

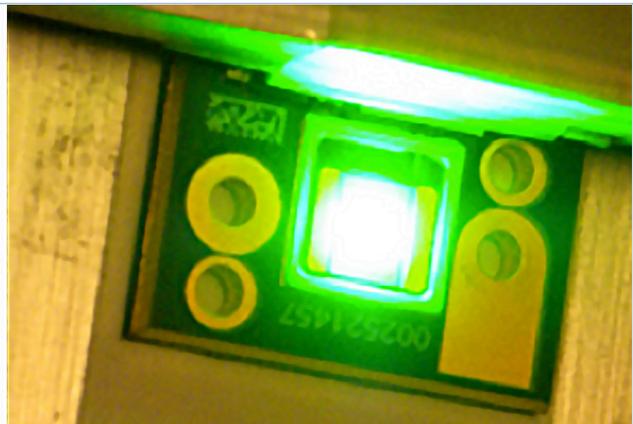
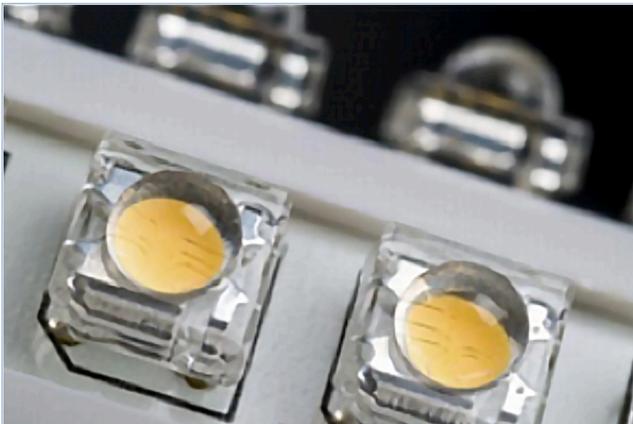
Testing High Brightness LEDs Accurately using the Model 2460 High Current SourceMeter® SMU Instrument

Application Note

Visible high brightness light emitting diodes (HBLEDs) have gained a reputation for high efficiency and long lifetimes, which has led to their use in a growing list of applications, including automotive displays and exterior lights, backlighting for televisions and video monitors, street lights, outdoor signs, and interior lighting. Extensive research and development efforts by LED manufacturers have led to the creation of LEDs with higher luminous flux, longer lifetimes, greater chromaticity, and more lumens per watt, which has driven demand and encouraged an even wider array of applications. Accurate and

cost-effective testing is critical to ensuring the reliability and quality of these devices.

HBLEDs are commonly defined as LEDs that operate at 1W of power or higher, with typical operating ranges from 1W to 3W. Instead of running on 10–30mA of current and being packaged in small 3mm or 5mm plastic domes, HBLEDs run at 300mA–1A or more and are mounted on a small, thermally conductive board designed to draw heat away from the LED's junction.



LED testing involves different types of test sequences at various stages of design research and development, on-wafer measurements during production, and final tests of packaged parts. While concrete testing “recipes” often include a multitude of steps intended to verify product lifetime or extract data on specific performance characteristics, they are beyond the scope of this application note. Rather, this application note is intended to provide solid information on the needed “ingredients” for these recipes—basic tests that illustrate how to probe for the diodes’ characteristics and example test setups. This application note also illustrates how to use a Model 2460 SourceMeter with the Keithley KickStart Software to create a current vs. voltage (I-V) sweep on an HBLED.

Test Description

Testing LEDs typically involves both electrical and optical measurements. This application note focuses on electrical characterization. **Figure 1** illustrates the electrical I-V curve of a typical diode. A complete test includes a multitude of voltage values versus current operating points during the R&D phase, but a limited sample of points is generally sufficient to probe for the figures of merit, especially during the product validation phase and production.

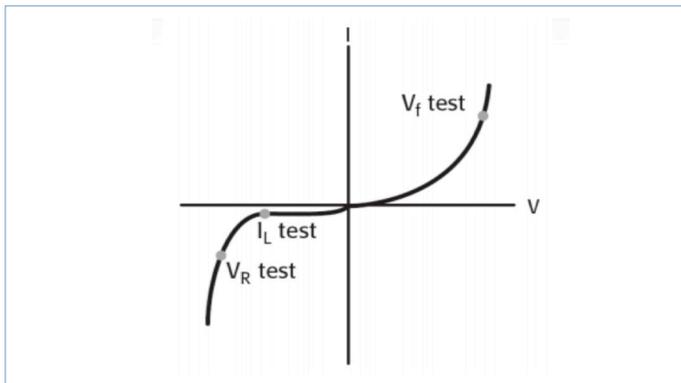


Figure 1. Typical HBLED DC I-V curve and test points (not to scale).

Some tests require sourcing a known current and measuring a voltage, while others require sourcing a voltage and measuring the resulting current. A SourceMeter® Source Measure Unit (SMU) Instrument is ideal for these types of tests, because it can be configured to source voltages or currents and can also measure each of these signal types.

Forward Voltage Test (V_f) and Optical Tests

The V_f test verifies the forward operating voltage of the visible LED. When a forward current is applied to the diode, it begins to conduct. During the initial low current source values, the voltage drop across the diode increases rapidly, but the

slope begins to level off as drive currents increase. The diode normally operates in this region of relatively constant voltage. It is also quite useful to test the diode under these operating conditions. The forward voltage test (V_f) is performed by sourcing a known current and measuring the resulting voltage drop across the diode. Typical test currents range from tens of milliamps to amps, while the resulting voltage measurement is typically in the range of a few volts. The results of this test are typically used by engineers and designers, as the forward voltage is directly related to the chromaticity of the LED.

Forward current biasing is also used for optical tests, because electrical current flow is closely related to the amount of light emitted. Optical power measurements can be made by placing a photodiode or integrating sphere close to the device under test to capture the emitted photons. This light is then converted to a current, which can be measured by an ammeter or a SourceMeter instrument.

In many test applications, the voltage and light output of the diode can be measured simultaneously using a fixed source current value. In addition, details such as spectral output can be obtained by using the same drive current value and a spectrometer.

Reverse Breakdown Voltage (V_R)

Applying a negative bias current to the LED will allow probing for the so-called Reverse Breakdown Voltage (V_R). The test current should be set to a level where the measured voltage value no longer increases significantly when the current is increased slightly more. At levels higher than this voltage, large increases in reverse bias current result in insignificant changes in reverse voltage. The specification for this parameter is usually a minimum value. The test is performed by sourcing a low-level reverse bias current for a specified time, then measuring the voltage drop across the LED. The measurement result is typically in the range of tens of volts.

Leakage Current (I_L)

Normally, moderate voltage levels (volts to tens of volts) are used to measure a Leakage Current (I_L). The Leakage Current Test measures the low-level current that leaks across the LED when a reverse voltage less than breakdown is applied. It is a common practice for leakage measurements, and more generally for isolation measurements, to make sure only that a certain threshold is not exceeded, especially in production. There are two reasons for this. First, low current measurements require longer settling times, so they take longer to complete. Second, environmental interference and electrical noise exert greater influence on low level signals, so extra

care in shielding is required. However, this extra shielding may complicate the test fixture and may interfere with automated handlers.

Making Connections to the LED

The LED is connected to the Model 2460 SourceMeter as shown in **Figure 2**. A four-wire connection is made to eliminate the effects of the lead resistance. When connecting the leads to the LED, the Force LO and Sense LO connections are made to the cathode terminal. The Force HI and Sense HI connections are made to the anode. Make the connections as close as possible to the cell to prevent the resistance of the LED's terminals from affecting the measurement accuracy.

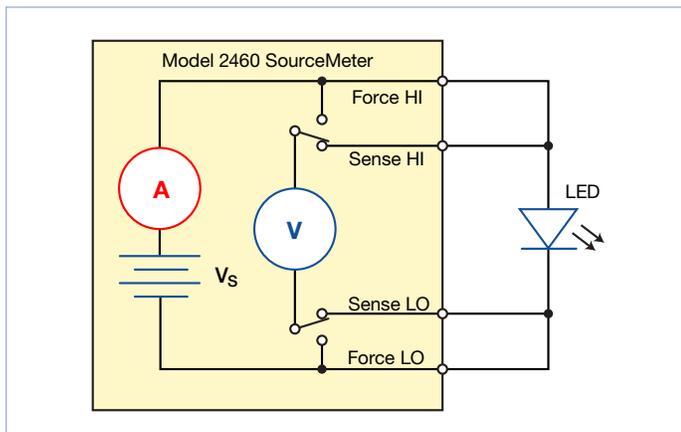


Figure 2: Model 2460 SourceMeter 4-wire connections to an LED

The following figures show the physical connections for the front and rear panels. **Figure 3** 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.

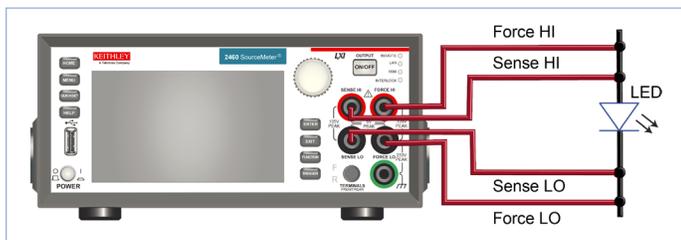


Figure 3: Model 2460 SourceMeter 4-wire front-panel connections to an LED

Figure 4 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.

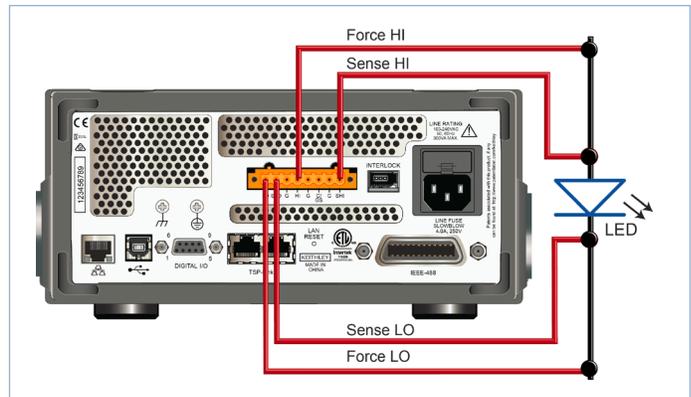


Figure 4: Model 2460 SourceMeter 4-wire rear-panel connections to an LED

Generating, Plotting, and Saving I-V Sweeps Using the User Interface in Three Easy Steps

The I-V sweep of an HBLED can be accomplished using the Model 2460 either from the front panel or over the bus. Just a few key strokes are needed to generate, graph, and save the data to a USB drive. Here are the three easy steps to generate and graph a voltage sweep and then save the data to a USB drive.

Step 1. Creating and executing an I-V sweep from the front panel graphical user interface

Description	Key Strokes
Reset instrument to default state	Menu key → Manage System → Reset
Set to source V and measure I	Home key → Function key → Source V Measure I
Set to four-wire sense	Menu key → Measure Settings → Sense Mode → 4-Wire Sense
Configure sweep parameters	Menu key → Source Sweep <ul style="list-style-type: none"> Set desired Start, Stop, and Step V Scroll down and set Source Limit Press Generate to create sweep
Execute I-V sweep	Home key → Trigger key

Step 2. Viewing the Graph

To view the data graphically, press the MENU key and then the Graph button. The graph of the I-V sweep will automatically be displayed. To repeat the test, just press the TRIGGER key.

Figure 5 shows the I-V curve of an HBLE LED generated by the Model 2460. **Figure 6** illustrates how bright an HBLE LED can get at the high levels of current.

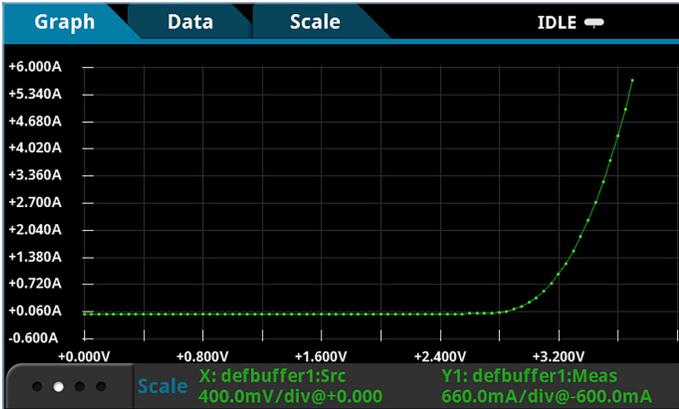


Figure 5. HBLE LED I-V sweep generated on the graph screen of the Model 2460.



Figure 6. HBLE LED illuminated at 4.1 volts and 4.8 amps

Step 3. Saving the Data to a USB Drive

To save the I-V data to a USB drive, just insert a USB drive, press the MENU key, select Reading Buffers, and then press SAVE TO USB (see **Figure 7**). Enter the name of the file. The data will be saved in a .csv format so it can later be downloaded to a spreadsheet and analyzed.

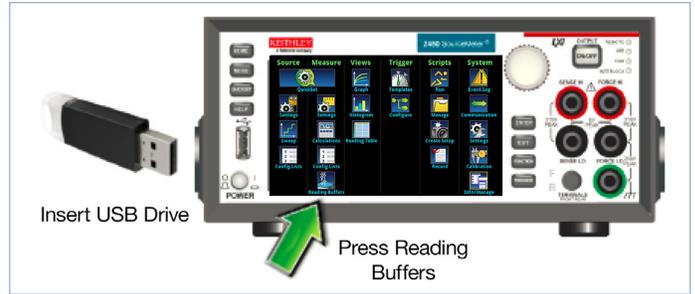


Figure 7. Saving data to a USB drive.

Generating an I-V sweep using KickStart Software

This example application uses Keithley KickStart Startup Software to generate a current-voltage sweep on a high-brightness LED. KickStart Instrument Control Software lets you start taking measurements in minutes without complex instrument programming. KickStart enables you to perform I-V characterization, data acquisition and logging, and power supply control on a variety of Keithley products. The software interfaces to the instrumentation through any of the standard interfaces: LAN, USB, and GPIB. Data can be displayed in graphical, chart, or both formats. All data can be stored and exported for further analysis in a software environment such as Microsoft Excel®. Graphs can also be exported for installation in technical papers.

In this example application, you will:

- Launch the KickStart software
- Create a new test project
- Select an instrument
- Select a test type
- Configure the test parameters
- Configure and view the graph screen
- Run the test
- View and save the test data

The Model 2460 must be set to use the Test Script Processor (TSP®) command set before you can use the KickStart software. By default, the Model 2460 is configured to use the SCPI command set.

To enable TSP commands:

1. Press the **MENU** key.
2. Under System, select **Settings**.
3. For Command Set, select **TSP**.

- At the prompt to reboot, select **Yes**.

Launch KickStart and set up the test

Once the communication cable (GPIB, USB, or LAN) is connected to the computer and the TSP command set is enabled, you are ready to launch the KickStart software.

To create a new test project:

- Launch the KickStart software. The Start Page is displayed, as shown in the following figure.



Figure 8: KickStart Startup Software Start Page

- On the Start Page, click **New KickStart Test** (see **Figure 8**). The Save As dialog box opens.
- Navigate to the location where you want to save your test projects (you do not need to create a folder; KickStart does that for you). You can also use the default location for KickStart projects, which is C:\Users\My Documents\Keithley Instruments\KickStart.
- Enter a name for the test and click **Save**. The test is saved as a .kst file in a folder with the name of the test project.
- Click **Select Instrument** in the bottom left corner of the screen. If the Model 2460 is configured properly, it appears in the Instrument Configuration panel.
- Right-click **Model 2460:1** and select **Add Instrument** (see **Figure 9**). Information about the connected Model 2460 automatically appears in the bottom half of the Instrument Configuration panel.



Figure 9: Select instrument by right-clicking on Model 2460:1 in the Instrument Configuration panel

- At the bottom of the screen, click **Select Test Type**. The Test Types panel opens on the left side of the screen, showing the available test types (see **Figure 10**).

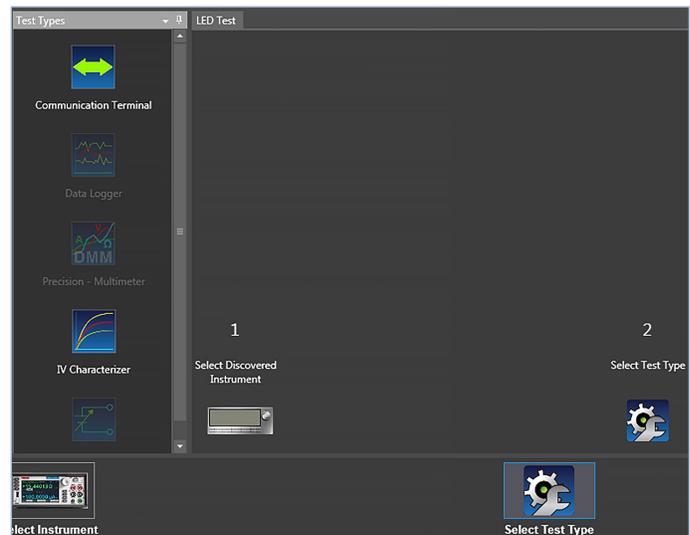


Figure 10: Selecting the test type

- Right-click the **I-V Characterizer** test type and select **Add Test Type**. The Source Measure Settings window opens. (See **Figure 11**.)

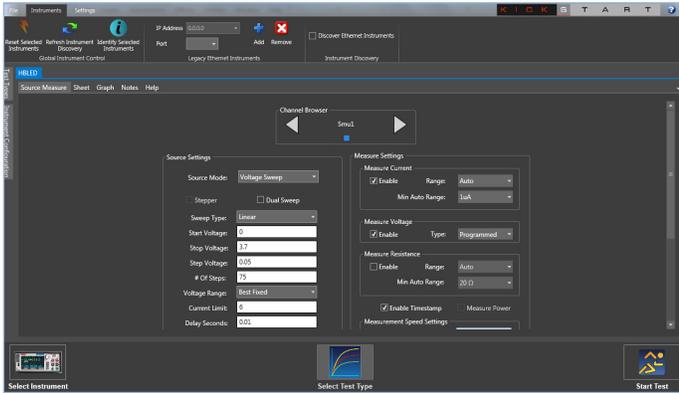


Figure 11: KickStart source and measure settings screen

- Use the values in the following tables to specify the source and measure parameters for this example test (you can change these values for your own application).

Source settings

Parameter	Value
Source Mode	Voltage Sweep
Sweep Type	Linear
Start Voltage	0
Stop Voltage	3.7
Step Voltage	0.05
# Of Steps	This automatically populates based on the step voltage setting. For this example, the value is 75.
Current Limit	6
Delay Seconds	0.01

Measure settings

Parameter	Value
Current Measure	Enabled, Auto Range
Voltage Measure	Enabled, Programmed Value

- In the lower part of the Measure Settings column, select the button next to Advanced Configuration and set the parameters listed in the following table.

Advanced settings

Parameter	Value
Input Jacks	Front or Rear
Sensing Mode	4-wire
Output OFF State	Normal
High Capacitance	Off
Offset Compensation	Off

- To configure the graphing function, select the **Graph** tab.
- Click the button next to X-Axis and select **Smu1.V** (sweep voltage).
- Click the button next to Y-Axis and select **Smu1.I** (measure current).

You are now ready to run the test.

Run the test and view the graph

To run the test, select **Start Test** in the lower right corner of the screen (see **Figure 12**). An I-V sweep is generated automatically and the results appear in real time on the graph screen. The data on the graph is scaled automatically as the test progresses.

The following figure shows the result of running this example application.

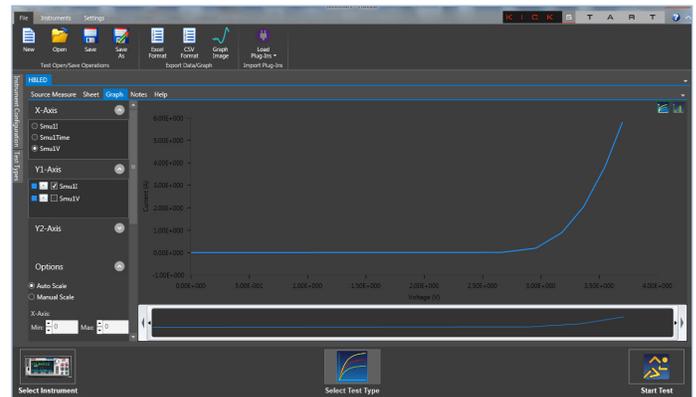


Figure 12: Results of running an I-V sweep on a high-brightness LED

To save the graph as a .png file, click **Graph Image** in the Export Data/Graph area of the ribbon at the top of the screen.

View and save the test data in tabular form

You can also view the results of the test in tabular form by selecting the **Sheet** tab. **Figure 13** shows the test results on the Sheet tab.

Item	Smu1_Time(1)(1)	Smu1_V(1)(1)	Smu1_I(1)(1)
13	4.036450E-001	6.000000E-001	-6.696246E-008
14	4.372756E-001	6.500000E-001	-6.491246E-008
15	4.709218E-001	7.000000E-001	-6.230221E-008
16	5.045762E-001	7.500000E-001	-5.987022E-008
17	5.382011E-001	8.000000E-001	-5.655056E-008
18	5.718388E-001	8.500000E-001	-5.180118E-008
19	6.054962E-001	9.000000E-001	-4.727553E-008
20	6.391267E-001	9.500000E-001	-4.148569E-008
21	6.727613E-001	1.000000E+000	-3.380774E-008
22	7.064065E-001	1.050000E+000	-2.437446E-008
23	7.400410E-001	1.100000E+000	-1.316585E-008
24	7.736943E-001	1.150000E+000	1.637090E-010
25	8.073444E-001	1.200000E+000	1.631997E-008
26	8.409777E-001	1.250000E+000	3.916466E-008
27	8.746159E-001	1.300000E+000	6.929258E-008
28	9.082567E-001	1.350000E+000	1.080552E-007
29	9.419032E-001	1.400000E+000	1.603257E-007
30	9.755412E-001	1.450000E+000	2.292691E-007

Figure 13: Test data on the KickStart Sheet tab

To export the data as a .csv or .xls file, click **Excel Format** or **CSV Format** in the Export Data/Graph area of the ribbon at the top of the screen.

Typical Sources of Error

Junction Self-Heating

With increasing test times, the semiconductor junction of the LED will tend to heat. (See **Figure 14**.) The two tests susceptible to junction heating are the forward voltage and leakage current tests. As the junction heats, the voltage will drop or, more importantly, the leakage current will increase during the constant voltage test. Therefore, it is important to shorten the test time as much as possible without sacrificing measurement accuracy or stability.

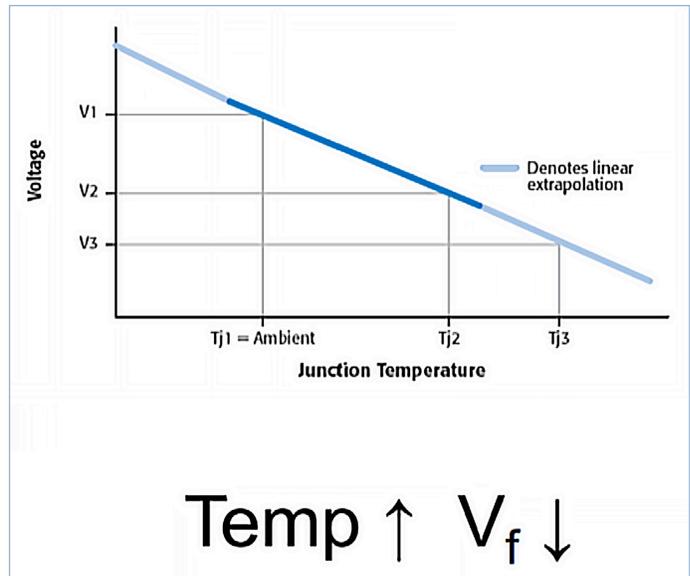


Figure 14. An HBLED's junction heats as current is sourced through it. An HBLED's forward voltage drops as its junction heats.

The Model 2460 SourceMeter can configure the device soak time before the measurement, as well as the amount of time the input signal is acquired. The soak time allows any circuit capacitance to settle before the measurement begins. The measurement integration time is determined by the number of power line cycles (NPLC). If the input power were at 60Hz, a 1NPLC measurement would require 1/60th of a second or 16.667ms. The integration time defines how long the analog-to-digital converter (ADC) acquires the input signal, and it represents a trade-off between speed and accuracy.

Typical polarization times for the V_f test are from less than a few hundred microseconds to five milliseconds, and from five to 20 milliseconds for the I_L test. By using these short test times, errors due to the junction heating are reduced. Also, the junction heating characteristics can be determined by performing a series of tests and only varying the test time.

The 2460 can easily be programmed for this type of test, or the equivalent of a pulsed I-V curve test. An example test script is shown in Appendix A of this application note. When the test is executed, the I-V curve in **Figure 15** is displayed on the front panel of the instrument. **Figure 16** shows the plot zoomed in so that you can see the short pulses and the very tight timing of the Model 2460.

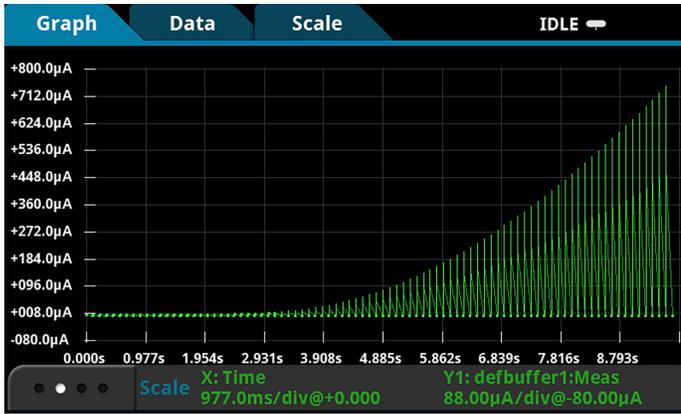


Figure 15. Pulsed I-V test of the same HBLEDD previously tested and plotted in Figure 5.

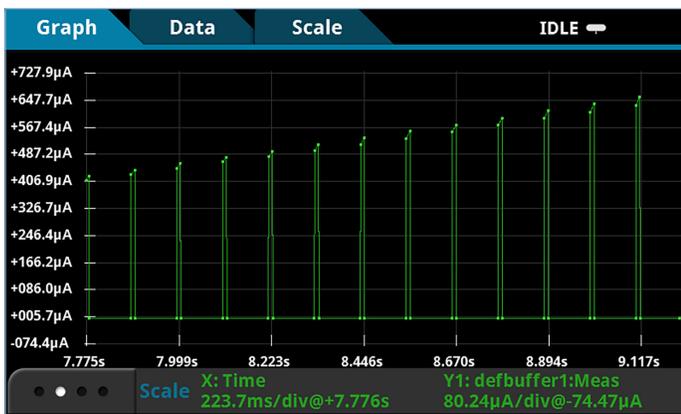


Figure 16. Pulsed I-V HBLEDD plot zoomed in to see the individual pulses.

Lead Resistance

A common source of voltage measurement error is the series resistance from the test leads running from the instrument to the LED. This series resistance is added into the measurement when making a two-wire connection. The effects of lead resistance are particularly detrimental when long connecting cables and high currents are used, because the voltage drop across the lead resistance becomes significant compared to the measured voltage.

To eliminate this problem, use the four-wire remote sensing method, rather than the two-wire technique. With the four-wire method (see Figures 3 and 4), a current is forced through the LED using the Force HI/LO test leads, and the voltage across the LED is measured using the Sense HI/LO set of leads. As a result, only the voltage drop across the LED is measured.

Leakage Current

Stray leakage in cables and fixtures can be a source of error in measurements involving very low currents, such as for leakage currents. To minimize this problem, construct test fixturing

with high resistance materials. Another way to reduce leakage currents is to use the built-in guard of the SourceMeter instrument. The guard is a low impedance point in the circuit that has nearly the same potential as the high impedance point to be guarded.

This concept is best illustrated by example (Figure 17). In this example, the LED to be measured is mounted on two insulated standoffs. Guarding is used in this circuit to ensure that all the current flows through the diode and not through the standoffs. In general, guarding should be used when sourcing or measuring currents less than 1μA. Connecting the Guard terminal of the instrument to the metal guard plate guards this circuit. This puts the bottom of the DUT insulator standoffs at almost the same potential as the top. Both ends of the insulator are at nearly the same potential, so no significant current can flow through it. All the current will then flow through the LED as desired.

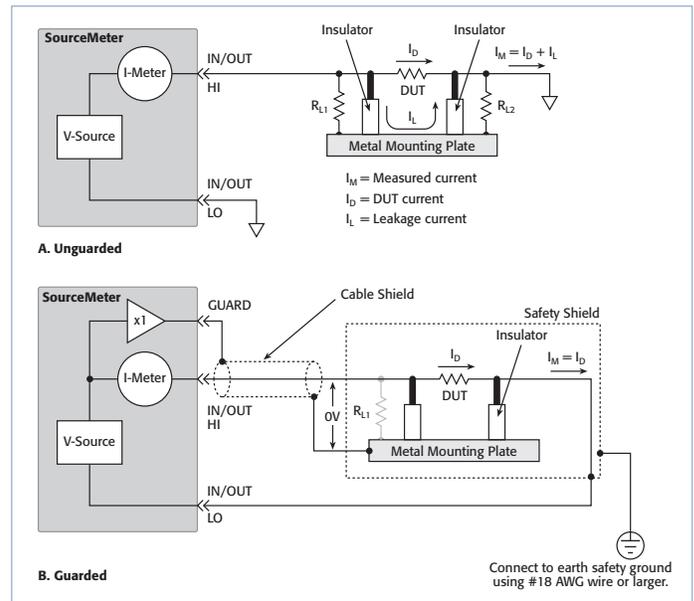


Figure 17. Comparison of unguarded and guarded measurements.

WARNING: Guard is at the same potential as Force HI. Therefore, if hazardous voltages are present at Force HI, they are also present at the Guard terminal.

Electrostatic Interference

High resistance measurements can be affected by electrostatic interference, which occurs when an electrically charged object is brought near an uncharged object. To reduce the effect of electrostatic fields, a shield can be built to enclose the circuit being measured. As shown in Figure 17B, a metal shield connected to ground surrounds the LED under test.

The Force LO terminal of the SourceMeter instrument must be connected to the metal shield to avoid noise due to common mode and other interference. Using this type of shield will also help shield operators from contacting the standoff metal plate, because the plate is at guard potential.

Test System Safety

Many electrical test systems or instruments are capable of measuring or sourcing hazardous voltage and power levels. It is also possible, under single fault conditions (e.g., a programming error or an instrument failure), to output hazardous levels even when the system indicates no hazard is present.

These high voltage and power levels make it essential to protect operators from any of these hazards at all times. Protection methods include:

- Design test fixtures to prevent operator contact with any hazardous circuit.
- Install High Brightness LEDs onto heat sinks to protect from junction heating, thermal failures and to ensure operational reliability. Protect heat sink from hazardous voltages.
- Make sure the device under test is fully enclosed to protect the operator from any flying debris. For example, capacitors and semiconductor devices can explode if too much voltage or power is applied.
- Double insulate all electrical connections that an operator could touch. Double insulation ensures the operator is still protected, even if one insulation layer fails.
- Use high reliability, fail-safe interlock switches to disconnect power sources when a test fixture cover is opened.

- Where possible, use automated handlers so operators do not require access to the inside of the test fixture or have a need to open guards.
- Provide proper training to all users of the system so they understand all potential hazards and know how to protect themselves from injury. It is the responsibility of the test system designers, integrators, and installers to make sure operator and maintenance personnel protection is in place and effective. Specifications are subject to change without notice.

Conclusion

HBLEDs are advancing at an incredible pace. Researchers, LED design engineers, and manufacturers are working hard to make them the lighting source choice of the future. In order to get there, LED developers and manufacturers must jump several hurdles, ever trying to reduce the cost of manufacturing LEDs while simultaneously trying to increase their efficiency and light output. At the center of meeting these objectives, manufacturers require accurate, reliable, and repeatable source and measurement equipment with the power and flexibility to adapt to their ever-changing testing needs.

The Model 2460 High Current SourceMeter offers the features and flexibility to keep up with LED testing and development needs of researchers and engineers. Innovative features like the graphical user interface, real-time I-V curve plotting, and the 7A, 100 watt analog capability allow the 2460 to make repeatable measurements accurately, making it the perfect choice for testing HBLEDs.

Appendix A: Pulsed HBLED I-V Test Script Code

```
--[[
```

```
This example program pulse sweeps a High Brightness LED
```

```
arguments:
```

```
*bias: the offset voltage for the pulse sweep, between each step
*start: The starting voltage for the sweep
*stop: The stopping voltage for the sweep
*points: The number of measurement points and number of steps in the sweep
*Ton: the time on for each step voltage
*Toff: the time at the bias level for each step
*limit: the source current limit level
```

```
For this example, we will start the voltage sweep at 1 volt, stop at 4 volts, 100 points,
and an on time of 10 milliseconds and off time of 100 milliseconds.
```

```
]]
bias=0.0
start=1.0
stop=4.0
points = 100
Ton=5e-3
Toff=100e-3
limit=4.0
reset()

--Config List Setup
smu.source.configlist.create("levelList")
smu.source.configlist.create("biasList")

smu.source.func = smu.FUNC_DC_VOLTAGE
smu.measure.func = smu.FUNC_DC_CURRENT

smu.measure.nplc          = 0.01
smu.measure.autozero.enable = smu.OFF -- Need to turn off autozero for accurate timing.
smu.measure.range        = limit
smu.measure.sense = smu.SENSE_2WIRE

-- Set the source range large enough to fit both the bias and level.
-- This also turns off autoranging which will ruin our timing.
smu.source.range          = math.max(math.abs(start), math.abs(stop), math.abs(bias))
smu.source.delay          = 0
smu.source.ilimit.level = limit
smu.source.readback = smu.OFF

--Use start, stop and points parameters to calculate the step size.
--Compute the measure delay time.
stepsize = (stop - start)/(points - 1)
measuredelay = Ton-((1/localnode.linefreq)*smu.measure.nplc + 1e-3)

--Set up levelList config list
--Make ending point a little higher, so it will be included
--(Problem with floating point representation of stepsize)
stop = stop + 0.00000001
for step = start, stop, stepsize do
    delay(0.001)
    smu.source.level = step
    smu.source.configlist.store("levelList")
end

smu.source.level = bias
```

```

--Save settings to biasList config list (only one element)
smu.source.configlist.store("biasList")

--Timer setup
trigger.timer[1].reset()
trigger.timer[1].start.stimulus = trigger.EVENT_NOTIFY1
trigger.timer[1].start.generate = trigger.OFF
trigger.timer[1].delay = Ton
trigger.timer[1].enable = trigger.ON

--Trigger model setup
trigger.model.setblock(1, trigger.BLOCK_BUFFER_CLEAR)
trigger.model.setblock(2, trigger.BLOCK_SOURCE_OUTPUT, smu.ON)
trigger.model.setblock(3, trigger.BLOCK_CONFIG_RECALL, "levelList")
trigger.model.setblock(4, trigger.BLOCK_NOTIFY, trigger.EVENT_NOTIFY1)
trigger.model.setblock(5, trigger.BLOCK_BRANCH_ONCE, 7)
trigger.model.setblock(6, trigger.BLOCK_CONFIG_NEXT, "levelList")
trigger.model.setblock(7, trigger.BLOCK_MEASURE)
trigger.model.setblock(8, trigger.BLOCK_DELAY_CONSTANT, measuredelay)
trigger.model.setblock(9, trigger.BLOCK_MEASURE)
trigger.model.setblock(10, trigger.BLOCK_WAIT, trigger.EVENT_TIMER1)
trigger.model.setblock(11, trigger.BLOCK_CONFIG_RECALL, "biasList")
trigger.model.setblock(12, trigger.BLOCK_MEASURE)
trigger.model.setblock(13, trigger.BLOCK_DELAY_CONSTANT, Toff)
trigger.model.setblock(14, trigger.BLOCK_MEASURE)
trigger.model.setblock(15, trigger.BLOCK_BRANCH_COUNTER, points, 4)
trigger.model.setblock(16, trigger.BLOCK_SOURCE_OUTPUT, smu.OFF)
display.changescreen(display.SCREEN_GRAPH)
--Start the trigger model
trigger.model.initiate()
--display.changescreen(display.SCREEN_GRAPH)

```

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