Section 8

Measuring I-V characteristics of a solar panel

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Introduction

This example application demonstrates how to use the Model 2460 Interactive SourceMeter® instrument to measure the I-V characteristics of a solar panel.

From the I-V characteristics measured by the Model 2460, you can determine important parameters about the solar panel, including:

- Maximum current (I_{max}) and voltage (V_{max})
- Maximum power (P_{max})
- Open circuit voltage (V_{oc})
- Short-circuit current (I_{sc})

Because the Model 2460 has four-quadrant source capability, it can sink up to 7 A of cell current as a function of the applied voltage.

Equipment required

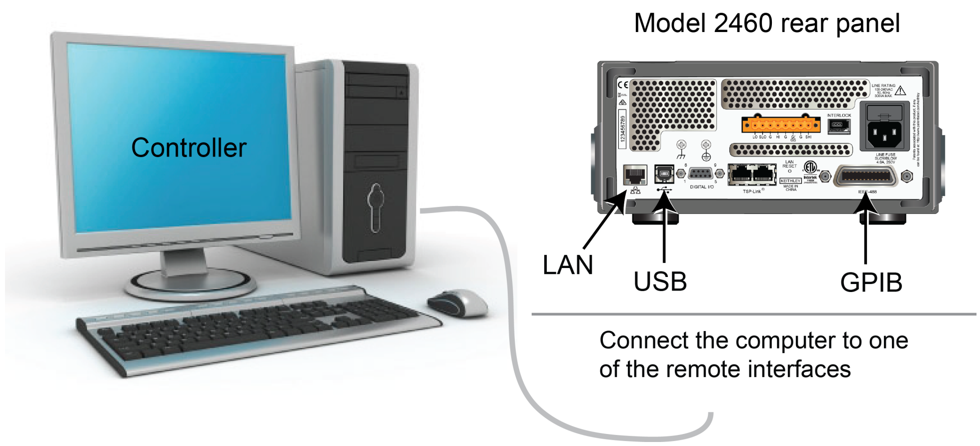
- One Model 2460 Interactive SourceMeter® instrument
- For front-panel connections, use four insulated banana cables such as the Keithley Instruments Model 8608 High-Performance Clip Lead Set (one set included with the Model 2460; you will need another set)
- For rear-panel connections, use one Model 2460-KIT Screw-Terminal Connector Kit (provided with the Model 2460), or you can use one set of Model 2460-BAN Banana Test Leads/Adapter Cables (with appropriate connections to the device)
- One solar panel

Set up remote communications

You can run this application from the front panel or any of the supported communication interfaces for the instrument (GPIB, USB, or ethernet).

The following figure shows the rear-panel connection locations for the remote communication interfaces. For additional information about setting up remote communications, see Remote communications interfaces (on page 3-1).

Figure 41: Model 2460 remote interface connections



Device connections

Connect the Model 2460 to the solar panel in a 4-wire configuration to provide the best measurement accuracy and eliminate the effects of the lead resistance on the measurement.

To use the 4-wire connection method:

- Connect the FORCE LO and SENSE LO leads to the cathode terminal.
- Connect the FORCE HI and SENSE HI leads to the anode terminal.
- Make the connections as close to the solar panel as possible to avoid including the resistance of the test leads in the measurement.

You can use either the front-panel or the rear-panel terminals for this application.

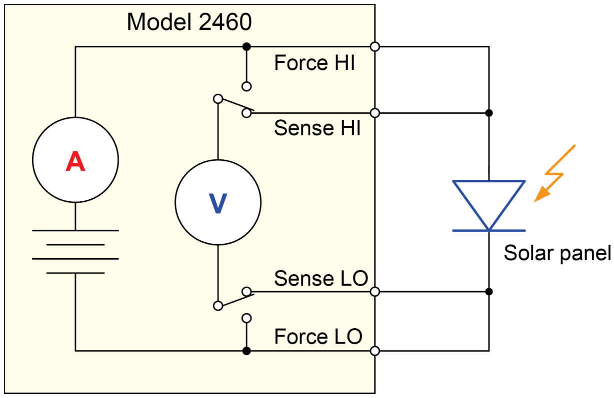
⚠ WARNING

Hazardous voltages may be present on all output and guard terminals. To prevent electrical shock that could cause injury or death, never make or break connections to the Model 2460 while the output is on.

To prevent electric shock, test connections must be configured such that the user cannot come in contact with conductors or any device under test (DUT) that is in contact with the conductors. It is good practice to disconnect DUTs from the instrument before powering the instrument. Safe installation requires proper shields, barriers, and grounding to prevent contact with conductors.

The following figure shows the schematic for the application.

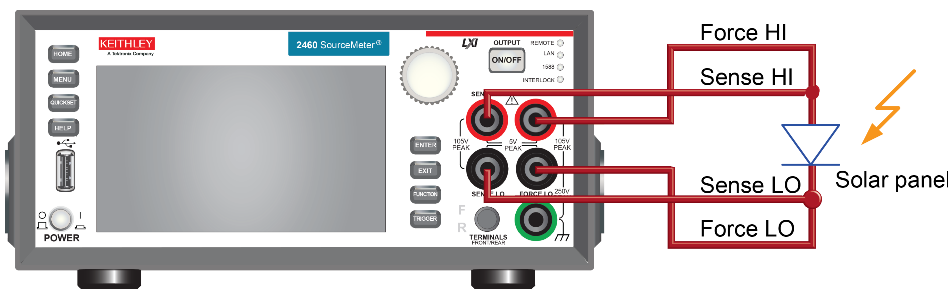
Figure 42: Model 2460 connections to a solar panel



The following figures show the physical connections for the front and rear panels. Note that you must use either the front-panel terminals or rear-panel terminals — you cannot mix connections.

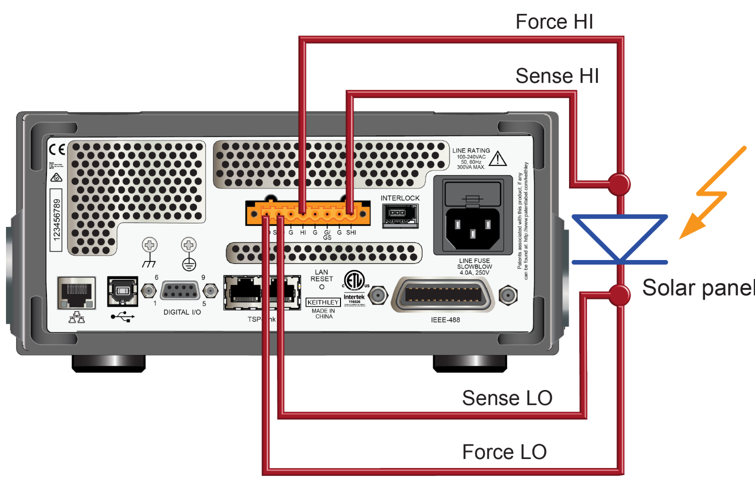
The figure below shows the front-panel connections. You can make these connections with four insulated banana cables that are rated to the maximum current (7 A) such as two sets of the Keithley Instruments Model 8608 High-Performance Clip Lead Set.

Figure 43: Model 2460 4-wire connections to the front panel



The figure below shows the rear-panel connections. You can make these connections with either the Model 2460-KIT Screw-Terminal Connector Kit (included with the Model 2460) or a Model 2460-BAN Banana Test Leads/Adapter Cable with appropriate cabling.

Figure 44: Model 2460 4-wire connections to the rear panel



Solar panel characterization

This application demonstrates how to use the Model 2460 to characterize a solar panel. The examples show how to use the front panel, SCPI code over a remote interface, and TSP code over a remote interface.

For this test, you will:

- Reset the instrument.
- Select the source voltage function and measure current function.
- Set the current limit.
- Select four-wire (remote sense) mode.
- Set up and generate a voltage sweep.
- Initiate the trigger model, which will turn the output on.
- Record the measurements.
- After the voltage sweep is complete, turn off the output.
- Retrieve the measurements.
- View the data on the front-panel graph.

NOTE

You must control the light source for this application; you will run the test with the light source on and again with the light source off.

Set up the solar panel I-V sweep from the front panel

This is an example of an I-V test that sweeps voltage from 0 V to 20 V in 115 steps and measures the resulting current. You can then view the data on the graph screen.

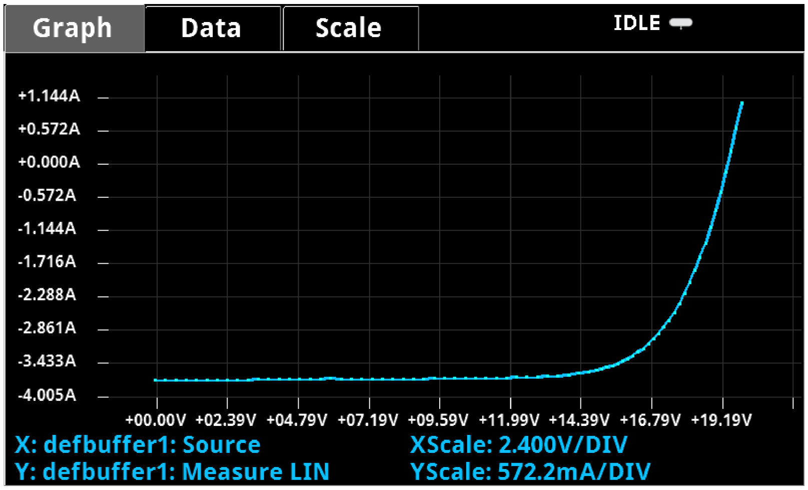
To set up the application from the front panel:

1. Make connections to the instrument and device under test (DUT) as described in Device connections (on page 5-2, on page 8-2).
2. Press the **POWER** switch on the front panel to turn on the instrument.
3. Reset the instrument:
   a. Press the **MENU** key.
   b. Under System, select **Manage**.
   c. Select **System Reset**.
   d. Select **OK**.
4. Press the **HOME** key.
5. Press the **FUNCTION** key.
6. Under Source Voltage and Measure, select **Current**.

7. Press the **MENU** key.
8. Under Measure, select **Settings**.
9. Select the button next to Sense Mode and select **4-Wire Sense**.
10. Press the **MENU** key.
11. Under Source, select **Sweep**.
12. Set the Start level to `0 V` and select **OK**.
13. Set the Stop level to `20 V` and select **OK**.
14. Select the button next to Definition and select **Number of Points**.
15. Select the button next to Points, enter `115`, and select **OK**.
16. Swipe the SWEEP SETTINGS screen until you see Source Limit.
17. Select the button next to Source Limit, enter `4 A`, and select **OK**.
18. Select the button next to Delay and select **Specify Delay Manually**.
19. Enter `50 ms` and select **OK**.
20. Select **Generate**. This sets up a trigger model for the sweep.
21. Press the **MENU** key.
22. Under Measure, select **Data Buffers**.
23. Select **defbuffer1** to open the Settings for defbuffer1 dialog box.
24. Select **Clear Buffer,** select **Yes**, and select **OK**.
25. Press the **MENU** key.
26. Under Views, select **Graph**.
27. Press the **TRIGGER** key to initiate the trigger model. The output turns on and a RUN indicator is visible at the top of the screen while the sweep is running.
28. Press the trigger key again to repeat the sweep.

The following figure shows an example of solar panel I-V measurements on the front-panel graph. Note that the current is negative on the graph because the Model 2460 is sinking current.

Figure 45: Example of solar panel measurements on the Model 2460 front-panel graph



Set up the solar panel I-V sweep using SCPI commands

This example sequence of SCPI commands generates an I-V sweep on a solar panel. You may need to make changes so that this code will run in your programming environment.

In this example, the voltage is swept from 0 V to 20 V in 115 steps. The resulting solar panel current is measured. The current and voltage measurements are stored in default buffer 1 (`defbuffer1`).

Send the following commands for this example application:

Command	Description
`*RST`	• Reset the Model 2460.
`SENS:FUNC "CURR"`	• Set to measure current.
`SENS:CURR:RANG:AUTO ON`	• Set to measure with autorange enabled.
`SENS:CURR:RSEN ON`	• Set to use 4-wire sense mode.
`SOUR:FUNC VOLT`	• Set to source voltage.
`SOUR:VOLT:RANG 20`	• Set to the 20 V source range.
`SOUR:VOLT:ILIM 4`	• Set the current limit to 4 A.
`SOUR:SWE:VOLT:LIN 0, 20, 115, 0.05`	• Set to sweep voltage from 0 to 20 V in 115 steps with a 0.05 s delay.
`INIT`	• Initiate the sweep.
`*WAI`	• Wait until the sweep is finished.
`TRAC:DATA? 1, 115, "defbuffer1", SOUR, READ`	• Read the source and measure values from `defbuffer1`.

Set up the solar panel I-V sweep using TSP commands

NOTE

The following TSP code is designed to be run from Keithley Instruments Test Script Builder (TSB). TSB is a software tool that is available from the Keithley Instruments website. You can install and use TSB to write code and develop scripts for TSP-enabled instruments. Information about how to use TSB is in the online help for TSB and in the “Introduction to TSP operation” section of the *Model 2460 Reference Manual*.

To use other programming environments, you may need to make changes to the example TSP code.

By default, the Model 2460 is configured to use the SCPI command set. You must select the TSP command set before sending TSP commands to the instrument.

To enable TSP commands:

1. Press the **MENU** key.
2. Under System, select **Settings**.
3. For Command Set, select **TSP**.
4. At the prompt to reboot, select **Yes**.

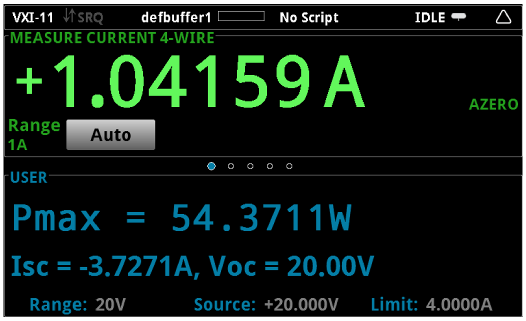
In this example, a linear voltage sweep is configured to output voltage from 0 V to 20 V in 115 steps. The instrument measures the resulting current from the solar panel during the sweep.

Send the following commands for this example application:

```
--Define the number of points in the sweep.
num = 115
--Reset the Model 2460 and clear the buffer.
reset()
--Set the source and measure functions.
smu.measure.func = smu.FUNC_DC_CURRENT
smu.source.func = smu.FUNC_DC_VOLTAGE
--Configure the measurement settings.
smu.measure.terminals = smu.TERMINALS_FRONT
smu.measure.sense = smu.SENSE_4WIRE
smu.measure.autorange = smu.ON
smu.measure.nplc = 1
--Configure the source settings.
smu.source.highc = smu.OFF
smu.source.range = 20
smu.source.readback = smu.ON
smu.source.highc = smu.OFF
smu.source.ilimit.level = 4
smu.source.sweeplinear("SolarCell", 0, 20, num, 0.05)
--Start the trigger model and wait for it to complete.
trigger.model.initiate()
waitcomplete()
--Define initial values.
voltage = defbuffer1.sourcevalues
current = defbuffer1
isc = current[1]
mincurr = current[1]
imax = current[1]
voc = voltage[1]
vmax = voltage[1]
pmax = voltage[1]*current[1]
--Calculate values.
for i = 1, num do
   print(voltage[i],current[i],voltage[i]*current[i])
   if (voltage[i]*current[i] < pmax) then
      pmax = voltage[i]*current[i]
      imax = current[i]
      vmax = voltage[i]
   end
   if math.abs(current[i]) < math.abs(mincurr) then
      voc = voltage[i]
   end
end
pmax = math.abs(pmax)
imax = math.abs(imax)
print("Pmax=",pmax,",Imax=",imax,",Vmax=",vmax,",Isc=",isc,",Voc=",voc)
--Display values on the Model 2460 front panel.
display.changescreen(display.SCREEN_USER_SWIPE)
display.settext(0, string.format("Pmax = %.4fW", pmax))
display.settext(1, string.format("Isc = %.4fA, Voc = %.2fV", isc, voc))
```

In the example above, the instrument is programmed to display custom text on the USER swipe screen using the `display.changescreen` and `display.settext` commands. After the test is finished, the display will indicate the maximum power (P_{max}), the short circuit current (I_{SC}), and the open circuit voltage (V_{OC}), as shown in the figure below.

Figure 46: Solar panel I-V sweep results on the USER swipe screen



After the code is executed, five values are returned in the Instrument Console of Test Script Builder (TSB), and the measured current, voltage, and calculated power are displayed on the front panel of the Model 2460. You can copy the data from the TSB Instrument Console into a spreadsheet such as Microsoft® Excel® for graphing and further analysis. The figure below shows the results of graphing the data in an Excel spreadsheet. Notice that the test on the solar panel was executed with light (light ON) and in the dark (light OFF).

Figure 47: Solar panel I-V characteristics generated with and without light