Application Note Series

Production Testing of High Current Varistors with the Model 2430-C 1kW Pulse SourceMeter®

Introduction

Varistors provide fast, energy absorbing, transient and over-voltage protection to a load placed across them. *Figure 1* shows a typical circuit containing a varistor protection scheme. Multi-Layer Varistors (MLVs) typically have much lower clamping voltages (up to ~100V) than Metal-Oxide Varistors (MOVs). MLVs are popular protection devices for portable, battery-operated electronics due to their small size and surface-mountability.
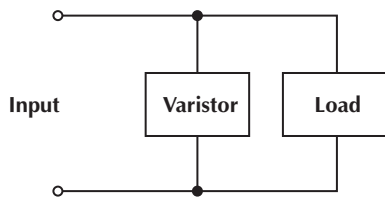

Figure 1. Typical varistor placement in circuit

Varistors can suppress both positive and negative transients. If the applied voltage is less than a specified threshold value, the varistor has a very high resistance, so very little current flows through it. Once a transient voltage reaches the specified level, the varistor begins conducting electricity and absorbs the energy from the transient. When the varistor is conducting, it effectively clamps the transient voltage to a specified level that will protect the load. *Figure 2* illustrates a typical current-voltage (I-V) relationship for a varistor.
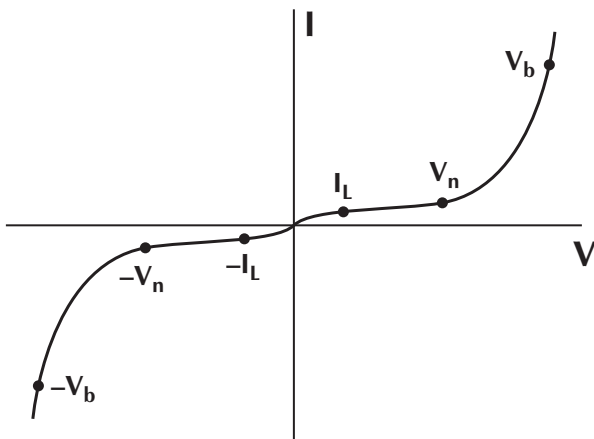

Figure 2. Typical varistor I-V curve with test points (not drawn to scale)

Tests typically performed on varistors using the Model 2430-C 1kW Pulse SourceMeter include bipolar nominal voltage, maximum clamping (breakdown) voltage, leakage current, and alpha coefficient tests. The nominal voltage (V_n) of a varistor is the voltage at which the varistor changes from the off (non-conducting) state to the on (clamping) state and is typically characterized at 1mA. The maximum clamping (breakdown) voltage (V_b) is the peak voltage appearing across the varistor when measured at a specific high current pulse. The leakage current (I_L) test ensures the varistor does not drain too much current from the source when in its non-conducting electrical region. *Figure 2* also illustrates how these six test points relate to a varistor I-V curve.

The 2430-C's greatest advantage is its tight integration of source and measurement capabilities, which allows performing all of these tests with one half-rack instrument. This application note describes how to use a 2430-C to perform these tests.

Test System Configuration

Two Series 2400 SourceMeter instruments are ideal for varistor testing. The Model 2410-C is ideal for testing MOVs because of its ability to source up to 1100V at 21mA. The Model 2430-C Pulse SourceMeter is capable of producing 10A/100V pulses, which allows it to test most MLVs completely. Testing both types of varistors is very similar—only the dynamic source-measure ranges of the tests differ.

MLVs are typically produced in single discrete or four-element array packages. Testing a single device (*Figure 3*) requires only one 2430-C. Testing four-element arrays can be accomplished in either of two ways:

- The first method is to use four SourceMeter instruments to test the four elements simultaneously.

- The second method is to use one SourceMeter instrument and a switch mainframe to connect to each element in succession. While this method typically reduces the initial system cost, throughput is significantly lower than with the first technique.

Single DUT Testing

The most straightforward way to implement a test system is to use one meter for every device in the batch. The 2430-C's 10A/100V pulsing capability makes it the ideal solution for testing MLVs. *Figure 3* illustrates the basic components of a single element (discrete) varistor production test system.
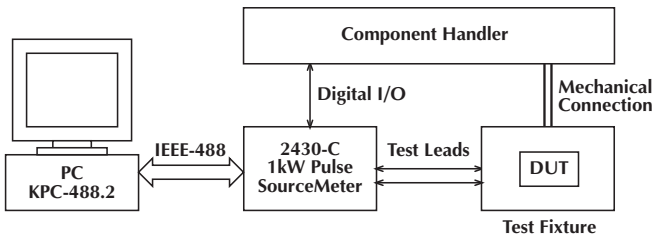
Figure 3. Model 2430-C Based Varistor Production Test System

As *Figure 3* shows, the Model 2430 has both an IEEE-448 communication bus and a digital I/O port to communicate with external devices. The digital I/O port can be configured to send typical end-of-test pulses (EOT) and receive start-of-test (SOT) signals. High and low measurement limit values can be configured within the 2430-C and compared to what is measured at the input terminals. This provides built-in go/no-go testing and binning capabilities for production testing. The information on limit pass or failure can be extracted from the 2430-C via the front panel, GPIB, or digital I/O port.

The 2430-C's Source Memory capabilities allow users to download the various tests for varistors and sequence through the tests rapidly. Another aspect of the Source Memory is that each test can have its own limit parameters and each test suite for a particular device can be initialized by the handler with an SOT pulse. Once the 2430-C has completed testing, EOT and pass/fail information is passed to the component handler. The effect is that the 2430-C is initially set up with the PC or over the front panel, but once testing has commenced, the bus and front panel are not used. Utilizing the digital I/O port effectively can dramatically reduce test cycle times.

Simultaneous Testing of Multiple Varistors in an MLV array

Figure 4 is a system very similar to the single element varistor test system. All four SourceMeter instruments are programmed the same and utilize the /BUSY line offered by the digital output. The /BUSY digital output line is held LO while the instrument is performing a test and will transition HI once testing is idled. Tying all four /BUSY lines of the instruments in parallel enables any one of the four 2430-C's to hold the input to the handler LO. One start-of-test (SOT) signal from the component handler initiates testing with the four SourceMeter instruments, and the four /BUSY lines tied together guarantee that all of the 2430-C's have completed testing before the handler moves to the next DUT. The SOT and /BUSY functionality is controlled from the rear panel through the digital I/O port (male DB-9 connector).
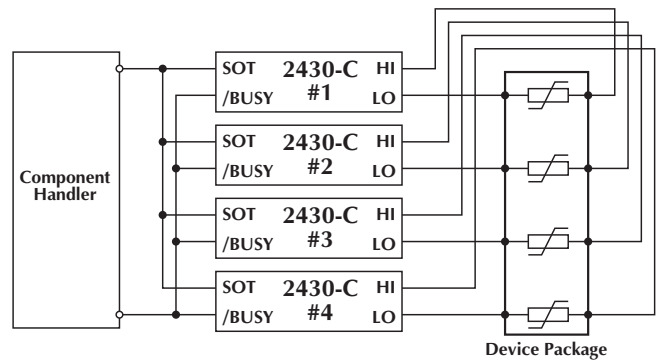

Figure 4. System diagram for testing a 4-device package.

Switching Multiple Varistors in an MLV array

Certain applications require connecting multiple devices to the same SourceMeter instrument for testing. A switch mainframe with scanner/relay card installed is used to control which varistor is tested. *Figure 5* illustrates the topology for connecting the input/output of the SourceMeter instrument to any of four varistors using the Model 7001 Scanner Mainframe and the Model 7053 High Current Switch Card. The method shown in *Figure 5* is for a 2-wire testing method. Testing is done sequentially, closing one channel at a time and testing the corresponding varistor for that channel.

Keithley has tested the Model 7053 card and confirmed that it will operate under *10A pulsed conditions* and is compatible for use with the Model 2430-C, even though the relays on the card are rated to carry 5A continuously. The channels on the 7053 card must never make or break the circuit while a current is flowing or while a potential is across the relay contacts. Ensuring that the source is disabled before actuating the relay is known as cold switching. *Cold switching is required for using the 7053 with the 2430-C SourceMeter instrument.*
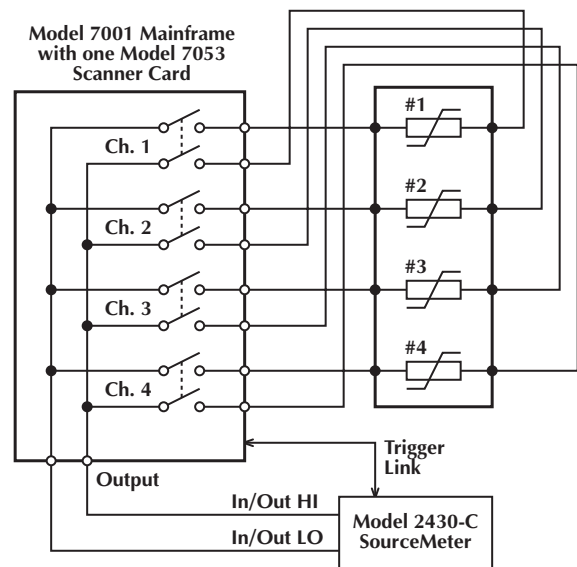

Figure 5. Using a switch mainframe for multi-point testing.

When implementing a system with high-test currents, the lead resistance of the wiring connecting to the DUT may introduce error into the results. If this level of lead resistance error is unacceptable, the system should be configured for 4-wire measurements. *Figure 6* shows the topology for making 4-wire connections between a 2430-C and the devices under test. This method is useful for preventing the test lead resistance from introducing error into the measurements (see the section titled "Lead Resistance"). Note that two 2-pole relays are used to connect each varistor to the 2430-C SourceMeter instrument.

The actual number of varistors under test may vary, depending on the system requirements. Switch systems can be configured for any number of varistors and for various electrical specifications. When used with the 7053 card, each Keithley Model 7001 can support up to twenty varistors connected for 2-wire measurements and ten devices for 4-wire measurements. The Model 7002 Switch Mainframe can accommodate up to 100 varistors in the 2-wire topology and 50 for 4-wire measurements.

The Trigger-Link feature included in all the instruments in the SourceMeter family and the Series 7000 Mainframes can interface the 2430-C with the 7001 or 7002. Trigger-Link is a hardware digital bus used for handshaking; the Trigger-Link connection between the SourceMeter instrument and the switch mainframe is a single cable (Model 8501). The SourceMeter and mainframe send digital pulses to each other to signal whether a channel is closed and a measurement can be taken or the measurement is complete and the next channel can be selected. This architecture allows tight control over the system and increased operating speed by eliminating the need for external triggering hardware or control via GPIB.
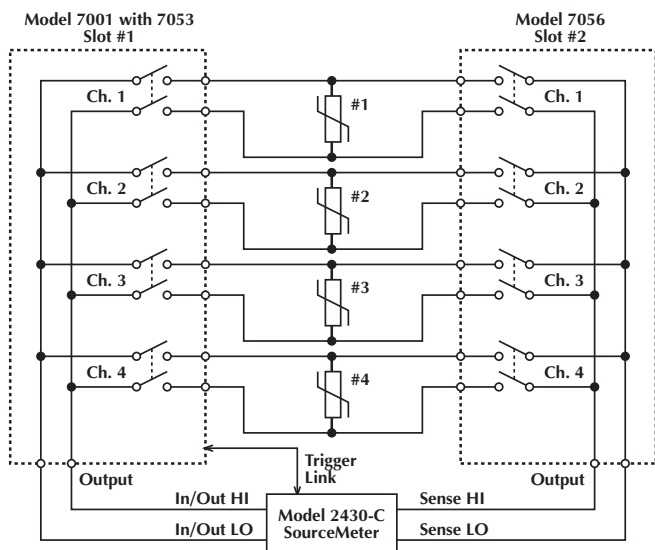
Figure 6. Switching multiple varistors to the 2430-C SourceMeter using 4-wire method

As shown in *Figure 6*, the Model 7053 switch card is used to connect the source to the device and the Model 7056 is used to control the sense lines. The relays on the 7053 card are capable of carrying the current that is delivered by the 2430-C. Due to the size and configuration of these relays, they have a minimum voltage (1V) and current (100µA). If these relays are operated below these levels, over time, oxides on the relay contacts will degrade performance. Varistor testing requires the use of high test voltages and currents, so the oxides will not build up. However, when using the 2430-C in 4-wire mode, the sense lines for the source typically do not carry enough current for the minimum levels required by the 7053 relays. Therefore, using the Model 7056 to switch the sense lines eliminates the minimum signal issue with the relays.

Methods and Techniques

Contact Check

The SourceMeter Contact Check function helps eliminate measurement errors and false product failures that can result from contact fatigue, breakage, or contamination, loose or broken connections, or relay failures. Before each automated test sequence begins, contact is verified, which can help reduce tooling and false failure costs.

Contact check verifies that the resistance between the HI/LO test lead pairs is less than a certain threshold level. Contact verification is done between the Output HI/LO, Sense HI/LO, and Guard/Guard Sense pairs. By using pulse transformers and a reference resistance, the contact can be verified very quickly (typically within 350µs). The reference resistance can be set to three different values (i.e. 5Ω, 15Ω, 50Ω). Contact Check does not pass a signal through the DUT—only between the three HI/LO pairs mentioned. If a Contact Check failure is detected, the test will abort and give a failure indication over the front panel, the IEEE-488 interface bus, and the digital I/O port.

The following SCPI commands control the contact check function via the IEEE-488 bus:

`:SYST:CCH ON|OFF`
Enables or disables contact checking

`:CALC2:LIM4:STAT ON|OFF`
Enables pass/fail on contact check. If there is an open lead, the limit test fails.

`:CALC2:LIM4:SOUR2 <0-15>`
Pattern to be placed on digital I/O lines if contact check fails.

`:SYST:CCH:RES 2/15/50`
Selects threshold resistance

Contact checking is only performed when the SourceMeter is placed in 4- or 6-wire modes (see "Lead Resistance") and from the front or rear terminals. When active, the Contact Check verifies all six leads from the 2430-C. Contact Check is a global function that can not be controlled through Source Memory. That means that if only four wires are connected to the DUT, the Guard/Guard Sense terminals must be shorted to avoid false failures. Shorting these terminals will not affect performance. Contact Check is a factory-installed option and SourceMeter

instruments can be ordered without the "-C" extension (i.e. 2400, 2410, 2420, and 2430) if Contact Check is not required.

Scale Factor

Scale Factor is used in conjunction with the Source Memory and Source Memory Sweep functions. Scale Factor allows the user to take a measured value from one Source Memory point and multiply it by some defined value and use the calculated value as the source value for the next point. The scale factor can be set from –1e+21 to +1e+21, but the scale factor is typically a percentage (e.g. 75% would be a scale factor of 0.75). For example, if the 2430-C reads 10.0V in the first Source Memory Location (Source I, Measure V), then in the second Source Memory Location (Source V, Measure I), the 2430 will output 1.0V if the scale factor is set to 0.1.

Typically, this function is used when testing MLVs to measure leakage current at a fixed percentage of the measured forward voltage.

The following commands are used to control Scale Factor in the 2430-C:

`:SOUR:VOLT:TRIG:SFAC:STAT ON|OFF`
Enable the voltage scale factor function

`:SOUR:CURR:TRIG:SFAC:STAT ON|OFF`
Enable the current scale factor function

`:SOUR:VOLT:TRIG:SFAC <n>`
Instructs 2430-C to source (Scale Factor) * (the previous voltage reading)

`:SOUR:CURR:TRIG:SFAC <n>`
Instructs 2430-C to source (Scale Factor) * (the previous current reading)

Pulse Mode

The pulse capability unique to the 2430 and 2430-C allow these instruments to source high levels of power into a varistor without heating the device excessively and damaging the DUT (see "Device Self-Heating" in the "Typical Sources of Error" section), and allows for an instrument with a small, half-rack design. The 2430-C can produce 1kW (10A, 100V) pulses on the order of 150μs to 2ms duration (with measurement) and is duty cycle limited under certain conditions. On lower source ranges, 150μs to 5ms pulses are possible.

When testing an MLV, high power pulses are needed to verify Maximum Clamping Voltage. The small size of MLVs makes them unable to withstand high voltages. Since MLVs are mostly used in handheld, battery-operated devices, their lower clamping voltage and small geometries are allowing for wide acceptance. Test stands developed for testing MOVs are not always suitable for testing the lower voltage MLVs. A majority of the MLVs being produced can be tested within the 10A/100V range the 2430-C can supply and measure.

The various parameters of the pulse width and overall duty cycle of the Model 2430-C output are shown in *Figure 7*. Of the

parameters listed in the figure, auto zero and the reading are either enabled or disabled, while the others always affect the output on and off times. The amount of time required for auto zero and the reading of the signal depends on the user-defined measurement integration rate. The integration rate of the measurement can only be set from 0.004 to 0.1 line cycles in Pulse mode (e.g. with integration rate set to 0.01, the equivalent time for 60Hz would be 0.167ms and 0.2ms for 50Hz). The user can set pulse widths from 150μs to 5ms, while pulse delay can be set from 0 to ~10,000 seconds. The 2430 calculates the "delay" for the output on time by subtracting 80μs and the signal measurement time from the pulse width setting. System overhead, rise time, and fall time are defined by hardware limits and can't be determined by the user. The parameters for the pulse mode can also be controlled through the Source Memory Sweep function.
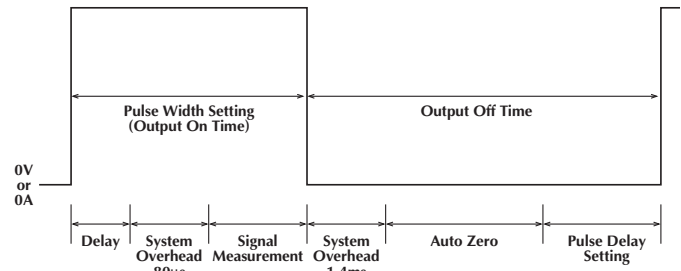

Figure 7. Pulse width components for Model 2430-C output (Not to scale).

To control the pulse capability over the front panel:

1. Press the **CONFIG** button and either the **SOURCE I** or **SOURCE V** button.
2. From the menu that appears, move the cursor using the ◄ and ► arrows and select **SHAPE**.
3. Press the **ENTER** key.
4. Use the ◄ and ► arrows to select **PULSE**, then press **ENTER**. Press **EXIT** once.
5. Press either **SOURCE I** or **SOURCE V** for the desired source mode. The source display will show "Vpls" for sourcing voltage or "Ipls" for current.
6. Press the green **EDIT** button once to set the desired source level, then once more to set the compliance limit.
7. Press the **OUTPUT ON/OFF** button to output a pulse.

The following commands are used to control the 2430-C pulse mode via the GPIB:

`:SOUR:FUNC:SHAP DC|PULSE`
Select either DC or PULSE operation. The 10A/100V range is only enabled in pulse mode.

`:SOUR:FUNC VOLT|CURR`
Set to source either voltage or current.

`:SOUR:PULS:DEL <n>`
Set off time of pulse (see *Figure 7*).

`:SOUR:PULS:WIDT 0.00020 – 0.00500`
Set pulse on time (see *Figure 7*).

Varistor Alpha

The non-linear exponent (alpha) test is typically performed during device characterization. The Model 2430-C can calculate the alpha coefficient directly and display the result on the front panel or return the value over the bus. Limit testing can also be done based on the result of the alpha test. Although not typically used in a production setting, the alpha test is useful for determining the linearity of a device within its transition from the non-conducting to conducting region of operation. Some manufacturers do, however, use the alpha coefficient as one criterion for binning during production.

The varistor I-V relationship can be described by the equation $I = kV\alpha$, where k is a constant dependent on the geometry of the device and α is determined from two points on the I-V curve as:

$$\alpha = \frac{\log I_2/I_1}{\log V_2/V_1}$$

This measurement is performed by measuring the voltages (V_1 and V_2) across the varistor at two specified test currents (I_1 and I_2), where $I_1 \leq I \leq I_2$.

To configure the varistor alpha test from the front panel:

1. Press the **CONFIG** key followed by the **FCTN** button.

2. Use the ◄ and ► arrows to select **VAR-ALPHA** and press **ENTER**.

3. Use the **RANGE** ▲ and ▼ buttons to select the desired range for the first test "I1."

4. Use the ◄, ►, ▲ and ▼ buttons to select the desired source value and press **ENTER**.

5. Repeat Steps 3 and 4 for the second test "I2."

6. Turn the output on using the **OUTPUT ON/OFF** button.

The varistor alpha test is not configured using built-in bus commands. Instead, it can be configured over the bus by defining each parameter of the test. The following command sequence will configure the instrument to perform the test and return a single reading.

```
*RST
:SENS:FUNC "VOLT","CURR"
:SOUR:FUNC CURR
:SOUR:CURR:STAR <n>
:SOUR:CURR:STOP <n>
:SOUR:CURR:MODE SWE
:TRIG:COUN 2
:CALC:MATH:EXPR:NAME "VARALPHA"
:CALC:STAT ON
:OUTPUT ON
:INIT
:CALC:DATA?
```

Basic Programming Guideline

This section describes the steps to program a typical test suite for varistors. The result is a test sequence with six points in this order of execution: $+V_n$, $+I_L$, $-V_n$, $-I_L$, $+V_b$, $-V_b$.

Note that each test set-up is saved in a Source Memory Location (SML). The Source Memory can be programmed either from the front panel or via GPIB. Source Memory is a function that allows the user to configure discrete tests and save them in memory in order. Once all of the tests are configured, the 2430 will sequence through each test rapidly until the all tests are performed, then commnicate the results of the test sequence and pass/fail criteria to the user or test system. Keithley recommends performing these steps over the bus—programming the Source Memory from the front panel can be cumbersome.

This description contains both positive and negative polarities for the source to duplicate the test points shown in *Figure 2* with the system setup shown in *Figure 3*.

1. Reset the 2430-C and initialize the GPIB interface card.

2. Set 2430-C parameters that will be common to all three tests (e.g. data format, autozero, line cycle integration, etc.)

3. Enable Contact Check.

4. Configure Trigger Model – settings in parentheses are suggested for one test cycle.

   a. Configure arm layer: set count (1), source (SOT).

   b. Configure trigger layer: set count (6), source (Immediate), output (sense), input (source), delay (0.001s).

5. Define the Nominal Varistor Voltage Test.

   a. Set 2430-C to DC output mode.

   b. Set 2430-C to source positive current: set source value, range and delay.

   c. Set 2430-C to measure voltage: set sense range and compliance.

   d. Set limit values and digital output bit patterns for each pass/fail outcome.

   e. Save Positive Nominal Voltage Test set-up in SML #1.

   f. Change polarity of the source and limits.

   g. Save Negative Nominal Voltage Test in SML #3.

6. Define the Varistor Leakage Current Test.

   a. Set 2430-C to source voltage: set source value, range and delay.

      Utilizing Scale Factor will automatically set the source voltage value, depending on the nominal voltage measured in the previous test.

   b. Set 2430-C to measure current: set sense range and compliance.

c. Set limit values and digital output bit patterns for each pass/fail outcome.

d. Save Positive Varistor Leakage Current Test set-up in SML #2.

e. Change polarity of the source and limits.

f. Save Negative Varistor Leakage Current Test set-up in SML #4.

7. Define the Maximum Clamping Voltage Test.

a. Set 2430-C to Pulse mode as opposed to the DC mode used in steps 4 and 5.

The Pulse mode of the 2430-C enables the 1kW pulse capabilities.

b. Set 2430-C to source current: set source value, range and delay.

c. Set 2430-C to measure voltage: set sense range and compliance.

d. Set limit values and digital output bit patterns for each pass/fail outcome.

e. Save Positive Maximum Clamping Voltage Test set-up in SML #5.

f. Change polarity of the source and limits.

g. Save Negative Maximum Clamping Voltage Test set-up in SML #6.

8. Command 2430-C to perform Source Memory Sweep.

a. Define number of points in sweep. (In this example, there are six points.)

b. Set 2430-C to perform sweep (:SOUR:FUNC MEM).

9. Initialize testing.

10. Store data.

Typical Sources of Error

Device Self-Heating

With long test times, a varistor being tested may begin to heat up because the energy used for testing dissipates within the device. This temperature increase can introduce errors into the measurement. The leakage current test would be the most affected test. With higher temperatures, the measured leakage value will increase. It is possible to heat a varistor to the point where it will fail the leakage current test limits.

The most effective way to avoid device self-heating is to keep test times as short as possible. With reduced test times, the source is not engaged long enough to heat the device discernably. The longer the source is active and connected to the varistor, the more the part's temperature will rise.

To reduce test times, use the lowest NPLC setting (typically 0.01NPLC), fixed source range (i.e. disable auto range), fixed measurement range, and use the shortest allowable source delay.

The source delay is the amount of time between the point the source is enabled and the point a measurement is taken. The source delay is intended to allow the source to settle into the load before the measurement is taken, in order to produce more stable readings. But the longer power is applied to the device, the more self-heating will occur, resulting in possible error. Therefore, experimentation is needed to determine the optimal source delay that will yield the best balance between speed and accuracy.

Lead Resistance

A common source of voltage measurement error is the series resistance from the test leads running from the 2430-C to the varistor. This series resistance is added into the measurement when making a 2-wire connection (see *Figure 8*). The effects of lead resistance are particularly detrimental when long connecting cables and high current are used, because the voltage drop across the lead resistance becomes significant compared to the measured voltage.
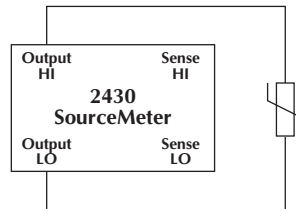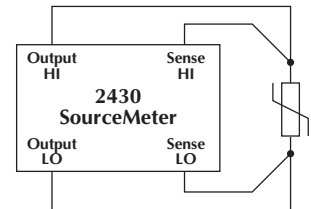

Figure 8. Two-wire connection   *Figure 9. Four-wire connection*

To eliminate this problem, use the 4-wire remote sensing method rather than the 2-wire technique. With the 4-wire method (*Figure 9*), a current is forced through the varistor using the Output HI/LO leads and the voltage across the varistor is measured through the Sense HI/LO leads. As a result, only the voltage drop across the device is measured.

To control sensing over the front panel:

1. Press the **CONFIG** button followed by the **MEAS V** button.

2. Use the ◄ and ► buttons to select either **2-WIRE** or **4-WIRE**.

3. Once the desired mode is selected, press the **ENTER** button.

To control sensing over the GPIB interface use the following command:

`:SYST:RSEN ON|OFF`
Enable or disable remote sensing

Whenever the 2430-C is in remote sense mode, the "4W" annunciator will appear on the front panel. The 2430-C can switch back and forth between 2- and 4-wire modes within the same Source Memory test sequence.

Example Programs

Keithley has developed a program to execute the bipolar Nominal Varistor Voltage, Varistor Leakage Current, Maximum Clamping Voltage tests on varistors. This Microsoft Visual Basic 5.0 application allows the user to set the various parameters for these six tests and displays the results after testing is complete. In order to create a Visual Basic application, add the form "mlv.frm" file to a standard Visual Basic application, along with the "ieeevb.bas" module. The file "ieee-32m.dll" is also needed and should reside in the Windows directory. The "mlv.frm" file could also be viewed, but not run, with any text editor.

The digital files for the Example Program are available via Keithley's WWW site **<http://www.keithley.com>** or ftp server **<ftp://ftp.keithley.com/pub/instr/SourceMeter/>**.

Equipment List

To assemble the varistor production test system shown in *Figure 3* and run the listed program, the following equipment is required:

1. Keithley Model 2430-C 1kW Pulse SourceMeter
2. PC with KPC-488.2AT GPIB Interface Card
3. Model 7007 IEEE-488 Interface Cable
4. Custom cable to connect the 2430-C to a component handler or test fixture

Alternative Solutions

Other instruments in the SourceMeter family can be configured into varistor production test systems. Instrument programming for each member of the SourceMeter Series is identical. The only differences between the instruments are the dynamic ranges of their sources and the availability of Pulse Mode. *Table 1* lists the source/measure ranges for each SourceMeter instrument. A suitable SourceMeter model can be selected based on the specific requirements of the test.

Model Number	Maximum Voltage	Maximum Current (Mode)	Recommended Switch Card Model
2400/2400-C	210V @ 105mA	1A @ 21V	7011, 7154
2410/2410-C	1100V @ 21mA	1A @ 21V	7154
2420/2420-C	60V @ 1A	3A @ 21V	7053
2430/2430-C	100V @ 1A	3A @ 21V (DC)	7053
	100V @ 10A	10A @ 100V (Pulse)	7053

Reference

For more information on varistors, see:

Philips Passive Components. "Introduction to Varistors." 1996 Nov 14. **<http://www.passives.comp.philips.com/pdf/intro_09.pdf>** (19 Mar. 1999).

Keithley Instruments, Inc., "Varistor Verification with the 2400 Digital SourceMeter™," Keithley Instruments, Inc., Cleveland, OH. Application Note No. 803, April 1996.

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