

APPLICATION NOTE

Using Current Sense Resistors for Accurate Current Measurement



INTRODUCTION

Global trends such as the demand for lower CO₂ emissions, the smartening of the electricity supply grid and the electrification of our automobiles are all driving the need for electronic circuits to become more efficient. For circuit designers and systems operators, understanding what level of current is flowing through a circuit and being delivered to a load can be very helpful. Maximizing the operating performance of a battery, controlling motor speeds, and the ability to hot swap server units are examples of applications that can all benefit from the use of accurate current measurement.

This application note will present why current sense resistors are optimal, low-cost solutions that help OEMs create more efficient circuit designs in a wide range of applications.

HOW CURRENT SENSE RESISTORS WORK

Current sense resistors are recognized as cost-effective components that help improve system efficiency and reduce losses due to their high measurement accuracy compared to other technologies. While they are ideal for applications in virtually all market segments, current sense resistors are particularly useful in helping developers precisely measure current in their automotive, industrial and computer electronics designs.

Current sense resistors work by detecting and converting current to voltage. These devices feature very low resistance values, and therefore, cause only an insignificant voltage drop of 10 to 130 mV in the application. A shunt resistor is placed in series with the electrical load whereby all the current to be measured will flow through it. Following Ohm's law, a voltage drop is generated across the resistor of known value, which is proportional to the current. The voltage drop across the resistor can be measured by various amplifier options such as operational, difference and instrumentation amplifiers.

To choose the right current sense resistor for a given application, it is important to look at the input common-mode voltage specification. Input common-mode voltage is the average voltage present at the input terminals of the amplifier.

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CSS Series
Current Sense Resistors



CSM Series
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HOW CURRENT SENSE RESISTORS WORK (*Continued*)

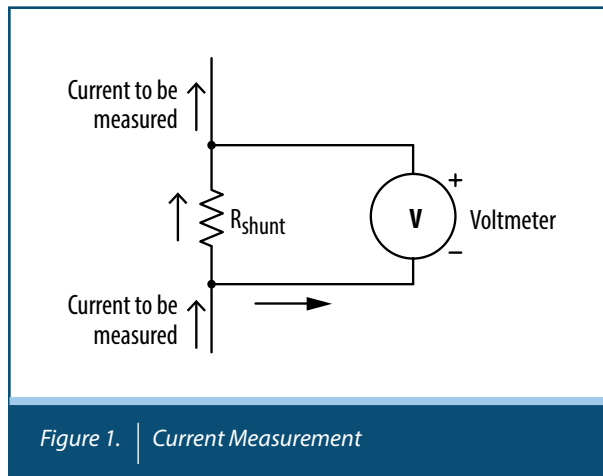


Figure 1. | Current Measurement

As shunt resistors sit in series with the load, they are able to directly measure the current. This is in contrast to indirect current measurement techniques such as coils where voltage is induced across the coil that is proportional to the current. The fact that shunt resistors use direct current sensing techniques means power is dissipated from the resistor, resulting in very low resistance values.

Current sense resistors also feature a very low Temperature Coefficient of Resistance (TCR), which defines drift with varying ambient temperature, and excellent long term stability. These characteristics make current measurement accuracy very high and the temperature dependency of the measurement is very low.

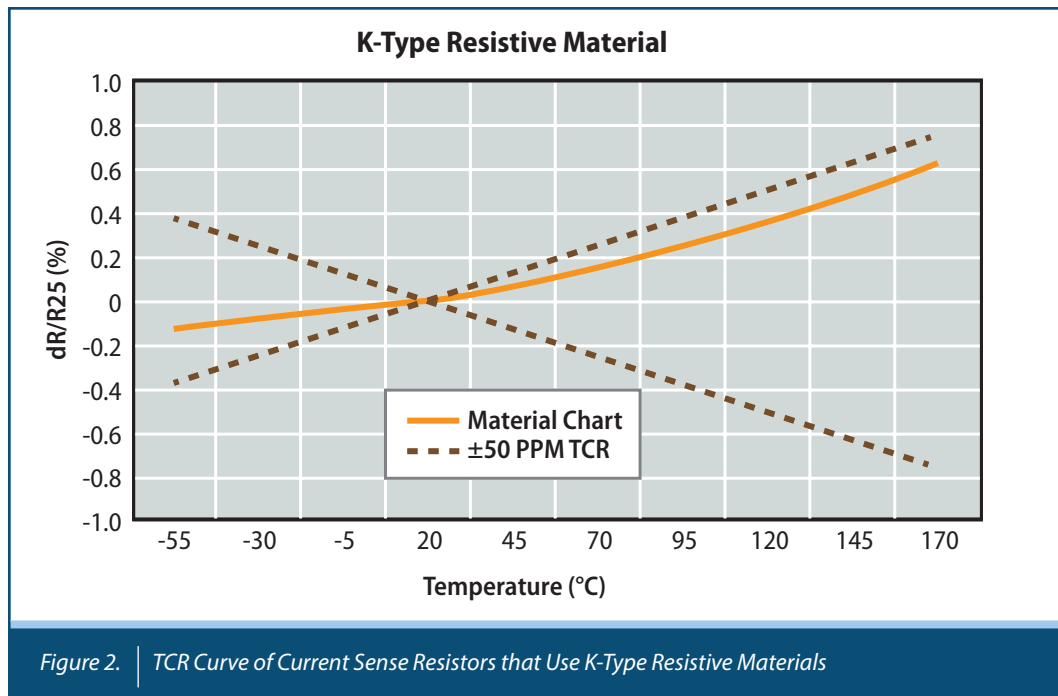


Figure 2. | TCR Curve of Current Sense Resistors that Use K-Type Resistive Materials

The charts above illustrate the TCR curve of current sense resistors that use K-Type resistive materials, demonstrating that they operate within the range of ± 50 PPM/ $^{\circ}C$.

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KELVIN PRINCIPLE MEASUREMENT

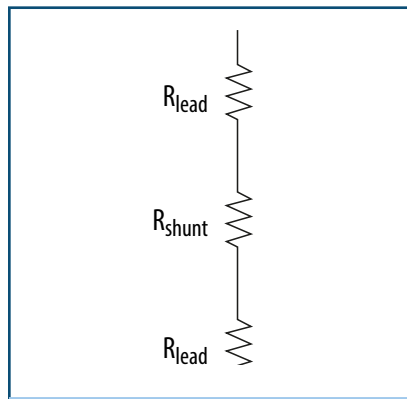


Figure 3. TCR of R Lead

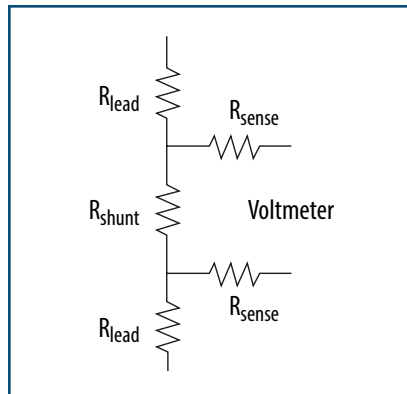


Figure 4. TCR of R Shunt

Designs that use very low ohmic 2-terminal surface mount resistors can find that the contact resistance of the solder pad and the traces of the printed circuit board (R_{lead}) are uncertain and usually higher than the resistance of the current sense shunt itself (R_{shunt}) -- $R_{lead} + R_{lead} \gg R_{shunt}$. This can cause inaccuracies in the current measurement. Additionally, the TCR of copper trace of the printed circuit board (3900 ppm/°C) is also much higher than the TCR of the shunt resistive element (< 50 ppm/°C). These issues cause the resistance value change of the leads to be much higher than the resistance value change of the resistance element resulting in the temperature dependency of the current circuit to be very high.

In order to mitigate these negative effects, designers can use current sense resistors implementing the 4-wire Kelvin principle. It employs additional leads for the current measurement independently from the main current flow.

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KELVIN PRINCIPLE MEASUREMENT (*Continued*)

A 2-terminal resistor can also employ the 4-wire Kelvin method. By separating the current path through the resistor, directly sensing the voltage drop across the resistor improves the measurement accuracy. Unless extreme precision is required, the 2-terminal resistor is the economical choice with PCB traces added to provide the 4-terminal connection.

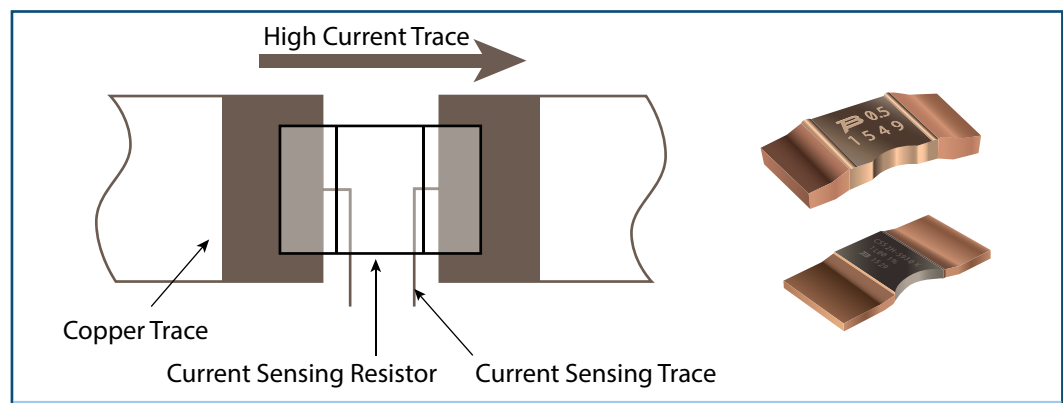


Figure 5. | A 2-Terminal Current Sense Resistor with the 4-Wire Kelvin Principle

If the design permits, it is recommended to utilize a 4-terminal current sense resistor with the 4-wire Kelvin principle to allow separate terminations for current flow and voltage drop measurement, which helps ensure higher current measurement accuracy. An additional advantage of utilizing the Kelvin principle is to reduce the effect of TCR by providing improved stability of the sense amplifier as the temperature rises.

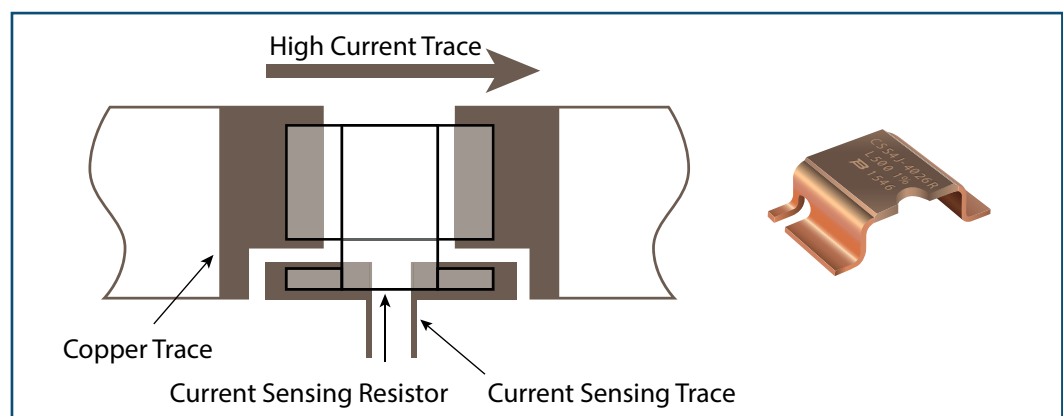


Figure 6. | A 4-Terminal Current Sense Resistor with the 4-Wire Kelvin Principle

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SOLUTIONS FOR EFFICIENT CIRCUIT DESIGN

Bourns developed its Model CSS and CSM series high power current sense resistors to satisfy the accurate measurement requirements of a wide range of applications. These resistors are manufactured using an electron beam-welded metal strip with iron chrome or manganese copper alloy resistive element giving them excellent electrical characteristics. They also feature copper alloy terminations that deliver additional mechanical strength and enable ease of solderability.

Because of their very low resistance, low thermal electromagnetic field (EMF), low TCR, very high power and excellent long term stability, Bourns® CSS and CSM series products are optimal high accuracy current measurement solutions. For applications that require even higher measurement accuracy, in addition to Bourns® 2-terminal CSS product, the company also offers a 4-terminal version. The series' low thermal EMF delivers low voltage drop and higher measuring accuracy along with outstanding long term stability at $\Delta R/R$ max 1% for 21,000 hours rated power at 130 °C.

Providing superior quality, the CSS and CSM series devices are automotive-grade AEC-Q200 compliant. The CSS series features rated power from 2 to 15 watts to handle high current requirements with very low resistance (0.2 to 5 milliohms). The CSM series comes with a permanent power ratings from 36 W to 50 W and resistance values from 25 to 200 microohms. The CSS and CSM series offer a very low drift of resistance with temperature due to their low TCR of 50 PPM/°C in the 20 °C to 60 °C temperature range.

The new CSS and CSM series current sense resistor families complement the Bourns array of circuit conditioning components including power inductors and rectifier diodes. In addition to RoHS compliancy*, the new CSS and CSM series feature extended temperature operation (-55 to +170 °C) for reliability in harsh environments. Upon request, Bourns can offer customized parts to meet a customer's required shape and mechanical and electrical characteristics.

Model	Photo	Current Rating	Power Rating	Resistance Range	No. of Terminals
CSS2H-2512		up to 140 A	2 to 6 W	0.3 to 5 mΩ	2 terminals
CSS2H-3920		up to 245 A	3 to 12 W	0.2 to 5 mΩ	2 terminals
CSS2H-5930		up to 273 A	4 to 15 W	0.2 to 3 mΩ	2 terminals
CSS4J-4026		up to 158 A	3 to 11 W	0.2 to 5 mΩ	4 terminals
CSM2F-6918		up to 848 A	36 W	50 to 200 μΩ	2 terminals
CSM2F-7036		up to 1414 A	50 W	25 to 100 μΩ	2 terminals
CSM2F-8518		up to 848 A	36 W	50 to 200 μΩ	2 terminals
CSM2F-8536		up to 1414 A	50 W	25 to 100 μΩ	2 terminals

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RECOMMENDED SOLDER PROFILE

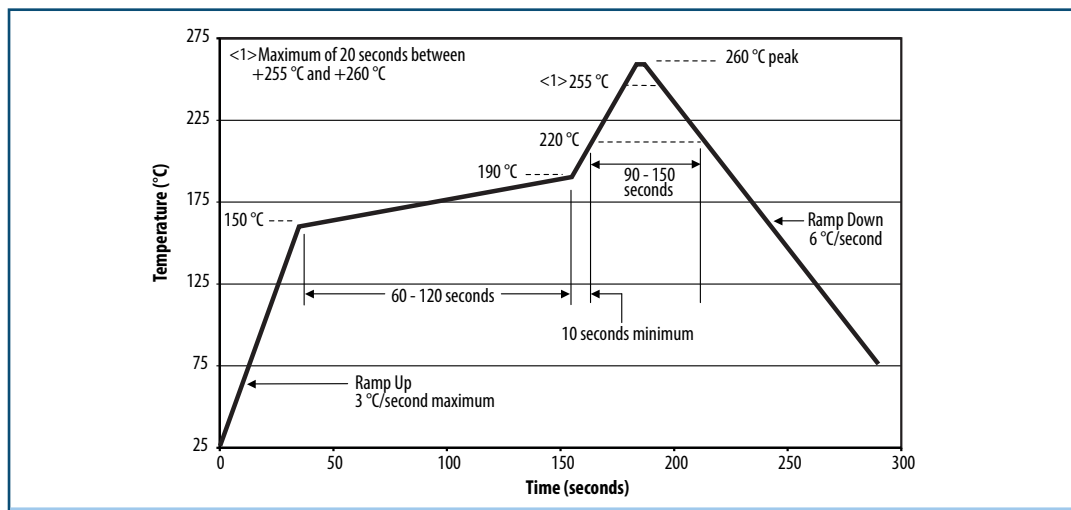


Figure 7. Solder Profile

Applications that require the use of very low value resistors that are a few milliohms or less, typically find that the resistance of the solder becomes a substantial portion of the sense element resistance and can contribute substantially to measurement errors. Bourns recommends a solder profile for its CSS and CSM series products in accordance with IPC/JEDEC-J-STD-020.

APPLICATION EXAMPLES

Battery Management Systems

Proper battery management requires the continuous monitoring of current flow through the electrical circuit. The status of the battery is essential in automotive and other market segments where rechargeable batteries are used. Using current sense resistors such as the Bourns® CSS and CSM series for battery management provides a very accurate and cost-effective method to meet these needs. They provide low ohms at less than a milliohm, meeting the low voltage drop and high accuracy requirements. Current sense resistors can handle the high current of a 100-1000 amp engine starter. Their low TCR is particularly well-suited for automotive applications because of the high temperature fluctuation.

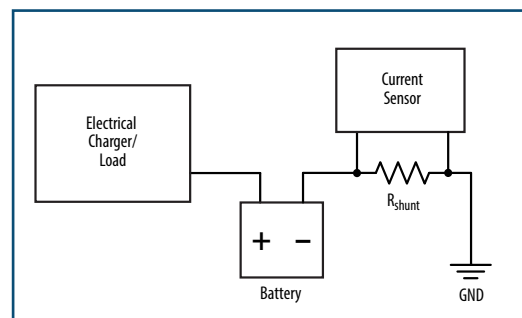


Figure 8. Battery Management System

Main tasks of battery management systems:

- Overcurrent protection
- Overvoltage protection during charging
- Limit the charging/discharging current

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APPLICATION EXAMPLES (Continued)

DC/DC Converters

High performance power supplies have growing importance for the rapidly increasing market of mobile devices, especially in consumer and IT segments. The efficiency needed in switching power supplies used in current-mode DC/DC converters is higher than traditional linear power supplies. High stability and power efficiency is extremely important to ensuring the safety of the sensitive circuits and to helping to extend valuable battery life.

The example below shows how the CSS series resistors can provide tight tolerance of resistance values.

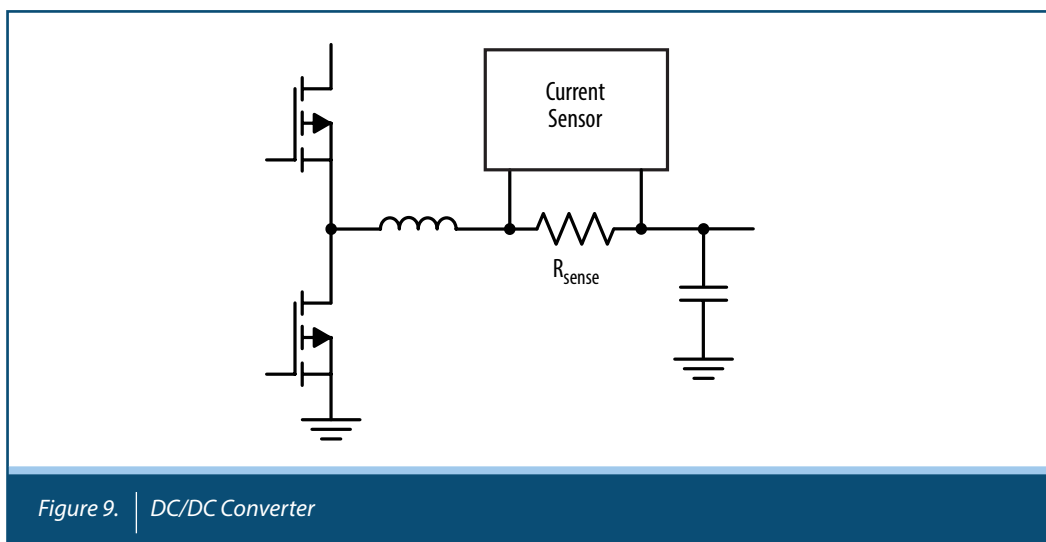


Figure 9. | DC/DC Converter

The characteristics of a current sense resistor for DC/DC converters offer a low resistance value of less than 10 - 20 milliohms for low power loss. Their low TCR and low thermal EMF minimizes or even eliminates the negative impact of self-heating of the devices and effects of various ambient temperatures.

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APPLICATION EXAMPLES (Continued)

Digital Motor Control

Current sense resistors form part of a trend in motor control by adapting new digital technologies which offer high reliability levels to designers with the introduction of the component level standard IEC 60747-17. Digital control offers other benefits such as faster loop responses allowing for integrated overcurrent protection as well as narrower dead times. This enables smoother output voltages that, in turn, contribute to improved torque control.

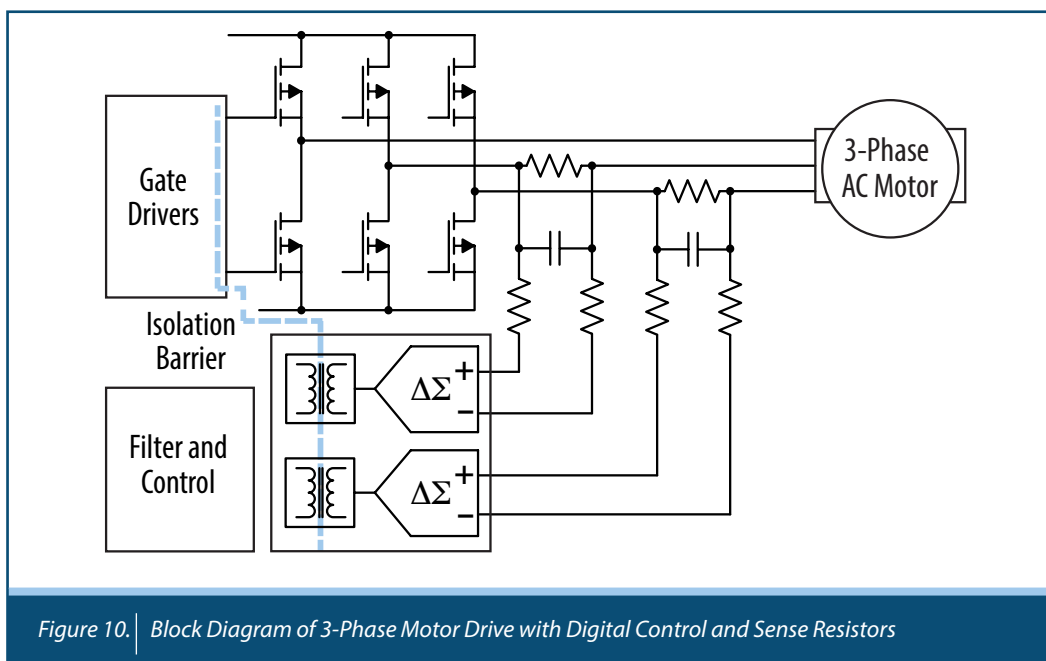


Figure 10. Block Diagram of 3-Phase Motor Drive with Digital Control and Sense Resistors

The figure above shows a typical 3-phase permanent magnet motor drive using sense resistors for measuring the winding current. The Sigma-Delta Modulator has reinforced isolation allowing the current sense resistor voltage to be measured directly by the modulator with no extra components, apart from a simple discrete low pass filter comprised of a resistor and capacitor.

Current sense resistors are ideal solutions for motor controls due to their low resistance value of 0 to 2 milliohms depending on the maximum power. Their low TCR helps designers to minimize the drift of the resistance with temperature. An important consideration in selecting a current sense resistor is that motor drivers will experience short circuits from time to time and the current sense resistor must be able to handle short overloads without being damaged.

Bourns® CSS Series Current Sense Resistors, manufactured using special alloys, have low resistance drift overtemperature and produce output voltages which can be read with an adjustable scaling factor by an Isolated Sigma-Delta Modulator.

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APPLICATION EXAMPLES (Continued)

Hot-Swap Circuit

Hot-swapping or hot-plugging is mainly used for IT and telecommunication systems where it is very important to replace components or modules without interruption to the rest of the system. Once software is running on the computer, the user can remove equipment and plug in its replacement while the system remains running. It is also vital that the hot-swap circuit protects the modules from short circuit, overcurrent, surge current and undervoltage conditions.

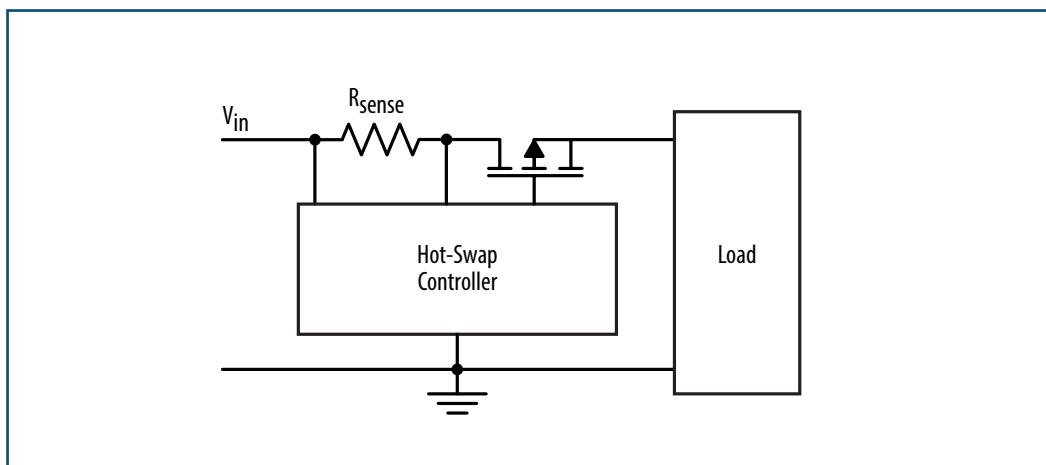


Figure 11. | Hot-Swap Circuit

In this application, hot-swap controllers sense the current flow through the current sense resistor. Current sense resistors are ideal for hot-swap circuits because of their low resistance value (down to 0.2 milliohm) with the capability to handle high current in the hundreds of amps for telecom applications.

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APPLICATION EXAMPLES (Continued)

Smart Electricity Meters

Smart electricity metering is growing in popularity because it offers an accurate, cost-effective solution for real time energy monitoring. Low value resistors can provide current sensing and current feedback inside a smart meter. This solution is ideal for residential smart meters as these precise low value resistors are very cost-effective and straightforward to use. In an electricity meter, a resistor simply is placed in series with the high current electric bus bar, and the current flowing through it is calculated. The calculation can be performed based on the proportional relationship of voltage and current in a resistor of known value. This current value and the instantaneous voltage are multiplied to get the power consumed at any instant, and is continually monitored by the microcontroller. Resistors can be placed between the voltage and signal lines where the supply current may need to be limited to prevent damage to other components. Adding flexibility to deployment, it is also possible for power resistors to be used in a heating function to stabilize the internal meter temperature in frigid environments.

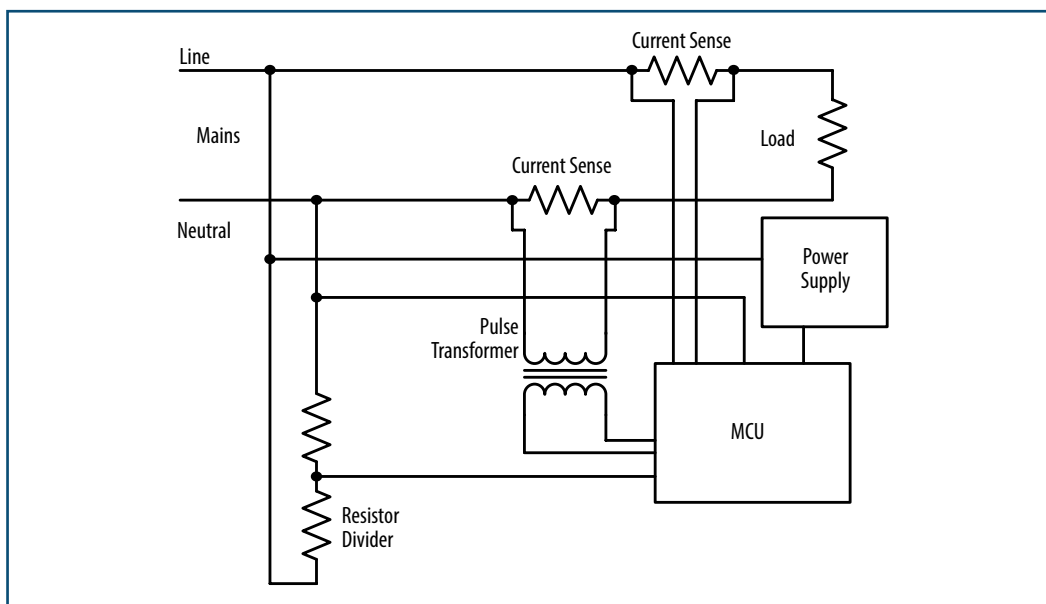


Figure 12. | Smart Electricity Meter

Current sense resistors and resistor dividers provide current and voltage measurements to the microcontroller inside a smart meter.

For more details, please refer to the Bourns Smart Meter Solutions White Paper: http://www.bourns.com/docs/technical-documents/technical-library/circuit-protection/publications/Bourns_Smart_Meter_White_Paper.pdf

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SIMPLE, COST-EFFECTIVE CURRENT MEASUREMENT

Current sense resistors provide a simple and cost-effective direct method of accurate current measurement. Other benefits include a low TCR, low thermal EMF and long-term stability. Low resistance electron beam-welded metal alloy-based current sense products, such as the Bourns® CSS and CSM Series, offer exceptional electrical characteristics and surge performance for efficient and highly reliable protection from short circuit and overcurrent threats.

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