Application Brief

Shunt Resistor Selection for Isolated Data Converters

TEXAS INSTRUMENTS

Alex Smith

Introduction

A low-ohmic, precise, in-line resistor is known as a shunt resistor. In high-voltage automotive and industrial applications such as Hybrid, electric and powertrain systems, EV charging infrastructure, Motor drives, and shunt resistors are often paired with an isolated data converter to measure a current whose magnitude drives the feedback algorithm of a control loop while protecting the digital circuitry from the high-voltage circuit performing a function. Texas Instruments has an extensive portfolio of isolated amplifiers, isolated ADCs, and isolated comparators featuring a capacitive isolation barrier to help customers address their isolated data conversion needs. Texas Instruments' capacitive isolation barrier often allows for over 100 years of operation. For more information on TI's capacitive isolation barrier, see the Isolation link.

As the Accuracy Comparison of Isolated Shunt and Closed-Loop Current Sensing Application Brief shows, shunt-based current sensing allows for industry-leading accuracy, immunity to magnetic interference, long-term stability, high linearity, low offset drift, scalability to multiple projects, and a reduced price. Shunts can be chassis mounted, surface mounted, or leaded for through-hole connections to the printed circuit board (PCB). Many shunt resistors are available to choose from and selecting the correct shunt resistor for a given application is not always straightforward. This application brief discusses shunt resistors that are often used for isolated current sensing and their tradeoffs.

Calculating Resistance and Power Dissipation Requirements

To select a shunt resistor, the first step is to calculate the required resistance and power-dissipation rating based on the continuous and maximum current magnitudes and the linear full-scale input voltage range of the isolated data converter as discussed in the Design considerations for isolated current sensing article. However, care must be taken to maintain that the shunt resistors maximum temperature does not exceed the rating listed in the data sheet due to self-heating. Under normal conditions, shunt resistors cannot operate continuously beyond two-thirds of their rated current, assuming that the design allows for adequate heat dissipation. Heat dissipation techniques vary by application and can be accomplished in multiple ways: an increased weight or size of the current carrying PCB trace or primary conductor, heat sinks, or fans for forced air cooling. If the application does not allow for adequate heat dissipation, then the shunt resistor may not be able to operate beyond as low as one-fourth rated current. Beyond this current, further decreasing the resistance or increasing the power dissipation rating of the selected shunt resistor can be necessary.

For surface mount resistors, roughly 90% of the self-generated heat is dissipated by conduction to the PCB trace. Figure 1 demonstrates that increasing the size of the current carrying PCB trace is an effective heat dissipation technique. The simulated thermal performance of surface mounted, metal element, 1-mΩ, 2512 (5 W) and 3920 (8 W) package shunt resistors are shown with natural and forced air cooling. The results are presented as Shunt Rated Current (%) vs PCB Size (mm^2); where the maximum temperature of the selected shunt resistor (170°C) was reached.

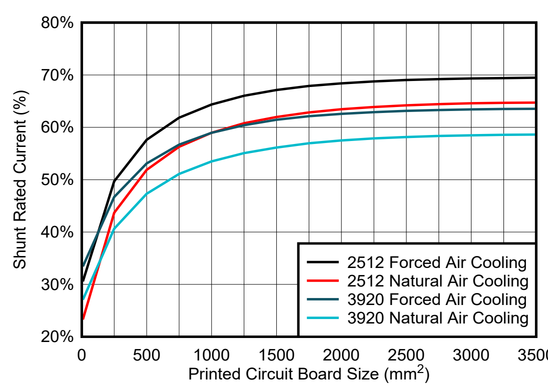

Figure 1. Shunt Rated Current vs PCB Size

To verify the performance of the shunt resistor in an application, measure the terminal temperature of the shunt resistor during maximum nominal operation and consult the power derating curve in the data sheet of the shunt resistor to verify that operation is within the specified range. This practice not only maintains that the resistive material does not exceed the specified maximum temperature, but also that the specified temperature drift coefficient is valid.

When calculating expected output voltage and power dissipation, consider transient and short-circuit current magnitudes. The short-term overload power dissipation specification of the shunt resistor, as specified in the data sheet, must not be violated because there is risk of permanently altering the physical properties of the shunt resistor or creating an open circuit. Additionally, verify that the isolated data converter absolute maximum input voltage specification is not violated for either condition as shown in the Absolute Maximum Ratings table of the data sheet. The input pins of isolated data converters from Texas Instruments are typically rated to withstand voltages between –6 V and up to the high-side supply voltage +500 mV with respect to the high-side ground without risk of being damaged.

Mounting, Construction, and Material Types

Once an approximate resistance and power dissipation requirement is calculated, additional selection criteria must be considered as summarized in Table 1.

Table 1. Shunt Selection Summary

Technology	Metal Element	Metal Foil	Metal Element	Wire-Wound
Installation Method	Surface Mount	Surface Mount	Chassis Mount	Chassis Mount or Leaded
Resistance Range (Ω)	0.1 m – 1	0.5 m – 0.7	25 μ – 0.1	R > 5 m
Wattage Range (W)	1/16 – 20	1/80 – 10	¼ – 100	½ – 1 k
Tolerance Range (%)	0.1 – 5	0.01 – 10	0.1 – 1	0.1 – 10
Drift Range (ppm/C°)	15 – 750	0.2 – 1 k	20 – 100	20 – 400
Pulse Capability (C°)	Up to 275	Up to 225	Up to 175	275+
Cost	+	++	+++	+++/+

Surface mount, metal element shunt resistors are the most popular choice for isolated current sensing because these offer low resistances, high wattage capability, fair initial accuracy, and low cost. Shunt resistor series such as CSS2H from Bourns® and WSLP from Vishay® are well equipped for isolated current sensing. Applications requiring a higher initial accuracy, or lower drift over temperature than what metal element can provide, can consider metal foil such as FC4L from Ohmite®; however, power dissipation ratings are typically lower and the cost is higher compared to the metal element. Layout considerations for surface mount resistors include placement close to the isolated data converter with short and evenly matched sensing connections to the inputs as explained in this Current Sense Amplifiers Shunt Resistor Layout video from TI precision labs. Additionally, take care when designing the PCB pads for surface mount resistors with low resistance (< 500 μΩ) as discussed in this TI E2E™ blog. Lastly, verify establishment of the correct soldering reflow process when working with the PCB manufacturer because incorrect installation can lead to a high initial error due to solder contact resistance on the pads, imbalanced heat dissipation during operation, or an open circuit.

Chassis mounted resistors are often used in applications that require high currents since these resistors allow for in-line conductor installation and do not dissipate the self-generated heat to the PCB. Metal element chassis mounted resistors allow for resistances as low as 25 μΩ and wattage up to 100 W, whereas chassis mounted wire-wound resistors have exceptional pulse-power capability. When installing, take special care to not over- or under-torque bolts, rivets, or crimp joints of the primary connections because additional resistance can be added to the primary conductor line resulting in unnecessary or imbalanced power dissipation and analog errors. Consult the chassis mount resistor manufacturer for additional guidance.

For applications that require the highest accuracy, consider four terminal shunt resistors with differential sensing connections independent of the primary current carrying leads (Kelvin connections). Kelvin connections offer higher accuracy compared to two terminal shunts due to reduced temperature drift in the sensing element leads; however, cost is typically higher and there is additional risk because improper installation allows for the primary current to flow through the sensing connections, potentially damaging the isolated data converter. Temperature measurements local to the shunt resistor can also be made to periodically update a calibration table because most shunt resistors offer a relatively predictable change in resistance over temperature allowing for exceptional accuracy in spite of changes in ambient temperature or self-heating due to power dissipation.

Conclusion

Pairing the correct shunt resistor with an isolated amplifier, isolated ADC, or isolated comparator from TI, can achieve a measurement that features industry leading accuracy, immunity to magnetic interference, long-term stability, high linearity, low drift, scalability to multiple projects, and low price.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265