Eaton current sense resistors

Overview

The current flowing through a resistor depends on the voltage difference across the resistor terminals. Current sense resistors (CSRs) rely on this voltage-current relationship to achieve accurate current measurements in electronic applications (e.g., energy storage optimization, server unit hot swapping, and motor speed control). Additionally, the rising need for high-efficiency electronic circuits due to promising trends in electric vehicles, smart electricity supply grids, and emission minimization has led to a corresponding increase in the need for high accuracy in measuring current flow through a circuit. This Eaton application note highlights the working principle of current sense resistors and explores how designers can incorporate them into circuit designs in a host of applications.

Working principle

CSRs depend on the conversion of current to voltage. This resistor type exhibits a negligible voltage drop (within the range of 10 to 130 mV) when incorporated into applications. With CSRs, designers can enhance system efficiency and minimize losses by placing them in series with the electrical load. This placement allows the current flow measurement through the resistor. Designers then measure the voltage drop across the CSR of known value using various amplifier options such as difference, operational, and instrumentation amplifiers. Since there is a proportional relationship between voltage and current within a circuit (Ohm's law), designers can evaluate the current flow through the CSR with the previously measured voltage drop. Designers must first identify the input common-mode voltage specification of the CSR before incorporating it into any application. Figure 1 on the next page shows a typical circuit diagram for CSR or shunt resistor current measurement.

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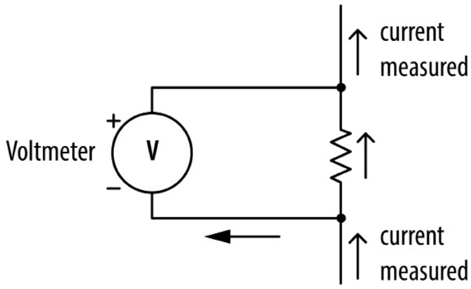

Figure 1: Current measurement with CSR

Unlike indirect current measurement techniques, which leverage the voltage induction across a coil to measure current, this technique connects the shunt resistor in series with the load to directly measure the current. This direct measurement technique emphasizes power dissipation from the resistor, resulting in minimal resistance values.

CSRs are ideal for precisely measuring current in a wide range of applications, including consumer and industrial electronics. Consequently, manufacturers offer these devices in several designs, such as chip resistors with thick film, electron-beam welded metal shunts, and an integration of metal foil and metal strip resistive elements. Manufacturers also achieve high-accuracy current measurements by ensuring their CSR solutions exhibit low resistance, high current, low thermal electromagnetic field (EMF), superior long-term stability, and low Temperature Coefficient of Resistance (TCR).

Applications of CSRs

This section explores practical applications of CSRs in battery management systems, DC/DC converters, and smart electricity meters.

Battery management systems

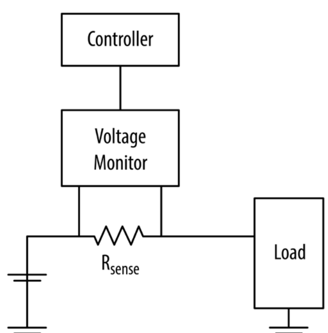

Figure 2: Battery management system-based CSR application

Battery management systems (BMS) offer various functions in battery-based applications, including overcurrent protection, overvoltage protection during charging, and charging/discharging current limiting. To adequately carry out these functions, these systems constantly monitor the flow of current through the electrical circuit. Designers can achieve cost-effective and accurate current measurements by incorporating CSRs in BMS. Battery-based applications, including automotive and solar inverters, require these low TCR devices due to the high-temperature fluctuations.

DC/DC converters

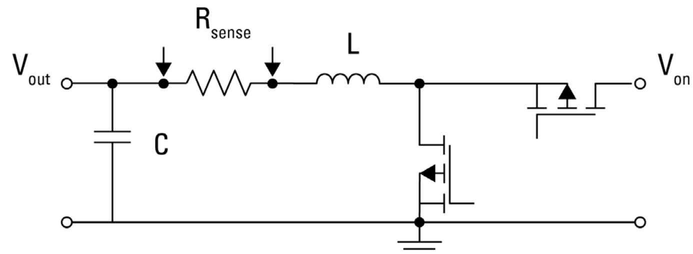

Figure 3: DC/DC converter-based CSR application

Current-mode DC/DC converters, which are essential for high-performance power supplies, require higher switching efficiency when compared to conventional linear power supplies. The converters also require high stability and power efficiency to ensure the safety of circuits and extend battery life. CSRs play a crucial role in ensuring current-mode DC/DC converters adequately meet these efficiency and stability requirements. Designers can incorporate low resistance CSRs (ranging from 10 to 20 milliohms) into DC/DC converter applications to minimize power loss. Similarly, the low thermal EMF and low TCR values of CSRs significantly minimize the adverse effects of device self-heating during switching operations.

Smart electricity meters

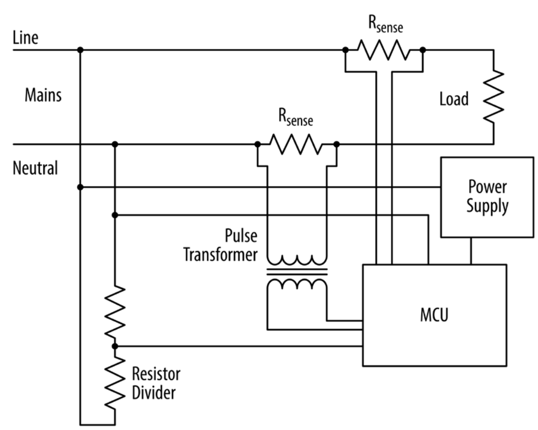

Figure 4: Smart electricity meter-based CSR application

The growing demand for real-time energy monitoring has led to the development and implementation of smart electricity metering. Designers achieve this real-time monitoring by incorporating low resistance CSRs, which offer current sensing and current feedback capabilities, into smart meters. Figure 4 shows that placing the current sense resistor in series with the high current electric bus bar allows for efficient calculation of the current flow.

The smart meter then evaluates power consumption at any instant by multiplying the calculated current with the instantaneous voltage and ensures continuous monitoring with the aid of the microcontroller (MCU). Note that to minimize the chances of damage to other circuit components, designers place the CSRs between the voltage and signal lines. Incorporating ESD suppressors between keypads and I/O controllers helps protect electronics from ESD-induced damage. Engineers can also install ESD suppressors between antenna elements and RF amplifiers modules to mitigate ESD in RF applications. Similarly, ESD suppressors can be integrated between HDMI ports and HDMI transmitters/receivers.

Digital motor control

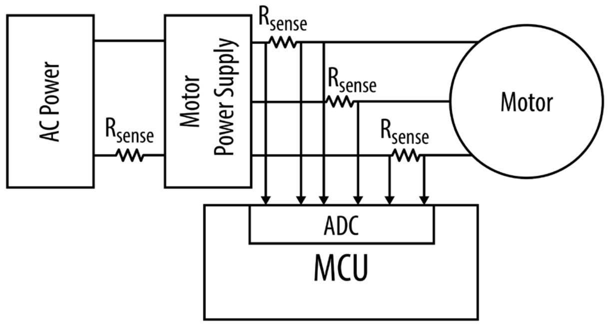

Figure 5: Digital motor control-based CSR application

CSRs are crucial elements of motor control dependent on digital technologies. These resistors offer high reliability in line with guidelines from the component-level IEC 60747-17 standard. Integrating digital technologies with motor control offers designers several functional benefits, including faster loop responses, which provide in-built overcurrent protection and minimized dead times, smoother output voltage, and improved torque control. Figure 5 shows that designers can take accurate current measurements with simpler circuit designs by incorporating CSRs into digital motor control. The motor drive leverages CSRs for winding current measurements. Note that the low resistance values of CSRs make them ideal for motor controls. Similarly, the low TCR values of these resistors allow for optimum resistance drift minimization regardless of temperature.

Hot-swap circuit

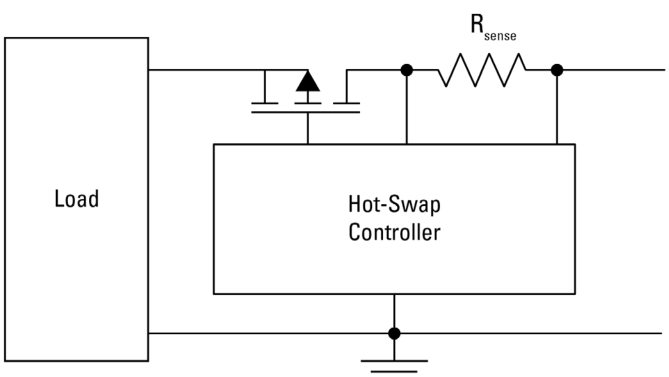

Figure 6: Hot swap circuit-based CSR application

IT and telecommunication system users can replace a component of a system without interrupting the normal functioning of the rest of the system by harnessing the capabilities of a hot-swap circuit. This circuit is critical in situations where system interruptions may adversely impact the user. However, to efficiently use a hot-swap circuit, users must ensure that it can protect systems or modules from a wide range of events, including overcurrent, under-voltage, short circuit, and surge current, of which the functions depend on the sophistication of the controller itself. Consequently, designers incorporate CSRs into hot-swap circuits, which can handle high currents (>100 amps) associated with telecommunication applications, due to their ultra-low resistance values.

Key considerations in implementing CSRs

To implement the ideal current sense resistor, designers should note the following considerations:

- Ensuring accurate measurement
- Heat dissipation
- Considerations in parallel placement

Measurement

Due to challenges with solder pad and PCB traces in low ohmic 2-terminal surface mount resistors, some designers leverage the Kelvin principle to ensure highly accurate current measurements. The unusually higher resistance of the solder pad and PCB traces, when compared to the sensing resistors, accounts for significant errors in current measurements, while their higher temperature coefficient of resistance of up to 3900 ppm/$^{\circ}$C results in high-temperature dependency of the circuit. Thus, designers can adequately handle the adverse effects of the solder pad and PCB traces by implementing the 4-wire Kelvin principle.

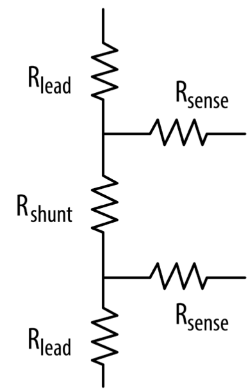

Figure 7: Kelvin principle measurement

Unlike the conventional current measurement technique with CSR explained in Figure 1, Figure 7 implements the 4-wire Kelvin principle for higher accuracy current measurements. This method achieves higher current measurement accuracy by incorporating extra lead resistors. These lead resistors ensure accurate current measurements, which are independent of the main current flow.

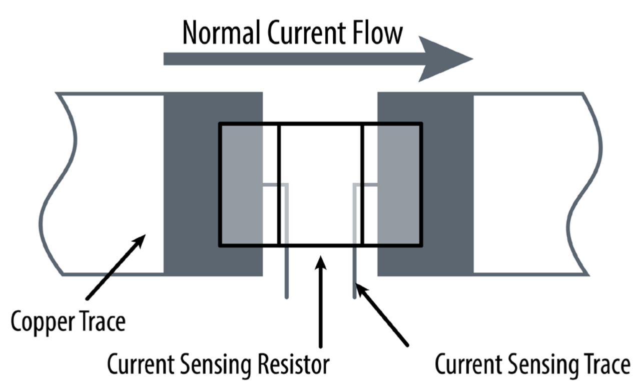

Figure 8: 2-Terminal CSR with the 4-wire Kelvin principle

Designers can choose between 2- or 4-terminal CSRs when implementing the 4-wire Kelvin principle depending on precision, design requirements, and costs. Integrating a 2-terminal CSR with the 4-wire Kelvin principle involves separating the current path through the resistor, allowing designers to directly sense voltage drop across the resistor at improved measurement accuracy. Conversely, the 4-terminal CSR integration with the 4-wire Kelvin principle allows for discrete terminations for current flow and voltage drop measurement, ensuring higher current measurement accuracy. The Kelvin principle also provides improved stability to the sense amplifier regardless of temperature rises by reducing the overall effect of TCR.

Parallel placement

Although designers can opt for series CSR placement in current measurement applications, they sometimes mount these components in parallel, resulting in significant circuit complexities. A key recommendation to ensure designers still achieve highly accurate current measurements in parallel CRS placement involves identifying an optimum voltage measurement position on the PCB, which significantly depends on the component layout and current path. Simulations have shown that this optimum position lies around the mid-portion of the mounting land of one of the resistors. Figure 9 shows optimum voltage measurement position identification in light of parallel CSR placement.

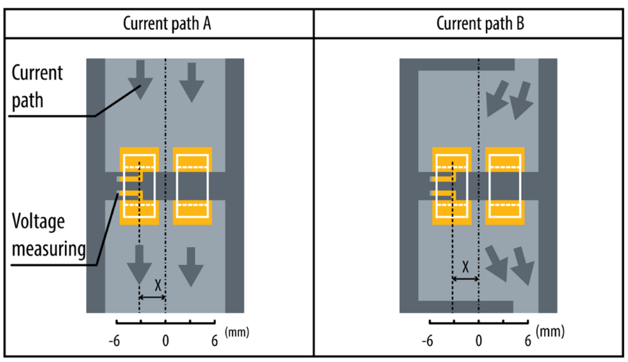

Figure 9: Identifying the optimum voltage measurement position in parallel placement

Heat dissipation

Heat dissipation is a key factor to consider when implementing CSR-based current measurements in various applications. The ability of CSRs to efficiently dissipate heat significantly depends on the structure of the resistor. For example, unlike metal plate CSRs (whose entire body remains in contact with the PCB after mounting due to its flat design), a shunt CSR exhibits higher heat dissipation capabilities due to its open-air structure. With this excellent heat dissipation capability, high current shunts afford CSRs high power ratings. Additionally, CSRs with excellent heat dissipation capabilities are suitable for high-temperature applications, including electronic power steering (EPS) systems, high-intensity discharge (HID) headlights, power systems, and EV BMS.

Conclusion

Eaton's CSRs are suitable for high-precision current sensing a host of consumer and industrial applications. The low TCR, thermal EMF, resistance, and inductance values of these resistors and their high power, excellent heat dissipation, and superior long-term stability capabilities make them ideal for high accuracy current measurements in a wide variety of market segments.

Eaton's CSRs provide high-accuracy current sensing with low resistance values and high power and current handling capability. The CSR series is available in metal foil or plate constructions. The metal foil type offers high accuracy and lower tolerances which comes at higher resistances, while the strip CSRs offer lower resistance and higher power.

Eaton metal foil CSR series are constructed using high accuracy foil on a substrate to provide industry-leading thermal performance, low inductance, and low noise. They are offered in 0402 to 2512 EIA footprints as well as short or wide terminal configurations. Eaton's metal foil CSRs have power ratings up to 3 W and resistances up to 1 ohm. Eaton metal plate CSRs are designed using a metal plate with epoxy overcoat and end terminations to provide a low-temperature coefficient of resistance (TCR), low resistance, and high power capability. They are offered in standard 0603 to 2512 EIA footprints with short and wide terminal configurations.

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Printed in USA
Publication No. ELX1237 BU-ELX22098
September 2022