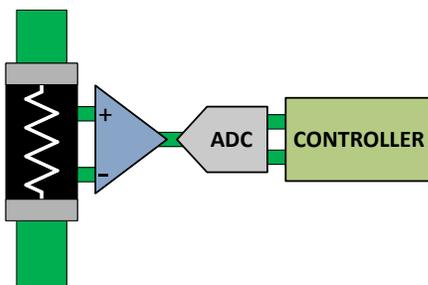


Scott Hill, Current Sensing Products

Current is one of the most common signals used for evaluating and diagnosing the operational effectiveness of an electronic system. However, measuring this signal directly is very challenging. Instead, many types of sensors are used to measure the proportional effects that occur due to current flowing throughout the system.

The most common sensing element used for detecting current flowing in a system is a resistor. Placing a resistor, called a shunt, in series with the current path develops a differential voltage across the resistor as current passes through it.

One common signal chain configuration for monitoring a current signal involves an analog front-end (AFE), an analog to digital converter (ADC), and a system controller as shown in [Figure 1](#). An AFE, such as an operational amplifier or dedicated current sense amplifier, converts the small differential voltage developed across the shunt resistor to a larger output voltage that the ADC can digitize before sending the information to a controller. The system controller uses the current information to optimize the system's operational performance or reduce functionality in the event of an out-of-range condition to prevent potential damaging conditions from occurring.



**Figure 1. Current Sensing Signal Chain**

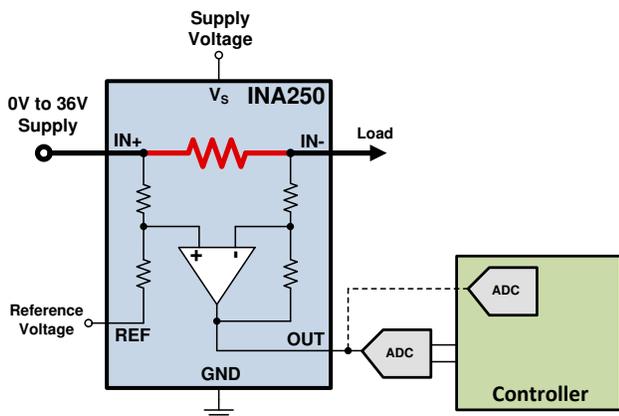
The proper resistance value selection is critical in optimizing the signal chain path. The resistance value and corresponding voltage developed across the shunt results in a system power loss. To limit the power loss, it is preferred to minimize the shunt resistance. The resistor value is directly proportional to the signal developed and sent to the current sensing amplifier.

Amplifiers have fixed inherent errors associated with them, input offset voltage for example, that impact the measurement accuracy. As the input signal increases, the influence of these internal errors on the total measurement accuracy decreases. When the input signal decreases the corresponding measurement error is a higher. This relationship between the signal level and the acceptable measurement accuracy provides general lower limits for the current sensing resistor selection. The upper limit value for the current sensing resistor should be limited based on an application's acceptable power loss for this component.

One benefit of using resistors for current measurement is the availability of accurate components that provide both high precision and temperature stable measurements. Precision current sensing amplifiers are available featuring measurement capabilities optimized for interfacing with very small signals to accommodate small value resistors and low power losses.

There are two trends for resistors as the ohmic value decreases into the single digit milliohm level and below. One trend for this segment of resistors is the reduced package availability and resistor value combinations. The other trend is the increased cost for precision and low temperature coefficient components. Pairing a low ohmic, low temperature coefficient current sensing resistors with precision tolerance levels (~0.1%) result in solution costs in the several dollar range without including the cost associated with the precision amplifier.

A component such as the [INA250](#), shown in [Figure 2](#), helps reduce the challenges of selecting these increased accuracy, higher cost resistors for applications needing precise and temperature stable measurements. This device pairs a precision, zero-drift, voltage output current sense amplifier with a 2mΩ integrated current sensing resistor with a 0.1% maximum tolerance and a temperature drift of 15ppm/°C over the device's entire temperature range of -40°C to +125°C. This device can accommodate continuous currents flowing through the on-board resistor of up to 15A.



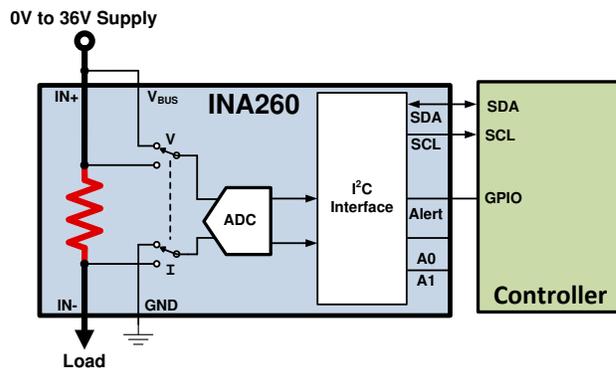
**Figure 2. Integrating The Current Sensing Resistor**

In addition to the integrated precision resistor inside this device, the [INA250](#) also addresses one of the most common issues associated with implementing a current sensing solution. A low-ohmic shunt resistor is used to reduce the current sensing power dissipation. A challenge in accommodating this low resistance value is the potential impact of parasitic resistance on the PCB. Parasitic resistance in series with the shunt resistor can cause additional measurement errors as current flows through the resistance to create the shunt voltage. The most common source for these measurement errors is poor layout techniques. A Kelvin connection, also known as a four terminal connection or a force-sense, is required to ensure that minimal additional resistance is present to alter the differential voltage developed between the amplifier's input pins. There are PCB layout techniques to reduce the effect of parasitic resistance, however, this concern is removed with the [INA250](#).

For applications that require measuring current in a high dv/dt common mode transients like motor control and solenoid control, the [INA253](#) is specifically design to reject PWM signals with a settling time of <math><10\mu\text{s}</math>.

As previously described, the typical current sensing signal chain path includes the current sensing resistor, the analog front-end, ADC and system controller. The [INA250](#) combines the shunt resistor and the current sensing amplifier. The [INA260](#) combines the current sensing resistor, measurement front-end and the ADC into one single device.

[Figure 3](#) shows the [INA260](#) featuring the same precision, integrated sensing resistor, pairing it with a 16-bit, precision ADC optimized for current sensing applications. This combination provides an even higher performance measurement capability than the [INA250](#) resulting in a maximum measurement gain error of 0.5% over the entire temperature range and a maximum input offset current of 5mA.



**Figure 3. Integrated Signal Path**

Pairing the precision, low-drift current sensing with these precision current sensing devices provides measurement solutions that are challenging to accomplish using discrete amplifier and resistor combinations. There are few catalog current sensing resistors available that are capable of enabling the combination of precision and temperature stable measurements but achieving this level of accuracy in a solution size comparable to TSSOP-16 packaged integrated solutions doesn't exist.

### Alternate Device Recommendations

For additional design flexibility, many stand-alone current sensing amplifiers and digital power monitors are also available. For lower performance applications with higher current requirements than the integrated solutions support, use the [INA210](#) stand-alone current sensing amplifier. For applications requiring a stand-alone digital power monitor, use the [INA226](#). For applications implementing over-current detection, the [INA301](#) features an integrated comparator for on-chip over-current detection as fast as  $1\mu\text{s}$ .

**Table 1. Alternative Device Recommendations**

Device	Optimized Parameter	Performance Trade-Off
<a href="#">INA210</a>	35 $\mu\text{V}$ $V_{OS}$ , Package: SC70-6, QFN-10	No on-board current sensing resistor
<a href="#">INA226</a>	10 $\mu\text{V}$ $V_{OS}$ , Package: MSOP-10	No on-board current sensing resistor
<a href="#">INA301</a>	Signal Bandwidth, On-Board Comparator	No on-board current sensing resistor

### Related Documentation

1. [Integrated-Resistor Current Sensors Simplify PCB Design](#)
2. [Precision Current Measurements on High-Voltage Power Supply Rails](#)
3. [Integrating the Current Sensing Signal Path](#)
4. [Precision, Low-Side Current Measurement](#)

## IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to [TI's Terms of Sale](#) or other applicable terms available either on [ti.com](http://ti.com) or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265  
Copyright © 2022, Texas Instruments Incorporated