

Solutions for Production Testing of Connectors

Introduction

As electronics have become increasingly pervasive, the importance of electrical connectors has increased dramatically.¹ Quality connectors are vital to ensuring overall product reliability in applications ranging from motor vehicles to transatlantic telecom systems. The degree and type of electrical testing that connectors undergo typically depends on how crucial they are to the overall performance of the systems in which they are installed. Stringent electrical tests are often specified when high reliability is required. Isolation and continuity are the two most commonly measured parameters in connector testing. Isolation measurements are usually performed between each of the connector pins or between the pins and the outer shell of the connector. Isolation measurements are used to verify that signals are not misdirected and insulation is sufficient under the operating conditions of the connector. Continuity is measured between pins to ensure that once the connector is installed, the electrical signals will be transmitted properly.

There are a number of instruments that may be used in connector testing; thus, selecting the optimal solution for a particular application may not be an easy task. This note addresses many of the issues involved in implementing a connector characterization system.

Test Description

Isolation (Insulation) Resistance

Given today's ever-shrinking circuit geometry and the higher frequencies of electronic signals, isolation is an important consideration for reliability and crosstalk. Environmental conditions such as high heat and vibration may also cause degradation of insulation and shorts within the connector. Isolation is typically tested by applying a voltage across two pins in a connector and measuring the resulting current that flows between them. The corresponding resistance from the test is compared to a predetermined threshold value. If the resistance level is too low, the connector is rejected. Common threshold levels range from $1\text{M}\Omega$ to $1\text{T}\Omega$. **Figure 1** shows the electrical equivalent of a connector; the isolation resistance is identified as R_{iso} . When testing very high ohmic devices, the measured resistance may change significantly in response to a change in the applied voltage, an effect known as the voltage coefficient of resistance. This effect makes it preferable to test high value resistors with the source voltage, measure current method.

The actual test voltage chosen depends on the capabilities of the instrumentation and the degree of current measurement sensitivity available, as well as the ratings of the connector material. For a given resistance value, a higher voltage will result in a higher current signal, which can be measured with higher resolution. **Figure 2** illustrates the constant voltage method for measuring high resistances. When the measured current is fairly low, the likelihood of measurement errors increases. Contributors to error include noise generated by electrically charged objects in the environment, leakage current in the test fixture, and the amount of cable capacitance present. Strategies for overcoming these measurement obstacles are discussed in the "Typical Sources of Error" section in this note.

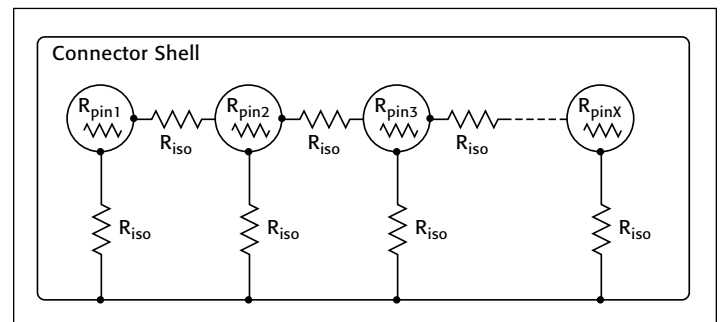


Figure 1. Electrical Equivalent of a Connector, Showing Pin Continuity and Isolation Resistance.

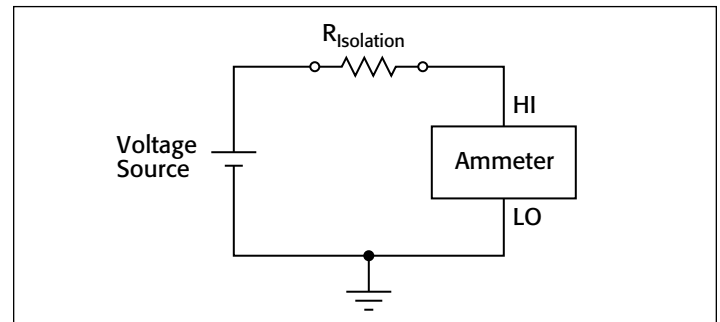


Figure 2. Constant Voltage Method for Measuring High Resistance.

Pin Continuity

As long-term performance of connectors becomes increasingly important, the continuity performance from the input to the output of the connector will also become more important. Connector pins are often made from metal alloys, so the measurement result is a very low resistance value. Typically, continuity is tested by sourcing a constant current through the pin and measuring the corresponding voltage drop. Pin continuity is identified as R_{pin} in **Figure 1**. Using high currents to

¹ Although this application note targets connector production testing, engineers in cable assembly manufacturing operations perform tests similar to those presented here. These engineers may find the information in this note helpful when selecting test equipment.

test continuity has two advantages. First, using a sufficiently high test current ensures the resulting voltage signal will be above the noise floor of the test system. The noise floor includes the error related to the voltage drop in lead resistances and the voltages due to the variation of temperature at junctions of dissimilar metals. Second, a higher test current can also serve as a stress test for the connector. Often, the connector will be tested at a current level higher than the rated current level in order to verify performance margin. **Figure 3** illustrates how a current source and voltmeter are used to measure resistance. Most instruments designed to measure low resistances have a built-in current source and voltmeter and can be configured to measure resistance with one instrument bus command or button on the front panel.

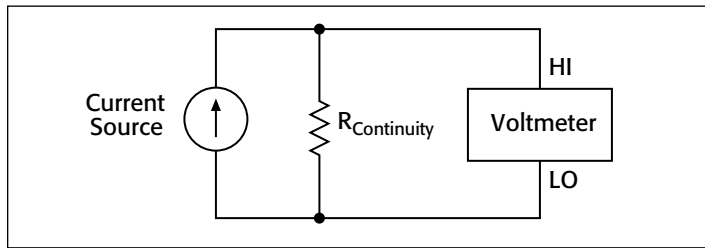


Figure 3. Constant Current Method for Measuring Low Resistance

Solutions Overview

Table 1 shows a representative selection of Keithley test equipment solutions for connector testing. Use this table to identify the solution that best fits the specific measurement parameters.

When selecting test equipment, the user/design engineer needs to determine appropriate accuracy and speed requirements, the range of resistances to be measured, the method of measuring resistance, and whether or not it's necessary to control the value of test current or voltage. Additional features such as handler interfacing and limit testing may also be of importance to the user.

Selection of a switch solution requires a plan of the test environment and the sequence of tests to be performed. Answering the following questions will assist the engineer in designing a switch system:

- How many devices are to be tested?
- Is parallel testing needed?
- Will the system be performing multi-pin/pin-to-pin testing?
- What are the maximum voltage and current levels to be sourced and/or measured?

Table 1. Instrument Selection Guide for Connector Test.

Test Equipment	Pin Continuity	Isolation Test	Measurement Ranges	Notable Features
Model 2750 Multimeter/ Switch System	•	•	Pin Continuity: 1mΩ+ Isolation: Up to 100MΩ	Optional internal switching. Offset compensation. Common-side ohms configuration. Enhanced low ohms measurement capability.
Model 2790 SourceMeter/ Switch System	•	•	Pin Continuity: 10mΩ+ Isolation: Up to 1GΩ	Optional internal switching. Offset compensation. 500V programmable voltage source (low power). 50mA programmable current source.
Model 2400 SourceMeter® SMU Instruments	•	•	Pin Continuity: 1mΩ+ Isolation: ~ 1GΩ	Programmable test current (pin continuity). Programmable voltage source (isolation test). Ability to save 100 test setups in memory. Auto output-off → reduce device heating. Contact check option.
Model 2400 SourceMeter and Model 2182A Nanovoltmeter	•		Pin Continuity: 1μΩ+	Programmable test current. Delta mode—current reversal technique for 2400 and 2182A.
Model 3706A System Switch/ Multimeter	•	•	Pin Continuity: 1mΩ+ Isolation: Up to 100MΩ	Optional internal switching. Offset compensation. Common-side ohms configuration. Enhanced low ohms measurement capability. Up to 576 two-wire multiplexer channels.
Model 6487 Picoammeter with Voltage Source		•	Isolation: 1kΩ–1TΩ	Independent programmable voltage source (±500V). V/I Ohms.
Model 6517B Electrometer		•	Isolation: 200kΩ–1e17Ω	Independent programmable voltage source (±1000V). Optional internal switching. Optional temperature and humidity measurements.
Model 2001/2002 High Performance Multimeter	•	•	Pin Continuity: 10mΩ Isolation: Up to 1GΩ	Offset compensation. Optional internal switching. Optional Model 1801 Nanovolt Preamp to increase sensitivity (with this preamp, pin continuity range can extend down to 5mΩ at a test current of 9.2mA).
Model 6221 Current Source and Model 2182A Nanovoltmeter	•	•	Pin Continuity: 100nΩ Isolation: Up to 100GΩ	Delta Mode for low thermal, low resistance measurements.

- What are the speed and accuracy requirements?

After having determined the specific application needs, the designer may wish to review the switching and measurement solution with a Keithley Applications Engineer.

Test System Option Descriptions

Series 3700A or Series 2700/Integra Systems

Choosing the appropriate test equipment can be difficult. Series 3700A or Series 2700 Systems simplify the test setup by combining the switch and measurement hardware into a single unit. These products incorporate a precision digital multimeter with a wide assortment of switching cards and switching topologies (multiplexer, matrix, etc...). **Table 2** provides an overview of the Series 3700A and 2700. For more details on the available switching modules, see the keithley.com website.

Both of these systems measure all ranges of resistance using the constant current method. The instruments' range (up to 100MΩ) may be adequate for measuring isolation resistance in many applications. These models also offer four-wire connections, dry circuit testing (3706A and 2750), offset compensation and low current source to prevent device heating in low resistance measurements. The section of this note titled "Typical Sources of Error" discusses how these features can be useful in reducing or eliminating measurement errors.

The Model 3706A and Model 2750 mainframes have an enhanced ability to measure low ohms accurately. This makes it an ideal choice for pin continuity tests. Pairing the Model 3721 Switch Card with the 3706A or the Model 7701 Switch Card with the Model 2750 permits four-wire connections without comprising channel count. These cards offer the same channel count (3721: 40 channels, 7701: 32 channels) for four-wire resistance measurements as it does for two-wire measurements by using a common-side ohms configuration. As shown in **Figure 4**, a four-wire measurement is made by connecting the Sense HI and Input HI to a bus that is common with one side of all the devices. With such a configuration, up to 240 low resistance devices may be tested using the Model 3706A and six Model 3721 Switch Cards.

Testing multi-pin connectors may require a switch configuration in which measurements are made from any one pin to any other. A matrix switch card permits convenient

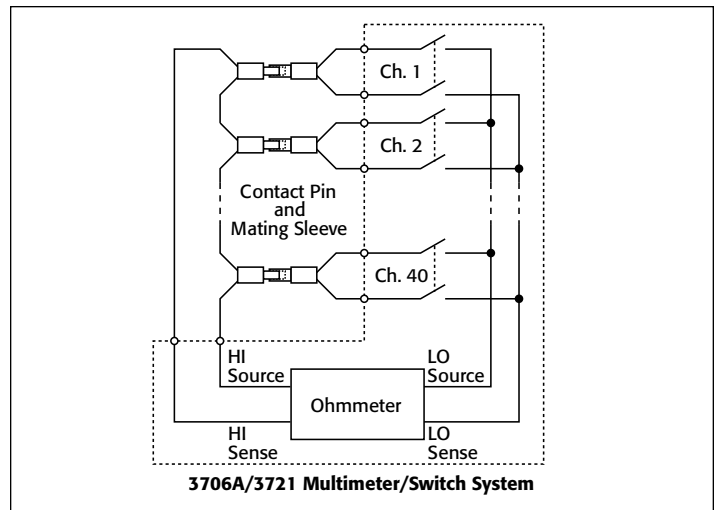


Figure 4. Common-Side Ohms Configuration

pin-to-pin testing and are available in both the Model 3700A and Series 2700 instruments.

Model 2790 SourceMeter/Switch System

If source programmability is required, consider the Model 2790 SourceMeter Switch System as a possible solution. A member of the Integra Series family of products, the Model 2790 has the multimeter functions of the Model 2700 with optional switching modules that include voltage and/or current sources. Three optional modules for the Model 2790 are available: Model 7751 High Voltage Source/Switch Module, Model 7752 Low Voltage Current-Source-Only Source/Switch Module, and Model 7702 40-Channel General Purpose Multiplexer Module.

The Model 7751 module contains a low power programmable 500V voltage source with a maximum current output of 50μA. It also has a 50mA programmable current source. Additionally, an I-V converter is included on the 7751 module in order to make more accurate measurements than are possible with the ammeter internal to the Model 2790 mainframe. These enhanced source and measure capabilities allow making isolation measurements up to 1GΩ and continuity measurements down to 10mΩ with the Model 2790. The Model 7752 switch card is also an option for the Model 2790. Containing just the 50mA programmable current source, the 7752 is ideal for applications where only continuity measurements will be made.

Table 2. Integra Series Comparison Chart

Integra Series Product	Number of Slots	Communication Interface	Maximum Channel Count or Crosspoints	Internal Data Buffer Capacity	Maximum Reading Rate, Single Channel (readings/second)	Additional Features
Model 2700	2	GPIB, RS-232	80 channels or 96 crosspoints	55,000	2000	
Model 2701	2	Ethernet, RS-232	80 channels or 96 crosspoints	450,000	3500	Portable, ½ rack, 2U design
Model 2750	5	GPIB, RS-232	200 channels or 240 crosspoints	110,000	2500	Low ohms capability (1μΩ max. sensitivity)
Model 3706A	6		576 channels or 576 crosspoints	650,000	14,000	Low ohms capability (0.1μΩ max. sensitivity)

Each Model 7751 or 7752 module allows two-wire connections to 12 DUTs. If more connections are required, consider using the Model 7702 40-Channel multiplexer card in the second slot of the Model 2790. In addition to higher channel count, this card permits routing to the DMM for general measurements, including voltage, current, and resistance. The sources on the Model 7751/2 cards are accessible via screw terminals and may be routed to the Model 7702 card for measurement.

For some applications, the measurement range of the Series 2700 instruments may not be broad enough to accommodate the test requirements for both isolation and continuity measurements. The engineer may also want more flexibility in the level of source current or voltage used in the test. In these cases, one of the Series 2400 SourceMeter® SMU instruments may be a more suitable solution.

Series 2400 SourceMeter® SMU Instruments

SourceMeter SMU instruments consist of a voltage source, current source, voltmeter, ammeter, and ohmmeter in a single half-racksized package. With these components, SourceMeter SMU instruments offer greater measurement sensitivity for pin continuity tests and extended range for isolation resistance tests. Some devices, however, may not be able to withstand such a high level of current without experiencing device heating, which can introduce significant error to the measurement. The SourceMeter products have an auto output-off feature that keeps the source turned on only long enough to complete the measurement (only a few milliseconds), which reduces device heating. As an added benefit, auto output-off provides cold switching, for extended relay life in switch systems. Series 2400 instruments also include offset compensation, as well as programmable compliance settings that allow users to apply dry circuit conditions.

For extremely low resistance devices that require a high degree of test accuracy, a more sensitive voltmeter, such as the Model 2182A Nanovoltmeter, will likely need to be paired with the SourceMeter SMU instrument. Using the Model 2182A and a SourceMeter SMU instrument, the uncertainty of a 1m Ω measurement with a 10mA source is 0.45%. Comparing these specifications with the example in the previous paragraph (where the SourceMeter SMU instrument alone was used), the 2182A/2400 configuration with a 100 \times reduction in source current leads to only a 0.15% increase in uncertainty. The combination of these two instruments offers wider flexibility in source current and measurement time. The Delta Mode feature of the Model 2182A also allows coordination with the SourceMeter SMU instrument to add offset compensation to the measurement.

Another potential source is to use the Model 6221 Current Source with the Model 2182A Nanovoltmeter. They were designed to work together for low resistance measurements.

At 100mA test current from the Model 6221 and the sensitivity of the Model 2182A at 10nV, the low resistance measurement is sensitive to 1e-7 Ω (100n Ω).

Like the Model 2400, you have control over the test current. And the Model 6221 has the trigger link connection to trigger the Model 2182A for delta measurements. The main advantage to using Models 6221/2182A over Models 2400/2182A is that the Model 6221 controls the two units. The data is shown on the Model 6221 in volts, ohms, watts, or siemens. Since the two units were developed with delta mode in mind, the system is very simple to configure.

Once the serial cable and trigger link cable are connected between the two instruments, it takes only a few button pushes to configure and start the delta mode. The Model 6221's maximum current is 100mA.

The 2400 Series' maximum current is 5A. If using 100mA and below, then Models 6221/2182A are recommended. If using above 100mA, then the 2400 Series with the Model 2182A is recommended.

As discussed previously, it's generally preferable to test high value resistors with the source voltage method. Given that Series 2400 instruments all have a voltage source, these instruments may be used to measure isolation resistances of up to 1G Ω or more with reasonable accuracy. With a 1100V source, the Model 2410 offers the possibility of testing very large resistances. Testing a 10G Ω resistor at 500V, the Model 2410 offers just 0.67% uncertainty.

Additional Isolation Test Equipment

Other solutions for high insulation resistance measurement include the Model 2001, Model 2002, and Model 3706A Digital Multimeters. These instruments offer the ability to measure up to 1G Ω using the constant current method, in addition to standard multimeter functions such as AC voltage, AC current, and temperature. The Model 6487 Picoammeter has an independent 500V programmable source voltage and a "V/I resistance mode," which make it suitable and convenient for measuring insulation resistance. The Model 6517B electrometer, with an independent 1000V programmable source and 3fA offset on its ammeter, offers the best high resistance measurement accuracy of all standard Keithley instruments. This instrument may be necessary for extremely high insulation resistances (hundreds of gigaohms or teraohms).

Obviously, there are many instrumentation options available. Therefore, when choosing test equipment, the project engineer should carefully consider the entire range of resistance to be tested and other measurements or applications for which the instrument may be used.

Switching Solutions

Once it's clear what instrumentation option is most appropriate, the project engineer can focus on the switching requirements of the application. While the Series 2700 Integra Systems and Model 3706A can be used for switching alone, Keithley also offers the Series 7000 line of switching products, which are designed for use with measurement hardware. The Model 7001 and 7002 mainframes house and control the plug-in switch cards,

which contain the relays that will connect the test equipment to the test points of the connector. Plug-in switch cards are available in a variety of relay configurations. The multiplexer and the matrix are the two most common switch topologies. Multiplexer cards are used to connect one instrument to many test points or vice versa. *Figure 5* shows a simple multiplexer configuration in which resistors are connected across each relay. When only one channel is closed, a device is connected to the inputs of the SourceMeter SMU instrument and can be tested. A matrix configuration, on the other hand, provides the flexibility required to test many different channel patterns. In a matrix, any one point in the system may be connected to any other point in the system. For example, this configuration is useful when more than one instrument is needed to test each device. *Figure 6* shows a simple matrix configuration with connections to two instruments and five pins of a six-pin device. Although two channels must be closed in order to perform a measurement, the matrix configuration allows testing any possible combination of connector pins.

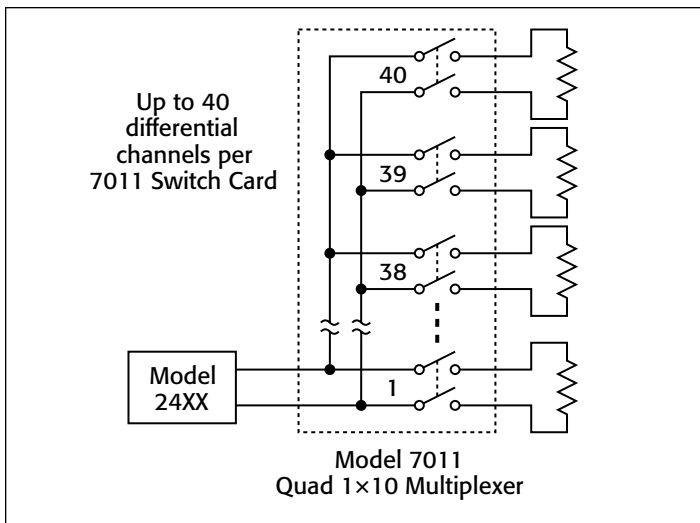


Figure 5. Multiplexer Configuration

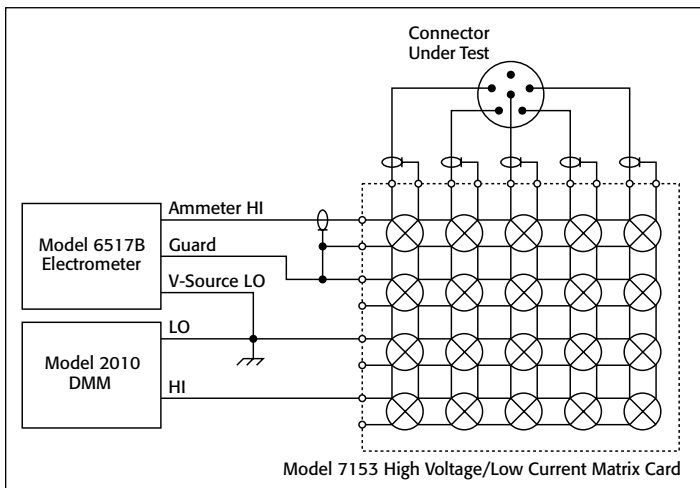


Figure 6. Matrix Configuration

The Series 7000 switch mainframes are “smart” in that they can save switch patterns and sequences. These mainframes also have built-in trigger hardware (see the Trigger Link description in the section titled “Optimizing the Measurement”) that affords hardware handshaking between the switch mainframe and the measurement equipment. With this external triggering, the instruments can execute the programmed test sequence without operator intervention.

In addition to the relay configuration, it’s very important to consider the specifications of the switch card when choosing switch hardware. The goal of switching is to make connections without compromising the measurement. When measuring pin continuity (low resistances), it’s important to choose a switch card with low contact potential and a current rating high enough to withstand test current. When measuring insulation resistances, choose a switch card with low offset current, high isolation resistance, and a voltage rating high enough to withstand source voltage. For more detailed information on selecting appropriate switch hardware, refer to Keithley’s *Switching Handbook*.

Optimizing the Measurement

Trigger Link

The Trigger Link is a hardware handshake bus used by the instruments to ensure proper test sequencing. It’s a standard feature on all newer Keithley instruments, including those mentioned in this note. When the meter and switch mainframe are connected via a Trigger Link cable, they can trigger each other to allow faster test completion. This built-in bus eliminates the need for direct PC control of most system synchronization functions. When the Trigger Link function is used properly, the only functions the PC performs are initiating the test and retrieving data from the system.

Solutions to Typical Sources of Error

Noise

Noise can come from many sources in the production environment. When electrically charged objects, such as machinery, electrical motors, or fluorescent lights are brought near an uncharged object (i.e., the device under test), small, unwanted voltages may be generated. To minimize the effects of this electrostatic interference, ensure all system cabling is properly shielded. All shields should be connected to a single common point such as the signal LO. Whether the system cabling is single- or multi-conductor, it’s best to use one shield around the wire bundle.

Leakage Current

Stray or leakage current in cables and fixtures can be a source of error in measurements of extremely low currents, such as for high impedance devices or parameters. To minimize leakage current problems, the test fixture insulation must be made of materials with resistances much higher than the impedances being tested. If proper care is not taken, some portion of the test current will flow through any low impedance path to ground,

affecting measurement results. An alternate method of reducing leakage currents is to guard the test. When testing multi-pin connectors, it's also important to guard the other pins that are not being tested because the resistance between the other pins and ground may affect the final measurement. By connecting the guard output from the meter to the other pins, the undesirable resistance and subsequent leakage to ground is eliminated. Refer to Keithley's *Low Level Measurements* handbook for detailed information on guarding.

Figure 7 illustrates how to connect the Model 6517B Electrometer to make a high resistance measurement properly to minimize leakage current, cable capacitance, and noise.

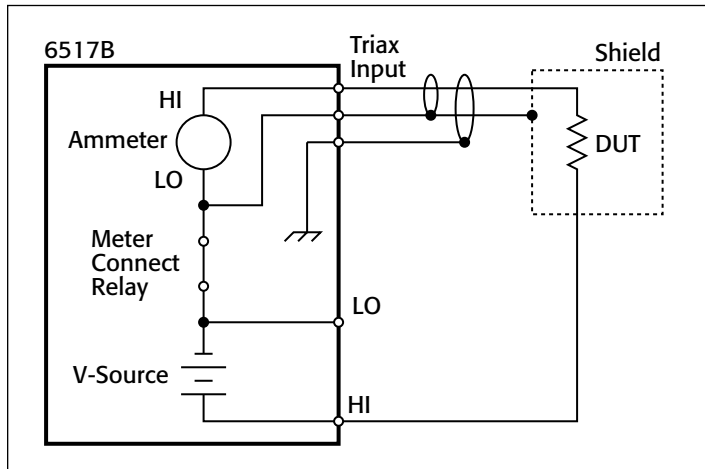


Figure 7. Model 6517B Connections for Making Guarded Ohms Measurement

Cable Capacitance

The amount of capacitance in the test system cabling will determine the settling time required to obtain an accurate reading. Settling time is determined by the system's RC time constant; a large resistance value can result in significant settling times, even with a relatively small capacitance value. For best accuracy, let four to five time constants elapse before taking the measurement. System capacitance, and thereby settling time, can be reduced by keeping cable lengths as short as possible, guarding the system properly, and using the source voltage, measure current method of making high resistance measurements.

Lead Resistance

A common source of error for low impedance occurs when only two test leads are connected to the DUT. In this configuration, both the current source and voltmeter use the same pair of leads. The lead resistance, being in series with the DUT, is added to the final measurement. Such a setup is especially detrimental for testing connector pins because the test lead resistance may actually be greater than the resistance of the connector itself.

Figure 8a illustrates this effect. To eliminate lead resistance effects, the current source and voltmeter must be separated so that four wires (force and sense leads) are used to connect to the device. The amount of current in the sense leads is negligible and so the lead resistance is insignificant. **Figure 8b** shows how

the voltmeter senses the voltage drop across the DUT without the effect of the lead resistance.

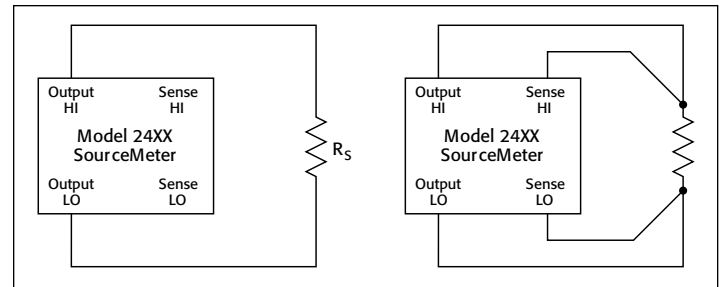


Figure 8a. Two-Wire Measurement

Figure 8b. Four-Wire Measurement

Thermoelectric EMFs

Thermoelectric EMFs may cause measurement problems for low impedance measurements. The voltage drop across low impedance devices is typically very small. Thermoelectric EMFs may be on the same order of magnitude as the test signal, thereby introducing significant error. Most of the instruments discussed in this note can be programmed to cancel the effects of thermoelectric offsets automatically through the offset compensation or current reversal technique. This technique involves taking two measurements. The first measurement is taken at the desired positive source level, then the second is taken at the opposite source polarity (or at 0A, depending on the instrument). These two measurements are then subtracted from each other and the resulting resistance is calculated as follows:

$$\text{Delta Mode Ohms} = \frac{(V_2 - V_1)}{(I_2 - I_1)}$$

where: I_1 is the source current set to a specified positive value.
 I_2 is the same current value as I_1 with opposite polarity.
 V_1 is the voltage measured at I_1 .
 V_2 is the voltage measured at I_2 .

Equipment List

The equipment needed to build the connector test system illustrated in **Figure 6** includes:

- Keithley Model 6517B Electrometer/High Resistance System
- Keithley Model 2010 Low Noise Multimeter
- Keithley Model 7001 (or 7002) Switching Mainframe
- Model 7153 4x5 High Voltage Low Current Matrix Switching cards. Each card can accommodate up to five connector pins.
- Model 7153-TRX cables for connecting to the 7153 card. Two cables are required for each switch card in the system.
- Model 237-TRX-T 3-slot Triax T adapters. Four adapters are required for each switch card in the system.
- PC with Model KUSB-488 Interface Card
- Three Model 7007 IEEE-488 Interface Cables

Test System Safety

Many electrical test systems or instruments are capable of measuring or sourcing hazardous voltage and power levels. It's also possible, under single fault conditions (e.g., a programming error or an instrument failure), to output hazardous levels even when the system indicates no hazard is present. These high voltage and power levels make it essential to protect operators from any of these hazards at all times. Protection methods include:

- Design test fixtures to prevent operator contact with any hazardous circuit.
- Make sure the device under test is fully enclosed to protect the operator from any flying debris. For example, capacitors and semiconductor devices can explode if too much voltage or power is applied.
- Double insulate all electrical connections that an operator could touch. Double insulation ensures the operator is still protected, even if one insulation layer fails.
- Use high reliability, fail-safe interlock switches to disconnect power sources when a test fixture cover is opened.
- Where possible, use automated handlers so operators do not require access to the inside of the test fixture or have a need to open guards.
- Provide proper training to all users of the system so they understand all potential hazards and know how to protect themselves from injury. It's the responsibility of the test system designers, integrators, and installers to make sure operator and maintenance personnel protection is in place and effective.

Alternative Solutions

Some types of connectors must be tested over wider voltage and current ranges than those described here. Keithley Application Note #2154, "Testing Devices with High Voltage and High Current," describes how to configure a test system based on SourceMeter SMU instruments that supports testing isolation resistance up to 1100V and continuity up to 3A.

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