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Making Sense of Two-Wire Current-Sense Resistors

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Four-wire sense resistors provide two power connections and two sense wires in order to make a precision measurement. Newer two-wire devices are available in values as low as 250 micro-ohms (µΩ), with wide pads to minimize inductance. In this article we will focus on an Ohmite FCSL Series metal-foil current-sense resistor, for no other reason than we have some here from a previous article on measuring low impedances.

Ohmite specifies the tolerance of the 1-milliohm (mΩ) FCSL90 series device as 5%, so that the 1-mΩ resistor is within 50 µΩ of the 1-mΩ value.

In the most simplistic case, we could assume that the device can be represented as a single resistor with two connections. As we will show in this article, this would lead to incorrect measurements.

In a prior article (see the reference) we mounted the sense resistor to a 2-oz copper, double-sided PCB with SMA connections at each end and one side of the resistor connected to a ground plane using multiple vias. Since we have this mounted resistor we might as well use it for this article also.

To measure this resistor we used a bench power supply, an M3510A precision low-noise ammeter and an M3500A precision low-noise 6.5-digit voltmeter. The power supply is connected through the ammeter to the µcurrent-sense-resistor body. A picture of the setup and a connection diagram are shown in Fig 1.

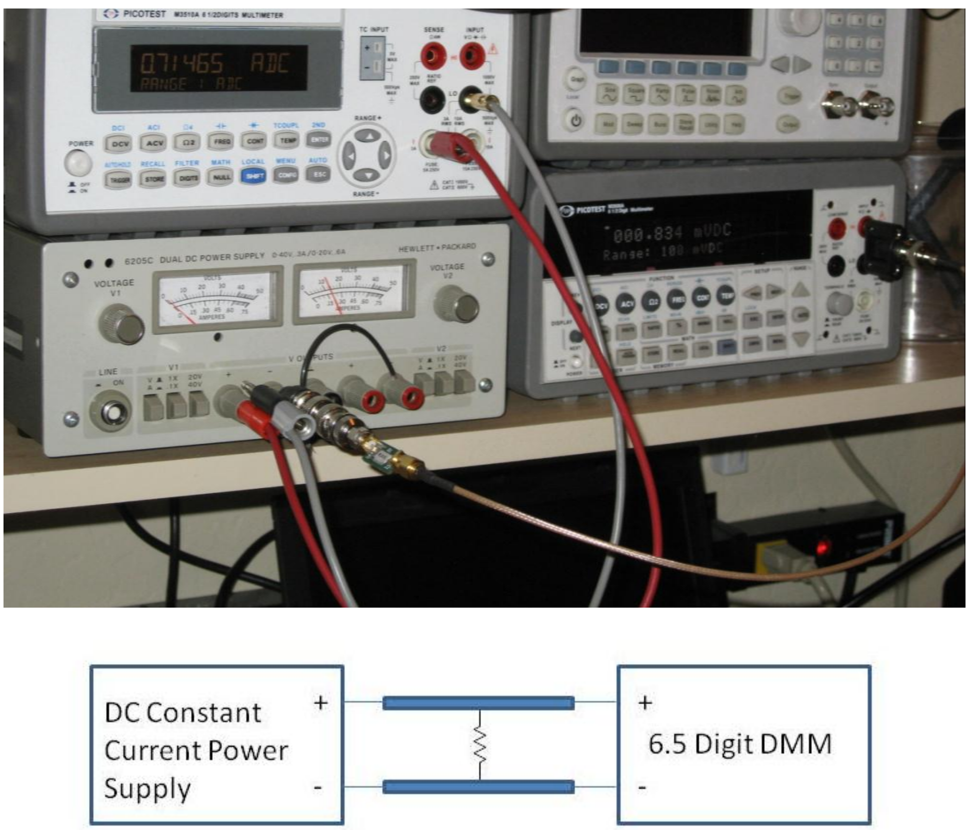


Fig. 1. Test setup (photo) and the associated connection diagram. The power supply is operated in current limit through the sense resistor while the precision ammeter measures the current and the precision low-noise voltmeter measures the voltage at various points along the resistor pads. At 700 mA the voltage measured at the resistor pads closest to the power supply is 965 µV while at the load end (unloaded) it measures 700 µV. The voltage across the ground pad measures 40 µV and the voltage across the hot pad measures 225 mV.

A close-up of the sense resistor in Fig. 2 shows an example of how the voltmeter probes are placed on the resistor pads during voltage measurements.

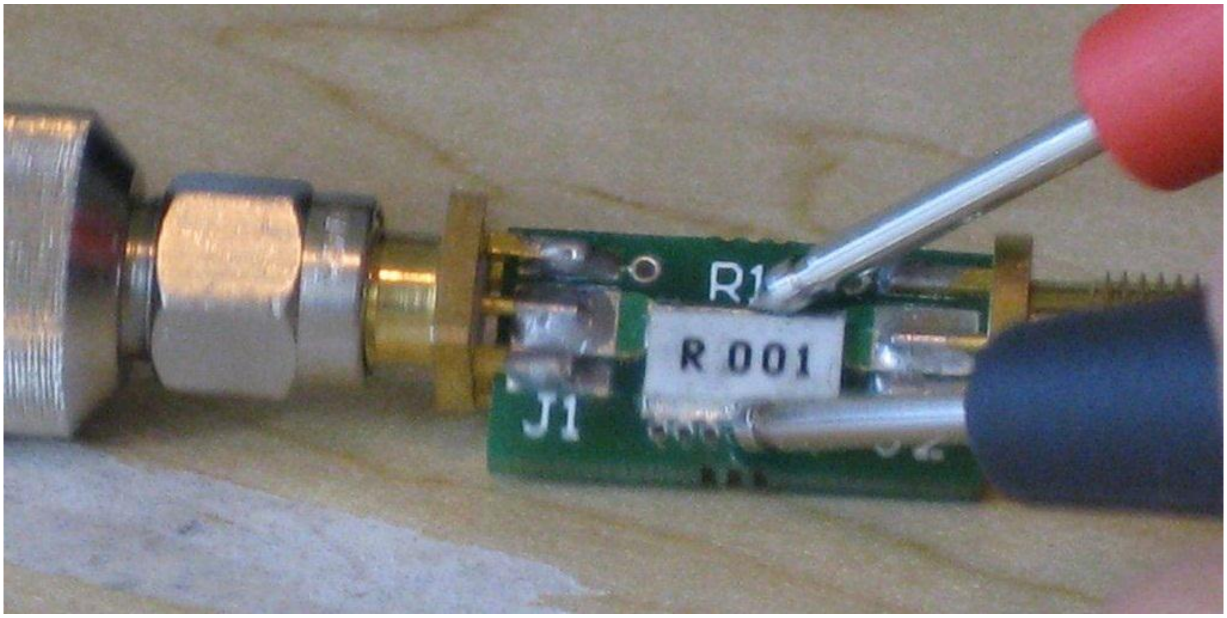


Fig. 2. Close-up of sense resistor under test.

While there is no current flowing out of the resistor (i.e. no load) the voltage across the resistor changes depending on where along the resistor pads the measurement is made. The measurements also show that the voltage across the ground side pad is very different than the voltage across the positive or "hot" side pad. The measured data is used to construct a finite element (FE) model of the resistor, shown in Fig. 3. Five sections are used in the model to keep it simple, but if voltages are required at more intervals, additional elements can be used.

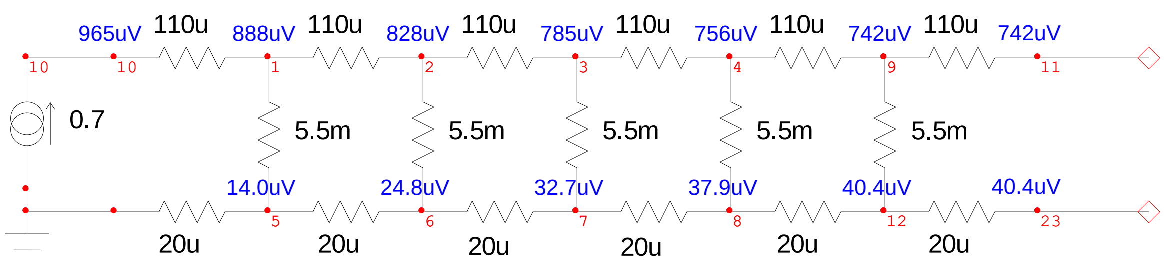


Fig. 3. A five-section FE model of the resistor shows the unequal ground and hot pad resistances and shows the gradients along the sense resistor pads. Note that the voltage across the ground pads is much lower than the voltage across the hot pads and that measurement of 1 mΩ is correct at the LOAD end of the resistor.

The voltages in the model agree very well with the measurements and show that even without any load connected to the resistor the voltage drops along the pad length due to the FE nature of the resistor.

This brings up several key issues in using this resistor type accurately. The datasheet does not provide recommendations for making connections to the resistor, PCB copper weight or other application-oriented information, but we can determine some insight from our model.

We can see that the ground-side resistance is much lower than the hot-side resistance and this is due to the ground plane used on the ground side, compared with a simple pad on the hot side. This implies that the resistance in a particular application will be sensitive to the weight of the copper used and also the dimensions of the pads or planes the resistor is connected to. A heavier weight copper or a larger connection plane will result in a lower measured resistance.

From our model we can also see that for the given mounting we have used here, the current should enter one side of the resistor and exit from the other side. In our sample test and model, the resistance is almost exactly 1 mΩ as measured from the load side.

If both the power and signal connections to the resistor were made at the center of each resistor pad, as shown in Fig. 4, the sense voltage of 806 µV for a 700-mA current corresponds with 1.15 mΩ, 15% above the specified value. If the power connection is made at the center of the resistor and the signal connection is made at either end of the resistor the measured voltage is 752 µV or 1.075 mΩ, half the error measured at the center of the pads. Using heavier copper or copper planes for both connections can improve the accuracy of the resistor, in either case.

This model also shows that since there is voltage across the ground pad, the connections between power ground and analog signal ground must be carefully considered.

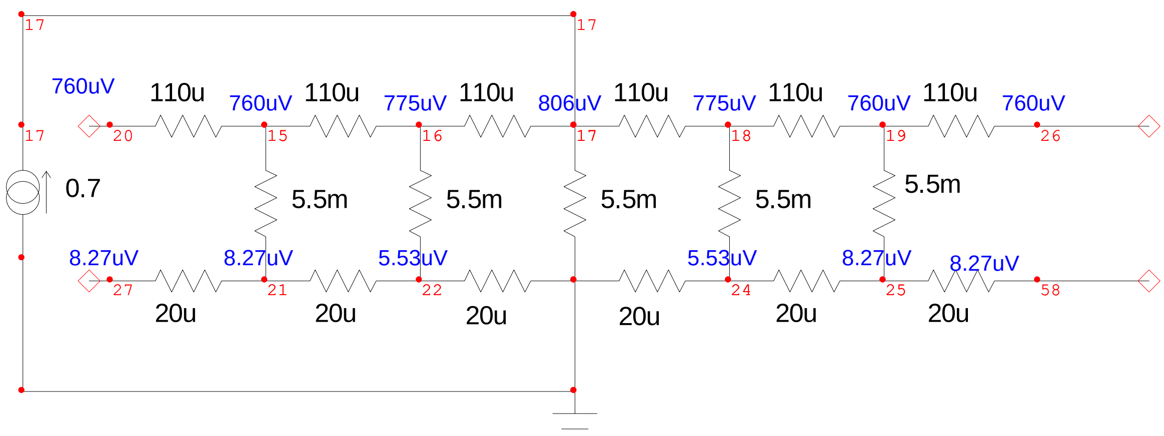


Fig. 4. Connecting both the power and signal connections to the center of each resistor pad results in 806 µV or 1.15 mΩ, a 15% error from the nominal value while measuring the signal at either end of the resistor results in 1.075 mΩ, in much better agreement with the specified resistance value.

The physical design of the resistor is for very low inductance, which is not discussed in the datasheet, nor is a specification provided. The impedance of the resistor was measured using the method described in the previous article with the test setup pictured in Fig. 5. The resulting measurement of impedance magnitude is shown in Fig. 6.

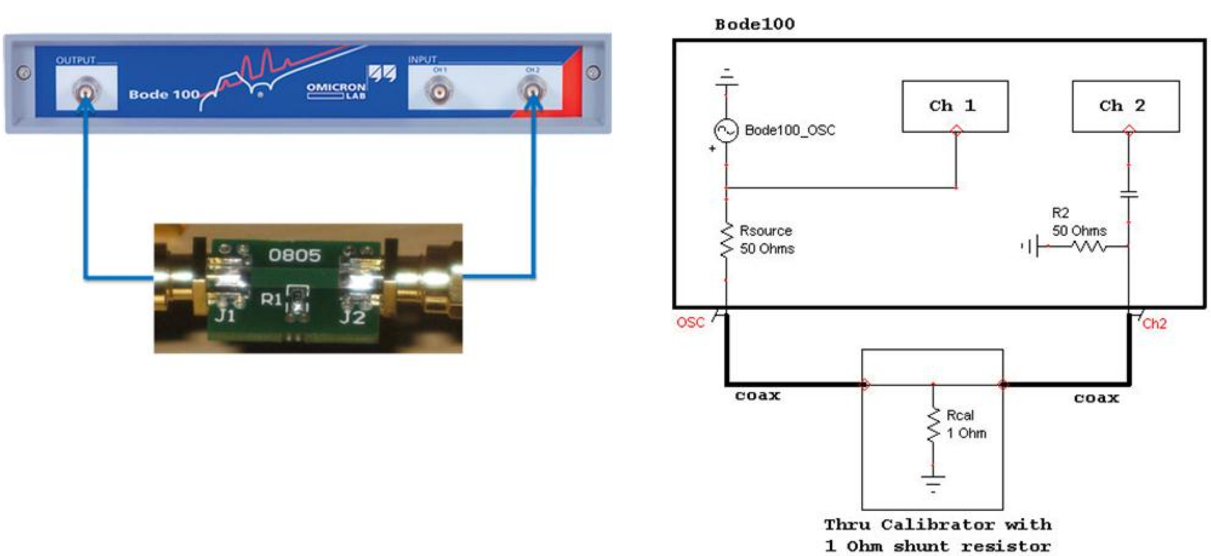


Fig. 5 Connection diagram for vector network analyzer (Bode 100) and resistor under test.

In the impedance measurement, the positive 6-dB/octave slope identifies the inductive region of the resistor and the specific impedance of 60 mΩ at a frequency of 20 MHz is used to compute the inductance of 480 pH. That value could easily be added to our FE model as a single element inductor in series with the resistor.

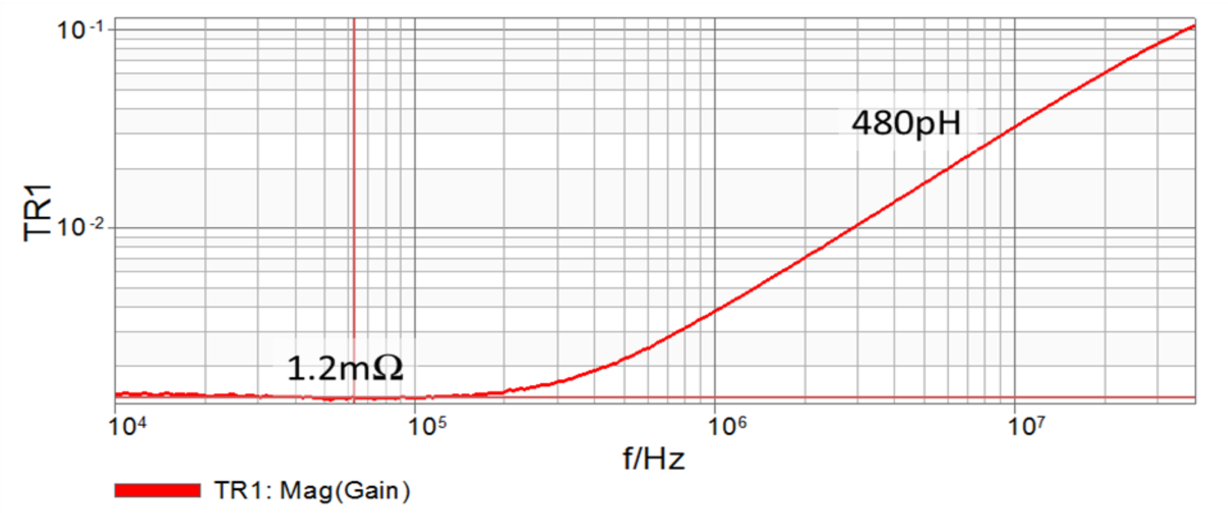


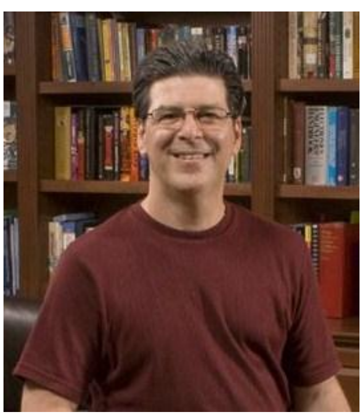
Fig. 6. Using the two-port shunt-thru impedance method to measure the resistor is the most accurate method of measuring low impedances. This measurement is used to determine the reactance in the inductive region of the measurement, identified by the 6-dB/octave slope. The specific point at 60 mΩ at 20 MHz allows the calculation of the 480-pH inductance of the resistor.

This article provided insight into the physical nature of two-wire current-sense resistors and a realistic FE model that can be used to represent the model. It also showed that care must be taken in order to obtain the desired or specified resistance value, considering the copper weight of the PCB, the locations of the terminations and the effect of a simple copper trace versus the use of copper planes. As always, we recommend measuring the final circuit to assure that the desired result is obtained.

Reference

"How To Measure Ultra-Low Impedances" by Steven Sandler and Charles Hymowitz, Electronic Design, July 2012.

About The Author



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For further reading on test and measurement issues, see the How2Power Design Guide, select the Advanced Search option, go to Search by Design Guide Category, and select "Test and Measurement" in the Design Area category.