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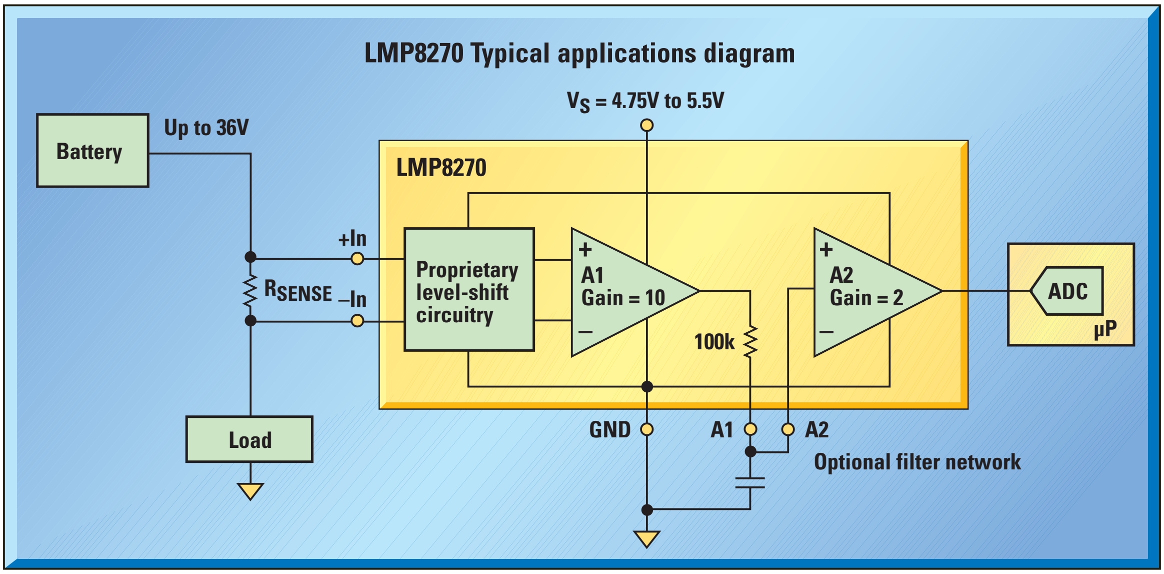
Only National guarantees TC_{VOS} by tri-temp testing each device



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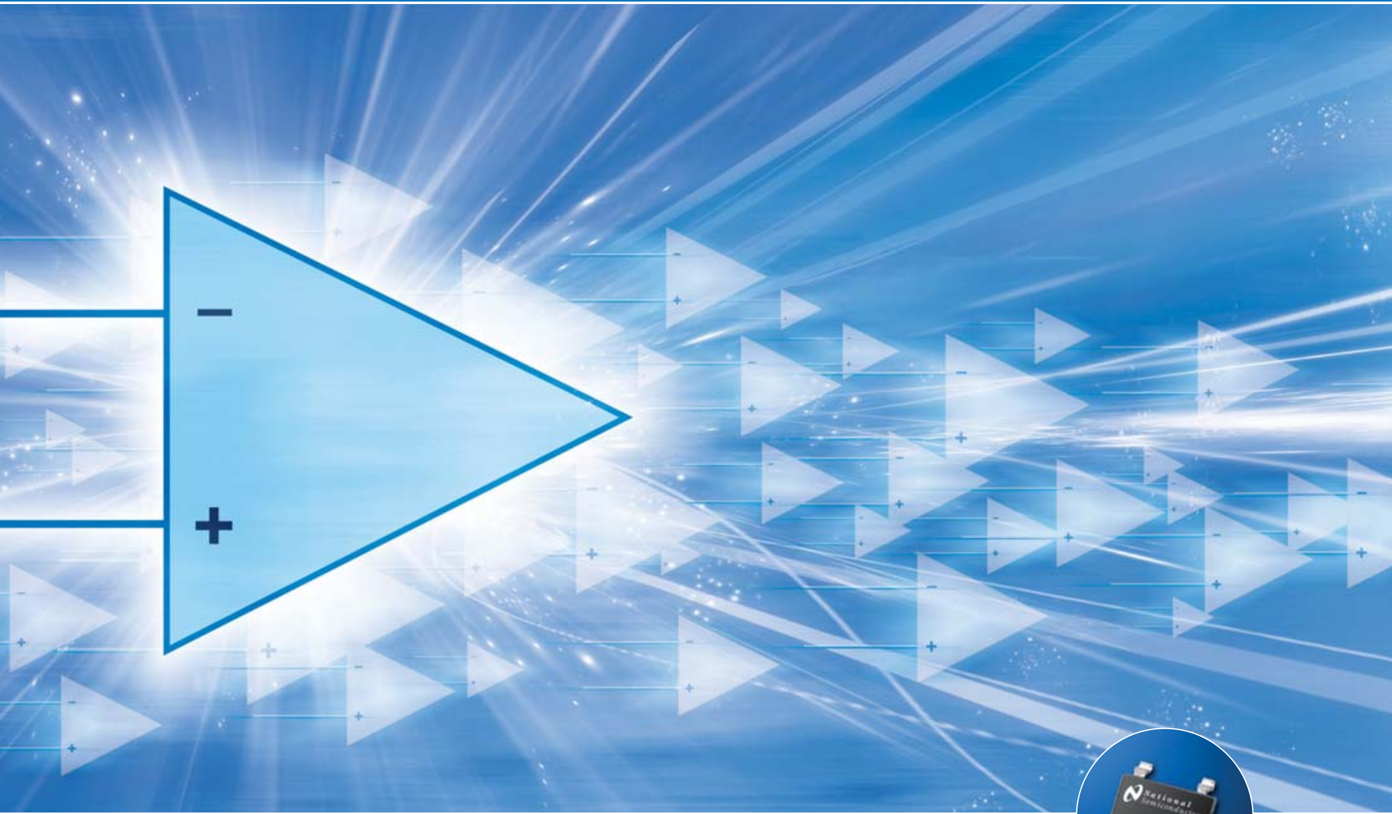

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The Sight & Sound of Information

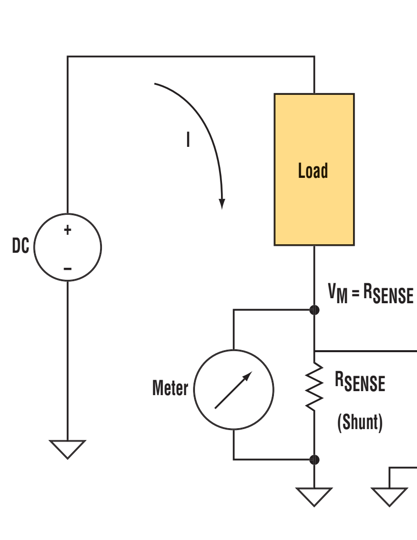
Don Tuite, Analog/Power Editor

Take The Right Steps To Achieve Accurate Measurements

It Starts With Ohm's Law (Then It Gets Interesting)

Current measurements are used in a variety of equipment for control or safety functions. Measuring the voltage drop across a low-value resistor is the most common method of measuring the current flowing in a circuit (**Fig. 1**). The current flow through the load also flows through the R_{SENSE} resistor, also known as a shunt resistor, which creates a voltage drop, V_M, across the resistor.

Figure 1 depicts two current-measurement approaches. Ammeters were developed in the early history of electronics, and they're still used today. Typically, the meter itself may read full-scale when the current through it is 100 µA or 1 µA. So to read larger currents, it is connected in parallel with a resistor that shunts most of the current around the meter. That way, the meter can be scaled to measure any magnitude of current.



1. The classic approach to current measurement shunts a milliammeter with a resistor to scale the current through the meter. The contemporary approach amplifies the voltage drop across the resistor and applies the amplified voltage to a meter or an analog-to-digital converter.

Resistor Sizing and Op-Amp Gain

A more contemporary approach for measuring current uses an operational amplifier, or op amp, to amplify the voltage dropped by the sense resistor. Often, the output is connected to an analog-to-digital converter (ADC). The first steps are to choose a value for the sense resistor and to set the amplifier's gain.

For example, suppose the current through the load varies from 0 to 10 A, and the ADC is designed for a maximum input signal of 5 V. Because the current is relatively high, a very low-value shunt resistor is required. To simplify calculations, choose 0.025 | . At the maximum current of 10 A, the voltage, V_M, across the shunt is $10 \times 0.025 = 250$ mV. The physical size of the shunt resistor is determined by the power dissipation, $Pd = I^2R$. Using the values from above, $Pd = 10^2 \times 0.025 = 2.5$ W. A power rating of 5 W or more should be used to minimize heat on the shunt resistor.

To satisfy the ADC's input requirements, the gain required by the amplifier is:

$$Av = \frac{5.0v}{0.250v} = 20$$

If the signal from the shunt resistor is applied to the non-inverting input of the amplifier, gain Av is one plus the ratio of the feedback and input resistors. Choosing a value of 5 k| for R1 and a value of 95 k| for R2 sets the gain to 20.

Consider Shunt Resistor Thermal Characteristics

The above example points to several areas that need additional consideration. The heating of the shunt resistor due to power dissipation or to ambient temperature changes affects the measurement accuracy by changing the resistance of the shunt. The various metals used in resistors offer different temperature coefficients (**see the table**).

Temperature Coefficients Of Metals Used In Resistors

Material	Resistivity ρ	Temperature coefficient α
Copper	1.7×10^{-6} Ω-cm	0.004041
Nickel	7.8×10^{-6} Ω-cm	0.005866
Platinum	10×10^{-6} Ω-cm	0.003729
Manganin	44×10^{-6} Ω-cm	0.000015
Nichrome	110×10^{-6} Ω-cm	0.00017

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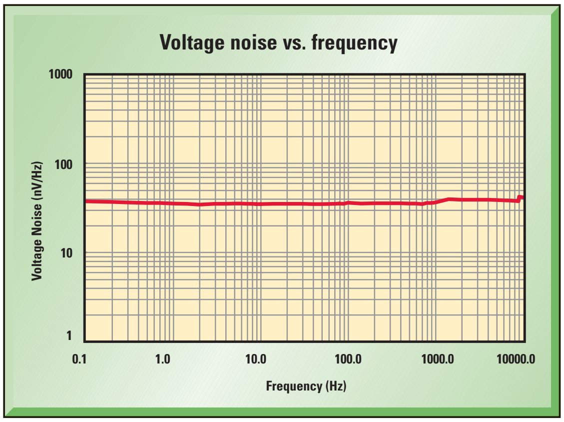

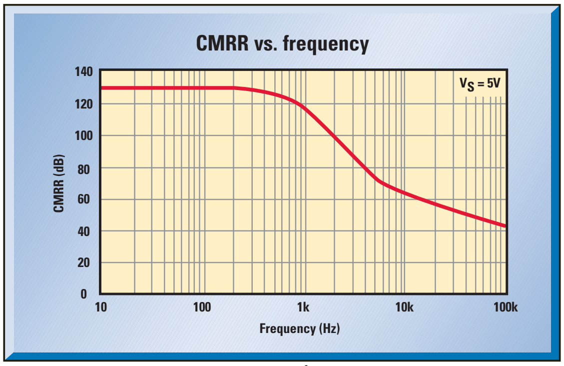

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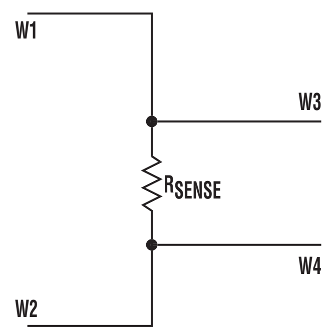
BASICS of Design

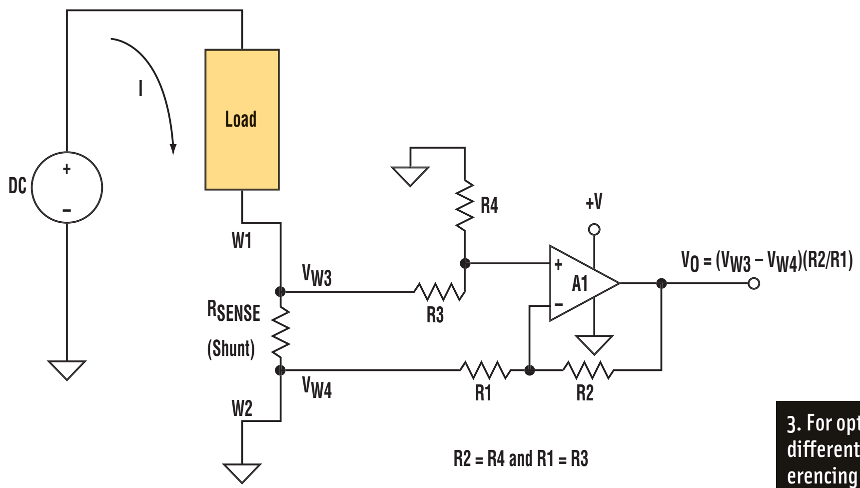
Kelvin Sense Resistors

A second area of concern is the connection between the shunt resistor and the amplifier's input. In the example we've been using, an ordinary 5-W resistor would have 20-gauge copper leads. Assume the leads are trimmed to 0.5 in. on either side of the resistor and soldered in place. Twenty-gauge copper wire has a resistance of about 0.001 | /in., which represents a 4% error, relative to the resistor's nominal value.

To avoid introducing such an error, two additional features are needed: a Kelvin connection to the shunt resistor and a differential-input amplifier. A Kelvin connection is a four-wire connection with two force leads and two sense leads (**Fig. 2**). Two of the wires (W1 and W2) are force leads, and they connect the shunt resistor to the high-current side of the circuit. The other two wires (W3 and W4) are sense leads, and they connect the voltage across the shunt resistor to the amplifier. This arrangement separates the load-current-carrying wires from the measurement circuit. The voltage drops in W1 and W2 are removed from the measurement of the voltage across the shunt resistor. To take full advantage of the Kelvin connection, a differential amplifier, as in Figure 3, is necessary.



2. To avoid measurement errors caused by the voltage drops across conventional resistors' leads, Kelvin-connection sense resistors are supplied with four leads: two for the forcing current, and two others, connected right at the resistance element, for the high-impedance measurement circuit. Kelvin resistors come in a number of configurations.



3. For optimal measurement accuracy, a differential amplifier avoids ground-referencing the current-sense voltage.

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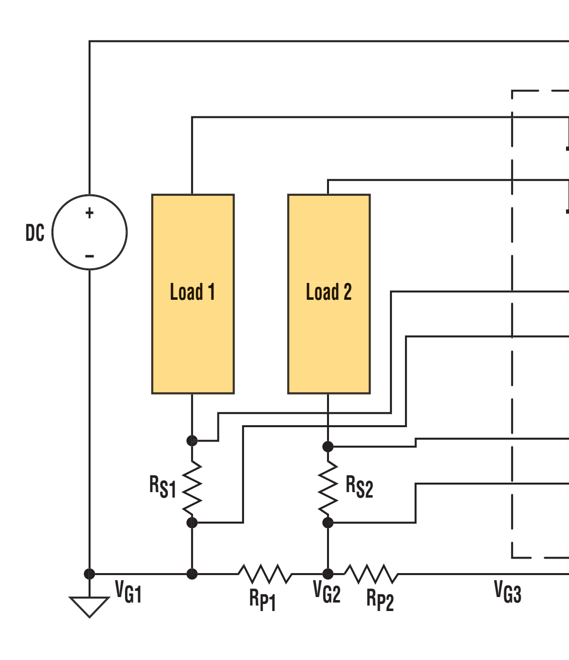
Placing the sense resistor between the load and ground is called low-side sensing. Low-side sensing is acceptable when the input voltages are positive and close to ground. However, problems arise when op amps are used and those conditions are not met. Low-side current measurements can cause a problem for op amps by exceeding the negative common-mode voltage limit of the op amp.

Due to the way they are designed, op amps only work correctly when the input common-mode voltage is within a certain range between the positive and negative power-supply voltages. A rail-to-rail-input op amp that operates from a single 5-V supply might have a datasheet common-mode input voltage spec of 0 to +5 V.

As an example of a low-side measurement that would create common-mode problems, consider the distributed-load system in Figure 4. A control unit (dashed line) uses MOSFETs to control power to two loads. Parasitic resistances, RP_1 and RP_2, between the power source, the loads, and the control unit represent the sum of ground wiring resistance and connector resistance. In a real circuit, they can easily have values of several tenths of an ohm. For this example, assume RP_1 and RP_2 are 0.2 | . Differential amplifiers 1 and 2 are just like the differential amplifiers in Figure 3.

As in Figure 1, the current in each load is 10 A, and the shunt resistors (RS_1 and RS_2) are 0.025 | . The control unit's current is 1 A. When load two is on, the voltage at point V_{G2} is two volts more positive than point V_{G1} (0.2 | × 10 A = 2 V), and V_{G3} is 0.2 volts more positive then V_{G2}. As a result, the inputs to differential amplifier 1 are –2.2 V relative to the common connection at the control unit. This is greater then the negative



4. Locating the sense resistor between the load and the circuit's common node, a practice called low-side sensing can introduce measurement inaccuracies when parasitic resistances between the sense resistor and the common node are significant.

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High-side current sensing solves all
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common side. This arrangement perm
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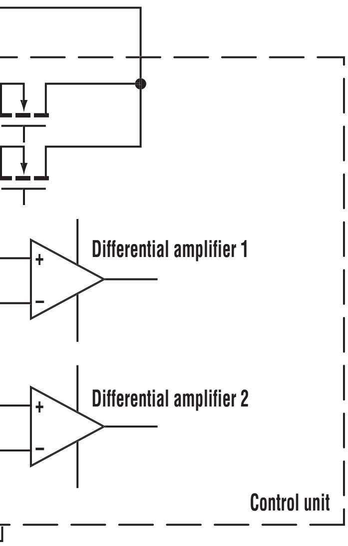

power source and use an amplifier that has an input common-mode voltage specification that includes the positive supply. Another way is to use an amplifier that is designed for high input common-mode voltages. These have the advantage of operating from the same supply voltage as the other control circuits when the inputs are connected to the higher positive voltage.

In general, measuring current flow in electrical circuits requires amplifiers with input common-mode voltage specifications that extend beyond the positive and negative supply voltages of the amplifier while maintaining low input offset voltage and gain accuracy.

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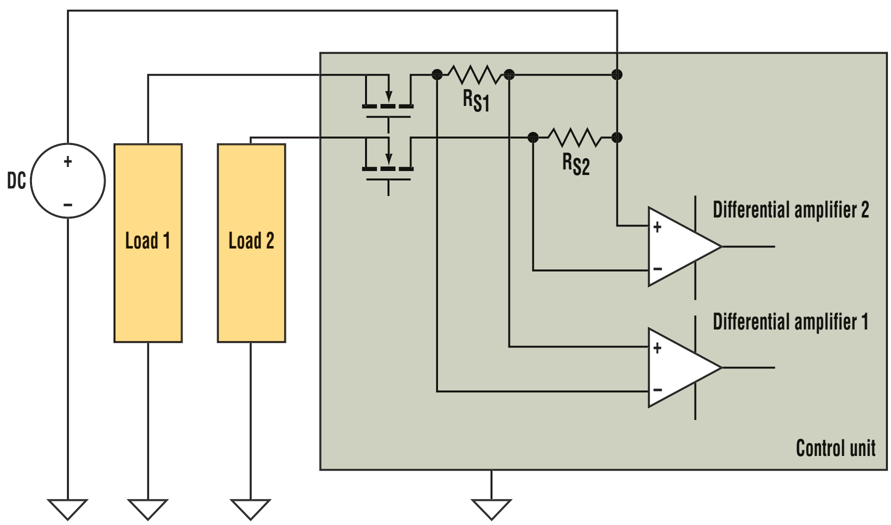

5. High-side sensing eliminates the disadvantages of low-side sensing, but it requires differential amplifiers with inputs that can accommodate the supply voltage within their common-mode input range.