Current Sensing – General

High precision resistors used for current sensing are usually low ohmic value devices suitable for four terminal connection.

Two terminals, called "current terminals", are connected to let the electrical current pass through the resistor and voltage drop $V_s$ is measured on other two, called "sense" or "voltage drop" terminals. According to Ohm's law, the sensed voltage drop $V_s$ divided by the known resistance $R_s$ gives the sensed current $I_s$.

The accuracy of measurement depends on the stability of ohmic resistance $R_s$ between the nodes – points of connection of the sense leads.

This arrangement, called "Kelvin connection", reduces, especially for low ohmic resistance values, a measurement error due to the resistance of the lead wires and the solder joints as the sensing is performed inside the resistor, in or close to the active resistive foil.

The foil technology is best suited for manufacture of low values due to the superior resistor's stability compared to thick film or thin film technologies.

Temperature Coefficients – TCR and PCR

The best known parameter used to specify resistor's stability is the TCR – Temperature Coefficient of Resistance – which expresses, in parts per million per degree centigrade (ppm/°C), the resistance change $\Delta R/R$ due to the change in ambient temperature, over a specified temperature range.

The change of resistance with temperature is caused by a change of the resistivity of foil's material and by thermal stresses when foil and substrate expand. In the case of a thin NiCr foil cemented to a ceramic substrate, the foil cannot expand freely – the ceramic forces the foil to expand or contract with it.

Second, less known parameter is the power coefficient – PCR, or "Power Coefficient of Resistance." It quantifies the effect of the self-heating due to the Joule effect – the $RI^2$ losses.

When high precision is not required, the ambient temperature rise and the temperature rise due to self-heating can be combined and multiplied by TCR in order to assess the $\Delta R/R$, but this approach can lead to an excessive error in high precision measurements.

These phenomena are reversible – when the ambient temperature and the dissipated power return to the original ones, so does the resistance value.

Other non-reversible phenomena are quantified in resistor datasheets in the form of tables of environmental tests – like long-term load life at a specified ambient temperature, high temperature exposure and others. Precision measurements usually permit avoidance of harsh environmental conditions while special cases must be handled individually.

Additional sources of measurement errors are electrical noise and thermoelectric effect.

Noise is negligible in Bulk Metal® Foil resistors.

Thermoelectric effect (called Seebeck effect) occurs when...
Dealing efficiently with the PCR requires collaboration with temperature and due to self-heating. The range must encompass both changes – due to changing ambient conditions and through foil. In case of current sensors, the relevant temperature resistance versus temperature curve of resistors produced with a wide temperature range. This is due to the inherent flatness of the resistors family. Vishay developed several proprietary technologies(1) for production of high precision current sensing resistors(2). The use of Z-Foil allows the achievement of very low TCR over a wide temperature range. This is due to the inherent flatness of resistance versus temperature curve of resistors produced with Z-Foil. In case of current sensors, the relevant temperature range must encompass both changes – due to changing ambient temperature and due to self-heating.

Dealing efficiently with the PCR requires collaboration with the customer because it is influenced by customer's assembly method, anticipated current fluctuations and requirements of accuracy and speed of response.

The temperature difference between resistive foil and substrate can be evaluated from the \( \Delta R / R \) losses(2) and the resistor's internal thermal resistance. But power rating is limited by foil's maximum temperature, which depends on total thermal resistance between the foil and the ambient, and this is influenced by assembly method and resistor's construction. Heat sink mounted, surface-mounted and through-hole molded devices will show different substrate's temperature when their foil selfheats to the same temperature. Heat sink mounting increases the power rating of a resistor, but sometimes at the expense of the PCR, which increases due to larger temperature difference, for a given power, between the foil and the substrate.

**Power Ratings**

A statement of power rating for a given resistor should be always evaluated in context with definition of service conditions. Sometimes more than one number is stated in the datasheet, and sometimes the service conditions stated are not relevant for a given customer's application. For instance, two different values of power rating are sometimes stated for two different ambient temperatures.

In case a power rating is given for an assembly method which is capable of maintaining the resistor's substrate at room temperature, a very high figure can be claimed for power rating, but such service condition is costly to achieve.

Vishay's datasheets for precision heat sink mounted resistors usually state two values of power rating – for free air cooling and for mounting on a heat sink as defined by the US Military Standards. Such a heat sink can dissipate heat only when the temperature of resistor's substrate is higher than the ambient temperature.

So a current sensor of the heat sink mounted style can be assigned three different power ratings (and, accordingly, three different PCR's) – for mounting in free air, on a standard heat sink and on a Peltier type electronic cooling device which keeps resistor's substrate at room temperature. Therefore, optimal stability can be obtained only by evaluation of customer's application – mounting method and performance requirements – and choosing the most fitting technical solution among the various types of power sensing resistors available.

**Conclusions**

Vishay achieves a very high precision in current sensing resistors.
High Precision Current Sensing

sensing by:

• Using Z-Foil for very low TCR (0.2 ppm/°C typical) over wide temperature ranges. Z-Foil also provides a PCR (Power Coefficient of Resistance) of 4 ppm/Watt typical.
• Applying proprietary methods of manufacturing precision 4-terminal resistors.
• Applying its expertise in stress analysis.

References