Device Characterization Techniques using Keithley SourceMeter® Instruments with LabTracer Software

Introduction

SourceMeter instruments (sometimes referred to as Source-Measure Units or SMUs) combine a programmable power source with the measurement functions of a digital multimeter. The Keithley LabTracer application allows users to coordinate the measurement and sourcing activities of up to four SourceMeter instruments at once, and collect voltage and/or current readings from any of the instruments, as well as a timestamp for each measurement set. The example software developed for this application note programs one SourceMeter instrument to sweep voltage or current while another one is stepping current or voltage, allowing collection of complete test sequences. Results can be exported to a spreadsheet for datalogging, calculation, and analysis. This software represents a simple method of collecting important device characteristics in a familiar format. The techniques incorporated into the software can simplify experiments.

While the LabTracer software provided is only an *unsupported example program* for use with Keithley SourceMeter instruments, this modular approach offers several advantages over a traditional curve tracer system. For example, a SourceMeter instrument's automated measurement features offer greater flexibility for making a wide array of other lab experiments. These instruments also provide more source/measure range options than a curve tracer because it's possible to choose an instrument that offers the specific ranges needed. By using a Windows platform to collect and store data, the LabTracer software allows control and data interpretation without using a floppy disk.

Keithley has always taken its responsibility to provide affordable technical solutions for researchers and students seriously. This system combines basic device characterization with greater functionality and versatility than ever before available at an economical cost. When used in conjunction with Keithley's measurement handbooks and other lab packages, this setup offers a useful upgrade for almost any teaching lab.

Test System Setup

Selecting the most appropriate SourceMeter instrument for a particular application is a critical first step in configuring a test system. This decision is based largely on the voltage and current levels required. All of the instruments in the SourceMeter line operate in all four quadrants, i.e., they can source or sink voltage or current while measuring both voltage and current. However, it's important to remember that each SourceMeter instrument is designed to accommodate different current and/or voltage ranges. For instance, if one of the sweeps for a particular test requires sourcing more than 220V, a Model 2400 SourceMeter instrument would be inadequate—a Model 2410 High Voltage version would be required because it can source up to 1000V. Similarly, if high step currents are needed, the Model 2420 High Current version is probably the best choice because it can source up to 3A. For even higher current levels, the Model 2440 5A instrument may be required.

The example software was written to allow easy instrument swapping as application needs change. Therefore, a Model 2410 can replace a Model 2400 in a test rack to use the Model 2410's high voltage capabilities without changing any other software settings. If more precise low current measurements are required, the software also offers the option of substituting a more sensitive instrument, like the Model 6430 Sub-Femtoamp Remote SourceMeter instrument. The Model 6430 can be used as a Source-Measure Unit (SourceMeter) with the LabTracer software simply by connecting it like a Series 2400 instrument, except that it requires sourcing and measuring between the red (HI) and green (LO) leads on the triax-to-alligator clip cable. The black lead from the triax cable is the guard, which must float to ensure proper functionality in this setup. To allow greater testing flexibility and more affordable system upgrades as needs changes, the example software uses only commands that are common to the entire SourceMeter line.

The next step after selecting the correct SourceMeter models is to determine the number of these instruments required. LabTracer software supports up to four SourceMeter instruments for testing four-terminal devices such as FETs. To determine how many instruments will be needed, first consider the types of devices to be tested and how many sources will be needed during any single test.

Once the types and number of instruments needed are decided, it's time to integrate them into a system that the LabTracer software can control. First, connect the set of SourceMeter instruments to one GPIB bus by daisy-chaining the GPIB cables. Then, connect the instruments to the computer using either a KPCI-488 or KPCMCIA-GPIB card. Also, connect the SourceMeter instruments together using Model 8501 and 8505 Trigger Link cables. For two instruments, one Model 8501 cable will be required. To integrate a third SourceMeter instrument, add a Model 8505 cable and another Model 8501 cable. For four instruments, two Model

8505 and three Model 8501 cables are required. Refer to **Figure 1** for specific connection guidance.
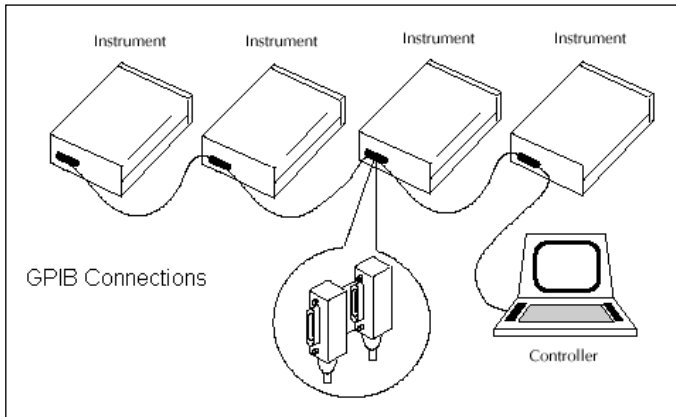
Figure 1. *GPIB connections*

Finally, after powering up the instruments, use the menu key to enter the communication configuration and set each instrument to a unique GPIB Address number. Be sure to record and save these numbers because it will be necessary to enter them in the LabTracer application in order to complete the communication link.

To help ensure measurement accuracy, make certain the output LOs of all the SourceMeter instruments are connected together when connecting the DUT to the instruments. The only time to make an exception to this rule is when purposely attempting to float one of the sources. For the sake of brevity, Source-Meter instruments are referred to as SMUs in the LabTracer software interface.
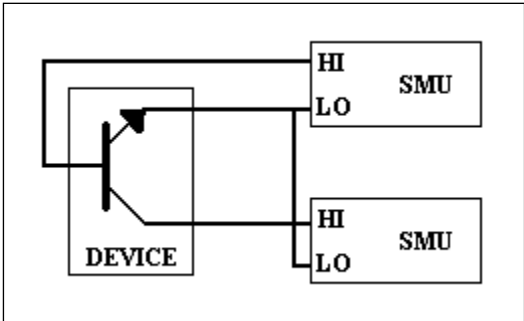
Figure 3. *Configuration with two SourceMeter instruments*

Example: In this test setup, the transistor emitter is grounded. The LO outputs of both SourceMeter instruments are connected to the device's third pin to ground it. If a bias is needed on the third terminal, add another SourceMeter instrument with the HI connected to the device and the LO connected to the LO of SourceMeter 1 and SourceMeter 2. The output LO of every SourceMeter instrument should be connected to ensure the correct potentials are present.

The LabTracer software includes some important timesaving features, including file- and data-saving functions. The **Options** panel allows saving programmed test configurations for later recall and reuse. The "Save Data" feature on the **Sheet** panel can simplify preparing reports on multiple tests. Collecting data in a tabular format allows exporting it to a spreadsheet, where data from different tests can be compared or multiple elements from the same data set can be graphed. With the LabTracer program, the dropdown boxes for the x and y axes on the **Graph** panel make it easy to change the elements on the graph. Complete test setups can be created and saved, including functions, values, and all SourceMeter settings. This makes testing easy once user test sets are defined. Use the **Open** button on the **Options** tab to open these tests.
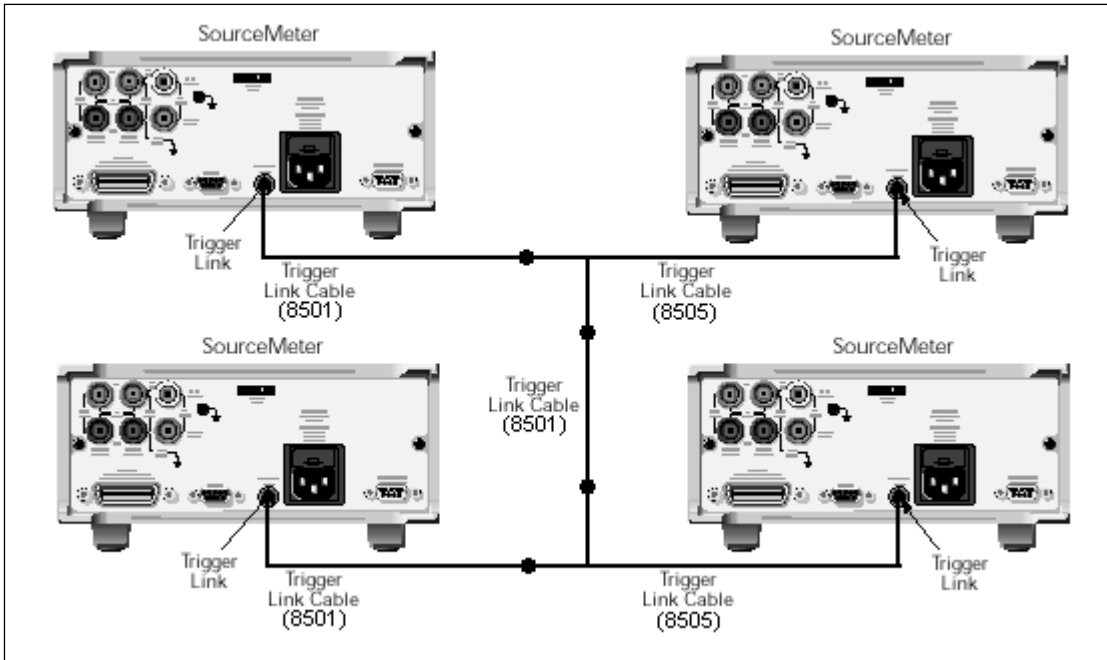
Figure 2. *Trigger Link connections*

Test Descriptions

The LabTracer software supports making many standard tests with SourceMeter instruments. The following example describes a test that uses two Model 2400s to create a transistor curve family. The variables settings shown in **Figures 5–9** will return data similar to that shown in **Figures 10** and **11** when connected to a standard BJT device like the PNP 3906 used for this example.

After starting LabTracer from the start menu shortcut, a short splash message will appear, followed by the main interface window, displaying the **Options** tab (**Figure 4**). The **sweep number** and **points per sweep** displays are indicators calculated from the values selected in the SourceMeter set-up windows. The **Execute** button is for running a test, the **Abort** button stops a test after its current sweep, the **Clear Data** button will erase all data from the **Sheet** and **Graph** tabs, and the **Exit** button exits the program. The **Options** tab allows opening and saving configuration files, selecting a number of SourceMeter instruments, and accessing the help files.

1. Select the number of SourceMeter instruments connected to the GPIB bus and that are to be used for this test.

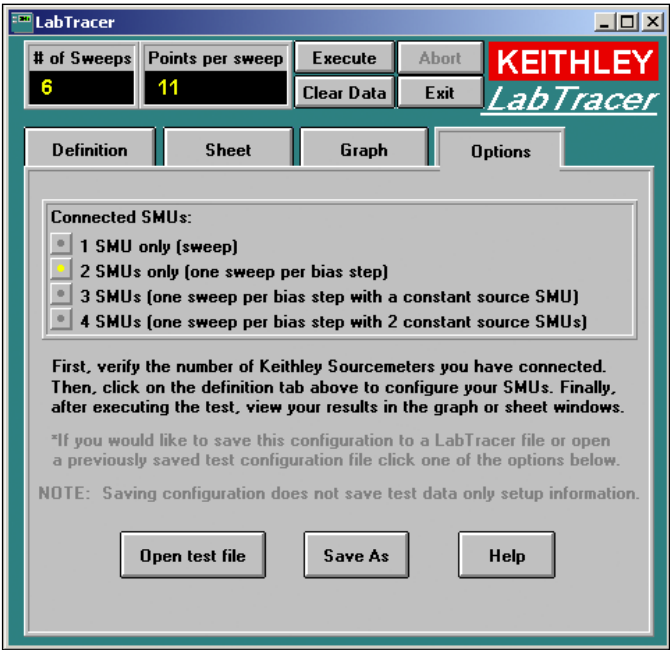2. Click the **Definition** tab to continue setting up the test.
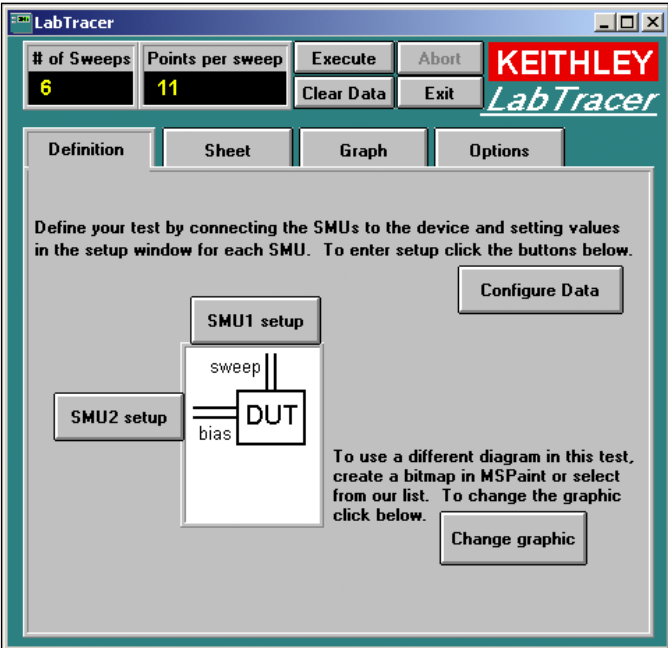

Figure 4. *Options tab*

Figure 5. *Definition tab*

3. Choose a bitmap to represent the device under test from the **Definition** panel (**Figure 5**). Click the **Change Graphic** button to select from the available images.

4. **Figures 6** and **7** illustrate the dialog boxes used to set up the SourceMeter instruments. Note that the dialog boxes for the two SMUs are very similar.
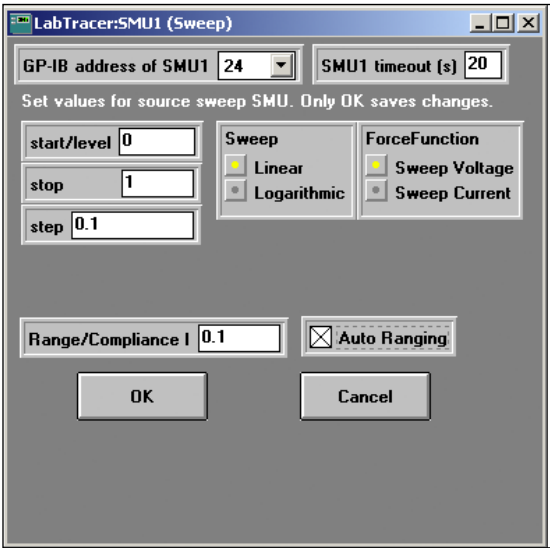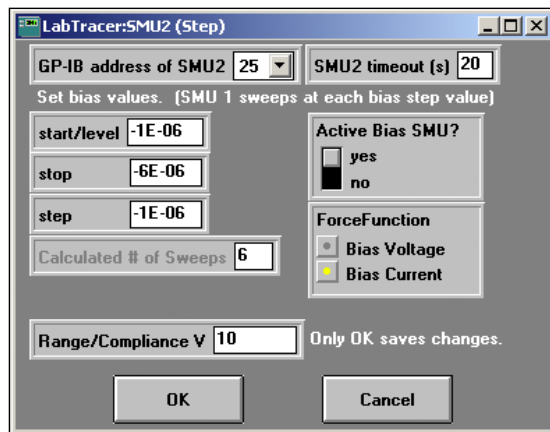

Figure 6. *SMU1 Setup*

Figure 7. *SMU2 Setup*

5. SMU1 is the sweeping SourceMeter instrument and SMU2 is a bias unit. Make certain the hardware bus address of each instrument matches the corresponding number in the GPIB address dropdown boxes. Set a reasonable timeout period (typically 10–30 seconds) for communication and set up your sweeps and bias levels. If SMU2 is activated, then one sweep of SMU1 occurs for each step value. The number of sweeps is updated and displayed in the grayed out display box. Notice the voltages and currents can be positive or negative. The start, stop, and step values for each SMU determine the direction and amplitude of the sweep, as well as the number of points that will be collected. One measurement is made for each sweep value of SMU1. The compliance is a safety limit for the test. The assigned SMU will not exceed this limit, but may cut off the graph if the compliance is set too low. SMU1 also has an autorange setting. When enabled, this function allows making more precise measurements throughout the sweep, but it will take longer between measurements, and the time between points is more likely to fluctuate slightly. When these variables are set correctly, click **OK** and return to the main window. Open only one set-up window at a time. Click **OK** to save changes.

6. Enter the data configuration panel (**Figure 8**) by clicking on the **Configure Data** button on the **Definition** panel (**Figure 5**). When the box to the left of the data set is yellow this data will be collected. Adjust these settings as needed, then set the ranging and speed variables.

7. If the formula data is activated (the light is turned on), then click the **formula** button to bring up the Formulator (**Figure 9**). From here, enter a formula using the TestPoint function calls. For more information on function calls, open the TESTPT.hlp file in the LabTracer Install pack. The math function section contains a complete list of functions. This formula is not checked for validity, so if the formula is incorrect, it may return incorrect data or cause errors like divide by zero during the test. Feel free to ignore any errors and continue the test because formula errors won't affect the collected data.
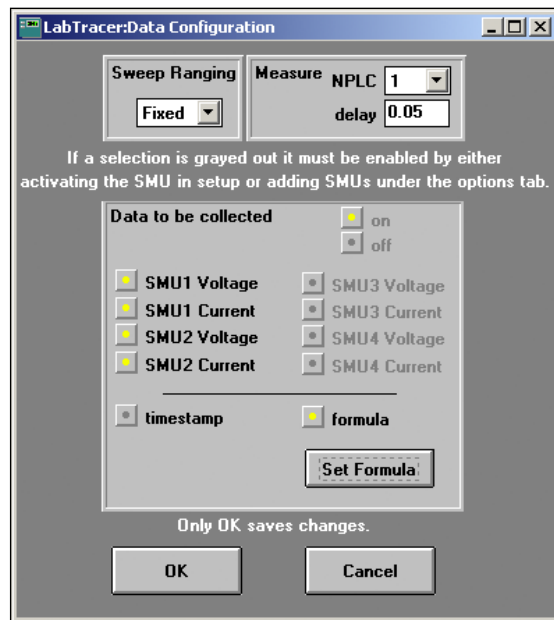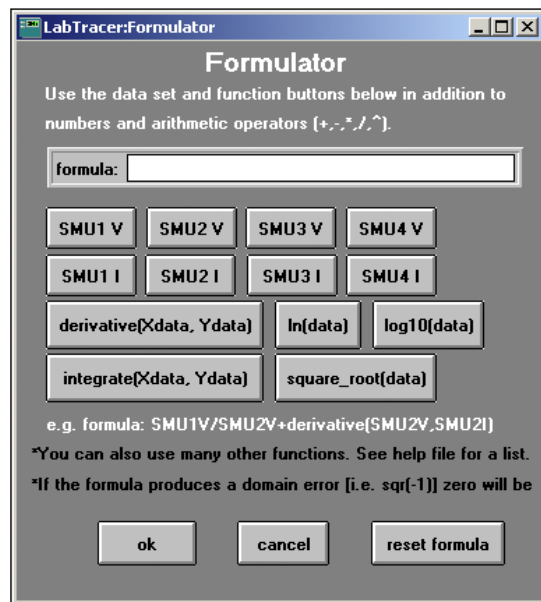

Figure 8. *Data configuration*

Figure 9. *Formulator*

8. Start the test using the **Execute** button. To observe the results, click either the **Data** sheet tab (**Figure 10**) to see the data in a table or the **Graph** sheet tab (**Figure 11**) to see it in graphical form.
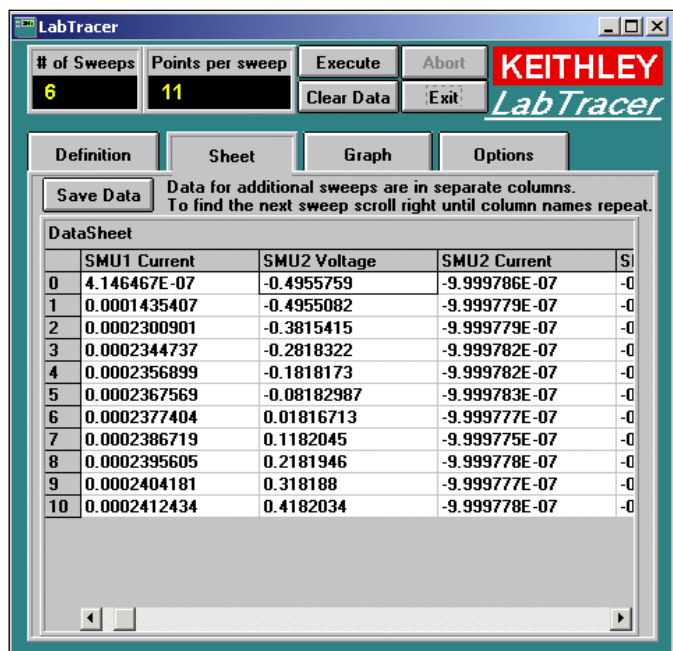
Device Characterization Techniques using Keithley SourceMeter® Instruments with LabTracer Software
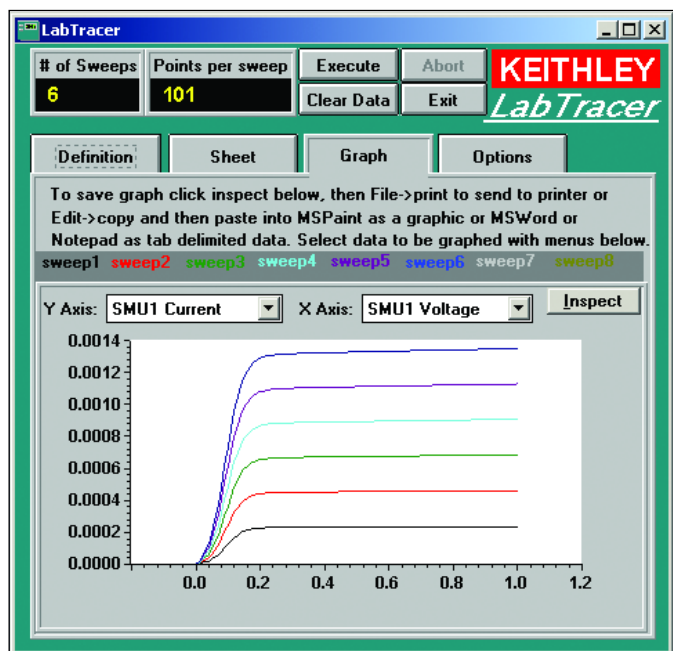
Figure 10. *Sheet*

Figure 11. *Graph*

9. After the test is complete, save the data or edit and save the graph as needed. The **Save Data** button on the **Sheet** panel allows saving comma-separated values in text files that can be easily imported into most analysis and spreadsheet programs. The graph can be saved as a graphic by clicking **Inspect** on the graph, then selecting **Copy** from the **Edit** menu that appears on the window. Functions like zooming, auto-scaling, and printing are also available here. Double-click the graph to change properties like trace markers, colors, titles, and linear or logarithmic axis scaling.

10. Return to the **Options** menu to save the test configuration.

For any further questions or information, refer to the help documentation on the **Options** panel or contact Keithley Instruments directly. Refer to the specifications for the SourceMeter family of instruments or call Keithley's applications department (1-888-KEITHLEY or 1-440-248-0400) to determine which model is best for a particular application. Data sheets and specifications for these instruments are available at www.keithley.com.

Test System Safety

All SourceMeter instruments are capable of outputting harmful or lethal voltages. It is possible to reach the full power potentials of the instruments using this example software. Take special care in protecting the contacts during testing so that injury will not result. As long as the instruments are plugged in, dangerous levels may occur with or without the LabTracer software running, depending on programming, mechanical failure, or other single fault errors. Never operate the instruments while touching any part of the device or circuit and do not exceed voltage or current specifications of the device under test.

It is the responsibility of the test system integrators and installers to make sure operator and maintenance personnel protection is in place and effective. This responsibility also includes training in the safe use of the test system.

Equipment List

The following equipment is needed to set up the LabTracer test system described in this note.

- One to four SourceMeter instruments (2400, 2410, 2420, 2430*, 2440, 6430.) *LabTracer does not allow pulsed measurements, so the Model 2430 functions only in DC mode.

- Model 8501 and/or 8505 Trigger Link cables, based on number of SourceMeter instruments. Refer to **Figure 2** and the accompanying explanation of Trigger Link requirements.

- Model 7008-X GPIB cables (one per SourceMeter instrument)

- KPCI-488 or KPCMCIA-GPIB interface card.

- Windows®-based PC to run example software.

- Cabling to connect SourceMeter instruments to test devices.

- Install pack for LabTracer example software available for download from www.keithley.com

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