KEITHLEY

Application Note Series

Number 2218

Production Testing of High-Intensity, Visible LEDs

Introduction

Due to their long life and high reliability, visible light emitting diodes (LEDs) are finding their way into more and more applications. LEDs are now found in most automobiles, street lights, outdoor signs, etc. Also, with the development of new colors and new critical applications, there is an ever-increasing need for cost-effective testing methods to ensure the reliability of the LED. With the advent of technologies such as high-intensity and organic LEDs, demands on test equipment in terms of measurement performance and throughput continue to increase.

LEDs produce light as the result of the transition of charged particles across the semiconductor energy gap. The value of this energy gap determines the wavelength of the light emitted. LED development has yielded surface and edge emitting technologies for varying performance along wavelength and power attributes.

This document will illustrate methods and issues related to creating production test system solutions that verify the performance of single and multiple (array) LED devices.

Test Description

Five tests are typically performed on high performance LEDs. These tests include three tests in the DC spectrum (forward voltage, reverse breakdown, and leakage current) and two tests in the optical spectrum (luminous intensity and wavelength verification). In the production environment, generally only the DC tests are performed due to throughput concerns. Optical tests, while useful, are often slow and are typically reserved for the engineering or quality control lab. Details of the various tests and testing requirements follow.

DC Tests

Figure 1 illustrates the test points for each of the three DC tests described in this note.

Forward Voltage Test (V_F)

The V_F test verifies the forward operating voltage of the visible LED. Beyond this operating voltage, large increases in circuit current will result in an insignificant increase in forward voltage, as illustrated in ***Figure 1***. A specified forward bias current (for example, 10mA) is applied for a specified period of time (for example, 1ms), and the voltage drop across the LED is measured. The measurement result is typically in the range of hundreds of millivolts.

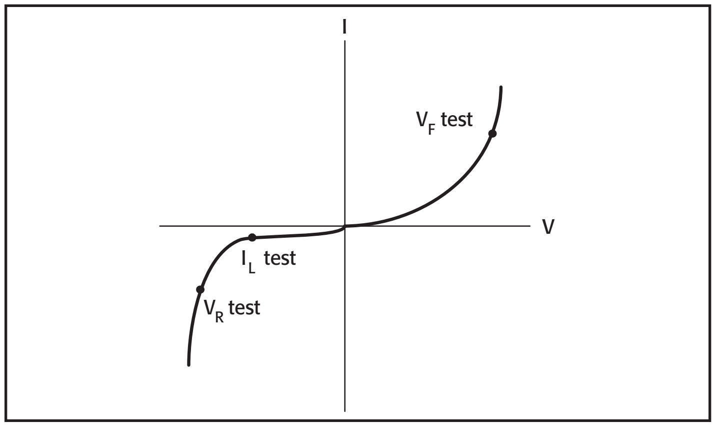

Figure 1. Typical LED DC I-V Curve and Test Points (Not to Scale)

Reverse Breakdown Voltage Test (V_R)

The V_R test verifies the reverse breakdown voltage of the LED, similar to a diode. 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 and measuring the voltage drop across the LED. The measurement result is typically in the range of volts to tens of volts.

Leakage Current Test (I_L)

The I_L test verifies the LED's leakage current, which is the low-level current that leaks across the LED when a reverse voltage less than breakdown is applied. A specified reverse voltage is applied, and the corresponding current flowing through the LED is measured after a certain amount of time. Testing involves verifying that the measured leakage current is below a certain threshold. These current measurements typically range from nanoamps to microamps.

Optical Tests

Light and Radiant Intensity Tests

Luminous (or light) intensity is measured in lumens/sterad or candela. Values typically range from millicandela to many candela. This parameter can be used to calculate radiant intensity in watts/sterad. The radiant intensity measurement accounts for the total output of the LED, while luminous intensity measures output over the visible range. Radiant intensity may range from slightly less than 1μW/sr to tens of mW/sr. Luminous efficiency can also be calculated by dividing the total luminous output in lumens/watt by the input power.

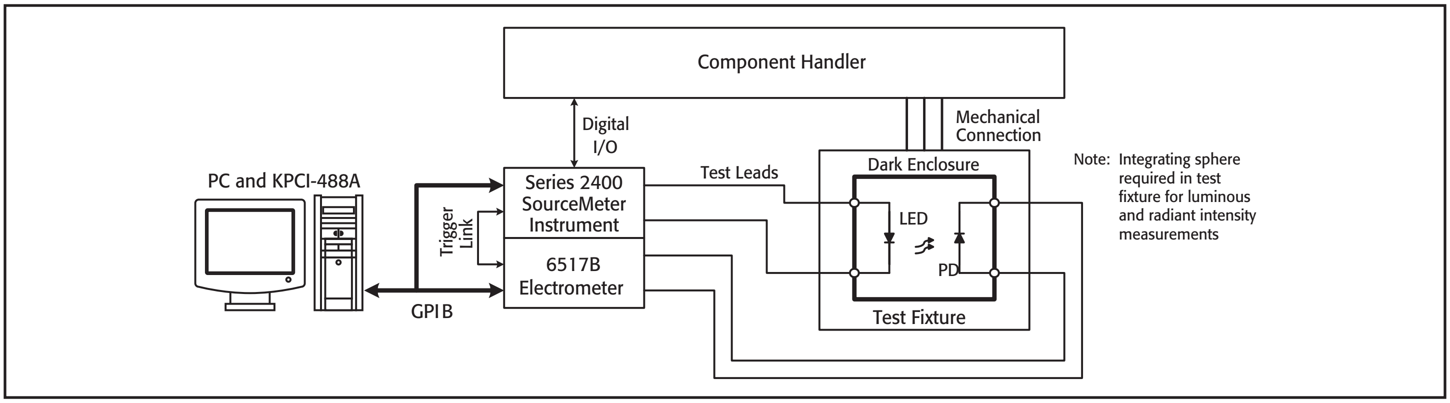

Figure 2. Block diagram of a typical SourceMeter®/electrometer-based test system for visible LED production testing

Light intensity is often measured using a photodetector (PD). The amount of reverse leakage current present through the PD is proportional to the amount of light shining on it. Therefore, when an LED shines on a PD and the corresponding leakage current is measured across the PD, the light intensity can be extrapolated. Using this method to perform light intensity measurement enables the entire test system for DC and optical test to be constructed of high-speed DC instruments. If this DC method is not preferred, then an integrating sphere must be used, which is not discussed in detail in this document.

Wavelength and Chromatic Tests

Wavelength data is typically obtained using a spectrometer, which measures the dominant and peak wavelengths of the LED output. The output spectrum for an LED, known as the far-field pattern (FFP), resembles a bell curve centered on the peak wavelength of the LED. Full width at half maximum (FWHM) is calculated as the spectral bandwidth at half intensity and is used to specify the operating wavelength range of the LED. The color information for the LED output can be obtained using an ISO/CIE standard colorimetric system, which measures the output based on the amount of the three fundamental colors (red, blue, and green) it contains.

Test System Description

Single LED Test System

The LED is placed in a test fixture and connections are made to the input of the SourceMeter® instrument. Device placement and connections to the device under test (DUT) are often done with a component handler in order to automate the production process. The test fixture is typically shielded from light to avoid corruption of the test data due to ambient light. A photodetector (PD) is integrated into the test fixture and is used to test each of the LEDs as the handler places them into the fixture. ***Figure 2*** illustrates the typical DC characterization system described previously.

The SourceMeter instrument performs the three DC tests on the LED. Since the instrument is capable of sourcing current or voltage with either polarity, the entire DC characterization of the LED can be performed without flipping or moving the LED from the initial test position. The SourceMeter instrument and electrometer are used in conjunction to capture light intensity data. To characterize the light intensity of a laser diode, the SourceMeter instrument performs a multi-point current sweep on the LED over its operating range (see ***Figure 3a***), and the resulting light output is measured via the PD with a Model 6517B (see ***Figure 3b***). For high throughput applications, the light intensity is generally measured at only one or a very small number of test points.

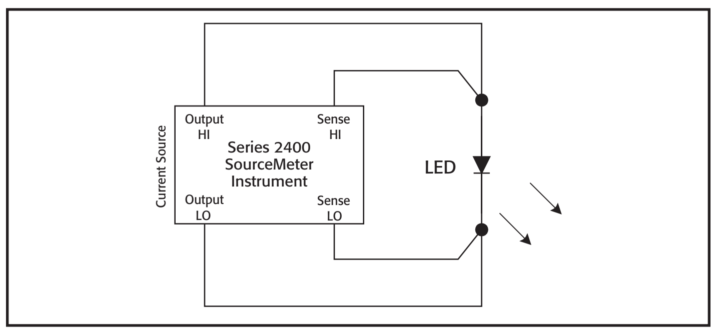

Figure 3a. Photodetector Measurement Circuit

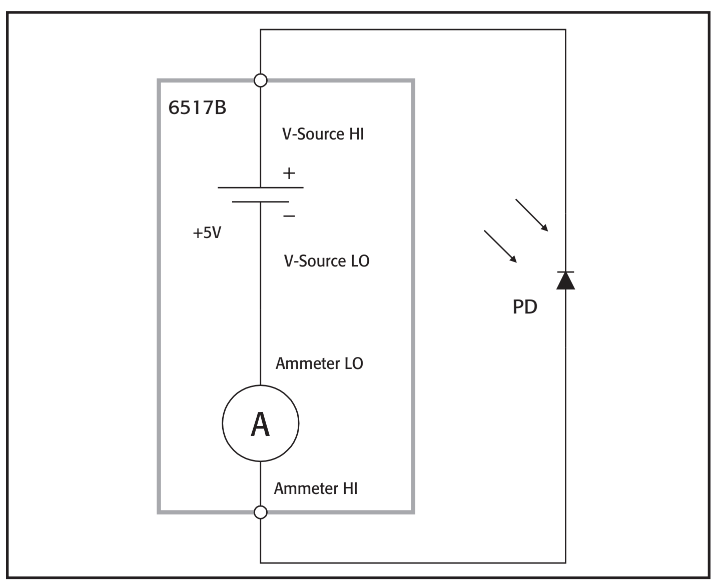

Figure 3b. LED Source Circuit

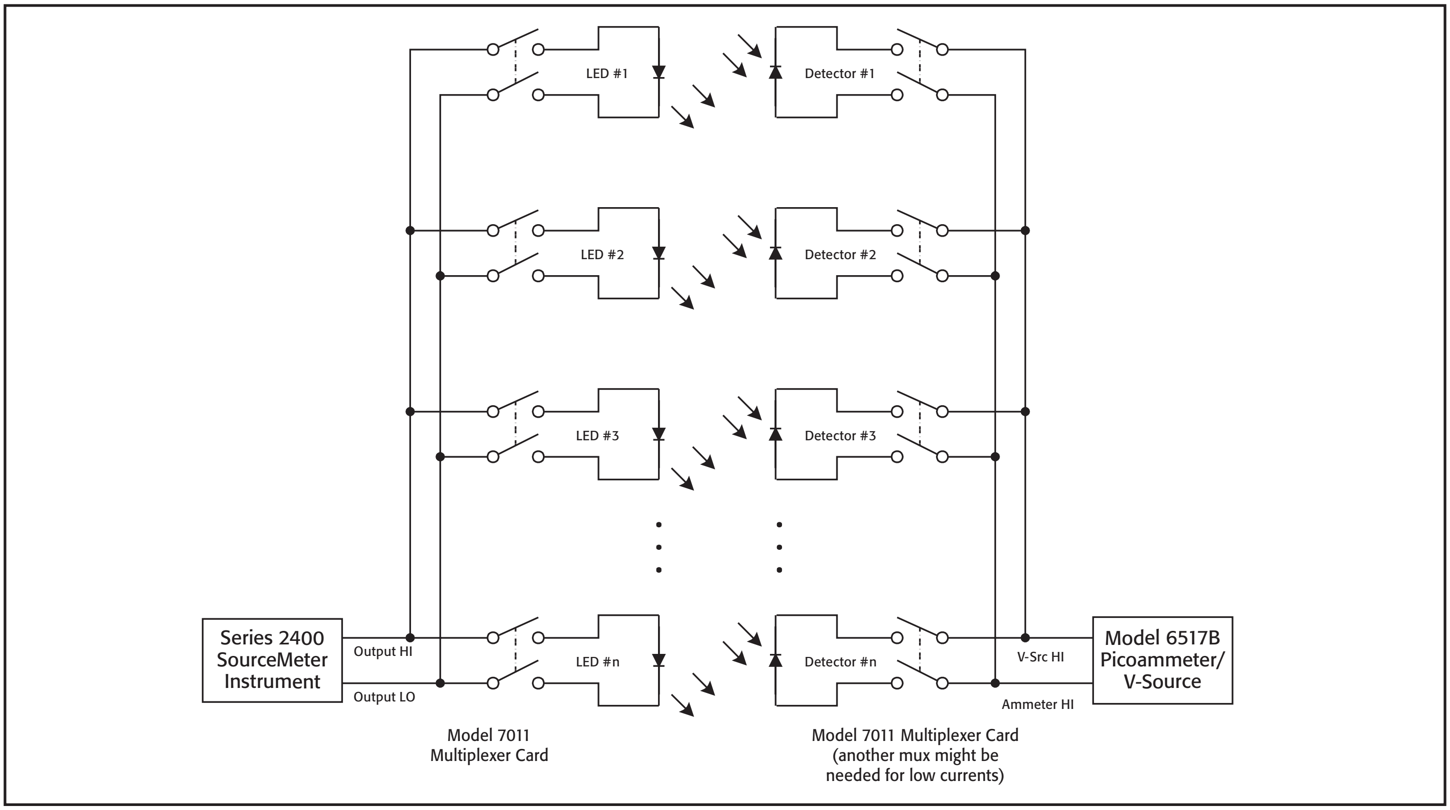

Figure 4. Switching multiple LEDs to a Series 2400 SourceMeter Instrument and PDs to Model 6517B Electrometer

Multiple/Array LED System

For LED arrays, multi-die packages, or burn-in applications, it is often necessary to test many LEDs at once. The most cost-effective way to test many devices at one time is to include switching in the test system configuration. Burn-in applications often require powering each LED for extended periods, which requires dedicated source capabilities without switching. The measurements of the PDs in a burn-in system are generally multiplexed to monitor the LED performance over time. ***Figure 4*** is an example of an LED switching test system configuration. Actual systems can be configured for any number of diode elements and for various electrical specifications.

In the multiple device test system, an individual LED is selected for testing, and the corresponding relay is closed both for the LED and the PD used to verify light intensity. The SourceMeter instrument performs the necessary DC tests, then forces enough current to light the LED, and while the LED is on, the Model 6517B measures the increased leakage of the PD. Once this testing process has completed, the switching channels for the next device are selected.

The offset specification for the Model 7011 Multiplexer Card is <100pA, which may exceed the error budget for the test system. Therefore, replacing the Model 7011 with a Model 7158 Low Current Scanner Card will lower the offset value to <1pA (<30fA typical). It is important to note that using a low current card will lower the available channel density in the system. The low current cards only have ten channels available for scanning, which implies that four times as many cards are required when they are used to substitute for the Model 7011.

Integrated Devices

Many sensors today integrate both LEDs and PDs into the same package for applications such as reflective object sensors, optical switches, or other hybrid devices. Integrated devices require verifying the performance of both the LED and PD. An external PD or other light sensing device is used to monitor the output of the LED independently. DC tests are performed using the SourceMeter instrument, but when the light intensity measurements are taken, both the internal and external PDs are measured. Not only must the LED pass all of the required DC and optical tests, but the internal PD data also must correlate to the data taken on the "standard" external device. An example of this type of test system using three SourceMeter instruments is shown in ***Figure 5***.

Measuring the PDs can be done with either the Model 2400 or 6517B, depending on the current sensitivity required by the test specifications. The Model 2400 is useful for measuring currents down to approximately 10nA, while the Model 6517B reliably measures currents less than 10fA.

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

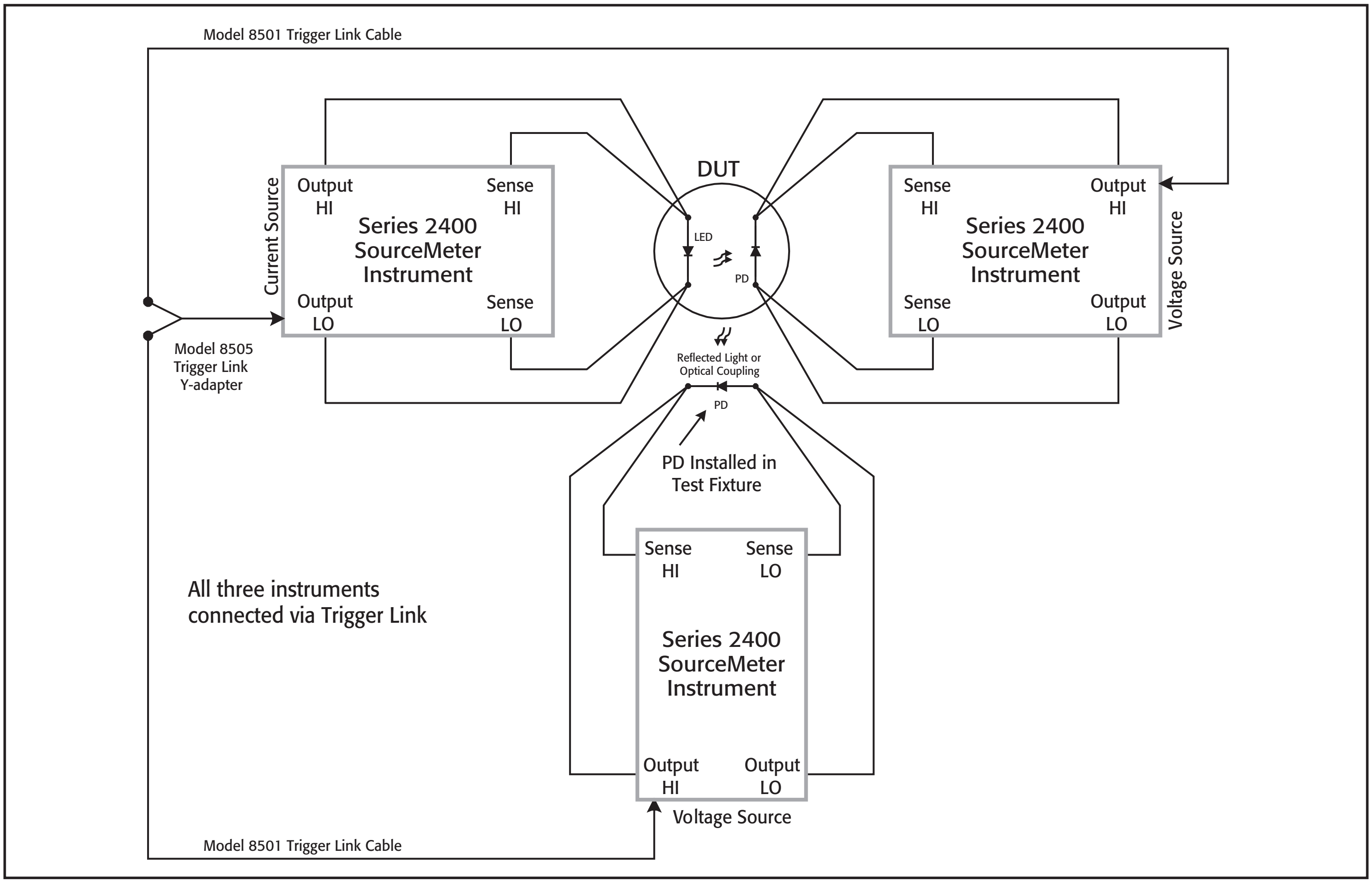

Figure 5. Measuring an Integrated LED/PD Device with Series 2400 SourceMeter Instruments

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.
- 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.

Methods and Techniques

Synchronization with Trigger Link

The Trigger Link is a hardware handshake bus used by the instruments in the test system to ensure proper test sequencing. It is a standard feature on all newer Keithley instruments, including all the instruments mentioned in this document. When the meter and switch mainframe are connected via a Trigger Link cable, they can trigger each other to allow faster test execution. This built-in bus eliminates the need for direct PC control of most system functions. When the Trigger Link function is used properly, the only functions the PC performs are initiating the test and retrieving data from the system.

For more detailed information dealing with how to configure synchronized test systems with Trigger Link, refer to Keithley Application Note #2217 “Trigger Synchronization of Multiple Instruments.”

Contact Check

The SourceMeter Contact Check function helps eliminate measurement errors and false product failures resulting from contact fatigue, breakage, or contamination, loose or broken connections, or relay failures. Before each automated test sequence begins, contact to the device under test (DUT) is verified, which can help reduce tooling and false failure costs.

The Contact Check function verifies that the resistance between the HI/LO test lead pairs is less than a certain threshold. Contact verification is done between the Output HI and Sense HI, Output LO and Sense LO, and Guard/Guard Sense pairs. By using pulse transformers and a reference resistance, the contact can be verified very quickly (typically within 350μs). The reference resistance can be set to three different values (5Ω, 15Ω, 50Ω). The Contact Check function does not pass a signal through the DUT—only between the three HI/LO pairs mentioned. If a Contact Check failure is detected, the test will abort and give a failure indication over the front panel, the IEEE-488 interface bus, and the digital I/O port.

Verifying LED Polarity

It is possible to add a polarity test to the testing suite. The polarity test is designed to determine the orientation of the LED safely and quickly prior to completing functional tests on the device. The breakdown characteristics of the LED are used to generate an indication of the LED's polarity in one of two ways. A positive current can be sourced through the LED and the voltage measured. A voltage of less than 1V (typically) indicates forward polarity of the diode, while a high voltage indicates breakdown and reverse polarity. Alternately, a negative current can be sourced, in which case a voltage measurement less than 1V indicates reverse polarity, while a high voltage indicates breakdown and forward polarity. The choice of these two methods for polarity testing depends primarily on the overall structure of the test program.

For more detailed information dealing with how to use the results of the polarity test and the various options available to the SourceMeter products and the component handler options, refer to Keithley Application Note #1805 "Diode Production Testing with the Series 2400 SourceMeter."

Typical Sources of Error

Junction Self-Heating

With increasing test times, the semiconductor junction of the LED will tend to heat. 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.

The SourceMeter family can configure both 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 is at 60Hz, a 1NPLC measurement would require 1/60th of a second, or 16.667 ms. 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 soak times for the VF test are from 1 to 5 milliseconds, and for the IL test are from 5 to 20 milliseconds. 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.

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 2-wire connection (see ***Figure 6a***). 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.

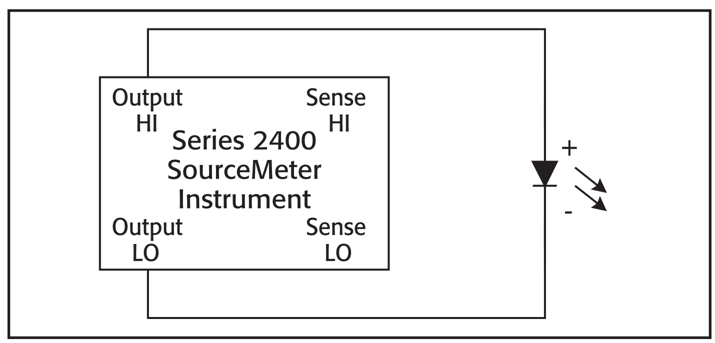

Figure 6a. Two-Wire Connection

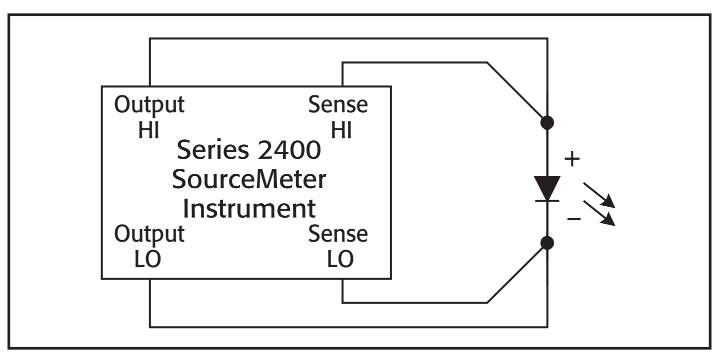

Figure 6b. Four-Wire Connection

To eliminate this problem, use the 4-wire remote sensing method, rather than the 2-wire technique. With the 4-wire method (see ***Figure 6b***), a current is forced through the LED

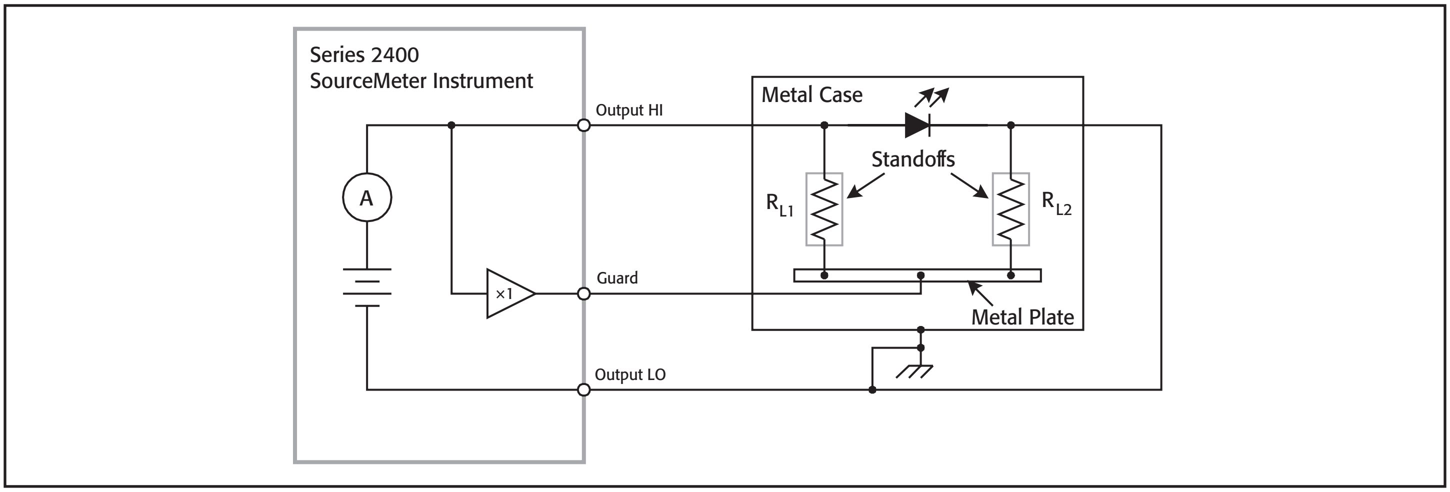

Figure 7. Series 2400 Guarding Technique

using the Output 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 the example in ***Figure 7***.

In this example, the LED to be measured is mounted on two insulated standoffs (R_{L1} and R_{L2}). Guard is used in this circuit to ensure that all the current flows through the diode and not through the standoffs. In general, cable guard should be used when sourcing or measuring currents less than 1μA. Connecting the Guard terminal of the instrument to the metal plate guards this circuit. This puts the bottom of insulator R_{L1} and R_{L2} at almost the same potential as the top. Since both ends of the insulator are at nearly the same potential, no significant current can flow through it. All the current will then flow through the LED as desired.

WARNING: Guard is at the same potential as Output HI. Therefore, if hazardous voltages are present at output 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 7***, a metal shield connected to ground surrounds the LED under test. The Output 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, since the plate is at guard potential.

Light Interference

Since testing LEDs involves detecting the amount and intensity of light produced by the LED, the test fixture should be shielded from light. Typically the inside of a test fixture is painted black in order to reduce reflection within the fixture.

Example Programs

An example Microsoft® Visual Basic program has been developed by Keithley to perform the multi-point LED/PD tests presented by the test system in ***Figure 4***. To obtain a copy of the program (VisibleLED.zip), visit Keithley's World Wide Web site (www.keithley.com). Also, you may wish to download 3x2400.zip, which illustrates the triggering scheme and test system shown in ***Figure 5***. These example programs are effective in illustrating how to configure the Models 2400 and 6517B for each test parameter and fast test sequencing using Trigger Link.

NOTE: The test programs provided are intended to illustrate the concepts presented in this document. The programs may need to be altered in order to accommodate desired test parameters and timing.

Equipment List

The following equipment is needed to configure the system shown in ***Figure 2***:

1. Model 2400 SourceMeter Instrument
2. Model 6517B Electrometer/High Resistance System
3. Model 8501 Trigger Link Cable
4. Two Model 7007 IEEE-488 Interface Cables
5. Model KPCI-488A IEEE-488 computer interface board with PC

6. Light-shielded enclosure with calibrated photodetector
7. Custom digital I/O cable for connecting the 9-pin male D-subconnector of the SourceMeter instrument to the component handler
8. Custom wiring harness for connecting the test equipment to the DUT and photodetector

The following equipment is needed to configure the system shown in ***Figure 4***:

1. Model 2400 SourceMeter Instrument
2. Model 6517B Electrometer/High Resistance System
3. Model 7001 (or 7002) Switch Mainframe
4. Model 7011 Quad 1×10 Multiplexer Card (each card can support 20 LED/PD pairs)
5. Three Model 8501 Trigger Link Cables
6. Three Model 7007 IEEE-488 Interface Cables
7. Model KPCI-488A IEEE-488 computer interface board with PC
8. Custom wiring harness for connecting the test equipment to the devices under test

The following equipment is needed to configure the system shown in ***Figure 5***:

1. Three Model 2400 SourceMeter instruments
2. Two Model 8501 Trigger Link Cables
3. Model 8505 Trigger Link Y-Adapter
4. Three Model 7007 IEEE-488 Interface Cables
5. Model KPCI-488A IEEE-488 computer interface board with PC
6. Calibrated photodetector to be installed into test fixture
7. Custom wiring harness for connecting the test equipment to the device under test

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