QuadTech

Application Note

Errors in Low Resistance Measurements

Let's take a look at variables in measuring low resistance values and the errors that may occur in making those measurements. Two-wire versus four-wire connection to the device under test (DUT) is an important factor in obtaining accurate results. Another consideration is the thermal EMF produced at the junctions of dissimilar metals that can cause decreased accuracy at very small voltage levels. Device heating and inductive devices may add to the EMF error. Dry circuit testing may be implemented to avoid oxidation puncture of the test leads. Determining temperature rise in the self-heating of motors, transformers solenoids and coils provides motor and transformer manufacturers with a more accurate characterization of their device.

The 2-Wire versus 4-Wire Debate

Most of today's digital multi-meters (DMM) and some dedicated resistance measurement instruments utilize a 2-wire test method. In the 2-wire method, the test current (I_{TEST}) is forced through the test leads and across the resistance (R_{DUT}) being measured. The meter then measures the voltage across the resistance through the same set of leads and the resistance value is computed. Figure 1 illustrates the 2-wire connection to DUT.

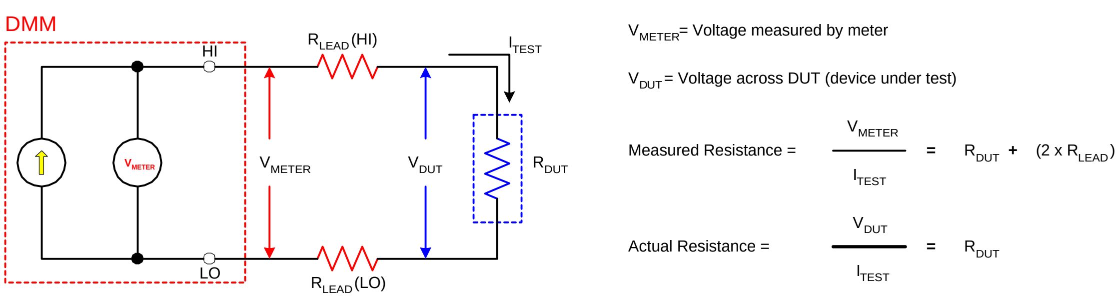


Figure 1: 2-Wire Connection to DUT

The resistance of the test lead (R_{LEAD}) is the concern with the 2-wire method when making low resistance measurements. The test current (I_{TEST}) causes a small yet significant voltage drop across the lead resistances. The voltage drop (V_{METER}) measured by the meter will not be exactly the same as the voltage (V_{DUT}) directly across the device under test (R_{DUT}) and considerable errors can result. Typical lead resistances commonly range from 0.01Ω - 1Ω making accurate 2-wire measurements below 10Ω difficult to obtain.

The 4-Wire Kelvin Connection

Due to the limitations of the 2-wire method, the 4-wire (Kelvin) connection is implemented in most milliohmmeters. With a 4-wire configuration, one set of leads drives the current (or voltage) and the second set of leads senses the voltage (or current). Figure 2 illustrates the 4-wire connection to DUT. In the 4-wire configuration, the test current (I_{TEST}) is forced through the DUT (R_{DUT}) through one set of leads, while the voltage across the DUT (V_{DUT}) is measured by a second set of leads. Although some small current may flow through the voltage leads it is usually small enough to be ignored. Since the voltage drop across the voltmeter leads is negligible, the voltage across the meter can be considered the voltage across the DUT. In essence the resistance of the DUT (R_{DUT}) can be measured more accurately with the 4-wire method. The voltage sensing leads should be connected as close as possible to the DUT to avoid including the effects of the voltage drop across the test leads in the final measurement.

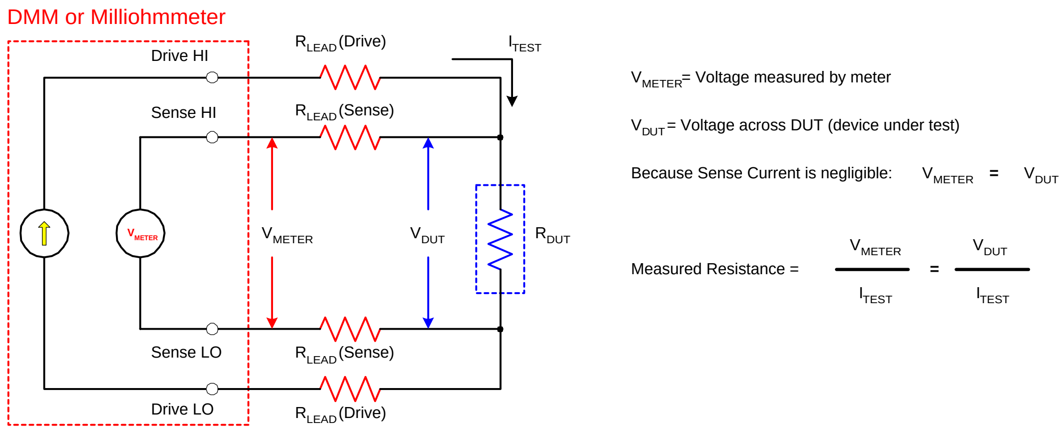


Figure 2: 4-Wire Connection to DUT

The Thermal EMF Factor

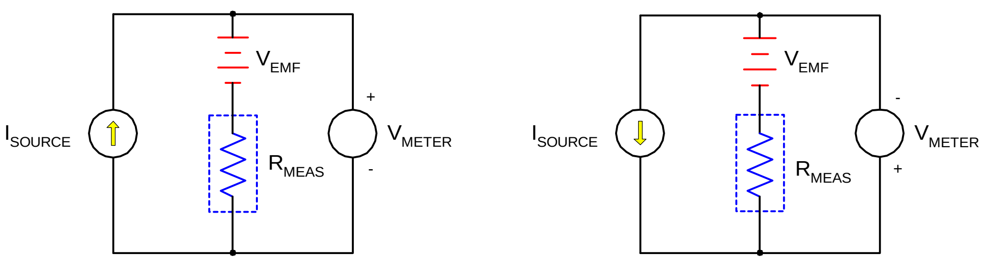
Thermal EMFs are small voltages developed at the junctions of dissimilar metals. The magnitude of thermal EMF depends on both the type of metal used and the temperature difference between the junctions. Since low resistance measurements are dependent on the test instrument's ability to measure very low voltage levels, thermal EMF can significantly contribute to low resistance measurement error.

External to the DUT, each connection or connector in a test setup is a possible thermal EMF source. These include connections between the DUT and the input cables; connections within the input cables and connections between the input cable and the instrument's input connector. Even connections internal to the instrument can cause thermal EMF. Thermal EMF sources external to the DUT can be canceled out by the zeroing function of most of today's instrumentation, like the QuadTech LR2000 Milliohmmeter.

Getting Rid of the Heat

Simple instrument zeroing will not compensate for the thermal EMF sources associated with connections within the DUT or in other connections beyond the instruments input terminals (the point at which zeroing is performed). Suggested techniques for minimizing thermal EMF include using only clean crimped-on similar metal (copper to copper) connections and keeping all junctions at the same temperature. This is not practical in all test applications so there are two common methods that are used in many milliohmmeters to circumvent this problem. The two methods are Current Reversal and Offset-Compensated Ohms.

Using the Current Reversal method, thermal EMF is canceled by making two measurements with currents of opposite polarity. The positive current ($+I_{SOURCE}$) is applied and the voltage is measured (V_{METER+}). A negative current ($-I_{SOURCE}$) is applied and the voltage is measured a second time (V_{METER-}). The two measurements are then combined to cancel any effect of thermal EMF. Refer to Figure 3 for equations. The measured resistance is then computed using Ohm's Law as $R_{MEAS} = V_{SOURCE}/I_{SOURCE}$. Figure 3 illustrates the Current Reversal method.



V_{METER} = Meter Voltage

V_{EMF} = Thermal EMF

I_{SOURCE} = Source Current

R_{MEAS} = Measured Resistance

$$V_{METER+} = V_{EMF} + (I_{SOURCE})(R_{MEAS})$$

$$V_{METER-} = V_{EMF} - (I_{SOURCE})(R_{MEAS})$$

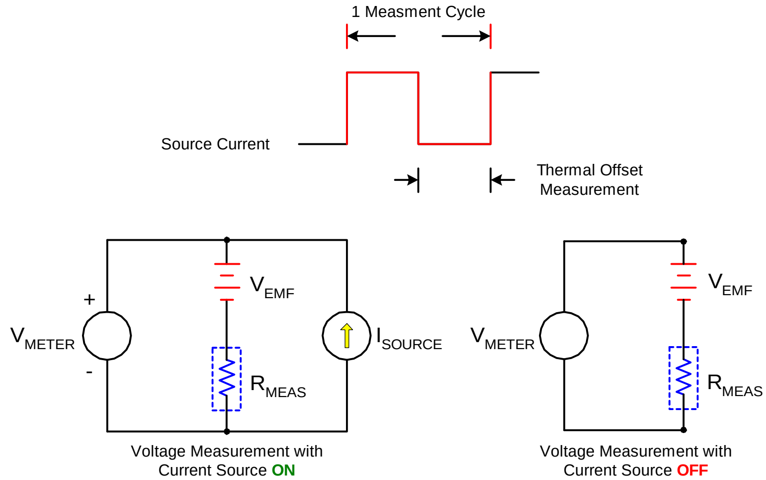
$$V_{METER} = \frac{[V_{METER+}] - [V_{METER-}]}{2} = \frac{[V_{EMF} + (I_{SOURCE})(R_{MEAS})] - [V_{EMF} - (I_{SOURCE})(R_{MEAS})]}{2}$$

$$V_{METER} = (I_{SOURCE})(R_{MEAS})$$

Figure 3: Current Reversal Method

Offset-Compensated Ohms

The Offset-Compensated Ohm method for minimizing thermal EMF applies the source current (I_{SOURCE}) to the resistance being measured (R_{MEAS}) only during one part of the test cycle. When the source is ON, the total voltage measured ($V_{METER\ 1}$) includes the resistor as well as any thermal EMF as illustrated in Figure 4.



V_{METER} = Meter Voltage

V_{EMF} = Thermal EMF

I_{SOURCE} = Source Current

R_{MEAS} = Measured Resistance

$$V_{METER\ 1} = V_{EMF} + (I_{SOURCE})\ (R_{MEAS})$$

$$V_{METER\ 2} = V_{EMF}$$

$$V_{METER} = [V_{METER\ 1}] - [V_{METER\ 2}]$$

$$V_{METER} = [V_{EMF} + (I_{SOURCE})\ (R_{MEAS})] - [V_{EMF}]$$

$$V_{METER} = (I_{SOURCE})\ (R_{MEAS})$$

Figure 4: Offset-Compensated Ohms Method

The second voltage measurement ($V_{METER\ 2}$) is made with the Current Source OFF. The two voltage measurements are then combined to determine the voltage measurement for the full test cycle. This voltage is termed the offset-compensated voltage.

What's a DUT got to do with it?

Thermistors

Device heating may be a source for error in making low resistance measurements on temperature sensitive devices like thermistors. Due to the high test current being supplied by the milliohmmeter, the power dissipated by the DUT can cause heat spikes large enough to alter the DUT's resistance. Although the test current is not adjustable in most milliohmmeters there is a way of addressing the problem of DUT heating. A triggered measurement mode in which a single momentary current pulse is applied to the DUT during the measurement cycle to reduce errors caused device heating.

Inductors

Although pulsing the test current provides the benefits of compensating for thermal EMF and minimizing device heating, current pulsing may cause errors in testing inductive devices. The inductance of the DUT may prevent the current through the device from reaching its maximum value before the voltage measurement is made. This phenomenon is due to the L/R time constant being larger than the current pulse width. When this is the case the current never reaches its maximum value and the measured voltage is too low which results in an erroneous resistance measurement. The solution is to use 'straight', non-pulsed DC test current when testing an inductive device. Take into consideration the previous discussion that such test currents could produce device heating depending upon the DUT.

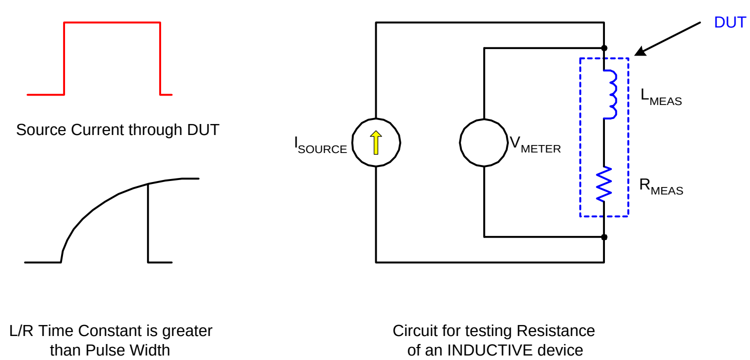


Figure 5: Inductive DUT

The QuadTech LR2000 Milliohmmeter is an excellent solution for most inductive device measurement applications.

Dry Circuit Testing

Many low resistance measurements are made on contacts of devices such as switches and relays. This test can determine if oxidation has increased the resistance of these contacts. If the voltage across the contacts is too high the oxidation layer will be punctured and the validity of the test is then compromised. To avoid oxidation puncture these measurements are usually made using 'dry circuit' testing. The open circuit voltage across the instrument's test leads is held constant (clamped) at 20mV or less. The LR2000 Milliohmmeter features dry circuit mode for this purpose.

Determining Temperature Rise of Motors and Transformers

The determination of the temperature rise in motors and transformers due to self-heating is a very common measurement. Motors, transformers, solenoids and coils all exhibit symptoms of heat rise during use. The internal power losses of the device result in heating which increases the operating temperature of the unit. In most cases it is impractical to measure the temperature with thermocouples or other temperature sensors, hence the change in resistance method for temperature determination.

The majority of magnetic devices use either copper or aluminum wire in the construction of their core. These wires have precise temperature coefficients (TC) which can be used with resistance measurements to calculate the temperature rise (ΔT) of the device under test (DUT). The change in temperature is equal to the resistance of the DUT before use (R_{COLD}) minus the resistance of the DUT during use (R_{HOT}) divided by the temperature coefficient times R_{COLD}.

$$\Delta T = \frac{R_{HOT} - R_{COLD}}{R_{COLD}\ (TC)}$$

Let's look at the calculation of temperature rise for a motor after 8 hours of operation at a specified rated load. The field winding of the motor is constructed of copper wire. Copper wire has a temperature coefficient of 3931ppm/°C (ΔR = 0.3931%/°C). Before running at a load the ambient winding resistance is measured as 1.2367Ω. After 8 hours of operation at full load, the winding resistance is measured as 1.6211Ω. Therefore the computation of the temperature rise is:

$$\Delta T = \frac{1.6211\Omega - 1.2367\Omega}{1.2367\Omega\ (0.003931)} = 78.45°C$$

Ambient temperature changes could have significant impacts on the test results. Some milliohmmeters have a temperature sensing function to measure the ambient temperature or capability for entering this data. The test results and temperature conditions are then automatically referenced to nominal ambient temperature (23°C). QuadTech has created a Visual Basic application wizard for the LR 2000 Milliohmmeter that calculates temperature compensation. Just enter the temperature and select your material (or enter your coefficient) and both resistance values are displayed and logged with a click on the [TRIGGER] button.

QuadTech Model LR2000 Milliohmmeter

Figure 6 illustrates the QuadTech Model LR2000 Milliohmmeter. A compact, portable user-friendly unit designed for highly accurate low resistance measurements on switches, relays, connectors and cables. The LR2000 unit provides eight automatic or manually selectable measurement ranges from 20mΩ to 2MΩ with constant current ranging from 1A to 1µA. For remote operation and production applications, the LR2000 comes standard with an RS232 interface and has an optional IEEE-488/Handler interface.

In addition, the LR2000 instrument has comparator, binning and remote functions making it ideal for Go/NoGo testing. The LR2000 unit provides 4-Terminal Kelvin connection to the DUT making accurate low resistance measurements down to 1µΩ possible. Combine that with the automatic zeroing feature and you have a highly accurate milliohmmeter in one neat little package.

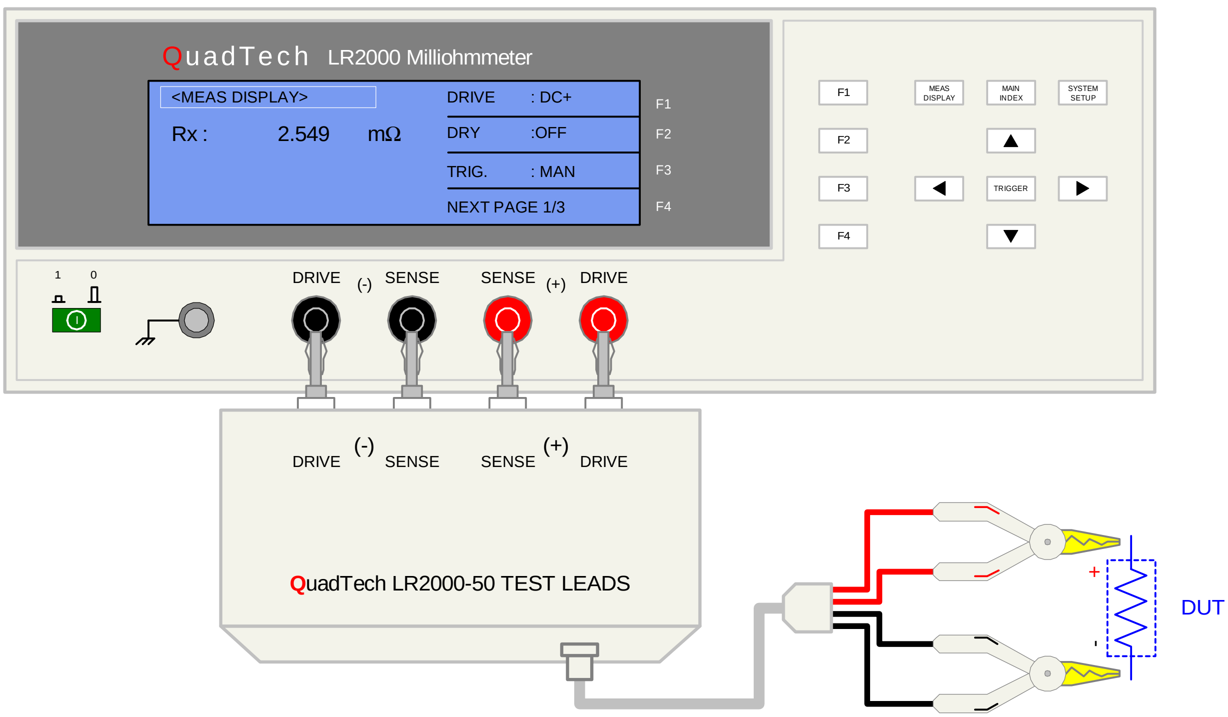


Figure 6: LR2000 Milliohmmeter

For complete product specifications on the LR2000 Milliohmmeter or any of QuadTech's products, visit us at http://www.quadtech.com/products. Call us at 1-800-253-1230 or email your questions to info@quadtech.com.

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