

Varistor Verification with the 2400 Digital SourceMeter™ Instrument

Introduction

Varistors are active circuit protection devices, designed to protect electronic circuits from surges and spikes. As with any electronic device, varistors have a number of electrical parameters that must be verified through production testing to ensure they meet the manufacturer's specifications. Testing must be performed as quickly as possible to ensure acceptable throughput, but also reliably to assure product quality.

Usually, several instruments are required to make these tests, such as a DMM, voltage source, and current source. However, as the number of instruments in the test system increases, the slower the overall measurement process becomes, slowing test throughput. A system configured with a separate DMM and sources takes up substantially more rack space than a system built with all these functions in one unit. In addition to higher equipment costs, three separate instruments also means there are three sets of instrument commands to learn, complicating system programming and maintenance. Using multiple instruments and sources also makes trigger timing more complex and increases triggering uncertainty.

The Model 2400 Digital SourceMeter Instrument can source and measure both current and voltage quickly, so it's an ideal solution for DC electrical testing of varistors. It also offers the advantage of a source memory list, which allows for storing a complete test set-up that can be initiated over the IEEE bus with a single command. This saves IEEE bus time, so it increases throughput. Some of these tests include the Nominal Varistor (Breakdown) Voltage, DC Standby (Leakage) Current and Non-Linear Exponent (Alpha) measurements. This application note describes how to set up and take these measurements using the Model 2400, including calculating the source/measure cycle speed, outputting pulses for the breakdown and leakage tests, displaying alpha, and setting up a pass/fail limit structure. The front panel operation mode is outlined here to illustrate the testing process.

Test Descriptions

Nominal Varistor (or Breakdown) Voltage

The varistor peak terminal voltage is the voltage across the varistor measured at a specified DC current of specified duration.

DC Standby (or Leakage) Current

The DC standby current is measured with the rated maximum operating voltage applied across the varistor for a specific

duration. The maximum operating voltage corresponds to the rest state of the varistor and is the maximum allowable steady state DC applied voltage.

Non-Linear Exponent (or Alpha) Test

The varistor voltage-current characteristic follows the equation $I = kV^\alpha$, where k is a constant dependent on geometry and α is the non-linear exponent. Alpha can be calculated from the following equation:

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

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

Typical varistor V-I characteristics are shown in **Figure 1**. The test points for the varistor voltage (V_n), standby current (I_d), and non-linear exponent (α) test are shown.

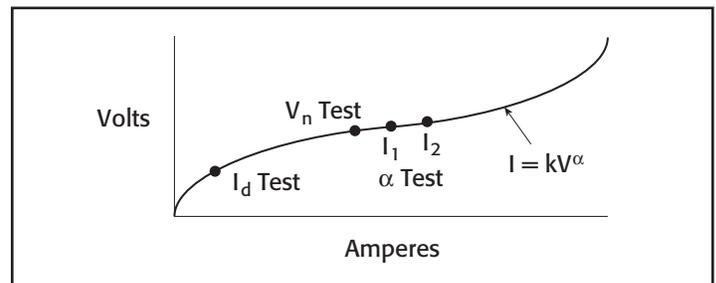


Figure 1. Typical Varistor Voltage-Current Curve Plotted on a Log-Log Scale

Test System Configuration

The varistor voltage, standby current, and non-linear exponent tests can be run automatically using a Model 2400-based varistor test system, as shown in **Figure 2**. This configuration assumes devices will be tested one at a time. If batch operation is needed, additional switching hardware will be required.

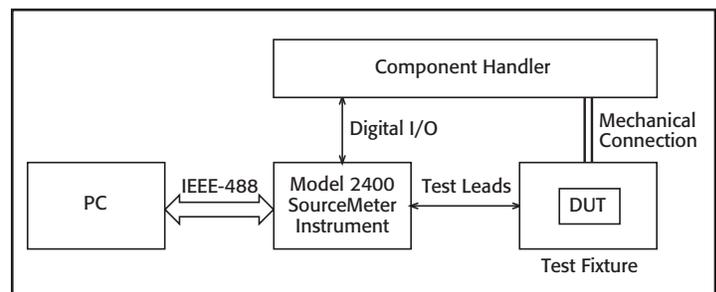


Figure 2. Model 2400-Based Varistor Production Test System

As **Figure 2** illustrates, the Model 2400 has both an IEEE-488 output and a digital I/O output. The digital I/O output port can send signals directly to and receive signals from most component handlers. High and low measurement limit values can be set in the digital SourceMeter Instrument and compared to a varistor measured at the input of the instrument. A TTL level signal generated from the Model 2400's digital I/O port indicates whether the device passed or failed the tests. These pass/fail limits can be sent over the IEEE-488 bus to a computer, read directly from the front panel, or detected by the handler for fast binning of the varistors. The Model 2400 can interface directly with a component handler, freeing the PC during handling operations and allowing test data to be downloaded and stored while a new varistor is being positioned in the test fixture.

The following algorithm describes the operation of the varistor verification system. It assumes a continuous-feed operation involving only one varistor in the test fixture at a time.

1. Operator indicates to a PC that a reel of varistors is in place and ready to be tested.
2. PC initiates Model 2400 operation.
3. The Model 2400 waits for Start of Test trigger from handler.
4. Handler sends Start of Test trigger signal to the Model 2400, indicating varistor is positioned in fixture and ready for testing.
5. The Model 2400 runs varistor verification tests in order, makes pass/fail determinations and saves data for each test: Nominal Varistor Voltage Test, DC Standby Current Test, and Non-Linear Exponent Test.
6. The Model 2400 sends overall pass/fail status and End of Test signal to handler and also sends test data to PC (operations occur in parallel).
7. Repeat Steps 3–6 for remainder of varistors on reel or in tube.
8. The Model 2400 returns to idle state. The operator installs new tube or reel of varistors in handler.
9. Repeat Steps 1–8 as required.

IEEE Bus Operation

Here are some general steps to follow when writing a program to set-up and execute the three basic varistor tests and indicate whether the device passes or fails each test. Note that each test set-up is stored in a Source Memory Location. The Source Memory is programmable only over the IEEE bus and not from the front panel.

1. Initialize GPIB and Model 2400.
2. Set Model 2400 parameters that will be common to all three tests (e.g. autozero, data format, etc.).
3. Define the Nominal Varistor Voltage Test.
 - a. Command the Model 2400 to source current: set source value, range and delay.

- b. Command the Model 2400 to measure voltage: set sense range and compliance.
 - c. Set limit values and digital output bit patterns for each pass/fail outcome.
 - d. Save Nominal Varistor Voltage Test Set-up in Source Memory Location #1.
4. Define the DC Standby Current Test.
 - a. Command the Model 2400 to source voltage: set source value, range and delay.
 - b. Command the Model 2400 to measure current: set sense range and compliance.
 - c. Set limit values and digital output bit patterns for each pass/fail outcome.
 - d. Save DC Standby Current Test Set-up in Source Memory Location #2.
5. Define the Alpha Test.
 - a. Command the Model 2400 to source current #1: set source value, range and delay.
 - b. Command the Model 2400 to measure voltage #1: set sense range and compliance.
 - c. Save Alpha Test #1 Set-up in Source Memory Location #3.
 - d. Command the Model 2400 to source current #2: set source value, range and delay.
 - e. Command the Model 2400 to measure voltage #2: set sense range and compliance.
 - f. Save Alpha Test #1 Set-up in Source Memory Location #4.
 - g. Feed values of voltage #1 and voltage #2 into function: (CALC1:MATH:NAME 'VARALPHA'). This function will automatically calculate the Alpha value.
 - h. Set limit values and digital output bit patterns for each pass/fail outcome.
6. Set-up Trigger Model.
7. Initiate Testing.
8. Store Data.

Methods and Techniques

Some of the steps involved in using a Model 2400 Digital SourceMeter Instrument in a system include calculating the source/measure speed cycle, outputting pulses for the breakdown and leakage tests, using math functions to calculate alpha, and setting up a limit structure.

Calculating Source/Measure Speed

Speed is one of the most important features of a production test instrument. The Model 2400 can complete a source/measure cycle within 1ms. Because several factors affect source/measure speed, it becomes necessary to calculate the actual time the Model 2400 source is turned ON, especially if DUT

soak times are critical. A Source/Delay/Measure timing chart is shown in **Figure 3**. This example assumes that the Auto Zero function is turned off and only one function (e.g. current) is being measured.

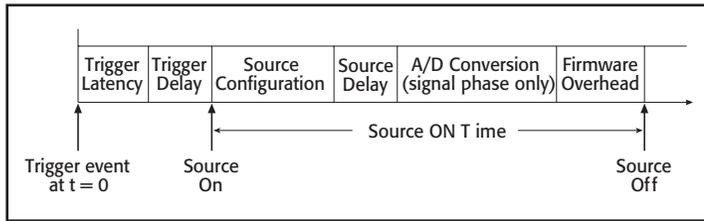


Figure 3. Source/Delay/Measure Timing Chart

Trigger Latency is the time from the point when the trigger event occurs to the point when the Model 2400 detects it. This is approximately 225µs.

Trigger Delay is the time between the detection of the trigger event and the point when source configuration occurs. This delay is user-programmable from 0.0000 seconds to 999.9999 seconds.

Source Configuration is the time it takes to configure the source DAC. This is approximately 50µs.

Source Delay is the time delay between the source configuration and the start of the first A/D conversion. With auto-delay enabled, 100µs is added to the user-programmed source delay. This value is user-selectable from 0.0000 seconds to 999.9999 seconds.

A/D Conversion is the time it takes to measure the specified A/D converter phase. In the example provided, only the signal phase is measured because AutoZero is turned off. Autozero compensates for zero drift by measuring a precise voltage reference with each reading. With AutoZero turned off, only the signal phase of the measurement cycle is done, decreasing the measurement time.

Firmware Overhead is the time associated with A/D communication, reading calibration, and other operations necessary to perform the Source-Delay-Measure cycle. This time is not illustrated in the timing diagram.

To determine the source ON time for this example, use the following equation:

$$\text{Source ON Time} = \text{Source Configuration} + \text{Source Delay} + \text{A/D Conversion} + \text{Firmware Overhead}$$

where:

$$\text{Trigger Latency} = 225\mu\text{s max.}$$

$$\text{Source Configuration} = 50\mu\text{s max.}$$

$$\text{A/D Conversion} = [\text{NPLC Setting} \times (1/\text{power line frequency})] + 185\mu\text{s}$$

$$\text{Firmware Overhead} = 640\mu\text{s} - \text{Source I}; 300\mu\text{s} - \text{Source V}$$

Example: Source Delay = 0µs

$$\text{NPLC Setting} = 0.08\text{PLC}$$

$$\text{Power Line Frequency} = 60\text{Hz}$$

Source I

$$\begin{aligned} \text{Source ON Time} &= 50\mu\text{s} + 0 + [(0.08 \times 1/60) + 185\mu\text{s}] + 640\mu\text{s} \\ &= 2.2\text{ms} \end{aligned}$$

The timing equation assumes that both the filter and auto range are off. These features would add extra time to the Source/Delay/Measure cycle.

Since accuracy is dependent on the integration time (NPLC), note from the timing equation that there is a direct relationship between measurement speed and accuracy. The higher the speed, the less precise the measurement will be.

Determining the Source OFF time is more complicated because this time is affected by several factors, including the source of the event trigger, math functions, and use of limits. The source OFF time can be adjusted using the trigger delay, either from the front panel or over the bus. This is especially useful when creating pulses.

Outputting Pulses for the Breakdown Voltage or Leakage Current Measurements

The breakdown voltage or leakage current are measured across the varistor at a specified pulsed DC current or voltage. Since many factors may affect the timing of these pulses, it is important to calculate the waveform precisely. To do this, the source ON time equation must be resolved.

This is best shown by an example, which starts out with this equation:

$$\text{Source ON Time} \cong \text{Source Configuration} + \text{Source Delay} + \text{A/D Conversion} + \text{Firmware Overhead}$$

Example 1. Setting up a 1ms pulse from the front panel

1. Return the Model 2400 to factory default conditions.
 - Press: **MENU**
 - Select: **SAVE SETUP** (enter)
 - RESET** (enter)
 - BENCH** (enter)
 - Press: **ENTER** twice to restore bench default conditions
 - Press: **EXIT** twice to return to the measurement display.
 - Send the following command to reset: ***RST**
2. Set the Model 2400 to the desired source and measure values.
3. Turn AutoZero OFF.
 - Press: **MENU**
 - Select: **GENERAL** (enter)
 - Select: **A/D CONTROLS** (enter)
 - Select: **AUTO-ZERO** (enter)
 - Select: **OFF** (enter)
 - Press: **EXIT** three times to return to main measurement display.

- Send the following SCPI command to disable AutoZero:
:SYSTEM:AZERO:STATE OFF
4. For a 1ms pulse, use the minimum integration time (NPLC), 0.01. To change the NPLC to 0.01:
Press: **SPEED**
Select: **FAST** (enter)
Notice the number of digits decreases to 3.5 digits.
Send the following SCPI command to select FAST:
:SENSE:CURRENTorVOLTAGE:NPLC 0.01
 5. Solve the Source ON Time equation for the Source Delay. Using the values chosen above, 60Hz line frequency, and Source V mode, the equation becomes:
$$\text{Source Delay} \cong 1\text{ms} - 50\mu\text{s} - [(0.01 \times 1/60) + 185\mu\text{s}] - 300\mu\text{s}$$
$$\cong 0.298\text{ms}$$

The resolution of the source delay is $100\mu\text{s}$, so $300\mu\text{s}$ should be used. To enter this time:
Press: **CONFIG** and then either **I SOURCE** or **V SOURCE**
Select: **DELAY** (enter)
Enter the delay time by using the arrow keys and then press **ENTER**.
Press: **EXIT** to return to the main measurement display.
Send the following SCPI command to set source delay:
:SOURCE:DELAY 0.0
 6. Auto range affects the timing, so turn this feature off by pressing **AUTO**. The **AUTO** annunciator on the front panel should no longer be illuminated.
Send the following SCPI command to disable Auto range:
:SENSE:CURRENT:RANGE:AUTO ON
 7. The filter should be turned off by pressing **FILTER**. The **FILT** annunciator should no longer be illuminated. (NOTE: The filter should be off by factory default.)
Send the following SCPI command to disable the filter:
:SENSE:AVERAGE:STATE OFF
 8. To shut the source off after 1ms, the auto-off feature must be enabled as follows:
Press: **CONFIG** and then **OUTPUT**
Select: **AUTO-OFF** (enter)
Select: **ENABLE** (enter)
Press: **EXIT** to return to the main measurement display.
Send the following SCPI command to enable Auto Clear:
:SOURCE:CLEAR:AUTO:ON
 9. Output the pulse by pressing **OUTPUT** or **TRIG**. A train of pulses begins with an ON time of 1ms and an OFF time based on the trigger delay value.
Send the following SCPI command to enable the output:
:OUTPUT:STATE ON
 10. Change the OFF time to the desired value. Remember that several factors affect the source OFF time.
Press: **CONFIG** and then **TRIG**
Select: **TRIG-LAYER** (enter)
Select: **DELAY** (enter)
Input the desired delay time (enter)
Press: **EXIT** twice to return to the main measurement display
Send the following SCPI command to set Trigger Delay:
:TRIGGER:DELAY 0.0
 11. In the **NORMAL** Output OFF state, the output is a current limited short; therefore, the output may take longer than the trigger delay time to discharge, depending on the connections to the Model 2400. For a much faster settling time in the Source V mode only, set the Output OFF state to **ZERO**. This will set the source value to 0, but keep the current compliance at its programmed value. To change the Output OFF state to **ZERO**:
Press: **CONFIG** and then **OUTPUT**
Select: **OFF-STATE** (enter)
Select: **ZERO** (enter)
Press: **EXIT** to return to the measurement display
Press: **OUTPUT** to turn output back ON
Note on the display that the settling time is much faster.
In the **ZERO** mode, even though the output may be turned off, it still remains an active circuit, and therefore “ZER” is displayed.
NOTE: A continuous square wave can be output from the front panel. However, over the IEEE-488 bus, a square wave is limited to 2500 cycles.
Send the following SCPI command to set Output OFF to **ZERO** state:
:OUTPUT:SMODE ZERO
 12. Verify the voltage source ON and OFF times with an oscilloscope. If necessary, make adjustments using source delay and trigger delay.
 13. To stop the square wave, press **OUTPUT**. To start a new square wave, repeat step 8.
Send the following SCPI command to disable the output:
:OUTPUT:STATE OFF
 14. To output only one pulse rather than a continuous waveform:
Press: **CONFIG** and then **TRIG**
Select: **ARM-LAYER** (enter)
Select: **ARM-IN** (enter)
Select: **MANUAL** (enter)
Press: **EXIT** twice to return to the main measurement display
Press: **TRIG** twice to output one pulse.

Press: **TRIG** only once to generate subsequent pulses.

Notice the OUTPUT light shuts off after the programmed delay time.

Send the following SCPI command to set ARM-IN source to manual:

```
:ARM:SOURCE MANUAL
```

Displaying the Alpha Value

The Model 2400 can automatically calculate and display the alpha (α) value on the front panel. Set up the alpha function as follows:

Example 2. Displaying the Alpha value

First, return the Model 2400 to factory default conditions as described in Example 1, Step 1.

Next, input the desired voltage compliance and measurement range.

Press: **CONFIG** and then **FCTN**

Select: **VAR-ALPHA** (enter)

Enter an I_1 value (enter)

Enter an I_2 value (enter)

Press: **EXIT** to return to main display

Press: **FCTN** to get into the MATH mode (notice the MATH annunciator)

Send the following SCPI command to set for VAR-ALPHA:

```
:CALCULATE:MATH"VARALPHA"
```

```
:CALCULATE:STATE ON
```

```
:OUTPUT:STATE ON
```

Press: **OUTPUT** to begin measurements.

The display now measures and displays the alpha (α) value continuously. The varistor may heat up quickly, so turn off the measurement cycle by pressing **OUTPUT**.

To take only one alpha reading every time TRIG is pressed:

Press: **CONFIG** and then **TRIG**

Select: **ARM-LAYER** (enter)

Select: **ARM-IN** (enter)

Select: **MANUAL** (enter)

Press: **EXIT** twice to return to the measurement display.

Press: **OUTPUT** to turn source ON.

Press: **TRIG** twice to take one alpha measurement.

Press: **TRIG** only once to take subsequent alpha measurements.

Press: **OUTPUT** to turn source OFF.

To turn ALPHA function OFF, press one of the other function keys (i.e., V Meas or I Meas).

Setting up a Limit Structure from the Front Panel

High and low measurement limit values can be set in the Model 2400 and compared to a component measured at the input of

the instrument. These limits can be set directly through the front panel. A TTL level signal generated from the output of the digital I/O port of the Model 2400 indicates whether the device passed or failed the tests.

Two examples are provided that illustrate setting up a limit structure from the front panel. Example 3 will indicate a pass or fail on the display of the instrument, depending upon whether the instrument is in or out of compliance. Example 4 describes how to send a pass or fail indication from the digital I/O port.

Example 3. Pass/Fail In Compliance

1. Return the Model 2400 to factory default conditions as described in Example 1, Step 1.
2. Select desired functions, for example, Source I and Measure V.
3. Set-up Limit 1. (NOTE: Limit 1 is simply a test of whether or not the measurement is in compliance. The compliance condition can be defined as either passing or failing, depending on the application.)

Press: **CONFIG** and **LIMIT**

Select: **LIMIT-1** (enter)

4. Indicate the test FAILS if the Model 2400 goes into compliance.

Select: **FAIL-MODE** (enter)

Select: **IN** (enter)

If using the digital I/O port, select a bit pattern at this time (and enter), otherwise:

Press: **EXIT** once

5. Enable control of Limit-1.

Select: **CONTROL** (enter)

Select: **ENABLE** (enter)

Press: **EXIT** twice to return to measurement display.

6. Begin Pass/Fail Mode.

Press: **LIMIT** to activate the PASS/FAIL mode.

Connect a device and turn the OUTPUT ON. Notice the display indicates PASS or FAIL.

Example 4. Pass/Fail Indication from the Digital I/O Port

In this example, any nominal varistor voltage value between 135V and 165V passes. Any values outside these boundaries fail. Only the high and low values of Limit 2 will be used. A limit test chart follows:

Limit	Value	Pattern	Action
V<LOLIM	V<135	1110	DIGOUT#1=LOW, All Others HI
LOLIM<V<HILIM	135<V<165	1101	DIGOUT#2=LOW, All Others HI
V>HILIM	V>165	1011	DIGOUT#3=LOW, All Others HI

Follow these steps to send a signal to an external handler to indicate PASS/FAIL:

1. Return to factory default conditions as described in Example 1, Step 1.
2. Select desired source and compliance values.
3. Configure Limit 2.
Press: **CONFIG** and then **LIMIT**.
Select: **LIMIT-2** (enter)
Press: **CONTROL** (enter)
Press: **ENABLE** (enter)
4. Set LO limit value and bit pattern.
Press: **LOLIM** (enter)
Enter in the low limit value. In this example, it would be 135V (enter)
Enter the desired digital output bit pattern (enter).
5. Set HI limit value and bit pattern.
Press: **HILIM** (enter)
Enter in the high limit value. In this example, it would be 165V (enter).
Enter the desired digital output bit pattern (enter).
Press: **EXIT** once to return to the Limits Menu.
6. Set the bit pattern for when the component passes the limit test.
Select: **PASS** (enter)
Enter the desired digital output bit pattern (enter).
7. Some handlers require a signal to indicate that a measurement cycle has finished. To send a bit to the handler:

Select: **DIGOUT-CLEAR** (enter)

Select: **ENABLE** (enter)

Enter in desired delay time (enter).

Enter the desired digital output bit pattern (enter).

Press: **EXIT** once to return to measurement display.

Equipment List

The following equipment is required to assemble the varistor production test system and run the listed program:

1. Keithley Model 2400 Digital SourceMeter Instrument
2. PC with KPCI-488A Interface Card
3. Component handler with test fixture
4. IEEE-488 interface cable
5. Custom DB-9 digital I/O handler interface cable (to interface the 2400 to handler)
6. Test leads to connect the Model 2400 to the test fixture

Alternative Solutions

It would be possible to configure an alternative solution for varistor production testing by using separate sources and measurement instruments to replace the functions provided by the Model 2400. For varistor tests that require test voltages >200V, a separate high voltage source and measuring instrument, such as the Model 237 Source-Measure Unit or Model 2410 SourceMeter Instrument, would likely have to be used.

Specifications are subject to change without notice.

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