FlexiForce® Sensors
User Manual
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WELCOME

ISO

Tekscan is registered to the following standard(s):

- ISO 9001: 2000
- ISO 13485: 2003
INTRODUCTION

This manual describes how to use Tekscan's FlexiForce Sensors. These sensors are ideal for designers, researchers, or anyone who needs to measure forces without disturbing the dynamics of their tests. The FlexiForce sensors can be used to measure both static and dynamic forces (up to 1000 lbf.), and are thin enough to enable non-intrusive measurement.

The FlexiForce sensors use a resistive-based technology. The application of a force to the active sensing area of the sensor results in a change in the resistance of the sensing element in inverse proportion to the force applied.

GETTING ASSISTANCE

Tekscan, Inc. will provide technical assistance for any difficulties you may experience using your FlexiForce system.

Write, call or fax us with any concerns or questions. Our knowledgeable support staff will be happy to help you. Comments and suggestions are always welcome.

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OVERVIEW

This section outlines Sensor Construction and Application.

FLEXIFORCE SENSORS

The FlexiForce sensor is an ultra-thin and flexible printed circuit, which can be easily integrated into most applications. With its paper-thin construction, flexibility and force measurement ability, the FlexiForce force sensor can measure force between almost any two surfaces and is durable enough to stand up to most environments. FlexiForce has better force sensing properties, linearity, hysteresis, drift, and temperature sensitivity than any other thin-film force sensors. The "active sensing area" is a 0.375” diameter circle at the end of the sensor.

The sensors are constructed of two layers of substrate. This substrate is composed of polyester film (or Polyimide in the case of the High-Temperature Sensors). On each layer, a conductive material (silver) is applied, followed by a layer of pressure-sensitive ink. Adhesive is then used to laminate the two layers of substrate together to form the sensor. The silver circle on top of the pressure-sensitive ink defines the “active sensing area.” Silver extends from the sensing area to the connectors at the other end of the sensor, forming the conductive leads.

FlexiForce sensors are terminated with a solderable male square pin connector, which allows them to be incorporated into a circuit. The two outer pins of the connector are active and the center pin is inactive. The length of the sensors can be trimmed by Tekscan to predefined lengths of 2”, 4” and 6” or can be trimmed by the customer. If the customer trims the sensor, a new connector must be attached. This can be accomplished by purchasing staked pin connectors and a crimping tool. A conductive epoxy can also be used to adhere small wires to each conductor.

The sensor acts as a variable resistor in an electrical circuit. When the sensor is unloaded, its resistance is very high (greater than 5 Meg-ohm); when a force is applied to the sensor, the resistance decreases. Connecting an ohmmeter to the outer two pins of the sensor connector and applying a force to the sensing area can read the change in resistance.

*Sensors should be stored at temperatures in the range of 15°F (-9°C) to 165°F (74°C)*

Standard FlexiForce Sensors

The Standard A201 sensor is available in the following force ranges:

- Sensor A201-1 (0-1 lb. force range)
- Sensor A201-25 (0-25 lb. force range)
- Sensor A201-100 (0-100 lb. force range)*

*In order to measure forces above 100 lbs. (up to 1000 lbs), apply a lower drive voltage and reduce the resistance of the feedback resistor (1kΩ min.). See the sample drive circuit below.*
**High-Temperature FlexiForce Sensors**

The High-Temperature HT201 sensor is available in the following force ranges* (as tested with the sample drive circuit).

- Sensor HT201-L  Low: 0-30lb (133N) force range
- Sensor HT201-H  High: 0-100lb (445N) force range

*In order to measure forces outside specified ranges, use recommended circuit and adjust drive voltage and/or reference resistance

**APPLICATION**

There are many ways to integrate the FlexiForce sensor into an application. One way is to incorporate it into a force-to-voltage circuit. A means of calibration must then be established to convert the output into the appropriate engineering units. Depending on the setup, an adjustment could then be done to increase or decrease the sensitivity of the sensor.

An example circuit is shown below. In this case, it is driven by a -5 V DC excitation voltage. This circuit uses an inverting operational amplifier arrangement to produce an analog output based on the sensor resistance and a fixed reference resistance (R_f). An analog-to-digital converter can be used to change this voltage to a digital output. In this circuit, the sensitivity of the sensor could be adjusted by changing the reference resistance (R_f) and/or drive voltage (V_T); a lower reference resistance and/or drive voltage will make the sensor less sensitive, and increase its active force range.

In the circuit shown, the dynamic force range of the sensor can be adjusted by changing the reference resistor (R_f) or by changing the Drive Voltage (V_o). Refer to the Saturation section for additional information.
SENSOR LOADING CONSIDERATIONS

The following general sensor loading guidelines can be applied to most applications, and will help you achieve the most accurate results from your tests. It is important that you read the Sensor Performance Characteristics section for further information on how to get the most accurate results from your sensor readings.

SENSOR LOADING

The entire sensing area of the FlexiForce sensor is treated as a single contact point. For this reason, the applied load should be distributed evenly across the sensing area to ensure accurate and repeatable force readings. Readings may vary slightly if the load distribution changes over the sensing area.

Note that the sensing area is the silver circle on the top of the sensor only.

It is also important that the sensor be loaded consistently, or in the same way each time.

If the footprint of the applied load is smaller than the sensing area, the load should not be placed near the edges of the sensing area, to ensure an even load distribution.

It is also important to ensure that the sensing area is the entire load path, and that the load is not supported by the area outside of the sensing area.

If the footprint of the applied load is larger than the sensing area, it may be necessary to use a "puck." A puck is a piece of rigid material (smaller than the sensing area) that is placed on the sensing area to ensure that the entire load path goes through this area. The puck must not touch any of the edges of the sensing area, or these edges may support some of the load and give an erroneous reading.

The FlexiForce sensor reads forces that are perpendicular to the sensor plane. Applications that impart "shear" forces could reduce the life of the sensor. If the application will place a "shear" force on the sensor, it should be protected by covering it with a more resilient material.

If it is necessary to mount the sensor to a surface, it is recommended that you use tape, when possible. Adhesives may also be used, but make sure that the adhesive will not degrade the substrate (polyester) material of the sensor before using it in an application. Adhesives should not be applied to the sensing area; however, if it is necessary, ensure that the adhesive is spread evenly. Otherwise, any high spots may appear as load on the sensor.

SATURATION

The Saturation force is the point at which the device output no longer varies with applied force. The saturation force of each sensor is based on the maximum recommended force specified by Tekscan, which is printed on the system packaging or the actual sensor, along with the "Sensitivity."
The saturation value is based on using the circuit and the values shown in the example circuit in the ‘Application’ section. In this example, the saturation force (maximum force) of each sensor is related to the RF (reference resistance), and can be altered by changing the sensitivity. The sensitivity of the sensor would be adjusted by changing the reference resistance (RF); a lower reference resistance will make the system less sensitive, and increase its active force range.

*It is essential that the sensor(s) do not become saturated during testing.*

**CONDITIONING SENSORS**

Exercising, or **Conditioning** a sensor before calibration and testing is essential in achieving accurate results. It helps to lessen the effects of *drift* and *hysteresis*. Conditioning is required for new sensors, and for sensors that have not been used for a length of time.

To condition a sensor, place 110% of the test weight on the sensor, allow the sensor to stabilize, and then remove the weight. Repeat this process four or five times. The interface between the sensor and the test subject material should be the same during conditioning as during *calibration* and actual testing.

*IMPORTANT! Sensors must be properly conditioned prior to calibration and use.*
CALIBRATION

Calibration is the method by which the sensor’s electrical output is related to an actual engineering unit, such as pounds or Newtons. To calibrate, apply a known force to the sensor, and equate the sensor resistance output to this force. Repeat this step with a number of known forces that approximate the load range to be used in testing. Plot Force versus Conductance (1/R). A linear interpolation can then be done between zero load and the known calibration loads, to determine the actual force range that matches the sensor output range.

![Resistance Curve](image1.png) ![Conductance Curve](image2.png)

**CALIBRATION GUIDELINES**

The following guidelines should be considered when calibrating a sensor:

- Apply a calibration load that approximates the load to be applied during system use, using dead weights or a testing device (such as an MTS or Instron). If you intend to use a "puck" during testing, also use it when calibrating the sensor. See Sensor Loading Considerations for more information on using a puck.

- Avoid loading the sensor to near saturation when calibrating. If the sensor saturates at a lower load than desired, adjust the "Sensitivity."

- Distribute the applied load evenly across the sensing area to ensure accurate force readings. Readings may vary slightly if the load distribution changes over the sensing area.

- Sensors should be calibrated at the same temperature for which testing will occur. This is especially important for High-Temp Sensors, as these sensors have a wide operating temperature range. If multiple temperatures are used during testing, calibrate the sensors at those same multiple temperatures.

Note: Read the Sensor Performance Characteristics section before performing a Calibration.
SENSOR PERFORMANCE CHARACTERISTICS

There are a number of characteristics of sensors, which can affect your results. This section contains a description of each of these conditions, and recommendations on how to lessen their effects.

REPEATABILITY

Repeatability is the ability of the sensor to respond in the same way to a repeatedly applied force. As with most measurement devices, it is customary to exercise, or "condition" a sensor before calibrating it or using it for measurement. This is done to reduce the amount of change in the sensor response due to repeated loading and unloading. A sensor is conditioned by loading it to 110% of the test weight four or five times. Follow the full procedure in the Conditioning Sensors section.

LINEARITY

Linearity refers to the sensor’s response (digital output) to the applied load, over the range of the sensor. This response should ideally be linear; and any non-linearity of the sensor is the amount that its output deviates from this line. A calibration is performed to "linearize" this output as much as possible. FlexiForce standard sensors are linear within +/- 3%. FlexiForce High-Temperature sensors have a linearity that is 1.2% of full scale.

HYSTERESIS

Hysteresis is the difference in the sensor output response during loading and unloading, at the same force. For static forces, and applications in which force is only increased, and not decreased, the effects of hysteresis are minimal. If an application includes load decreases, as well as increases, there may be error introduced by hysteresis that is not accounted for by calibration.

DRIFT

Drift is the change in sensor output when a constant force is applied over a period of time. If the sensor is kept under a constant load, the resistance of the sensor will continually decrease, and the output will gradually increase. It is important to take drift into account when calibrating the sensor, so that its effects can be minimized. The simplest way to accomplish this is to perform the sensor calibration in a time frame similar to that which will be used in the application.

TEMPERATURE SENSITIVITY

In general, your results will vary if you combine high loads on the sensor with high temperatures.

To ensure accuracy, calibrate the sensor at the temperature at which it will be used in the application. If the sensor is being used at different temperatures, perform a calibration at each of these temperatures, save the calibration files, then load the appropriate calibration file when using the sensor at that temperature.
SENSOR LIFE / DURABILITY

Sensor life depends on the application in which it is used. Sensors are reusable, unless used in applications in which they are subjected to severe conditions, such as against sharp edges, or shear forces. *FlexiForce* sensors have been successfully tested at over one million load cycles using a 50 lb. force.

Rough handling of a sensor will also shorten its useful life. For example, a sensor that is repeatedly installed in a flanged joint will have a shorter life than a sensor installed in the same joint once and used to monitor loads over a prolonged period. After each installation, visually inspect your sensors for physical damage.

It is also important to keep the sensing area of the sensor clean. Any deposits on this area will create uneven loading, and will cause saturation to occur at lower applied forces.
SENSOR PROPERTIES

STANDARD FLEXIFORCE SENSOR (MODEL A201)

<table>
<thead>
<tr>
<th>Sensor Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness</td>
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<tr>
<td>Length</td>
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<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td>Width</td>
</tr>
<tr>
<td>Sensing Area</td>
</tr>
<tr>
<td>Connector</td>
</tr>
</tbody>
</table>

**Typical Performance**

| Force Ranges | 0-1 lb (4.4 N) |
| | 0-25 lbs (110 N) |
| | 0-100 lbs (440 N)* |
| Operating Temperature Range | 15°F to 140°F (-9°C to 60°C) |
| Linearity (Error) | +/- 3% |
| Repeatability | +/- 2.5% of full scale (conditioned sensor, 80% force applied) |
| Hysteresis | <4.5% of full scale (conditioned sensor, 80% force applied) |
| Drift | <5% per logarithmic time scale (constant load of 90% sensor rating) |
| Response Time | <5 microseconds |
| Output Change/Degree F | Up to 0.2% (~0.36% / °C). Loads <10 lbs, operating temperature can be increased to 165°F (74°C). |

HIGH-TEMPERATURE FLEXIFORCE SENSOR (MODEL HT201)

<table>
<thead>
<tr>
<th>Sensor Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness</td>
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<tr>
<td>Length</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Width</td>
</tr>
<tr>
<td>Sensing Area</td>
</tr>
<tr>
<td>Connector</td>
</tr>
<tr>
<td>Substrate</td>
</tr>
</tbody>
</table>

**Typical Performance**

| Force Ranges | 0-30 lbs (133N) |
| | 0-100 lbs (445N) |
| Operating Temperature Range | 15°F to 400°F (-9°C to 204°C) |
| Repeatability | +/- 3.5% of full scale |
| Linearity | +/- 1.2% of full scale |
| Hysteresis | 3.6% of full scale |
| Drift | 3.3% per log time |
| Output Change/Degree F | 0.16% |
**FEATURES**

- **LOW BIAS CURRENT:** ±4pA
- **LOW QUIESCENT CURRENT:** ±450μA
- **LOW INPUT OFFSET VOLTAGE:** ±200μV
- **LOW INPUT OFFSET DRIFT:** ±2μV/°C
- **LOW INPUT NOISE:**
  \[20\text{mV/√Hz at } f = 1\text{kHz (G =100)}\]
- **HIGH CMR:** 106dB
- **WIDE SUPPLY RANGE:** ±2.25V to ±18V
- **LOW NONLINEARITY ERROR:** 0.001% max
- **INPUT PROTECTION TO** ±40V
- **8-PIN DIP AND SO-8 SURFACE MOUNT**

**APPLICATIONS**

- **LOW-LEVEL TRANSDUCER AMPLIFIERS**
  Bridge, RTD, Thermocouple
- **PHYSIOLOGICAL AMPLIFIERS**
  ECG, EEG, EMG, Respiratory
- **HIGH IMPEDANCE TRANSDUCERS**
- **CAPACITIVE SENSORS**
- **MULTI-CHANNEL DATA ACQUISITION**
- **PORTABLE, BATTERY OPERATED SYSTEMS**
- **GENERAL PURPOSE INSTRUMENTATION**

**DESCRIPTION**

The INA121 is a FET-input, low power instrumentation amplifier offering excellent accuracy. Its versatile three-op amp design and very small size make it ideal for a variety of general purpose applications. Low bias current (±4pA) allows use with high impedance sources.

Gain can be set from 1V to 10,000V/V with a single external resistor. Internal input protection can withstand up to ±40V without damage.

The INA121 is laser-trimmed for very low offset voltage (±200μV), low offset drift (±2μV/°C), and high common-mode rejection (106dB at G = 100). It operates on power supplies as low as ±2.25V (+4.5V), allowing use in battery operated and single 5V systems. Quiescent current is only 450μA.

Package options include 8-pin plastic DIP and SO-8 surface mount. All are specified for the −40°C to +85°C industrial temperature range.
### SPECIFICATIONS: \( V_S = \pm 15V \)

At \( T_A = \pm 25°C, V_S = \pm 15V, R_L = \pm 10kΩ, \) and IA reference \( = 0V, \) otherwise noted.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>INA121P, U</th>
<th>INA121PA, UA</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INPUT</strong></td>
<td></td>
<td>MIN</td>
<td>TYP</td>
<td>MAX</td>
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<tr>
<td>Offset Voltage, RTI</td>
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<td>±500</td>
<td>±500</td>
<td>±500</td>
</tr>
<tr>
<td>vs Temperature</td>
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<td>±12/2</td>
<td>±12/2</td>
<td>±12/2</td>
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<tr>
<td>vs Power Supply</td>
<td></td>
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<td>±520</td>
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<td>Long-Term Stability</td>
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<td>Impedance, Differential Common-Mode Rejection</td>
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<td>10Ω/12Ω</td>
<td>10Ω/12Ω</td>
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<td>Input Voltage Range</td>
<td>See Text and Typical Curves</td>
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<td>vs Temperature</td>
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<td>Offset Current</td>
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<td><strong>NOISE, RTI</strong></td>
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<td>Voltage Noise: ( f = 10Hz )</td>
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<td>*</td>
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<tr>
<td>( f = 100Hz )</td>
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<tr>
<td>( f = 1kHz )</td>
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<td>Current Noise: ( f = 1kHz )</td>
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<td>Gain Equation</td>
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<tr>
<td>Gain Error</td>
<td></td>
<td>±0.1%</td>
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<td>±0.1%</td>
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<tr>
<td>Gain vs Temperature(1)</td>
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<td>±0.5%</td>
<td>±0.5%</td>
<td>±0.5%</td>
</tr>
<tr>
<td>Nonlinearity</td>
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<td>±0.002%</td>
<td>±0.002%</td>
<td>±0.002%</td>
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<tr>
<td><strong>OUTPUT</strong></td>
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<td>±0.001%</td>
<td>±0.001%</td>
<td>±0.001%</td>
</tr>
<tr>
<td>Voltage: Positive</td>
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<td>*</td>
<td>*</td>
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<tr>
<td>Negative</td>
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<td>±0.0015%</td>
<td>±0.0015%</td>
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<tr>
<td>Positive</td>
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<td>±0.001%</td>
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<td>Capacitance Load Drive</td>
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<tr>
<td>Short-Circuit Current</td>
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<td>±14</td>
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<td>±525</td>
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<td>Bandwidth, −3dB</td>
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<td>±18</td>
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</tr>
<tr>
<td>G = 1</td>
<td></td>
<td>±15</td>
<td>±15</td>
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<tr>
<td>G = 10</td>
<td></td>
<td>±450</td>
<td>±450</td>
<td>±450</td>
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<tr>
<td>Slew Rate</td>
<td></td>
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<td>±0.7</td>
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<tr>
<td>Settling Time, 0.01%</td>
<td></td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
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<tr>
<td>Overload Recovery</td>
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<tr>
<td><strong>POWER SUPPLY</strong></td>
<td></td>
<td>±18</td>
<td>±18</td>
<td>±18</td>
</tr>
<tr>
<td>Voltage Range</td>
<td></td>
<td>±2.25</td>
<td>±2.25</td>
<td>±2.25</td>
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<tr>
<td>Quiescent Current</td>
<td></td>
<td>±525</td>
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<td>±525</td>
</tr>
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<td><strong>TEMPERATURE RANGE</strong></td>
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<td>±525</td>
<td>±525</td>
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</tr>
<tr>
<td>Specification</td>
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<td>±525</td>
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<tr>
<td>Operating</td>
<td></td>
<td>±525</td>
<td>±525</td>
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<tr>
<td>Storage</td>
<td></td>
<td>±525</td>
<td>±525</td>
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<tr>
<td>Thermal Resistance, ( \theta_J )</td>
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<td>±525</td>
<td>±525</td>
<td>±525</td>
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<tr>
<td>8-Lead DIP</td>
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<td>±525</td>
<td>±525</td>
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<tr>
<td>SO-8 Surface Mount</td>
<td></td>
<td>±525</td>
<td>±525</td>
<td>±525</td>
</tr>
</tbody>
</table>

* Specification same as INA121P. U.

NOTE: (1) Temperature coefficient of the “Internal Resistor” in the gain equation. Does not include TCR of gain-setting resistor, \( R_G. \)
This integrated circuit can be damaged by ESD. Burr-Brown recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

ABSOLUTE MAXIMUM RATINGS

<table>
<thead>
<tr>
<th>Supply Voltage</th>
<th>±18V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog Input Voltage Range</td>
<td>±40V</td>
</tr>
<tr>
<td>Output Short-Circuit (to ground)</td>
<td>Continuous</td>
</tr>
<tr>
<td>Storage Temperature</td>
<td>–55°C to +125°C</td>
</tr>
<tr>
<td>Junction Temperature</td>
<td>+150°C</td>
</tr>
<tr>
<td>Lead Temperature (soldering, 10s)</td>
<td>+300°C</td>
</tr>
</tbody>
</table>

NOTE: (1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability.

PACKAGE/ORDERING INFORMATION

<table>
<thead>
<tr>
<th>PRODUCT</th>
<th>PACKAGE</th>
<th>PACKAGE DRAWING NUMBER(1)</th>
<th>SPECIFIED TEMPERATURE RANGE</th>
<th>PACKAGE MARKING</th>
<th>ORDERING NUMBER(2)</th>
<th>TRANSPORT MEDIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>INA121P</td>
<td>8-Pin DIP</td>
<td>006</td>
<td>–40°C to +85°C</td>
<td>INA121P</td>
<td>INA121P</td>
<td>Rails</td>
</tr>
<tr>
<td>INA121PA</td>
<td>8-Pin DIP</td>
<td>006</td>
<td>–40°C to +85°C</td>
<td>INA121PA</td>
<td>INA121PA</td>
<td>Rails</td>
</tr>
<tr>
<td>INA121U</td>
<td>SO-8 Surface-Mount</td>
<td>182</td>
<td>–40°C to +85°C</td>
<td>INA121U</td>
<td>INA121U</td>
<td>Rails</td>
</tr>
<tr>
<td>INA121UA</td>
<td>SO-8 Surface-Mount</td>
<td>182</td>
<td>–40°C to +85°C</td>
<td>INA121UA</td>
<td>INA121UA/2K5</td>
<td>Tape and Reel</td>
</tr>
</tbody>
</table>

NOTES: (1) For detailed drawing and dimension table, please see end of data sheet, or Appendix C of Burr-Brown IC Data Book. (2) Models with a slash (/) are available only in Tape and Reel in the quantities indicated (e.g., /2K5 indicates 2500 devices per reel). Ordering 2500 pieces of “INA121U/2K5” will get a single 2500-piece Tape and Reel. For detailed Tape and Reel mechanical information, refer to Appendix B of Burr-Brown IC Data Book.
TYPICAL PERFORMANCE CURVES

At $T_A = +25^\circ C$, $V_S = \pm 15V$, unless otherwise noted.

**Gain vs Frequency**

**Power Supply Rejection vs Frequency**

**Common-Mode Rejection vs Frequency**

**Input Common-Mode Range vs Output Voltage, $V_S = \pm 15V$**

**Input Common-Mode Range vs Output Voltage, $V_S = \pm 5V, \pm 2.5V$**
TYPICAL PERFORMANCE CURVES (CONT)

At \( T_A = +25^\circ C, V_S = \pm 15V \), unless otherwise noted.

**INPUT BIAS CURRENT vs TEMPERATURE**

- Bias Current (pA) vs Temperature (°C)
- Flat region represents normal linear operation.

**INPUT OVER-VOLTAGE V/I CHARACTERISTICS**

- Input Voltage (V) vs Input Current (mA)
- Flat region represents normal linear operation.

**QUIESCENT CURRENT AND SLEW RATE vs TEMPERATURE**

- Quiescent Current (µA) vs Temperature (°C)

**SHORT-CIRCUIT CURRENT vs TEMPERATURE**

- Short-Circuit Current (µA) vs Temperature (°C)

**SETTLING TIME vs GAIN**

- Setting Time (µs) vs Gain (V/V)

**INPUT BIAS CURRENT vs COMMON-MODE INPUT VOLTAGE**

- Input Bias Current (A) vs Common-Mode Voltage (V)

**SHORT-CIRCUIT CURRENT**

- \( +I_{SC} \) and \( -I_{SC} \) vs Temperature (°C)
TYPICAL PERFORMANCE CURVES (CONT)

At $T_A = +25^\circ C$, $V_S = \pm 15V$, unless otherwise noted.

OUTPUT VOLTAGE SWING vs OUTPUT CURRENT

MAXIMUM OUTPUT VOLTAGE vs FREQUENCY

INPUT OFFSET VOLTAGE WARM-UP

INPUT OFFSET VOLTAGE DRIFT PRODUCTION DISTRIBUTION

INPUT-REFERRED NOISE VOLTAGE vs FREQUENCY

VOLTAGE NOISE 0.1 TO 10Hz

INPUT-REFERRED, $G \geq 100$
TYPICAL PERFORMANCE CURVES (CONT)

At $T_A = +25^\circ$C, $V_S = \pm 15V$, unless otherwise noted.

**SMALL-SIGNAL STEP RESPONSE**

- $G = 1, 10$
  - $G = 1$
  - $50\text{mV/div}$
  - $G = 10$
  - $50\text{mV/div}$
  - $10\mu\text{s/div}$

- $G = 100, 1000$
  - $G = 100$
  - $50\text{mV/div}$
  - $G = 1000$
  - $100\mu\text{s/div}$

**LARGE-SIGNAL STEP RESPONSE**

- $G = 1, 10$
  - $G = 1$
  - $5\text{V/div}$
  - $G = 10$
  - $5\text{V/div}$
  - $100\mu\text{s/div}$

- $G = 100, 1000$
  - $G = 100$
  - $5\text{V/div}$
  - $G = 1000$
  - $100\mu\text{s/div}$
APPLICATION INFORMATION

Figure 1 shows the basic connections required for operation of the INA121. Applications with noisy or high impedance power supplies may require decoupling capacitors close to the device pins as shown.

The output is referred to the output reference (Ref) terminal which is normally grounded. This must be a low-impedance connection to assure good common-mode rejection. A resistance of 8Ω in series with the Ref pin will cause a typical device to degrade to approximately 80dB CMR (G = 1).

SETTING THE GAIN

Gain of the INA121 is set by connecting a single external resistor, R_G, connected between pins 1 and 8:

\[ G = 1 + \frac{50k\Omega}{R_G} \] (1)

Commonly used gains and resistor values are shown in Figure 1.

The 50kΩ term in Equation 1 comes from the sum of the two internal feedback resistors of A_1 and A_2. These on-chip metal film resistors are laser trimmed to accurate absolute values. The accuracy and temperature coefficient of these resistors are included in the gain accuracy and drift specifications of the INA121.

The stability and temperature drift of the external gain setting resistor, R_G, also affects gain. R_G’s contribution to gain accuracy and drift can be directly inferred from the gain equation (1). Low resistor values required for high gain can make wiring resistance important. Sockets add to the wiring resistance which will contribute additional gain error (possibly an unstable gain error) in gains of approximately 100 or greater.

DYNAMIC PERFORMANCE

The typical performance curve “Gain vs Frequency” shows that, despite its low quiescent current, the INA121 achieves wide bandwidth, even at high gain. This is due to the current-feedback topology of the INA121. Settling time also remains excellent at high gain.

FIGURE 1. Basic Connections.
The INA121 provides excellent rejection of high frequency common-mode signals. The typical performance curve, “Common-Mode Rejection vs Frequency” shows this behavior. If the inputs are not properly balanced, however, common-mode signals can be converted to differential signals. Run the $V_{IN}$ and $V_{IN}$ connections directly adjacent each other, from the source signal all the way to the input pins. If possible use a ground plane under both input traces. Avoid running other potentially noisy lines near the inputs.

**NOISE AND ACCURACY PERFORMANCE**

The INA121’s FET input circuitry provides low input bias current and high speed. It achieves lower noise and higher accuracy with high impedance sources. With source impedances of $2k\Omega$ to $50k\Omega$ the INA114, INA128, or INA129 may provide lower offset voltage and drift. For very low source impedance ($\leq 1k\Omega$), the INA103 may provide improved accuracy and lower noise. At very high source impedances ($> 1M\Omega$) the INA116 is recommended.

**OFFSET TRIMMING**

The INA121 is laser trimmed for low offset voltage and drift. Most applications require no external offset adjustment. Figure 2 shows an optional circuit for trimming the output offset voltage. The voltage applied to Ref terminal is summed at the output. The op amp buffer provides low impedance at the Ref terminal to preserve good common-mode rejection. Trim circuits with higher source impedance should be buffered with an op amp follower circuit to assure low impedance on the Ref pin.

![Figure 2. Optional Trimming of Output Offset Voltage.](image)

**INPUT BIAS CURRENT RETURN PATH**

The input impedance of the INA121 is extremely high—approximately $10^{12}\Omega$. However, a path must be provided for the input bias current of both inputs. This input bias current is typically $4pA$. High input impedance means that this input bias current changes very little with varying input voltage. Input circuitry must provide a path for this input bias current if the INA121 is to operate properly. Figure 3 shows various provisions for an input bias current path. Without a bias current return path, the inputs will float to a potential which exceeds the common-mode range of the INA121 and the input amplifiers will saturate.

If the differential source resistance is low, the bias current return path can be connected to one input (see the thermocouple example in Figure 3). With higher source impedance, using two resistors provides a balanced input with possible advantages of lower input offset voltage due to bias current and better high-frequency common-mode rejection.

![Figure 3. Providing an Input Common-Mode Current Path.](image)

**INPUT COMMON-MODE RANGE**

The linear input voltage range of the input circuitry of the INA121 is from approximately $1.2V$ below the positive supply voltage to $2.1V$ above the negative supply. A differential input voltage causes the output voltage to increase. The linear input range, however, will be limited by the output voltage swing of amplifiers $A_1$ and $A_2$. So the linear common-mode input range is related to the output voltage of the complete amplifier. This behavior also depends on supply voltage—see typical performance curve “Input Common-Mode Range vs Output Voltage”.

---

**Diagram Note:**

Crystal or Ceramic Transducer

Thermocouple

Bridge V REF

IN103

INA121

Center-tap provides bias current return.

Bridge resistance provides bias current return.

NOTE: (1) For wider trim range required in high gains, scale resistor values larger.
A combination of common-mode and differential input voltage can cause the output of $A_1$ or $A_2$ to saturate. Figure 4 shows the output voltage swing of $A_1$ and $A_2$ expressed in terms of a common-mode and differential input voltages. For applications where input common-mode range must be maximized, limit the output voltage swing by connecting the INA121 in a lower gain (see performance curve “Input Common-Mode Voltage Range vs Output Voltage”). If necessary, add gain after the INA121 to increase the voltage swing.

Input-overload can produce an output voltage that appears normal. For example, if an input overload condition drives both input amplifiers to their positive output swing limit, the difference voltage measured by the output amplifier will be near zero. The output of $A_3$ will be near 0V even though both inputs are overloaded.

LOW VOLTAGE OPERATION
The INA121 can be operated on power supplies as low as ±2.25V. Performance remains excellent with power supplies ranging from ±2.25V to ±18V. Most parameters vary only slightly throughout this supply voltage range—see typical performance curves. Operation at very low supply voltage requires careful attention to assure that the input voltages remain within their linear range. Voltage swing requirements of internal nodes limit the input common-mode range with low power supply voltage. Typical performance curves, “Input Common-Mode Range vs Output Voltage” show the range of linear operation for ±15V, ±5V, and ±2.5V supplies.

INPUT FILTERING
The INA121’s FET input allows use of an R/C input filter without creating large offsets due to input bias current. Figure 5 shows proper implementation of this input filter to preserve the INA121’s excellent high frequency common-mode rejection. Mismatch of the common-mode input time constant ($R_1C_1$ and $R_2C_2$), either from stray capacitance or mismatched values, causes a high frequency common-mode signal to be converted to a differential signal. This degrades common-mode rejection. The differential input capacitor, $C_3$, reduces the bandwidth and mitigates the effects of mismatch in $C_1$ and $C_2$. Make $C_3$ much larger than $C_1$ and $C_2$. If properly matched, $C_1$ and $C_2$ also improve ac CMR.

\[ f_{-3dB} = \frac{1}{4 \pi R_1 \left( \frac{C_3}{2} + \frac{C_1}{2} \right)} \]

FIGURE 4. Voltage Swing of $A_1$ and $A_2$.

FIGURE 5. Input Low-Pass Filter.

NOTE: To preserve good low frequency CMR, make \( R_1 = R_2 \) and \( C_1 = C_2 \).

FIGURE 7. High-Pass Input Filter.


FIGURE 9. AC-Coupled Instrumentation Amplifier.

FIGURE 10. Voltage Controlled Current Source.

FIGURE 11. Capacitive Bridge Transducer Circuit.
NOTE: Due to the INA121’s current-feedback topology, $V_G$ is approximately 0.7V less than the common-mode input voltage. This DC offset in this guard potential is satisfactory for many guarding applications.

FIGURE 13. Shield Driver Circuit.

FIGURE 14. ECG Amplifier With Right-Leg Drive.
**Features**

- **Low Quiescent Current:** 60µA
- **Wide Power Supply Range**
  - Single Supply: 2.2V to 36V
  - Dual Supply: −0.9/+1.3V to ±18V
- **Common-Mode Range to (V–)−0.1V**
- **Rail-to-Rail Output Swing**
- **Low Offset Voltage:** 250µV max
- **Low Offset Drift:** 3µV/°C max
- **Low Noise:** 60nV/√Hz
- **Low Input Bias Current:** 25nA max
- **8-Pin DIP and SO-8 Surface-Mount**

**Applications**

- **Portable, Battery Operated Systems**
- **Industrial Sensor Amplifier:** Bridge, RTD, Thermocouple
- **Physiological Amplifier:** ECG, EEG, EMG
- **Multi-Channel Data Acquisition**

**Description**

The INA122 is a precision instrumentation amplifier for accurate, low noise differential signal acquisition. Its two-op-amp design provides excellent performance with very low quiescent current, and is ideal for portable instrumentation and data acquisition systems.

The INA122 can be operated with single power supplies from 2.2V to 36V and quiescent current is a mere 60µA. It can also be operated from dual supplies. By utilizing an input level-shift network, input common-mode range extends to 0.1V below negative rail (single supply ground).

A single external resistor sets gain from 5V/V to 10000V/V. Laser trimming provides very low offset voltage (250µV max), offset voltage drift (3µV/°C max) and excellent common-mode rejection.

Package options include 8-pin plastic DIP and SO-8 surface-mount packages. Both are specified for the —40°C to +85°C extended industrial temperature range.
## SPECIFICATIONS

At $T_A = +25^\circ C$, $V_S = +5V$, $R_L = 20\Omega$ connected to $V_S/2$, unless otherwise noted.

### INPUT

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offset Voltage, RTI vs Temperature</td>
<td>$V_S = +2.2V$ to $+36V$</td>
<td>±1</td>
<td>±3</td>
<td>*</td>
<td>±5</td>
<td>µV</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td><strong>Input Impedance</strong></td>
<td>$R_S = 0$</td>
<td>10</td>
<td>30</td>
<td>*</td>
<td>100</td>
<td>µΩ</td>
<td>pF</td>
<td></td>
</tr>
<tr>
<td>Safe Input Voltage</td>
<td>$R_S = 10k\Omega$</td>
<td>(V–)–0.3</td>
<td>(V+)0.3</td>
<td>*</td>
<td>*</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Common-Mode Voltage Range</strong></td>
<td>$V_{CM} = 0V$ to 3.4V</td>
<td>0</td>
<td>3.4</td>
<td>*</td>
<td>*</td>
<td>V</td>
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<td></td>
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</tbody>
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### INPUT BIAS CURRENT

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offset Current vs Temperature</td>
<td>±1</td>
<td>±2</td>
<td>±5</td>
<td>nA</td>
<td></td>
</tr>
<tr>
<td>vs Temperature</td>
<td>±40</td>
<td>±25</td>
<td>±5</td>
<td>pA/°C</td>
<td></td>
</tr>
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</table>

### GAIN

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offset Current Gain Equation</td>
<td>$G = 5$ to $10k\Omega$</td>
<td>*</td>
<td>V/V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>vs Temperature Gain Error</td>
<td>$G = 5$</td>
<td>±0.05</td>
<td>±0.1</td>
<td>±0.15</td>
<td>%</td>
</tr>
<tr>
<td>vs Temperature Gain Error</td>
<td>$G = 100$</td>
<td>5</td>
<td>10</td>
<td>±1</td>
<td>%</td>
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</table>

### NOISE (RTI)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Noise, $f = 1kHz$</td>
<td>60</td>
<td>*</td>
<td>nV/√Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$f = 100Hz$</td>
<td>100</td>
<td>*</td>
<td>nV/√Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$f = 1kHz$</td>
<td>110</td>
<td>*</td>
<td>nV/√Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$f = 0.0Hz$ to $0Hz$</td>
<td>2</td>
<td>*</td>
<td>µV/√Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current Noise, $f = 1kHz$</td>
<td>80</td>
<td>*</td>
<td>IA/√Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$f = 0.0Hz$ to $10Hz$</td>
<td>2</td>
<td>*</td>
<td>µA/√Hz</td>
<td></td>
<td></td>
</tr>
</tbody>
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### OUTPUT

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage, Positive $V_S = ±15V$</td>
<td>(V+)–0.1</td>
<td>*</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative $V_S = ±15V$</td>
<td>(V–)+0.15</td>
<td>*</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short-Circuit Current Short-Circuit to Ground</td>
<td>+3/–30</td>
<td></td>
<td>mA</td>
<td></td>
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### FREQUENCY RESPONSE

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<thead>
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<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth, –3dB $G = 5$</td>
<td>120</td>
<td>*</td>
<td>kHz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$G = 100$</td>
<td>5</td>
<td>*</td>
<td>kHz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$G = 500$</td>
<td>0.9</td>
<td>*</td>
<td>kHz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slew Rate</td>
<td>+0.08–0.16</td>
<td>*</td>
<td>V/µs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Settling Time, 0.01%</td>
<td>$G = 5$</td>
<td>350</td>
<td>*</td>
<td>µs</td>
<td></td>
</tr>
<tr>
<td>$G = 100$</td>
<td>450</td>
<td>*</td>
<td>µs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$G = 500$</td>
<td>1.8</td>
<td>*</td>
<td>ms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overload Recovery</td>
<td>3</td>
<td>*</td>
<td>µs</td>
<td></td>
<td></td>
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### POWER SUPPLY

<table>
<thead>
<tr>
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<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Range, Single Supply</td>
<td>$V_S = +2.2V$</td>
<td>5</td>
<td>36</td>
<td>*</td>
<td>°C</td>
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<tr>
<td>Dual Supplies</td>
<td>$I_O = 0$</td>
<td>±18</td>
<td>*</td>
<td>*</td>
<td>V</td>
</tr>
<tr>
<td>Current</td>
<td>$I_O = 0$</td>
<td>60</td>
<td>85</td>
<td>*</td>
<td>µA</td>
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### TEMPERATURE RANGE

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<tr>
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<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
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</thead>
<tbody>
<tr>
<td>Specification</td>
<td>–40</td>
<td>±85</td>
<td>*</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>Operation</td>
<td>–55</td>
<td>±85</td>
<td>*</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>Storage</td>
<td>–55</td>
<td>±125</td>
<td>*</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>Thermal Resistance, $\theta_{JA}$</td>
<td>8-Pin DIP</td>
<td>150</td>
<td>*</td>
<td>°C/W</td>
<td></td>
</tr>
<tr>
<td>SO-8 Surface-Mount</td>
<td>150</td>
<td>*</td>
<td>°C/W</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Specification same as INA122P, INA122U.
PIN CONFIGURATION

Top View 8-Pin DIP, SO-8

ABSOLUTE MAXIMUM RATINGS(1)

Supply Voltage, V+ to V– .............................................. 36V
Signal Input Terminals, Voltage(V) ...................... (V–)–0.3V to (V+)0.3V
Current ................................................................. 5mA
Output Short Circuit ................................................................. Continuous
Operating Temperature ................................................. –40°C to +125°C
Storage Temperature ..................................................... –55°C to +125°C
Lead Temperature (soldering, 10s) ............................................... +300°C

NOTES: (1) Stresses above these ratings may cause permanent damage.
(2) Input terminals are internally diode-clamped to the power supply rails.
Input signals that can exceed the supply rails by more than 0.3V should be current-limited to 5mA or less.

PACKAGE INFORMATION

<table>
<thead>
<tr>
<th>PRODUCT</th>
<th>PACKAGE</th>
<th>PACKAGE DRAWING NUMBER(1)</th>
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<tbody>
<tr>
<td>INA122PA</td>
<td>8-Pin DIP</td>
<td>006</td>
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<tr>
<td>INA122P</td>
<td>8-Pin DIP</td>
<td>006</td>
</tr>
<tr>
<td>INA122UA</td>
<td>SO-8 Surface Mount</td>
<td>182</td>
</tr>
<tr>
<td>INA122U</td>
<td>SO-8 Surface Mount</td>
<td>182</td>
</tr>
</tbody>
</table>

NOTE: (1) For detailed drawing and dimension table, see end of data sheet, or Appendix C of Burr-Brown IC Data Book.

ELECTROSTATIC DISCHARGE SENSITIVITY

This integrated circuit can be damaged by ESD. Burr-Brown recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.
TYPICAL PERFORMANCE CURVES

At $T_A = +25^\circ C$ and $V_S = \pm 5V$, unless otherwise noted.

**Gain vs Frequency**

- $G = 1000$
- $G = 100$
- $G = 20$
- $G = 5$

**Common-Mode Rejection vs Frequency**

- $G = 1000$
- $G = 100$
- $G = 5$

**Positive Power Supply Rejection vs Frequency**

- $G = 500$
- $G = 100$
- $G = 5$

**Negative Power Supply Rejection vs Frequency**

- $G = 500$
- $G = 100$
- $G = 5$

**Input Common-Mode Range vs Output Voltage, $V_S = \pm 15V$, $G = 5$**

**Input Common-Mode Voltage vs Output Voltage, $V_S = \pm 5V$, $G = 5$**

Limited by $A_2$ output swing—see text.
TYPICAL PERFORMANCE CURVES (CONT)

At $T_A = +25^\circ C$ and $V_S = \pm 5V$, unless otherwise noted.

VOLTAGE and CURRENT NOISE DENSITY vs FREQUENCY (RTI)

SETTLING TIME vs GAIN

INPUT-REFERRED OFFSET VOLTAGE WARM-UP

QUIESCENT CURRENT vs TEMPERATURE

TOTAL HARMONIC DISTORTION+NOISE vs FREQUENCY

OUTPUT VOLTAGE SWING vs OUTPUT CURRENT

Turn-on time $\leq$ 1ms. Settling time to final value depends on Gain—see settling time.

$V_{+}$

$V_{-}$
TYPICAL PERFORMANCE CURVES (CONT)

At $T_A = +25^\circ C$ and $V_S = \pm 5V$, unless otherwise noted.

**SMALL-SIGNAL STEP RESPONSE**

$G = 5$

- $50\mu s/div$
- $100mV/div$

**SMALL-SIGNAL STEP RESPONSE**

$G = 100$

- $100\mu s/div$
- $100mV/div$

**LARGE-SIGNAL STEP RESPONSE**

$G = 5$

- $50\mu s/div$
- $2V/div$

**INPUT-REFERRED NOISE VOLTAGE**

- $0.1Hz$ to $10Hz$
- $500ms/div$
- $2V/div$
APPLICATION INFORMATION

Figure 1 shows the basic connections required for operation of the INA122. Applications with noisy or high impedance power supplies may require decoupling capacitors close to the device pins.

The output is referred to the output reference (Ref) terminal which is normally grounded. This must be a low-impedance connection to ensure good common-mode rejection. A resistance of 10Ω in series with the Ref pin will cause a typical device to degrade to approximately 80dB CMR.

SETTING THE GAIN

Gain of the INA122 is set by connecting a single external resistor, \( R_G \), as shown:

\[
G = 5 + \frac{200k\Omega}{R_G} \quad (1)
\]

Commonly used gains and \( R_G \) resistor values are shown in Figure 1.

The 200kΩ term in equation 1 comes from the internal metal film resistors which are laser trimmed to accurate absolute values. The accuracy and temperature coefficient of these resistors are included in the gain accuracy and drift specifications of the INA122.

The stability and temperature drift of the external gain setting resistor, \( R_G \), also affects gain. \( R_G \)'s contribution to gain accuracy and drift can be directly inferred from the gain equation (1).

OFFSET TRIMMING

The INA122 is laser trimmed for low offset voltage and offset voltage drift. Most applications require no external offset adjustment. Figure 2 shows an optional circuit for trimming the output offset voltage. The voltage applied to the Ref terminal is added to the output signal. An op amp buffer is used to provide low impedance at the Ref terminal to preserve good common-mode rejection.

**TABLE 1**

<table>
<thead>
<tr>
<th>DESIRED GAIN (V/V)</th>
<th>( R_G ) (Ω)</th>
<th>NEAREST 1% ( R_G ) VALUE</th>
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<tr>
<td>5</td>
<td>NC</td>
<td>NC</td>
</tr>
<tr>
<td>10</td>
<td>40k</td>
<td>40.2k</td>
</tr>
<tr>
<td>20</td>
<td>13.33k</td>
<td>13.3k</td>
</tr>
<tr>
<td>50</td>
<td>4444</td>
<td>4420</td>
</tr>
<tr>
<td>100</td>
<td>2105</td>
<td>2100</td>
</tr>
<tr>
<td>200</td>
<td>1026</td>
<td>1020</td>
</tr>
<tr>
<td>500</td>
<td>404</td>
<td>402</td>
</tr>
<tr>
<td>1000</td>
<td>201</td>
<td>200</td>
</tr>
<tr>
<td>2000</td>
<td>100.3</td>
<td>100</td>
</tr>
<tr>
<td>5000</td>
<td>40</td>
<td>40.2</td>
</tr>
<tr>
<td>10000</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

NC: No Connection.

INPUT BIAS CURRENT RETURN PATH

The input impedance of the INA122 is extremely high—approximately 10^10Ω. However, a path must be provided for the input bias current of both inputs. This input bias current is approximately –10nA (current flows out of the input terminals). High input impedance means that this input bias current changes very little with varying input voltage.
Input circuitry must provide a path for this input bias current for proper operation. Figure 3 shows various provisions for an input bias current path. Without a bias current path, the inputs will float to a potential which exceeds the common-mode range of the INA122 and the input amplifiers will saturate.

If the differential source resistance is low, the bias current return path can be connected to one input (see the thermocouple example in Figure 3). With higher source impedance, using two equal resistors provides a balanced input with possible advantages of lower input offset voltage due to bias current and better high-frequency common-mode rejection.

**INPUT PROTECTION**

The inputs of the INA122 are protected with internal diodes connected to the power supply rails (Figure 4). These diodes will clamp the applied signal to prevent it from damaging the input circuitry. If the input signal voltage can exceed the power supplies by more than 0.3V, the input signal current should be limited to less than 5mA to protect the internal clamp diodes. This can generally be done with a series input resistor. Some signal sources are inherently current-limited and do not require limiting resistors.

**INPUT COMMON-MODE RANGE**

The common-mode range for some common operating conditions is shown in the typical performance curves. The INA122 can operate over a wide range of power supply and V\text{REF} configurations, making it impractical to provide a comprehensive guide to common-mode range limits for all possible conditions. The most commonly overlooked overload condition occurs by attempting to exceed the output swing of A\text{2}, an internal circuit node that cannot be measured. Calculating the expected voltages at A\text{2}’s output (see equation in Figure 4) provides a check for the most common overload conditions.

The design of A\text{1} and A\text{2} are identical and their outputs can swing to within approximately 100mV of the power supply rails, depending on load conditions. When A\text{2}’s output is saturated, A\text{1} can still be in linear operation, responding to changes in the non-inverting input voltage. This may give the appearance of linear operation but the output voltage is invalid.

A single supply instrumentation amplifier has special design considerations. Using commonly available single-supply op amps to implement the two-op amp topology will not yield equivalent performance. For example, consider the condition where both inputs of common single-supply op amps are

![Figure 3: Providing an Input Common-Mode Current Path.](image)

![Figure 4: INA122 Simplified Circuit Diagram.](image)
equal to 0V. The outputs of both $A_1$ and $A_2$ must be 0V. But any small positive voltage applied to $V_{IN}^+$ requires that $A_2$'s output must swing below 0V, which is clearly impossible without a negative power supply.

To achieve common-mode range that extends to single-supply ground, the INA122 uses precision level-shifting buffers on its inputs. This shifts both inputs by approximately +0.5V, and through the feedback network, shifts $A_2$'s output by approximately +0.6V. With both inputs and $V_{REF}$ at single-supply, $A_2$'s output is well within its linear range. A positive $V_{IN}^+$ causes $A_2$'s output to swing below 0.6V. As a result of this input level-shifting, the voltages at pin 1 and pin 8 are not equal to their respective input terminal voltages (pins 2 and 3). For most applications, this is not important since only the gain-setting resistor connects to these pins.

**LOW VOLTAGE OPERATION**

The INA122 can be operated on a single power supply as low as +2.2V (or a total of +2.2V on dual supplies). Performance remains excellent throughout the power supply range up to +36V (or ±18V). Most parameters vary only slightly throughout this supply voltage range—see typical performance curves.

Operation at very low supply voltage requires careful attention to ensure that the common-mode voltage remains within its linear range.

**LOW QUIESCENT CURRENT OPERATION**

The INA122 maintains its low quiescent current (60µA) while the output is within linear operation (up to 200mV from the supply rails). When the input creates a condition that overdrives the output into saturation, quiescent current increases. With $V_O$ overdriven into the positive rail, the quiescent current increases to approximately 400µA. Likewise, with $V_O$ overdriven into the negative rail (single supply ground) the quiescent current increases to approximately 200µA.

**OUTPUT CURRENT RANGE**

Output sourcing and sinking current values versus the output voltage ranges are shown in the typical performance curves. The positive and negative current limits are not equal. Positive output current sourcing will drive moderate to high load impedances. Battery operation normally requires the careful management of power consumption to keep load impedances very high throughout the design.


**FIGURE 5. Micropower Single Supply Bridge Amplifier.**
GENERAL PURPOSE SINGLE OPERATIONAL AMPLIFIER

- LARGE INPUT VOLTAGE RANGE
- NO LATCH-UP
- HIGH GAIN
- SHORT-CIRCUIT PROTECTION
- NO FREQUENCY COMPENSATION REQUIRED
- SAME PIN CONFIGURATION AS THE UA709

DESCRIPTION
The UA741 is a high performance monolithic operational amplifier constructed on a single silicon chip. It is intended for a wide range of analog applications.
- Summing amplifier
- Voltage follower
- Integrator
- Active filter
- Function generator

The high gain and wide range of operating voltages provide superior performances in integrator, summing amplifier and general feedback applications. The internal compensation network (6dB/octave) insures stability in closed loop circuits.

ORDER CODES

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Temperature Range</th>
<th>Package</th>
</tr>
</thead>
<tbody>
<tr>
<td>UA741C</td>
<td>0°C, +70°C</td>
<td>•</td>
</tr>
<tr>
<td>UA741I</td>
<td>-40°C, +105°C</td>
<td>•</td>
</tr>
<tr>
<td>UA741M</td>
<td>-55°C, +125°C</td>
<td>•</td>
</tr>
</tbody>
</table>

Example: UA741CN

PIN CONNECTIONS (top view)

1 - Offset null 1
2 - Inverting input
3 - Non-inverting input
4 - \( V_{cc}^- \)
5 - Offset null 2
6 - Output
7 - \( V_{cc}^+ \)
8 - N.C.
ABSOLUTE MAXIMUM RATINGS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>UA741M</th>
<th>UA741I</th>
<th>UA741C</th>
<th>Unit</th>
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</thead>
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<td>Supply Voltage</td>
<td>±22</td>
<td>V</td>
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<tr>
<td>Vid</td>
<td>Differential Input Voltage</td>
<td>±30</td>
<td>V</td>
<td></td>
<td></td>
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<tr>
<td>Vi</td>
<td>Input Voltage</td>
<td>±15</td>
<td>V</td>
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<td></td>
</tr>
<tr>
<td>Ptot</td>
<td>Power Dissipation</td>
<td>500</td>
<td>mW</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Output Short-circuit Duration</td>
<td>Infinite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toper</td>
<td>Operating Free Air Temperature Range</td>
<td>-55 to +125</td>
<td>-40 to +105</td>
<td>0 to +70</td>
<td>°C</td>
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<tr>
<td>Tstg</td>
<td>Storage Temperature Range</td>
<td>-65 to +150</td>
<td>-65 to +150</td>
<td>-65 to +150</td>
<td>°C</td>
</tr>
</tbody>
</table>
ELECTRICAL CHARACTERISTICS

\( V_{CC} = \pm 15\,\text{V}, T_{amb} = +25^\circ\,\text{C} \) (unless otherwise specified)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{io} )</td>
<td>Input Offset Voltage ((R_S \leq 10,\text{k},\Omega))</td>
<td>mV</td>
</tr>
<tr>
<td>( I_{io} )</td>
<td>Input Offset Current (T_{amb} = +25^\circ,\text{C})</td>
<td>nA</td>
</tr>
<tr>
<td>( I_{ib} )</td>
<td>Input Bias Current (T_{amb} = +25^\circ,\text{C})</td>
<td>nA</td>
</tr>
<tr>
<td>( A_{vd} )</td>
<td>Large Signal Voltage Gain * ((V_{O} \pm 10,\text{V}, R_L = 2,\text{k},\Omega))</td>
<td>V/mV</td>
</tr>
<tr>
<td>( SVR )</td>
<td>Supply Voltage Rejection Ratio ((R_S \leq 10,\text{k},\Omega))</td>
<td>dB</td>
</tr>
<tr>
<td>( I_{CC} )</td>
<td>Supply Current, no load (T_{amb} = +25^\circ,\text{C})</td>
<td>mA</td>
</tr>
<tr>
<td>( V_{km} )</td>
<td>Input Common Mode Voltage Range (T_{amb} = +25^\circ,\text{C})</td>
<td>V</td>
</tr>
<tr>
<td>( CMR )</td>
<td>Common-mode Rejection Ratio ((R_S \leq 10,\text{k},\Omega))</td>
<td>dB</td>
</tr>
<tr>
<td>( I_{OS} )</td>
<td>Output Short-circuit Current</td>
<td>mA</td>
</tr>
<tr>
<td>( \pm V_{DPP} )</td>
<td>Output Voltage Swing (T_{amb} = +25^\circ,\text{C})</td>
<td>V</td>
</tr>
<tr>
<td>( SR )</td>
<td>Slew Rate ((V_i = \pm 10,\text{V}, R_L = 10,\text{k},\Omega, C_L = 100,\text{pF}, T_{amb} = 25^\circ,\text{C}, \text{unity gain}))</td>
<td>V/\mu s</td>
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<tr>
<td>( t )</td>
<td>Rise Time ((V_i = 120,\text{mV}, R_L = 10,\text{k},\Omega, C_L = 100,\text{pF}, T_{amb} = 25^\circ,\text{C}, \text{unity gain}))</td>
<td>\mu s</td>
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<tr>
<td>( K_{OV} )</td>
<td>Overshoot ((V_i = 20,\text{mV}, R_L = 2,\text{k},\Omega, C_L = 100,\text{pF}, T_{amb} = 25^\circ,\text{C}, \text{unity gain}))</td>
<td>%</td>
</tr>
<tr>
<td>( R_I )</td>
<td>Input Resistance</td>
<td>M\Omega</td>
</tr>
<tr>
<td>( GBP )</td>
<td>Gain Bandwidth Product ((V_i = 10,\text{mV}, R_L = 2,\text{k},\Omega, C_L = 100,\text{pF}, f = 100,\text{kHz}))</td>
<td>MHz</td>
</tr>
<tr>
<td>( THD )</td>
<td>Total Harmonic Distortion ((f = 1,\text{kHz}, A_V = 20,\text{dB}, R_L = 2,\text{k},\Omega, V_O = 2,\text{VPP}, C_L = 100,\text{pF}, T_{amb} = 25^\circ,\text{C}))</td>
<td>%</td>
</tr>
<tr>
<td>( e_n )</td>
<td>Equivalent Input Noise Voltage ((f = 1,\text{kHz}, R_S = 100,\Omega))</td>
<td>nV/\sqrt{\text{Hz}}</td>
</tr>
<tr>
<td>( \phi )</td>
<td>Phase Margin</td>
<td>Degrees</td>
</tr>
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</table>
MEASUREMENT DIAGRAMS

OFFSET VOLTAGE NULL CIRCUIT

TRANSIENT RESPONSE TEST CIRCUIT

CURRENT TO VOLTAGE CONVERTER

NEUTRALIZING INPUT CAPACITANCE TO OPTIMIZE RESPONSE TIME

POSITIVE VOLTAGE REFERENCE

NEGATIVE VOLTAGE REFERENCE
## PACKAGE MECHANICAL DATA
8 PINS - PLASTIC DIP

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<thead>
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<th>Millimeters</th>
<th>Inches</th>
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<tr>
<td>a1</td>
<td>0.51</td>
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<tr>
<td>B</td>
<td>1.15</td>
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<tr>
<td>b</td>
<td>0.356</td>
<td>0.55</td>
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<tr>
<td>b1</td>
<td>0.204</td>
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<tr>
<td>D</td>
<td>10.92</td>
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<tr>
<td>E</td>
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<td>9.75</td>
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<td>e</td>
<td>2.54</td>
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### PACKAGE MECHANICAL DATA

8 PINS - PLASTIC MICROPACKAGE (SO)

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<td>a2</td>
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<td>1.65</td>
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<tr>
<td>a3</td>
<td>0.65</td>
<td>0.85</td>
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<tr>
<td>b</td>
<td>0.35</td>
<td>0.48</td>
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<tr>
<td>b1</td>
<td>0.19</td>
<td>0.25</td>
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<tr>
<td>C</td>
<td>0.25</td>
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<td>c1</td>
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<td>D</td>
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<tr>
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</tr>
<tr>
<td>L</td>
<td>0.4</td>
<td>1.27</td>
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<tr>
<td>M</td>
<td>0.6</td>
<td></td>
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<tr>
<td>S</td>
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Datasheets for electronics components.
Features

- High-performance, Low-power Atmel® AVR® 8-bit Microcontroller
- Advanced RISC Architecture
  - 130 Powerful Instructions – Most Single-clock Cycle Execution
  - 32 x 8 General Purpose Working Registers
  - Fully Static Operation
  - Up to 16MIPS Throughput at 16MHz
  - On-chip 2-cycle Multiplier
- High Endurance Non-volatile Memory segments
  - 8Kbytes of In-System Self-programmable Flash program memory
  - 512Bytes EEPROM
  - 1Kbyte Internal SRAM
  - Write/Erase Cycles: 10,000 Flash/100,000 EEPROM
  - Data retention: 20 years at 85°C/100 years at 25°C
  - Optional Boot Code Section with Independent Lock Bits
    - In-System Programming by On-chip Boot Program
    - True Read-While-Write Operation
    - Programming Lock for Software Security
- Peripheral Features
  - Two 8-bit Timer/Counters with Separate Prescaler, one Compare Mode
  - One 16-bit Timer/Counter with Separate Prescaler, Compare Mode, and Capture Mode
  - Real Time Counter with Separate Oscillator
  - Three PWM Channels
  - 8-channel ADC in TQFP and QFN/MLF package
    - Eight Channels 10-bit Accuracy
  - 6-channel ADC in PDIP package
    - Six Channels 10-bit Accuracy
  - Byte-oriented Two-wire Serial Interface
  - Programmable Serial USART
  - Master/Slave SPI Serial Interface
  - Programmable Watchdog Timer with Separate On-chip Oscillator
  - On-chip Analog Comparator
- Special Microcontroller Features
  - Power-on Reset and Programmable Brown-out Detection
  - Internal Calibrated RC Oscillator
  - External and Internal Interrupt Sources
  - Five Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, and Standby
- I/O and Packages
  - 23 Programmable I/O Lines
  - 28-lead PDIP, 32-lead TQFP, and 32-pad QFN/MLF
- Operating Voltages
  - 2.7V - 5.5V (ATmega8L)
  - 4.5V - 5.5V (ATmega8)
- Speed Grades
  - 0 - 8MHz (ATmega8L)
  - 0 - 16MHz (ATmega8)
- Power Consumption at 4Mhz, 3V, 25°C
  - Active: 3.6mA
  - Idle Mode: 1.0mA
  - Power-down Mode: 0.5µA
Pin Configurations

PDIP

TQFP Top View

MLF Top View

NOTE:
The large center pad underneath the MLF packages is made of metal and internally connected to GND. It should be soldered or glued to the PCB to ensure good mechanical stability. If the center pad is left unconnected, the package might loosen from the PCB.
Overview

The Atmel® AVR® ATmega8 is a low-power CMOS 8-bit microcontroller based on the AVR RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega8 achieves throughputs approaching 1MIPS per MHz, allowing the system designer to optimize power consumption versus processing speed.

Block Diagram

Figure 1. Block Diagram
The Atmel® AVR® core combines a rich instruction set with 32 general purpose working registers. All the 32 registers are directly connected to the Arithmetic Logic Unit (ALU), allowing two independent registers to be accessed in one single instruction executed in one clock cycle. The resulting architecture is more code efficient while achieving throughputs up to ten times faster than conventional CISC microcontrollers.

The ATmega8 provides the following features: 8 Kbytes of In-System Programmable Flash with Read-While-Write capabilities, 512 bytes of EEPROM, 1 Kbyte of SRAM, 23 general purpose I/O lines, 32 general purpose working registers, three flexible Timer/Counters with compare modes, internal and external interrupts, a serial programmable USART, a byte oriented Two-wire Serial Interface, a 6-channel ADC (eight channels in TQFP and QFN/MLF packages) with 10-bit accuracy, a programmable Watchdog Timer with Internal Oscillator, an SPI serial port, and five software selectable power saving modes. The Idle mode stops the CPU while allowing the SRAM, Timer/Counters, SPI port, and interrupt system to continue functioning. The Power-down mode saves the register contents but freezes the Oscillator, disabling all other chip functions until the next Interrupt or Hardware Reset. In Power-save mode, the asynchronous timer continues to run, allowing the user to maintain a timer base while the rest of the device is sleeping. The ADC Noise Reduction mode stops the CPU and all I/O modules except asynchronous timer and ADC, to minimize switching noise during ADC conversions. In Standby mode, the crystal/resonator Oscillator is running while the rest of the device is sleeping. This allows very fast start-up combined with low-power consumption.

The device is manufactured using Atmel’s high density non-volatile memory technology. The Flash Program memory can be reprogrammed In-System through an SPI serial interface, by a conventional non-volatile memory programmer, or by an On-chip boot program running on the AVR core. The boot program can use any interface to download the application program in the Application Flash memory. Software in the Boot Flash Section will continue to run while the Application Flash Section is updated, providing true Read-While-Write operation. By combining an 8-bit RISC CPU with In-System Self-Programmable Flash on a monolithic chip, the Atmel ATmega8 is a powerful microcontroller that provides a highly-flexible and cost-effective solution to many embedded control applications.

The ATmega8 is supported with a full suite of program and system development tools, including C compilers, macro assemblers, program simulators, and evaluation kits.

Disclaimer

Typical values contained in this datasheet are based on simulations and characterization of other AVR microcontrollers manufactured on the same process technology. Minimum and Maximum values will be available after the device is characterized.
Pin Descriptions

VCC
Digital supply voltage.

GND
Ground.

Port B (PB7..PB0)
Port B is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port B output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port B pins that are externally pulled low will source current if the pull-up resistors are activated. The Port B pins are tri-stated when a reset condition becomes active, even if the clock is not running.

Depending on the clock selection fuse settings, PB6 can be used as input to the inverting Oscillator amplifier and input to the internal clock operating circuit.

Depending on the clock selection fuse settings, PB7 can be used as output from the inverting Oscillator amplifier.

If the Internal Calibrated RC Oscillator is used as chip clock source, PB7..6 is used as TOSC2..1 input for the Asynchronous Timer/Counter2 if the AS2 bit in ASSR is set.

The various special features of Port B are elaborated in “Alternate Functions of Port B” on page 58 and “System Clock and Clock Options” on page 25.

Port C (PC5..PC0)
Port C is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port C output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port C pins that are externally pulled low will source current if the pull-up resistors are activated. The Port C pins are tri-stated when a reset condition becomes active, even if the clock is not running.

If the RSTDISBL Fuse is programmed, PC6 is used as an I/O pin. Note that the electrical characteristics of PC6 differ from those of the other pins of Port C.

If the RSTDISBL Fuse is unprogrammed, PC6 is used as a Reset input. A low level on this pin for longer than the minimum pulse length will generate a Reset, even if the clock is not running. The minimum pulse length is given in Table 15 on page 38. Shorter pulses are not guaranteed to generate a Reset.

The various special features of Port C are elaborated on page 61.

Port D (PD7..PD0)
Port D is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port D output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port D pins that are externally pulled low will source current if the pull-up resistors are activated. The Port D pins are tri-stated when a reset condition becomes active, even if the clock is not running.

Port D also serves the functions of various special features of the ATmega8 as listed on page 63.

RESET
Reset input. A low level on this pin for longer than the minimum pulse length will generate a reset, even if the clock is not running. The minimum pulse length is given in Table 15 on page 38. Shorter pulses are not guaranteed to generate a reset.
## Ordering Information

<table>
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<th>Speed (MHz)</th>
<th>Power Supply (V)</th>
<th>Ordering Code(2)</th>
<th>Package(1)</th>
<th>Operation Range</th>
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Notes:  
1. This device can also be supplied in wafer form. Please contact your local Atmel sales office for detailed ordering information and minimum quantities  
2. Pb-free packaging complies to the European Directive for Restriction of Hazardous Substances (RoHS directive). Also Halide free and fully Green  
3. Tape & Reel  
4. See characterization specification at 105°C

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<td>28-lead, 0.300° Wide, Plastic Dual Inline Package (PDIP)</td>
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<td>32M1-A</td>
<td>32-pad, 5 × 5 × 1.0 body, Lead Pitch 0.50mm Quad Flat No-Lead/Micro Lead Frame Package (QFN/MLF)</td>
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</table>
Notes:
1. This package conforms to JEDEC reference M5-026, Variation ABA.
2. Dimensions D1 and E1 do not include mold protrusion. Allowable protrusion is 0.25mm per side. Dimensions D1 and E1 are maximum plastic body size dimensions including mold mismatch.
3. Lead coplanarity is 0.10mm maximum.

**COMMON DIMENSIONS**
(Unit of measure = mm)

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2010-10-20
Note: 1. Dimensions D and E1 do not include mold Flash or Protrusion. Mold Flash or Protrusion shall not exceed 0.25mm (0.010").

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Title: 32M1-A, 32-pad, 5 x 5 x 1.0mm Body, Lead Pitch 0.50mm, 3.10mm Exposed Pad, Micro Lead Frame Package (MLF)

Common Dimensions (Unit of Measure = mm):

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Note: JEDEC Standard MO-220, Fig. 2 (Anvil Singulation), VHHD-2.

5/25/06

2325 Orchard Parkway
San Jose, CA 95131
Errata

The revision letter in this section refers to the revision of the ATmega8 device.

ATmega8
Rev. D to I, M

- First Analog Comparator conversion may be delayed
- Interrupts may be lost when writing the timer registers in the asynchronous timer
- Signature may be Erased in Serial Programming Mode
- CKOPT Does not Enable Internal Capacitors on XTALn/TOSCn Pins when 32KHz Oscillator is Used to Clock the Asynchronous Timer/Counter2
- Reading EEPROM by using ST or STS to set EERE bit triggers unexpected interrupt request

1. First Analog Comparator conversion may be delayed
   If the device is powered by a slow rising $V_{CC}$, the first Analog Comparator conversion will take longer than expected on some devices.
   **Problem Fix / Workaround**
   When the device has been powered or reset, disable then enable the Analog Comparator before the first conversion.

2. Interrupts may be lost when writing the timer registers in the asynchronous timer
   The interrupt will be lost if a timer register that is synchronized to the asynchronous timer clock is written when the asynchronous Timer/Counter register(TCNTx) is 0x00.
   **Problem Fix / Workaround**
   Always check that the asynchronous Timer/Counter register neither have the value 0xFF nor 0x00 before writing to the asynchronous Timer Control Register(TCCRx), asynchronous Timer Counter Register(TCNTx), or asynchronous Output Compare Register(OCRx).

3. Signature may be Erased in Serial Programming Mode
   If the signature bytes are read before a chip erase command is completed, the signature may be erased causing the device ID and calibration bytes to disappear. This is critical, especially, if the part is running on internal RC oscillator.
   **Problem Fix / Workaround**
   Ensure that the chip erase command has exceeded before applying the next command.

4. CKOPT Does not Enable Internal Capacitors on XTALn/TOSCn Pins when 32KHz Oscillator is Used to Clock the Asynchronous Timer/Counter2
   When the internal RC Oscillator is used as the main clock source, it is possible to run the Timer/Counter2 asynchronously by connecting a 32KHz Oscillator between XTAL1/TOSC1 and XTAL2/TOSC2. But when the internal RC Oscillator is selected as the main clock source, the CKOPT Fuse does not control the internal capacitors on XTAL1/TOSC1 and XTAL2/TOSC2. As long as there are no capacitors connected to XTAL1/TOSC1 and XTAL2/TOSC2, safe operation of the Oscillator is not guaranteed.
   **Problem Fix / Workaround**
   Use external capacitors in the range of 20pF - 36pF on XTAL1/TOSC1 and XTAL2/TOSC2. This will be fixed in ATmega8 Rev. G where the CKOPT Fuse will control internal capacitors also when internal RC Oscillator is selected as main clock source. For ATmega8 Rev. G, CKOPT = 0 (programmed) will enable the internal capacitors on XTAL1 and XTAL2. Customers who want compatibility between Rev. G and older revisions, must ensure that CKOPT is unprogrammed (CKOPT = 1).
5. **Reading EEPROM by using ST or STS to set EERE bit triggers unexpected interrupt request.**

Reading EEPROM by using the ST or STS command to set the EERE bit in the EECR register triggers an unexpected EEPROM interrupt request.

**Problem Fix / Workaround**

Always use OUT or SBI to set EERE in EECR.
Sistema de medición de fuerza para Módulo de Transmisibilidad
Programa Principal de uC

;******************************************************************************
; Sistema envía paquetes de 12 en 12 (Lee, almacena, tx 12)
; aceleración con rango de 1.5g
;******************************************************************************

.include "C:\VMLAB\include\m8def.inc"

; Define here the variables
;
.def temp =r16

; Define here Reset and interrupt vectors, if any
;
reset:
    rjmp start
    reti ; Addr $01
    reti ; Addr $02
    reti ; Addr $03
    reti ; Addr $04
    rjmp MidePeriodo; Addr $05 Interrupción por captura de entrada ;;;;;
    reti ; Addr $06 Use 'rjmp myVector'
    reti ; Addr $07 to define a interrupt vector
    reti ; Addr $08
    reti ; Addr $09
    reti ; Addr $0A
; Datos para configurar Acelerómetro
CONFIG_ACEL:
;POWER_CTL -00-link=0autosleep=1measurement=0(standby)sleep=0wakeup=0
.db 0b00101101,0b00000000 ; db 0x2D,0x00
;DATA_FORMAT selftest=0 SPI=0(4-wire)-00-Fullres=1 justify=0 range=01(3g)
.db 0b00110001,0b00001000 ; db 0x31,0x09
;FIFO_CTL fifomode=00trigger=0samples=00000
.db 0b00111000,0b00000000 ; db 0x38,0x00
;BW_RATE -000-lowpower=0rate=1111(3200Hz)
.db 0b00101100,0b00001111 ; db 0x2C,0x0D
;THRESH ACT
.db 0b00100100,0b00000000 ; db 0x24,0x00
start:
  ldi   R16,high(RAMEND)
  out   SPH,R16
  ldi   R16,low(RAMEND)
  out   SPL,R16
  rcall IniPorts
rcall IniSerial
rcall IniTimer1
rcall IniSPI
rcall ConfigAcelerometro
rcall IniADC
rcall IniVariables
cli

lazo:
clr R17
clr R18
rcall RxDato
cpi R16,'W' ; recibe caracter de inicio
brne lazo

sensa:
rcall MideFuerza1
rcall MideFuerza2
rcall MideFuerza3
rcall MideFuerza4
rcall MideAcel
cli
rcall TxVariables
sei

loop:
inc R17
ctpi R17,200 ; muestras
    brne sensa

inc R18
cpi R18,4
breq lazo
clr R17
rjmp sensa

;********************************************************************************
;********************************************************************************
;********************************************************************************

;******Subrutinas*****
;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

IniPorts:
push R16
    ldi R16,0b00101100 ; salidas: SCK,MOSI,SS entradas: MISO,ICP1
    out DDRB,R16
    pop R16
    ret

IniSerial: ;38400,8,n,1
push R16

ldi  R16,$00
out  UBRRH,R16
ldi  R16,$0C
out  UBRRL,R16
ldi  R16,$02
out  UCSRA,R16
ldi  R16,$86
out  UCSRC,R16
ldi  R16,$18
out  UCSRB,R16

pop  R16
ret

;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

IniTimer1: ; Timer 1 en modo normal, PRE=256, Capturador: flanco de bajada
push  R16

ldi  R16,$00
out  TCCR1A,R16
ldi  R16,$84  ;
out  TCCR1B,R16

;;;; ;;;;;;;;;;;;;;;;;;;;;;;

ldi      R16,0B00100000
out      TIMSK,R16

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

ldi  R16,0B00100000
out  TIMSK,R16

;===========================================
pop R16
ret

;******************************************************************************
;******************************************************************************
IniSPI: ; Configurado a 2 MHz
push R16

ldi R16,0b01011100 ; SPI master, CPOL=1 CPHA=1 Fosc/8
out SPCR, R16 ; MSB of the data word is transmitted first
ldi R16,0b00000001 ; SPI2X=1
out SPSR, R16

pop R16
ret

;******************************************************************************
;******************************************************************************
ConfigAcelerometro:
push R16
push R17
push R18
push ZL
push ZH

ldi R18,0 ; contador
ldi ZH,high(CONFIG_ACEL*2)
ldi ZL,low(CONFIG_ACEL*2)

configacel:
lpm R16,Z+
lpm R17,Z+
rcall Tx_SPI
inc R18
cpi R18,14 ; fin de transmision
brne configacel

pop ZH
pop ZL
pop R18
pop R17
pop R16
ret

;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

Tx_SPI: ; envía por SPI los valores almacenados en r16 y r17
cbi PORTB,2 ; SS = 0
out SPDR, R16 ; se envía por el SPI

Tx_SPI_espera1:
sbis SPSR, SPIF ; Se espera a que se termine la transmisión
rjmp Tx_SPI_espera1
out SPDR, R16 ; se envía por el SPI

Tx_SPI_espera2:
sbis SPSR, SPIF ; Se espera a que se termine la transmisión
rjmp Tx_SPI_espera2
sbi PORTB,2 ; SS = 1

ret

;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
IniADC:
    push   R16

    ldi   R16,0b10000101   ; ADC habilitado, fosc/32 125kHz 101 ...011 500Khz
    out   ADCSR,R16

    ldi   R16,0b01000000   ; AVCC, ADLAR=0, canal 0
    out   ADMUX,R16

    pop   R16
    ret

;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

IniVariables:                 ; borra todas las variables
    push  R16
    push  R17
    push  XL
    push  XH

    clr  R16
    clr  R17

    ldi  XH,high(fuerza1)
    ldi  XL,low(fuerza1)

IniVariables_lazo:
    st    X+,R16
    inc   R17
    cpi   R17,14
    brne  IniVariables_lazo
pop XH
pop XL
pop R17
pop R16
ret

;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

RxDato:
sbis UCSRA,RXC
rjmp RxDato
in R16,UDR
ret

TxDatos:
sbis UCSRA,UDRE
rjmp TxDato
out UDR,R16
ret

;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
MideFuerza1:

push     R16
push     R17

ldi     R16, 0b01000000   ; canal 0
out     ADMUX, R16
sbi     ADCSR, ADSC      ; inicia conversion

MideFuerza1_espera:

sbis    ADCSR, ADIF
rjmp    MideFuerza1_espera
in      R16, ADCL
in      R17, ADCH
sts     fuerza1, R17     ; ADCH
sts     fuerza1+1, R16   ; ADCL
sbi     ADCSR, ADIF      ; limpia bandera ADIF

pop     R17
pop     R16
ret

MideFuerza2:

push     R16
push     R17

ldi     R16, 0b01000001   ; canal 1
out     ADMUX, R16
sbi     ADCSR, ADSC      ; inicia conversion
MideFuerza2_espera:

sbis ADCSR, ADIF
rjmp MideFuerza2_espera
in R16, ADCL
in R17, ADCH
sts fuerza2, R17
sts fuerza2+1, R16
sbi ADCSR, ADIF ; limpia bandera ADIF

pop R17
pop R16
ret

MideFuerza3:
push R16
push R17
ldi R16, 0b01000010 ; canal 2
out ADMUX, R16
sbi ADCSR, ADSC ; inicia conversion

MideFuerza3_espera:

sbis ADCSR, ADIF
rjmp MideFuerza3_espera
in R16, ADCL
in R17, ADCH
sts fuerza3, R17
sts fuerza3+1, R16
sbi ADCSR, ADIF ; limpia bandera ADIF
pop  R17
pop  R16
ret

MideFuerza4:
push  R16
push  R17
ldi   R16,0b01000011   ; canal 3
out   ADMUX,R16
sbi  ADCSR,ADSC        ; inicia conversion
MideFuerza4_espera:
sbis   ADCSR,ADIF
rjmp  MideFuerza4_espera
in   R16, ADCL
in   R17, ADCH
sts  fuerza4,R17
sts  fuerza4+1,R16
sbi  ADCSR, ADIF       ; limpia bandera ADIF
pop  R17
pop  R16
ret

;----------------------------------------------------------------------------
;----------------------------------------------------------------------------
;============================================================================
;============================================================================
MideAcel:
  push R16
  push R17

MideAcel_lazo:
  ldi R16,$B0
  rcall Rx_SPI2
  andi R16,0b00000010
  cpi R16,0
  breq MideAcel_lazo
  ldi R16,$F6 ;ID=>$C0 $F6 =>DATA Z0
  rcall Rx_SPI
  sts aceleracion,R16 ;ZH z1
  sts aceleracion+1,R17 ;ZL z0
  pop R17
  pop R16
  ret

Rx_SPI: ; envia por SPI la direccion almacenada en R16 y recibe el dato leido en R16
  cbi PORTB,2 ; SS = 0
  out SPDR, R16 ; se envia por el SPI

Rx_SPI_espera:
  sbis SPSR, SPIF ; Se espera a que se termine la transmision
  rjmp Rx_SPI_espera
  out SPDR, R16 ; se envia por el SPI
Rx_SPI_espera2:

sbis SPSR, SPIF ; Se espera a que se termine la transmision
rjmp Rx_SPI_espera2

in R17, SPDR ; se recibe por el SPI
out SPDR, R16 ; se envía por el SPI

Rx_SPI_espera3:

sbis SPSR, SPIF ; Se espera a que se termine la transmision
rjmp Rx_SPI_espera3

in R16, SPDR ; se recibe por el SPI
sbi PORTB,2 ; SS = 1
ret

Rx_SPI2: ; envía por SPI la dirección almacenada en R16 y recibe el dato leído en R16

cbi PORTB,2 ; SS = 0
out SPDR, R16 ; se envía por el SPI

Rx_SPI2_espera:

sbis SPSR, SPIF ; Se espera a que se termine la transmisión
rjmp Rx_SPI2_espera

out SPDR, R16 ; se envía por el SPI

Rx_SPI2_espera2:

sbis SPSR, SPIF ; Se espera a que se termine la transmisión
rjmp Rx_SPI2_espera2

in R16, SPDR ; se recibe por el SPI
sbi PORTB,2 ; SS = 1
ret
MidePeriodo:

```asm
push R16
in R16,SREG
push R16
push XL
push XH
push YL
push YH
push ZL
push ZH
```

MidePeriodo_Lazo: ; mide periodo y lo almacena en X

```asm
in XL,ICR1L ; lee el valor capturado
in XH,ICR1H
mov YL,XL ; copia el valor a reg Y
mov YH,XH
```

```asm
lds R16,flanco_ant ; calcula Periodo XHXL <- (Flanco actual - Flanco anterior)
sub XL,R16
lds R16,flanco_ant+1
sbc XH,R16
brcs calcula2
rjmp almacena_periodo
```
calcula2:

lds   XL,flanco_ant
lds   XH,flanco_ant+1

ldi   R16,$FF
mov   ZL,R16
mov   ZH,R16
sub   ZL,XL
sbc   ZH,XH
adiw  ZL,1
clr   R16
adc   ZH,R16 ; suma 65536=ZHZL+1

mov   XL,YL ; copia el valor a reg X
mov   XH,YH
       ; suma el valor actual=YHYl+65536=XHXH
add   XL,ZL
adc   XH,ZH

almacena_periodo:

sts   flanco_ant,YL  ; Flanco anterior <- Flanco actual
sts   flanco_ant+1,YH
inc   R20 ; bandera de periodo

cpi   R20,2
breq  almacena_RPM
rjmp  mantener_RPM

almacena_RPM:
sts     RPS,XH
sts     RPS+1,XL                ;GUARDO XLH PORQUE ENVIO XHXL.
clr     R20

mantener_RPM:
    pop     ZH
    pop     ZL
    pop     YH
    pop     YL
    pop     XH
    pop     XL
    pop     R16
    out    SREG,R16
    pop     R16
    reti

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

TxVariables:
    push     R16
    push     R17
    push     XL
    push     XH
    clr      R17
    ldi      XH,high(fuerza1)
    ldi      XL,low(fuerza1)

TxVariables_lazo:
    ld      R16,X+
rcall TxDato
inc R17
cpi R17,12
brne TxVariables_lazo

pop XH
pop XL
pop R17
pop R16
ret
• Meet or Exceed TIA/EIA-232-F and ITU Recommendation V.28
• Operate With Single 5-V Power Supply
• Operate Up to 120 kbit/s
• Two Drivers and Two Receivers
• ±30-V Input Levels
• Low Supply Current . . . 8 mA Typical
• Designed to be Interchangeable With Maxim MAX232
• ESD Protection Exceeds JESD 22 – 2000-V Human-Body Model (A114-A)
• Applications
  TIA/EIA-232-F
  Battery-Powered Systems
  Terminals
  Modems
  Computers

description/ordering information

The MAX232 is a dual driver/receiver that includes a capacitive voltage generator to supply EIA-232 voltage levels from a single 5-V supply. Each receiver converts EIA-232 inputs to 5-V TTL/CMOS levels. These receivers have a typical threshold of 1.3 V and a typical hysteresis of 0.5 V, and can accept ±30-V inputs. Each driver converts TTL/CMOS input levels into EIA-232 levels. The driver, receiver, and voltage-generator functions are available as cells in the Texas Instruments LinASIC™ library.

ORDERING INFORMATION

<table>
<thead>
<tr>
<th>TA</th>
<th>PACKAGE†</th>
<th>ORDERABLE PART NUMBER</th>
<th>TOP-SIDE MARKING</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°C to 70°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PDIP (N) Tube</td>
<td>MAX232N</td>
<td>MAX232N</td>
<td></td>
</tr>
<tr>
<td>SOIC (D) Tube</td>
<td>MAX232D</td>
<td>MAX232</td>
<td></td>
</tr>
<tr>
<td>SOIC (DW) Tube</td>
<td>MAX232DW</td>
<td>MAX232</td>
<td></td>
</tr>
<tr>
<td>SOP (NS) Tape and reel</td>
<td>MAX232NSR</td>
<td>MAX232</td>
<td></td>
</tr>
<tr>
<td>-40°C to 85°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PDIP (N) Tube</td>
<td>MAX232IN</td>
<td>MAX232IN</td>
<td></td>
</tr>
<tr>
<td>SOIC (D) Tube</td>
<td>MAX232ID</td>
<td>MAX232I</td>
<td></td>
</tr>
<tr>
<td>SOIC (DW) Tube</td>
<td>MAX232IDW</td>
<td>MAX232I</td>
<td></td>
</tr>
</tbody>
</table>

†Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at www.ti.com/sc/package.

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### Function Tables

**EACH DRIVER**

<table>
<thead>
<tr>
<th>INPUT</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIN</td>
<td>TOUT</td>
</tr>
<tr>
<td>L</td>
<td>H</td>
</tr>
<tr>
<td>H</td>
<td>L</td>
</tr>
</tbody>
</table>

H = high level, L = low level

**EACH RECEIVER**

<table>
<thead>
<tr>
<th>INPUT</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>RIN</td>
<td>ROUT</td>
</tr>
<tr>
<td>L</td>
<td>H</td>
</tr>
<tr>
<td>H</td>
<td>L</td>
</tr>
</tbody>
</table>

H = high level, L = low level

### Logic Diagram (Positive Logic)

```
T1IN 11 T1OUT 14
  |    |
  | 10  |
T2IN 10 T2OUT 7
  |    |
  | 12  |
R1OUT 12 R1IN 13
  |    |
  | 9   |
R2OUT 9 R2IN 8
```
absolute maximum ratings over operating free-air temperature range (unless otherwise noted)†

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test Conditions</th>
<th>Min</th>
<th>Nom</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{CC} )</td>
<td>Supply voltage</td>
<td>4.5</td>
<td>5</td>
<td>5.5</td>
<td>V</td>
</tr>
<tr>
<td>( V_{IH} )</td>
<td>High-level input voltage (T1IN, T2IN)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( V_{IL} )</td>
<td>Low-level input voltage (T1IN, T2IN)</td>
<td>2</td>
<td></td>
<td>0.8</td>
<td>V</td>
</tr>
<tr>
<td>R1IN, R2IN</td>
<td>Receiver input voltage</td>
<td></td>
<td></td>
<td>±30</td>
<td>V</td>
</tr>
<tr>
<td>( T_A )</td>
<td>Operating free-air temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAX232</td>
<td></td>
<td>0</td>
<td>70</td>
<td></td>
<td>°C</td>
</tr>
<tr>
<td>MAX232I</td>
<td></td>
<td>–40</td>
<td></td>
<td>85</td>
<td></td>
</tr>
</tbody>
</table>

† Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTE 1: All voltage values are with respect to network ground terminal.
2. The package thermal impedance is calculated in accordance with JESD 51-7.

recommended operating conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test Conditions</th>
<th>Min</th>
<th>Nom</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{CC} )</td>
<td>Supply current</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>10</td>
<td></td>
<td>mA</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test Conditions</th>
<th>Min</th>
<th>Typ‡</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{CC} )</td>
<td>Supply current</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>10</td>
<td></td>
<td>mA</td>
</tr>
</tbody>
</table>

‡ All typical values are at \( V_{CC} = 5 \text{ V} \) and \( T_A = 25^\circ \text{C} \).
NOTE 3: Test conditions are C1–C4 = 1 µF at \( V_{CC} = 5 \text{ V} \pm 0.5 \text{ V} \).
MAX232, MAX232I
DUAL EIA-232 DRIVERS/RECEIVERS


DRIVER SECTION

electrical characteristics over recommended ranges of supply voltage and operating free-air temperature range (see Note 3)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP†</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOH</td>
<td>T1OUT, T2OUT</td>
<td>5</td>
<td>7</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>VOL</td>
<td>T1OUT, T2OUT</td>
<td>-7</td>
<td>-5</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>rO</td>
<td>T1OUT, T2OUT</td>
<td>300</td>
<td></td>
<td></td>
<td>Ω</td>
</tr>
<tr>
<td>IOS†</td>
<td>T1OUT, T2OUT</td>
<td>±10</td>
<td></td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>IOS§</td>
<td>T1IN, T2IN</td>
<td>200</td>
<td></td>
<td></td>
<td>μA</td>
</tr>
</tbody>
</table>

† All typical values are at VCC = 5 V, TA = 25°C.
‡ The algebraic convention, in which the least positive (most negative) value is designated minimum, is used in this data sheet for logic voltage levels only.
§ Not more than one output should be shorted at a time.

NOTE 3: Test conditions are C1–C4 = 1 μF at VCC = 5 V ± 0.5 V.

switching characteristics, VCC = 5 V, TA = 25°C (see Note 3)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP†</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR</td>
<td>Rl = 3 kΩ to 7 kΩ, See Figure 2</td>
<td>30</td>
<td></td>
<td></td>
<td>V/μs</td>
</tr>
<tr>
<td>SR(t)</td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td>V/μs</td>
</tr>
<tr>
<td>Data rate</td>
<td>One TOUT switching</td>
<td>120</td>
<td></td>
<td></td>
<td>kbit/s</td>
</tr>
</tbody>
</table>

NOTE 3: Test conditions are C1–C4 = 1 μF at VCC = 5 V ± 0.5 V.

RECEIVER SECTION

electrical characteristics over recommended ranges of supply voltage and operating free-air temperature range (see Note 3)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP†</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOH</td>
<td>R1OUT, R2OUT</td>
<td>3.5</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>VOL</td>
<td>R1OUT, R2OUT</td>
<td>0.4</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>VIT+</td>
<td>R1IN, R2IN</td>
<td>1.7</td>
<td>2.4</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>VIT−</td>
<td>R1IN, R2IN</td>
<td>0.8</td>
<td>1.2</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Vhys</td>
<td>R1IN, R2IN</td>
<td>0.2</td>
<td>0.5</td>
<td>1</td>
<td>V</td>
</tr>
<tr>
<td>rI</td>
<td>R1IN, R2IN</td>
<td>3</td>
<td>5</td>
<td>7</td>
<td>kΩ</td>
</tr>
</tbody>
</table>

† All typical values are at VCC = 5 V, TA = 25°C.
‡ The algebraic convention, in which the least positive (most negative) value is designated minimum, is used in this data sheet for logic voltage levels only.

NOTE 3: Test conditions are C1–C4 = 1 μF at VCC = 5 V ± 0.5 V.

switching characteristics, VCC = 5 V, TA = 25°C (see Note 3 and Figure 1)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TYP</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>tPLH(R)</td>
<td>500</td>
<td>ns</td>
</tr>
<tr>
<td>tPHL(R)</td>
<td>500</td>
<td>ns</td>
</tr>
</tbody>
</table>

NOTE 3: Test conditions are C1–C4 = 1 μF at VCC = 5 V ± 0.5 V.
PARAMETER MEASUREMENT INFORMATION

TEST CIRCUIT

WAVEFORMS

NOTES:  
A. The pulse generator has the following characteristics: $Z_O = 50 \, \Omega$, duty cycle $\leq 50\%$.  
B. $C_L$ includes probe and jig capacitance.  
C. All diodes are 1N3064 or equivalent.

Figure 1. Receiver Test Circuit and Waveforms for $t_{PHL}$ and $t_{PLH}$ Measurements
PARAMETER MEASUREMENT INFORMATION

**TEST CIRCUIT**

- **Input**:
  - $T_{PHL}$
  - $T_{PLH}$

- **Output**:
  - $V_{OL}$
  - $V_{OH}$

- **Waveforms**:
  - $SR = \frac{0.8 (V_{OH} - V_{OL})}{T_{TLH}}$ or $\frac{0.8 (V_{OL} - V_{OH})}{T_{THL}}$

**NOTES**:
A. The pulse generator has the following characteristics: $Z_O = 50 \, \Omega$, duty cycle $\leq 50\%$.
B. $C_L$ includes probe and jig capacitance.

**Figure 2. Driver Test Circuit and Waveforms for $t_{PHL}$ and $t_{PLH}$ Measurements (5-µs Input)**

**Figure 3. Test Circuit and Waveforms for $t_{THL}$ and $t_{TLH}$ Measurements (20-µs Input)**
APPLICATION INFORMATION

C\textsubscript{BYPASS} = 1 \mu F

C\textsubscript{1+}  C\textsubscript{1-}  C\textsubscript{2+}  C\textsubscript{2-}

From CMOS or TTL

To CMOS or TTL

\[ V\text{CC} \]

\[ V\text{S+} \]

\[ V\text{S-} \]

\[ 0 \text{ V} \]

\[ 15 \text{ GND} \]

\[ 16 \]

\[ 5 \text{ V} \]

\[ 2 \]

\[ 6 \]

\[ 7 \]

\[ 8 \]

\[ 10 \]

\[ 11 \]

\[ 12 \]

\[ 14 \]

\[ 13 \]

C\textsubscript{3}\textsuperscript{†}  1 \mu F

C\textsubscript{4}\textsuperscript{†}  1 \mu F

† C\textsubscript{3} can be connected to \text{VCC} or \text{GND}.

Figure 4. Typical Operating Circuit
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