KEITHLEY

Application Note Series

Number 2639

Production Testing of High Intensity, Visible LEDs using Series 2600 System SourceMeter® Instruments

Introduction

Visible light emitting diodes (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, street lights, outdoor signs, and video monitors. Extensive research and development efforts by LED manufacturers have led to the creation of LEDs with higher brightness, new colors, and longer lifetimes, which has driven demand and encouraged an even wider array of applications. Now, more than ever, cost-effective testing methods are needed to ensure the reliability and quality of these devices.

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 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 note also outlines how to achieve throughput advantages by using new test technologies, including instruments enabled with Keithley's Test Script Processor (TSP™).

Test Description

Testing LEDs typically involves both electrical and optical measurements. This note focuses on electrical characterization, including light measurement techniques where appropriate. ***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.

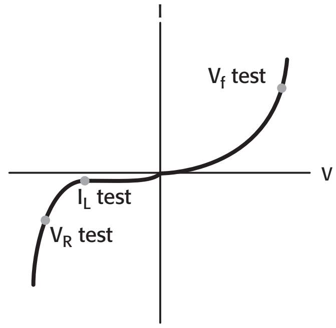

Figure 1. Typical LED DC I-V curve and test points (not to scale).

Some tests require sourcing a known current and measuring a voltage, while others require sourcing a voltage and measuring the resulting current. A SourceMeter 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 are in the milliamps range, while the resulting voltage measurement is typically in the range of few volts.

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 channel of 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) and Leakage Current (I_L) Tests

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.

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 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. This extra shielding complicates the test fixture and may interfere with automated handlers.

Test System Description

Single LED Test System

Figure 2 is a simplified block diagram of an LED test station. For automation purposes, a PC and a component handler—a probe station for on-wafer measurements—are included.

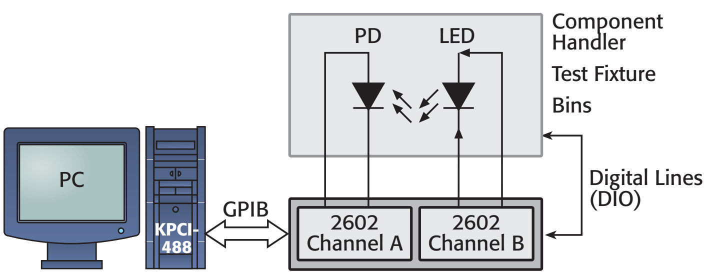

Figure 2. Block Diagram of a 2602 SourceMeter-Based Single LED Test System

The main purpose of the PC is to store measurement data in a database for documentation. A secondary purpose is to reconfigure the test sequence for different parts.

Series 2600 instruments are unique in terms of their independence from the PC controller. Their internal Test Script Processor supports writing a complete test plan that operates on the instrument itself. In other words, a user can write a complete PASS/FAIL incoming inspection test sequence script and run it from the front panel of the Model 2602 without instrument reprogramming.

A more production-oriented scenario would look a bit different. In production, there may be a component handler to transport the individual LEDs to a test fixture, where it can be electrically contacted. The fixture is shielded from ambient light and houses a photodetector (PD) for light measurements. In this setup, a single Model 2602 Dual-Channel System SourceMeter instrument can be used for both connections. Source Measure Unit A (SMUA) can be used to supply the test signal to the LED and measure its electrical response while SMUB can be used to monitor the photodiode during optical measurements.

The test sequence can be programmed to begin using a digital line from the component handler that can serve as a "start of test" (SOT) signal. After the SourceMeter instrument detects the SOT signal, the tests for characterization of the LED will begin.

After all electrical and optical tests are completed, a digital line to flag "measurement complete" can be set for the component handler. In addition, the 2602's built-in intelligence can perform all pass/fail operations and send a digital command through the digital I/O port on the 2602 to the component handler to bin the LED based on the pass/fail criteria. Then, usually two actions can take place synchronously: data transfer to the PC for statistical process control (SPC) and the mechanical placement of a new DUT in the testing fixture.

LED Test System for Multiple Devices/Arrays

In addition to single device testing, there are also multiple device tests, such those that involve a burn-in process. In these tests, multiple parts are measured over a specified time period. A continuous current flow is usually mandatory to drive the DUTs, but multiple light detectors may be multiplexed to a current meter by a switching system. The appropriate choices for switching system and meter will be dictated by the dynamic range of electrical currents of interest.

Keithley offers a number of switch options applicable to testing multiple LEDs. Mainframes range from the two-slot Model 7001, capable of up to 80 channels of switching, to the ten-slot Model 7002 mainframe, which can handle up to 400 channels. Another option is the 7002-HD, which allows up to 320 channels in one of the world's highest density switch mainframes. For low-level current measurements, Keithley offers the Model 6485 Picoammeter and the Model 6487 Picoammeter/Voltage Source. One of the Model 2602 SourceMeter channels can also be used to measure currents.

For smaller numbers of LEDs, multiple Series 2600 System SourceMeter instruments can be used. ***Figure 3*** illustrates a three-LED device test system with one PD channel.

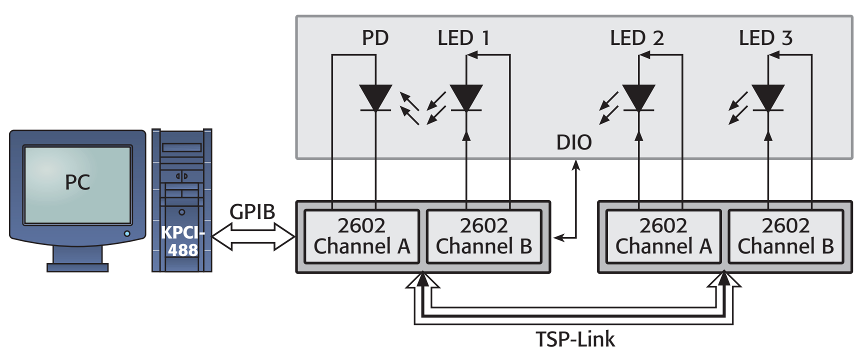

Figure 3. Block Diagram with scalable Model 2602 SourceMeter channels for an LED Array Test System

Test Sequence Script Code

The following code snippets illustrate a test sequence script for the Model 2602 to perform three electrical tests on an LED. The intention of the test steps is to serve as building blocks for creating more specialized applications.

The first part after the enumeration of tests is a one-time-only configuration providing a well-defined starting condition of the instrument. Next, the output of the SMU channel is activated and the tests follow sequentially. The measurement data is stored in the variable "Reading" and are sent to a PC via "print" commands at the end of the listing.

Note: double hyphens (--) indicate comment lines.

First, let's put the instrument into a default setting by sending the following function:

```
-- Example LED Test Sequence
-- 1.) Forward Voltage Test VF at   10 mA
-- 2.) Leakage Current Test IL at  -10  V
-- 3.) Reverse Breakdown Voltage Test VR at -5E-6 A

function ResetLED()
-- One Time Reset & Setup
 Reading = {} --Create table for readings
 smua.reset() --reset SMU
 smua.measure.nplc = 0.01 --Set measurement aperture
 smua.measure.autozero = smua.AUTOZERO_OFF --Disable autozero
 smua.sense = smua.SENSE_REMOTE --Enable 4-wire measurement
 --GlobalVar = 1
end--function ResetLED()
```

To perform the test sequence, we need another function that sets up each test and performs the proper actions:

```
function LEDTest()
--configure LED Test Sequence.
--Performs VF, IL, and VR tests

     smua.source.levelv = 0 --Set source value
     smua.source.output = smua.OUTPUT_ON --Enable source

     --1.) Forward Voltage Test VF at 10 mA
     smua.measure.rangev = 6 --Set measurement range
     smua.source.limiti = 0.001 --Set source current compliance
     smua.source.rangei = 0.1 --Set source range
     smua.source.leveli = 0.01 --Set source level
     --Select output function
     smua.source.func = smua.OUTPUT_DCAMPS
     smua.source.limitv = 6 --Set source voltage compliance
     --delay (0.001) --Delay
     Reading[1] = smua.measure.v() --Perform Vf measurement

     --2.) Leakage Current Test IL at  -10  V
     --Select current measurement range
     smua.measure.rangei = 1E-5smua.source.rangev = 40 --Select voltage source range
     smua.source.levelv = -10 --Select voltage source value
     --Set source function
     smua.source.func = smua.OUTPUT_DCVOLTS smua.source.limiti = 0.1 --Set source current compliance
     --delay (0.005) --Delay
     Reading[2] = smua.measure.i() --Perform IL measurement

     --3.) Reverse Breakdown Voltage Test VR at -5E-6 A
     smua.measure.rangev = 40 --Set voltage measurement range
     smua.source.rangei = 1E-5 --Set current source range
     smua.source.leveli = -5E-6 --Set current source level
     smua.source.limitv = 40 --Set source voltage copliance
     smua.source.func = smua.OUTPUT_DCAMPS --Set source function
     delay (0.005) --Delay
     Reading[3] = smua.measure.v() --Perform VR measurement

     smua.source.leveli = 0 --Set source level
     smua.source.output = smua.OUTPUT_OFF --Disable output

end--function LEDTest()
```

And finally, we need to return the data to the computer:

```
function ReturnData()

-- Data Printing
    print ("")
    print ("Measurement reading at  10 mA:".. Reading[1].." V")
    print ("Measurement reading at -10  V:".. Reading[2].." A")
    print ("Measurement reading at  -5 uA:".. Reading[3].." V")

end --function ReturnData()
```

These functions can now be called by an external program, such as Visual Basic® or LabVIEW™ simply by sending the string of the function name.

Here is an example for a system using VB6 and a Keithley 488 GPIB card:

NOTE: The single quote (') denotes a comment in Visual Basic® 6.

```
Call Send(KeithleyMeter, "ResetLED()", status) 'Calls ResetLED()

Call Send(KeithleyMeter, "LEDTest()", status) 'Calls LEDTest()

'Calls ReturnData()
Call Send(KeithleyMeter, "ReturnData()", status)
```

We now need to enter the data to our external program:

```
     For I = 1,4
--There are 4 print statements.. so we need 4 enters
Call enter(Data, 1000, Length, KeithleyMeter, status)     ' Get info back from meter
Data = Data & Data 'Concatenate data string
     Loop
```

This will return the characters that are held in the output buffer queue in the order they were written. The data return in this case was ASCII. This is not the fastest method of data return, but it is the easiest to start with. Consult the software program and instrument manuals for directions on more expedient data transfer techniques, such as binary data transfer and buffered data storage.

Programming tests for speed: TSP

With many instruments, the PC controls all aspects of the test. In each element of a test sequence, the instruments must be configured for each test, perform the desired action, and then return the data to the controlling PC (***Figure 4***). The controlling PC then must evaluate the pass/fail criteria and perform the appropriate action for binning the DUT. Each command sent and executed consumes precious production time and lowers throughput.

Obviously, a large percentage of this test sequence time is consumed by communicating information to and from the PC. Series 2600 instruments offer the unique ability to increase the throughput of complicated test sequences dramatically by decreasing the amount of traffic over the communications bus. In these instruments, the majority of the test sequence is embedded in the instrument. The Test Script Processor (TSP) is a full-featured test sequence engine that allows control of the test sequence, with internal pass/fail criteria, math, calculations, and control of digital I/O (see the Test Sequence with 2602 illustrated in ***Figure 5***). The TSP can store a user-defined test sequence in memory and execute it on command. This limits the set-up and configuration time for each step in the test sequence and increases throughput by lessening the amount of communications to and from the instrument and PC.

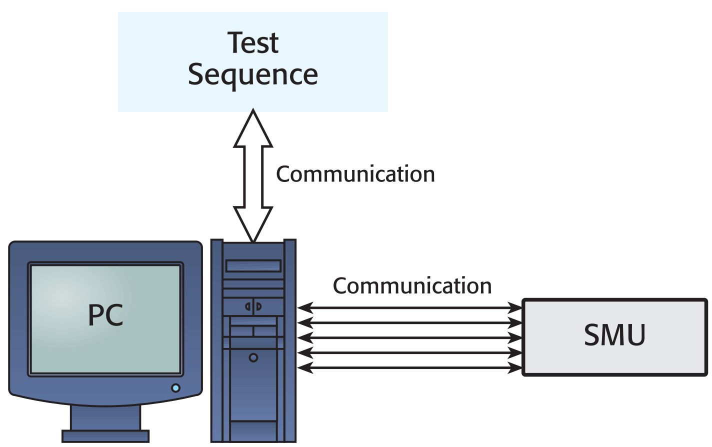

Figure 4. PC control of standard instruments.

Here is a simple step-by-step process for programming the Model 2602:

1) Create the script.

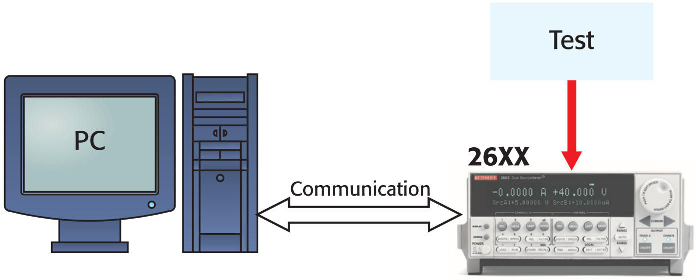

Figure 5. Use of the embedded Test Script Processor (TSP) in the Model 2602 to store the test sequence. Note decreased communications traffic.

2) Download the script to the instrument.

3) Call the script to run.

The 2602 script can be written in the Test Script Builder software provided with the instrument or downloaded to the instrument using another program, such as Visual Basic or LabVIEW. See Section 2 of the 2602 User's Manual for more information on programming the 2602.

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.

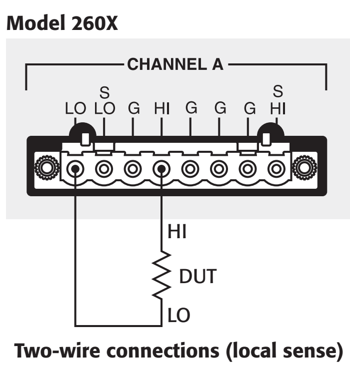

Figure 6. Two-wire connections to a 260X SourceMeter channel.

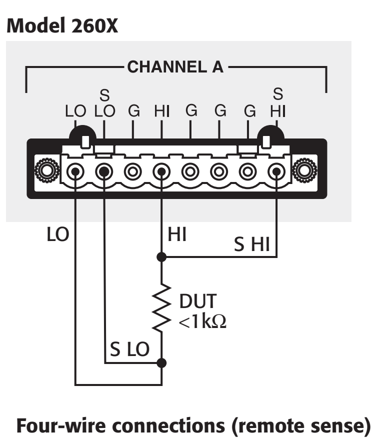

Figure 7. Four-wire connections to a 260X SourceMeter channel.

Therefore, it is important to shorten the test time as much as possible without sacrificing measurement accuracy or stability.

The Series 260x System SourceMeter family 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 soak times for the V_F test are from less than one millisecond 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.

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 (see ***Figures 6*** and ***8***). 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 8 depicts the situation with lead resistances drawn as 'lumped' components. The gray 'rounded rectangle' sketches current flow, which is nearly unaffected by high impedance voltage meters.

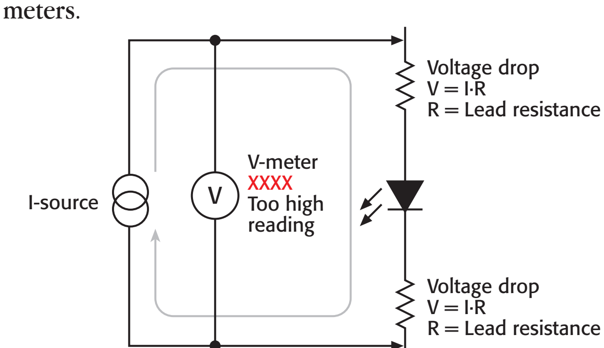

Figure 8. Two-wire connections to an LED.

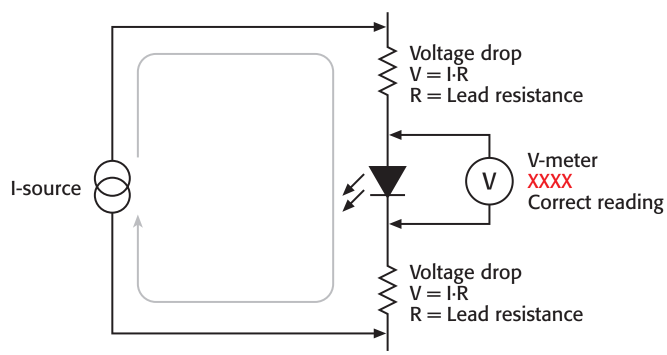

Figure 9. Four-wire connections to an LED

To eliminate this problem, use the four-wire remote sensing method, rather than the two-wire technique. With the four-wire method (see ***Figures*** 7 and *9*), a current is forced through the LED 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 example ***(Figure 10)***. 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.

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 10B***, 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

Testing LEDs involves detecting the amount and intensity of light produced by the LED, so 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.

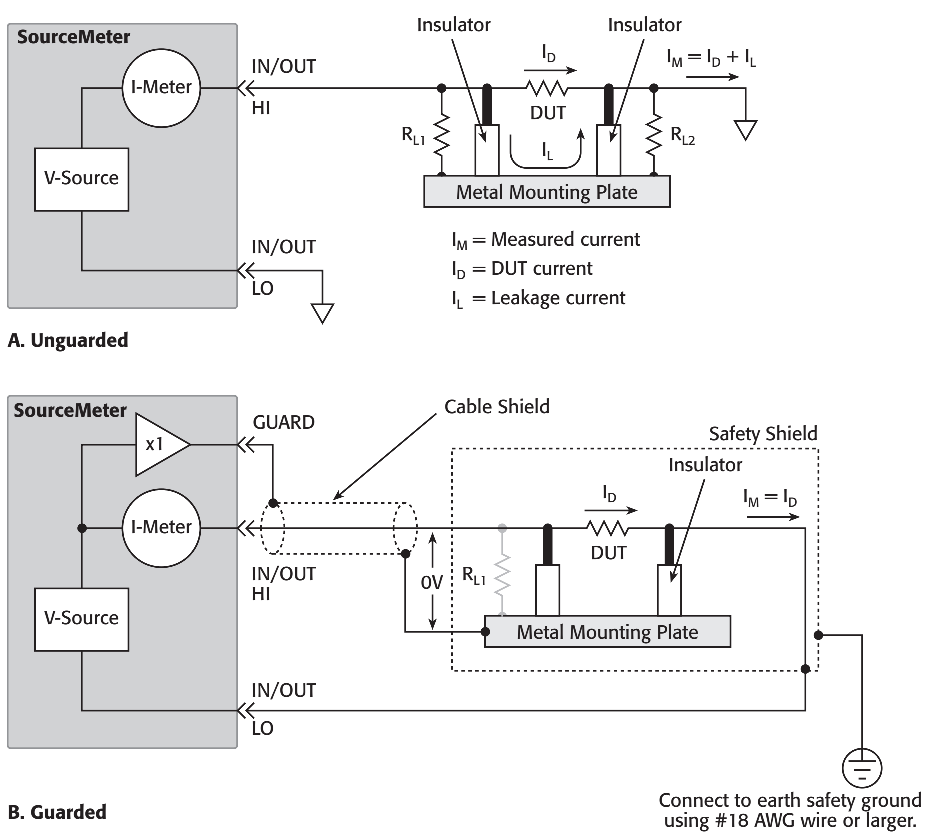

Figure 10. Comparison of unguarded and guarded measurements.

Equipment List

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

- Model 2602 System SourceMeter instrument.
- Model KPCI-488 IEEE-488 computer interface board with PC or KUSB-488 USB-to-GPIB Adapter for use on USB ports.
- Light-shielded enclosure with calibrated photodetector.
- Custom digital I/O cable for connecting the 25-pin male D-sub connector of the SourceMeter to the component handler.
- Custom wiring harness for connecting the test equipment to the DUT and photodetector.

One additional Model 2602 and one TSP-Link cable are needed to configure the system shown in ***Figure 3***.

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.
- 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.

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