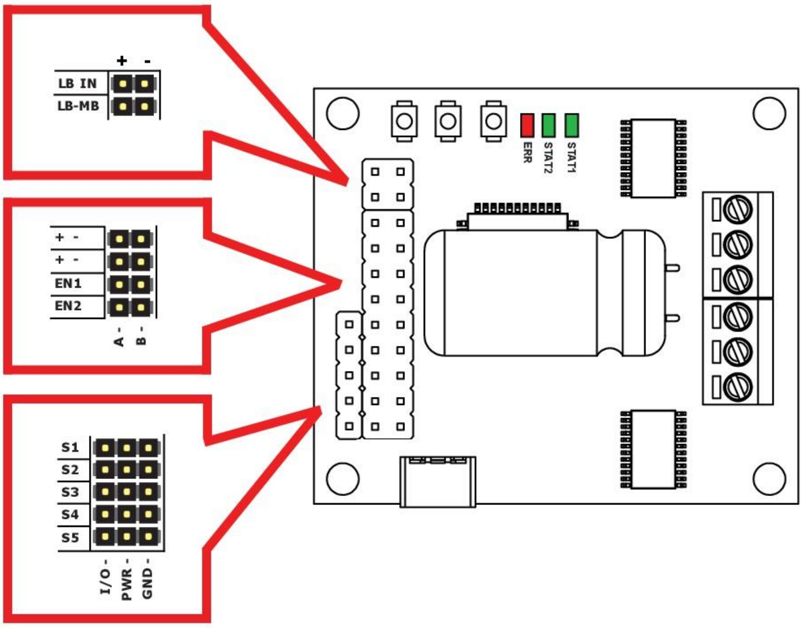
Hardware Overview:



ID	Function	DESCRIPTION
A	Status LEDs	Provides RoboClaw status information.
B	USB Port	Communicate with RoboClaw via USB.
C	Control Inputs	S1,S2,S3,S4 and S5 control inputs.
D	Encoder Inputs	Dual encoder input and power pins.
E	Logic Battery	Logic battery jumper setup and logic battery power input.
F	Motor Channel 1	Motor driver output screw terminals for channel 1.
G	Main Battery	Main battery screw terminal input.
H	Motor Channel 2	Motor driver output screw terminals for channel 2.
I	Setup Buttons	Configure RoboClaw. Can bypass and use IonMotion PC setup utility.

Control Interface

The RoboClaw use standard male pin headers with 0.100" (2.54mm) spacing. The pin headers are ideal for use with standard servo cables and other popular interface connectors. The table below list the pins and their respective functions. All pins are 5V tolerant and output 3.3V for compatibility with processor such as Raspberry Pi and Arduino. R/C pulse input, Analog and TTL can be generated from any microcontroller such as a Arduino or Raspberry Pi. The R/C Pulse input pins can also be driven by any standard R/C radio receiver. There are several user configurable options available. To configure RoboClaw install the IonMotion PC utility and connect RoboClaw to an available USB port.



NAME	UART TTL	ANALOG	R/C PULSE	FLIP SWITCH	E-STOP	HOME	LIMIT	V-CLAMP	Encoder
S1	RX	Motor 1	Motor 1						
S2	TX	Motor 2	Motor 2						
S3				X	X			X	
S4					X	Motor 1	Motor 1	X	
S5					X	Motor 2	Motor 2	X	
EN1									Motor 1
EN2									Motor 2

Logic Battery (LB IN)
The logic side of RoboClaw can be powered from a secondary battery wired to LB IN. The positive (**+**) terminal is located at the board edge and ground (**-**) is the inside pin closest to the heatsink. Remove the LB-MB jumper if a secondary battery for logic will be used.

BEC Source (LB-MB)
RoboClaw logic requires 5VDC which is provided from the on board BEC circuit. The BEC power source input is set with the LB-MB jumper. Install a jumper on the 2 pins labeled LB-MB to use the main battery as the BEC power source. Remove the LB-MB jumper if using a separate logic battery. On models without this jumper the power source is selected automatically.

Failure to remove LB-MB jumper when a logic battery is in use, will result in damage.

Encoder Power (+ / -)
The pins labeled + and - are the source power pins for encoders. The positive (**+**) is located at the board edge and supplies +5VDC. The ground (**-**) pin is near the heatsink. On RoboClaw screw terminal models all power must come from the single 5v screw terminal and the single GND screw terminal

Encoder Inputs (1B / 1A / 2B / 2A)
The encoders inputs are labeled EN1 and EN2. EN1 is for encoder 1 and EN2 is for encoder 2 which also correspond to motor channel 1 and motor channel 2. Quadrature encoder inputs are typically labeled 1B, 1A, 2B and 2A. Channel A of both EN1 and EN2 are located at the board edge on the pin header. Channel B pins are located near the heatsink on the pin header. When connecting encoders make sure the leading channel for the direction of rotation is connected to A. If one encoder is backwards to the other you will have one internal counter counting up and the other counting down. Refer to the data sheet of the encoder you are using for channel direction. Encoders channels orientation to the motor channels can be swapped using the IonMotion PC setup utility.

Control Inputs (S1 / S2 / S3 / S4 /S5)
S1, S2, S3, S4 and S5 are setup for standard servo style headers I/O(except on ST models), +5V and GND. S1 and S2 are the control inputs for serial, analog and RC modes. S3 can be used as a flip switch input when in RC or Analog modes. In serial mode S3, S4 and S5 can be used as emergency stop inputs or as voltage clamp control outputs. When set as E-Stop inputs they are active when pulled low and have internal pull-ups so they will not accidentally trip when left floating. S4 and S5 can also optionally be used as home switch and limit switch inputs. The pins closest to the board edge are the I/0s, center pin is the +5V and the inside pins are ground. Some RC receivers have their own supply and will conflict with the RoboClaw's 5v logic supply. It may be necessary to remove the +5V pin from the RC receivers cable in those cases.

Main Battery Screw Terminals
The main power input can be from 6VDC to 34VDC on a standard RoboClaw and 10.5VDC to 60VDC or 80VDC on an HV (High Voltage) RoboClaw. The connections are marked **+** and **-** on the main screw terminal. The plus (**+**) symbol marks the positive terminal and the negative (**-**) marks the negative terminal. The main battery wires should be as short as possible.

Do not reverse main battery wires or damage will occur.

Disconnect
The main battery should have a disconnect in case of a run away situation and power needs to be cut. The switch must be rated to handle the maximum current and voltage from the battery. This will vary depending on the type of motors and or power source you are using. A typically solution would be an inexpensive contactor which can be source from sites like Ebay. A power diode rated for the maximum current the battery will deliver should be placed across the switch/contactor to provide a path back to the battery when disconnected while the motors are spinning. The diode will provide a path back to the battery for regenerative power even if the switch is opened.

Motor Screw Terminals
The motor screw terminals are marked with M1A / M1B for channel 1 and M2A / M2B for channel 2. For both motors to turn in the same direction the wiring of one motor should be reversed from the other in a typical differential drive robot. The motor and battery wires should be as short as possible. Long wires can increase the inductance and therefore increase potentially harmful voltage spikes.

RoboClaw Modes

There are 4 main modes with variations totaling 14 modes in all. Each mode enables RoboClaw to be controlled in a very specific way. The following list explains each mode and the ideal application. All modes can be configured using the built in buttons or from IonMotion PC setup utility. See the RoboClaw user manaul for addtional information.

USB can be connected in any mode. Even when the Roboclaw is not in packet serial mode USB packet serial commands can be used to read status information and set configuration settings, however motor movement commands will not function. When in packet serial mode if another device such as an Arduino is connected to S1 and S2 pins and sending commands to the RoboClaw, both those commands and USB packet serial commands will execute.

1. R/C Mode 1 & 2

With R/C mode RoboClaw can be controlled from any hobby R/C radio system. R/C input mode also allows low powered microcontrollers such as a Basic Stamp to control RoboClaw. RoboClaw expects servo pulse inputs to control the direction and speed. Very similar to how a regular servo is controlled. R/C mode can use encoders if properly setup(See Encoder section).

2. Analog Mode 3 & 4

Analog mode uses an analog signal from 0V to 2V to control the speed and direction of each motor. RoboClaw can be controlled using a potentiometer or filtered PWM from a microcontroller. Analog mode is ideal for interfacing RoboClaw with joystick positioning systems or other non microcontroller interfacing hardware. Analog mode can use encoders if properly setup (See User Manual).

3. Standard Serial Mode 5 & 6

In standard serial mode RoboClaw expects TTL level RS-232 serial data to control direction and speed of each motor. Standard serial is typically used to control RoboClaw from a microcontroller or PC. If using a PC, a MAX232 or an equivalent level converter circuit must be used since RoboClaw only works with TTL level inputs. Standard serial includes a slave select mode which allows multiple RoboClaws to be controlled from a signal RS-232 port (PC or microcontroller). Standard serial is a one way format, RoboClaw only receives data. Encoders are not supported with Standard Serial mode.

4. Packet Serial Mode 7 through 14

In packet serial mode RoboClaw expects TTL level RS-232 serial data to control direction and speed of each motor. Packet serial is typically used to control RoboClaw from a microcontroller or PC. If using a PC a MAX232 or an equivalent level converter circuit must be used since RoboClaw only works with TTL level input. In packet serial mode each RoboClaw is assigned a unique address. There are 8 addresses available. This means up to 8 RoboClaws can be on the same serial port. Encoders are support in Packet Serial mode(See Encoder section).

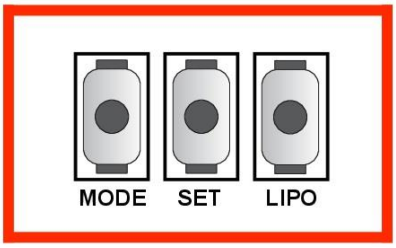
USB Control

USB can be connected in any mode. When the Roboclaw is not in packet serial mode USB packet serial commands can be used to read status information and/or set configuration settings, however motor movement commands will not function. When in packet serial mode if another device, for example an Arduino, is connected to the S1 and S2 pins and sending commands to the Roboclaw both those commands and USB packet serial commands will execute.

Configuring RoboClaw Modes

RoboClaw modes can be easily configured with the IonMotion PC setup utility (see user manual). Otherwise RoboClaw modes and configuration options can be configured using the 3 on board buttons. The MODE button sets the interface method such as Serial or RC modes. The SET button is used to configure the options for the mode. The LIPO button doubles as a save button and configuring the low battery voltage cut out function of RoboClaw. To set the desired mode follow the steps below.

1. Press and release the MODE button to enter mode setup. The STAT2 LED will begin to blink out the current mode each blink is a half second with a long pause at the end of the count. Five blinks with a long pause equals mode 5 and so on.
2. Press SET to increment to the next mode. Press MODE to decrement to the previous mode.
3. Press and release the LIPO button to save this mode to memory.



Modes

Mode	Function	Description
1	R/C mode	Control with standard R/C pulses from a R/C radio or MCU. Controls a robot like a tank. S1 controls motor 1 forward or reverse and S2 controls motor 2 forward or reverse.
2	R/C mode with mixing	Same as Mode 1 with mixing enabled. Channels are mixed for differentially steered robots (R/C Car). S1 controls forward or reverse and S2 controls left or right.
3	Analog mode	Control using analog voltage from 0V to 2V. S1 controls motor 1 and S2 controls motor 2.
4	Analog mode with mixing	Same as Mode 3 with mixing enabled. Channels are mixed for differentially steered robots (R/C Car). S1 controls forward or reverse and S2 controls left or right.
5	Standard Serial	Use standard serial communications for control.
6	Standard Serial with slave pin	Same as Mode 5 with a select pin. Used for networking. RoboClaw will ignore commands until pin goes high.
7	Packet Serial Mode - Address 0x80	Control using packet serial mode with a specific address for networking several motor controllers together.
8	Packet Serial Mode - Address 0x81	
9	Packet Serial Mode - Address 0x82	
10	Packet Serial Mode - Address 0x83	
11	Packet Serial Mode - Address 0x84	
12	Packet Serial Mode - Address 0x85	
13	Packet Serial Mode - Address 0x86	
14	Packet Serial Mode - Address 0x87	

Configuring Mode Options

Each mode will have several possible configuration settings. The settings need to be setup after the initial mode is selected. Follow the steps below.

1. After the desired mode is set and saved press and release the SET button for options setup. The STAT2 LED will begin to blink out the current option setting.

2. Press SET to increment to the next option. Press MODE to decrement to the previous option.

3. Once the desired option is selected press and release the LIPO button to save the option to memory.

RC and Analog Mode Options

Option	Function	Description
1	TTL Flip Switch	Logic level switch. Toggle to change all motor direction. Used when a robot is flipped upside down to reverse steering control.
2	TTL Flip and Exponential Enabled	Option 1 combined with increased control range at slow speed.
3	TTL Flip and MCU Enabled	Disables auto calibrate. Allows slow MCU to send R/C pulses at lower than normal R/C rates.
4	TTL Flip and Exp and MCU Enabled	Option 2 and 3 combined.
5	RC Flip Switch	R/C pulse switched. Use radio channel to toggle and change all motor direction. Used when a robot is flipped upside down to reverse steering control.
6	RC Flip and Exponential Enabled	Option 5 combined with increased control range at slow speed.
7	RC Flip and MCU Enabled	Disables auto calibrate and auto stop due to R/C signal loss. Allows slow MCU to send R/C pulses at lower than normal R/C rates.
8	RC Flip and Exponential and MCU Enabled	Option 6 and 7 combined.

Standard Serial and Packet Serial Mode Options

Option	Baud Rate	Description
1	2400bps	Standard RS-232 serial data rate.
2	9600bps	Standard RS-232 serial data rate.
3	19200bps	Standard RS-232 serial data rate.
4	38400bps	Standard RS-232 serial data rate.
5	57600bps	Standard RS-232 serial data rate.
6	115200bps	Standard RS-232 serial data rate.
7	230400bps	Standard RS-232 serial data rate.
8	460800bps	Standard RS-232 serial data rate.

Battery Cut Off Settings

The RoboClaw is able to protect the main battery by utilizing a battery voltage cut off. The cut off voltage will vary depending on the size of battery used. The table below shows the battery option setting with the type of battery it will protect and at what voltage the cutoff will kick in. The battery settings can be set by following the steps below.

1. Press and release the LIPO button. The STAT2 LED will begin to blink out the current setting.

2. Press SET to increment to the next setting. Press MODE to decrement to the previous setting.

3. Once the desired setting is selected press and release the LIPO button to save this setting to memory.

Battery Options

Option	Setting	Description
1	Disabled	6VDC is the default cut off when disabled.
2	Auto Detect	Battery must not be overcharged or undercharge!
3	3 Cell	9VDC is the cut off voltage.
4	4 Cell	12VDC is the cut off voltage.
5	5 Cell	15VDC is the cut off voltage.
6	6 Cell	18VDC is the cut off voltage.
7	7 Cell	21VDC is the cut off voltage.
8	8 Cell	24VDC is the cut off voltage.

Automatic Battery Detection on Startup

Auto detect will sample the main battery voltage on power up or after a reset. All Lipo batteries, depending on cell count will have a minimum and maximum safe voltage range. The attached battery must be within this acceptable range to be detected properly. Undercharged or overcharged batteries will cause false readings and RoboClaw will not protect the battery properly. If the automatic battery detection mode is enabled the Stat2 LED will blink to indicate the detected battery type. Each blink indicates the number of LIPO cells detected. When automatic battery detection is used the number of cells detected should be confirmed on power up.

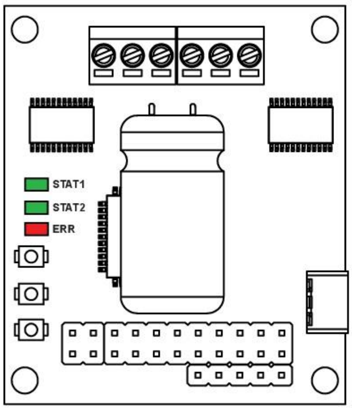
Undercharged or overcharged batteries can cause an incorrect auto detection voltage.

Manual Voltage Settings

The minimum and maximum voltage can be set using the IonMotion software or packet serial commands. Values can be set to any value between the boards minimum and maximum voltage limits. This is useful when using a power supply. A minimum voltage just below the power supply voltage (2 to 3v below) will prevent the power supply voltage from dipping too low under heavy load. A maximum voltage set just above the power supply voltage(2 to 3v above) will help protect the power supply and RoboClaw from regenerative voltage spikes if an external voltage clamp circuit is not being used.

Status and Error LEDs

RoboClaw has two status LEDs labeled STAT1 and STAT2 and an error LED labeled ERR. When the motor controller is first powered on all 3 LEDs should flash briefly to indicate all LEDs are functional. The LEDs will behave differently depending on the mode. During normal operation the status 1 LED will remain on continuously or blink when data is received in RC Mode or Serial Modes. The status 2 LED will light when either drive stage is active.



Error and Warning States

When an error occurs, both motor channel outputs will be disabled and RoboClaw will stop any further actions until the unit is reset, or in the case of non-latching E-Stops, the error state is cleared. When warnings occur both motor channel outputs will be controlled automatically depending on the warning condition(s).

LED Status	Condition	Type	Description
All three LEDs lit.	E-Stop	Error	Motors are stopped by braking.
Error LED lit while condition is active.	Over 85c Temperature	Warning	Motor current limit is recalculated based on temperature.
Error LED blinks once with short delay. Other LEDs off.	Over 100c Temperature	Error	Motors freewheel while condition exist.
Error LED lit while condition is active.	Over Current	Warning	Motor power is automatically limited.
Error LED blinking twice. STAT1 or STAT2 indicates channel.	Driver Fault	Error	Motors freewheel. Damage detected.
Error LED blinking three times.	Logic Battery High	Error	Motors freewheel until reset.
Error LED blinking four times.	Logic Battery Low	Error	Motors freewheel until reset.
Error LED blinking five times.	Main Battery High	Error	Motors are stopped by braking until reset.
Error LED lit while condition is active.	Main Battery High	Warning	Motors are stopped by braking while condition exist.
Error LED lit while condition is active.	Main Battery Low	Warning	Motors freewheel while condition exist.
Error LED lit while condition is active.	M1 or M2 Home	Warning	Motor is stopped and encoder is reset to 0
All 3 LED cycle on and off in sequence after power up.	RoboClaw is waiting for new firmware.	Notice	RoboClaw is in boot mode. Use IonMotion PC setup utility to clear.

Important Notices

The following information is required for safe and reliable operation. It is up to the user to ensure the following criteria is met. Several external factors can influence how a motor controller operates. Following basic safety procedures can prevent dangerous situations.

Warnings

The following guidelines should be followed when using any motor controller or damage will result. There are several factors that will affect the operation of RoboClaw.

1. Battery wire should be no longer than 20 inches in length.
2. Motor wire should be no longer than 20 inches in length.
3. DO NOT overload the BEC. Logic power is drawn from the same source and brownouts can occur.
4. DO NOT reverse the battery polarity. Damage will result.
5. ALWAYS Incorporate an emergency main battery cut off switch.
6. Cut off should always be on the positive (+) of power to prevent ground loops.
7. Power diode, fuse and pre charge resistor should be added to all power switch circuits.
8. DO NOT get RoboClaw wet and avoid high moisture environments without proper moisture control.

Mounting

RoboClaw will generate heat. The motor controller should be mounted to a metal surface that will dissipate the heat away from the motor controller during operation. The maximum current ratings can only be achieved and maintained with adequate heat dissipation.

Emergency Stop

The motor controller should be wired using an external contactor or relay to ultimately control the main power input. A second power source should be used to power the logic section in situations where the main power will be under heavy load. Voltage drops can occur from constant full load or high speed direction changes. Voltage drop can cause logic brown outs if only a main battery is used without a logic battery.

USB

The motor controllers USB port should be used for configuration and debugging. The USB protocol is not designed for electrically noisy environments. The USB port will likely disconnect and not automatically recover during operation in electrically noisy environments. To recover from a dropped USB port, the motor controllers USB cable would require unplugging and re-plugging. The TTL serial control should be the preferred method of control in electrically noisy environments.

Firmware Updates

Firmware updates will be made available to add new features or resolve any technical issue. It is recommended to update to the latest firmware. Firmware updates are handled by the IonMotion PC utility. IonMotion is free to download from Ionmc.com. Once IonMotion is installed, connect the motor controller to your computer running Windows 7 or newer. Once IonMotion is launched it will detect the attached motor controller, then attempt to download the latest firmware from Ionmc.com website before performing the update. Before updating the motor controllers firmware, ensure you have adequate power and no interruptions will occur while the update is in progress.

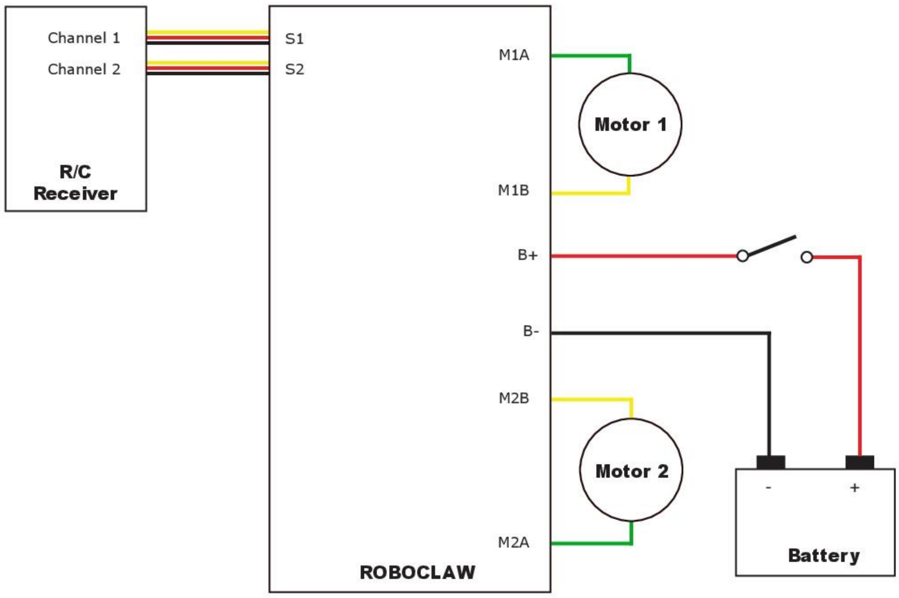
Wiring Basics

There are several wiring configurations for RoboClaw. Each configuration will have unique wiring requirements to ensure safe and reliable operation. The diagram below illustrates a very basic wiring configuration used in a small motor system where safety concerns are minimal. This is the most basic wiring configuration possible. All uses of RoboClaw should include some kind of main battery shut off switch, even when safety concerns are minimal. Never underestimate a system with movement when an uncontrolled situation arises.

In addition, RoboClaw is a regenerative motor controller. If the motors are moved when the system is off, it could cause potential erratic behavior due to the regenerative voltages powering the system. The regenerative voltages can will cause problems if a power supply is used to power RoboClaw. A voltage clamping circuit is required to dump the excessive voltages. See the RoboClaw user manual for voltage clamping setup and wiring diagrams.

R/C Mode

The below wiring diagram is very basic and for use with R/C mode. R/C mode is used when the RoboClasw is paired with a radio controller or microcontroller and controlled by PWM servo pulses like in a standard R/C system. The RoboClaw supplies power to the R/C system. If the R/C receiver used, has its own power the 5V pin on the 3 pin header must be remove otherwise it will interfere with RoboClaw's BEC.

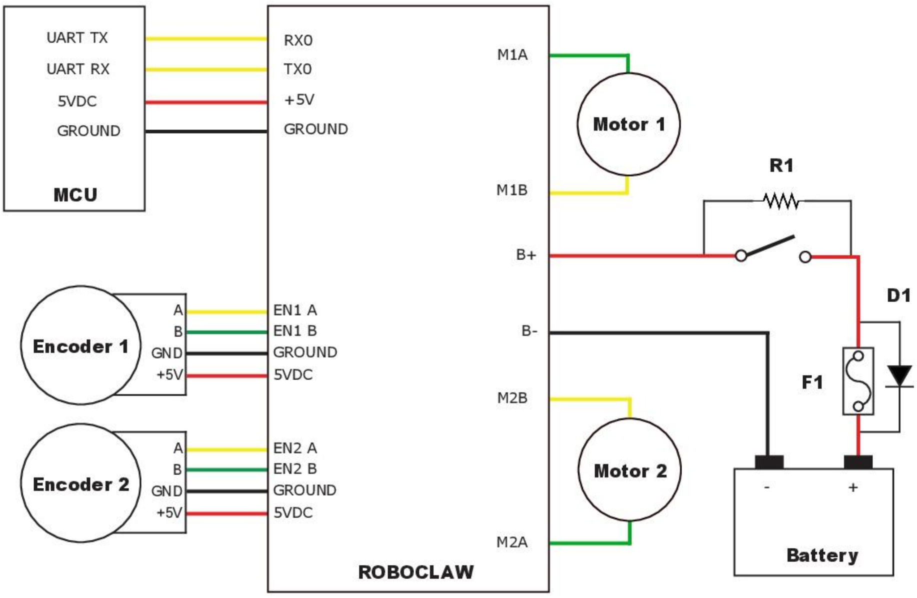


Wiring Safety

In all system with movement, safety is a concern. The wiring diagram below illustrates a properly wired system for safety. An external main power cut off is required for safety. When the RoboClaw is switched off or the fuse is blown, a high current diode (D1) is required to create a return path to the battery for any regenerative voltages. The use of a pre-charge resistor (R1) is required to avoid high inrush currents and arcing. A pre-charge resistor (R1) should be 1K, 1/2Watt for a 60VDC motor controller which will give a pre-charge time of about 15 seconds. A lower resistances can be used with lower voltages to decrease the pre-charge time.

Closed Loop Mode

A wide range of sensors are supported for closed loop operation. RoboClaw supports dual quadrature encoders (up to 19.6 million QPPS), absolute encoders, potentiometers and hall effect sensors. The wiring diagram below is an example of closed loop mode using quadrature encoders. Quadrature encoders are directional. RoboClaw's internal counters will increment for clockwise rotation (CW) and decrement for counter clockwise rotation (CCW). When wiring encoders A and B channels it is important they are wired to match the direction of the motor. If the encoder is wired in reverse it can cause a run away condition. All motor and encoder combinations will need to be tuned (see the RoboClaw user manual).

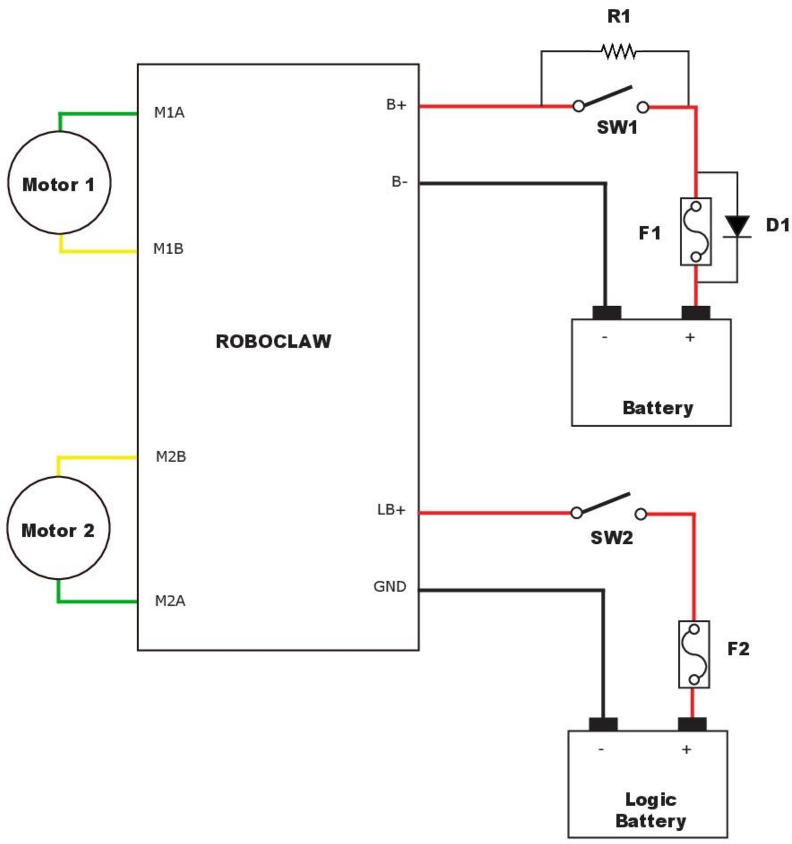


Logic Battery

An optional logic battery is supported. Under heavy loads the main power can suffer voltage drops, causing potential logic brown outs which may result in uncontrolled behavior. A separate power source for the motor controllers logic circuits, can remedy potential problems from main power voltage drops. The logic battery maximum input voltage is 34VDC with a minimum input voltage of 6VDC. The 5V regulated user output is supplied by the secondary logic battery if supplied. The mAh of the logic battery should be determined based on the load of attached devices powered by the regulated 5V user output.

Logic Battery Jumper

The configuration below utilizes a logic battery. Some models of RoboClaw have a logic battery jumper. On models where the LB-MB header is present the jumper must be removed when using a seperate logic battery. If the header for LB-MB is not present, then the RoboClaw will automatically set the logic battery power source.

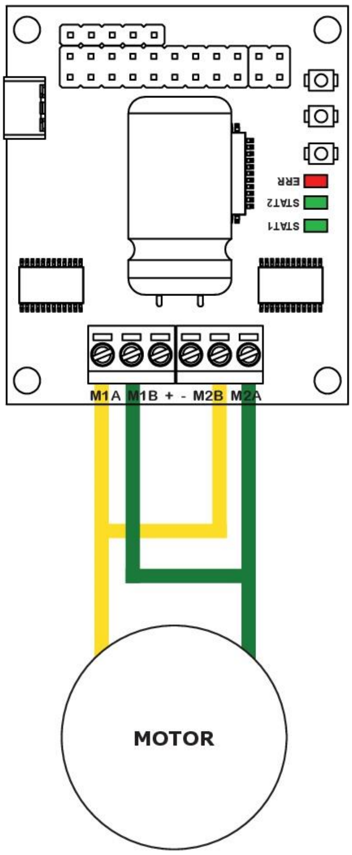


Bridging Channels

RoboClaws dual channels can be bridge to run as one channel, effectively doubling its current capability for one motor. Damage will result if RoboClaw is not set to bridged channel mode before wiring. Download and install IonMotion PC setup utility. Connect the motor controller to the computer using an available USB port. Run IonMotion and in general settings check the option to combine channels. Then click "Save Settings" in the device menu. When operating in bridged channel mode the total peak current output is combined from both channels. The peak current run time is dependant on heat build up. Adequate cooling must be maintained. For more information see the RoboClaw user manual.

Bridged Channel Wiring

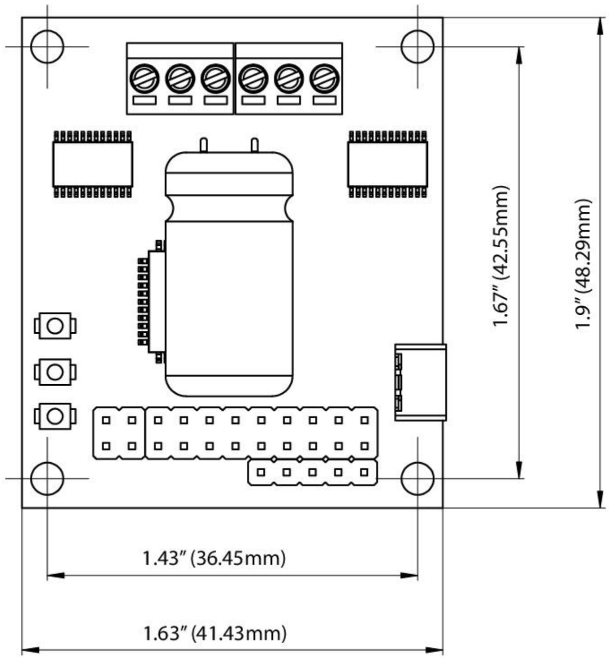
When bridged channel mode is active the internal driver scheme for the output stage is modified. The output leads must be wired correctly or damage will result. One side of the motor is connected to M1A and M2B. The other side of the motor is then connected to M1B and to M2A.

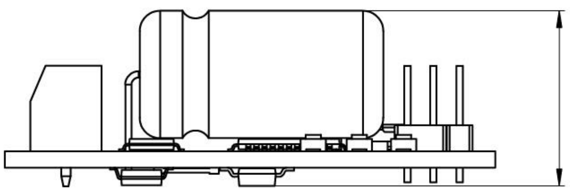


Mechanical Specifications

Characteristic	Model	Min	Typ	Max	Rating
Weight	2X7A		0.65 (18)		Oz (g)

Dimensions





Electrical Specifications

Characteristic	Min	Typ	Max	Rating
Main Battery	6		34	VDC
Logic Battery	6	12	34	VDC
Maximum External Current Draw (BEC)			1.2	A
Motor Current Per Channel		7(2)	15(1,2)	A
Motor Current Bridged		15(2)	30(1,2)	
On Resistance		10		mOhm
Logic Circuit Current Draw		90mA		mA
Input Impedance		100		Ω
Input	0		5	VDC
Input Low	-0.3		0.8	VDC
Input High	2		5	VDC
I/O Output Voltage	0		3.3	VDC
Digital and Analog Input Voltage			5	VDC
Analog Useful Range	0		2	VDC
Analog Resolution		1		mV
Pulse Width	1		2	mS
Encoder Counters		32		Bits
Encoder Frequency			19.66	Mhz
RS232 Baud Rate (Note 3)			460,800	Bits/s
RS232 Time Out (Note 3)	10			ms
Temperature Range	-40	40	100	°C
Temperature Protection Range	85		100	°C
Humidity Range			100 (4)	%

Notes:

1. Peak current is automatically reduced to the typical current limit as temperature approaches 85°C.
2. Current is limited by maximum temperature. Starting at 85°C, the current limit is reduced on a slope with a maximum temperature of 100°C, which will reduce the current to 0 amps. Current ratings are based on ambient temperature of 25°C.
3. RS232 format is 8Bit, No Parity and 1 Stop bit.
4. Condensing humidity will damage the motor controller.

Warranty

Ion Motion Control warranties its products against defects in material and workmanship for a period of 1 year. If a defect is discovered, Ion Motion Control will, at our discretion, repair, replace, or refund the purchase price of the product in question. Contact us at sales@ionmc.com. No returns will be accepted without the proper authorization.

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Disclaimer

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Contacts

Email: sales@ionmc.com
Tech support: support@ionmc.com
Web: http://www.ionmc.com

Discussion List

A web based discussion board is maintained at http://www.ionmc.com

Technical Support

Technical support is available by sending an email to support@ionmc.com, by opening a support ticket on the Ion Motion Control website or by calling 800-535-9161 during normal operating hours. All email will be answered within 48 hours.

I.4 Hojas técnicas Módulo GY-283. FUENTE: HONEYWELL

3-Axis Digital Compass IC HMC5983

Honeywell

Advanced Information

The Honeywell HMC5983 is a temperature compensated three-axis integrated circuit magnetometer. This surface-mount, multi-chip module is designed for low-field magnetic sensing for applications such as automotive and personal navigation, vehicle detection, and pointing.

The HMC5983 includes our state-of-the-art, high-resolution HMC118X series magnetoresistive sensors plus an ASIC containing amplification, automatic degaussing strap drivers, offset cancellation, and a 12-bit ADC that enables 1° to 2° compass heading accuracy. The I²C or SPI serial bus allows for easy interface. The HMC5983 is a 3.0x3.0x0.9mm surface mount 16-pin leadless chip carrier (LCC).

The HMC5983 utilizes Honeywell's Anisotropic Magnetoresistive (AMR) technology that provides advantages over other magnetic sensor technologies. Honeywell's anisotropic, directional sensors excel in linearity, low hysteresis, null output and scale factor stability over temperature, and with very low cross-axis sensitivity. These sensors' solid-state construction is designed to measure both the direction and the magnitude of magnetic fields, from milli-gauss to 8 gauss. Honeywell's Magnetic Sensors are among the most sensitive and reliable low-field sensors in the industry.

FEATURES	BENEFIT
3-Axis Magnetoresistive Sensors and ASIC in a 3.0x3.0x0.9mm LCC Surface Mount Package	Small size for Highly Integrated Products. Just add a micro-controller interface, plus two external SMT Capacitors designed for high volume, cost sensitive OEM Designs. Easy to assemble & compatible with High Speed SMT Assembly.
Temperature Compensated Data Output and Temperature Output	Automatically maintains sensor's sensitivity under wide operating temperature range
Automatic Offset Compensation	Maximizes sensor's full dynamic range and resolution
12-Bit ADC Coupled with Low Noise AMR Sensors Achieves 2 milli-gauss Field Resolution	Enables 1° to 2° degree compass heading accuracy
I²C (Standard, Fast, High-Speed modes) or SPI Digital Interface	High-speed interfaces for fast data communications. I²C up to 3.4 MHz and SPI up to 8.0 MHz
Fast 220 Hz Maximum Output Rate	Enables Pedestrian Navigation and LBS Applications
Built-in Self Test	Enables low-cost functionality test after assembly in production
Low Voltage Operations (2.16 to 3.6V) and Low Power Consumption (100 µA)	Compatible for battery powered applications
Built-In Strap Drive Circuits	Set/reset and offset strap drivers for degaussing, self test, and offset compensation. Eliminates sensor calibration necessary for other magnetic sensor technologies.
Lead Free Package Construction	RoHS Compliance
Wide Magnetic Field Range (+/-8 Oe)	Sensors can be used in strong magnetic field environments with a 1° to 2° degree compass heading accuracy
Software and Algorithm Support Available	Compassing Heading, Hard Iron, Soft Iron, and Auto Calibration libraries available

HMC5983

SPECIFICATIONS (* Tested and specified at 25°C except stated otherwise.)

Characteristics	Conditions*	Min	Typ	Max	Units
Power Supply					
Supply Voltage	VDD Referenced to AGND VDDIO Referenced to DGND	2.16 1.71	2.5 1.8	3.6 VDD+0.1	Volts Volts
Average Current Draw	Idle Mode Measurement Mode (7.5 Hz ODR; No measurement average, MA1:MA0 = 00) Specified at: VDD = 2.5V, VDDIO = 1.8V	- -	2 100	- -	μA μA
Performance					
Field Range	Full scale (FS)	-8		+8	gauss
Mag Dynamic Range	3-bit gain control	±1		±8	gauss
Sensitivity (Gain)	VDD=3.0V, GN=0 to 7, 12-bit ADC	230		1370	LSb/gauss
Digital Resolution	VDD=3.0V, GN=0 to 7, 1-LSb, 12-bit ADC	0.73		4.35	milli-gauss
Noise Floor (Field Resolution)	VDD=3.0V, GN=0, No measurement average, Standard Deviation 100 samples (See typical performance graphs below)		2		milli-gauss
Linearity	±2.0 gauss input range			0.1	±% FS
Hysteresis	±2.0 gauss input range		±25		ppm
Cross-Axis Sensitivity	Test Conditions: Cross field = 0.5 gauss, Happlied = ±3 gauss		±0.2%		%FS/gauss
Output Rate (ODR)	Continuous Measurment Mode Single Measurement Mode	0.75		220 160	Hz
Measurement Period	From receiving command to data ready		6		ms
Turn-on Time	Ready for I²C commands Analog Circuit Ready for Measurements		200 50		μs ms
Gain Tolerance	All gain/dynamic range settings		±5		%
I²C Address	8-bit read address 8-bit write address		0x3D 0x3C		hex
Clock Rate	Controlled by I²C /SPI Master I²C SPI			 3400 8000	kHz
I²C Hysteresis	Hysteresis of Schmitt trigger inputs on SCL and SDA - Fall (VDDIO=1.8V) Rise (VDDIO=1.8V)		0.2*VDDIO 0.8*VDDIO		Volts
Self Test	X & Y Axes Z Axis		±1.16 ±1.08		gauss
	X & Y & Z Axes (GN=5) Positive Bias X & Y & Z Axes (GN=5) Negative Bias	243 -575		575 -243	LSb
Temperature Sensor Accuracy	3σ at T ≥ 0°C 3σ at T = -25°C 3σ at T = -40°C			7 11 14	°C
Sensitivity Tempco	T_A = -40 to 85°C, Compensated Output Temperature Sensor On		-0.03 (3σ =0.12)		%/°C

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Characteristics	Conditions*	Min	Typ	Max	Units
General					
ESD Voltage	Human Body Model (all pins) Charged Device Model (all pins)			2000 750	Volts
Operating Temperature	Ambient	-30		85	°C
Storage Temperature	Ambient, unbiased	-40		125	°C
Reflow Classification	MSL 3, 260 °C Peak Temperature				
Package Size	Length and Width	2.85	3.00	3.15	mm
Package Height		0.8	0.9	1.0	mm
Package Weight			18		mg

Absolute Maximum Ratings (* Tested at 25°C except stated otherwise.)

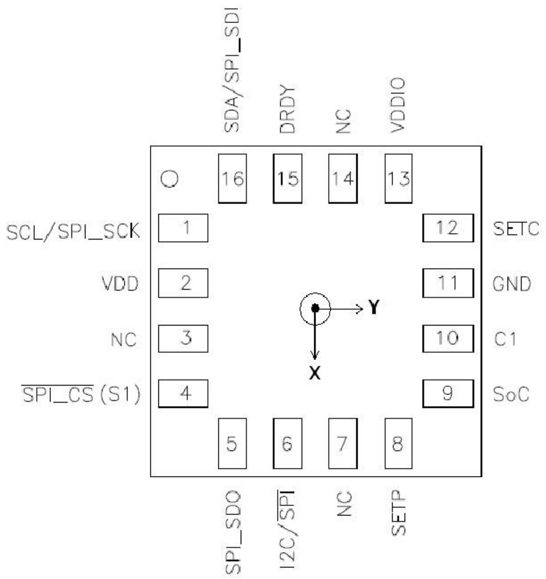
Characteristics	Min	Max	Units
Supply Voltage VDD	-0.3	4.8	Volts
Supply Voltage VDDIO	-0.3	4.8	Volts
Reflow Classification	MSL 3, 260 °C Peak Temperature		

PIN CONFIGURATIONS

Table 1: Pin Configurations

Pin	Name	Description
1	SCL/SPI_SCK	Serial Clock – I^2C Master/Slave Clock or SPI Serial Clock
2	VDD	Power Supply (2.16V to 3.6V)
3	NC	Not to be Connected
4	SPI_CS	Chip Select line for SPI (active low). Tie to VDDIO for I^2C Interface
5	SPI_SDO	SPI Serial Data Out
6	I^2C /~SPI	I^2C / SPI selection pin. Connect to VDD for I^2C (Also connect SPI_CS to VDDIO). Connect to GND for SPI.
7	NC	Not to be Connected
8	SETP	Set/Reset Strap Positive – S/R Capacitor (C2) Connection
9	SoC	Start of Conversion (leading edge active) Connect to Ground when this function/pad is not used in application.
10	C1	Reservoir Capacitor (C1) Connection
11	GND	Supply Ground
12	SETC	S/R Capacitor (C2) Connection – Driver Side
13	VDDIO	IO Power Supply (1.71V to VDD)
14	NC	Not to be Connected. No internal connection.
15	DRDY	Data Ready, Interrupt Pin. Internally pulled high. Optional connection. Low for >200 µsec when data are placed in the data output registers.
16	SDA/SPI_SDI	Serial Data – I^2C Master/Slave Data or SPI Serial Data In or SPI Serial Data I/O (SDI/O) for 3-wire interface

HMC5983

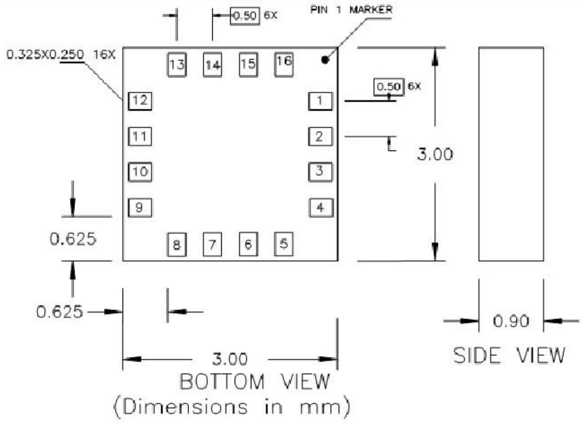


TOP VIEW (Looking Through)

Arrow indicates direction of magnetic field that generates a positive output reading in Normal Measurement configuration.

PACKAGE OUTLINES

PACKAGE DRAWING HMC5983 (16-PIN LPCC, dimensions in millimeters)



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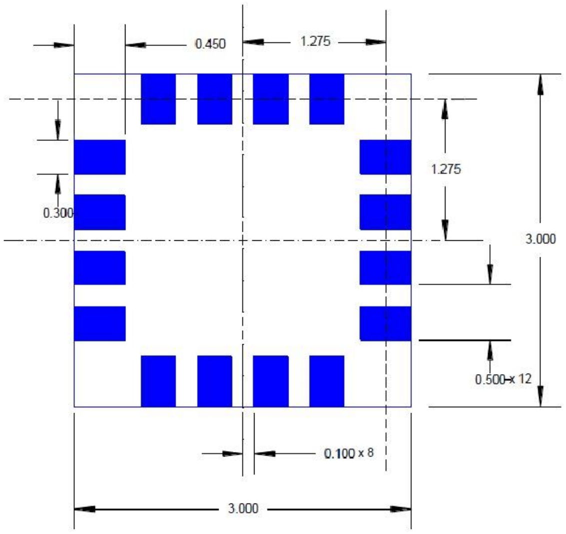
MOUNTING CONSIDERATIONS

The following is the recommend printed circuit board (PCB) footprint for the HMC5983.



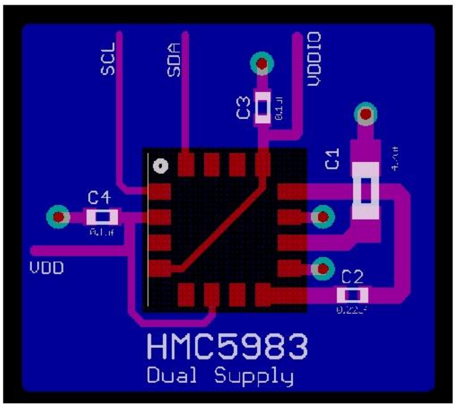
HMC5983 Land Pad Pattern
(All dimensionsare in mm)

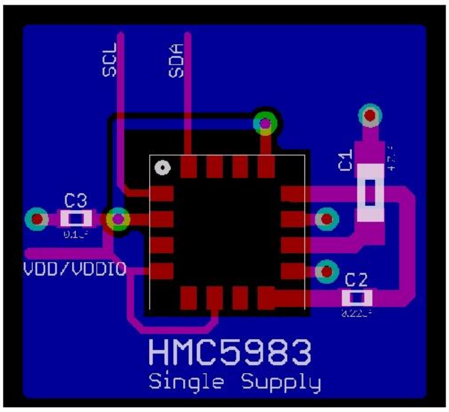
LAYOUT CONSIDERATIONS

Besides keeping all components that may contain ferrous materials (nickel, etc.) away from the sensor on both sides of the PCB, it is also recommended that there is no conducting copper under/near the sensor in any of the PCB layers. See recommended layout below.

I²C Layout Examples: Notice that the one trace under the sensor in the dual supply mode is not expected to carry active current since it is for pin 4 pull-up to VDDIO. Power and ground planes are removed under the sensor to minimize possible source of magnetic noise. For best results, use non-ferrous materials for all exposed copper coding.

HMC5983





**Layout examples are for I^2C (dual supply and single supply) modes only.*

PCB Pad Definition and Traces

The HMC5983 is a fine pitch LCC package. Refer to previous figure for recommended PCB footprint for proper package centering. Size the traces between the HMC5983 and the external capacitors (C1 and C2) to handle the 1 ampere peak current pulses with low voltage drop on the traces.

Stencil Design and Solder Paste

A 4 mil stencil and 100% paste coverage is recommended for the electrical contact pads.

Reflow Assembly

This device is classified as MSL 3 with 260°C peak reflow temperature. As specified by JEDEC, parts with an MSL 3 rating require baking prior to soldering if the part is not kept in a continuously dry (< 10% RH) environment before assembly. Refer to Table 4-1 "Reference Conditions for Drying Mounted or Unmounted SMD Packages" in the IPC/JEDEC standard J-STD-033 "Handling, Packing, Shipping and Use of Moisture/Reflow Sensitive Surface Mount Devices" for additional information.No special reflow profile is required for HMC5983, which is compatible with lead eutectic and lead-free solder paste reflow profiles. Honeywell recommends adherence to solder paste manufacturer's guidelines. Hand soldering is not recommended. Built-in self test can be used to verify device functionalities after assembly.

External Capacitors

The two external capacitors should be ceramic type construction with low ESR characteristics. The exact ESR values are not critical but values less than 200 milli-ohms are recommended. Reservoir capacitor C1 is nominally 4.7 µF in capacitance, with the set/reset capacitor C2 nominally 0.22 µF in capacitance. Low ESR characteristics may not be in many small SMT ceramic capacitors (0402), so be prepared to up-size the capacitors to gain Low ESR characteristics.

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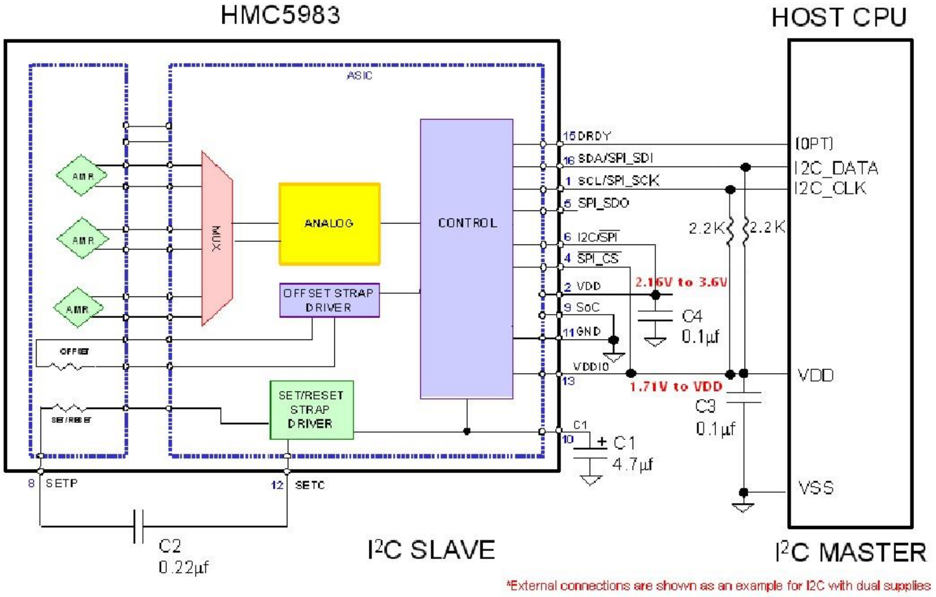
INTERNAL SCHEMATIC DIAGRAM
HMC5983



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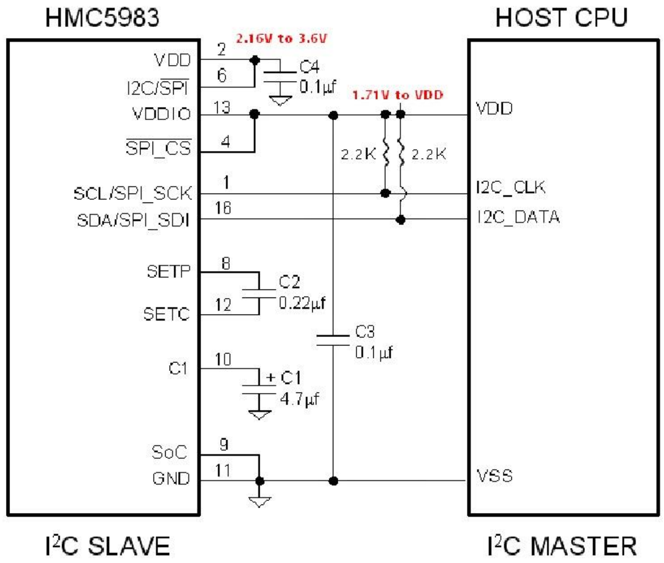
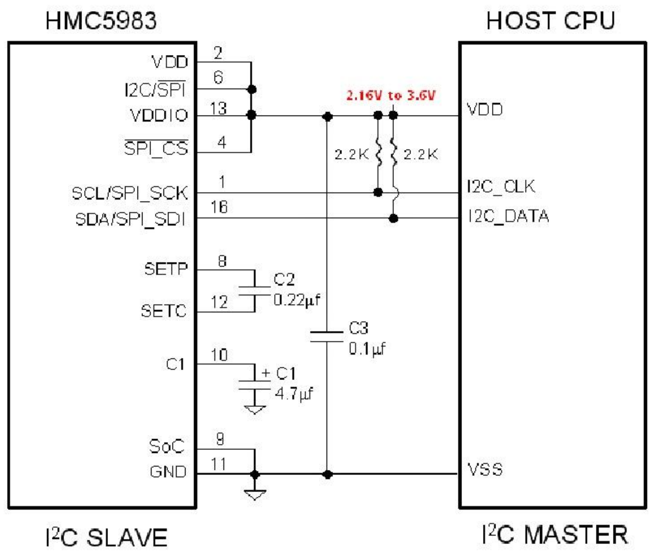
DUAL SUPPLY REFERENCE DESIGN (I²C)

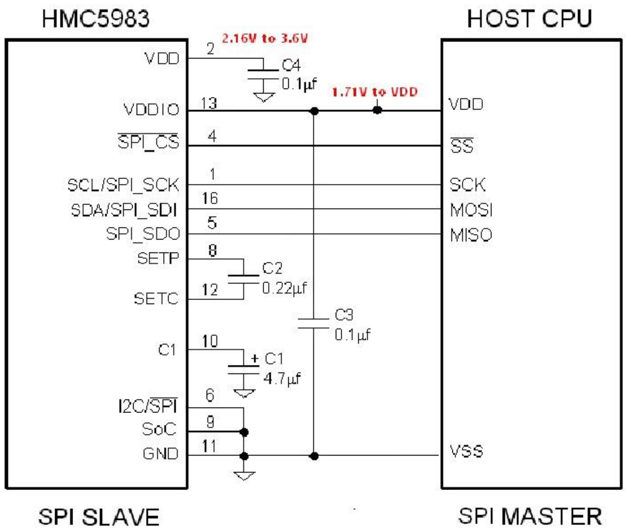


SINGLE SUPPLY REFERENCE DESIGN (I²C)

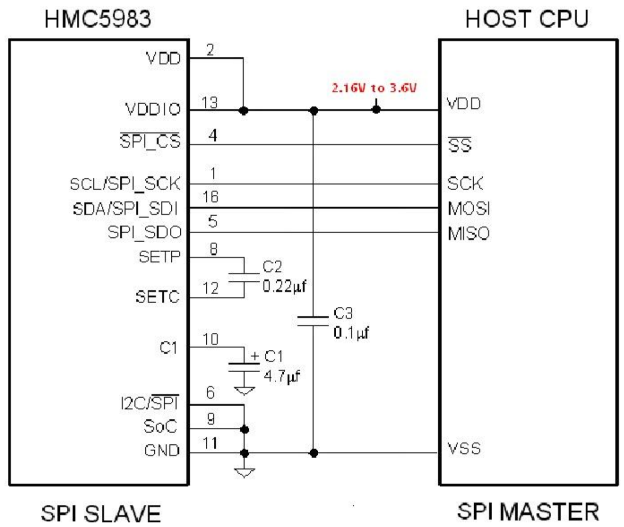


HMC5983

DUAL SUPPLY REFERENCE DESIGN (SPI)



SINGLE SUPPLY REFERENCE DESIGN (SPI)



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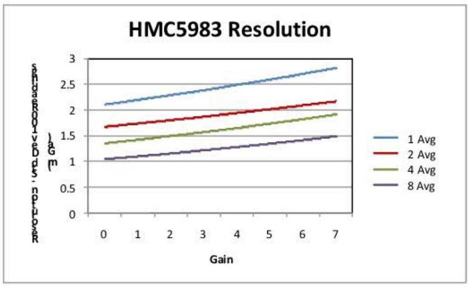
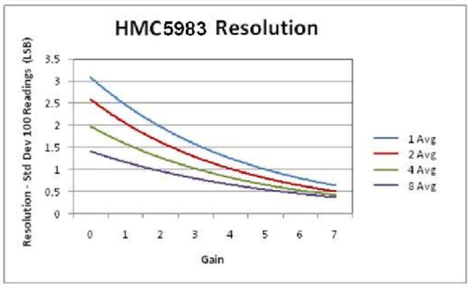
PERFORMANCE

The following graph(s) highlight HMC5983's performance.

Typical Noise Floor (Field Resolution)





BASIC DEVICE OPERATION

Anisotropic Magneto-Resistive Sensors

The Honeywell HMC5983 magnetoresistive sensor circuit is a trio of sensors and application specific support circuits to measure magnetic fields. With power supply applied, the sensor converts any incident magnetic field in the sensitive axis directions to a differential voltage output. The magnetoresistive sensors are made of a nickel-iron (Permalloy) thin-film and patterned as a resistive strip element. In the presence of a magnetic field, a change in the bridge resistive elements causes a corresponding change in voltage across the bridge outputs.

These resistive elements are aligned together to have a common sensitive axis (indicated by arrows in the pinout diagram) that will provide positive voltage change with magnetic fields increasing in the sensitive direction. Because the output is only proportional to the magnetic field component along its axis, additional sensor bridges are placed at orthogonal directions to permit accurate measurement of magnetic field in any orientation.

Self Test

To check the HMC5983 for proper operation, a self test feature is incorporated in which the sensor is internally excited with a nominal magnetic field (in either positive or negative bias configuration). This field is then measured and reported. This function is enabled and the polarity is set by bits MS[n] in the configuration register A. An internal current source generates a DC current (about 10 mA) from the VDD supply. This DC current is applied to the offset straps of the magneto-resistive sensor, which creates an artificial magnetic field on the sensor. The difference of this measurement and the measurement of the ambient field will be put in the data output register for each of the three axes. By using this built-in function, the manufacturer can quickly verify the sensor's full functionality after the assembly without additional test setup. The self test results can also be used to estimate/compensate the sensor's sensitivity drift due to temperature.

For each "self test measurement", the ASIC:

1. Sends a "Set" pulse
2. Takes one measurement (M1)
3. Sends the (~10 mA) offset current to generate the (~1.1 Gauss) offset field and takes another measurement (M2)
4. Puts the difference of the two measurements in sensor's data output register:

   Output = [M2 – M1] (i.e. output = offset field only)

See SELF TEST OPERATION section later in this datasheet for additional details.

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Power Management

This device has two different domains of power supply. The first one is VDD that is the power supply for internal operations and the second one is VDDIO that is dedicated to IO interface. It is possible to work with VDDIO equal to VDD; Single Supply mode, or with VDDIO lower than VDD allowing HMC5983 to be compatible with other devices on board.

Communication Bus Interface

This device will be connected to a serial interface bus as a slave device under the control of a master device, such as the processor. Control of this device is carried out via I²C or SPI interfaces. Use pin 6 (I²C /~SPI) to select between I²C and SPI interface modes.

I²C Interface

This device is compliant with *I²C -Bus Specification*, document number: 9398 393 40011. As an I²C compatible device, this device has a 7-bit serial address and supports I²C protocols. This device supports standard, fast, and high speed modes, 100kHz, 400kHz, and 3400kHz, respectively. External pull-up resistors are required to support all these modes.

Activities required by the master (register read and write) have priority over internal activities, such as the measurement. The purpose of this priority is to not keep the master waiting and the I²C bus engaged for longer than necessary.

SPI Interface

This device is compliant with both 4-wire and 3-wire SPI interface standards. Selection 3-wire mode is by setting SIM (SPI serial interface mode selection) bit (MR2) in mode register to 1. See SPI Communication Protocol section later in this datasheet for additional details.

Internal Clock

The device has an internal clock for internal digital logic functions and timing management. This clock is not available to external usage.

H-Bridge for Set/Reset Strap Drive

The ASIC contains large switching FETs capable of delivering a large but brief pulse to the Set/Reset strap of the sensor. This strap is largely a resistive load. There is no need for an external Set/Reset circuit. The controlling of the Set/Reset function is done automatically by the ASIC for each measurement. One half of the difference from the measurements taken after a set pulse and after a reset pulse will be put in the data output register for each of the three axes. By doing so, the sensor's internal offset and its temperature dependence is removed/cancelled for all measurements. The set/reset pulses also effectively remove the past magnetic history (magnetism) in the sensor, if any.

For each "measurement", the ASIC:

1. Sends a "Set" pulse
2. Takes one measurement (Mset)
3. Sends a "Reset" pulse
4. Takes another measurement (Mreset)
5. Puts the following result in sensor's data output register:

   Output = [Mset – Mreset] / 2

Charge Current Limit

The current that reservoir capacitor (C1) can draw when charging is limited for both single supply and dual supply configurations. This prevents drawing down the supply voltage (VDD).

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Temperature Compensation

Temperature compensation of the measured magnetic data is enabled by default at the factory. Temperature measured by the built-in temperature sensor will be used to compensate the sensor's sensitivity change due to temperature based on the sensor's typical sensitivity temperature coefficient. The compensated data will be placed in the Data Output Registers automatically. Temperature sensor must be enabled (set CRA7 =1) for compensation to work.

Temperature Output

HMC5983 has a built-in temperature sensor that its output can be enabled by setting bit 7 of Configuration Register A (CRA7). This bit is disabled at power-on by default. When this feature is enabled, a temperature measurement will be taken at each magnetic measurement and the output is placed in Temperature Output Registers (0x31 and 0x32).

Automatic Offset Compensation

HMC5983 automatically adjusts the sensor's internal (bridge) offset to zero before each measurement is taken. This feature allows the full dynamic range of the sensor to be available for measuring the external magnetic field. This feature is particularly important when the gain setting is high (lower GN#) because the dynamic range is smaller at higher gain. As long as the sensor does not saturate within the full range of the external field to be measured, higher gain usually means better resolution and better accuracy.

MODES OF OPERATION

This device has several operating modes whose primary purpose is power management and is controlled by the Mode Register. This section describes these modes.

Continuous-Measurement Mode

During continuous-measurement mode, the device continuously makes measurements, at user selectable rate, and places measured data in data output registers. Data can be re-read from the data output registers if necessary; however, if the master does not ensure that the data register is accessed before the completion of the next measurement, the data output registers are updated with the new measurement. To conserve current between measurements, the device is placed in a state similar to idle mode, but the Mode Register is not changed to Idle Mode. That is, MD[n] bits are unchanged. Settings in the Configuration Register A affect the data output rate (bits DO[n]), the measurement configuration (bits MS[n]), when in continuous-measurement mode. All registers maintain values while in continuous-measurement mode. The I²C bus is enabled for use by other devices on the network in while continuous-measurement mode.

Single-Measurement Mode

This is the default power-up mode. During single-measurement mode, the device makes a single measurement and places the measured data in data output registers. After the measurement is complete and output data registers are updated, the device is placed in idle mode, and the Mode Register *is* changed to idle mode by setting MD[n] bits. Settings in the configuration register affect the measurement configuration (bits MS[n]) when in single-measurement mode. All registers maintain values while in single-measurement mode. The I²C bus is enabled for use by other devices on the network while in single-measurement mode.

Idle Mode

During this mode the device is accessible through the I²C bus, but major sources of power consumption are disabled, such as, but not limited to, the ADC, the amplifier, and the sensor bias current. All registers maintain values while in idle mode. The I²C bus is enabled for use by other devices on the network while in idle mode.

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REGISTERS

This device is controlled and configured via a number of on-chip registers, which are described in this section. In the following descriptions, *set* implies a logic 1, and *reset* or *clear* implies a logic 0, unless stated otherwise.

Register List
The table below lists the registers and their access. All address locations are 8 bits.

Table2: Register List

Address Location		Name	Access
00	0x00	Configuration Register A	Read/Write
01	0x01	Configuration Register B	Read/Write
02	0x02	Mode Register	Read/Write
03	0x03	Data Output X MSB Register	Read
04	0x04	Data Output X LSB Register	Read
05	0x05	Data Output Z MSB Register	Read
06	0x06	Data Output Z LSB Register	Read
07	0x07	Data Output Y MSB Register	Read
08	0x08	Data Output Y LSB Register	Read
09	0x09	Status Register	Read
10	0x0A	Identification Register A	Read
11	0x0B	Identification Register B	Read
12	0x0C	Identification Register C	Read
49	0x31	Temperature Output MSB Register	Read
50	0x32	Temperature Output LSB Register	Read

Register Access

This section describes the process of reading from and writing to this device. The devices uses an address pointer to indicate which register location is to be read from or written to. These pointer locations are sent from the master to this slave device and succeed the 7-bit address (0x1E) plus 1 bit read/write identifier, i.e. 0x3D for read and 0x3C for write.

To minimize the communication between the master and this device, the address pointer updated automatically without master intervention. The register pointer will be incremented by 1 automatically after the current register has been read successfully.

The address pointer value itself cannot be read via the I²C bus.
Any attempt to read an invalid address location returns 0's, and any write to an invalid address location or an undefined bit within a valid address location is ignored by this device.

To move the address pointer to a random register location, first issue a "write" to that register location with no data byte following the commend. For example, to move the address pointer to register 10, send 0x3C 0x0A.

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Configuration Register A

The configuration register is used to configure the device for setting the data output rate and measurement configuration. CRA0 through CRA7 indicate bit locations, with *CRA* denoting the bits that are in the configuration register. CRA7 denotes the first bit of the data stream. The number in parenthesis indicates the default value of that bit.CRA default is 0x10.

Table 3: Configuration Register A

CRA7	**CRA6**	**CRA5**	**CRA4**	**CRA3**	**CRA2**	**CRA1**	**CRA0**
(0)	MA1(0)	MA0(0)	DO2 (1)	DO1 (0)	DO0 (0)	MS1 (0)	MS0 (0)

Table 4: Configuration Register A Bit Designations

Location	**Name**	**Description**
CRA7	TS	Set this bit to enable temperature sensor. Temperature sensor will be measured at each magnetic measurement. Enable Temperature sensor for automatic compensation of Sensitivity over temperature.
CRA6 to CRA5	MA1 to MA0	Select number of samples averaged (1 to 8) per measurement output. 00 = 1(Default); 01 = 2; 10 = 4; 11 = 8
CRA4 to CRA2	DO2 to DO0	Data Output Rate Bits. These bits set the rate at which data is written to all three data output registers.
CRA1 to CRA0	MS1 to MS0	Measurement Configuration Bits. These bits define the measurement flow of the device, specifically whether or not to incorporate an applied bias into the measurement.

The Table below shows all selectable output rates in continuous measurement mode. All three channels shall be measured within a given output rate. Other output rates with maximum rate of 160 Hz can be achieved by monitoring DRDY interrupt pin in single measurement mode.

Table 5: Data Output Rates

DO2	**DO1**	**DO0**	**Typical Data Output Rate (Hz)**
0	0	0	0.75
0	0	1	1.5
0	1	0	3
0	1	1	7.5
1	0	0	15 (Default)
1	0	1	30
1	1	0	75
1	1	1	220

Table 6: Measurement Modes

MS1	MS0	Measurement Mode
0	0	Normal measurement configuration (Default). In normal measurement configuration the device follows normal measurement flow. The positive and negative pins of the resistive load are left floating and high impedance.
0	1	Positive bias configuration for X, Y, and Z axes. In this configuration, a positive current is forced across the resistive load for all three axes.
1	0	Negative bias configuration for X, Y and Z axes. In this configuration, a negative current is forced across the resistive load for all three axes.
1	1	Temperature sensor only. Magnetic sensor will not be enabled during measurement.

Configuration Register B

The configuration register B for setting the device gain. CRB0 through CRB7 indicate bit locations, with *CRB* denoting the bits that are in the configuration register. CRB7 denotes the first bit of the data stream. The number in parenthesis indicates the default value of that bit. CRB default is 0x20.

Table 7: Configuration B Register

CRB7	CRB6	CRB5	CRB4	CRB3	CRB2	CRB1	CRB0
GN2 (0)	GN1 (0)	GN0 (1)	(0)	(0)	(0)	(0)	(0)

Table 8: Configuration Register B Bit

Designations Location	Name	Description
CRB7 to CRB5	GN2 to GN0	Gain Configuration Bits. These bits configure the gain for the device. The gain configuration is common for all channels.
CRB4 to CRB0	N/A	These bits must be cleared for correct operation.

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The table below shows nominal gain settings. Use the "Gain" column to convert counts to Gauss. The "Digital Resolution" column is the theoretical value in term of milli-Gauss per count (LSb) which is the inverse of the values in the "Gain" column. The effective resolution of the usable signal also depends on the noise floor of the system, i.e.

Effective Resolution = Max (Digital Resolution, Noise Floor)

Choose a lower gain value (higher GN#) when total field strength causes overflow in one of the data output registers (saturation). Note that the very first measurement after a gain change maintains the same gain as the previous setting. The new gain setting is effective from the second measurement and on.

Table 9: Gain Settings

GN2	GN1	GN0	Recommended Sensor Field Range	Gain (LSb/ Gauss)	Digital Resolution (mG/LSb)	Output Range
0	0	0	± 0.88 Ga	1370	0.73	0xF800–0x07FF (-2048–2047)
0	0	1	± 1.3 Ga	1090 (default)	0.92	0xF800–0x07FF (-2048–2047)
0	1	0	± 1.9 Ga	820	1.22	0xF800–0x07FF (-2048–2047)
0	1	1	± 2.5 Ga	660	1.52	0xF800–0x07FF (-2048–2047)
1	0	0	± 4.0 Ga	440	2.27	0xF800–0x07FF (-2048–2047)
1	0	1	± 4.7 Ga	390	2.56	0xF800–0x07FF (-2048–2047)
1	1	0	± 5.6 Ga	330	3.03	0xF800–0x07FF (-2048–2047)
1	1	1	± 8.1 Ga	230	4.35	0xF800–0x07FF (-2048–2047)

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Mode Register

The mode register is an 8-bit register from which data can be read or to which data can be written. This register is used to select the operating mode of the device. MR0 through MR7 indicate bit locations, with *MR* denoting the bits that are in the mode register. MR7 denotes the first bit of the data stream. The number in parenthesis indicates the default value of that bit. Mode register default is 0x01.

Table 10: Mode Register

MR7	MR6	MR5	MR4	MR3	MR2	MR1	MR0
(0)	(0)	(0)	(0)	(0)	(0)	MD1 (0)	MD0 (1)

Table 11: Mode Register Bit Designations

Location	Name	Description
MR7	HS	Set this pin to enable I²C High Speed mode, 3400 kHz.
MR6	N/A	Clear this bit for correct operation.
MR5	LP	Lowest power mode. When set, ODR=0.75 Hz, and Averaging = 1.
MR4	N/A	This bit has no functionality.
MR3	N/A	Clear this bit for correct operation.
MR2	SIM	SPI serial interface mode selection: 0: 4-wire SPI interface 1: 3-wire SPI interface
MR1 to MR0	MD1 to MD0	Mode Select Bits. These bits select the operation mode of this device.

Table 12: Operating Modes

MD1	MD0	Operating Mode
0	0	Continuous-Measurement Mode. In continuous-measurement mode, the device continuously performs measurements and places the result in the data register. RDY goes high when new data is placed in all three registers. After a power-on or a write to the mode or configuration register, the first measurement set is available from all three data output registers after a period of $2/f_{DO}$ and subsequent measurements are available at a frequency of f_{DO}, where f_{DO} is the frequency of data output.
0	1	Single-Measurement Mode (Default). When single-measurement mode is selected, device performs a single measurement, sets RDY high and returned to idle mode. Mode register returns to idle mode bit values. The measurement remains in the data output register and RDY remains high until the data output register is read or another measurement is performed.
1	0	Idle Mode. Device is placed in idle mode.
1	1	Idle Mode. Device is placed in idle mode.

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Data Output X Registers A and B

The data output X registers are two 8-bit registers, data output register A and data output register B. These registers store the measurement result from channel X. Data output X register A contains the MSB from the measurement result, and data output X register B contains the LSB from the measurement result. The value stored in these two registers is a 16-bit value in 2's complement form, whose range is 0xF800 to 0x07FF. DXRA0 through DXRA7 and DXRB0 through DXRB7 indicate bit locations, with *DXRA* and *DXRB* denoting the bits that are in the data output X registers. DXRA7 and DXRB7 denote the first bit of the data stream. The number in parenthesis indicates the default value of that bit.

In the event the ADC reading overflows or underflows for the given channel, or if there is a math overflow during the bias measurement, this data register will contain the value -4096. This register value will clear when after the next valid measurement is made.

Table 13: Data Output X Registers A and B

DXRA7	DXRA6	DXRA5	DXRA4	DXRA3	DXRA2	DXRA1	DXRA0
(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
DXRB7	**DXRB6**	**DXRB5**	**DXRB4**	**DXRB3**	**DXRB2**	**DXRB1**	**DXRB0**
(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)

Data Output Y Registers A and B

The data output Y registers are two 8-bit registers, data output register A and data output register B. These registers store the measurement result from channel Y. Data output Y register A contains the MSB from the measurement result, and data output Y register B contains the LSB from the measurement result. The value stored in these two registers is a 16-bit value in 2's complement form, whose range is 0xF800 to 0x07FF. DYRA0 through DYRA7 and DYRB0 through DYRB7 indicate bit locations, with *DYRA* and *DYRB* denoting the bits that are in the data output Y registers. DYRA7 and DYRB7 denote the first bit of the data stream. The number in parenthesis indicates the default value of that bit.

In the event the ADC reading overflows or underflows for the given channel, or if there is a math overflow during the bias measurement, this data register will contain the value -4096. This register value will clear when after the next valid measurement is made.

Table 14: Data Output Y Registers A and B

DYRA7	DYRA6	DYRA5	DYRA4	DYRA3	DYRA2	DYRA1	DYRA0
(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
DYRB7	**DYRB6**	**DYRB5**	**DYRB4**	**DYRB3**	**DYRB2**	**DYRB1**	**DYRB0**
(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)

Data Output Z Registers A and B

The data output Z registers are two 8-bit registers, data output register A and data output register B. These registers store the measurement result from channel Z. Data output Z register A contains the MSB from the measurement result, and data output Z register B contains the LSB from the measurement result. The value stored in these two registers is a 16-bit value in 2's complement form, whose range is 0xF800 to 0x07FF. DZRA0 through DZRA7 and DZRB0 through DZRB7 indicate bit locations, with *DZRA* and *DZRB* denoting the bits that are in the data output Z registers. DZRA7 and DZRB7 denote the first bit of the data stream. The number in parenthesis indicates the default value of that bit.

In the event the ADC reading overflows or underflows for the given channel, or if there is a math overflow during the bias measurement, this data register will contain the value -4096. This register value will clear when after the next valid measurement is made.

Table 15: Data Output Z Registers A and B

DZRA7	DZRA6	DZRA5	DZRA4	DZRA3	DZRA2	DZRA1	DZRA0
(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
DZRB7	**DZRB6**	**DZRB5**	**DZRB4**	**DZRB3**	**DZRB2**	**DZRB1**	**DZRB0**
(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)

Data Output Register Operation

When one or more of the output registers are read, new data cannot be placed in any of the output data registers until all six data output registers are read. This requirement also impacts DRDY and RDY, which cannot be cleared until new data is placed in all the output registers.

Status Register

The status register is an 8-bit read-only register. This register is used to indicate device status. SR0 through SR7 indicate bit locations, with *SR* denoting the bits that are in the status register. SR7 denotes the first bit of the data stream.

Table 16: Status Register

SR7	SR6	SR5	SR4	SR3	SR2	SR1	SR0
(0)	(0)	(0)	(0)	(0)	(0)	LOCK (0)	RDY(0)

Table 17: Status Register Bit Designations

Location	Name	Description
SR7 to SR5	0	These bits are reserved.
SR4	DOW	Data Over Written. Set when the measurement data are not read before the subsequent data measurements are posted to the output registers. This happens when master device skips reading one or more data samples. Bit is cleared at the beginning of a data read.
DR3 to DR2	N/A	Reserved.
SR1	LOCK	Data output register lock. This bit is set when: 1.some but not all of of the six data output registers have been read, 2. Mode register has been read. When this bit is set, the six data output registers are locked and any new data will not be placed in these register until one of these conditions are met: 1.all six bytes have been read and the next measurement starts, 2. The mode register is written, 3. The measurement configuration (CRA) is written, 4. Power is reset.
SR0	RDY	Ready Bit. Set when data is written to all six data registers. Cleared when device initiates a write to the data output registers and after one or more of the data output registers are written to. When RDY bit is clear it shall remain cleared for >200 µs. DRDY pin can be used as an alternative to the status register for monitoring the device for measurement data.

Identification Register A

The identification register A is used to identify the device. IRA0 through IRA7 indicate bit locations, with *IRA* denoting the bits that are in the identification register A. IRA7 denotes the first bit of the data stream. The number in parenthesis indicates the default value of that bit.

The identification value for this device is stored in this register. This is a read-only register.
Register values. ASCII value *H*

Table 18: Identification Register A Default Values

IRA7	IRA6	IRA5	IRA4	IRA3	IRA2	IRA1	IRA0
0	1	0	0	1	0	0	0

HMC5983

Identification Register B

The identification register B is used to identify the device. IRB0 through IRB7 indicate bit locations, with *IRB* denoting the bits that are in the identification register A. IRB7 denotes the first bit of the data stream.

Register values. ASCII value *4*

Table 19: Identification Register B Default Values

IRB7	IRB6	IRB5	IRB4	IRB3	IRB2	IRB1	IRB0
0	0	1	1	0	1	0	0

Identification Register C

The identification register C is used to identify the device. IRC0 through IRC7 indicate bit locations, with *IRC* denoting the bits that are in the identification register A. IRC7 denotes the first bit of the data stream.

Register values. ASCII value *3*

Table 20: Identification Register C Default Values

IRC7	IRC6	IRC5	IRC4	IRC3	IRC2	IRC1	IRC0
0	0	1	1	0	0	1	1

Temperature Output Registers H and L

The temperature output registers are two 8-bit registers, temperature output register H and temperature output register L. These registers store the measurement result from the internal temperature sensor. Temperature output register H contains the MSB from the measurement result, and temperature output register L contains the LSB from the measurement result. The value stored in these two registers is a 16-bit value in 2's complement form, whose range is 0xF800 to 0x07FF. TEMPH0 through TEMPH7 and TEMPL0 through TEMPL7 indicate bit locations, with *TEMPH* and *TEMPL* denoting the bits that are in the temperature output registers. TEMPH7 and TEMPL7 denote the first bit of the data stream. The number in parenthesis indicates the default value of that bit.

Table 21: Temperature Output Registers H and L

TEMPH7	TEMPH 6	TEMPH 5	TEMPH 4	TEMPH 3	TEMPH 2	TEMPH 1	TEMPH 0
(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
TEMPL 7	**TEMPL 6**	**TEMPL 5**	**TEMPL 4**	**TEMPL 3**	**TEMPL 2**	**TEMPL 1**	**TEMPL 0**
(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)

Temperature output in °C is related to the temperature output register values as follows.

Temperature = (MSB * 2^8 + LSB) / (2^4 * 8) + 25 in °C

HMC5983

I²C COMMUNICATION PROTOCOL

If selected, the HMC5983 communicates via a two-wire I²C bus system as a slave device. The HMC5983 uses a simple protocol with the interface protocol defined by the I²C bus specification, and by this document. The data rate is at the standard-mode 100kbps, 400kbps, or 3400kbps rates as defined in the I²C Bus Specifications. The bus bit format is an 8-bit Data/Address send and a 1-bit acknowledge bit. The format of the data bytes (payload) shall be case sensitive ASCII characters or binary data to the HMC5983 slave, and binary data returned. Negative binary values will be in two's complement form. The default (factory) HMC5983 8-bit slave address is 0x3C for write operations, or 0x3D for read operations.

The HMC5983 Serial Clock (SCL) and Serial Data (SDA) lines require resistive pull-ups (Rp) between the master device (usually a host microprocessor) and the HMC5983. Pull-up resistance values of about 2.2K to 10K ohms are recommended with a nominal VDDIO voltage. Other resistor values may be used as defined in the I²C Bus Specifications that can be tied to VDDIO.

The SCL and SDA lines in this bus specification may be connected to multiple devices. The bus can be a single master to multiple slaves, or it can be a multiple master configuration. All data transfers are initiated by the master device, which is responsible for generating the clock signal, and the data transfers are 8 bit long. All devices are addressed by I²C 's unique 7-bit address. After each 8-bit transfer, the master device generates a 9th clock pulse, and releases the SDA line. The receiving device (addressed slave) will pull the SDA line low to acknowledge (ACK) the successful transfer or leave the SDA high to negative acknowledge (NACK).

Per the I²C spec, all transitions in the SDA line must occur when SCL is low. This requirement leads to two unique conditions on the bus associated with the SDA transitions when SCL is high. Master device pulling the SDA line low while the SCL line is high indicates the Start (S) condition, and the Stop (P) condition is when the SDA line is pulled high while the SCL line is high. The I²C protocol also allows for the Restart condition in which the master device issues a second start condition without issuing a stop.

All bus transactions begin with the master device issuing the start sequence followed by the slave address byte. The address byte contains the slave address; the upper 7 bits (bits7-1), and the Least Significant bit (LSb). The LSb of the address byte designates if the operation is a read (LSb=1) or a write (LSb=0). At the 9th clock pulse, the receiving slave device will issue the ACK (or NACK). Following these bus events, the master will send data bytes for a write operation, or the slave will clock out data with a read operation. All bus transactions are terminated with the master issuing a stop sequence.

I²C bus control can be implemented with either hardware logic or in software. Typical hardware designs will release the SDA and SCL lines as appropriate to allow the slave device to manipulate these lines. In a software implementation, care must be taken to perform these tasks in code.

SPI COMMUNICATION PROTOCOL

If selected, the HMC5983 communicates via a 3-wire or 4-wire SPI bus as a slave device. The SPI allows writing and reading the registers of the device.

The standard Serial Interface interacts with the outside world with 4 wires: **CS**, **SCK, SDI** and **SDO** that correspond to commonly used notations **SS, SCK, MOSI and MISO,** respectively.

HMC5983

Read and Write protocol

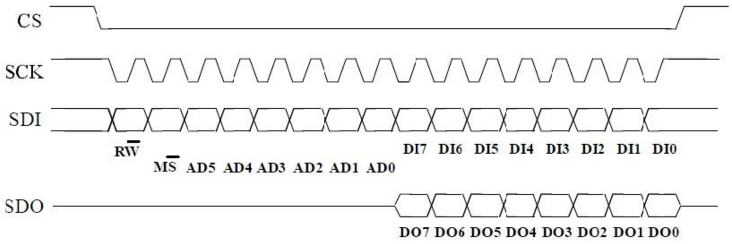


Figure 1: Read & Write Protocol

CS (SPI_CS) is the Serial Port Enable and it is controlled by the SPI master. It goes low at the start of the transmission and goes back high at the end. **SCK (SPI_SCK)** is the Serial Port Clock and it is controlled by the SPI master. It is stopped high when **CS** is high (no transmission). **SDI (SPI_SDI)** and **SDO (SPI_SDO)** are respectively the Serial Port Data Input and Output. Those lines are driven at the falling edge of **SCK** and should be captured at the rising edge of **SCK**.

Both the Read Register and Write Register commands are completed in 16 clocks pulses or in multiple of 8 in case of multiple byte read/write. Bit duration is the time between two falling edges of **SCK**. The first bit (bit 0) starts at the first falling edge of **SCK** after the falling edge of **CS** while the last bit (bit 15, bit 23, ...) starts at the last falling edge of **SCK** (SPI_CS) just before the rising edge of **CS**.

bit 0: RW bit. When 0, the data DI(7:0) is written into the device. When 1, the data DO(7:0) from the device is read. In latter case, the chip will drive **SDO** at the start of bit 8.

bit 1: MS bit. When 0, the address will remain unchanged in multiple read/write commands. When 1, the address will be auto incremented in multiple read/write commands.

bit 2-7: address AD(5:0). This is the address field of the indexed register.

bit 8-15: data DI(7:0) (write mode). This is the data that will be written into the device (MSb first).

bit 8-15: data DO(7:0) (read mode). This is the data that will be read from the device (MSb first).

In multiple read/write commands further blocks of 8 clock periods will be added. When MS bit is 0 the address used to read/write data remains the same for every block. When MS bit is 1 the address used to read/write data is incremented at every block.

The function and the behavior of **SDI** and **SDO** remain unchanged.

HMC5983

SPI Read

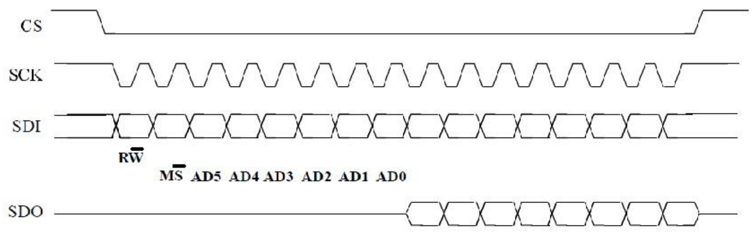


Figure 2: SPI Read Protocol

The SPI Read command is performed with 16 clocks pulses. Multiple byte read command is performed adding blocks of 8 clocks pulses at the previous one.

bit 0: READ bit. The value is 1.

bit 1: MS bit. When 0 do not increment address, when 1 increment address in multiple reading.

bit 2-7: address AD(5:0). This is the address field of the indexed register.

bit 8-15: data DO(7:0) (read mode). This is the data that will be read from the device (MSb first).

bit 16-... : data DO(...-8). Further data in multiple byte reading.

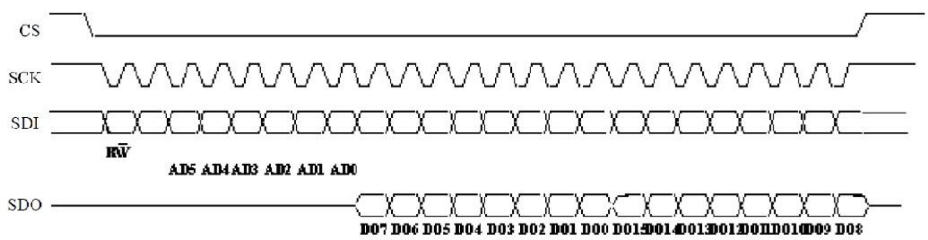


Figure 3: Multiple Bytes SPI Read Protocol (2 bytes example)

SPI Write

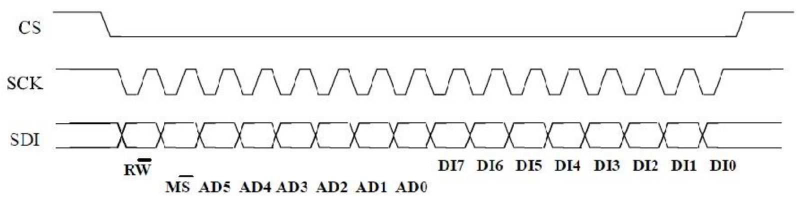


Figure 4: SPI Write Protocol

The SPI Write command is performed with 16 clocks pulses. Multiple byte write command is performed adding blocks of 8 clocks pulses at the previous one.

bit 0: WRITE bit. The value is 0.

bit 1: MS bit. When 0 do not increment address, when 1 increment address in multiple writing.

bit 2 -7: address AD(5:0). This is the address field of the indexed register.

bit 8-15: data DI(7:0) (write mode). This is the data that will be written inside the device (MSb first).

bit 16-... : data DI(...-8). Further data in multiple byte writing.

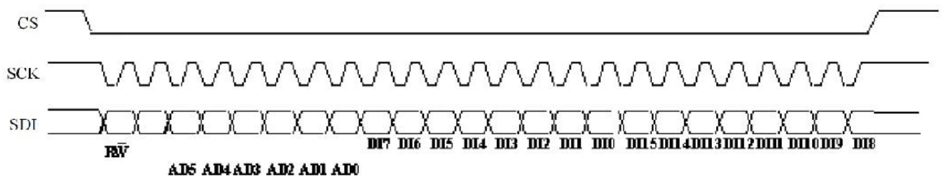


Figure 5: Multiple bytes SPI Write Protocol (2 bytes example)

SPI Read in 3-wires mode

3-wires mode is entered by setting to 1 bit SIM (SPI Serial Interface Mode selection) in MODE_REG(2).

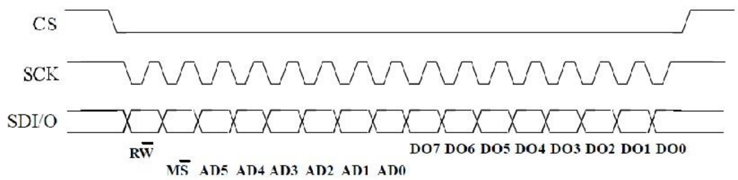


Figure 6: SPI Read Protocol in 3-wires Mode

The SPI Read command is performed with 16 clocks pulses:

bit 0: READ bit. The value is 1.

bit 1: MS bit. When 0 do not increment address, when 1 increment address in multiple reading.

bit 2-7: address AD(5:0). This is the address field of the indexed register.

bit 8-15: data DO(7:0) (read mode). This is the data that will be read from the device (MSb first).

Multiple write command is also available in 3-wires mode.

HMC5983

I^2C OPERATIONAL EXAMPLES

The HMC5983 has a fairly quick stabilization time from no voltage to stable and ready for data retrieval. The nominal 56 milli-seconds with the factory default single measurement mode means that the six bytes of magnetic data registers (DXRA, DXRB, DZRA, DZRB, DYRA, and DYRB) are filled with a valid first measurement.

To change the measurement mode to continuous measurement mode, after the power-up time send the three bytes:

0x3C 0x02 0x00

This writes the 00 into the second register or mode register to switch from single to continuous measurement mode setting. With the data rate at the factory default of 15Hz updates, a 67 milli-second typical delay should be allowed by the I^2C master before querying the HMC5983 data registers for new measurements. To clock out the new data, send:

0x3D, and clock out DXRA, DXRB, DZRA, DZRB, DYRA, and DYRB located in registers 3 through 8. The HMC5983 will automatically re-point back to register 3 for the next 0x3D query. All six data registers must be read properly before new data can be placed in any of these data registers.

Below is an example of a (power-on) initialization process for “continuous-measurement mode” via I^2C interface:

1. Write CRA (00) – send **0x3C 0x00 0x70** (8-average, 15 Hz default, normal measurement)
2. Write CRB (01) – send **0x3C 0x01 0xA0** (Gain=5, or any other desired gain)
3. Write Mode (02) – send **0x3C 0x02 0x00** (Continuous-measurement mode)
4. Wait 6 ms or monitor status register or DRDY hardware interrupt pin
5. Loop
    - Send **0x3D 0x06** (Read all 6 bytes. If gain is changed then this data set is using previous gain)
    - Convert three 16-bit 2’s compliment hex values to decimal values and assign to X, Z, Y, respectively.
    - Send **0x3C 0x03** (point to first data register 03)
    - Wait about 67 ms (if 15 Hz rate) or monitor status register or DRDY hardware interrupt pin

   End_loop

Below is an example of a (power-on) initialization process for “single-measurement mode” via I^2C interface:

1. Write CRA (00) – send **0x3C 0x00 0x70** (8-average, 15 Hz default or any other rate, normal measurement)
2. Write CRB (01) – send **0x3C 0x01 0xA0** (Gain=5, or any other desired gain)
3. For each measurement query:
    - Write Mode (02) – send **0x3C 0x02 0x01** (Single-measurement mode)
    - Wait 6 ms or monitor status register or DRDY hardware interrupt pin
    - Send **0x3D 0x06** (Read all 6 bytes. If gain is changed then this data set is using previous gain)
    - Convert three 16-bit 2’s compliment hex values to decimal values and assign to X, Z, Y, respectively.

SPI OPERATIONAL EXAMPLES

To read Configuration B register Lower CS line Write 0x81 to the SPI bus Read 1 byte from SPI bus Raise CS line	To read Status Lower CS line Write 0x89 to the SPI bus Read 1 byte from SPI bus Raise CS line
To write Configuration B register Lower CS line Write 0x01 to the SPI bus Write 0xVV to the SPI bus (VV is the value to be written to register B) Raise CS line	To read output Lower CS line Write 0xC3 to the SPI bus Read 6 byte from SPI bus Raise CS line

HMC5983

SELF TEST OPERATION

To check the HMC5983 for proper operation, a self test feature is incorporated in which the sensor offset straps are excited to create a nominal field strength (bias field) to be measured. To implement self test, the least significant bits (MS1 and MS0) of configuration register A are changed from 00 to 01 (positive bias) or 10 (negative bias).

Then, by placing the mode register into single or continuous-measurement mode, two data acquisition cycles will be made on each magnetic vector. The first acquisition will be a set pulse followed shortly by measurement data of the external field. The second acquisition will have the offset strap excited (about 10 mA) in the positive bias mode for X, Y, and Z axes to create about a 1.1 gauss self test field plus the external field. The first acquisition values will be subtracted from the second acquisition, and the net measurement will be placed into the data output registers.

Since self test adds ~1.1 Gauss additional field to the existing field strength, using a reduced gain setting prevents the sensor from being saturated and the data registers from overflowing. For example, if the configuration register B is set to 0xA0 (Gain=5), values around +452 LSb (1.16 Ga * 390 LSb/Ga) will be placed in the X and Y data output registers and around +421 (1.08 Ga * 390 LSb/Ga) will be placed in Z data output register. To leave the self test mode, change MS1 and MS0 bit of the configuration register A back to 00 (Normal Measurement Mode). Acceptable limits of the self test values depend on the gain setting. Limits for Gain=5 are provided in the specification table.

Below is an example of a "positive self test" process using continuous-measurement mode via I²C interface:

1. Write CRA (00) – send **0x3C 0x00 0x71** (8-average, 15 Hz default, positive self test measurement)
2. Write CRB (01) – send **0x3C 0x01 0xA0** (Gain=5)
3. Write Mode (02) – send **0x3C 0x02 0x00** (Continuous-measurement mode)
4. Wait 6 ms or monitor status register or DRDY hardware interrupt pin
5. Loop
   Send **0x3D 0x06** (Read all 6 bytes. If gain is changed then this data set is using previous gain)
   Convert three 16-bit 2's compliment hex values to decimal values and assign to X, Z, Y, respectively.
   Send **0x3C 0x03** (point to first data register 03)
   Wait about 67 ms (if 15 Hz rate) or monitor status register or DRDY hardware interrupt pin
   End_loop
6. Check limits –
   If all 3 axes (X, Y, and Z) are within reasonable limits (243 to 575 for Gain=5, adjust these limits based on the gain setting used. See an example below.) Then
   All 3 axes pass positive self test
   Write CRA (00) – send **0x3C 0x00 0x70** (Exit self test mode and this procedure)
   Else
   If Gain<7
   Write CRB (01) – send **0x3C 0x01 0x*n*0** (Increase gain setting to next value;*n*, and retry. Skip the next data set)
   Else
   At least one axis did not pass positive self test
   Write CRA (00) – send **0x3C 0x00 0x70** (Exit self test mode and this procedure)
   End If

Below is an example of how to adjust the "positive self test" limits based on the gain setting:

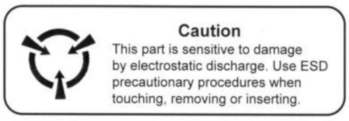
1. If Gain = 6, self test limits are:
   Low Limit = 243 * 330/390 = 206
   High Limit = 575 * 330/390 = 487

2. If Gain = 7, self test limits are:
   Low Limit = 243 * 230/390 = 143
   High Limit = 575 * 230/390 = 339

HMC5983

ORDERING INFORMATION

Ordering Number	Product
HMC5983-TR	Tape and Reel 4k pieces/reel



CAUTION: ESDS CAT. 1B

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U.S. Patents 4,441,072, 4,533,872, 4,569,742, 4,681,812, 4,847,584 and 6,529,114 apply to the technology described

Honeywell

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Plymouth, MN 55441
Tel: 800-323-8295
www.magneticsensors.com

Form # 900425
January 2012

I.5 Hoja técnica Power HD Mini Servo HD-1160A. FUENTE: POWER HD

Apply Environmental Condition：

No.	Item	Specification
1-1	Storage Temperature Range	-20℃～60℃
1-2	Operating Temperature Range	-10℃～50℃
1-3	Operating Voltage Range	4.5V～6V

Standard Test Environment：

2-1	Standard Test Environment	Every characteristic of the inspect must be normal temperature and humidity carry out the test , temperature 25±5℃ and relative humidity 65±10% of judgment made in accordance with this specification standard testing conditions.

Electrical Specification (Function of the Performance)：

No.	Item	4.8V	6.0V
4-1	Operating speed (at no load)	0.12 sec/60°	0.11 sec/60°
4-2	Running current (at no load)	160 mA	180 mA
4-3	Stall torque (at locked)	2.0 kg-cm	2.7 kg-cm
4-4	Stall current (at locked)	680 mA	800 mA
4-5	Idle current (at stopped)	4 mA	5 mA

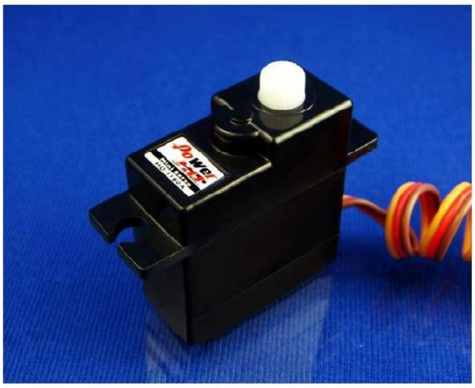
Note: Item 4-2 definition is average value when the servo running with no load

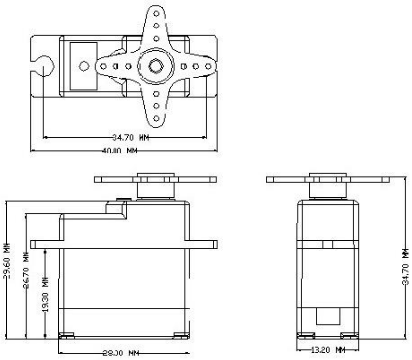
Mechanical Specification：

No.	Item	Specification
5-1	Overall Dimensions	See the drawing
5-2	Limit angle	180°± 10°
5-3	Weight	17 ± 1 grams (without servo horn)
5-4	Connector wire gauge	#26 PVC
5-5	Connector wire length	150 ± 5 mm
5-6	Horn gear spline	25T/ φ 5.77
5-7	Horn type	Cross , Disk , Star , Bar
5-8	Reduction ratio	1/313

Control Specification：

No.	Item	Specification
6-1	Control system	Pulse width modification
6-2	Amplifier type	Analog controller
6-3	Operating travel	90° (when1000→2000 μsec)
6-4	Neutral position	1500 μsec
6-5	Dead band width	7 μsec
6-6	Rotating direction	Clockwise (when1500→2000 μsec)
6-7	Pulse width range	800→2200 μsec
6-8	Maximum travel	Approx 165°(when800→2200 μsec)





Power HD	Product Name	Model No.	Version	Page
	SERVO	HD-1160A	V1	1/1

ANEXO J. COSTOS DE ENVÍO

Tabla 8 Costos de envío de los componentes electrónicos. Fuente: Elaboración propia

<table>
<tr><th>Componentes</th><th>Unid.</th><th>Proveedor</th><th>Costo ($)</th></tr>
<tr><td>Servomotor</td><td>1</td><td>Pololu</td><td rowspan="3">54.45</td></tr>
<tr><td>Driver Roboclaw</td><td>2</td><td>Pololu</td></tr>
<tr><td>Motor con encoder</td><td>4</td><td>Pololu</td></tr>
<tr><td>Raspberry pi</td><td>1</td><td>Mercadolibre</td><td rowspan="5">0</td></tr>
<tr><td>Arduino Mega</td><td>1</td><td>Mercadolibre</td></tr>
<tr><td>Cámara web</td><td>1</td><td>Logitech</td></tr>
<tr><td>Adaptador wifi</td><td>1</td><td>TP-Link</td></tr>
<tr><td>Módulo GY-283 (x5)</td><td>1</td><td>AliExpress</td></tr>
<tr><td>Sensor termográfico</td><td>1</td><td>AliExpress</td><td>5.26</td></tr>
<tr><td>Batería 8Ah+cargador</td><td>1</td><td>AliExpress</td><td>0</td></tr>
<tr><td>Batería 10Ah</td><td>1</td><td>AliExpress</td><td>10.53</td></tr>
<tr><td>Botón LED</td><td>1</td><td>AliExpress</td><td>0</td></tr>
<tr><td>Base y ventilador Pi B</td><td>1</td><td>Amazon</td><td>35.67</td></tr>
<tr><td></td><td></td><td></td><td>105.91</td></tr>
</table>

En la Tabla 8 se muestra el costo de envío hacia una dirección en Perú (la residencia del tesista) extraído de la página web de cada proveedor. Los componentes que no poseen costos de envío se deben a que:

- El proveedor indicaba que el envío del componente era gratuito a Perú. (Ej.: AliExpress).
- El local del proveedor se encuentra en Lima y se realiza envío gratuito o el cliente puede acercarse al local para adquirir el componente. (Ej.: Logitech, Mercadolibre y TP-Link)

Adicionalmente se deben incluir costos de desaduanaje, que utilizando el tarifario de SICE (Sistema de información sobre comercio exterior) para Perú se debería emplear un 12% como caso más crítico al monto total que ingresa al país (ver Tabla 9). Aplicando el porcentaje se obtiene un monto total de $ 91.94.

Tabla 9 Costo de desaduanaje. Fuente: Elaboración propia

Componentes	Unid.	Proveedor	Costo ($/unid.)	Costo total ($)
Servomotor	1	Pololu	7.95	7.95
Driver Roboclaw	2	Pololu	69.95	139.9
Motor con encoder	4	Pololu	36.95	147.8
Módulo GY-283 (x5)	1	AliExpress	24	24
Sensor termográfico	1	AliExpress	377	377
Batería 8Ah+cargador	1	AliExpress	13.56	13.56
Batería 10Ah	1	AliExpress	44.1	44.1
Botón LED	1	AliExpress	2.88	2.88
Base y ventilador Pi B	1	Amazon	8.99	8.99
				766.18

ANEXO K. CÓDIGOS DE SIMULACIÓN

K.1 Localización de intensidades

```
close all;
x=imread('b3.png');
r=x(:,:,1);
g=x(:,:,2);
b=x(:,:,3);
t=find(r<230 & g<80 | g>215 & b<20);
ng=g;
ng(t)=0;
nr=r;
nr(t)=0;
nb=b;
nb(t)=0;
im=cat(3,nr,ng,nb);
im2=medfilt2(rgb2gray(im),[3,3]);
im2=imbinarize(im2,0.6);
im2=bwareaopen(im2,100);
bw=logical(im2);
s=regionprops(bw,'BoundingBox','Centroid');
imshow(x);
hold on
for i=1:length(s)
    Box=s(i).BoundingBox;
    Centroid=s(i).Centroid;
   rectangle('Position',Box,'Edgecolor','b','LineWidth',2)
   plot(Centroid(1),Centroid(2),'-m+')
end
```

K.2 Estimación de temperatura

```
close all;
img=imread('b3.png');
TA=[255,223,30];%temp=90°
TB=[0,0,80];%temp=30°
deltaTemp=60;
d_escala=norm(TA-TB);
imshow(img)
b=1;
while b==1
    [x,y,b]=ginput(1);
    p=im2double(impixel(img,x,y));
    d_90=norm(cross(p-TB,TA-TB))/norm(TA-TB);
    d_orig=sqrt((norm(p-TB))^2-(d_90)^2);
    varT=d_orig*deltaTemp/d_escala;
    T_final=30+varT;
    hold on;
    plot(x,y,'g+');
    annot = sprintf('T:%.2f°',T_final);
    text(x,y,annot,'Fontsize',10,'Color','g');
end
```

K.3 Gráfica de curvas de nivel

```
close all;
doc =
textscan(fopen('Mapeo.txt'),'%s',100,'HeaderLines',1,'Delimiter','\n');
```

```
for i=1:1:length(doc{1,1})
    temp=strsplit(doc{1,1}{i,1});
    B(i,1)=str2double(temp{1});
    B(i,2)=str2double(temp{2});
    B(i,3)=str2double(temp{3});
end

z=zeros(ceil(sqrt(length(B))));
for i=1:1:length(z)
    for j=1:1:length(z)
        for w=1:1:length(B)
            if i==B(w,2)
                if j==B(w,3)
                    z(i,j)=B(w,1);
                end
            end
        end
    end
end


figure;
min_x=1;
max_x=10;
min_y=1;
max_y=10;
img=imread('SE.jpg');
imagesc([min_x max_x], [min_y max_y], flip(img,1));
hold on;

[gx,gy]=meshgrid(1:length(z));
u=contour(gx,gy,z,4);
c = colorbar;
c.Label.String = 'Intensity fo magnetic field (mG)';
grid on
set(gca,'ydir','normal');
```

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