Low Resistance Measurement Guide

Test & Measurement Solutions

Preface

The intent of this reference guide is to define low resistance, its measurement methods and the common sources of error inherent in measuring such a small quantity. This guide provides a general overview of electrical resistance including mathematical equations, connection methods to the device under test and methods used by measuring instruments to accurately characterize resistance. Temperature compensation, conductors and milliohmmeter applications are also discussed.

Low Resistance Measurement Guide
1st Edition, June 2005
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Terms and Definitions

Resistance	the opposition to the flow of current characteristic of a medium, substance or circuit element.
Low Resistance:	Electrical resistance typically below 10 ohms, often expressed in terms of milliohms (10^{-3}) or micro-ohms (10^{-6}).
Bonding Resistance:	Electrical resistance across weld joints, crimped connections and bolted joints.
Contact Resistance:	Measured resistance of closed contacts, typically that of switches, relays and connectors.
Dry Contact Resistance:	Resistance across closed contacts is usually decreased, with applied voltage, due to attraction of molecules on the surface of contacts. By limiting the test voltage and current, electrical changes to the contacts are minimized.
Winding Resistance:	Electrical resistance of windings which comprise motors, coils, transformers, relays and ballasts.
Resistivity:	the electrical resistance of a material to the flow of current times the cross-sectional area of current flow and per unit length of current path. It is also known as 'specific resistance'.
Conductivity:	the ratio of electric current density to the electric field in a material. Conductivity is also known as 'specific conductance' and is the reciprocal of resistivity.
Current:	the flow of electric charge per unit time.
Constant Current:	Current that the measuring instrument will output during a resistance test, independent of device loading.
Current Polarity:	Test signal type: positive or negative DC, or positive or negative pulse. Helps reduce thermal emf effects.
emf:	Electromotive force: the difference in electric potential that exists between two dissimilar electrodes immersed in the same electrolyte or otherwise connected by ionic conductors.
Thermal emf:	the voltage generated by connecting two dissimilar metals, at different temperatures, together.
Temperature Compensation:	Measurements corrected from an ambient temperature back to a reference temperature (usually 20 degrees C)
Four Wire Kelvin Connection:	A four-terminal connection: one pair of terminals to apply current to a device and another pair to measure voltage across the device.
Zero Offset:	A correction for residual resistance resulting for the test leads and connection. Determined by a SHORT routine with the Kelvin lead test points shorted together.
Basic Measurement Accuracy:	the accuracy of most measurements in %, except the extreme low or high measurement range values.

Terms and Definitions

Table 1: Mathematical Prefixes

Multiple	Scientific	Prefix	Symbol
1000000000000000	10^{15}	Peta	P
1000000000000	10^{12}	Tera	T
1000000000	10^{9}	Giga	G
1000000	10^{6}	Mega	M
1000	10^{3}	Kilo	k
1	10^{0}	--	--
.001	10^{-3}	milli	m
.000001	10^{-6}	micro	μ
.000000001	10^{-9}	nano	n
.000000000001	10^{-12}	pico	p
.000000000000001	10^{-15}	femto	f

Table 1 lists mathematical prefixes used in quantifying electrical measurements. For low resistance measurements, the most common units are ohms (Ω), milli-ohms (mΩ) and micro-ohms (μΩ).

Note: The symbol for Kilo-ohms (kΩ) is a lower case k. An upper case K is the symbol for degrees Kelvin.

Refer to the GLOSSARY for a full set of electrical terms and definitions.

Resistance

Properties

Electrical resistance is a property of any material that opposes the flow of current. Resistance has units of ohms, with the Greek letter omega (Ω) being the standard symbol. Resistance cannot be directly measured. Instead, voltage and current are measured and the resistance calculated using Ohm's Law. Ohm's Law, after German physicist George Simon Ohm, is the algebraic relationship between voltage, current and resistance shown in Equation 1.

$$R = \left[\frac{V}{I}\right]$$

R = Resistance in ohms

V = Voltage in volts

I = Current in amperes

Equation 1: Ohm's Law

Depending upon the application of the material, the material is typically defined as a conductor or insulator. Materials designed to maximize opposition to current flow, thus having high resistance being classified as insulators. Materials such as glass, mylar and mica are examples of insulators. Materials designed to have a low resistance and thus minimizing opposition to current flow being classified as conductors. Materials such as copper, gold and steel are examples of conductors.

Measurement

The measurement of low resistance is accomplished using a signal source, a voltmeter, a current meter and Ohm's Law. The DUT is placed across the signal source and the voltage and current are measured. Figure 1 illustrates this basic circuit.

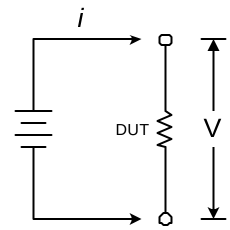


Figure 1: Signal Source

Most low resistance meters utilize a constant current source and a voltmeter circuit to measure the voltage across the DUT. The use of a constant current source simplifies the circuitry required to perform the measurement. Rather than having a signal generator and two measurement circuits one for current measurement and the other for voltage measurement. The use of a constant current means the current is a known and only the voltage has to be measured. This eliminates one entire measurement circuit. The resistance is then calculated by dividing the measured resistance by the constant current value. Refer to Figure 2.

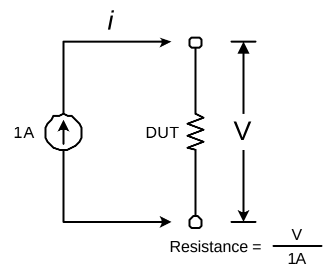


Figure 2: Constant Current Source

Instruments for the measurement of low resistance typically use two different connection methods. The 2-wire and 4-wire connection methods are both used for low resistance measurements. The resistance value being measured and the required accuracy dictate which method is used.

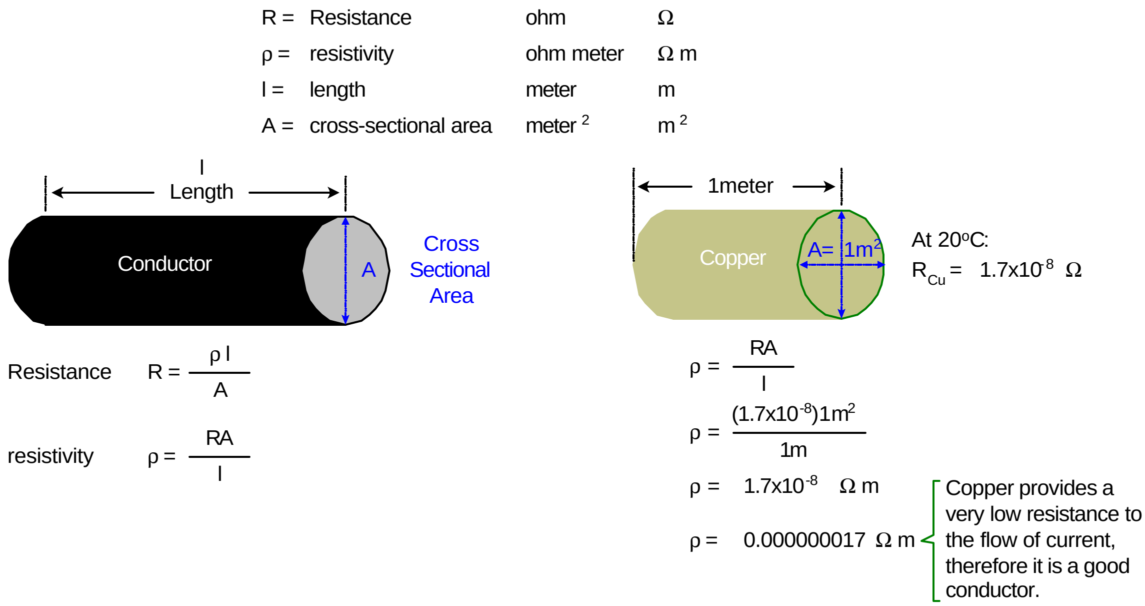


Figure 3: Copper Characteristics

Conductors

Prior to discussing the design characteristics and error sources inherent with milliohm measurements, a review of conductor resistance characteristics is beneficial. The material under test has unique resistance properties that may determine what method is used to measure it. Review for a moment the properties of a conductor as shown in Figure 3.

Conductive materials have one or two loosely bound electrons in the outer shell that can move easily when a voltage is applied and thus form a current. A material with a bulk resistivity between 10^{-6} and 10^{-4} ohm-cm is considered a decent conductor. Pure or elemental metals such as silver, copper, gold and aluminum are good conductors. When an impurity is added to a metal it increases the resistivity. Alloys which are combinations of metals have a higher resistivity than the metals they are made from. For example, at room temperature, nickel (Ni) has a resistivity of approximately 6.84×10^{-8} Ω-m. Nichrome, made of 80% nickel and 20% chromium ($Ni_{80}Cr_{20}$), has a resistivity of approximately 100×10^{-8} Ω-m.

Temperature Dependence

Notice the clarifier 'at room temperature'. For a conductive material, when the temperature of the material increases so does its resistivity. The resistivity of a typical metal increases linearly with a temperature increase. The resistivity of a typical semiconductor (silicon) decreases exponentially with a temperature increase. The resistivity of an insulator (glass, quartz, sulfur) decreases at an even greater rate with a temperature increase. All materials do not conduct electricity equally. For more information on temperature refer to the Temperature Compensation section.

Length and Cross-sectional Area

Two other factors affect the resistivity measurement: length and cross-sectional area. If one had two copper wires each 1-meter in length, one with a thickness of 0.45mm and the other 0.28mm, which would have the greater resistivity? The thickness of wire inversely affects resistivity which translates the thinner wire would have the greater resistivity. The thicker wire offers less resistance because its larger cross-section permits more electrons to

Table 2: Resistivity of Common Conductors

Resistivity at room temperature: 20°C, 300K, 68°F

Material	Symbol	Resistivity $\mu\Omega$-cm	Conductivity per Ω-m	Temperature Coefficient per °C
Element Metal				
aluminum	Al	2.65	3.77×10^7	0.0042
copper	Cu	1.67	5.95×10^7	0.0040
gold	Au	2.21	4.55×10^7	0.0037
iron	Fe	9.66	1.03×10^7	0.0056
lead	Pb	20.65	0.43×10^7	0.0042
magnesium	Mg	4.3	2.33×10^7	
manganese	Mn	144	0.072×10^7	
nickel	Ni	6.93	1.43×10^7	0.0058
platinum	Pt	10.5	0.96×10^7	0.0037
silver	Ag	1.59	6.29×10^7	0.0038
tantalum	Ta	13.1	0.76×10^7	
titanium	Ti	42	0.24×10^7	
tungsten	W	5.28	1.89×10^7	0.0044
zinc	Zn	5.92	1.69×10^7	0.0038
Alloy Metal				
nichrome	$Ni_{80}Cr_{20}$	110	0.095×10^7	0.00017
manganin*	CuMnNi	48.21	0.207×10^7	± 0.000015
steel**	FeC	16.62	0.502×10^7	0.003
Semiconductors				
carbon (graphite)	C	3500	2.9×10^4	-0.0005
germanium (pure)	Ge	46000	2.2	-0.048
silicon (pure)	Si	64000000	0.0016	-0.075

* Manganin composed of 83% copper, 13% manganese and 4% nickel

** Steel composed of 99.5% iron and 0.5% carbon

Note: Tables 2 & 7 contain data from different sources and thus have different values for Resistivity and Temp Coefficient. Refer to Appendix A for Tables and Sources.

interact with the electric field. Since there is more current than voltage, the resistance will be lower. Translated another way, if the area/cross-section of a wire is doubled, its resistance is cut in half.

As for the relationship of the length of a wire to its resistance: double the length of a wire and you double its resistance. Again, having two copper wires 1-meter in length each with its own specific resistance. If the two wires of equal resistance are put together, two equal resistances in series will add.

Conductor Size: AWG

In the United States, AWG or American Wire Gage is the standard designation for conductor size. AWG is based on two reference diameters: 0.4600 inches (4/0 AWG) and 0.5000 inches (36 AWG). Wire diameter decreases with increasing gauge number. If the gauge is increased by 6 AWG, then the diameter decreases by a factor of 2. Example: 30AWG wire has a diameter equal to 10mils. Add 6 gauge and a 36 AWG wire has a diameter equal to 5mils. Table 3 illustrates the general rule of thumb for the gauge and diameter relationship. Equation 2 defines the mathematical relationship between AWG number and wire diameter.

Table 3:
Relationship of Gauge to Diameter for Solid Wire

When the GAUGE increases by:	Then the DIAMETER decreases by factor of:
6	2
10	3
12	4
14	5
20	10
40	100

$$AWG: = 36 - \left[\frac{39 \times \left[\log (200D)\right]}{\log (92)} \right]$$

$$D = 0.005 \left[92^{\left[\frac{36 - AWG}{39}\right]} \right]$$

D = Diameter in inches

Equation 2: Relationship of AWG and D

AWG and Resistivity

Turning attention back to the discussion of conductor resistivity, the information herein is based on solid copper wire. Solid wire is often referred to as single end. Recall the resistivity of copper at 20°C is 1.724×10^{-8} ohm-meters.

Table 4: Solid Wire: AWG & Resistivity

AWG Size (Solid Wire)	Diameter (mm)	Diameter (inches)	Resistance Ω/1000feet	Resistance Ω/1000meters
0000 (4/0)	11.684	0.4600	0.049	0.1607
000 (3/0)	10.404	0.4096	0.0618	0.2027
00 (2/0)	9.266	0.3648	0.078	0.2555
0 (1/0)	8.252	0.3249	0.0983	0.3224
1	7.348	0.2893	0.124	0.4063
5	4.621	0.1819	0.3133	1.0276
10	2.588	0.1019	0.9989	3.28
12	2.052	0.0808	1.588	5.21
14	1.6256	0.0640	2.525	8.28
16	1.2903	0.0508	4.016	13.2
18	1.0236	0.0403	6.385	20.9
20	0.8128	0.0320	10.15	33.2
22	0.6451	0.0254	16.14	52.7
24	0.5105	0.0201	25.67	84.2
30	0.2540	0.0100	103.2	338.496
36	0.1270	0.0050	414.8	1360
40	0.0787	0.0031	1049	3440

Stranded Wire:

The size of stranded wire is determined using the equivalent cross-sectional area of the bundle. Stranded wire is a bundle of small-gauge wires wrapped in a single layer of insulation. Stranded wire has a larger cross section than solid wire and less resistance. (Figure 4)

Summary

All wires (conductors) are not created equal. A wire's resistivity is affected by the material(s) that it is made of, its thickness (cross-sectional area), its length and the temperature in which it is used. Wires are made of metal for their charge carrying capability. Yet heat metal and its molecular structure changes causing conductivity to decrease and resistivity to increase. Double the thickness of a wire and cut its resistance in half. Double the length of a wire and its resistance doubles. Choose the conductor material based on its end-use: copper has a resistivity of 1.72μΩ-cm which is good for low resistance applications; nichrome has a resistivity of 110μΩ-cm making it a good choice for high temperature applications like heat sensors.

Note:

Circular Mils is often used to describe conductor size.

Circular Mils = the square of the diameter of the wire in mils: $CM = (d(mil))^2$. 1 mil = .001 inch.

Copper Wire:	Single	7 Strand	19 Strand
#Strands/AWG:	1/30	7/38	19/42
AWG:	30	30	30
Nominal Diameter:	0.0100 inches	0.0114 inches	0.0123 inches
	0.254 mm	0.290 mm	0.312 mm
Resistance:	347.2 Ω/km	324.8 Ω/km	324.8 Ω/km

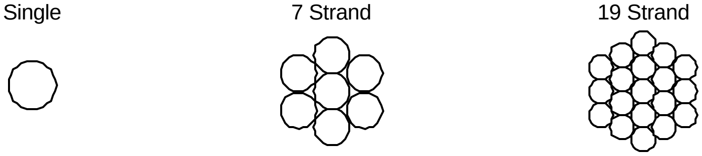


Figure 4: Stranded Wire

* Nominal Diameter (for reference only) and Resistance values from http://www.fiskalloy.com.

Milliohmmeter Design Characteristics

The 2-Wire Measurement

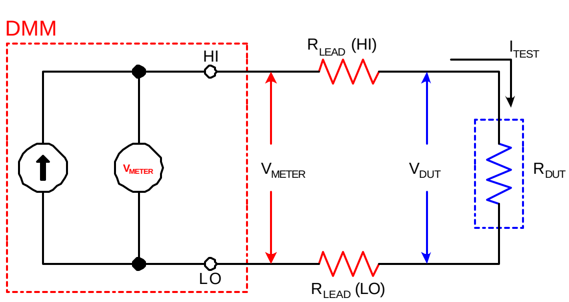
Most of today's digital multi-meters (DMM) and some dedicated resistance measurement instruments utilize a 2-wire test method. The 2-wire method is the simplest and most economical arrangement. As the name implies two wires are used to connect between the meter and the DUT. In the 2-wire method, the 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 calculated using Ohm's Law. Figure 5 illustrates the 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.

It is possible to zero out leads to improve 2-wire measurements. During a zero the test leads are shorted together and a measurement is performed. The measured value is the offset resistance and is subtracted from all future measurements. The use of offset works fine as long at the offset resistance is a constant.

If the offset resistance changes significantly in comparison with the resistance to be measured; due to contact resistance between leads and DUT, changing of lead length, or use of relays, then the offset cannot be used for accurate measurements. One way of determining if offset can be used, is to perform an offset then open and short the test leads. A measurement is then performed. Ideally with that previous offset performed, the measured value should be zero. It will never be exactly zero as the contact resistance will have changed. If the amount of change is small in comparison to the resistance being measured then a 2-wire measurement with offset can be used.

One example where the 2-wire method even with offset is not ideal for low resistance measurements is when relays are used to switch between multiple test points. This is due to each relay having a static contact resistance that is different from relay to relay as well as contact resistance stability that is the change of contact resistance over successive closures of the same relay.



V_{METER} = Voltage measured by meter

V_{DUT} = Voltage across DUT (device under test)

$$\text{Measured Resistance} = \frac{V_{METER}}{I_{TEST}} = R_{DUT} + (2 \times R_{LEAD})$$

$$\text{Actual Resistance} = \frac{V_{DUT}}{I_{TEST}} = R_{DUT}$$

Figure 5: 2-Wire Connection to DUT

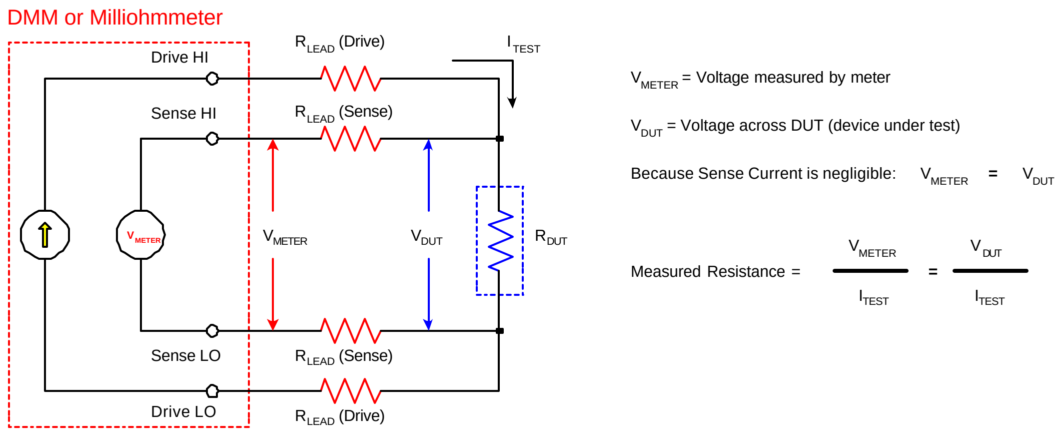


Figure 6: 4-Wire Connection to DUT

The 4-Wire Measurement

Due to the limitations of the 2-wire method, the 4-wire (Kelvin) connection is implemented in most milliohmmeters. In this connection 4 wires are connected between the meter and the DUT. One set of leads drives the current and the second set of leads senses the voltage across the DUT. Figure 6 illustrates a typical 4-wire connection to DUT. In this configuration, the test current (I_{TEST}) is forced through the DUT (R_{DUT}) through one set of leads called drive, while the voltage across the DUT (V_{DUT}) is measured by a second set of leads called sense.

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

The 4-wire method minimizes errors due to contact resistance of the leads to the DUT, changing lead lengths and use of relays. The 4-wire method is more expensive and complicated to implement. Care also has to be taken to make the Kelvin connection as close as possible to the DUT. The use of a 4-wire connection is ideal for use with relays because contact resistance does not effect the measurement. The drawback is that four relays are required for each DUT making switching expensive and complicated.

Figure 7 illustrates a typical milliohmmeter. The milliohmmeter has 2 black (Drive-, Sense-) and 2 red (Sense+, Drive+) connectors creating a 4 terminal Kelvin connection.

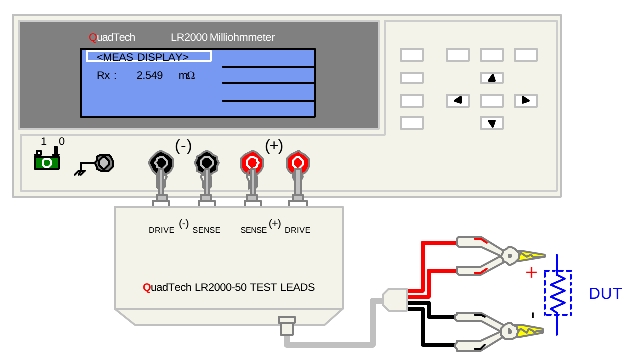


Figure 7: 4-Terminal Milliohmmeter

AC vs. DC Resistance Measurements

Resistance can be measured using an AC or a DC signal. The AC resistance, at low frequencies, is almost identical to the DC resistance (DCR). Resistance does increases as frequency increases due to additional losses within the material so at higher frequencies the AC resistance will be higher than DC resistance.

AC Milliohmmeters

AC milliohmmeters typically measure resistance at a frequency of 1kHz and are ideal for applications such as measuring internal battery resistance. There is not a lot of difference between an AC milliohmmeter and an LCR meter with the exception that AC milliohmmeters typically have higher drive currents up to 10mA. The higher drive currents help in making more accurate low resistance measurements down to 10µΩ. Some AC milliohmmeters can measure inductance, phase and other impedance parameters besides resistance.

LCR Meters

LCR meters are similar to an AC Milliohmmeter except they are not dedicated to measuring just AC resistance. LCR meters are designed to measure inductance, capacitance and resistance. Most LCR meters have a wide measurement range for resistance from a few milliohms to several megohms, programmable test frequency and programmable test signal level. LCR meters are ideal for measurement of battery impedance and resistance, equivalent series resistance of capacitors, and resistance and impedance characteristics of materials and components.

Figure 8: Example LCR Meter

Ground Bond Testers

Another type of an AC resistance-measuring instrument is the ground bond tester. A ground bond tester is similar to an AC milliohmmeter in design, consisting of a constant current source and voltmeter circuit. The big difference is the amount of current used during testing and a very limited range of resistance measurement. Test currents are typically from 3A to 45A with a measurement range from 1mΩ to 0.5Ω. Ground bond testers are designed to test the integrity of protective grounding conductor within an electrical product with a 3-prong power cord.

Figure 9: Ground Bond Tester

DC Milliohmmeters

Most milliohmmeters use a DC signal instead of an AC signal. DC milliohmmeters feature a wide measurement range from 1µΩ to 2MΩ. Most milliohmmeters have different current levels depending upon the resistance to be measured that range from 1uA to 1A with some instruments going as high as 10A.

Figure 10: Example Milliohmmeter

As discussed earlier in this guide a milliohmmeter must output a constant current, measure the voltage across the DUT and use Ohm's Law to calculate the resistance. When designing a milliohmmeter the designer wants to have the measured voltage across the DUT at a reasonable level to reduce errors due to noise, minimize the complexity of the measurement circuitry and make the instrument as safe as possible to use. Typically most milliohmmeters have a maximum measurement voltage of 4.5 volts and a maximum current level of 1A. There are milliohmmeters that do utilize higher current levels of up to 100A or more.

DC Sources

There are a number of different types of DC signals used for measurement. Some of the different types used in the LR2000 are shown in Figure 11. It is important to select the appropriate type of DC signal depending upon the DUT being measured.

The PULSE± mode is a positive/negative square wave that switches the source signal from +2V to 0V to -2V to 0V. This mode has the advantage that errors due to thermal emf are cancelled out due to polarity switching and a reduced duty cycle can limit heating of the DUT. Thermal emf errors are discussed later in this guide.

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 resulting in an over estimation of the measured resistance. 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.

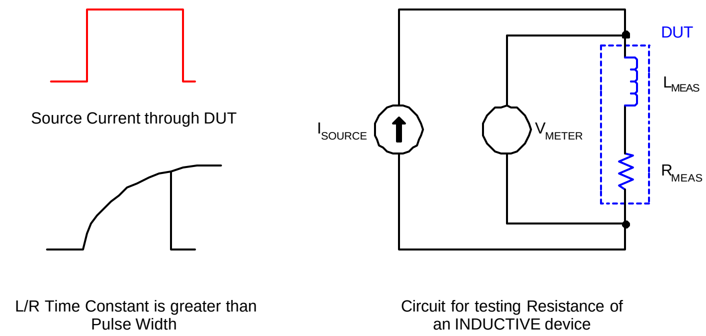


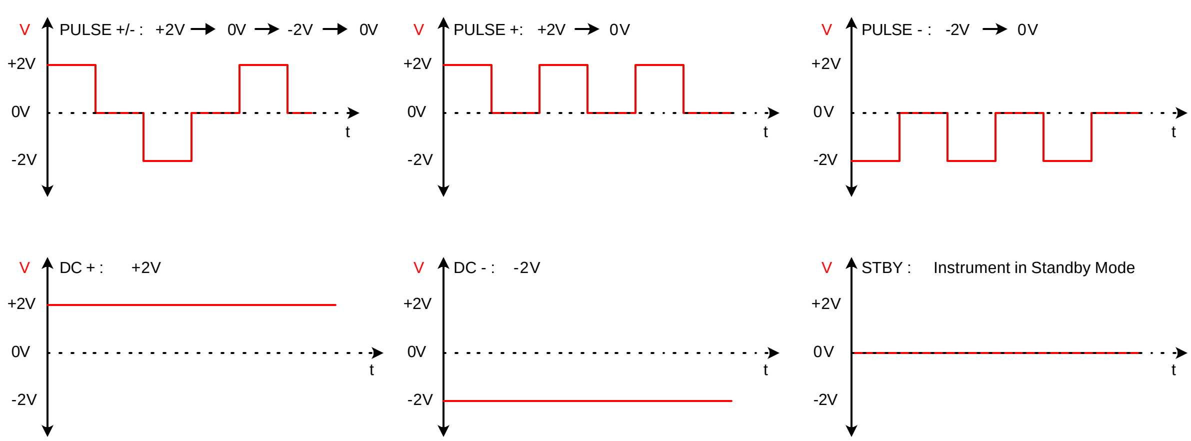
Figure 12: Inductive DUT

The PULSE+ mode is a positive square wave that switches the source signal for +2V to 0V. The PULSE- mode is a negative square wave that switches the source signal for -2V to 0V. These modes have the main advantage of a reduced duty cycle to minimize heating. As the square wave has only one polarity, errors due to thermal emf are not cancelled out.

The DC+ and DC- modes provide the source signal equal to +2V and -2V respectively. These modes are ideal for inductive devices.

The STBY mode puts the instrument in stand-by status with no signal being output to the DUT. This allows connection to the DUT without the worry of transients or dangerously high voltages being produced by cutting off the current to an inductive device.

Figure 11: DC Signal Types



Milliohm Measurement Parameters

When considering which milliohmmeter will best solve your test requirements, there are three important measurement parameters worth examining: accuracy, speed and ranging. Milliohm measurements can be made with instruments of all shapes and sizes yet measurement to the milli (10^{-3}) ohm requires accuracy and resolution below 10^{-3}.

Accuracy

Most quality milliohmmeters will state accuracy as having two parts: one being a % of reading and the second part as either a number of counts, least significant digits or a resistance value. The first part covers basic accuracy with the second part taking into account resolution and noise. The LR2000 Milliohmmeter accuracy is stated separately for each resistance range. For example, the 20mΩ range has an accuracy of ±[0.05% of reading+0.06mΩ]. This means that as the measured resistance value approaches 0.06mΩ the error approaches 100%.

The number of digits that are displayed determines the resolution of the instrument. A count is the least significant digit that can be displayed. For example if the accuracy specification is given as ±[0.05% of reading + 3counts] and the display resolution is 0.001mΩ, the accuracy specification then becomes ±[0.05% of reading + (3 * 0.001mΩ)] or ±[0.05% of reading + (0.003mΩ)].

Speed

Measurement speed is an important consideration when it comes to accuracy. Accuracy and speed are inversely proportional. That is the more accurate a measurement the more time it takes to perform the measurement. Milliohmmeters meters will generally have 3 measurement speeds (Fast, Moderate or Slow). The measurement speed can also be referred to as measurement time or integration time. Accuracy is always specified with the slowest measurement speed, generally 1 second per measurement.

Ranging

To maintain a balance between the maximum voltage and currents limits as well as make an accurate measurement, most milliohmmeters have several measurement ranges. Lower resistances ranges use higher currents and higher resistances ranges use lower current. For resistance ranges from 1µΩ to 2MΩ a milliohmmeter like the LR2000 uses currents from 1A to 1µA respectively. For example if when measuring a 2MΩ resistor a current source of 1µA might be used to keep the measured voltage to 2V. As the resistance is reduced the current would be increased at a similar rate so at 2kΩ a current source of 1mA would be used. At very low resistance values the voltage across the DUT even at current levels of 1A becomes very small, usually in the µV range. This typically results in noisy measurements and additional error. Errors in milliohmmeter measurements are discussed in the next section.

Range (Full-Scale)	Resolution	Accuracy	Test Current (Typical)
20mΩ	1µΩ	±(0.1% of rdg +.006mΩ)	1A
200mΩ	10µΩ	±(0.05% of rdg +.06mΩ)	100mA
2Ω	100µΩ	±(0.05% of rdg +.6mΩ)	10mA
20Ω	1mΩ	±(0.05% of rdg +6mΩ)	1mA
200Ω	10mΩ	±(0.05% of rdg +40mΩ)	1mA
2kΩ	100mΩ	±(0.05% of rdg +.2Ω)	1mA
20kΩ	1Ω	±(0.1% of rdg +2Ω)	100µA
200kΩ	10Ω	±(0.2% of rdg +20Ω)	10µA
2MΩ	100Ω	±(0.4% of rdg +200Ω)	1µA

Table 5: LR2000 Measurement Ranges

Error Sources in Milliohmmeters

There are a number of different sources of errors in low resistance measurements. Thermal emf (electro-motive force) and noise are common errors. Dry circuit and zero calibration errors also account for inaccuracies in low resistance measurements.

Noise

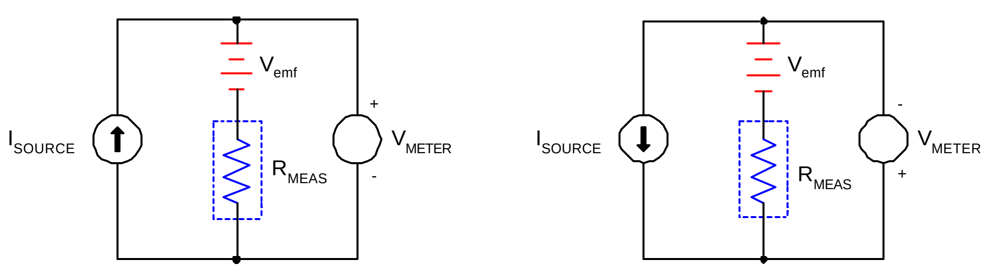
It is important to understand the different types of noise sources and techniques for minimize the noise effects. This goes for any type of low voltage measurement. Magnetic fields create noise in cables in two ways. Noise is created within test leads when the magnetic field changes with time or the test leads move within the magnetic field. The best way to prevent noise issues is to keep test leads short and eliminate motion in the leads. The leads should also be shielded.

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 instruments 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.

Simple instrument zeroing will not compensate for the thermal emf sources associated with connections within the DUT or in other connections beyond the instrument's 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.



V_{METER} = Meter Voltage

V_{emf} = Thermal emf

I_{SOURCE} = Source Current

R_{MEAS} = Measured Resistance

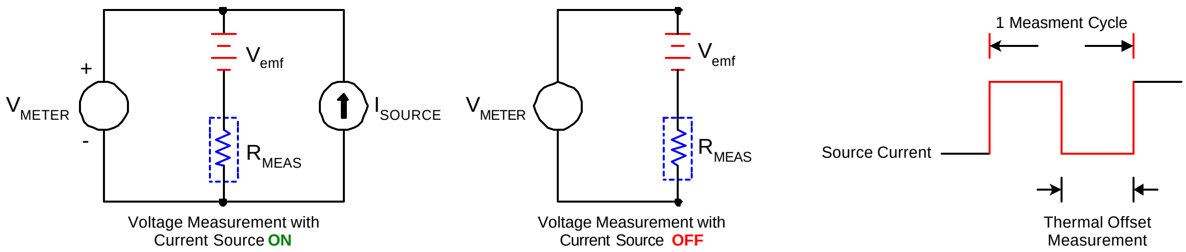
$$V_{METER+} = V_{emf} + (I_{SOURCE})(R_{MEAS})$$

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

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

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

Figure 13: Current Reversal Method



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 14: Offset-Compensated Ohms Method

Current Reversal

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_{MEAS}). A negative current ($-I_{SOURCE}$) is applied and the voltage is measured a second time (V_{MEAS}). The two measurements are then combined to cancel any effect of thermal emf. Refer to Figure 13 for equations. The measured resistance is then computed using Ohm's Law as $R_{MEAS}=V_{SOURCE}/I_{SOURCE}$. Figure 13 illustrates the 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 14.

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.

Dry Circuit Testing

Low resistance measurements are frequently made on the contacts of low current devices. Measuring contact resistance in accordance with ASTM B539 is common practice with switch and relay manufacturers. Contacts on these devices are made of tin, silver and gold and are not hermetically sealed. Over time, oxide can corrode these metal contacts. Surface contamination of the contacts can result in films (metalic oxides, sulfides and halides) building up. These films add series resistance on the order of a few milliohms to the contact resistance.

Using test voltages greater than 20mV can result in erroneous contact resistance measurements. This is due to the voltage beoing high enough to breakdown the oxide layer. Most milliohmmeters used for contact resistance measurements feature a dry circuit mode that limits the voltage to less than 20mV.

Offset/Zero Compensation

Most milliohmmeters have an electronic offset or zero compensation function. This allows the leads to be shorted together and a measurement to be performed. The measured resistance value is then subtracted from all future measurements.

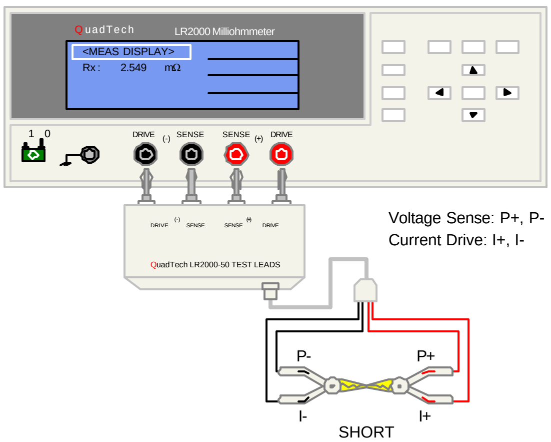


Figure 15: Offset/Zero Compensation

Even with a Kelvin connection there will still be a small residual resistance with the leads of the milliohmmeter shorted together. Offset is very useful in applications where it is not possible to maintain a 4 terminal Kelvin connection to the DUT. This could be due to the use of a switching matrix or just the fact that it is not practical to have 4 connections to the DUT.

It is important when performing a zero to have proper orientation of the Kelvin clips as shown in Figure 16. The drive and sense should be oriented in the same direction. This results in the sense connections having a close to zero volts as possible during the zero.

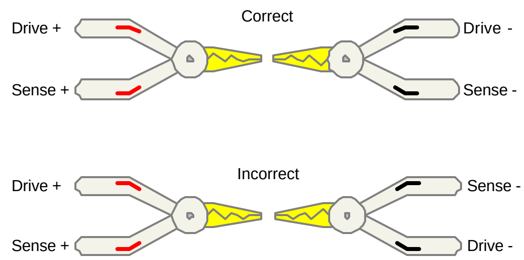


Figure 16: Orientation of Test Cables

Table 6: Common Sources of Error When Measuring Resistance

When Measuring:	Problem Encountered:	Potential Source:	Try This Method:
Low Resistance	Measured Value too HIGH	Lead Resistance	4-Wire Connection to DUT
	Measured Value out of spec	Thermal emf	Current Reversal or Offset Compensation
High Resistance	Noise	Charge in leads	Use Shielded Test Leads
	Measured Value too LOW	Shunt	Use Guarded Test Leads
	Measured Value out of spec	Offset Current	Adjust Offset Current or Suppress Offset Current using Zero Function

Temperature Compensation

Formula

When performing low ohm measurements, not only are the connections and zeroing of the meter important, the temperature of the DUT and even the ambient air can change the resistance reading. The resistivity of a metal conductor increases linearly with temperature as shown in Equation 3.

$$\rho = \rho o[1 + \alpha (T-To)]$$

ρ = measured resistance

ρo = resistance at reference temperature (20°C)

T = measured temperature

To = reference temperature

α = temperature coefficient of resistivity

Equation 3: Resistivity and Temperature

Conductor Resistance and Temperature

Using the data from Table 7, a plot can be made of resistance versus temperature to see how temperature can effect your milliohm measurement. Figure 17 shows the resistivity of both Copper and Nickel vs temperature. As shown in Figure 17 the resistance of Copper can change more than 3% over 10°C temperature change. This change could mean a part measured in the morning passes specification, but in the afternoon fails. This change must be accounted for when performing accurate low ohm measurements. There are milliohmmeters on the market that have internal temperature compensation capability. Typically these meters have one or two material coefficients and reference 20°C. This is useful if you are measuring copper, but if your material is Tungsten then this feature will not give you the data, which you may require. Computers have eased the burden of manual calculations, reduced human error and allow for flexibility in materials and temperature.

Table 7: Temperature Coefficients

Material	Resistivity (Ω*m) at 20°C	Temperature Coefficient α(°C)$^{-1}$
Silver	$1.59x10^{-8}$	$3.8x10^{-3}$
Copper	$1.7x10^{-8}$	$3.9x10^{-3}$
Gold	$2.44x10^{-8}$	$3.4x10^{-3}$
Aluminum	$2.82x10^{-8}$	$3.9x10^{-3}$
Tungsten	$5.6x10^{-8}$	$4.5x10^{-3}$
Iron	$10x10^{-8}$	$5.0x10^{-3}$
Platinum	$11x10^{-8}$	$3.92x10^{-3}$
Lead	$22x10^{-8}$	$3.9x10^{-3}$
Nichrome	$150x10^{-8}$	$0.4x10^{-3}$
Nickel	$8.7x10^{-8}$	$6.8x10^{-3}$
Carbon	$3.5x10^{-5}$	$-0.5x10^{-3}$
Germanium	0.46	$-48x10^{-3}$

Source: Physics for Scientists & Engineers, Raymond A. Serway, 3RD Edition, Volume II, 1990

Note:
Tables 2 & 7 contain data from different sources and thus have different values for Resistivity and Temp Coefficient. Refer to Appendix A.

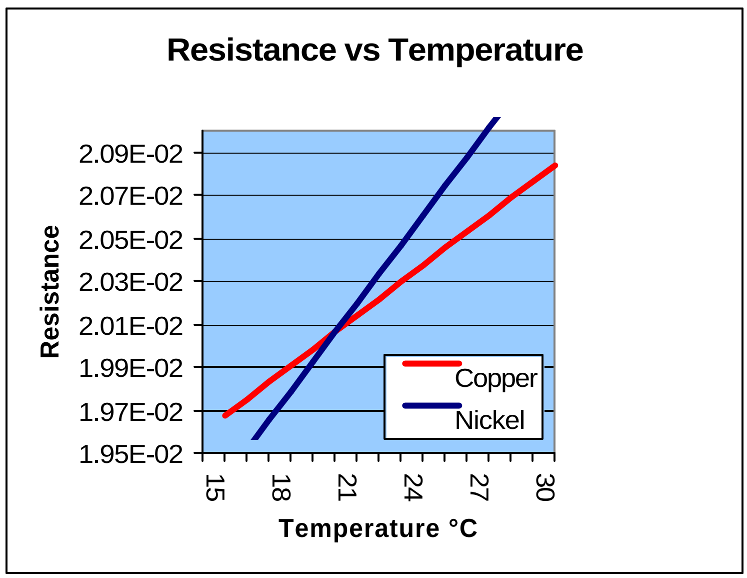


Figure 17: R vs. T for Copper & Nickel

The QuadTech LR2000 Wizard will calculate the resistance from its measured reading, the temperature and the coefficient, which is assigned by the user. The data is stored to a file where later the user can create his particular resistance vs. temperature chart.

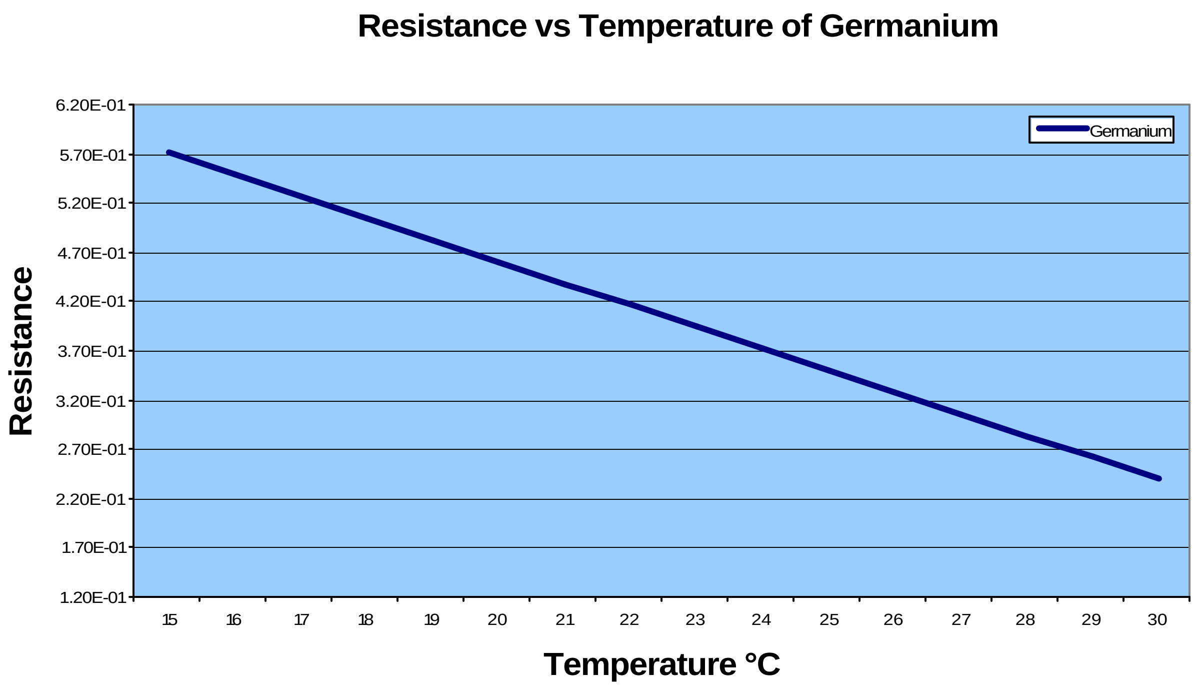


Figure 18: Germanium Resistance vs. Temperature

Semiconductors

It is worth noting that not all materials will increase in resistance with temperature as shown in Figure 18. The resistivity of semiconductor materials, such as Geranium, exhibit an exponential decrease in resistance as temperature increases. This characteristic allows us to consider a ceramic semiconductor as a Thermally Sensitive Resistor, more commonly known as a Thermistor. The resistance vs. temperature characteristic of a Thermistor forms a "scale" that allows it to function as a temperature sensor.

Superconductors

Superconductor materials have zero resistance at a given temperature known as a critical temperature (Tc). The critical temperatures for a few common substances are shown in Table 8. The resistance versus temperature for a superconductor resembles that of any typical metal as shown is Figure 17 for temperatures above Tc, once the temperature is at or below Tc the resistance drops to zero.

Material	Critical Temperature T_c (K)
Aluminum	1.20
Cadmium	0.56
Lead	7.2
Mercury	4.16
Niobium	8.70
Thorium	1.37
Tin	3.72
Titanium	0.39
Uranium	1.0
Zinc	0.91
Niobium/Tin	18.1
Cupric Sulphide	1.6

Table 8: Critical Temperature

Source: CRC Handbook of Chemistry and Physics, 78th Edition; Superconductivity data: Collier's Encyclopedia (Volume 21, 1968).

Note:

When using the Kelvin Temperature scale, the symbol is an uppercase K. There is no degree symbol used before the K.

Connection to a Milliohmmeter

Test Leads

Most milliohmmeters are delivered with a set of leads designed specifically for use with that instrument. It is important to use the correct leads or leads with similar characteristics to those specified by the manufacturer. Longer leads or leads that have higher resistance can limit the measurement range or output of the instrument. This is particularly important with high current milliohmmeters and ground bond testers. Put another way, the maximum drive current multiplied by the sum of drive lead resistance and the resistance to be measured should not exceed the clamping voltage of the instrument.

$$\left[I_{DRIVE\ MAX} \left[R_{DRIVE\ LEAD} + R_{MEAS} \right] \right] \leq V_{CLAMP}$$

Equation 4: Clamp Voltage

Accurate measurements using a 4 terminal Kelvin connection requires that the drive and sense leads come in contact with the DUT and not before. If the drive and sense leads come in contact with each other the voltage at the connection will cause an error in the measurement. Figure 19 illustrates an example of proper and improper connection to a DUT.

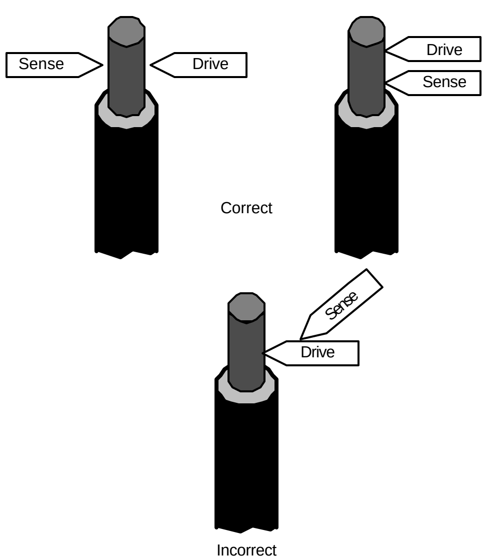


Figure 19: Drive and Sense Connection to DUT

It is possible to perform 2 terminal connections with a 4 terminal instrument. This would be adequate for measurements above 10 ohms. If a two terminal connection is to be made care in connection should still be made. The drive leads should be on the outside of the sense leads. Figure 20 illustrates a two terminal connection using banana plugs. The sense banana plugs would then be plugged into the DUT.

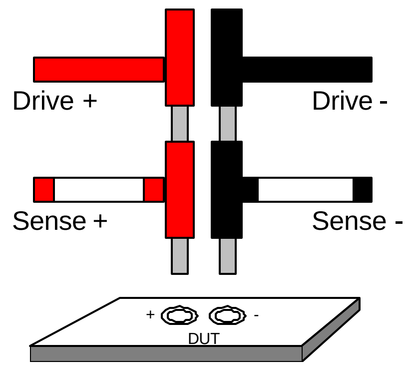


Figure 20: 2-Terminal Connection

Now that it has been established how important a 4-wire Kelvin connection is for low resistance measurements, let's consider connection techniques in more detail.

Kelvin Clip Leads

The Kelvin clip is the most common accessory used for these types of measurements. The 4-wire Kelvin clips are normally comprised of two identical clips, each of which has a current drive connection (one arm of the clip) and the other side the voltage sense connection. This is ideal for attaching to leaded devices or other relatively small contacts but in some applications other techniques must be employed.

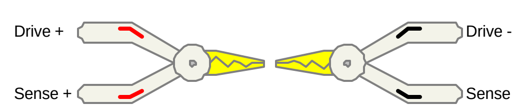


Figure 21: Kelvin Clip Lead Set

5940

6730

Figure 22: Example Kelvin Clip Leads
Source: Pomona Electronics
http://www.pomonaelectronics.com

There are a number of different types of commercially available Kelvin clips. Kelvin clips are available with different types of jaws and jaw widths. Pictured in Figure 22 are Pomona Kelvin Clips, Model Numbers 5940 and 6730.

Component Test Fixtures

For component sorting of low value resistors of axial lead construction a slotted test fixture is the most reliable means of connection. A four-terminal Kelvin fixture normally consists of four knife blades where one lead of the component under test is inserted between two blades for one connection and the other lead between two blades for the second connection. This type of fixture is convenient for an operator to install components, can be used some distance away from the instrument, while still maintaining the all important four terminal connection.

Figure 23: Slotted Test Fixture

Probe Lead Set

For access to surface mount devices, other small components, or contacts difficult to access, a set of Kelvin probe tips may prove to be the best solution. An example of such a probe set is the Pomona Model 6303 (www.pomonaelectronics.com). This lead set is terminated in double banana plugs but could be modified with other connections for compatibility with various measuring instruments.

Figure 24: Example Probe Lead Set

Source: Pomona Electronics
http://www.pomonaelectronics.com

Connection Techniques for Reducing Errors

Reliable Connections

Erratic noisy readings can be the result of improper connection to the device under test. An obvious example of this would be the failure of one of the connections of the 4-wire connections to the device under test. Generally the occurrence of this would cause unstable readings. Viewing the displayed value for several seconds is a method to make sure the measurement is stable.

Zeroing

For very low resistance measurements, the zeroing function of test leads of fixture is very important. During the zeroing function a residual correction of resistance is determined, stored, and applied to ongoing measurements. In the case of Kelvin clip leads (as illustrated in Figure 25) or other fixture types, the voltage sense connections (P+, P-) should be positioned adjacent to each other during the SHORT configuration. Likewise the current drive connections (I+, I-) should be positioned adjacent to each other.

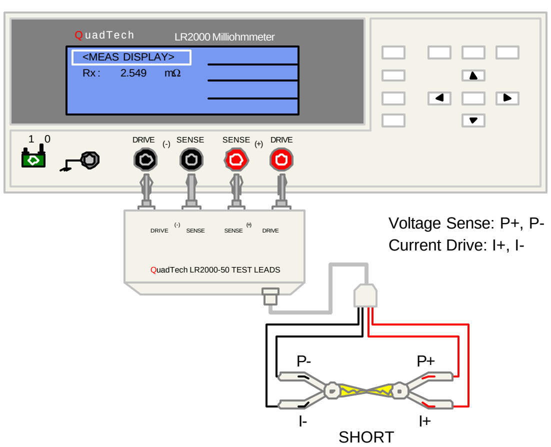


Figure 25: Kelvin Leads Zeroing Position

Proper 4-Terminal Positioning

When possible the four Kelvin connections should be configured to the device for maximum accuracy of the measurement, as seen in Figure 26.

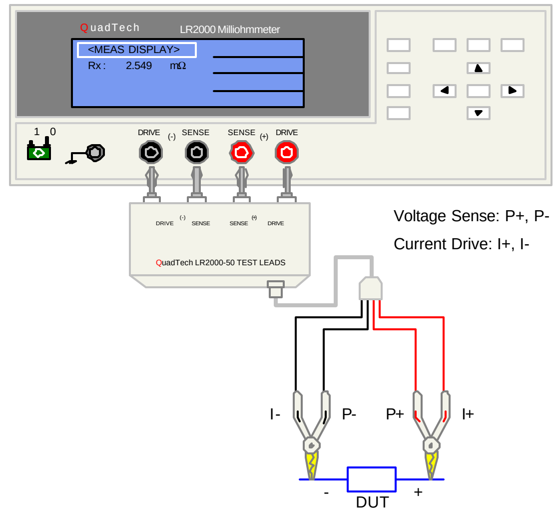


Figure 26: 4-Terminal Measurement

In order to determine the resistance value of a device, current is injected to the device through the I+, I- connections. The current that flows is dependent upon the resistance of the device. This current is measured and used in the resistance calculation. The current through the resistor will generate a voltage across the device. This voltage is measured by the P+, P- connections, note these connections are closer to the device than the I+, I-. Since the voltmeter would have a high impedance no current would flow through the P leads, thus having no influence on the voltage detected by these connection. A very precise calculation results from this measured current and voltage.

Verification of a Milliohmmeter

Standards

There are a number of different low resistance standards and resistors that can be used to verify the operation of a milliohmmeter. Precision Resistor manufactures a PLV-7 series of resistors (http://www.precisionresistor.com/PLV7.htm). The PLV-7 Series are 4-terminal resistors with resistance values from 5m to 100 , tolerances to 0.005%, excellent temperature and stability characteristics.

Current Shunt

There are also a wide variety of current shunts such as those from Deltec Company. A shunt is a very low resistance connection between two points in an electric circuit that forms an alternative path for a portion of the current*. The voltage drop across the shunt is is used with an ammeter to measure the amperage of a circuit. Figure 27 illustrates a typical WB current shunt from Deltec. Note that there are two large terminals on the outside for drive connection and two inner terminals for sense connection.

Figure 27: Example Current Shunt

***Courtesy Deltec Company**
http://www.deltecco.com

Shunts are specified in terms of voltage and current therefore a 50mV/50A shunt would have a resistance of 1mΩ. Typically current shunts are calibrated to an accuracy of 0.25%. Most calibration laboratories can calibrate current shunts to higher accuracy and at the appropriate current for the milliohmmeter being tested.

Safety

As with any instruments safety precautions should be taken. Most milliohmmeters have a relatively low clamping voltage however the instruments do produce high currents. Precautions should be taken per manufacturers recommendations. It is also important when measuring inductive devices (such as coils and inductors) to not disrupt the test by disconnecting the leads. This can result in a dangerously high voltage being produced in the inductor.

An inductor, a wire wound around a core material, stores energy in a magnetic field. If the current applied to an inductor is suddenly interrupted, a voltage transient occurs across the open circuit. The voltage can increase to a dangerous level. Proper protection must be taken when breaking the contact across the inductor (inductive circuit). Ground the circuit and ground the individual breaking the contact.

External Connection to a Milliohmmeter

Once correct connection to the device under test is established, the automation of milliohm measurements will save time and increase the efficiency of logging data. Remote control of test instrumentation, automation of tests and collection of the test results are indispensible in fast paced production environments.

Remote I/O

Remote operation decreases the potential for operator error thus increasing the accuracy and repeatability of the setup and data. A remote I/O interface can be configured as a 9-pin, 24-pin or 25-pin connector or a terminal strip. The simplest remote I/O interface typically accepts the input signals [START] and [STOP] and provides the output signals [PASS] and [FAIL]. When making measurements of a small magnitude, precison means leaving the test leads, DUT and setup alone. Remote operation provides that measurement reproducibility and stability.

Figure 28 illustrates a simple Remote I/O connection to illuminate green/red LEDs on a Pass/Fail result. Jumpers are placed between pins 11 & 10, 8 & 7 and 4 & 3 respectively. START switch is connected between pin 1 and ground, PASS from pin 21 and FAIL from the jumper between pins 4 & 3.

RS-232 Interface

The RS-232 interface is a serial port for transmission of information in serial bit format. RS-232 communication requires three lines: "receive data", "transmit data" and "signal ground". Serial port parameters are comprised of 8 data bits, 1 stop bit and Odd, Even or No parity. Depending on the instrument, baud rate is fixed or selectable in multiples of 1200bps (bits per second).

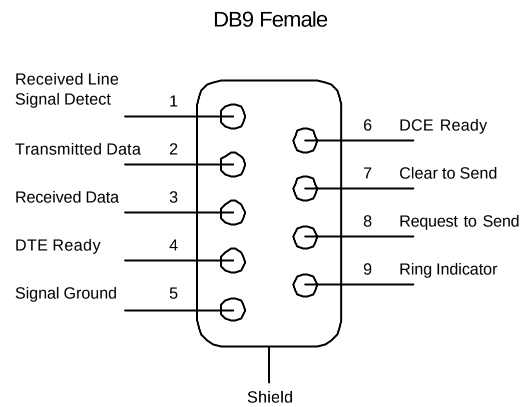


Figure 29: Typical RS-232 Pin Configuration

IEEE-488 Interface

The IEEE-488 interface is a parallel port for transmission of 8 bits (1 byte) of information at a time over 8 separate wires. The information travels on 3 buses: handshake, control and

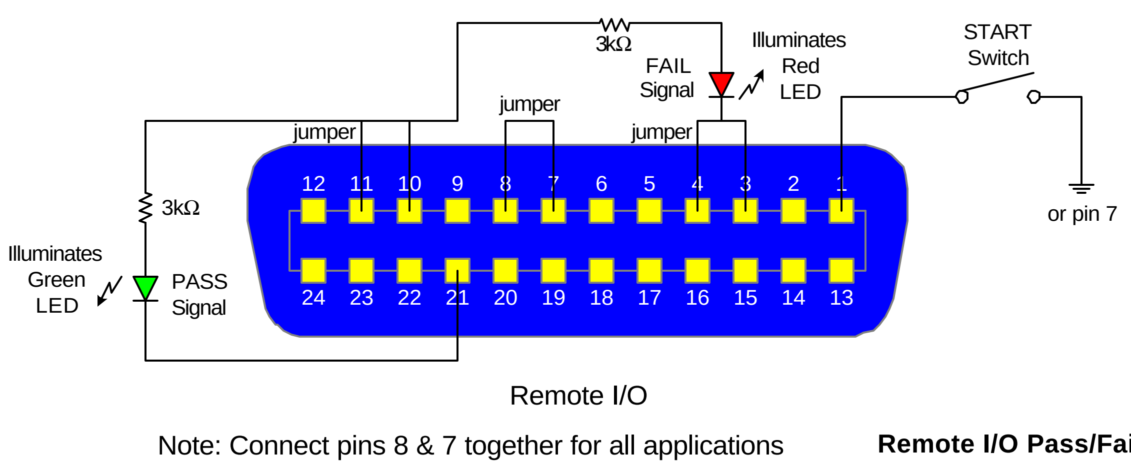


Figure 28: Remote I/O Pass/Fail Connection

data. IEEE-488 has a faster transfer rate (up to 1MB/second) than RS-232 but it's connection cable is limited to 20 meters. There is no limit to the communication cable length with the RS-232 interface.

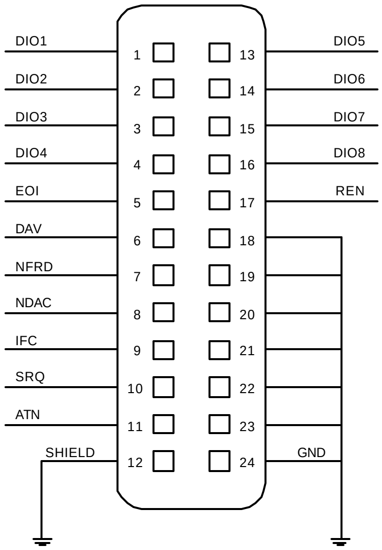


Figure 30: Typical IEEE-488 Pin Configuration

RS-232 & IEEE-488 Control

Commands for RS-232 and IEEE-488 communication are similar and some are identical depending upon the instrument. Each command line is terminated with a carriage return [CR] and a line feed [LF]. Multiple commands are separated with a semicolon.

In response to customer inquiries, QuadTech provides sample software for controlling and collecting data from its instruments. Executable QuickBasic and VisualBasic programs are available in the Software Resources section of http://www.quadtech.com.

The QuickBasic program for the LR2000 meter verifies communication between a PC and the LR2000. The program prompts the user for com port, queries IDN of the instrument, prompts the user for the number of measurements to be take, displays the measurements on the terminal and saves the data to a file.

LR2000 Virtual Front Panel Wizard

From any desktop PC, program the source, dry circuit, range, speed, average and delay functions and click [TRIGGER]. The test results are saved to an Excel-compatible log file. For temperature compensation, enter the temperature and select your material (or enter your coefficient) and both resistance values will be displayed and logged.

Pull up the log file, import it into Excel, select the parameters of interest and graph the results - a very nice visual and statistical tool for temperature compensation analysis or resistance characterization.

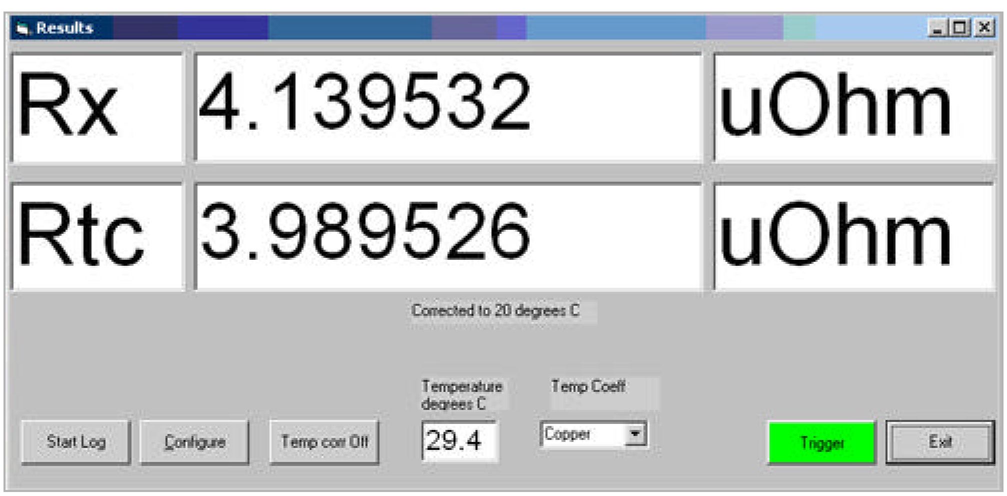


Figure 31: LR2000 Virtual Front Panel

Applications of Milliohmmeters

Surface Resistivity - Test Samples

Measurements with a Resistivity Cell

The LR2000 instrument can be used for measuring the resistivity of test samples as described by ASTM Standard D257, which details the techniques for both surface and volume resistivity measurements. The most common electrode arrangement is illustrated in Figure 31.

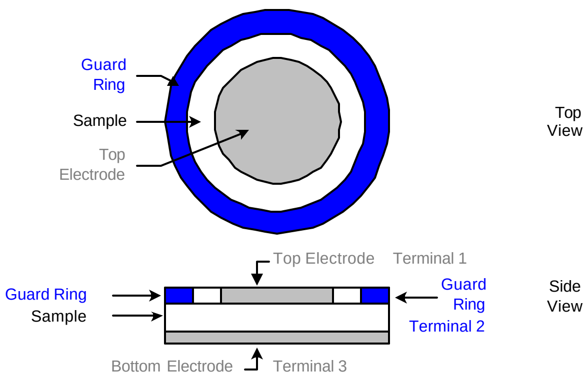


Figure 31: ASTM D257 Test Cell

In this configuration, surface resistivity is measured with terminal 1 tied to the - UNKNOWN terminal, terminal 2 tied to the +UNKNOWN terminal and terminal 3 tied to GUARD.

$$\text{Surface Resistivity} = \rho_s = \frac{P}{g} R_s$$

P = effective perimeter of measuring electrode

g = dimension of space between electrodes 2 and 1

R_s = measured surface resistance in ohms

Equation 5: Surface Resistivity: Test Cell

Equation 5 is the formual for determining the surface resistivity using the test cell in Figure 28. Refer to the ASTM standard for the formulas required to convert from measured resistance to resistivity. Or visit the American Society for Testing and Materials at http://www.astm.org for the latest information.

In electrical terms, resistivity is the resistance of a material to the flow of current times the cross-sectional area of current flow per unit length of the current path.

Cable Testing

Resistance & Capacitance Measurements

Milliohm measurements are frequently made on wires and cables since resistivity of the conducting wire/cable is a primary factor in its final application. As detailed in the conductor section, conductive materials are chosen for their specific resistivity/conductivity and temperature characteristics. More than a simple length of bare copper wire, a cable is comprised of plated copper (tin, silver, nickel) and bundled in strands for electrical as well as physical properties.

Cable strength and flexibility are primary parameters for cables used in dynamic environments where they are pulled, twisted and flexed often. Individual strands break causing the discontinuity in the cable. Cable made of strands of alloys (alloy 135) exhibit greater tensile strength than bare copper wire and stranded bare copper wires*. (*Calmont Wire & Cable Inc., 'Effect of Flex Life' Technical Bulletin)

Cables are comprised of more than one wire and here continuity is an important factor. Continuity of a cable means that all its intended connections are made. The sum of resistance of each of these connections is defined as the minimum continuity resistance of the cable. To find the problem in a discontinuous cable, resistance is measured between the end points of a shorted pair of points to reveal the defective cable end.

When an open is suspected (an intended connection in the cable is not made), capacitance is measured from two end points of the open circuit to all other wires in the cable to reveal the defective cable end. When measuring wire harnesses, one must consider the shielded wires and twisted pair cables that make up the harness. In this instance measuring the capacitance of the harness can reveal the continuity of an unterminated shield and/or the miswiring of twisted pair conductors.

Component Testing

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) that 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}.

$$\Delta T = \left[\frac{R_{HOT} - R_{COLD}}{R_{COLD}\,(TC)} \right]$$

Equation 6: Temperature Rise

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. This particular copper wire has a temperature coefficient of 3931ppm/^{o}C (ΔR = 0.3931%/^{o}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:

$$\Delta T = \left[\frac{1.6211\Omega - 1.2367\Omega}{1.2367\Omega\ (0.003931)} \right] = 78.45^{o}C$$

Equation 7: Temperature Rise

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^{o}C).

QuadTech Low Resistance Measurement Instruments

LR2000 Milliohmmeter

The LR2000 Milliohmmeter has a basic accuracy of 0.05% and a wide measurement range from 1µohm to 2Mohms. For remote operation and production applications the unit comes standard with an RS-232 interface, plus IEEE-488 and handler interfaces are available as options. For measurement integrity, contact to the test device is made via a 4-terminal Kelvin connection that incorporates an automatic zeroing function to compensate for lead errors.

The LR2000 provides eight measurement ranges from 20mΩ to 2MΩ with constant current between 1A and 1mA. For "dry" contact measurements (those contacts whose resistance can be altered by excessive voltage potential) the LR2000 can be limited to 20mV on selected measurement ranges.

- o 1µΩ - 2MΩ Measurement Range
- o 1mA - 1A Constant Current
- o 0.05% Basic Measurement Accuracy
- o Measurement Speed to 15/second
- o Test Signal: DC+, DC-, Pulse, Pulse+, Pulse-
- o Dry Circuit Test Current
- o Graphical LCD Display
- o Four-Terminal Kelvin Connection
- o Automatic Zeroing
- o RS-232 Interface Standard
- o IEEE and Handler Interfaces, Optional
- o Automatic Hi/Lo Comparator Limits
- o Pass/Fail Sorting (8 Bins)
- o Voltage Limiting for Dry Contact Testing
- o Keypad Lockout
- o Programmable Delay Times

Applications:

- o Production Testing of Contact Resistance of Switches, Relays, Connectors, Cables, and Other Low Resistance Devices
- o Testing of Low Value Resistors, Fuses, Squibs, and Heating Elements
- o Winding Resistance of Motors, Transformers, Solenoids, and Ballasts
- o Conductivity Evaluation in Product Design
- o Incoming Inspection and Quality Assurance Testing

LR2000 Virtual Front Panel Wizard

Written in Visual Basic 6.0, the Virtual Front Panel Wizard for the LR2000 will easily configure the LR2000 Milliohmmeter. From any desktop PC, program the source, dry circuit, range, speed, average and delay functions and click [TRIGGER]. The test results are saved to an Excel-compatible log file. Pull up the log file, import it into Excel, select the parameters of interest and graph the results - a very nice visual and statistical tool for temperature compensation analysis or resistance characterization.

Features:

- o Log Test Data to Excel-Compatible File
- o Remotely Configure Instrument from PC
- o Set Room Temperature
- o Set Temperature Coefficient

Requirements:

- o LR2000 Milliohmmeter
- o RS-232 Interface with Straight-Through Cable
- o PC with Windows and RS-232 Port

Cable Testers

QuadTech provides three Horizon Cable Testers designed for specific cable applications. The Horizon 1500 Series includes the LV1 Low Voltage Wiring Analyzer, the HV1 High Voltage Wiring Analyzer and the SCSI Wiring Analyzer. Resistance measurements can be made using two-wire connection for simple verification that two points are connected and continuous. For more accurate resistance measurement a 4 wire Kelvin connection is available for accuracy of $\pm$1mΩ on a 10mΩ measurement.

Similarly, capacitance measurements can be made using two-wire connection for verification that two points are connected and continuous. All three Horizon Wiring Analyzers (LV1, HV1 & SCSI) measure capacitance from 50pF to 1mF with a basic accuracy of 4% and from 50pF to 10,000mF with a basic accuracy of 10%.

Horizon LV1 Low Voltage Wiring Analyzer:

- Low Voltage Switching via Solid State Relays
- Resistance to 50MΩ
- 128 Test Points Expandable to 1024 Points
- Self Learn Known Good Products
- Twisted Pair Verification
- Resistors, Capacitors, and Diode Testing
- Built-in Pentium PC
- SPC and Data Management
- Test 500 Point Net in Less Than 1 sec.
- Auto Start Test When Product is Loaded
- Flex Test

Applications:

- Cable Verification
- Relay, Switch & LED Testing

Horizon HV1 High Voltage Wiring Analyzer:

- High Voltage Breakdown to 1500V
- Insulation Resistance to 1.5GΩ
- Programmable 1A Current Source
- 128 Test Points Expandable to 1024 Points
- Self Learn Known Good Products
- Flex Test
- Twisted Pair Verification
- Resistors, Capacitors, and Diode Testing
- Built-in Pentium PC
- SPC and Data Management
- Test 500 Point Net In Less Than 1 Sec.

Applications:

- Switch-hub Verification
- Cable Verification
- Relay, Switch & LED Testing
- Circuit Board Assembly Tests

The Horizon SCSI wiring analyzer combines all the features of the High Voltage Series Horizon with SCSI (Small Computer System Interface) test capability to enable fast, flexible and reliable SCSI terminator testing. To keep testing simple and quick, a comprehensive range of standard programs is included to fully verify SCSI terminators in less than 10 seconds. The TCL scripting language allows unlimited expansion of the Horizon SCSI terminator test program library.

Horizon SCSI Wiring Analyzer

- Fast SCSI Testing
- In Process Testing of Cable and Terminators
- Complete Trace Verification
- Verify Signal Voltages and Quiescent Current
- Verify Isolation of Reserved Pins
- High Voltage Breakdown to 1500V
- Insulation Resistance to 1.5GΩ
- Programmable 1A Current Source
- 128 Test Points Expandable to 1024 Points
- Self Learn Known Good Products
- Flex Test & Twisted Pair Verification
- Resistors, Capacitors, and Diode Testing
- Built-in Pentium PC, SPC and Data Management
- Test 500 Point Net in Less Than 1 Sec.

Applications:

- SCSI Cables
- SCSI terminators

Fusion Wire & Cable Analyzers

The Fusion Wire & Cable Analyzer is a fully integrated test system. Hipot, Megohmmeter, Milliohmmeter & Capacitance Measurements can be performed via a multi-channel scanner up to 72 points. For low resistance measurements, a 2-wire and 4-wire configuration is possible with resolution down to 1mΩ in the 4-wire mode. Make 2-wire measurements from 1mΩ to 50MΩ and 4-wire measurements from 1m. to 400k.. The unit is also capable of high resistance measurements to 50MΩ.

Fusion High Voltage Cable Analyzer

Dedicated Function Test Instruments

In addition to milliohmmeters and cable testers, QuadTech manufactures a full line of passive component and electrical safety testing instrumentation, including LCR Meters, Digibridges, Megohmeters, Hipot Testers and Electrical Safety Analyzers. View complete product specifications at http://www.quadtech.com.

LCR Meters

7400 Precision LCR Meter

Megohmmeters

1868A Megohmmeter

Hipot Testers

Sentry Plus Hipot Tester

Electrical Safety Analyzers

Guardian 6000 Electrical Safety Analyzer

Appendix A

Formulas

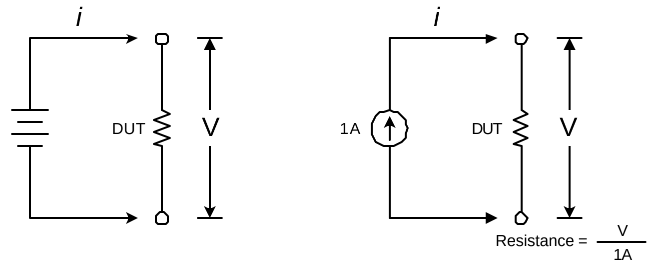
Resistance

$$R = \left[\frac{V}{i}\right]$$

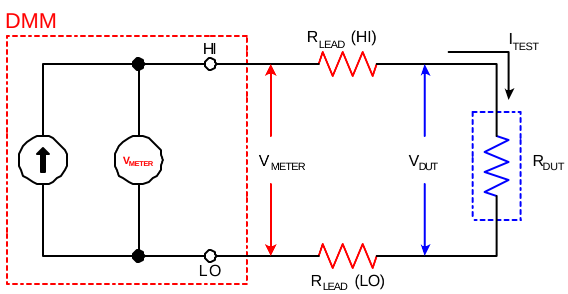
R = Resistance in ohms

V = Voltage in volts

I = Current in amperes



2-Wire Resistance Measurement



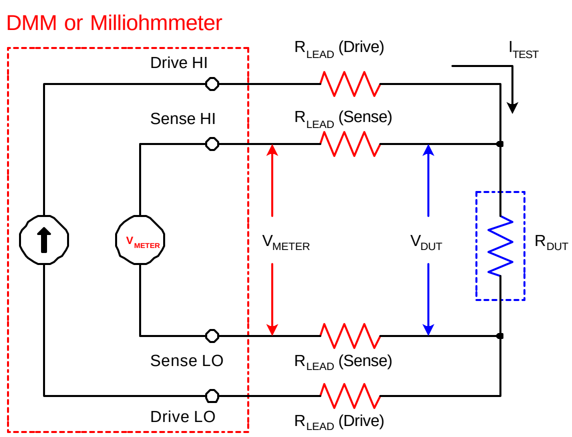
V_{METER} = Voltage measured by meter

V_{DUT} = Voltage across DUT (device under test)

Measured Resistance = $\dfrac{V_{METER}}{I_{TEST}} = R_{DUT} + (2 \times R_{LEAD})$

Actual Resistance = $\dfrac{V_{DUT}}{I_{TEST}} = R_{DUT}$

4-Wire Resistance Measurement



V_{METER} = Voltage measured by meter

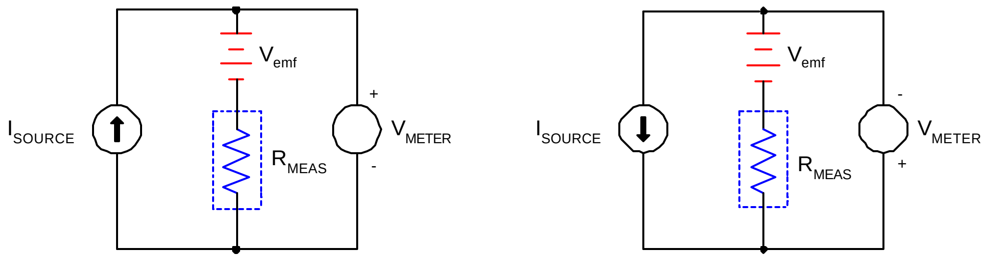
V_{DUT} = Voltage across DUT (device under test)

Because Sense Current is negligible: $V_{METER} = V_{DUT}$

Measured Resistance = $\dfrac{V_{METER}}{I_{TEST}} = \dfrac{V_{DUT}}{I_{TEST}}$

Formulas

Current Reversal



V_{METER} = Meter Voltage

V_{emf} = Thermal emf

I_{SOURCE} = Source Current

R_{MEAS} = Measured Resistance

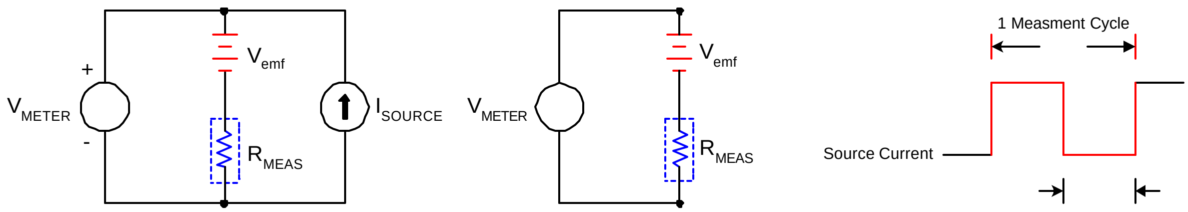
$$V_{METER+} = V_{emf} + (I_{SOURCE})(R_{MEAS})$$

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

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

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

Offset Compensated Ohms



Voltage Measurement with Current Source **ON**

Voltage Measurement with Current Source **OFF**

Thermal Offset Measurement

V_{METER} = Meter Voltage

V_{emf} = Thermal emf

I_{SOURCE} = Source Current

R_{MEAS} = Measured Resistance

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

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

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

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

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

Resistivity

$$\rho = \frac{RA}{l}$$

ρ	=	electrical resistivity	ohm-meter
R	=	resistance of conductor	ohm
A	=	cross-sectional area of conductor	meter ^{2}
l	=	length of conductor	meter

Resistivity and Temperature

$$\rho = \rho_0 \left[1 + \alpha \left[T - T_0 \right] \right]$$

ρ	=	measured resistivity
ρ_0	=	resistivity at reference temperature (20ºC)
T	=	measured temperature
T_0	=	reference temperature
α	=	temperature coefficient of resistivity

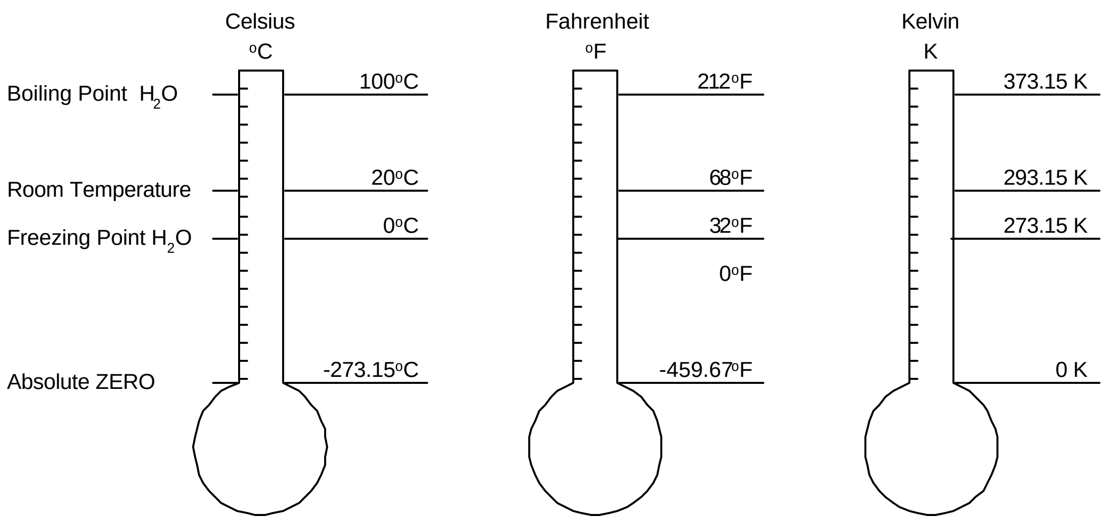
Formulas

Conductivity

$$\sigma = \frac{ne^2 l}{m_e V_{rms}}$$

σ	=	electrical conductivity
n	=	density of free electrons
e, m_e	=	charge and mass of an electron
V_{rms}	=	root-mean-square speed of electrons
l	=	mean free path length

Temperature Conversion



Known Temperature			Desired Temperature		Equation
Fahrenheit	°F	-	°C	Celsius	°C = (°F – 32)/1.8
Fahrenheit	°F	-	K	Kelvin	K = (°F + 459.67)/1.8
Celsius	°C	-	°F	Fahrenheit	°F = (1.8 x °C) + 32
Celsius	°C	-	K	Kelvin	K = °C + 273.15
Kelvin	K	-	°F	Fahrenheit	°F = (1.8 x K) – 459.67
Kelvin	K	-	°C	Celsius	°C = K – 273.15

AWG & Diameter

$$AWG: = 36 - \left[\frac{39 \times \left[\log(200D)\right]}{\log(92)} \right]$$

$$D = 0.005 \left[92^{\left[\frac{36 - AWG}{39}\right]} \right]$$

D = Diameter in inches

Tables

Note:
Tables 2 & 7 from the Conductor and Temperature Compensation sections of this guide contain data from different sources and thus have different values for Resistivity and Temperature Coefficient. Both tables are repeated here with the sources listed so the reader may verify the content according to his needs.

Table 2: Resistivity of Common Conductors

Resistivity at room temperature: 20°C = 293K = 68°F

Material	Symbol	Resistivity µΩ-cm	Conductivity per Ω-m	Temperature Coefficient per °C
Element Metal				
aluminum	Al	2.65	3.77×10^7	0.0042
copper	Cu	1.67	5.95×10^7	0.0040
gold	Au	2.21	4.55×10^7	0.0037
iron	Fe	9.66	1.03×10^7	0.0056
lead	Pb	20.65	0.43×10^7	0.0042
magnesium	Mg	4.3	2.33×10^7	
manganese	Mn	144	0.072×10^7	
nickel	Ni	6.93	1.43×10^7	0.0058
platinum	Pt	10.5	0.96×10^7	0.0037
silver	Ag	1.59	6.29×10^7	0.0038
tantalum	Ta	13.1	0.76×10^7	
titanium	Ti	42	0.24×10^7	
tungsten	W	5.28	1.89×10^7	0.0044
zinc	Zn	5.92	1.69×10^7	0.0038
Alloy Metal				
nichrome	$Ni_{80}Cr_{20}$	110	0.095×10^7	0.00017
manganin*	CuMnNi	48.21	0.207×10^7	± 0.000015
steel**	FeC	16.62	0.502×10^7	0.003
Semiconductors				
carbon (graphite)	C	3500	2.9×10^4	-0.0005
germanium (pure)	Ge	46000	2.2	-0.048
silicon (pure)	Si	64000000	0.0016	-0.075

* Manganin composed of 83% copper, 13% manganese and 4% nickel
** Steel composed of 99.5% iron and 0.5% carbon

This table was comprised of data from multiple sources including:

All About Circuits: C12 The Physics of Conductors and Insulators
http://www.allaboutcircuits.com/vol_1/chpt_12/1.html

Hyper Physics: Resistivity Table
http://hyperphysics.phy-astr.gsu.edu/hbase/Tables/rstiv.html#c1

MIT course 802: C.6 Current and Resistance
http://web.mit.edu/8.02t/www/802TEAL3D/visualizations/coursenotes/modules/current.pdf

Microwaves 101
http://www.microwaves101.com/encyclopedia/conductivity.cfm#conductor

The Physics HypertextbookTM: Electrical Resistance
http://hypertextbook.com/physics/electricity/resistance/

Tables

Table 7: Temperature Coefficients

Material	Resistivity (Ω*m) at 20°C	Temperature Coefficient $\alpha(°C)^{-1}$
Silver	1.59×10^{-8}	3.8×10^{-3}
Copper	1.7×10^{-8}	3.9×10^{-3}
Gold	2.44×10^{-8}	3.4×10^{-3}
Aluminum	2.82×10^{-8}	3.9×10^{-3}
Tungsten	5.6×10^{-8}	4.5×10^{-3}
Iron	10×10^{-8}	5.0×10^{-3}
Platinum	11×10^{-8}	3.92×10^{-3}
Lead	22×10^{-8}	3.9×10^{-3}
Nichrome	150×10^{-8}	0.4×10^{-3}
Nickel	8.7×10^{-8}	6.8×10^{-3}
Carbon	3.5×10^{-5}	-0.5×10^{-3}
Germanium	0.46	-48×10^{-3}

This table was comprised of data from:

Source: Physics For Scientists & Engineers, Raymond A. Serway, 3RD Edition, Volume II, 1990

Resistivity & AWG

Table 4: Solid Copper Wire: AWG & Resistivity

AWG Size (Solid Wire)	Diameter (mm)	Diameter (inches)	Resistance Ω/1000feet	Resistance Ω/1000meters
0000 (4/0)	11.684	0.4600	0.049	0.1607
000 (3/0)	10.404	0.4096	0.0618	0.2027
00 (2/0)	9.266	0.3648	0.078	0.2555
0 (1/0)	8.252	0.3249	0.0983	0.3224
1	7.348	0.2893	0.124	0.4063
5	4.621	0.1819	0.3133	1.0276
10	2.588	0.1019	0.9989	3.28
12	2.052	0.0808	1.588	5.21
14	1.6256	0.0640	2.525	8.28
16	1.2903	0.0508	4.016	13.2
18	1.0236	0.0403	6.385	20.9
20	0.8128	0.0320	10.15	33.2
22	0.6451	0.0254	16.14	52.7
24	0.5105	0.0201	25.67	84.2
30	0.2540	0.0100	103.2	338.496
36	0.1270	0.0050	414.8	1360
40	0.0787	0.0031	1049	3440

Helpful Links

Conductivity

Wikipedia Free Encyclopedia:
http://en.wikipedia.org/wiki/Electrical_conductivity

Microwaves 101
http://www.microwaves101.com/encyclopedia/conductivity.cfm#conductor

Fisk Alloy: Conductor Facts
http://www.fiskalloy.com/c-main-pages/c-welcome.html

All About Circuits: C12 The Physics of Conductors and Insulators
http://www.allaboutcircuits.com/vol_1/chpt_12/1.html

Hyper Physics: Superconductivity
http://hyperphysics.phy-astr.gsu.edu/hbase/solids/scond.html

Resistivity

HyperTextBook™:
http://hypertextbook.com/facts/index-topics.shtml#resistivity

The Physics Hypertextbook™: Electrical Resistance
http://hypertextbook.com/physics/electricity/resistance/

Free Dictionary
http://encyclopedia.thefreedictionary.com/electrical%20resistivity

Hyper Physics: Resistivity Table
http://hyperphysics.phy-astr.gsu.edu/hbase/Tables/rstiv.html#c1

MIT course 802: C.6 Current and Resistance
http://web.mit.edu/8.02t/www/802TEAL3D/visualizations/coursenotes/modules/current.pdf

Temperature

Temperature Conversion and Thermocouple Identification Table:
http://www.pmel.org/HandBook/HBpage16.htm

Wire AWG

Wikipedia Free Encyclopedia: American Wire Gauge
http://en.wikipedia.org/wiki/American_wire_gauge

Power Stream: Wire Gauge & Current Limits
http://www.powerstream.com/Wire_Size.htm

Hyper Physics: Wire Gage
http://hyperphysics.phy-astr.gsu.edu/hbase/Tables/wirega.html#c1

epanorama.net: Copper Wire AWG
http://www.epanorama.net/documents/wiring/wire_resistance.html

Tyco Electronics: AWG Chart
http://www.tycoelectronics.com/

Current Rating, Copper Wire Characteristics, AWG
http://allflexinc.com

Helpful Links

Cable Characteristics

National Semiconductor Application Note AN-916: Practical Guide to Cable Selection
http://www.national.com/an/AN/AN-916.pdf

Cable Guide
http://www.cvalim.co.il/pdf/electro.pdf

Cable Catalog, Cable AWG Characteristics
http://www.superior-cables.co.il

Current Carrying Capacity, Shielding, Copper Wire AWG
http://www.alphawire.com/pages/383.cfm
http://www.alphawire.com/pages/342.cfm

Current Rating, Copper Wire Characteristics, AWG
http://allflexinc.com

Aerospace Wire & Cable Catalog - Judd Wire
http://www.juddwire.com

Cable Flex Test- Calmont Wire & Cable Inc.
http://www.calmont.com/flex%20test%20summary.pdf

Technical Reference on Wire & Cable - Calmont Wire & Cable Inc.
http://www.calmont.com/tech_11.pdf

Current Shunts

Deltec Inc
http://www.deltecco.com

Resistance Standards

Precision Resistor
http://www.precisionresistor.com

Probe Leads, Kelvin Clips

Pomona Electronics
http://www.pomonaelectronics.com

QuadTech MEG/MIL Selection Guide

Milliohmmeters

Tester	Accuracy	Resistance Range	Voltage Range & Current	Test Time	Display	Output	Other Features
LR2000 Digital	0.05% Basic	1μΩ – 2MΩ	Test Signal: 0-2.0V DC+, DC-, Pulse+, Pulse-, Pulse+/-, Stby Test Current: 1A – 1uA	Trigger: 0-1000ms; Delay Time: 0-100s	LCD Full Menu Test Setup, Value, % Value Δ Value Bin #	RS232 Std. IEEE-488 & Handler Opt.	Dry Circuit Mode Comparator: H/L Limits Binning: 8 Bins P/F 4-Terminal Kelvin Clips Prog. Delay Time Measurement Average Range: Auto/Hold Trigger: Int, Ext, Man

Megohmmeters

Tester	Accuracy	Resistance Range	Voltage Range & Current	Test Time	Display	Output	Other Features
1863 Analog	3.0% Basic	50k – 20TΩ	50 – 500V <5mA	Manual	Analog Meter	Analog	Portable Steel Case
1864 Analog	3.0% Basic	50k – 200TΩ	10 – 1090V <5mA	Manual	Analog Meter	Analog	Portable Steel Case
1865 Digital	0.5% Basic	1k – 100TΩ LO limit	1 – 1000V <2mA	0 – 300s	LCD with Graphics	P/F Indicator HV Indicator RS232 I/O PORT OPTIONAL: IEEE-488	Floppy Option Auto Zero Store & Recall ENG or SCI display R or I display Safety Interlock OPTIONAL: Shielded Lead Set Comp Test Fixture
1867 Analog	2.0% Basic	50k – 200TΩ HI/LO limits	10 – 1090V: 10 – 500V <5mA 500 – 1090V <25mA	Manual	Analog Meter	Analog P/F Indicator P/F Alarm	Remote (Terminal Strip) IP: Trigger OP: High Fail, Low Fail and Pass
1868 Digital	2.0% Basic	10k – 1PΩ Auto Range or 4 user selectable ranges	1868A: 10 – 1000V 2mA/25mA/80mA 1868D: 50-5000V 2mA/10mA/18mA	Charge Measure Delay Discharge: 9999msec	LCD with: Text, Line Graph Bar Graph	HV Indicator RS232 I/O PORT IEEE-488 Binning	PCMCIA Interface Auto Zero Store & Recall R or I display Safety Interlock

Capacitor Leakage Current / IR Meter

Tester	Accuracy	Measurement Range	Voltage Range & Current	Test Time	Display	Output	Other Features
1855 LC & IR Meter	Basic: LC: 0.3% IR: 0.6%	LC:1nA-20mA IR: 10Ω – 99GΩ WV: 1-650V DC Tr: 0.05-120sec	1 – 650V DC Charge Current: 0.5 -500mA	Charge, Dwell 0-999sec	LCD Test Setup Value Pass/Fail	P/F Indicator P/F Alarm RS232 Optional: IEEE & Handler	Withstand Voltage Rise Time Auto Ranging Averaging 1-8 Comparator P/F

Application Note Directory

QuadTech Application Notes

Contained herein is a list of QuadTech application notes available for download in Adobe PDF format. To access the application notes visit: http://www.quadtech.com/resources and click on the Application Note link.

A/N P/N	Title/Description	Release
035000	Measuring Insulation Resistance of Capacitors	06-03-03
035001	Series & Parallel Impedance Parameters and Equivalent Circuits	07-09-03
035002	Equivalent Series Resistance (ESR) of Capacitors	07-09-03
035003	Increasing Test Voltage on the QuadTech Digibridge	10-10-00
035004	High Voltage DC Bias on the QuadTech Digibridge	10-10-00
035005	Application for Precision Impedance Meters in a Standards Laboratory	09-12-03
035006	Application for Precision Impedance Meters in a Standards Laboratory	07-18-00
035007		
035008	Application of DSP to Precision LCR Measurements	07-09-03
035009	Measuring Biased Inductors with the 7000 Precision LCR Meters	07-25-03
035010	A Guide to LCR Measurements	07-10-03
035011	A Practical Guide to Dielectric Testing	06-24-03
035012	Measurements of Dielectric Constant and Loss with the LD-3 Cell	08-04-03
035013	Sentry Series Light Ballast Application	10-03-02
035014	Guardian 1030S and Cable Reel Immersion Test	10-03-02
035015	Guardian 1030 used for IR Test on Adhesive Heat Shrink	10-03-02
035016	Sentry Series Panel Meter Application	10-03-02
035017		
035018		
035019	Helpful Tips on Measuring Capacitors	07-11-03
035020	Testing Capacitors with the QuadTech Model 1865 Megohmmeter/IR Tester	11-08-00
035021	What's Changing in Appliance Hipot Testing and Why	11-08-00
035022	Measuring Biased Inductors with the QuadTech Digibridge	11-08-00
035023	Characteristic Cable Impedance	01-24-03
035024	Calibrating Impedance Meters Using Resistance Standards	08-18-00
035025	Advanced Technique for Dielectric Analysis	06-24-03
035026	Medical Equipment Test Applications using the 7000 Precision LCR Meter	09-28-00
035027	Multi-Terminal Impedance Measurements (Why do these bridges use so…)	07-23-03
035028	Testing Automotive Engine Oxygen Sensors using the 1900 Precision LCR	02-11-02
035029	Hipot Testing of Motors and Safety Standard Compliance	12-19-00
035030	Transformer Turns Ratio using the 7000 Series RLC Meters	12-19-00
035031	The QuadTech 1865 as a Current Meter	12-19-00
035032	Measuring Large Capacitors with the 1865-52 Component Test Fixture	06-03-03
035033	Insulation Resistance of Cables	09-28-00
035034	1865 Remote Pass/Fail Lights	01-08-01
035035	1865 Specified Accuracy	01-08-01
035036	The QuadTech 1865 Average Function	09-19-02
035037	How to Connect a Foot Switch to the 1870 Dielectric Analyzer	01-08-01
035038	The 1880 Specified Accuracy & Constant Current Ranges	01-10-01
035039	External DC Supply for the 1536 Photoelectric Pickoff Cell	01-10-01
035040	Basic Program to Control the Flash on a 1539 Strobe	01-10-01
035041	Characteristic Cable Impedance	01-24-03
035042	Constant Current with the 1693 RLC Digibridge	05-26-00
035043	Charged Capacitor Protection Circuit for the QuadTech Digibridges	02-15-02
035044	Transformer Ratio Measured Directly on the 1689 & 1693 Digibridges	03-25-03
035045	How Much is One Joule	09-11-03
035046	7000 Series Connections to the LD-3 Dielectric Cell	08-05-03
035047	Digibridge Connections to the LD-3 Dielectric Cell	01-15-01
035048	Battery Impedance Measurements	07-18-00
035049	Charged Capacitor Protection for the 7000	02-13-01
035050	What Voltage and Current is Applied to the Unknown?	07-24-03
035051	Power Factor of a Capacitor (1900 Series)	07-28-03
035052	Tutorial on Safety Standard Compliance for Hipot Testing	06-24-03
035053	Benefits and Advantages of Digital Electrical Safety Testers	02-13-01
035054	Measuring Electrical Properties of Copier/Printer Toners	08-06-03
035055	Monitoring the Production Process of Tantalum Powder	08-07-03
035056	Transducers used in Monitoring Nuclear Waste Tanks	07-28-03
035057	Measuring the Dielectric Constant of PVC Compounds	08-08-03
035058	Testing Animal Identification Implants	07-28-03
035059	Testing Telecommunications Transformers	02-28-01
035060	Enhanced Protection When Measuring Charged Capacitors	02-28-01

QuadTech Application Notes

A/N P/N	Title/Description	Release
035061	Guardian 1000 Series Light Ballast Application	10-03-02
035062	Cable Reel IR Testing Application	10-03-02
035063	Adhesive Heat-Shrink IR Testing	10-03-02
035064	Why Perform Electrical Safety Testing?	06-23-03
035065	Ground Bond, Ground Continuity and Earth Continuity	06-23-03
035066	Appliance Testing with the Guardian 6200 Production Safety Analyzer	03-27-01
035067	Determining if a DUT is connected, using the Low Trip Limit (G1000 Series)	02-04-02
035068	UL Standards	03-27-01
035069	Guidelines for External Bias on the 7400 and 7600	04-24-01
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Glossary

AC
Alternating current, an electric current that has one polarity during part of the cycle and the opposing polarity during the other part of the cycle. Residential electricity is AC.

Accuracy
The difference between the measured value or reading and the true or accepted value. The accuracy of an LCR meter is typically given as a +/- percentage of the measured value for primary parameters and +/- an absolute value for the secondary parameter. Example: +/-0.05% for L, C & R and +/-0.0005 for Df.

ANSI
American National Standards Institute, an industry association that defines standards for
data processing and communication.

Basic Accuracy
The basic accuracy is specified at optimum test signal, frequency, highest accuracy setting or slowest measurement speed and impedance of the DUT. As a general rule this means 1VAC RMS signal level, 1kHz frequency, high accuracy which equates to 1 measurement/second and a DUT impedance between 10Ω and 100kΩ.

Binning
A procedure for sorting components into bins using sequential limits or nested limits.

Capacitor
Abbreviated as C (as in LCR). A capacitor is a passive component comprised of two conductors separated by a dielectric. A capacitor stores charge, blocks DC flow and allows AC flow based on frequency and capacitor design.

Capacitance
The ratio of charge on either plate of a capacitor to the potential difference (voltage) across the plates. When a voltage is applied, current flows immediately at a high rate and then decays exponentially toward zero as the charge builds up. If an ac voltage is applied, an ac current appears to flow continuously because the polarity of the voltage is reversed at the frequency of the applied voltage. The waveform of this current, however, is displaced in time from the applied voltage by 90°.

Capacitive Reactance
Measurement of the actual AC resistance of a capacitor. How effective a capacitor is in allowing AC to flows depends upon its capacitance and frequency.
$X_c = 1/2\pi fC$.

Clearance
Clearance is the shortest distance between two conductors through air or insulating medium.

Compare
A procedure for sorting components by comparing the component's measured value against a known standard.

Conductivity
The ratio of electric current density to the electric field in a material. Conductivity is also known as 'specific conductance' and is the reciprocal of resistivity.

Creepage
Creepage is the shortest path along the surface of an insulator or insulating medium that separates two conductors. The insulator or insulation medium cannot be air.

CSA
Canadian Standards Association.

Current

Constant Current
Current the measuring instrument will output during a resistance test, independent of device loading.

Current Polarity
Test signal type: positive or negative DC or positive or negative pulse. Helps reduce thermal emf effects.

DC
Direct current, non-reversing polarity. The movement of charge is in one direction. Used to describe both current and voltage. Batteries supply direct current.

Delay Time
The amount of time an instrument waits before performing a task.

Discharge
The act of draining off an electrical charge to ground. Devices that retain charge should be discharged after a DC hipot or IR test.

DUT
Device Under Test - the product being tested.

Dwell Time
The amount of time the DUT is allowed to stabilize at the test voltage before measurements are performed.

emf
Electromotive force: the difference in electric potential that exists between two dissimilar electrodes immersed in the same electrolyte or otherwise connected by ionic conductors.

Electric Current
The flow of electrons (or electron "holes") through a conducting material, which may be a solid, liquid, or gas; the rate of flow of charge past a given point in an electric circuit. The magnitude of current flow through the conductor is proportional to the magnitude of voltage or electrical potential applied across the conductor and inversely proportional to the resistance (or impedance) of the conductor. Current is expressed in amperes or milliamperes (amperes/1000).

Equivalent Circuit
The configuration of the device under test. The components of the DUT can be represented as a series or parallel equivalent circuit.

Fall Time
The amount of time it takes to gradually decrease the voltage to zero potential.

Frequency
The rate at which a current or voltage reverses polarity and then back again completing a full cycle, measured in Hertz (Hz) or cycles per second.

Ground
The base reference from which voltages are measured, nominally the same potential as the earth. Also the side of a circuit that is at the same potential as the base reference.

Handler
Device for remote control of test instrument in component handling operations.

Hertz
The unit of measure of frequency, equivalent to cycles per second.

High Limit
The upper value for a test to be considered a PASS. If the measured value is higher than the high limit the test is considered a FAIL.

IEEE
An acronym for Institute of Electrical and Electronic Engineers, a professional association of engineers.

IEEE 488
General Purpose Interface Bus (GPIB) - an industry standard definition of a parallel bus connection for the purpose of communicating data between devices.

Impedance
A term used with alternating current circuits to describe the "ac resistance" to the flow of current through a circuit when an ac voltage is applied across the terminals of that circuit. Impedance is a complex quantity composed of real (in phase with voltage) and reactive (out of phase by 90°) components. Impedance is calculated as voltage divided by current.

Impedance (Z) is a vector summation of resistance (R) and reactance (X).
Capacitors: Reactance = $X_C = 1/j\omega C$
Inductors: Reactance = $X_L = j\omega L$
Resistors: Resistance = R
Impedance = Z = square root $(X^2 + R^2)$

Inductor
Abbreviated L (as in LCR). An inductor is a coil of wire. It is used to create electromagnetic induction in a circuit.

Inductance
The property of a coil to oppose any change in current through it. If the turns (coils) of the wire are stretched out, the field intensity will be less and the inductance will be less. Unit of measure is the Henry (H).

Inductive Reactance
A measure of how much the counter electro-magnetic force (emf) of the coil will oppose current variation through the coil. The amount of reactance is directly proportional to the current variation: $X_L = 2\pi fL$.

Kelvin Connection
A circuit configuration that automatically compensates for measurement errors caused by resistance of leads between a tester and the point of measurement on a DUT.

Level
The test signal level is the programmed RMS voltage of the generator in an LCR meter. The actual test voltage across the DUT is always less than the programmed level.

Load
The total resistance or impedance of all circuits and devices connected to a voltage source.

Low Limit
The lower value for a test to be considered a PASS. If the measured value is lower than the low limit the test is considered a FAIL.

Milliohmmeter
An instrument designed to measure low values of resistance using a dc current or voltage.

NIST
National Institute of Standards and Technology, an agency of the U.S. Government that sets standards for physical measurements and references, formerly called the National Bureau of Standards.

NRTL
Acronym for Nationally Recognized Testing Laboratory, such as Underwriters Laboratories (UL), Factory Mutual (FM), or Canadian Standards Association (CSA).

Offset
An automatic zeroing function to correct for leakage currents or additional resistance due to test leads or fixtures. An offset is performed by making a measurement at the programmed test settings, calculating the difference between the leakage current or resistance measured and the ideal current or resistance and then subtracting this difference from all future measurements.

Ohm's Law
The fundamental law of electrical circuits that describes the relationship between voltage, current and impedance (or resistance). For DC circuits, Ohm's Law states that Current =Voltage/Resistance. For AC circuits, Current = Voltage/Impedance. Stated conversely, Voltage = Current x Resistance (DC) or Current x Impedance (AC). The difference between the dc resistance and ac impedance is that ac circuits must deal with phase and time relationships and dc circuits do not.

Ohms (W)
The unit of measure of resistance and impedance, derived from Ohm's Law.

OSHA
Occupational Safety and Hazards Administration, an agency of the U.S. Government that regulates industrial safety.

Parameter
Electrical property being tested. The primary parameter (L, C, R) is the first property characterized of the device under test. The secondary parameter (D, Q, θ) is the second property characterized of the device under test.

Permittivity
Abbreviated ε. The dielectric constant multiplied by the dielectric constant of empty space (ε_0), where the permittivity of empty space (ε_0) is a constant in Coulomb's law, equal to a value of 1 in centimeter-gram-second units and to 8.854 x 10^{-12} farads/meter in rationalized meter-kilogram-second units.

Phase
The time relationships between alternating voltages, currents, and impedances. Usually expressed as complex vectors with "real" (in-phase) and "reactive" (out of phase) components.

Polarization
A term used to describe a "one way" limitation on the insertion of a plug into a receptacle for a corded product. A polarized plug can be inserted in only one orientation and cannot be reversed.

Potential
Electrical potential is a term equivalent to "voltage".

Prefixes
The prefixes for Multiple Scientific Engineering Symbols are:

1000000000000000	10^{15}	Peta	P
1000000000000	10^{12}	Tera	T
1000000000	10^{9}	Giga	G
1000000	10^{6}	Mega	M
1000	10^{3}	Kilo	k
0.001	10^{-3}	milli	m
0.000001	10^{-6}	micro	µ
0.000000001	10^{-9}	nano	n
0.000000000001	10^{-12}	pico	p
0.000000000000001	10^{-15}	femto	f

Protective Earth
Conductor that connects between any protectively earthed parts of a Class I product and an external protective earth connection.

Microsecond
One millionth of a second.

Range
The resistance ranges the test instrument uses for reference in making the measurement.

Reactive
The component of an ac voltage, current, or impedance that is 90° out of phase with the "real" or in phase component. Reactive components are associated with capacitive or inductive circuits.

Real
The component of an ac voltage, current, or impedance that is in phase with the "real" component. Real components are associated with purely resistive circuits.

Regulation
When applied to electrical circuits, regulation refers to the variation in output voltage that occurs when the input voltage changes or when the connected load changes. When applied to test laboratories and agencies, refers to the control exercised by these entities over test specs and rules.

Repeatability
The difference between successive measurements with no changes in the test setup or test conditions.

Reproducibility
Similar to repeatability but adds the element of what could be expected under real life conditions. Reproducibility would take into account the variability in things like fixturing where the DUT being tested is removed from the fixture and then inserted again.

Resolution
The smallest value that can be shown on the display in a digital instrument. LCR meters typically specify a measurement range that is the largest and smallest value that can be shown on that meter's display.

Resistance
The electrical characteristic that impedes the flow of current through a circuit to which voltage has been applied. Resistance is calculated by Ohm's Law as voltage divided by current (for DC circuits). For AC circuits, it is the in-phase or "real" component of impedance. Units are expressed in ohms (Ω).

Bonding Resistance
Electrical resistance across weld joints, crimped connections and bolted joints.

Contact Resistance
Measured resistance of closed contacts, typically that of switches, relays and connectors.

Dry Contact Resistance
Resistance across closed contacts is usually decreased, with applied voltage, due to attraction of molecules on the surface of contacts. By limiting the test voltage and current, electrical charges to the contacts are minimized.

Low Resistance
Electrical resistance typically below 10 ohms, often expressed in terms of milliohms (10-3) or micro-ohms (10-6).

Winding Resistance
Electrical resistance of windings which comprise motors, coils, transformers, relays and ballasts.

Resistivity
the electrical resistance of a material to the flow of current times the cross-sectional area of current flow and per unit length of current path. It is also known as 'specific resistance'.

RS232
An industry standard definition for a serial line communication link or port.

SCC
The Standards Council of Canada, an agency of the Canadian Government analogous to OSHA in the United States.

Speed
The rate at which the instrument makes a measurement in measurements per second. Speed is inversely proportional to accuarcy.

Stabilization Time
The time required for a transient disturbance to decay to a steady state value.

Source Impedance
The impedance of the measuring instrument applied to the input terminals of the device under test (DUT). If 1V is the programmed voltage and the source impedance is 25 ohms, DUT is 25 ohms, then the voltage at the DUT is 0.5V.

Temperature Compensation
Measurements corrected from an ambient temperature back to a reference temperature (usually 20 degrees C)

Temperature, Critical
Temperature for superconductors at which the electrical resistivity of a metal drops to zero.

Thermal emf
the voltage generated by connecting two dissimilar metals, at different temperatures, together.

Trigger
The device for initiating the test (applying the voltage or current).

External Trigger
The test is initiated via an external source such as a computer with an IEEE-488 or Handler interface. One measurement is made each time the external trigger is asserted on the handler.

Internal Trigger
The instrument continuously makes measurements.

Manual Trigger
The operator initiates the test by pressing the [START] button. One measurement is made each time the trigger is pressed.

UL
Underwriters Laboratories, Inc., an NRTL located in Illinois.

Voltage
The electrical potential applied to a circuit.

Waveform
The instantaneous value of a variable such as voltage or current plotted against time.

X (Reactance)
Reactance is the imaginary component of Impedance.

Y (Admittance)
Admittance is the reciprocal of Impedance. $Y = 1/Z$

Z (Impedance)
Impedance is the sum of alternating current oppositions (capacitive reactance, inductive reactance and resistance). $Z = R + jX$

Zero Offset
A correction for residual resistance resulting for the test leads and connection. Determined by a SHORT routine with the Kelvin lead test points shorted together.

1ST Edition, June 2005, P/N 030144/A1

Printed in the U.S.A.