

# Configuring a Resistor Network Test System with the Model 2400 SourceMeter® Instrument

## Introduction

The purpose of resistor network production testing is to verify the performance of these devices at various stages in production, as well as in their final packaged form, as quickly as possible. The tests must also be reliable to assure that all products shipped meet the manufacturer's specifications.

In most cases, a resistance measurement is made on each element in the network. Resistance measurements are made either by applying constant current or constant voltage. Performing these tests requires the use of switching hardware to switch the source and measurement signals to and from each element of the network.

The Model 2400 SourceMeter® Instrument offers standard 4-wire, split Kelvin, and 6-wire guarded ohms measurement capabilities, and can be configured for either the constant current or constant voltage method. When combined with the Keithley Model 7001 or 7002 Switching System, the Model 2400 is well-suited for testing a wide range of resistor network devices.

To allow higher production testing throughput, the Model 2400 provides a direct interface to automated device handlers. Internal pass/fail determinations on the measurements allow for fast binning of the networks based on test results. Up to 100 different pass/fail patterns in seven different categories can be specified for each individual element.

This application note describes how to assemble and configure a resistor network test system built around the Model 2400, a Model 7001 switch mainframe, and the Model 7019 matrix card. It specifically outlines a 6-wire guarded ohm system that allows testing an 8-pin dual terminator network. In addition, the theoretical section of the note describes all four basic types of resistor networks — isolated, bussed, R/2R ladder, and dual terminator. The application note will also illustrate how the Model 2400 addresses the need for high production throughput. A test of a single element in a network can be completed in approximately 10msec., including switching, measurement, and processing time.

## Test Descriptions

Typically, tests on resistor networks fall into one of three general measurement categories:

- Standard 4-wire Kelvin measurements
- 6-wire guarded ohms or delta resistance measurements
- “Y” circuit or buried node resistance measurements (also called split Kelvin measurements).

Measured resistance values can range from  $5\Omega$  to  $1M\Omega$ , with specified accuracy of 0.5% to 10%.

All tests are basically single-point resistance measurements performed using either constant current or constant voltage. The 2400 allows the use of either technique and even allows alternating between the two methods. It can adjust the values for the source and measurement ranges to accommodate the manufacturer's specifications, to ensure maximum accuracy/reliability and measurement speed. It can also tolerate lead resistances up to  $1M\Omega$  for split Kelvin measurements.

A 100% test of a device involves the use of a switching solution to connect the instrumentation to each resistor in the network. Refer to the section entitled “Test System Configuration” for a typical test setup.

The 2400 is also capable of performing various product reliability tests, including isolation resistance, voltage coefficient, etc. For more information on how to perform these tests, refer to Keithley Application Note 805, “Configuring a Discrete Resistor Verification Test System.”

A variety of measurement techniques are used with the four basic types of resistor network devices.

### Isolated and bussed resistor networks

Testing isolated and bussed resistor networks is similar to testing single resistor elements. Standard 4-wire Kelvin connections can be used to eliminate the effects of lead resistance. The Model 2400's sensing circuit offers an input impedance  $>10^{10}\Omega$  to perform accurate 4-wire measurements. Unlike most DMMs or ohmmeters, the Model 2400 makes it possible to adjust the source values used in the constant current and constant voltage measurement techniques to match the resistor network manufacturer's specifications for their products.

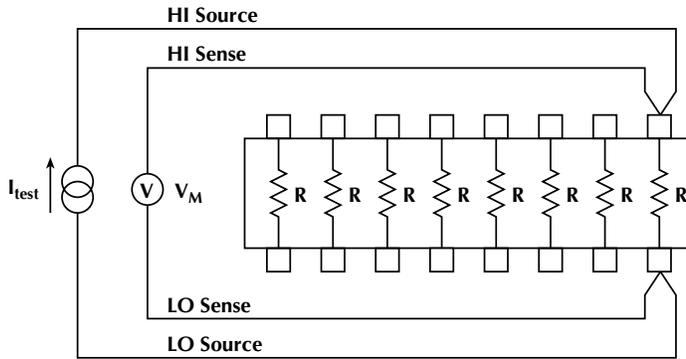


Figure 1. Isolated and Bussed Resistor Networks

Refer to the section on R/2R ladders for a description of how to perform a resistance check of the common bus for bussed networks.

### R/2R Ladder Resistor Networks

In R/2R ladder resistor networks, the resistor to be measured is buried with other resistors. This blocks access to the terminals of the resistor to be measured.

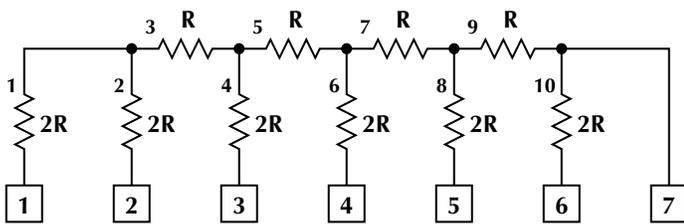
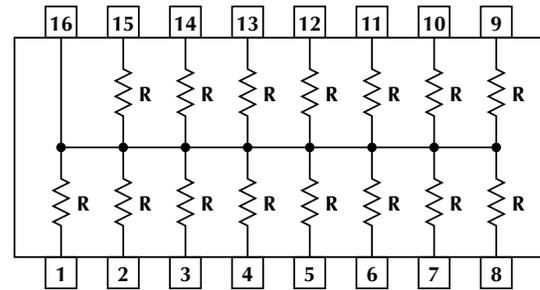


Figure 2. R/2R Ladder Network

To measure the individual resistors in this type of network, the traditional Kelvin connection has to be split up into four individual lines (hence the term “split Kelvin”). The access to the element under test through the other Rs and 2Rs adds a significant amount of additional resistance in the sense and source lines. This is a problem for testing the network with conventional 4-wire ohmmeters. Most ohmmeters specify the maximum lead resistance in 4-wire ohms as 1kΩ and/or 10% of range. Therefore, these ohmmeters aren’t an appropriate solution because the value for 2R (which becomes part of the “lead resistance”) can be up to 200kΩ.

One way to solve this impasse is to use two separate instruments — a current source and a voltmeter. Another technique is to use the Model 2400, which integrates these two instruments in a single unit to allow easier programming and faster response times. The meter specifies lead resistance up to 1MΩ in the sense leads at rated accuracy for both source modes. This dual functionality, plus its high sense input resistance, makes it a good solution to this measurement problem.

To illustrate this technique, follow these steps to measure the resistance of Resistor #3 in Figure 2. To make the measure-



ment, connect the source LO to Resistor #2 (pin 2), source HI to Resistor #4 (pin 3), sense LO to Resistor #1 (pin 1), and sense HI to Resistor #6 (pin 4), as shown in Figure 3. Remember, due to the high impedance of the sense input, there is no significant current flowing into the sense leads, so Resistors #1, #5, and #6 become negligible.

$$R_3 = V_R / I_{\text{test}} = V_M / I_{\text{test}}$$

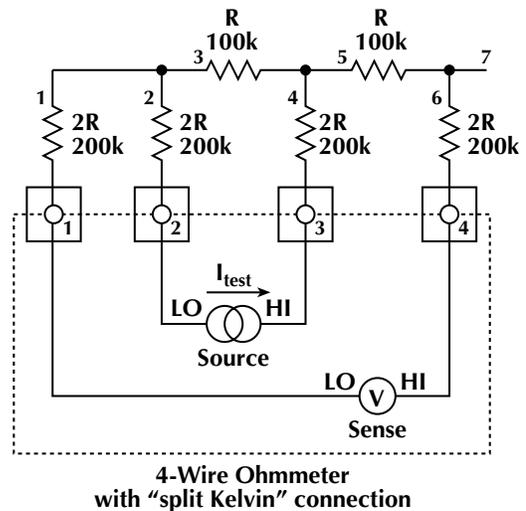


Figure 3.

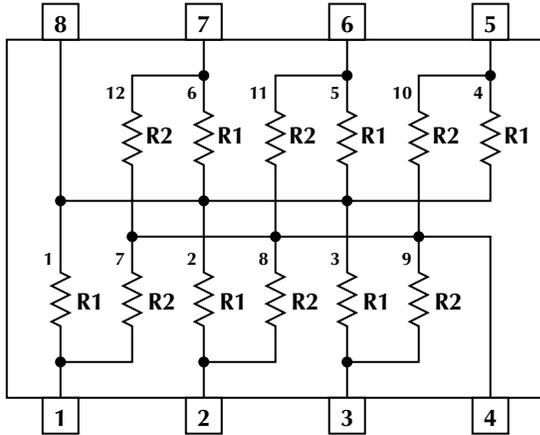
Assuming the R/2R ladder consists of both 100kΩ and 200kΩ resistors, the total series resistance in the sense circuit would be 500kΩ for measuring Resistor #3. With a test current of 10μA, the voltage measured across Resistor #3 will be 1V. Note that the total voltage developed by the source will be 5V, with 2V across Resistor #2 and across Resistor #4. The Model 2400 can tolerate up to 5V across each source “lead” resistance.

This same technique can be used to perform a common bus check for bussed resistor network devices.

NOTE: To allow testing each element in the network, the system must be able to switch each of the four measure/source lines to each pin of the network. Refer to the section entitled “Test System Configuration” for further details.

## Dual Terminator Resistor Networks

Dual terminator resistor network devices have a characteristic such that each individual resistor is bridged by a loop of other resistors, which form a parallel current path. It is not possible to make a physical break of the loop. With ordinary methods, a significant part of the test current will flow through the parallel path, producing a lower resistor reading than the actual value of the specific resistor being tested.



Figures 4. 8-Pin Dual Terminator Network

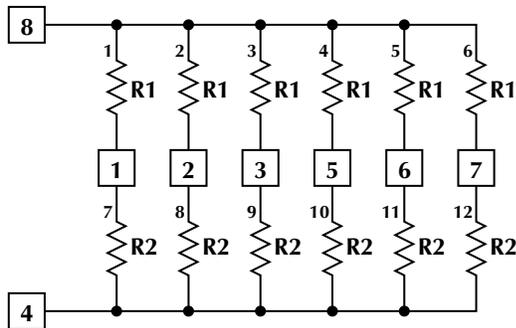


Figure 5. Electrical Equivalent of Figure 4

Figure 4 shows an 8-pin dual terminator device. Figure 5 is the electrical equivalent of this device.

In this example, resistor #1 (the first R1) may be measured by connecting the HI pair of the 4-wire ohmmeter to Pin 1 and the LO pair to Pin 8. Current will flow from HI to LO through the R1 under test, as well as through the other R1s and R2s in the series-parallel loop. The resistance reading on the meter would be significantly lower than the actual value of the first R1.

The solution to this problem is to guard out the parallel resistance by forcing the voltage at Pin 4 to the same potential as Pin 1, so no current will flow through the series-parallel loop. All the test current will flow from Pin 1 to Pin 8. By adding a low

impedance guard buffer with sufficient drive current, resistor #1 can be measured precisely. The Model 2400 has a built-in guard buffer of this type.

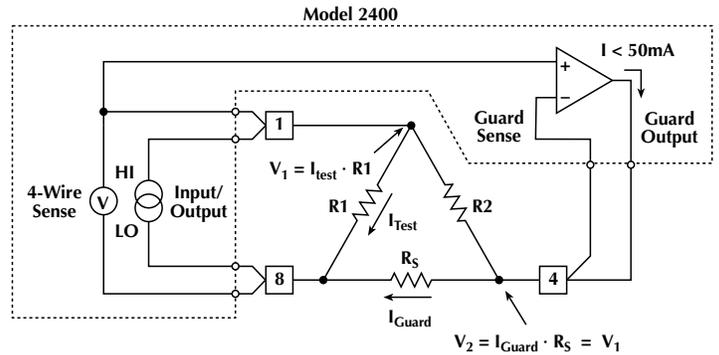


Figure 6. Model 2400 Connected to Dual Terminator Network

Essentially, the Model 2400's guard buffer is a unity-gain amplifier that will hold the voltage between its inputs to nearly zero volts. It can accomplish this only by forcing current through  $R_s$  until the voltage on Pin 4 is equal to Pin 1.  $R_s$  is the equivalent resistance of the series/parallel combinations of all the remaining R1, R2 pairs in the circuit. To eliminate any error due to the voltage drop in the Guard output lead, the inverting input of the buffer (called Guard Sense) is also connected to Pin 4 to allow feedback control of the Guard output.

The 6-wire guarded ohms and standard 4-wire ohms measurement techniques are very similar in terms of how a switching system would divide the individual lines to the device under test. Pairs of leads are always switched to the individual device pins, HI sense/HI source, LO sense/LO source, and Guard/Guard Sense.

The switching sequence for the 8-pin dual terminator shown in Figure 4 would be:

- Measurement of all R1s: The LO pair is connected to pin 8, the Guard pair to Pin 4. The HI pair is then scanned over the remaining pins as each measurement is taken.
- Measurement of all R2s: The LO pair is connected to pin 4, the Guard pair to Pin 8. The HI pair is then scanned over the remaining pins again as each measurement is taken.

The 2400 Guard buffer provides up to 50mA at a maximum voltage of 210V. This limits the maximum test voltage or current that can be used to test a given device. To calculate the maximum test current or voltage that can be used to measure the individual elements, the shunt resistance ( $R_s$ ) from the Guard pair to the LO pair has to be determined. The maximum allowable voltage across the resistor can be calculated as:  $V_{max} = R_s \cdot 50mA$ . This is also the maximum voltage over the individual resistor element under test, since  $V_2 = V_1$ .

# Test System Configuration

The resistor network test system outlined here is capable of handling a wide range of network devices with up to 12 pins, and is expandable for devices with up to 60 pins. An 8-pin dual terminator will be used as an example device.

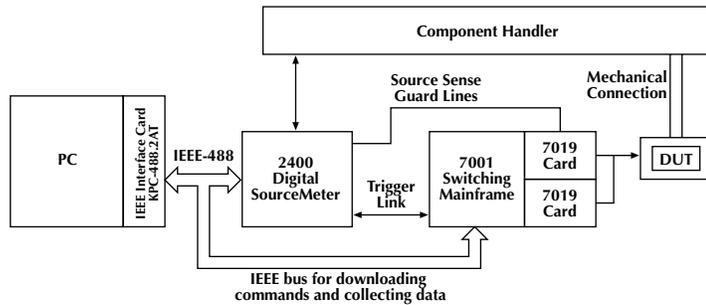


Figure 7. Resistor Network Test System

The block diagram in *Figure 7* shows how a system can be configured around the Model 2400, a Model 7001 switch mainframe with Model 7019 switch cards, and a personal computer with an IEEE-488 board. The system is interfaced to a user-supplied automatic component handler. The PC downloads the test sequence to the instruments and collects the data for statistical use.

The Model 7019 switching card is specifically-designed for testing resistor network devices. The topology of a single-pole dual  $3 \times 6$  matrix simplifies six-wire ohm measurements, as well as four-wire and split Kelvin tests, so it's a good choice for testing a wide range of resistor networks.

## Test Sequence

The test system is controlled by a PC or any other GPIB controller. The traditional view of the GPIB bus was as a slow laboratory type communication bus. With instruments like the 2400 and the 7001 Series, this has changed. These instruments contain enough self intelligence, memory, trigger handshaking, and fast data transfer capability to solve and overcome GPIB speed issues for production needs. The system shown is able to perform at a throughput of 10 ms per network element.

A resistor network test program would follow this sequence:

- Prompt the operator for the part number.
- Pull test setup for the part from a data base.
- Compute the configuration for the 7001 switching mainframe and the 2400 SourceMeter.
- Download the information to the instruments.

- Prompt the operator for the number of devices to be tested if known.
- Prompt the operator to start the test.
- At this point, control is passed to the instruments.
- The 2400 waits until the Start of Test line is set by the handler.
- After the handler indicates the DUT is in place, the 2400 and the 7001 handshake each other, measuring each individual element in the network. Also, the 2400 performs a limit test for each element. Up to 100 different limits are available.
- When all elements in the network are tested, the 2400 asserts the End of Test line and sends the pass/fail pattern to the handler. The measured value for each individual resistor element has already been transferred to the PC for further processing.
- The PC repeats the process until all the network devices in the batch are tested.

It is important to note that the control of the measurement and the switching to each element is done solely by the instruments. No additional GPIB bus or PC overhead time is required.

## Cabling

This section offers a brief overview on how to connect the 2400 to the switching cards and the switching cards to the DUT. For a complete description of the cabling, pin out, etc., refer to the Model 2400, 7001, and 7019 User Manuals.

As *Figure 7* illustrates, several connections must be made. Standard GPIB cables are used to connect the PC to the instruments. A Keithley Trigger-Link cable connects the Model 2400 and the Model 7001. A user supplied 9-pin cable with a female DB-9 connector on one end connects the Model 2400 to the device handler.

The Model 2400's six measurement lines are connected to the rows of one of the Model 7019 cards. The row connections from card to card are made inside the Model 7001. The columns are connected to the test fixture of the handler. See *Figure 8* for details. Each Model 7019 can handle up to six device pins. To avoid noise interference, it is important to use shielded cables and to keep the cables short.

## Switching Sequence

As described in the Test Descriptions section, the measurement of a dual terminator requires switching the LO pair, the HI pair, and the Guard pair to the device pins. To connect to one pin, two relays must be closed. For one element in the network, a total of six crosspoints must be closed. The Model 7001's channel

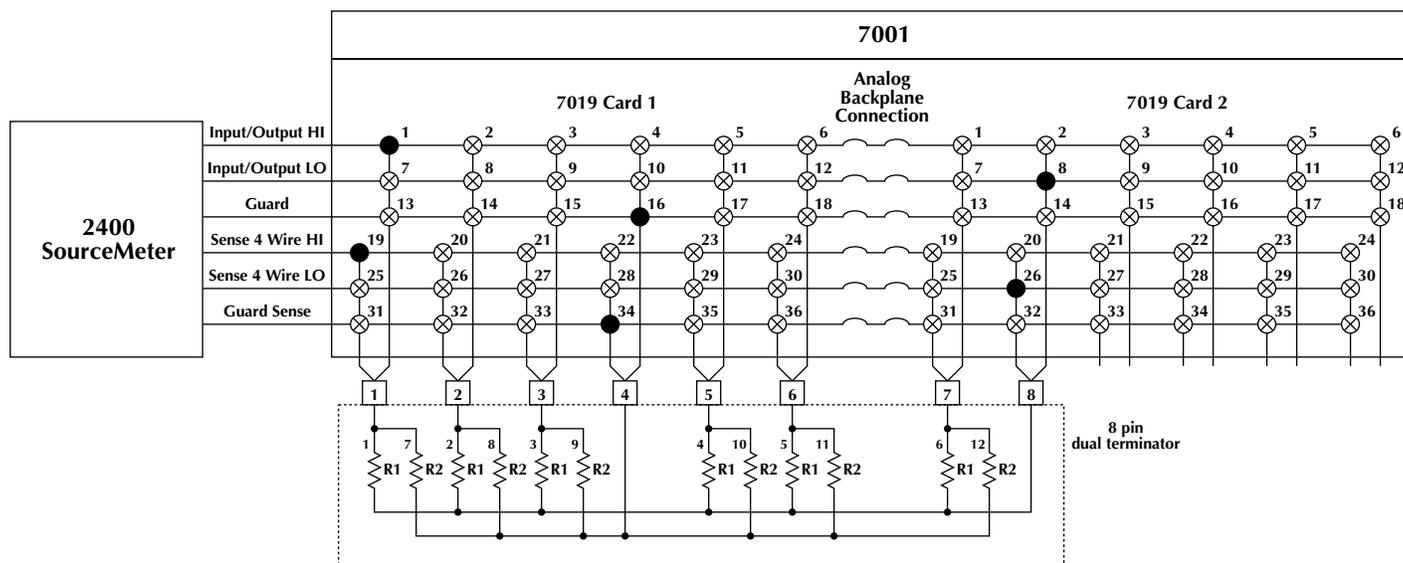


Figure 8. Model 2400 Connected to an 8-pin Dual Terminator Network via Two Model 7019 Switch Cards in a Model 7001 Mainframe

memory is used to store the relay pattern for each resistor. In Figure 8, the relays closed to measure the first R1 are shown as ●.

The following scanning sequence is used to measure the network shown in Figure 4:

Resistor	Card 1	Card 2
1	1, 19, 16, 34	8, 26
2	2, 20, 16, 34	8, 26
3	3, 21, 16, 34	8, 26
4	5, 23, 16, 34	8, 26
5	6, 24, 16, 34	8, 26
6	16, 34	1, 19, 8, 26
7	1, 19, 10, 28	14, 32
8	2, 20, 10, 28	14, 32
9	3, 21, 10, 28	14, 32
10	5, 23, 10, 28	14, 32
11	6, 24, 10, 28	14, 32
12	10, 28	1, 19, 14, 32

Figure 9

## 2400 Setup

Refer to the test description for the dual terminator. The maximum guard current of the Model 2400's guard buffer is 50mA. To calculate the current settings of the source in the example of the 8-pin R1/R2, 180/390Ω dual terminator, the maximum voltage is calculated as:

$$R_S = (180 + 390)\Omega / 5 = 114 \Omega$$

$$V_{\max} = R_S \cdot 0.05 \text{ A} = 5.7 \text{ V}$$

The maximum source current or measure current for R1 is:

$$I_{\max} = 5.7\text{V} / 180\Omega = 31.7\text{mA}.$$

For R2 it is:

$$I_{\max} = 5.7\text{V} / 390\Omega = 14.6\text{mA}.$$

Given the 31.7mA maximum for R1 and 14.6mA maximum for R2, the practical choice would be a 10mA test current for both R1 and R2 in order to stay under these maximums. It would also allow the Model 2400 to use the 2V measure range, keeping the test signal near full scale for good accuracy and avoiding range changes. Similarly, if constant voltage is used, then a choice of 1.8V test voltage would allow the Model 2400 to use the 10mA measure range. Of course, the maximum power consumption the part can tolerate is another limiting factor.

Another factor that limits test systems is the lifetime of the switching relays used. To maintain low contact resistance and high switching speed, the Model 7019 card uses reed relays. To achieve maximum relay life and minimize maintenance costs, the Model 2400 allows cold switching. To use cold switching, enable the Model 2400's source auto clear and the zero impedance standby mode. The source auto clear function automatically turns the output off after the programmed source and measure time.

## Example Program

Keithley Instruments has developed an example program that performs the test on the network device shown in Figure 4. While the program may require some modifications to meet specific requirements for your application, choice of computer controller and device handler, etc., it provides a good starting point for developing your specific test program.

To obtain a copy of the Example Program as a digital file, access Keithley's World Wide Web site (<http://www.keithley.com>).

## Typical Sources of Errors

Source of errors in a system can be divided into determinable systematic errors and random errors. Systematic errors are those caused by the measurement instruments, switching devices, and cabling. Random errors are the result of noise from the environment and the measurement devices.

Depending on the resistor network's specified accuracy range, the following description may or may not be applicable. A detailed description of potential error sources can be found in Keithley's *Low Level Measurements*, which is available on request.

### Noise

In a production environment, electrical noise can be a significant problem. Fluorescent lights, machinery, large metal areas that can act as antennae, such as the component handler, and other sources of noise can induce small voltages in the measurement circuit.

To minimize these effects, use shielded cables for all measurement leads. This includes the connection from the Model 2400 to the switching cards and from the cards to the component handler test fixture. Cables with one shield and multiple conductors are recommended; twisted pair cables should not be used unless they are shielded.

The shield of the cable must be connected in a star fashion to earth ground so that all grounds are connected at a single point. The LO input/output of the Model 2400 and the chassis of the component handler should also be connected to earth ground.

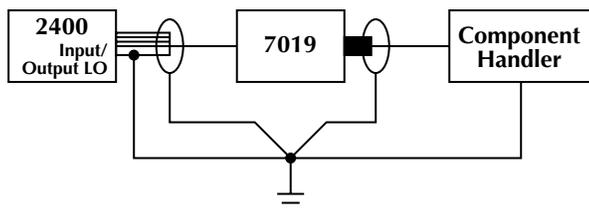


Figure 10.

Whenever possible, work with voltage levels well above the noise floor. The higher the voltages being measured, the higher the signal-to-noise ratio will be, making the measurement less susceptible to noise interference.

Another way to decrease noise susceptibility is to increase the measurement time. The Model 2400 allows adjusting the measurement time (integration time) in multiples of the power line cycle, ranging from 0.01 to 10. Using an integral number of line cycles (e.g. 1, 2, 5, etc.) as the integration time greatly reduces noise due to line cycle pick up. Refer to the Model 2400 User's Manual and specifications for details.

### Offset

In addition to the thermal offsets caused by the test fixture, the switching system and the Model 2400 can introduce certain temperature-dependent offsets to the system. When testing high-volume, low-precision parts, the errors due to these offsets are not significant in the final results. However, if higher accuracy measurements are required, the Model 2400 can be configured for an enhanced ohms mode, which uses the offset-compensated ohms measurement method to eliminate the effects of thermal offsets. In general, this method measures resistance at a specified source level, then subtracts a resistance measurement made with the source set to zero. With the source set to zero, only the voltage due to thermal EMFs will be measured.

### Guard Current

The Model 2400 provides up to 50mA of guard current. If the circuit resistance is so low that the guard current exceeds 50mA, a self-resetting thermal fuse will protect the circuit against damage. The readings, however, will be incorrect. The ratio between the resistor from Guard to source LO and the resistor from source HI to source LO determines the maximum usable test or measure current in a typical delta configuration:

$$I_{\max} = [R_s/R_{\text{HI-LO}}] \cdot 0.05\text{A}$$

### Guard Buffer Offset

As described in the Dual Terminator Resistor Networks section of Test Descriptions, the guard buffer holds the voltage between 4-WIRE SENSE HI and Guard Sense near 0V. However, there remains a small voltage difference, less than 150μV.

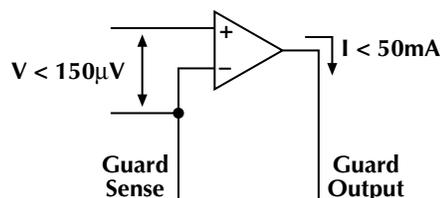


Figure 11.

This small voltage generates a current through the resistor between the Guard and HI leads. This current subtracts from the sourced or measured current and generates a small error. The error can be calculated as:

$$\text{error}_{\max} = [150 \cdot 10^{-6}\text{V} / (R \cdot I_{\text{Test}})] \cdot 100\%$$

If the error affects the test results significantly, the Model 2400's offset compensation mode can be used to minimize the error.

## Voltage Limit between Sense and Source

As noted in the discussion of R/2R ladder networks, there is a maximum limit of 5V allowed between the source and sense of both the HI and LO terminals. The 2400 does not check if this limit is exceeded because the maximum resistance in each lead must be known.

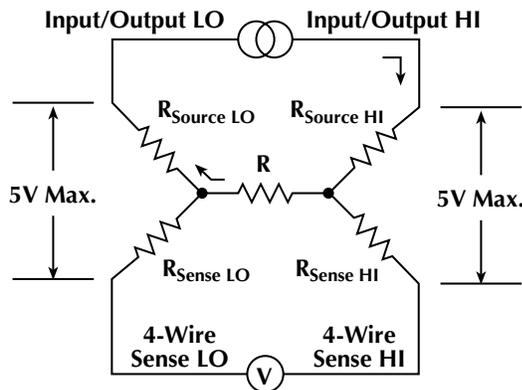


Figure 12.

The following calculation can be used to avoid measurement errors:

$$I_{\max} = 5V/R_{\max}$$

$R_{\max}$  is the maximum lead resistance in one of the source lines. For example, if  $R_{Source\ LO} = 200k\Omega$ ,  $R_{Source\ HI} = 350k\Omega$  and  $R = 200k\Omega$ , the maximum test or measure current would be  $5V/350k\Omega = 14\mu A$ . The measured voltage across  $R$  would be 2.8V.

## Cable Capacitance

The characteristic capacitance and length of the cabling to the DUT result in a capacitive value in parallel with the internal capacitance of the Model 2400 and the switch system. For resistances up to roughly  $100k\Omega$ , this effect usually is not significant and involves no special measurement considerations. Above this level, use the source voltage/measure current technique to minimize the additional time constant introduced by the cabling.

## Series Resistance

Testing isolated and bussed resistor networks is very similar to testing single resistor elements. A common source of errors when measuring these devices is the series resistance that is the sum of the cable resistance, the switching system (on resis-

tance of the relays), and the contact resistance of the contact finger of the handler to the device pins (due to contamination of the test fixture).

To minimize the impact of lead resistances, be sure to use a 4-wire resistance ohmmeter with high impedance sense input. This ensures that virtually no current is flowing into the sense lines when the voltage across the DUT is measured, so the series resistance error is effectively eliminated. The Model 2400 is well-suited for this test because it offers  $>10^{10}\Omega$  input impedance in both constant current and constant voltage modes.

## Equipment List

1. Keithley Model 2400 SourceMeter instrument
2. Keithley Model 7001 Switch Mainframe
3. Keithley Model 7019 6-wire ohm Switching Cards (2)
4. Keithley Model KPC-488.2(AT) GPIB Interface Card
5. Keithley Model 8501-1 Trigger-Link Cable
6. Keithley Model 7007-1 Shielded GPIB Cables (2)
7. Keithley Model 7011-KIT-R Connector Kits (2)
8. Banana Plugs (6)
9. 9-pin DIN Connector Kit - Female
10. 9-conductor computer cable
11. Cable #22 AWG, 6 conductors plus shield
12. Cable #22 AWG, 24 conductors plus shield

## WARNING

**With remote sensing enabled, an open sense lead will result in lethal voltages appearing at OUTPUT HI and GUARD. This voltage can cause injury or death, and damage external circuitry. Always make sure that the sense leads are properly connected before enabling remote sense. NEVER change connections with power applied. Be sure to always discharge and/or disconnect external power sources.**

Specifications are subject to change without notice.

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