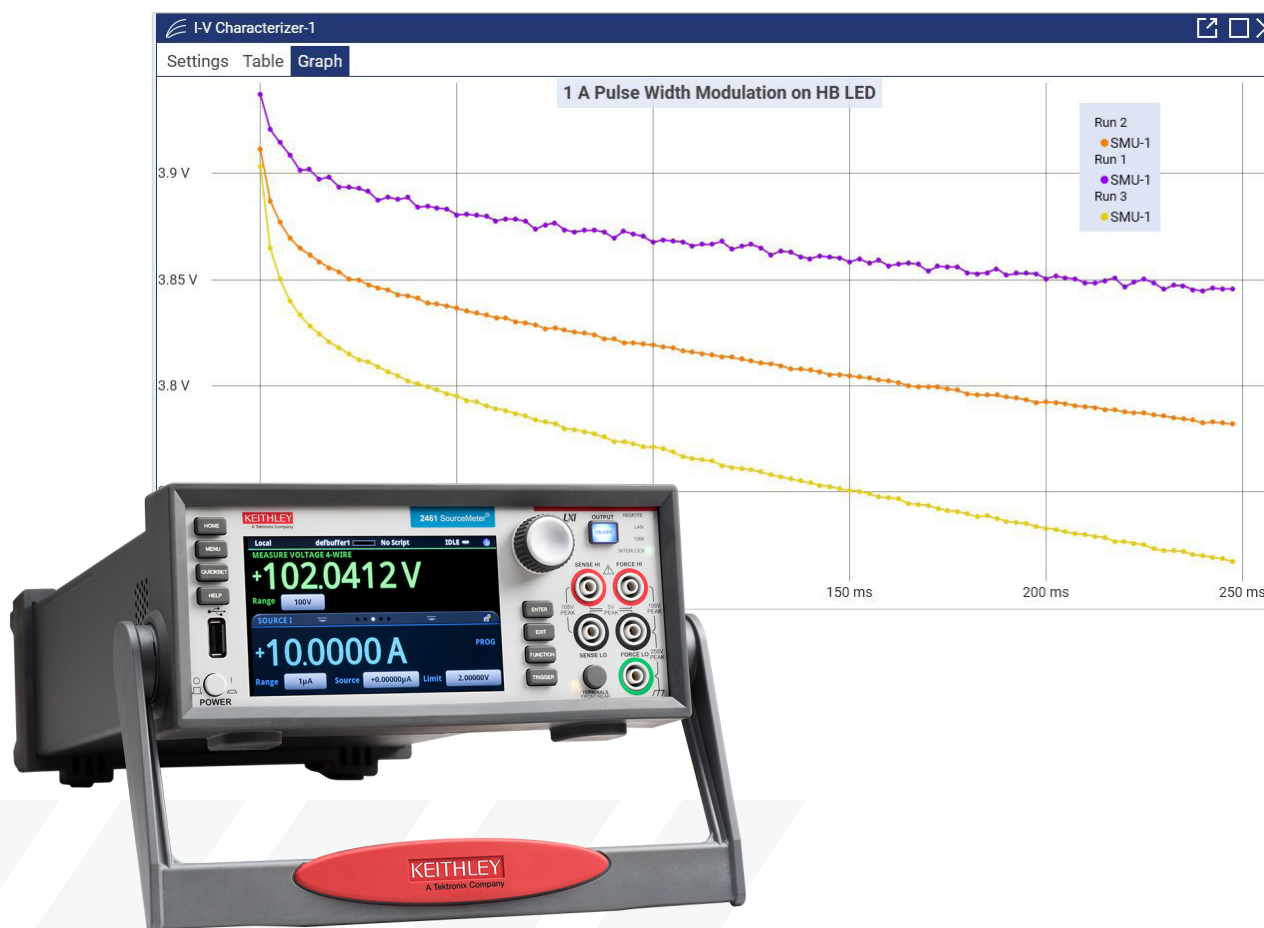# Tektronix®

Pulsed Characterization of HBLEDs Using Keithley KickStart Software

APPLICATION NOTE

Introduction

Manufacturers of devices like high-brightness light-emitting diodes (HBLEDs) tend to start their design prototype evaluations to yield characteristic information, while still working in their research and design labs. While straight DC testing is the norm in most cases, some of these devices are expected to be operated with a pulsed or briefly-on (switched) stimulus to yield a certain behavior or outcome. The test setups may seem simple on the surface but learning and understanding how to use the instrumentation involved in said tests can often require a steep learning curve. Even after learning to physically operate the equipment, generating the code to automate the testing process can also come with its own challenges as well as a time investment. Ideally, there would be some sort of existing software that can intuitively simplify as much of the testing and automation process as possible.

This application note will first introduce the reasons why pulse-based testing might be beneficial for a semiconductor device. Further details are supplied that specifically indicate the application of pulsed test for high-brightness LEDs. Additionally, specifics are provided to help guide the reader in using the Keithley KickStart Software to establish automated tests and generate both tabular and graphical representations of their data.

Benefits of Pulse Testing

The most common reason for using pulsed measurements is to reduce joule heating (i.e., device self-heating). When a test signal is applied to a device under test (DUT), the device consumes power and turns it into heat, increasing the device's temperature. The longer that power is applied, the hotter the device becomes, which affects its electrical characteristics. If a DUT's temperature can't be kept constant, it can't be characterized accurately. However, with pulsed testing, power is only applied to the DUT briefly, minimizing self-heating. Duty cycles of one percent or less are recommended to reduce the average power dissipated by the device over time. Pulsed measurements are designed to minimize the power applied to the device so much that its internal temperature rise is nearly zero, so heating will have little or no effect on the measurements.

Because they minimize joule heating, pulsed measurements are widely used in nanotechnology research, where it is necessary to characterize delicate materials and structures like CNT FETs, semiconductor nanowires, graphene-based devices, molecular-based electronics, and MEMs structures. The heat produced with traditional DC measurement techniques could easily alter or destroy them.

Pulsed measurements are also useful for extending instruments' operating boundaries. A growing number of power semiconductor devices are capable of operating at 100 A or higher but building an instrument capable of sourcing this much DC current would be prohibitive. However, when delivering pulse mode power, these high-power outputs are only needed for very short intervals, which can be done by storing the required energy from a smaller power supply within capacitors and delivering it all in one short burst. This allows instruments like a high-power source measure unit (SMU) to source high current (or voltage) levels with precision current and voltage measurements.

HBLED Testing – Forward Voltage and Pulse Width Modulation

Visible LEDs 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, streetlights, 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. To ensure the reliability and quality of these devices, accurate and cost-effective testing is critical.

LED testing involves different types of test sequences at various stages of production, such as during 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. This section of the document is intended to provide solid information on some elementary "ingredients" for these recipes—basic tests that illustrate how to probe for the diodes' characteristics and example test setups.

Testing LEDs typically involves both electrical and optical measurements. Here we focus on electrical characterization. **Figure 1** illustrates the electrical I-V curve of a typical diode. A complete test could include a multitude of voltage values versus current operating points, but a limited sample of points is generally sufficient to probe for the figures of merit.

Some tests require sourcing a known current and measuring a voltage, while others require sourcing a voltage and measuring the resulting current. A 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 simultaneously.
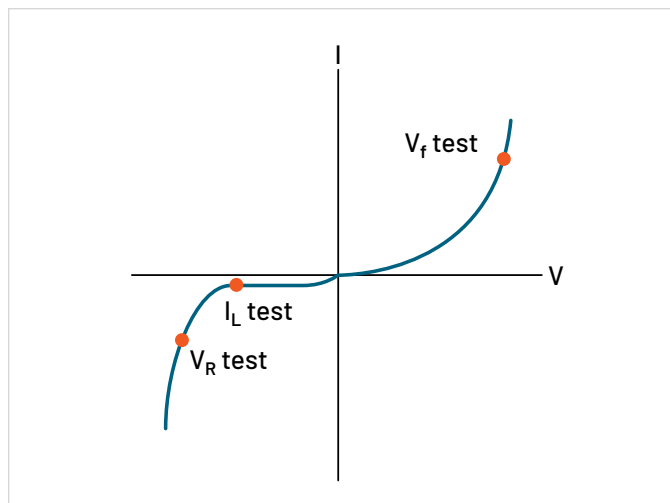

Figure 1: Typical LED DC I-V curve and test points (not to scale).

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 few volts. The results of this test are usually used by manufacturers for binning purposes as the forward voltage is directly related to the chromaticity of the LED.

While the traditional process for this testing involves applying constant direct current (DC) stimulus, changes in technology warrant changes in methodology. While voltage levels across LEDs have not shown a dramatic shift, HBLEDs are subject to higher currents and, therefore, higher power. Device designers have developed different means to operate and test them.

Pulse width modulation is a common method of controlling the brightness of LEDs. When using this technique, the current through the LED is pulsed at a constant frequency with a constant pulse level, but the width of the pulse is varied (**Figure 2**). Varying the width of the pulse changes the amount of time the LED is in the ON state, as well as the perceived level of brightness. In this drive scheme, the LED is actually flashing, but the frequency of the flashing is so high that it's indistinguishable to the human eye from a constant light level. Although it's possible to control the brightness of an LED simply by lowering the forward drive current, pulse width modulation is the preferable technique for a number of reasons.
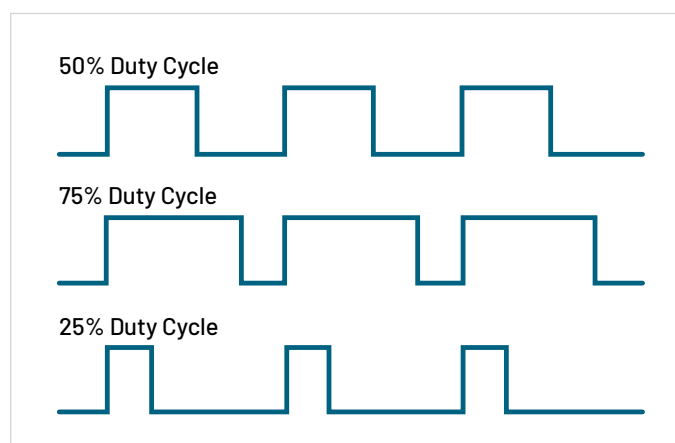

Figure 2: In pulse width modulation, the pulse level and frequency remain constant, but the duty cycle is varied.

Arguably, the most important reason for using pulse width modulation is to maintain consistency of the color of the light as the LED's brightness is reduced. In an LED, the color of the light it emits is related to the forward voltage at which it operates. Although the forward voltage of an LED will remain relatively constant as the forward current is changed, it actually does vary by as much as tens to even hundreds of millivolts. This occurs especially at lower current levels (**Figure 3**). This slight variation in forward voltage equates to a slight variation in light color, which is undesirable for the end user. If heating effects are ignored, in the pulse width modulation technique, the LED is pulsed using exactly the same current level on every pulse, so the forward voltage is the same for every pulse; therefore, the color of the light emitted will not vary.
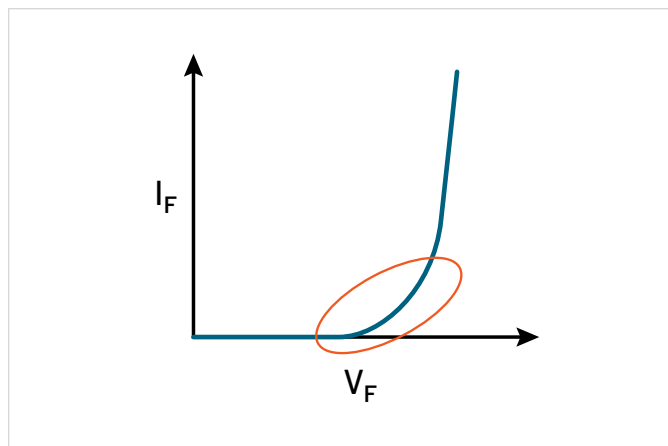

Figure 3: Forward voltage changes significantly when the forward current is low and becomes constant as forward current increases.

Another important reason pulse width modulation is preferable is because this technique provides linear control over brightness. The amount of light an LED emits is not linearly related to the amount of current used to drive it. In other words, reducing the drive current by 50% will not cut the light output by 50%; instead, it will drop by some other amount. This would make a dimming scheme based on varying current difficult to apply because it would be necessary to characterize each LED's light output vs. forward current then calibrate the drive scheme to that curve. Using pulse width modulation is a much simpler way to get linear control over brightness. With pulse width modulation, all that's necessary to make the LEDs output 50% as much light is to reduce the duty cycle by 50%. If the LEDs are only ON for half as long, only half as much light will be produced.

Power efficiency is another advantage of the pulse width modulation approach. Because pulse width modulation uses a constant current level for each pulse, it's possible to select a pulse level where the LED operates most efficiently, that is, where the lumen output per watt is the greatest. That means the LED is operating at maximum efficiency no matter what brightness level is used. Another way in which pulse width modulation enhances efficiency is that LEDs will actually output more light for a given drive current when pulsed rather than at DC. Many manufacturers' datasheets include a graph of forward current vs. luminous flux. If the manufacturer has characterized the LED under both pulsed and DC drive currents, one can observe that the pulsed characterization curve lies above the DC characterization curve. This is due to the reduced self-heating that the pulsed drive current produces. Finally, pulse width

modulation enhances power efficiency even in the circuitry that drives it. The switching circuitry used in pulsed width modulation wastes very little power. When the switch circuitry is turned off, virtually no current flows and virtually zero power is being used. When the switch is turned on, due to the very low ON-state resistances, nearly all the power is delivered to the LED and very little is consumed by the switch. In a variable current drive scheme, power to the LED is often reduced by consuming the excess power elsewhere in the circuit.

Generating a Pulse Modulated Output on an LED in KickStart

This example application demonstrates how to generate a pulsed current train on a high-brightness LED using the Keithley KickStart Startup Software and a 2461 High Current SourceMeter® SMU Instrument. KickStart allows you to set up your instrument and run a test quickly without writing any code. The data generated by KickStart can be plotted on a graph or viewed in a table. The measurements can also be saved to a file in .csv or .xlsx file format.

In this example, you will use the KickStart software to configure the 2461 to output various pulsed current train waveforms for an expected period and with a different duty cycle applied in each instance. The voltage versus time will be plotted on the graph, and all run instances will be selected for simultaneous comparison.

Equipment and Software Required

- One 2461 High-Current Graphical Touchscreen SourceMeter SMU Instrument.

- Keithley KickStart Startup Software version 2.6.0 or later, installed on your computer; you can download KickStart from https://www.tek.com/keithley-kickstart.

- For front-panel connections, use four insulated banana cables such as the Keithley 8608 High-Performance Clip Lead Set (one set included with the 2461; you will need another set).

- For rear-panel connections, use one 2460-KIT Screw-Terminal Connector Kit (provided with the 2461), or you can use one set of 2460-BAN Banana Test Leads/Adapter Cables (with appropriate connections to the device).

- One GPIB, USB, or ethernet cable to connect the 2461 to a computer.

- One high-brightness LED.

Set up Remote Connections

This application is configured to run remotely. You can run this application from any of the supported communication interfaces for the instrument (GPIB, USB, or ethernet).

Figure 4 shows the rear-panel connection locations for the remote communication interfaces.
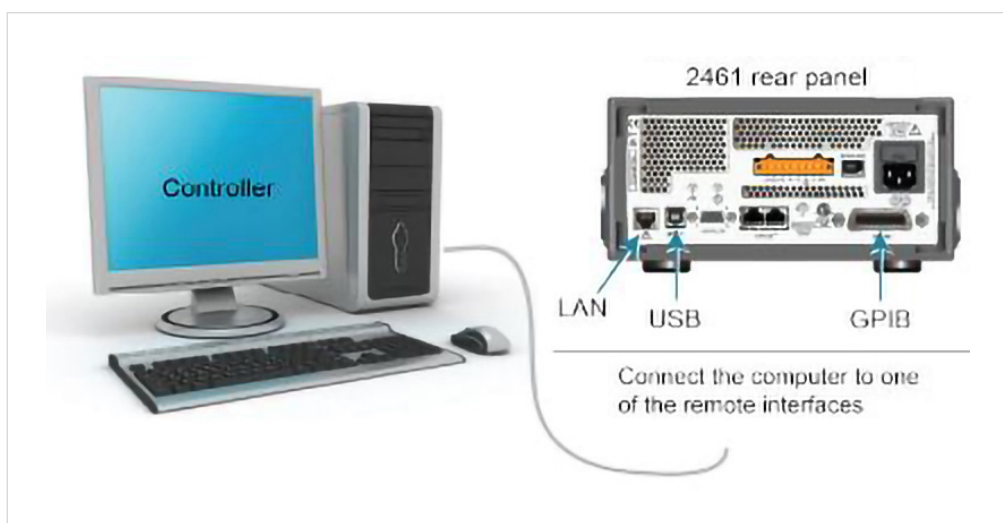

Figure 4: 2461 remote interface connections.

Device Connections

For best measurement accuracy and to eliminate the effects of test lead resistance when sourcing high current, connect the 2461 to the device under test (DUT) using the four-wire sense method.
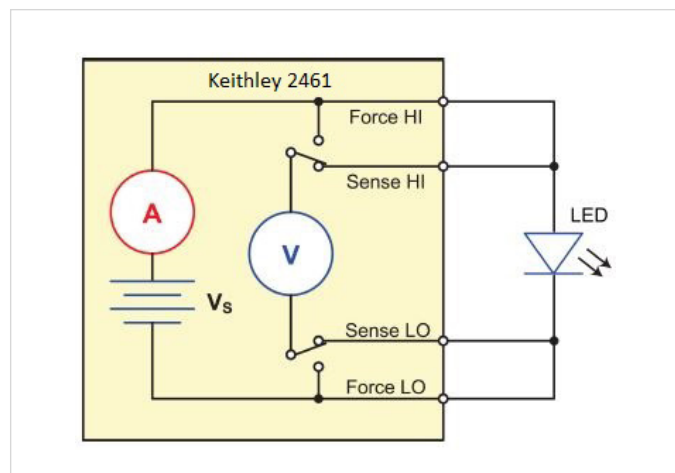

Figure 5: 2461 four-wire connections to an LED.

To use the four-wire sense connection method:

- Connect the FORCE HI and SENSE HI leads to the anode terminal of the LED.

- Connect the FORCE LO and SENSE LO leads to the cathode terminal of the LED.

- Make the connections as close to the DUT as possible to exclude the test-lead resistance from the measurement.

Figures 6 and 7 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.

Figure 6 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 8608 High-Performance Clip Lead Set.
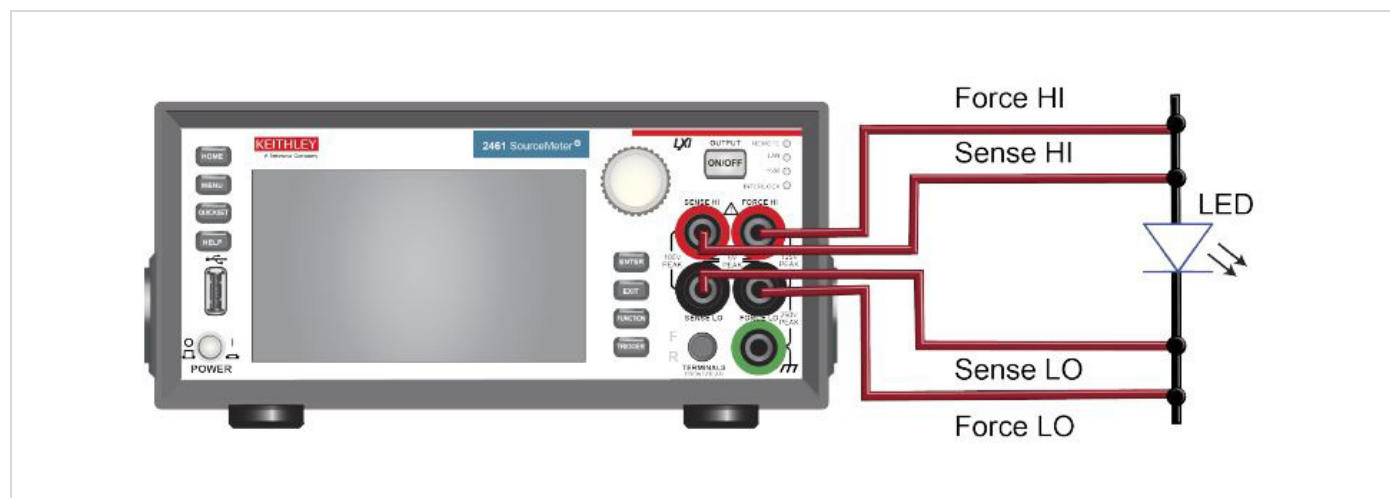

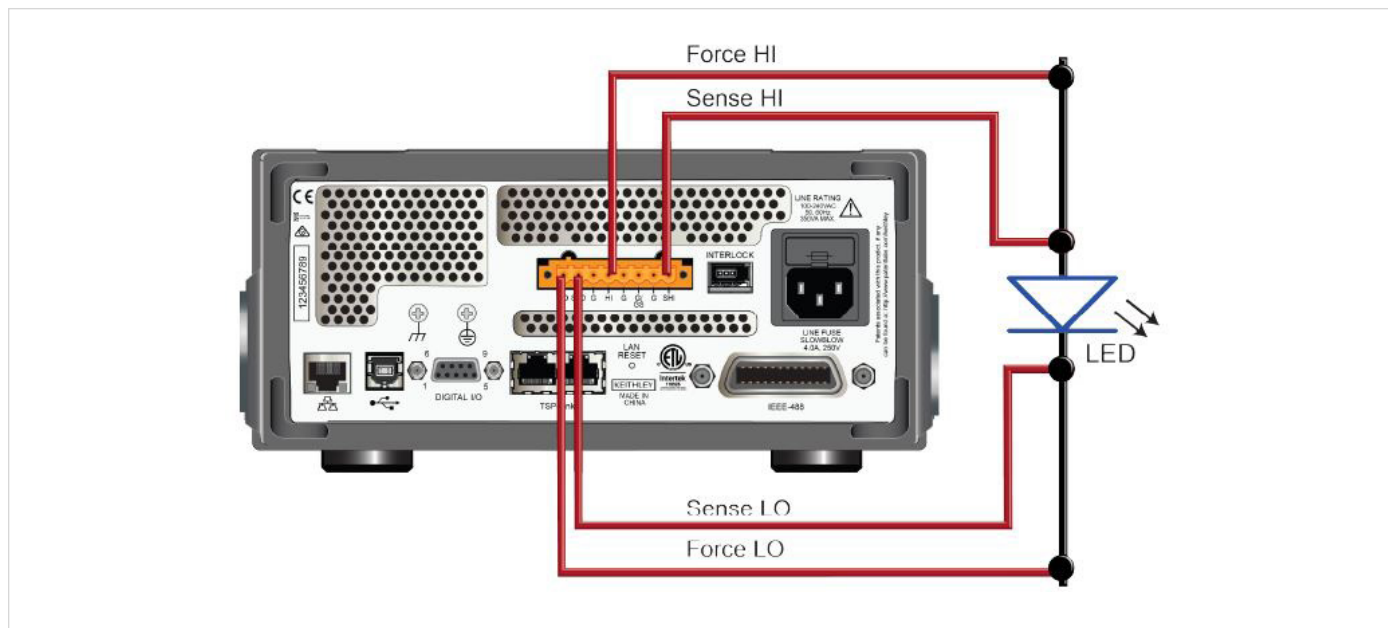**Figure 6: 2461 front panel 4-wire connections to an LED.**

Figure 7: 2461 rear panel 4-wire connections to an LED.

Figure 7 shows the rear-panel connections. You can make these connections with either the 2460-KIT Screw-Terminal Connector Kit (included with the 2461) or a 2460-BAN Banana Test Leads/Adapter Cable with appropriate cabling.

Configure the 2461 to Use the KickStart Software

The 2461 must be set to use the Test Script Processor (TSP®) command set before you can use the KickStart software. By default, the 2461 is configured to use the SCPI command set. You must select the TSP command set before using KickStart.

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**.

Launch KickStart and Set Up the Test

Once the communication cable is connected to the computer and the TSP command set is enabled, you are ready to launch the KickStart software.
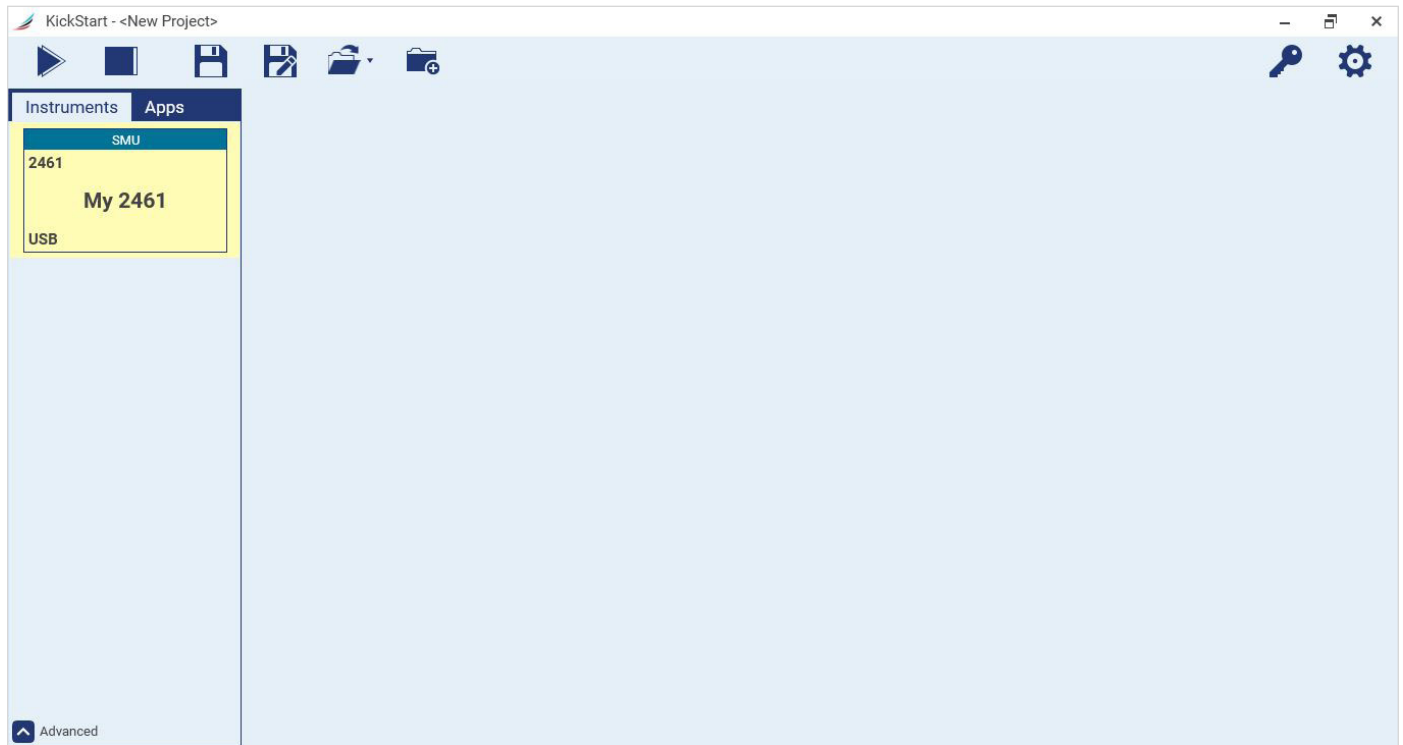

Figure 8: KickStart software startup page.

To create the test project:

1. Launch the KickStart software. The startup screen is displayed, as shown in the **Figure 8**.

2. Either double-click or drag the 2461 instrument into the main app staging area then select **I-V Characterizer.**

Figure 9: Select the I-V Characterizer App.

3. Navigate to the SMU-1 settings tab and apply the following source changes (illustrated **Figure 10**):

   a. Set the Type to **Pulse**.

   a. Set the Function to **Current**.

   a. Set the Mode to **Train**.
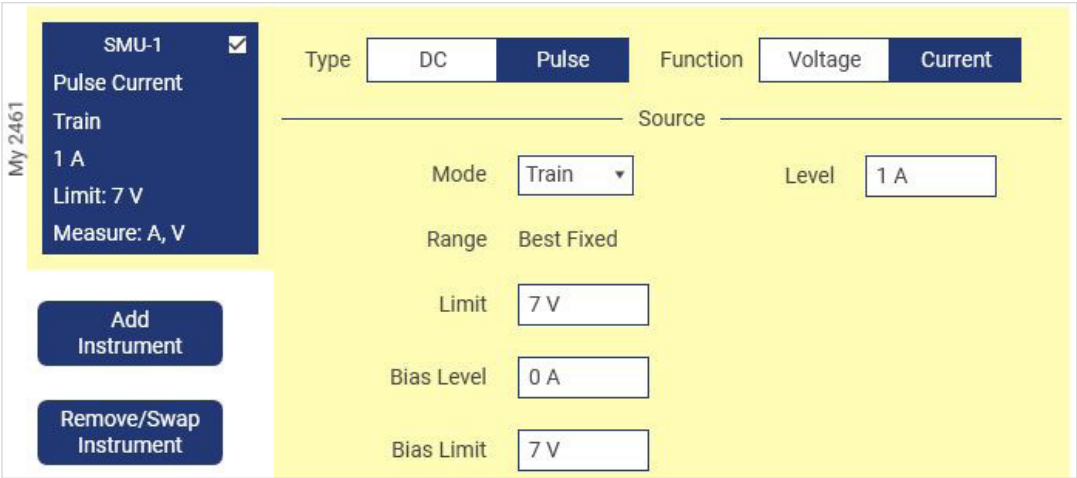
   a. Set the Level to **1 A**.

Figure 10: Apply source type and output settings.

4. Scroll to the Instrument Settings and set the Sense to **4-Wire**.

Figure 11: Apply Instrument Settings.

5. Navigate to the Common Settings pane. In this section you will apply a series of pulse width and off times that are defined for a given period of **2.5 ms** (or 400 Hz). The three test run cases are shown in the following table.

Table 1: Pulse definition settings.

Width	Off Time
625 μs	1.875 ms
1.25 ms	1.25 ms
1.875 ms	625 μs

For the first test case, apply the following settings:

-   Set the Source/Sweep Points to **100** (note that this defines the number of pulses).
-   Set the Source to Measure Delay to **5e-5 s**.
-   Set the Width to **625 μs**.
-   Set the Off Time to **1.875 ms**.

Note, too, how the Waveform Viewer pane updates to show that the output of the SMU can be expected to be of a pulse type with a duty cycle of 25%.
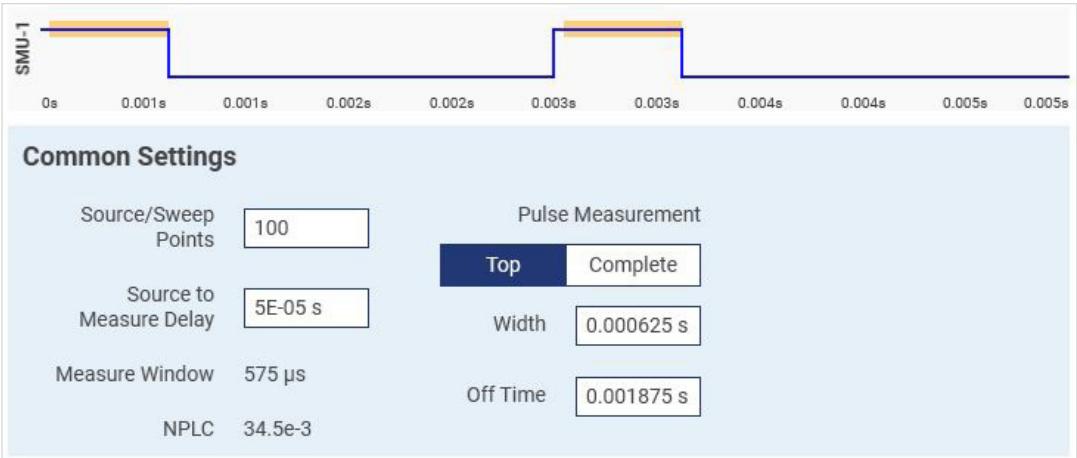
Figure 12: Common Settings and Waveform Viewer updated.

6. Click on the **Run** button to execute the test.

7. Upon completion, modify the Pulse Measurement attributes in the Common Settings pane such that both the Width and Off Time are set to **1.25 ms** (duty cycle of 50%).
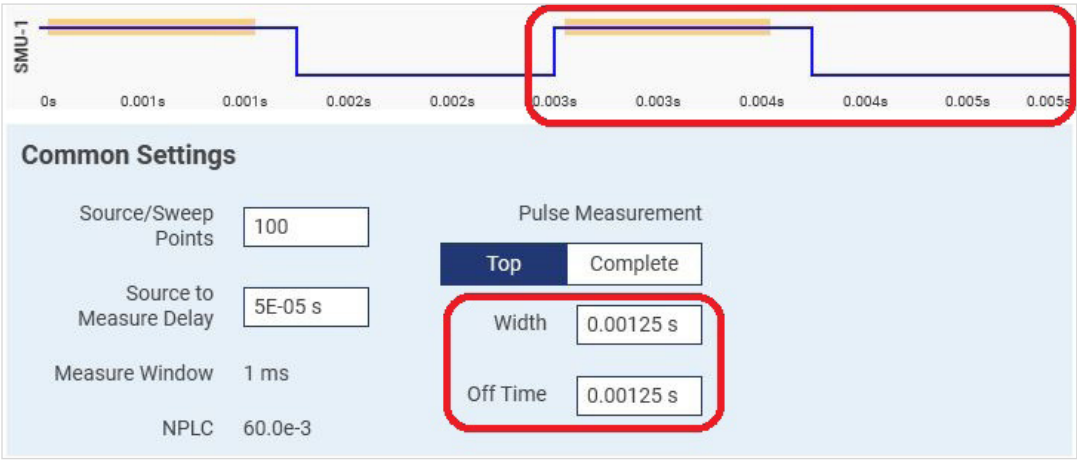

Figure 13: Common Settings and Waveform Viewer updated.

8. Click on the **Run** button to execute the test.

9. Upon completion, modify the Pulse Measurement attributes in the Common Settings pane and set the Width to **1.875 ms** and the Off Time to **625 μs** (duty cycle of 75%).
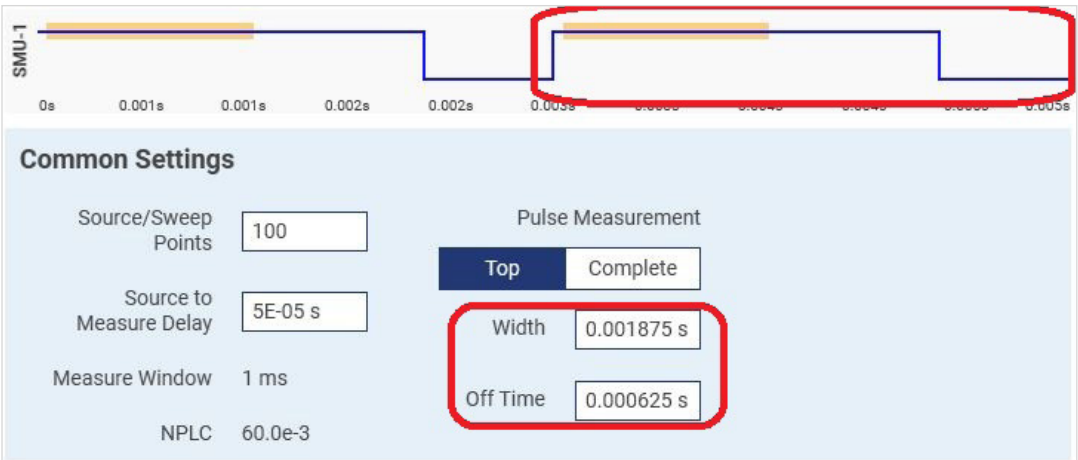
Figure 14: Common Settings and Waveform Viewer updated.

10. Click on the **Run** button to execute the test.

11. Click on the **Run History** button to expose the three app runs you just conducted.

12. Select each of the individual runs and update the area reading "Enter a run description here" to provide a general description of the test configuration run (see **Figure 15** for an example).
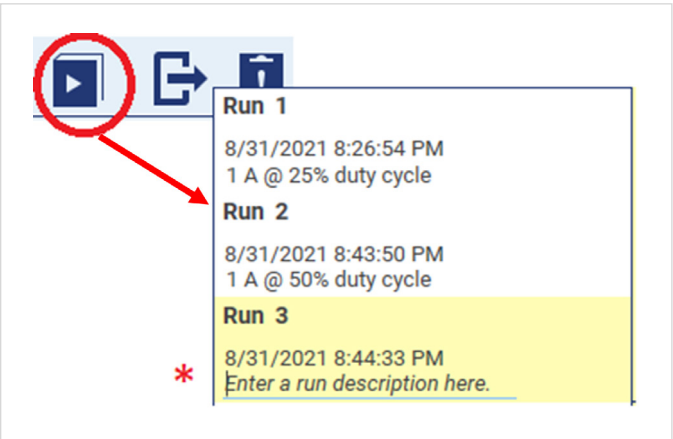

Figure 15: Use the Run History to help document changes to the app configuration.

13. Use the **Shift** or **Ctrl** keys on your keyboard (along with mouse clicks) to select all three runs for comparison.

14. Click on the **Graph** tab at the top of the KickStart user interface.

15. Hover your mouse cursor above the x-axis title to reveal the configuration options then change the Source to **Time**.

16. Hover your mouse cursor above the legend and select to plot **Voltage** then de-select current.
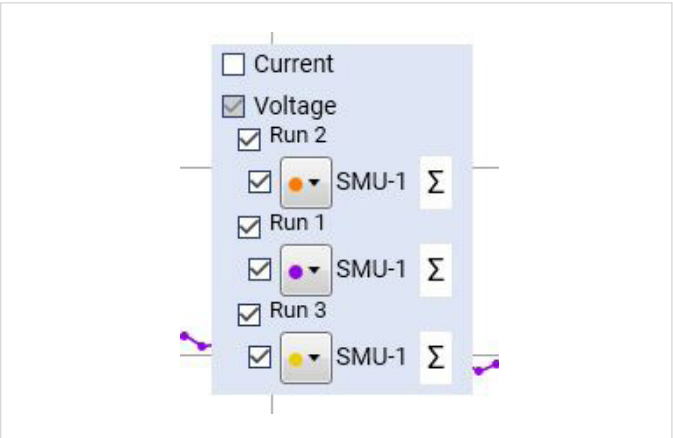

Figure 16: Update the legend settings to plot Voltage on the y-axis.

17. Hover your mouse cursor in the top center area of the graph to reveal the title entry field and provide a title of your choosing to your graph.

Figure 17: Provide your test data a title.

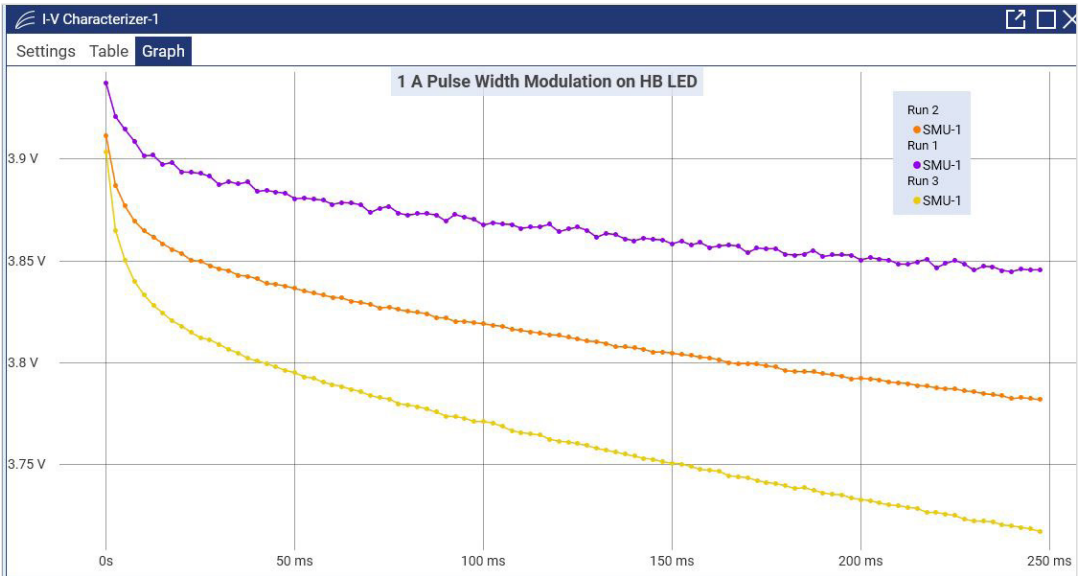18. Your final plotted output should look similar to the **Figure 18**.

Figure 18: Pulse width modulated output data presented graphically.

Summary

The primary reason for pulse testing is to reduce device self-heating that happens when the device is activated – especially at its maximum operating potential – for increasing periods of time.

Pulse width modulation is applied to high-brightness LEDs to control their light intensity during regular operation. The longer the pulse width (or higher the duty cycle), the stronger the luminosity. These LEDs are also PWM driven to help ensure color quality while a consistent forward current level is applied. Having the LED on for only a fraction of the time improves the efficiency of the device and helps to extend its lifespan.

Whatever your pulse-based testing needs are, Keithley source measure unit (SMU) instruments and KickStart Software are an ideal pairing to help quickly establish your test setups, collect data, and share tabular and graphical insights with your colleagues. The KickStart examples shared within this application note can use either the 2450 or 2461 SMU instruments, which are capable of achieving 1 A, 20 W and 10 A, 1000 W, respectively, in their pulse operating regions. However, keep in mind that KickStart also supports the Keithley 2651A (for higher current up to 50 A) and 2657A (for higher voltages up to 3000 V) SMU instruments.

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