Texas Instruments

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MAKING SENSE OF CURRENT SENSING

WHITE PAPER

MOUSER ELECTRONICS

Making Sense of Current Sensing

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Current sense resistors are very low value resistors used to measure the current flowing through it. The current through the resistor is represented by the voltage across the resistor, so by applying I = V/R as set down by the famous school teacher Georg Simon Ohm, the current is proportional to the voltage across the resistor.

This simple introduction to the topic is the beating heart of the rest of this current article. The topics covered here - resistor selection, high side or low side monitoring, and choosing a sense amplifier - are all based on this basic formula of electrical engineering.

Current sense monitoring helps to improve the efficiency of some systems and reduce losses. For example, many mobile phones have implemented current sensing to monitor and improve battery life while also improving reliability. If the current draw becomes too large, the phone can decide to throttle back the CPU frequency to reduce the load on the battery in order to extend battery life, while preventing the phone from overheating which increases reliability. There are even phone apps that can access the current sense reading circuit and make decisions to optimize the phone’s performance.

In addition to current sense monitoring using a resistor, two other less common methods are used. One uses a Hall Effect sensor to measure the flux field generated by a current. While this is non-intrusive and has the advantage of no insertion loss, it is somewhat expensive and requires a relatively large amount of PCB real estate. The other method, using a transformer to measure induced AC current, is also size and cost intensive; while also useful only for AC current.

This paper will cover three basic aspects of current sense monitoring using a resistor:

1. Choosing a low resistance precision sense resistor. If real estate is based on “Location, Location, Location,” then choosing a resistor is based on “Precision, Precision, Precision.”
2. Choosing a sense amplifier chip. When sensing voltages across a resistance that is less than one ohm, small changes in voltage can have significant sense consequences. The sense amplifier amplifies that voltage change, making the insignificant, significant.
3. The “location, location, location” of the sense resistor. This refers to either sensing at the power supply, called High-Side Sensing, or at the ground connection, called Low-Side Sensing.

Precision current sensing applications are no longer made-from-scratch circuits; manufacturers have done all of the research and most of the work for modern designers.

Selecting the Resistor

Selecting the resistor value, precision, and physical size is dependent upon the current expected to be measured. The larger the resistor value, the more accurate the measurement possible, but a large resistor value also results in greater current loss. For low power battery-powered devices that must reduce losses, resistors that are about a millimeter in length with values of hundredths or thousands of an ohm are often used. For higher currents of one amp or more, resistors of greater value can be used, which allows for more accurate measurements with acceptable losses.

Although a resistor is often thought of as a simple two-terminal device, for accurate measurements four terminal current sense resistors such as the Vishay WSK Series are used with two terminals at each end of the resistor This provides two terminals for the current path of the application circuit, and a second pair for the voltage detection path of the sense amplifier. This four-terminal setup, also known as *Kelvin Sensing*, insures that the resistance at each connection is the smallest possible, insuring that the voltage measured by the sense amplifier is the actual voltage across the resistor and does not include the small resistance of a combined connection. This allows ease of interconnections and reduces the effects caused by temperature coefficient of resistance (TCR). TCR is an effect where resistance increases as temperature rises. The power applied to a sense resistor can often heat up the resistor and connection to 100°C or more above the ambient temperature. While sense resistors are designed to have a very low TCR, the combined TCR of the connection including wires and PCB traces can raise the resistance by 5 to 10%. Kelvin sensing greatly reduces the effect of TCR by providing improved stability of the sense system over temperature.

The WSK0612 resistor with a 1.0% resistance tolerance can handle up to one watt of power and can be found in small DC/DC converters and some battery chargers. The WSK2512 series with a 0.5% tolerance targets laptop power supplies and instrumentation applications. The Vishay WSK2512 can handle up to one watt and are available with tolerances as accurate as 0.5% and resistances from 0.025Ω down to as small as 0.0005Ω.

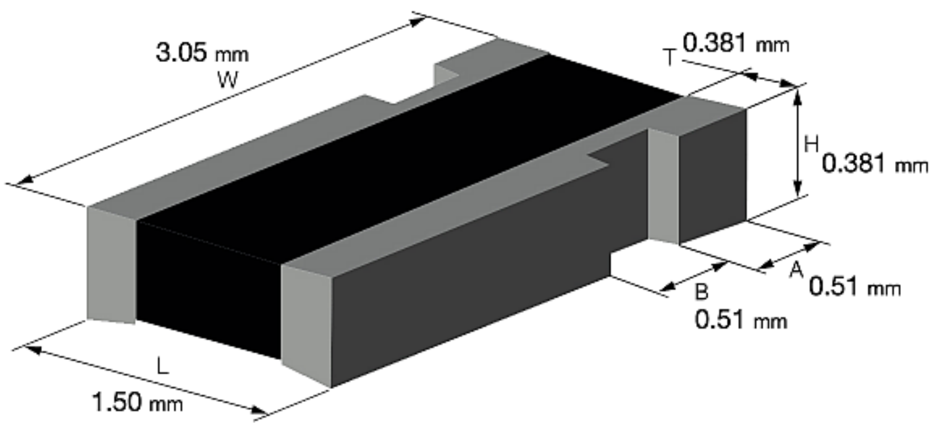

Figure 1: Vishay WSK0612 Current Sense Resistor and Dimensions

Another important sense resistor criteria is stability over temperature as demonstrated by the Vishay WSLS and WSLP Series. These are long-life resistors with a resistance stability as low as 0.25% over the operating temperature range and are used as current sense resistors in switching and linear power supplies and power amplifiers.

An unusual issue that can develop when dealing with very low resistor values is thermal EMF. Thermal EMF is a very small voltage, on the order of one thousandths of a volt, which is generated due to small differences in temperature across a conductor. The conventional use of thermal EMF is in the construction of a thermocouple where the microvoltage is proportional to the temperature; however, thermal EMF is unwanted in current sense resistors and can cause inaccurate readings. The Vishay WSL and WSR resistor series offer many performance benefits, including being specifically designed to minimize thermal EMF. Figure 2 plots the behavior of the Vishay WSL Power Metal Strip resistors against two competitor technologies. The plot demonstrates that the WSL series has a very low thermal EMF of 3µV/°C, while the competitor technologies are a high ±25µV/°C.

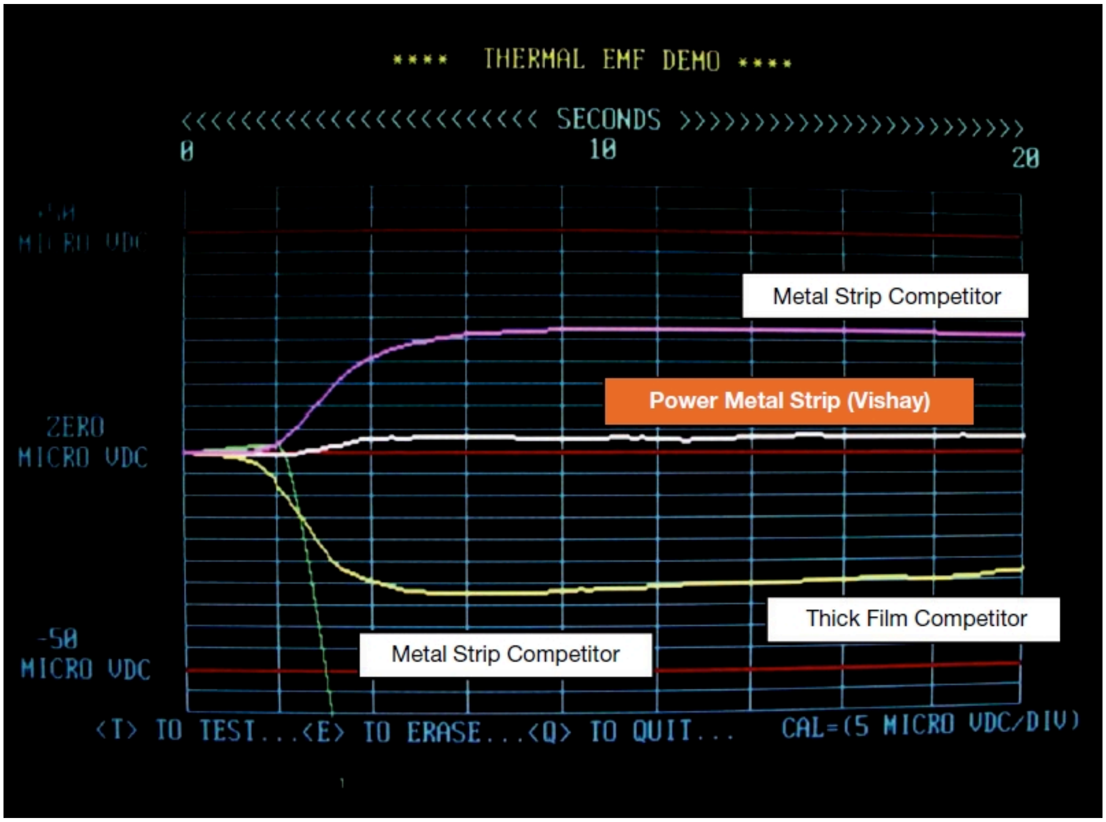

Figure 2: Thermal EMF characteristics of the Vishay 50 milliohm WSL2512 Power Metal Strip resistor compared to competitor resistor technologies.

Two of the resistors in Figure 2 are metal strip technologies, the third is from a low-value thick film resistor. All resistors are 50 mΩ nominal resistance. As the graph demonstrates, if thermal EMF is not taken into account it can result in inaccurate readings.

Certain applications have high power requirements, with half a watt or more being pushed through the resistor. The Vishay WSLP2010 and WSLP2512 can handle 2.0 and 3.0 Watts, respectively. The WSHM2818 are 7.0 Watt high power density current sense resistor is intended for high power current sense applications such as high wattage DC/DC converters, desktop PC power supplies, and brushless DC motor control. For high temperature applications the one-watt Vishay WSLT and WSR series can withstand temperatures up to 275°C.

Sense Monitoring - High Side or Low Side?

Current shunt monitor ICs, also called *current sense amplifiers*, accurately measure the tiny voltages across the sense resistor. To prevent the sense amplifier from interfering with the voltage being measured, these ICs have a very high input impedance. However, before selecting the current shunt monitor, a circuit decision must be made as to whether to place the current sense resistor at the supply voltage rail of the load (*high side monitoring*), or at the ground point of the load (*low side monitoring*). Each has its advantages and disadvantages.

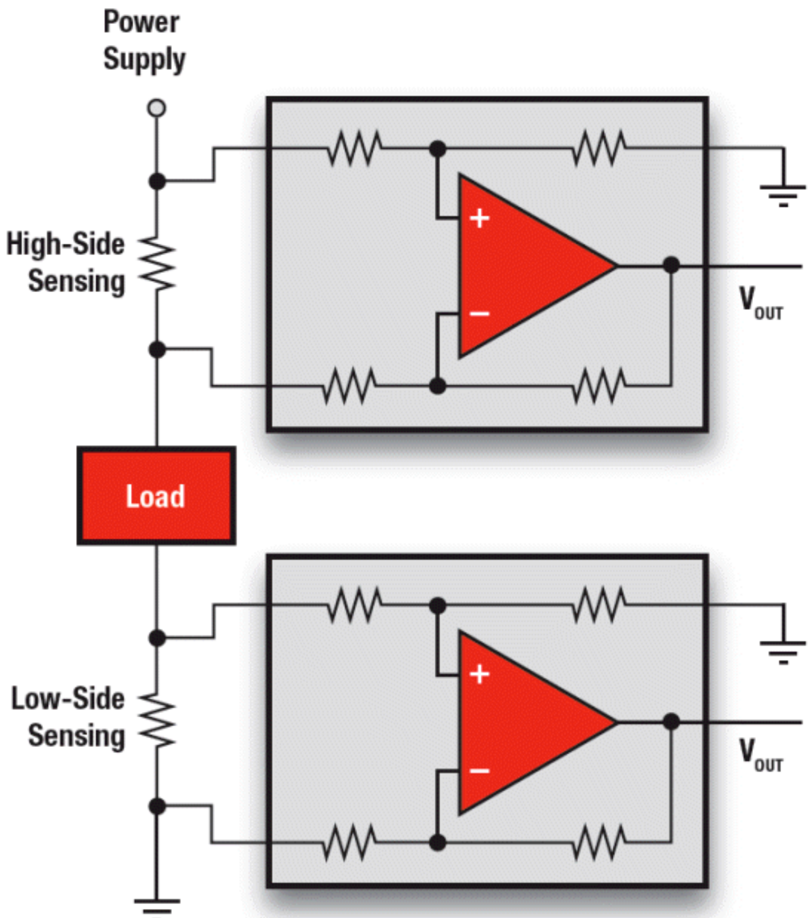

Figure 3: High-side vs. Low-side sensing

Low-side sensing is often the least expensive and simplest method to implement because if one end of the sense resistor is at system ground, and the other end of the resistor is at the ground side of the load whose current is to be measured, then the voltage across the resistor with respect to system ground can be amplified by a simple op-amp referencing the same system ground. This amplified voltage is then measured with an analog to digital converter (ADC).

However, the disadvantage of low-side sensing is related to its advantage, placing a resistor in the load's path to ground. This resistor placement results in the load's ground floating at a slightly higher voltage than the system ground. The most common issue with this arrangement is potential ground loop problems. Since the load is not at the same ground potential as the other loads in the system, the system can develop an audible noise, such as a hum, or even produce interference with nearby equipment, including audio and video interference. In addition, low side sensing cannot detect fault conditions such as a short or open circuit in the ground path due to connection problems or outside interference.

For this reason, low side sensing makes sense when dealing with large currents, one isolated load, or other situations where the system is immune to fluctuations in the ground path.

High side sensing is when a shunt resistor is placed inline between the system power source and the load. This configuration is more responsive to changes in the current flow and adds no disturbance to system ground. The main disadvantage is that because the shunt resistor is not at system ground, a differential voltage must be measured which requires the precise matching of the proper differential amplifier. However, this disadvantage is eliminated with the use of one of the precision current shunt monitors from Texas Instruments.

Current Shunt Monitors

Several factors go into the selection of a current shunt monitor:

Common Mode Range: This specification defines the permissible DC voltage range at the input of the amplifier with respect to ground. Current shunt monitors are usually specified to accept common mode voltages that are above the chip supply voltage. For example, the Texas Instruments INA225 current shunt monitor and the TI INA300 Current Sense Comparator can accept DC voltages from 0V to 36V. Both are very flexible, and can be used for either high- or low-side monitoring. The INA225 has an I²C interface, allowing a microcontroller to read the monitored current along with measured voltage and power dissipated. The TI INA282 boasts a very wide common mode range of -14V to +80V, with a low offset drift of just 1.5 µV/°C.

Offset voltage: This is the voltage measured across amplifier inputs if both positive and negative inputs are at the exact same voltage. Ideally this voltage would be zero, but in reality it is always a non-zero voltage. Small offset voltages can lead to large errors, which can increase over device age and operational temperature. The Texas Instruments INA230 Bidirectional Current Shunt Monitor has a low 50µV offset voltage over its temperature range of -40 to +125°C. However, for the best accuracy, the TI INA226 is one of the highest precision current sense monitors on the market today, with an offset voltage of just 10µV and a common mode range of up to 36V. Both implement an I²C serial port for easy interfacing to most microcontrollers.

Common Mode Rejection Ratio (CMRR): This specification is the ability of an amplifier to detect and reject signals that are present at both differential inputs. The physical placement of the amplifier on the circuit board can lead to noise coupling on the inputs due to thermal noise, high frequency signals, or high currents that induce magnetic current coupling. Many of Texas Instruments' current shunt monitors have a typical CMRR as high as 140dB, including the INA226, INA210, and INA282.

With such a wide selection of current shunt monitors, which one is applicable for the target circuit? As discussed here, the choice is system-dependent. Current shunt resistors and monitors are now being used in applications that previously did not require current monitoring but now require an increase in efficiency Examples include battery gauges, power supplies, wireless charging, tablets and mobile phones, industrial automation, battery powered medical devices, and solar power systems.

Conclusion

The need for current monitoring has become more important as systems strive to become more efficient, especially with regard to battery-powered equipment. Current sense monitoring can provide significant system advantages, and with a careful selection of the proper components can extend both battery life and the serviceable life of many electronic systems.