Integrated-Resistor Current Sensors Simplify PCB Design

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The most common method to measure current is to sense the voltage drop across a shunt or current sense resistor. To achieve a highly accurate measurement of the current, parametric values of both the resistor and current sense amplifier need to be examined. Also proper layout of the connections between the current sense resistor and current sense amplifier are critical to avoid a reduction in accuracy. The typical schematic of a current sense amplifier with connections for both high-side current sensing with the design critical areas shaded is shown in Figure 1.

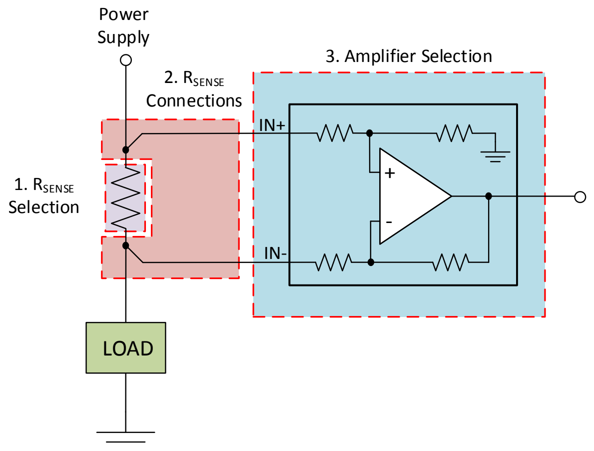

Figure 1. High-Side Current Sensing with Shaded Error Sources

One of the most important design decisions to make when using a current sense amplifier is the selection of the current sense or shunt resistor. The first design decision made is usually selection of the resistor value and wattage. The value of the resistor is usually based on achieving a desired maximum differential voltage at the highest expected current. The value of the resistor may also be selected based on a power loss budget for the resistor. Once the value and wattage of the current sense resistor is determined the second parameter to consider is the resistor tolerance since this will directly impact the accuracy of the sensed voltage and current measurement. However, a more subtle parameter that is often overlooked is the resistor temperature coefficient. The temperature coefficient is often specified in PPM/°C and is important since the temperature of the resistor will rise due to the power dissipated as current flows through the component. Often lower cost resistors will specify a tolerance less than 1%, but will suffer in the real application due to the resistor temperature drift.

Once the resistor is selected, attention needs to be paid to the resistor PCB layout in order to achieve accurate measurement results. To achieve accurate current measurements there must be 4 connections to the current sense resistor. Two connections should handle the current flow, while the other two sense the voltage drop across the resistor. Figure 2 shows various methods that can be used to monitor the current flow through a resistor.

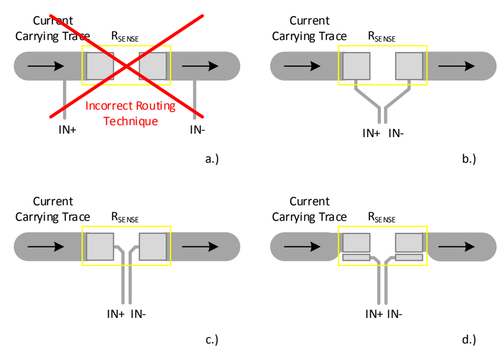

Figure 2. Current Sense Resistor Layout Techniques

One of the most common mistakes in laying out the current sense resistor is connecting the current sense amplifier inputs to the current carrying trace instead of directly to the current sense resistor as shown in Figure 2a. Other valid methods to layout the connections to the current sense resistor is shown in Figure 2b-d. The layout shown in Figure 2d features independent four-wire(Kelvin) connections to the current sense resistor. This technique is most commonly used when the value of the shunt resistor is below 0.5 mΩ and the solder resistance in series with resistor connections appreciably add to the overall shunt resistance. It is difficult to know which layout technique will yield the best results on the final PCB design since the resistance accuracy depends greatly on the measurement location used when the resistor was manufactured. If the resistor value was measured on the inside of the pads, then the layout shown in Figure 2c would provide the best measurement result. If the resistor value was measured at the side, then the layout shown in Figure 2b would provide the highest accuracy. The difficulty with selecting the best layout is that many resistor datasheets do not provide a layout recommendation for best current sensing accuracy or do not mention the measurement point used in the manufacturing process.

The difficulties concerning resistor selection and PCB layout are simplified when using a current sense amplifier with an integrated current sense resistor. Both the INA250 and INA260 devices feature a current sense resistor that is integrated inside the same package as the current sense amplifier. Connections to the current sense resistor are optimized to achieve best measurement accuracy and temperature stability. The INA250 is an analog output current sense amplifier, while the INA260 is a digital output current senor that reports the current, power, and bus voltage through an I^2C/SMBUS interface. A block diagram of the INA250 along with the resistor connections is shown in Figure 3 The INA250 provides external sense connections that allow for filtering of the shunt voltage or direct connections to the current sense amplifier. The connections to the shunt resistor are fixed internally therefore reducing the PCB layout difficulty. The gain of the amplifier is optimized for each resistor so the total system gain error is comparable to a using a 0.1% or better current sense resistor. The integrated shunt technology used in the INA250 and INA260 can support operating currents as high as 15A.

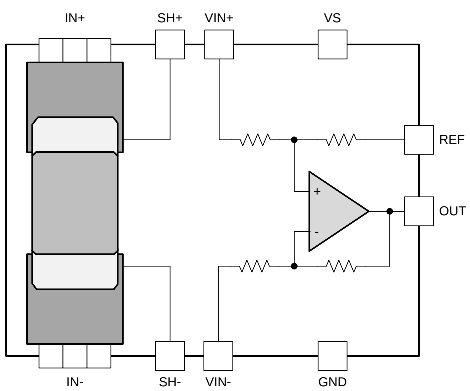

Figure 3. INA250 Block Diagram with internal resistor connections

Because the INA250 and INA260 accuracy specifications incorporate the resistor, component selection is simplified. The INA250 has a maximum total system gain error 0.3% at room temperature and 0.75% over the temperature range of -40°C to 125°C. Accuracy calculations with devices that do not have the integrated shunt resistor have to factor in the device gain error, gain error drift, resistor tolerance and resistor drift to get the overall system gain error; therefore, it can be difficult to pick components to meet an overall system accuracy specification. The INA260 is a digital current output device that features maximum total room temperature gain error of 0.15%. This total gain error already includes the variation of the integrated resistor and the gain error of the current sense amplifier. The connections to the current sense resistor are done internally to the package and calibrated for each device to remove variations due to the resistor connection points.

In designs were precision measurements of the current are required, integrated shunt products can provide higher accuracy and allow a lower cost total solution. To achieve similar accuracy to the INA260 would require a current sense amplifier with an gain error of less than 0.1% and a low-drift resistor with initial tolerance of less than 0.05%. In general, high wattage resistors with accuracy less than 0.1% are costly and can be as high as several dollars in 1000 unit volumes.

Another advantage of the integrated resistor in the INA260 is that the resistor value is already calibrated and set internally so returned values for current are easy converted to amperes. Other digital solutions require programming the value of the current sense resistor, either internally or in the host processor so the returned current readings are scaled appropriately.

The integrated shunt technology used in the INA250 and INA260 allows for precision current measurements, reduced layout complexity, better understanding of the total system error, and can be lower cost than solutions with equivalent accuracy. In applications that require precision but need to support currents higher than 15A, multiple INA250 devices can be paralleled in a daisy-chan configuration as shown in the product datasheet, or multiple INA260 devices could be used provided the host processor can sum the reported current readings. If paralleling multiple devices to monitor currents higher than 15A is not practical due to the solution size,Table 1 provides a list of devices that can be used to monitor higher currents using external shunt resistors.

Table 1. Alternative Device Recommendations

Device	Optimized Parameters	Performance Trade-Off
INA226	Digital Output with I2C interface, 0.1% gain error, 10µV offset	Shunt resistor is external
INA233	Digital Output with PMBus/I2C interface, 0.1% gain error, 10µV offset	Shunt resistor is external
INA210C	Analog Output, 0.5% gain error, 35µV offset	Shunt resistor is external

Table 2. Adjacent TechNotes

SBOA170	Integrating the Current Sensing Resistor
SBOA167	Integrating the Current Sensing Signal Path
SBOA160	Precision, Low-Side Measurement

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