KEITHLEY
Application Note Series
Number 2208

Solutions for Production Testing of Connectors

Introduction

As electronics have become increasingly pervasive, the importance of electrical connectors has also increased dramatically. Quality connectors are vital to ensuring overall product reliability in applications ranging from motor vehicles to trans-atlantic telecom systems. This application note addresses many of the issues involved in implementing a connector characterization system.

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're installed. Stringent electrical tests are often specified when high reliability is required. Obviously, connectors used in international telecommunications systems are more crucial than the serial port connector on the back of a desktop personal computer.

The two most commonly measured parameters in connector testing are isolation and continuity. Isolation measurements are usually performed between each of the connector pins or between the pins and the outer shell of the connector. Also, during connector manufacturing and testing (both mechanical and environmental testing), the continuity may become compromised. Testing the continuity of each pin ensures that once the connector is installed, the electrical signals will be transmitted properly.

Test Description

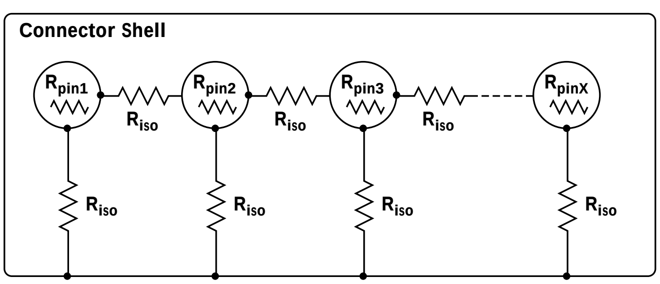

Figure 1. Electrical equivalent of a connector showing pin continuity and isolation resistance.

Isolation (Insulation) Resistance

Essentially, the isolation measurement verifies that none of the connector pins are shorted to each other. Given today's ever-shrinking circuit geometry and the higher frequencies of electronics, isolation is an important consideration for reliability and minimizing crosstalk. A connector with no shorts today may become shorted tomorrow in an environment with high heat and vibration, such as under the hood of a car.

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 1MΩ to 1TΩ. The isolation resistance is shown as R_{iso} in ***Figure 1.***

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 constant voltage, measure current method. The actual test voltage chosen depends on the capabilities of the instrumentation and the degree of current measurement sensitivity available. 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.

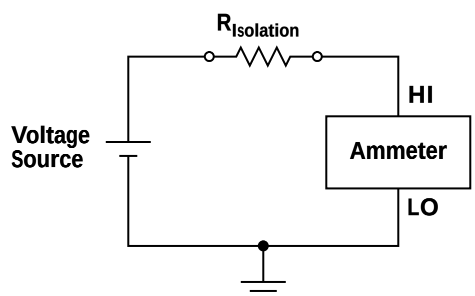

Figure 2. Constant Voltage Method for Measuring High Resistance.

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. Typically, continuity is tested by sourcing a constant current through the pin and measuring the corresponding voltage drop. Connector pins are often made from metal alloys, so the measurement result is a very low resistance value. Pin continuity is shown as R_{pin} in ***Figure 1.***

Using high currents to 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 ratio of the test current to the noise current will determine the signal-to-noise ratio and accuracy of the continuity test. Second, higher test currents 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.

If stress testing is unnecessary, a digital multimeter (DMM) with low voltage noise can be used to measure the pin resistance directly. ***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.

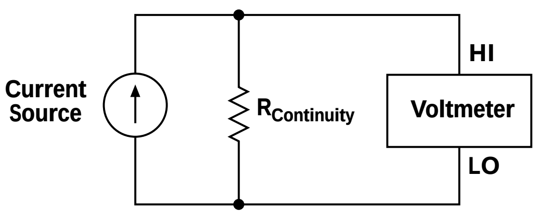

Figure 3. Constant Current Method for Measuring Low Resistance.

Test System Option Descriptions

Single Meter Connector Test System

The 2400 Series of SourceMeter® instruments provides low noise, bipolar constant current and voltage sources with precision readback measurement capabilities. Creating a test program that switches between constant current and voltage modes is relatively straightforward and seamless. All models in the SourceMeter family are programmed in exactly the same manner. The only differences between these instruments are the differing dynamic ranges of their voltage and current outputs.

The Model 2400 and Model 2410 are the most popular choices for connector testing. Both can source up to 1A. The 2400 can output 210V, while the 2410 is capable of 1100V. Both supplies are limited to 22W. These output ranges mean that only one measurement instrument is required for both isolation and continuity measurements, which greatly reduces programming, cabling, and potential error sources.

Connectors typically contain many pins, so many measurement channels are required to test each pin. The most cost-effective way of adding measurement channels is to include switching in the test system. When switching is added, the user can connect the SourceMeter instrument to specific points on the connector for testing while simultaneously isolating other points. Also, if a PC is added to the system to control the instrument and switching, the entire connector test assembly can be automated, eliminating the need for constant operator oversight. ***Figure 4*** illustrates a simple connector test configuration based on a SourceMeter instrument.

A SourceMeter-based connector test system is both cost effective and easy to implement in terms of cabling, programming, and complexity. Systems like this can typically resolve signals as low as 10μΩ and measure resistances as high as 20GΩ. ***Figure 5*** demonstrates how the SourceMeter can be used to test a connector.

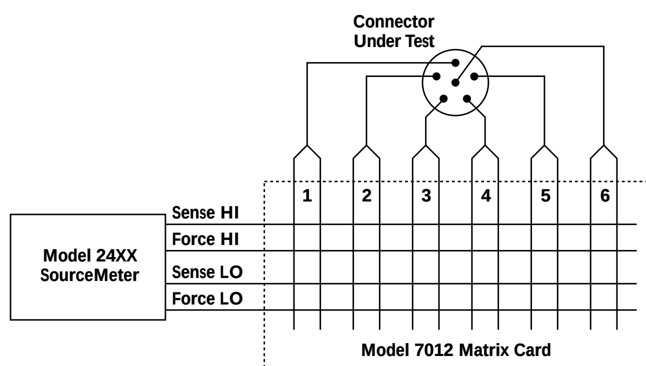

Figure 5. Electrical schematic for single-meter system.

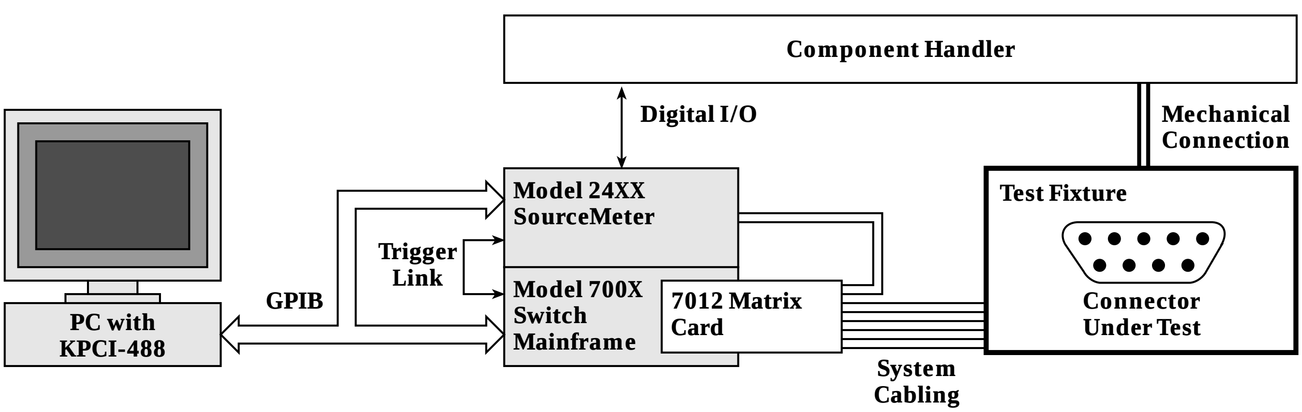

Figure 4. Test system block diagram.

High Resistance Test System

For many specialized connectors, the test specifications require greater resolution at resistance levels >1GΩ. When accuracy is critical when testing connectors at high resistances, the Model 6517A High Resistance Meter/Electrometer may be a more appropriate solution than a SourceMeter instrument.

The 6517A can measure up to $10^{15}\Omega$ by using its internal voltage source (up to 1000V) and picoammeter. It can be easily configured to measure the isolation resistance as shown in ***Figure 2*** with a 5½-digit picoamp measurement.

Low Resistance Test System

DMMs are often a convenient option for connector testing because they are capable of sourcing current and measuring the voltage drop across the connector pin. However, when testing connector pin continuity, it is often impossible to force enough current through the pin to produce a sufficient voltage drop to be measured by a typical DMM. Most DMMs have a noise floor of around 250nV. Realistically, the best DMM for low-noise, low-voltage measurements, the Model 2010, can only be used for measurements at or above 75nV or 500µΩ.

If a DMM can't provide satisfactory measurement performance, it is often necessary to use separate current source and voltage measurement instrumentation. When coupled with a Model 2400 SourceMeter, the Model 2182 Nanovoltmeter is capable of measuring 100nΩ reliably. The Model 2182's built-in delta mode, used in combination with the 2400, provides the best low ohms measurement for production applications (refer to the section titled "Thermoelectric EMFs"). ***Figure 6*** describes how to connect the 2182 and 2400 to perform a continuity test on a connector pin.

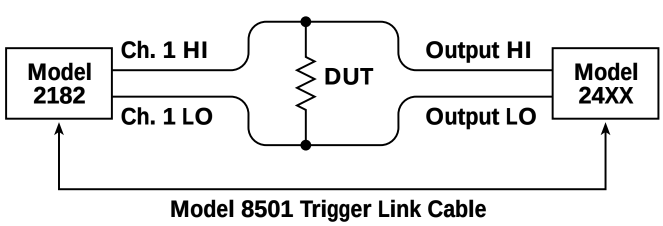

Figure 6. Delta Mode measurement using the Models 2182 and 2400.

Substituting the Model 2420 for the 2400 in the test will allow testing pin continuity with source current up to 3A to obtain a higher signal-to-noise ratio.

Switching Options

A switch card consists of relays that are configured to connect measurement instrumentation to many test points in the circuit under test. Each switch card is controlled by a switch mainframe that can be programmed with a desired test sequence. Keithley measurement instrumentation and switch mainframes have built-in trigger hardware (see the section titled "Trigger Link") that allows the measurement instrument to trigger the switch mainframe and vice versa. Both the instrument and switch mainframe can be pre-programmed with the desired test parameters and sequence. With the external triggering, the instruments can execute the programmed test routine without PC intervention.

The multiplexer and the matrix are the two most common switching topologies. Multiplexer switch cards are generally used when one instrument is to be connected to many discrete devices for testing. ***Figure 7*** 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 meter inputs and can be tested.

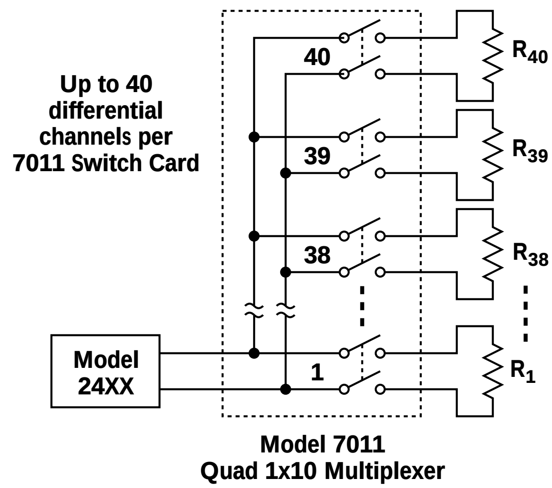

Figure 7. Multiplexer configuration.

The matrix configuration provides the flexibility required to test many different channel patterns. Matrices are useful for connecting any point in the system to any other point in the system. This configuration is also used when more than one instrument is needed to test each device. ***Figure 8*** shows a simple matrix configuration with two instruments. Two channels must be closed in order to perform a measurement, but with this layout, the instruments are able to test any possible combination of resistance values.

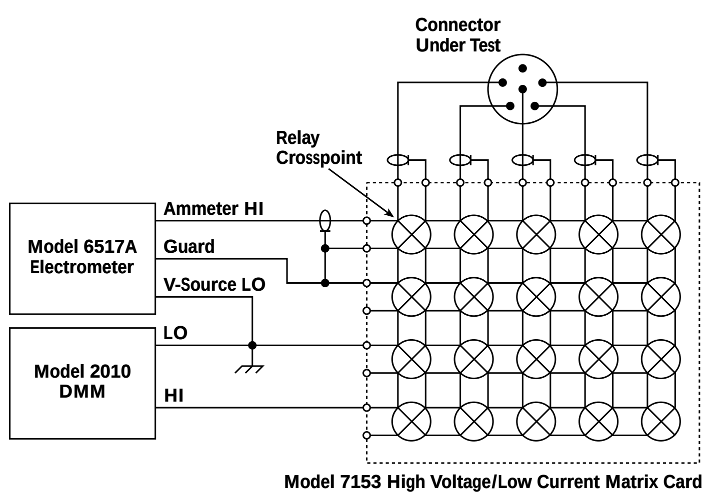

Figure 8. Matrix configuration.

Methods and Techniques

Guarding

When testing multi-pin connectors, it is important not only to guard the system cabling but also to guard the other pins that are not being tested. When testing from one pin to another, 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.

Trigger Link

The Trigger Link is a hardware handshake bus used by the instruments to ensure proper test sequencing. It is a standard feature on all newer Keithley instruments, including the ones 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.

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 ground point to eliminate the possibility of creating ground loops, which can also distort or alter test data. Whether the system cabling is single- or multi-conductor, it is 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 fixture from the measurement of the connector under test. ***Figure 9*** illustrates how to connect the 6517A Electrometer to make a high resistance measurement properly to minimize leakage current, cable capacitance, and noise.

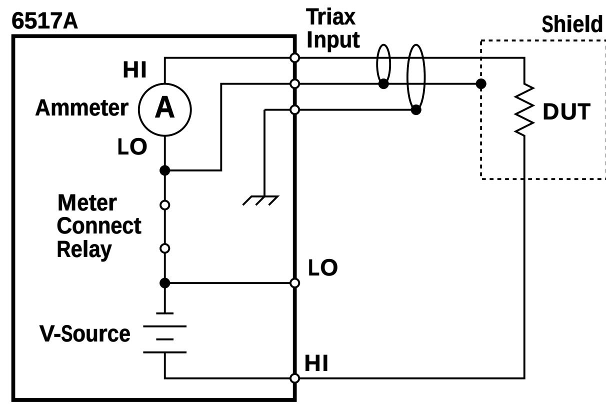

Figure 9. Model 6517A connections for making guarded Ohms measurement.

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, so 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. Settling times 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 measurements is the amount of series resistance present in the test leads connected to the DUT when only two test leads are used. Since the test lead resistance is in series with the DUT, this resistance value is added into the final measurement result. The series resistance is especially detrimental for testing connector pins since the test lead resistance may actually be greater than the pin itself, which would result in more than 100% error. ***Figure 10a*** illustrates the effect of series resistance when the current source and voltmeter use the same pair of test leads.

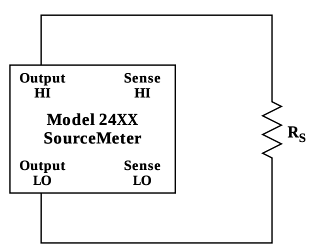

Figure 10a. 2-Wire Measurement

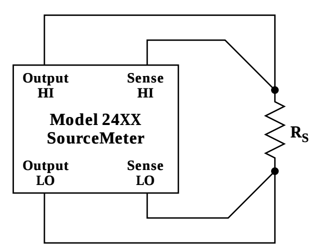

Figure 10b. 4-Wire Measurement

To eliminate lead resistance effects, the current source and voltmeter must be separated and four wires used to connect to the device. ***Figure 10b*** shows how the voltmeter senses the voltage drop across the DUT without the effect of the lead resistance.

Thermoelectric EMFs

Thermoelectric EMFs may cause measurement problems, especially for low impedance measurements. The voltage drop across low impedance devices is typically very small; therefore, thermoelectric EMFs may have sufficient magnitude to interfere with the test signal. Instruments like those in the SourceMeter Series can be programmed to cancel the effects of thermoelectric offsets automatically through the offset compensation, or delta, method of ohms measurement.

The delta method 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. 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.

Example Program

Keithley has developed an example program in Visual Basic program that's designed to perform the isolation and continuity tests presented by the test system in ***Figure 8***. To download a copy of the program (connector.bas), visit Keithley's World Wide Web site (**http://www.keithley.com**).

Note: The test programs provided are intended to illustrate the concepts presented in this note. Some modifications may be required to accommodate desired test parameters and timing.

Equipment List

Equipment needed to build the SourceMeter-based test system shown in ***Figure 4***:

1. Keithley Model 2400 SourceMeter
2. Keithley Model 7001 (or 7002) Switching Mainframe
3. Model 7012 4×10 General Purpose Matrix Switching cards. Each card can accommodate up to 10 connector pins.
4. PC with Model KPCI-488 IEEE-488 Interface Card
5. Two Model 7007 IEEE-488 Interface Cables
6. Model 8501 Trigger Link Cable
7. Test leads for connecting instrumentation to component handler.
8. Digital I/O connections from handler to interface with 9-pin male D-sub connector on SourceMeter

Equipment needed to build the connector test system illustrated in ***Figure 8***:

1. Keithley Model 6517A Electrometer/High Resistance System
2. Keithley Model 2010 Low-Noise Multimeter
3. Keithley Model 7001 (or 7002) Switching Mainframe
4. Model 7153 4×5 High Voltage Low Current Matrix Switching cards. Each card can accommodate up to 5 connector pins.
5. Model 7153-TRX cables for connecting to the 7153 card. Two cables are required for each switch card in the system.
6. Model 237-TRX-T 3-slot Triax T adapters. Four adapters are required for each switch card in the system.
7. PC with Model KPCI-488 IEEE-488 Interface Card
8. Three Model 7007 IEEE-488 Interface Cables

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 instruments that supports testing isolation resistance up to 1100V and continuity up to 3A.

Test System Safety

Many electrical test systems or instruments are capable of measuring or sourcing hazardous voltage and power levels. It is 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 is the responsibility of the test system designers, integrators, and installers to make sure operator and maintenance personnel protection is in place and effective.

Specifications are subject to change without notice.

KEITHLEY

Keithley Instruments, Inc. • 28775 Aurora Road • Cleveland, Ohio 44139 • 440-248-0400 • Fax: 440-248-6168 • www.keithley.com

BELGIUM:	**Keithley Instruments B.V.**	Bergensesteenweg 709 • B-1600 Sint-Pieters-Leeuw • 02/363 00 40 • Fax: 02/363 00 64
CHINA:	**Keithley Instruments China**	Yuan Chen Xin Building, Room 705 • 12 Yumin Road, Dewai, Madian • Beijing 100029 • 8610-62022886 • Fax: 8610-62022892
FRANCE:	**Keithley Instruments Sarl**	B.P. 60 • 3, allée des Garays • 91122 Palaiseau Cédex • 01 64 53 20 20 • Fax: 01 60 11 77 26
GERMANY:	**Keithley Instruments GmbH**	Landsberger Strasse 65 • D-82110 Germering • 089/84 93 07-40 • Fax: 089/84 93 07-34
GREAT BRITAIN:	**Keithley Instruments Ltd**	The Minster • 58 Portman Road • Reading, Berkshire RG30 1EA • 0118-9 57 56 66 • Fax: 0118-9 59 64 69
INDIA:	**Keithley Instruments GmbH**	Flat 2B, WILOCRISSA • 14, Rest House Crescent • Bangalore 560 001 • 91-80-509-1320/21 • Fax: 91-80-509-1322
ITALY:	**Keithley Instruments s.r.l.**	Viale S. Gimignano, 38 • 20146 Milano • 02/48 30 30 08 • Fax: 02/48 30 22 74
NETHERLANDS:	**Keithley Instruments B.V.**	Postbus 559 • 4200 AN Gorinchem • 0183-635333 • Fax: 0183-630821
SWITZERLAND:	**Keithley Instruments SA**	Kriesbachstrasse 4 • 8600 Dübendorf • 01-821 94 44 • Fax: 01-820 30 81
TAIWAN:	**Keithley Instruments Taiwan**	1 Fl. 85 Po Ai Street • Hsinchu, Taiwan, R.O.C. • 886-3572-9077• Fax: 886-3572-9031

Printed in the U.S.A.

No. 2208
0200-10KGDA