

A GREATER MEASURE OF CONFIDENCE

KEITHLEY
A Tektronix Company

HOW TO CHOOSE AND APPLY Source Measure Unit Instruments

INSTRUMENT SELECTION ■ KEY APPLICATIONS ■ MEASUREMENT CAPABILITIES



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Discover how you benefit from our legacy of innovation in source measure unit (SMU) instrument engineering

Our latest generation of System SourceMeter® instruments are the T&M industry's most powerful, fastest and highest resolution SMU instruments. When used individually, they bring together everything we've learned about engineering instruments that deliver unparalleled performance. They're also flexible, efficient, I-V source and measure building blocks for creating fast, powerful, and cost-effective test and measurement systems for electronic devices. Keithley has been a leading provider of integrated sourcing and measurement solutions since the late 1980s, when we introduced our first generation of SMU instruments.



Series 2600B SourceMeter SMU Instruments
Three new benchtop models offer best-in-class value and performance



Industry's first touchscreen SMU instrument - the Model 2450
Offers the capabilities of analyzers, curve tracers, and I-V systems, curve tracers, and semiconductor analyzers at a fraction of their cost.

First instrument-based SMU (Series 23X)

1989



First half-rack, DMM-like SMU instrument (Model 2400)

First two-channel, half-rack SMU instrument (Model 2602)
First script-based SMU instrument (Models 2601/2602)

2005



First 1000V SMU instrument (Model 237)



1995

First one-kilowatt pulsed SMU instrument (Model 2430)



2000

First sub-femtoamp SMU instrument (Model 6430)



2011

First one-microsecond per point digitizing SMU instrument (Model 2651A)
First 200W DC, 2000W pulsed SMU instrument (Model 2651A)
First 3,000V, 180W SMU with 1fA current measurement resolution (Model 2657A)



2008

First SMU instrument with parallel test expansion capability (Series 2600A)

today

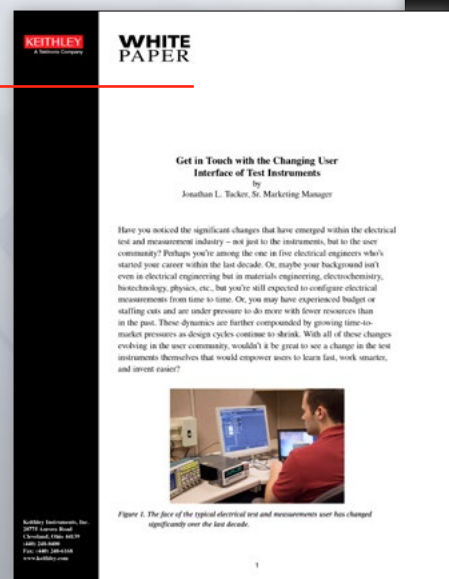
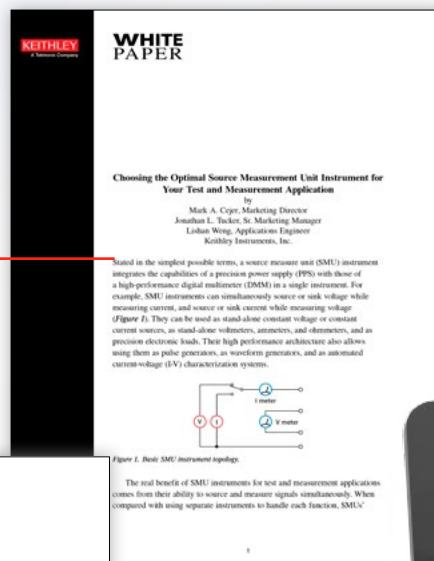


Learn how to choose the right SMU for your application

The popularity of SMU instruments has increased rapidly as more people discover that their tightly-integrated DMM and precision power supply capabilities can serve a wide variety of applications throughout the electronics and semiconductor industries. Learn how to evaluate instrument specifications carefully in order to choose the most appropriate SMU for a specific application. View our online webinar.

Read these white papers:

- [Choosing the Optimal Source Measurement Unit Instrument for Your Test and Measurement Application](#)
- [Rapidly Expanding Array of Test Applications Continues to Drive Source Measurement Unit Instrument Technology](#)
- [Get in Touch with the Changing User Interface of Test Instruments](#)



[Click here for an online discussion of SMU instruments versus power supplies or DMMs](#)

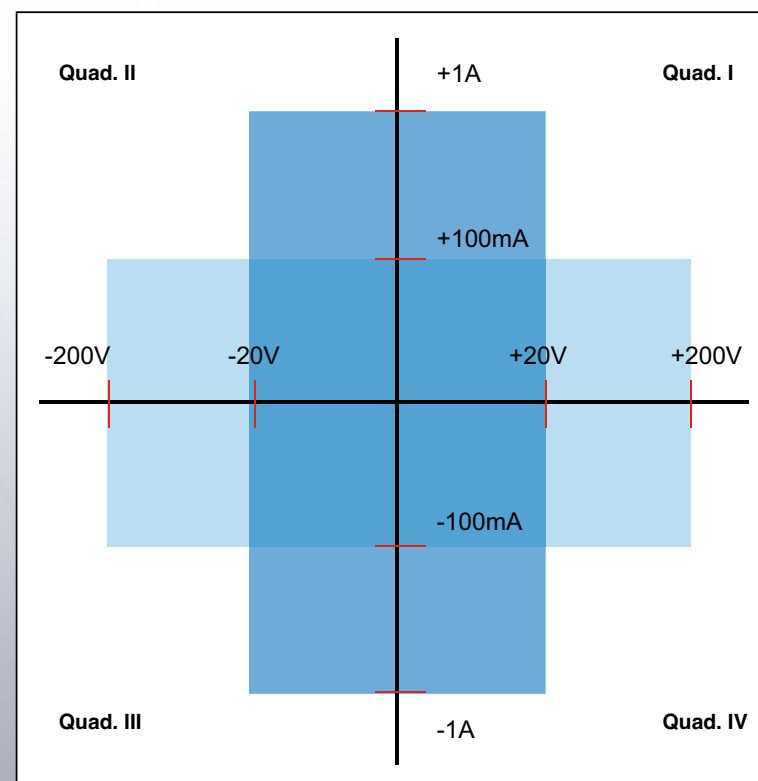
Want assistance, a quote, or to place an order?
Contact us online.

Join the discussion on our [application forum](#).

Touch, Test, Invent™ with the intuitively smart, touchscreen SMU

Learn faster, work smarter, and invent easier with the Model 2450 Touchscreen SMU Instrument, an innovative, compact I-V solution that offers the capabilities of I-V systems, curve tracers, and semiconductor analyzers at a fraction of their cost.

- Source and measure voltage, current, and resistance in a single instrument
- Advanced capacitive touchscreen enables a superior user experience for novice or experienced SMU users
- Faster speed to answer without paging through a manual
- Graphical interface provides I-V curve tracing functionality for a fraction of the cost of traditional curve tracers
- Extended low-level voltage, current, and resistance capabilities provide the application versatility that makes it the SMU for everyone



[Click here to learn more](#)



Interactive touchscreen enables a superior user experience.



The 2450 graphical interface provides I-V curve tracing functionality at a fraction of traditional curve tracer cost.

Get More Done in Less Time

The Model 2450 features an advanced, full-color, five-inch capacitive touchscreen with multi-point, pan-pinch-zoom-swipe operation that is incredibly easy to use right from power-on.

Want assistance, a quote, or to place an order?

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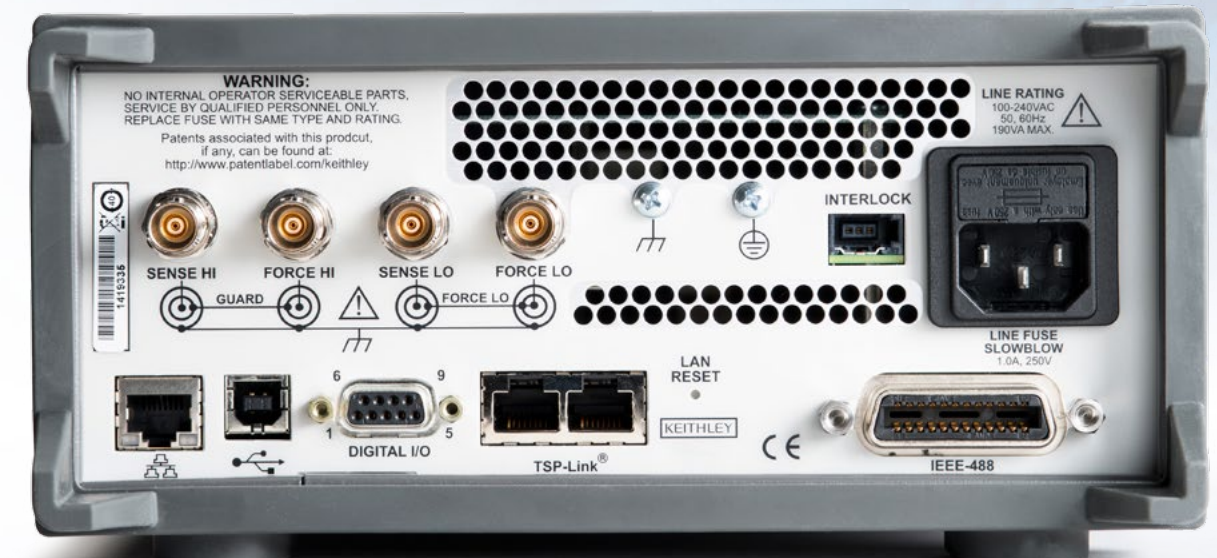
The go-to instrument that everyone's got to have

The Model 2450 is ideal for I-V functional test and characterization of a wide range of today's modern electronic devices, including scaled semiconductors, nano-scale devices and materials, organic /printed electronics, and other current and voltage testing applications.

A Smart Toolkit Beyond the Touchscreen



Front panel includes a HELP key, rotary navigation/control knob, front/rear input selector button, and banana jacks for basic bench applications.



Built-in connectivity options speed and simplify overcoming today's and tomorrow's measurement challenges.

Ready to learn more?

- [Download the Model 2450 data sheet.](#)
- [Download the Model 2450 brochure.](#)
- [View the Model 2450 product tour.](#)

Read these application notes:

- [Easy I-V Characterization of Diodes Using the Model 2450:](#) In particular, this application note describes how to take, graph, and store measurements using the front panel user interface, as well as how to automate the measurements over the bus.
- [I-V Characterization of Photovoltaic Cells Using the Model 2450:](#) This application note explains how to perform I-V testing from the Model 2450 front panel, including how to generate graphs and save the data to a USB drive. It also details how to automate the measurements over the bus.
- [Rechargeable Battery Charge/Discharge Cycling Using the Model 2450:](#) Learn how battery testing can be simplified by using a single instrument that has the flexibility to source/sink current as well as measure voltage and current.

Want assistance, a quote, or to place an order?

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Discover how the Series 2600B family of System SourceMeter instruments simplifies high speed R&D and functional testing

Series 2600B System SourceMeter instruments are designed for use as either bench-top I-V characterization tools or as building block components of multi-channel I-V test systems. Mix and match single- and dual-channel instruments for flexibility in building larger test systems. Individual models include:

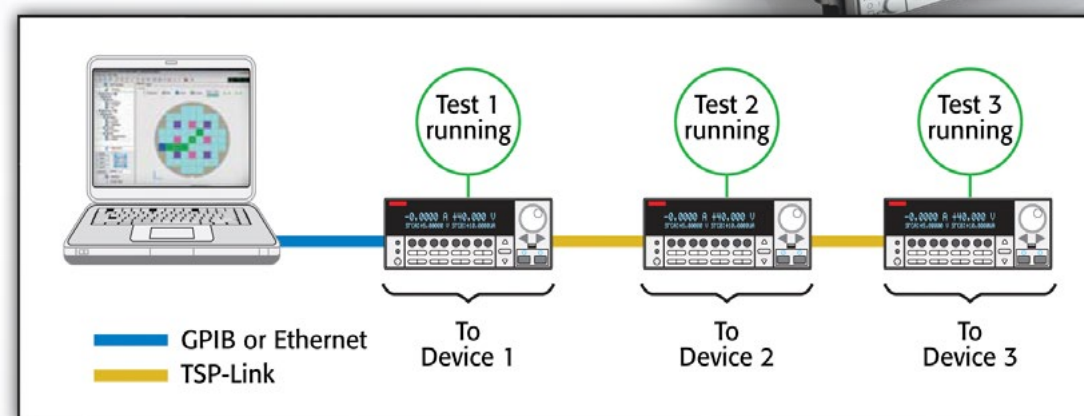
- Models 2602B and 2604B (Dual Channel Benchtop), and Model 2601B (Single Channel). Scalable, High Throughput. [Learn more.](#)
- Models 2612B and 2614B (Dual Channel Benchtop), and Model 2611B (Single Channel). High voltage and pulsed output. [Learn more.](#)
- Models 2636B and 2634B (Dual Channel Benchtop), and Model 2635B (Single Channel). Low current and pulsed output. [Learn more.](#)
- Model 2651A (Single Channel). High Current. [Learn more.](#)
- Model 2657A (Single Channel). High power/high voltage, low current and pulsed output. [Learn more.](#)

Common characteristics:

- Every model combines a power supply, true current source, DMM, arbitrary waveform generator, V or I pulse generator with measurement, electronic load, and trigger controller all in one instrument
- Family of products offers wide dynamic range (10A pulse to 0.1fA, 200V to 100nv)
- 20,000 rdgs/s (using integrating ADCs)
- Precision timing and channel synchronization (<500ns)

Equally suited to the bench and the rack

- In bench-top applications, you can quickly and easily perform common I-V tests without programming by using the free browser-based Plug & Play I/V characterization software provided with every instrument.
- For system-level applications, the Series 2600B's TSP-Link® bus supports dedicated trigger lines that provide synchronous operations between multiple Series 2600B instruments and other Test Script Processor (TSP®) technology-enabled instruments, such as Series 3700A DMM/Switch Systems without the need for additional trigger connections. TSP and TSP-Link architecture provides the highest throughput in the industry, lowering your cost of test.
- A free Test Script Builder software tool helps you create, modify, debug, and store TSP test scripts for either bench or system applications. To make it easier to test, verify, and analyze semiconductor components, optional ACS Basic Edition software is also available.



Parallel testing with Series 2600B instruments. Each instrument in the system runs its own complete test sequence, creating a fully multi-threaded test environment. Test throughput is dramatically improved and the overall cost of test is reduced.

Series 2600B Applications

I-V functional test and characterization of a wide range of devices, including:

- Discrete and passive components
 - Two-leaded – Sensors, disk drive heads, MOVs, diodes, zener diodes, sensors, capacitors, thermistors
 - Three-leaded – Small signal BJTs, FETs, and more
- Simple ICs – Optos, drivers, switches, sensors
- Integrated devices – Analog ICs, RFICs, ASICs, SOC devices
- Optoelectronic devices such as LEDs, laser diodes, HBLEDs, VCSELs, displays
- Wafer level reliability – NBTI, TDDB, HCI, electromigration
- Solar cells
- Batteries

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Ready to learn more?

■ Download the Series 2600B data sheet.

■ Read an application note:

– **High Speed Testing of High Brightness LEDs** – Learn how to achieve throughput advantages and reduce the cost of test by using new test technologies, including instruments enabled with an embedded Test Script Processor.

– **Methods to Achieve Higher Currents from I-V Measurement Equipment** – Discover how to achieve current levels during test sequencing that are higher than the published DC (direct current) specifications of a single SMU instrument.

■ Test applications:

– **Migrating from Keithley's Series 2400 SourceMeter® SMU instrument to a Series 2600B SourceMeter SMU Instrument?** Learn how the new Model 2600B instrument is capable of emulating the mode of operation of the Model 2400 by accepting SCPI commands.

Series 2600B
System SourceMeter® SMU (Source-Measure Unit) Instruments

- Tightly-integrated, 4-quadrant voltage/current source and measure instruments offer best in class performance with 6 1/2 digit resolution.
- Family of models offer industry's widest dynamic range: 10A pulse to 0.1A and 200V to 100mV.
- Built-in, Java-based test software enables true plug & play I/V characterization and test through any browser.
- TSP (Test Script Processing) technology embeds complete test programs inside the instrument for best-in-class system-level throughput.
- TSP-Like expansion technology for multi-channel parallel test without a mainframe.
- Software emulation for Keithley's Model 2400 SourceMeter SMU instrument.
- USB 2.0, LAN, GPIB, RS-232, and digital I/O interfaces.
- Free software drivers and development/debug tools.

The Series 2600B System SourceMeter SMU Instruments are the industry's leading current/voltage source and measure solutions, and are built from Keithley's 5th generation SMU technology. The Series 2600B offers single and dual-channel models that combine the capabilities of a Precision Power Supply, true Current Source, 6 1/2 digit 100k Arbitrary Waveform Generator, Pulse Generator, and Electronic Load – all into one tightly integrated instrument. The result is a powerful solution that significantly boosts productivity in applications ranging from benchtop I/V characterization through high-automated production test. For benchtop use, Series 2600B instruments feature built-in, Java-based software that enables plug & play I/V testing through any browser, on any computer, from anywhere in the world. For automated system applications, the Series 2600B Test Script Processor (TSP) runs complete test programs from inside the instrument for industry-best throughput. In larger, multi-channel applications, Keithley's TSP link technology works together with TSP to enable high-speed, SMU-to-SMU parallel testing. Because Series 2600B SourceMeter SMU Instruments have fully isolated channels that do not require a mainframe, they can be easily reconfigured and re-used as your test applications evolve.

KEITHLEY Number 2639
Application Note Series
High Speed Testing of High Brightness LEDs

Introduction
Visible light emitting diodes (LEDs) have gained a growing list of applications, including interior and exterior lights, backlighting for television sets, street lights, outdoor signs, and interior research and development efforts by LED manufacturers to the creation of LEDs with higher luminous flux, greater chromaticity, and more lumen driven demand and encouraged an even wider range of applications. To ensure the reliability and quality of rate and cost effective testing is critical.

LED testing involves different types of test stages of production, such as during development, on-wafer measurements during final tests of packaged parts. While concrete often include a multitude of steps intended to ensure the reliability and quality of the LEDs, the most common test is the I-V test. This test also outlines how to achieve throughput advantages by using new test technologies, including instruments enabled with an embedded Test Script Processor.

Test Description
Testing LEDs typically involves both electric current (I) and voltage (V) measurements. This note focuses on electrical characteristics including light measurement techniques with Figure 1 illustrates the electrical I-V curve of a complete test could include a multitude of current operating points, but a limited range is usually 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 a current.

KEITHLEY Number 3047
Application Note Series
Methods to Achieve Higher Currents from I-V Measurement Equipment

The most flexible test equipment for sourcing and measuring current (I) and voltage (V) are source-measure units (SMUs) such as Keithley's Series 2600B System SourceMeter® instruments. These specialized instruments are high performance I/V source-measure instruments that are designed for use either as benchtop I-V characterization tools or as building block components of multi-channel I-V test systems. Each Series 2600B SourceMeter instrument combines a precision power supply, a true current source, a DMM, an arbitrary waveform generator with measurement, an electronic load, and a trigger controller – all in one instrument. In short, they can source I or V, and then measure V or I, simultaneously. They also support both polarities of I and V (sinking and sourcing power), referred to as "four quadrant operation."

By design, there is a limit to the maximum current or voltage that a single SMU can source and measure. This paper will present methods to achieve current levels during test sequencing that are higher than the published DC (direct current) specifications of a single SMU. Two techniques will be explored:

- Pulse sweeps
- Combining multiple SMU channels together

These techniques can be used to source and measure currents up to 60A for high-power applications such as:

- Solar cells and other photovoltaics
- Power management devices such as power MOSFETs and IGBTs
- High brightness light emitting diodes
- RF power transistors

Pulse sweeps
There is a limit to the DC maximum current or voltage that a single SMU can source and measure. This limit is a function of the inherent equipment design and is typically dependent on design parameters such as the maximum output of the power supply internal to the SMU (self), the safe operating area (SOA) of the discrete components used in the SMU, the spacing of the metal lines on the SMU's internal printed circuit board, etc. Some of these design parameters are constrained by maximum current limits, some by maximum voltage limits, and some by maximum power limits (P_{max}). A typical expression of the DC I-V limits of a four quadrant SMU is shown in Figure 1. It shows a maximum DC current of 1A (point A in the figure) and a maximum voltage of 40V (point B). The maximum power the SMU can output is 40W, which is achieved at point B (1A x 40V). At point A the power is lower at 10W. The difference can be explained, for example, that the maximum at point B is constrained by the maximum allowed power output of the on-board power supply, whereas at point A the limit is based on the maximum current (test power) that a key component can handle.

KEITHLEY Number 3093
Application Note Series
Migrating Test Applications from the Keithley Model 2400 SourceMeter® SMU Instrument to a Series 2600B System SourceMeter SMU Instrument

Introduction
Keithley's Series 2600B System SourceMeter instruments are the test and measurement industry's fastest SMU (Source Measure Unit) instruments. Based on Keithley's third-generation SMU architecture, the Series 2600B line combines fast and accurate analog performance with up to two source and measure channels in a half-rack package. They are also capable of extremely high speed test sequencing and automation as a result of their embedded TSP (Test Script Processor) scripting engine. Additionally, the Series 2600B provides full software emulation of Keithley's second generation SMU architecture, found in the Model 2400 instruments, enabling these users to easily and quickly migrate their applications to the new, higher throughput Series 2600B instrument.

Advanced Capabilities of the 2400 Personality Script
Because of the Model 2400's industry popularity, other SMU instruments have been developed in an attempt to emulate it; however, many of the Model 2400's key capabilities are omitted. The Series 2600B are the only SMU instruments that emulate all Model 2400 commands, including source-memory sweeps, linear, log, and list sweeps, Trigger Link and digital I/O, status model, and identification query.

Source-Memory Sweeps
Source-Memory sweeps allow the instrument to be pre-loaded with multiple Source and Measure configurations and then cycle through them quickly from a single command. Source-Memory is critical to high-speed production testing with the Model 2400. The Persona2400 script has full support for Source-Memory sweeps, including highly advanced features like Source-Memory location branching.

Linear, Log and List Sweeps
Sweeps allow the instrument to cycle quickly through multiple source values, taking measurements at each point. The Persona2400 script uses the Series 2600B line's advanced trigger model to perform sweeps, giving sweeps more accurate timing with less timing jitter than sweeps performed on the original Model 2400, which results in even more consistent measurements.

Trigger Link and Digital I/O
The Persona2400 script supports the Trigger Link and digital I/O ports of the Model 2400. This is critical for high-speed automated binning applications and synchronization with other pieces of equipment. The pins from the Trigger Link and digital I/O ports on the Model 2400 have all been mapped to the pins of the 25-pin D-sub connector on the back of Series 2600B instruments. Table 1 outlines the complete pin mapping.

Status Model
The status model is used to monitor the state of the instrument and generate server requests (SRQs) to signal the controller to perform an operation on the instrument. It is often used to increase system responsiveness. The Persona2400 script supports all registers of the 2400 status model and generates SRQs from these registers.



PLUG & PLAY SOFTWARE:
View this demonstration of Java-based Plug & Play test software for I/V characterization of devices.

Want assistance, a quote, or to place an order?
Contact us online.

■ Join the discussion on our **application forum.**

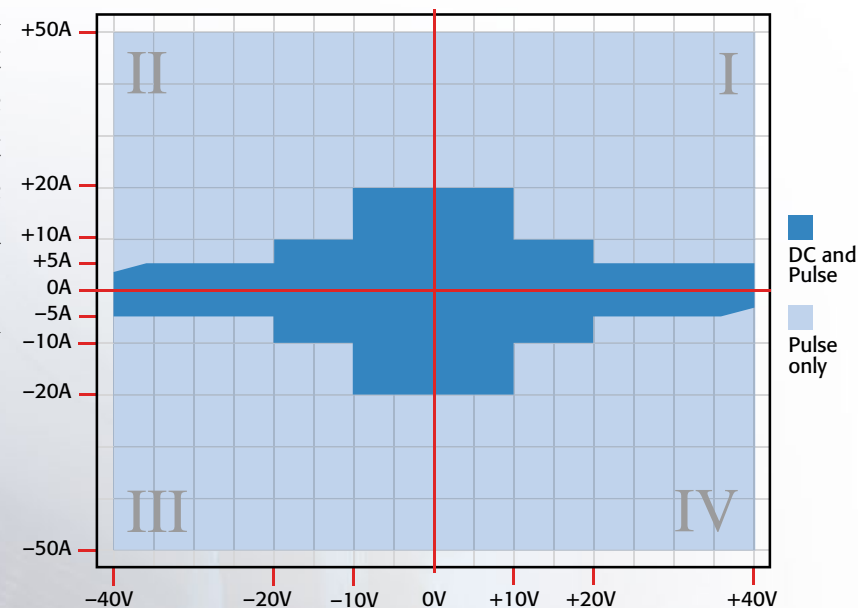
Get unmatched performance for characterizing and testing high power, high current electronics

Our **Model 2651A High Power System SourceMeter® Instrument** simplifies characterizing today's challenging high power electronics with unprecedented power, precision, speed, flexibility, and ease of use. It combines a highly flexible, four-quadrant voltage and current source/load with precision voltage and current meters.

- Source or sink 2,000W of pulsed power ($\pm 40V$, $\pm 50A$), 200W of DC power ($\pm 10V@ \pm 20A$, $\pm 20V@ \pm 10A$, $\pm 40V@ \pm 5A$)
- Easily connect two units (in series or parallel) to create solutions up to $\pm 100A$ or $\pm 80V$
- 1pA resolution enables precise measurement of very low leakage currents
- $1\mu s$ per point (1MHz), continuous 18-bit sampling, accurately characterizes transient behavior

Choice of digitizing or integrating measurement modes

With the Model 2651A, you can choose from either digitizing or integrating measurement modes for precise characterization of both transient and steady-state behavior. Two independent ADCs define each mode—one for current and the other for voltage—which run simultaneously for accurate source readback without sacrificing test throughput. The digitizing measurement mode's 18-bit ADCs can support continuous one-microsecond-per-point sampling, making it ideal for waveform capture and measuring transient characteristics with high precision. The integrating measurement mode, based on 22-bit ADCs, supports applications that demand the highest possible measurement accuracy and resolution. This ensures precise measurements of the very low currents and voltages common in next-generation devices.

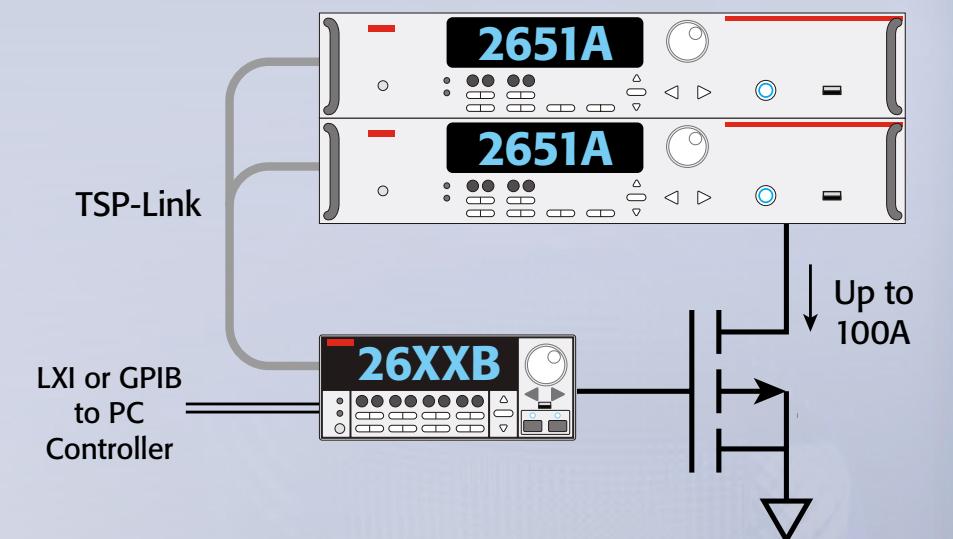


A single Model 2651A unit can source and sink up to $\pm 40V$ and $\pm 50A$. Connect two units in parallel via the built-in TSP-Link expansion bus to extend the system's current range to 100A or connect them in series to expand the voltage range to 80V. The embedded Test Script Processor (TSP®) technology simplifies testing by allowing you to address multiple units as a single instrument so that they act in concert. The built-in trigger controller can synchronize the operation of all linked channels to within 500 nanoseconds.



Model 2651A Applications

- Power semiconductor, high brightness LED (HBLED), and optical device characterization and testing
- Characterization of GaN, SiC, and other compound materials and devices
- Semiconductor junction temperature characterization
- Reliability testing
- High speed, high precision digitization
- Electromigration studies



Built for building systems. The embedded TSP controller and TSP-Link interface in each Series 2600B instrument make it easy to link multiple Model 2651As and other Series 2600B instruments to create an integrated test system with up to 64 channels. Precision timing and tight channel synchronization are guaranteed with built-in 500ns trigger controllers. The fully isolated, independent channels of Series 2600B instruments allow true SMU-per-pin testing without the power and/or channel limitations of mainframe-based systems.

Ready to learn more?

■ [Download the Model 2651A data sheet.](#)

■ Read these application briefs:

– [Achieving Fast Pulse Measurements for Today's High Power Devices.](#)

Learn how to achieve the fast, pulsed measurements needed for today's high power devices.

– [Testing to 100A by Combining Model 2651A High Power SourceMeter® Instruments.](#)

Learn how two of these instruments can be combined to test semiconductor devices for power management, even when those devices operate at currents beyond that of a single Model 2651A instrument.

2651A
High Power System SourceMeter® Instrument

- Source or sink:
 - 2,000W of pulsed power (140V, 250A)
 - 200W of DC power (±10V to ±230A, ±20V to ±10A, ±40V to ±25A)
- Easily connect two units (in series or parallel) to create solutions up to 100A or 200V
- 1pA resolution enables precise measurement of very low leakage currents
- 1ps per point (1MHz), continuous 18-bit sampling, accurately characterizes transient behavior
- 1% to 100% pulse duty cycle for pulse width modulation (PWM) drive schemes and device-specific drive stimulus
- Combines a precision power supply, current source, DMM, arbitrary waveform generator, V and I pulse generator with measurement, electronic load, and trigger controller—all in one instrument
- Includes TSP® Express characterization software, LABVIEW® driver, and Keithley's Test Script Builder software development environment

APPLICATIONS

- Power semiconductor, HLED, and optical device characterization and testing
- Characterization of GaN, SiC, and other compound materials and devices
- Semiconductor junction temperature characterization
- High speed, high precision digitization
- Electromigration studies
- High current, high power device testing

Two Measurement Modes: Digitizing or Integrating
Precisely characterize transient and steady-state behavior, including rapidly changing thermal effects, with the two measurement modes in the Model 2651A. Each mode is defined by its independent analog/digital A/D converters.

The Model 2651A can source or sink up to 100V and 100A.

1.888.KEITHLEY (US only)
www.keithley.com

Achieving Fast Pulse Measurements for Today's High Power Devices

Testing to 100A by Combining Keithley Model 2651A High Power SourceMeter® Instruments

Introduction
Source-measure units (SMUs), such as the Keithley Model 2651A High Power System SourceMeter instrument, are the most flexible and most precise equipment for sourcing and measuring current and voltage. Because of this, they are widely used to test semiconductor devices such as MOSFETs, IGBTs, diodes, high brightness LEDs, and more.

With today's focus on green technology, the amount of research and development being done to create semiconductor devices for power management has increased significantly. These devices, with their high current/high power operating levels, as well as their low on-resistances, require a unique combination of power and precision to be tested properly. A single Keithley Model 2651A is capable of sourcing up to 100A pulsed and measuring down to 1pA or less. For applications requiring even higher currents, the Model 2651As are capable of being combined to extend their operating range to 100A pulsed.

The high power Model 2651A is the newest addition to the Series 2600A family of System SourceMeter instruments. Specifically designed to characterize and test high power

electronics, it can help you improve productivity in applications across the R&D, reliability, and production spectrums, including high brightness LEDs, power semiconductors, DC-DC converters, batteries, and other high power materials, components, modules, and subassemblies.

When two Model 2651As are connected in parallel with Keithley's TSP Link® technology, the current range is expanded from 50A to 100A. When two units are connected in series, the voltage range is expanded from 40V to 80V. The built-in intelligence simplifies setting by enabling the units to be addressed as a single instrument, thus creating an industry-best dynamic range (800A to 1pA). This capability enables you to test a much wider range of power semiconductors and other devices. (See example in Figure 1.)

Theory
Kirchhoff's Current Law says that the sum of the currents entering a node is equal to the sum of the currents leaving the node. In Figure 2 two current sources representing SMUs and a device under test (DUT) are connected in parallel.

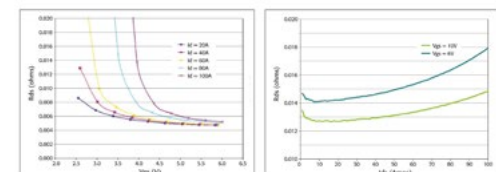


Figure 1: Example results after performing a pulsed MOSFET current sweep (500ns pulse width and 0.01 NPLC) to test up to 100A on a power MOSFET device using two Model 2651A SourceMeter instruments connected in parallel.

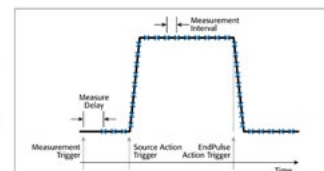


Figure 2: Precisely specify a pulse using the Model 2651A.

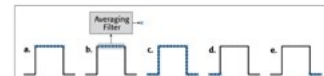


Figure 2a: Measuring at the top of the pulse.



Figure 2b: Performing a spot mean measurement at the top of the pulse.



Figure 2c: Digitizing the entire pulse.



Figure 2d: Triggering measurements to begin before the pulse.

Click on the video above to view our demo of how you can combine two Model 2651As to source currents as high as 100A!

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Contact us online.

■ Join the discussion on our [application forum](#).

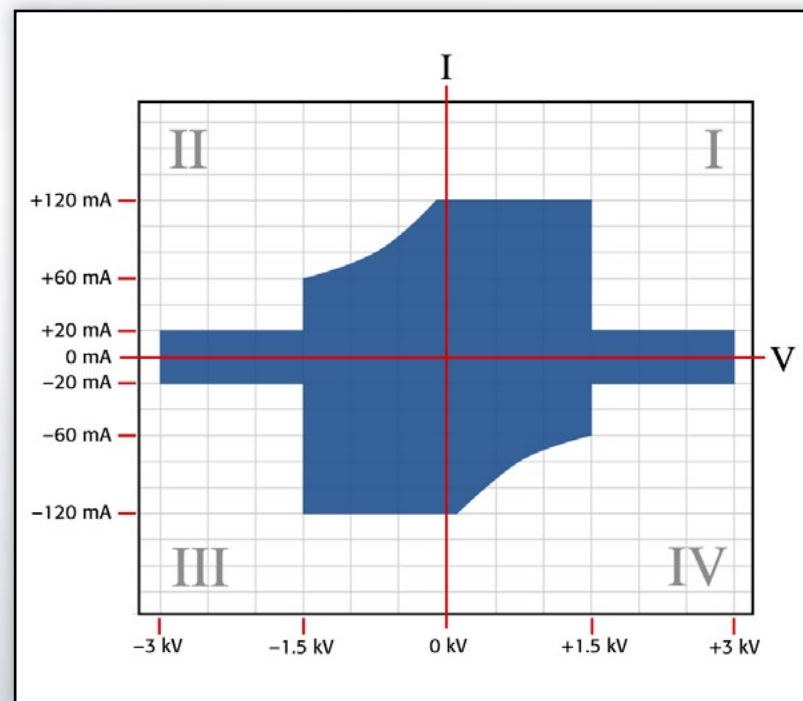
Characterize and test high voltage electronics and power semiconductors

The **Model 2657A High Power System SourceMeter® Instrument** is suitable for R&D, production, and QA/FA. The Model 2657A:

- Sources or sinks up to 3000V @ 20mA or 1500V @ 120mA – to capture important parametric data that other equipment can't
- Provides 1fA (femtoamp) current measurement resolution for measuring the low-leakage requirements of next-generation devices
- Eliminates the hassle of integrating power supplies and instruments by combining a precision power supply, current source, DMM, arbitrary waveform generator, V or I pulse generator, electronic 18-bit load, and trigger controller.

Like the Model 2651A, the Model 2657A comes with dual 22-bit precision ADCs and dual 18-bit $1\mu\text{s}$ per point digitizers for high accuracy and high speed transient capture. Like other Series 2600B SMU instruments, it includes TSP® Express characterization software, LabVIEW® driver, and Keithley's Test Script Builder software development environment.

The Model 2657A can source or sink up to 3000V @ 20mA or 1500V @ 120mA.



Model 2657A Applications

- Power semiconductor device characterization and testing
- Characterization of GaN, SiC, and other compound materials and devices
- Breakdown and leakage testing to 3kV
- Characterization of sub-millisecond transients



Keithley offers a broad spectrum of tools, both hardware and software, for power device characterization. A typical device test system could include the high voltage Model 2657A, one or two high current Model 2651A instruments, and up to three low power SMU instruments (other Series 2600B instruments or the Model 4200-SCS semiconductor characterization system). System configuration is made safer and simpler with the optional new Model 8010 High Power Device Test Fixture or individual protection modules. TSP-Link® technology links Series 2600B instruments to form powerful multi-channel systems that rival the system speed of large ATE systems that cost tens of thousands of dollars more.

Want assistance, a quote, or to place an order?


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Learn How to Perform a Simple Breakdown Test on a High Power, High Voltage IGBT Device. [Click here.](#)

Ready to learn more?

- Download the Model 2657A data sheet.



2657A High Power System SourceMeter Instrument

The Model 2657A is a high-voltage, high-power, low-current source measurement unit (SMU) instrument that delivers unprecedented power, precision, speed, flexibility, and ease of use to improve productivity in R&D, production test, and reliability environments. The Model 2657A is designed specifically for characterizing and testing high-voltage electronics and power semiconductor devices, such as diodes, IGBTs, and MOSFETs, as well as other components and materials in which high voltage, fast response, and precise measurements of voltage and current are required. The Model 2657A joins Keithley's Series 2600A family of power semiconductor characterization and test solutions to offer the highest power and low-leakage current performance in the industry. These customizable solutions are supported by the industry's most powerful parameter characterization software platforms to grow with you as your application evolves.

The Model 2657A, like every Series 2600A SourceMeter instrument, offers a highly flexible, four-quadrant voltage and current source load coupled with precision voltage and current sources. It can be used as a:

- Semiconductor characterization instrument
- V or I function generator
- Precision power supply with V and I readback
- True current source
- Digital multimeter (DCV, DCI, Ohms, and power with 6 1/2-digit resolution)
- Precision electronic load

TYPICAL APPLICATIONS

- Power semiconductor device characterization and testing
- Characterization of GaN, SiC, and other compound materials and devices
- Breakdown and leakage testing to 3kV
- Characterization of sub-millisecond transients

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- Read the application note:
 - **Creating Multi-SMU Systems for High Power Semiconductor Characterization.**

The recent push for higher power, more efficient semiconductor devices has spurred the development of devices based on advanced materials that surpass the limitations of devices built on silicon. DC characterization of power semiconductor devices requires test systems that incorporate high voltage and high current SMUs. The steps required to properly build these test systems are detailed in this new application note. [More...](#)

KEITHLEY Number 3103
Application Note Series

Creating Multi-SMU Systems with High Power System SourceMeter Instruments

Introduction

The design and configuration of test systems for DC characterization of power semiconductor devices using high voltage and high current source measurement units (SMUs) involves several steps:

- Selecting equipment to meet test demands
- Selecting cabling and fixturing to connect the instruments to the device under test (DUT)
- Verifying system safety and instrument protection
- Optimizing the instrument setup to ensure measurement integrity
- Controlling the instrumentation hardware

Power semiconductor discrete devices are designed so that in the ON state, a device delivers a lot of power to the load and consumes minimal power from the power source (high efficiency); in its OFF state, the device delivers nearly zero power to the load and consumes minimal power from the power source (standby current is small). Therefore, characterization or DC parameter test of power semiconductors can be broken into two categories: ON-state and OFF-state characterization. This application note considers the application of test to these two categories. Specific examples of test systems built with a variety of Keithley SourceMeter® Source Measurement Unit (SMU) instruments will also be presented.

Select Equipment to Meet Test Demands

Power devices typically require high power instrumentation at only one or two terminals. For example, characterizing the OFF-state of a high voltage n-channel MOSFET requires a high voltage supply at the drain, all other terminals are driven with lower voltage supplies. Conversely, when characterizing the ON-state performance, high current flows from drain to source, thereby requiring that only those two terminals be rated for maximum power. Test researchers who are making the transition from testing lower power devices to higher power devices can reuse some of their existing test equipment at the gate and substrate terminals. Being able to use the same test equipment for multiple devices allows users to maximize their return on investment.

In order to select appropriate test equipment, it's essential to know the minimum and maximum currents and voltages that will be necessary to source and measure. If at all possible, select equipment that has the capability to extend beyond these values in order to accommodate the development of new devices.

Keithley's Series 2600A SMUs were designed with evolving test systems in mind. The TSP-Lock™ inter-unit communication bus supports creating mainframe-less systems while still allowing sub-microsecond synchronization of multiple SMU channels.

One of the most powerful features of the Series 2600A is the ability to offer to build systems that address all of the application's test requirements while maintaining seamless system performance. The Series 2600A family includes eight models that offer a variety of functions and capabilities:

- Up to 50A pulse at 2000V (100A possible with two SMUs)
- Up to 3kV source at 60W, 1500V at 180W
- Sub-picoamp measurement capability
- Up to 1A or 3A DC on lower power SMUs. This is ideal when testing high power IGBTs with large base currents.

This level of capability is generally unavailable in an off-the-shelf commercial test mainframe and would have once required configuring a custom or semi-custom ATE. Moreover, using stand-alone instruments allows the test engineer to add new capabilities as new test needs evolve. Stand-alone high power SMUs can extend the current and voltage capabilities of semiconductor parametric analyzers and, therefore, the scope of devices that can be tested.

Selecting Cabling and Fixturing to Connect the Instruments to the Device

Determine the interface to the device

In the past, most power semiconductor manufacturers had to package a device in order to test it because there was no widely available technology that allowed delivering tens of amps or thousands of volts to a device on water.

The availability of commercial probe solutions is allowing many manufacturers to seize the opportunity to lower their cost of test by testing devices on water.

Deciding whether to test packaged devices or devices on water is a balance between the large capital costs of a probe versus the smaller (but repeated) costs of packaging devices prior to test. Keithley solutions apply to both packaged test and water-level testing.

For testing packaged devices, system developers should take advantage of commercial test fixtures, paying attention to the supported device packages and any opportunity for customization. Keithley offers the Model 8010 High Power



How to perform a simple breakdown test on a high power, high voltage IGBT device

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Click on the video above – Learn how to Perform a Simple Breakdown Test on a High Power, High Voltage IGBT Device.

Want assistance, a quote, or to place an order?
Contact us online.

- Join the discussion on our [application forum](#).

Explore the Series 2400 SourceMeter instrument family

Series 2400 SourceMeter instruments are designed specifically for testing devices that demand tightly-coupled precision voltage and current sourcing as well as measurement capabilities. Each is a single-channel instrument that is both a highly stable DC power source and a true instrument-grade 6½-digit multimeter. The power source characteristics include low noise, precision, and readback. The multimeter capabilities include high repeatability and low noise. The result is a compact, single-channel, DC parametric tester.

- Six models: 20–100W DC, 1000W pulsed, 1100V to 1μV, 10A to 10pA
- Source and sink (4-quadrant) operation, plus 2-, 4-, and 6-wire ohms functions
- 0.012% basic DCV measure accuracy with 6½-digit resolution
- Available high speed sense lead contact check function
- Programmable DIO port for automation/handler/prober control
- Up to 1700 readings/second at 4½ digits via the GPIB bus
- 5000 6½-digit readings can be stored in the non-volatile buffer memory

Built-In Test Sequencer

The Series 2400 Source Memory list provides faster and easier testing by allowing you to set up and execute up to 100 different test setups that can run without PC intervention.

- Stores up to 100 individual test configurations, each containing unique source settings, measurement settings, pass/fail criteria, etc., linked together to form a complete test suite
- Pass/fail limit test as fast as 500μs per point with onboard comparator that eliminates the delay caused when sending data to the computer for analysis
- Built-in, user definable math functions to calculate derived parameters

Series 2400 Applications

- Devices including discrete semiconductor devices, passive devices, transient suppression devices, ICs, RFICs, MMICs, laser diodes, laser diode modules, LEDs, photodetectors, circuit protection devices (TVS, MOV, fuses, etc.), connectors, switches, relays
- Tests including low voltages/resistances, LIV, IDDQ, I-V characterization, isolation and trace resistance, temperature coefficient, forward voltage, reverse breakdown, leakage current, DC parametric test, DC power source, HIPOT, dielectric withstanding



Series 2400 SourceMeter instruments are easy to set up and use, providing convenient DMM-like operation, while eliminating many of the connection, compatibility, and synchronization problems that occur when multiple instruments are used. You can source voltage or current while making measurements without changing connections. This not only makes it easier to use, it saves test time.

Want assistance, a quote, or to place an order?

Contact us online.

- Join the discussion on our [application forum](#).

Ready to learn more?

- Download the Series 2400 data sheet.
- Read these application notes:
 - Diode Production Testing with the Series 2400 SourceMeter Instrument – Read about the three basic DC parametric tests most diodes undergo during final inspection: forward voltage, breakdown voltage, and leakage current test.
 - Measuring Photovoltaic Cell I-V Characteristics with the Model 2420 SourceMeter Instrument – Discover how to use the Model 2420 High Current SourceMeter instrument to measure the current-voltage (I-V) characteristics of photovoltaic cells in order to characterize their conversion efficiency.

Series 2400 SourceMeter® Line



Five instruments in one (IV Source, IVR Measure)

- Six models: 20-100W DC, 1000W pulsed, 1100V to 1kV, 10A to 10pA
- Source and sink (4-quadrant) operation
- 0.01% basic measure accuracy with 5 1/2-digit resolution
- 2-, 4-, and 6-wire remote V-source and measure sensing
- 1700 readings/second at 400 digits via GPIB
- Pass/Fail comparator for fast sorting/binning
- Available high speed sense lead contact check function
- Programmable DIO port for automation/handler/prober control
- Standard SCPI, GPIB, RS-232 and Keithley Trigger Link interfaces
- Keithley LabTracer 2.0 I-V curve tracing application software (download)

Advantages of a Tightly Integrated Instrument

By linking source and measurement circuitry in a single unit, these instruments offer a variety of advantages over systems configured with separate source and measurement instruments. For example, they minimize the time required for test station development, setup, and maintenance, while lowering the overall cost of system ownership. They simplify the test process itself by eliminating some of the complex environmental and connection issues associated with using multiple instruments. And, their compact half-rack size conserves precious "real estate" in the test rack or bench.

Power of Five Instruments in One (IV Source, IVR Measure)

The tightly coupled nature of a SourceMeter instrument provides many advantages over separate instruments. For example, it provides faster test times by reducing GPIB traffic and stabilizing the remote programming interface. It also protects the device under test from overloads, thermal runaway, etc. Both the current and voltage source are back to help maximize device measurement integrity. If the feedback resistance limit, then the source is clamped at the limit, providing fast protection.

ACCESSORIES AVAILABLE

TEST LEADS AND PROBES	COMMUNICATION
2700 Series Current Probe Test Lead Kit	4000 Series 1000 WDC
2800 Series 20-100 WDC Test Lead Kit	4100 Series 100 WDC
2900 Series 1000 WDC Test Lead Kit	4200 Series 10 WDC
3000 Series 100 WDC Test Lead Kit	4300 Series 1 WDC
3100 Series 10 WDC Test Lead Kit	4400 Series 100 mWDC
3200 Series 1 WDC Test Lead Kit	4500 Series 10 mWDC
3300 Series 100 mWDC Test Lead Kit	4600 Series 1 mWDC
3400 Series 10 mWDC Test Lead Kit	4700 Series 100 µWDC
3500 Series 1 µWDC Test Lead Kit	4800 Series 10 nWDC
3600 Series 10 nWDC Test Lead Kit	4900 Series 1 pWDC
3700 Series 1 pWDC Test Lead Kit	5000 Series 100 fWDC
3800 Series 100 fWDC Test Lead Kit	5100 Series 10 pWDC
3900 Series 10 pWDC Test Lead Kit	5200 Series 1 nWDC
4000 Series 1 nWDC Test Lead Kit	5300 Series 100 pWDC
4100 Series 100 pWDC Test Lead Kit	5400 Series 10 nWDC
4200 Series 10 nWDC Test Lead Kit	5500 Series 1 pWDC
4300 Series 1 pWDC Test Lead Kit	5600 Series 100 fWDC
4400 Series 100 fWDC Test Lead Kit	5700 Series 10 pWDC
4500 Series 10 pWDC Test Lead Kit	5800 Series 1 nWDC
4600 Series 1 nWDC Test Lead Kit	5900 Series 100 pWDC
4700 Series 100 pWDC Test Lead Kit	6000 Series 10 nWDC
4800 Series 10 nWDC Test Lead Kit	6100 Series 1 pWDC
4900 Series 1 pWDC Test Lead Kit	6200 Series 100 fWDC
5000 Series 100 fWDC Test Lead Kit	6300 Series 10 pWDC
5100 Series 10 pWDC Test Lead Kit	6400 Series 1 nWDC
5200 Series 1 nWDC Test Lead Kit	6500 Series 100 pWDC
5300 Series 100 pWDC Test Lead Kit	6600 Series 10 nWDC
5400 Series 10 nWDC Test Lead Kit	6700 Series 1 pWDC
5500 Series 1 pWDC Test Lead Kit	6800 Series 100 fWDC
5600 Series 100 fWDC Test Lead Kit	6900 Series 10 pWDC
5700 Series 10 pWDC Test Lead Kit	7000 Series 1 nWDC
5800 Series 1 nWDC Test Lead Kit	7100 Series 100 pWDC
5900 Series 100 pWDC Test Lead Kit	7200 Series 10 nWDC
6000 Series 10 nWDC Test Lead Kit	7300 Series 1 pWDC
6100 Series 1 pWDC Test Lead Kit	7400 Series 100 fWDC
6200 Series 100 fWDC Test Lead Kit	7500 Series 10 pWDC
6300 Series 10 pWDC Test Lead Kit	7600 Series 1 nWDC
6400 Series 1 nWDC Test Lead Kit	7700 Series 100 pWDC
6500 Series 100 pWDC Test Lead Kit	7800 Series 10 nWDC
6600 Series 10 nWDC Test Lead Kit	7900 Series 1 pWDC
6700 Series 1 pWDC Test Lead Kit	8000 Series 100 fWDC
6800 Series 100 fWDC Test Lead Kit	8100 Series 10 pWDC
6900 Series 10 pWDC Test Lead Kit	8200 Series 1 nWDC
7000 Series 1 nWDC Test Lead Kit	8300 Series 100 pWDC
7100 Series 100 pWDC Test Lead Kit	8400 Series 10 nWDC
7200 Series 10 nWDC Test Lead Kit	8500 Series 1 pWDC
7300 Series 1 pWDC Test Lead Kit	8600 Series 100 fWDC
7400 Series 100 fWDC Test Lead Kit	8700 Series 10 pWDC
7500 Series 10 pWDC Test Lead Kit	8800 Series 1 nWDC
7600 Series 1 nWDC Test Lead Kit	8900 Series 100 pWDC
7700 Series 100 pWDC Test Lead Kit	9000 Series 10 nWDC
7800 Series 10 nWDC Test Lead Kit	9100 Series 1 pWDC
7900 Series 1 pWDC Test Lead Kit	9200 Series 100 fWDC
8000 Series 100 fWDC Test Lead Kit	9300 Series 10 pWDC
8100 Series 10 pWDC Test Lead Kit	9400 Series 1 nWDC
8200 Series 1 nWDC Test Lead Kit	9500 Series 100 pWDC
8300 Series 100 pWDC Test Lead Kit	9600 Series 10 nWDC
8400 Series 10 nWDC Test Lead Kit	9700 Series 1 pWDC
8500 Series 1 pWDC Test Lead Kit	9800 Series 100 fWDC
8600 Series 100 fWDC Test Lead Kit	9900 Series 10 pWDC
8700 Series 10 pWDC Test Lead Kit	10000 Series 1 nWDC

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Application Note Series

Measuring Photovoltaic Cell I-V Characteristics with the Model 2420 SourceMeter Instrument

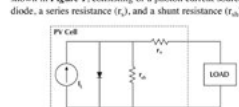
Introduction

Photovoltaic (PV) cells convert sunlight directly to electricity. Fabricated from a wide variety of materials using many different processing techniques, these devices are used for terrestrial power generation, as well as commercial, military, and research space power applications. PV cell characterization involves measuring the cell's electrical performance characteristics to determine conversion efficiency and critical equivalent circuit parameters. It is an important tool for R&D and production of cells and photovoltaic arrays. This application note describes how to use the Keithley Model 2420 High Current SourceMeter instrument to measure the current-voltage (I-V) characteristics of PV cells.

With the introduction of SMUs (Source-Measure Units), configuring device characterization systems that once required a rack of electronic equipment, including programmable power supplies, digital multimeters, and scanners, has been simplified significantly. The Model 2420's ability to source/sink up to 3A with 0.5% accuracy or better and its low noise, high impedance, repeatable DMM offers a cost-effective alternative to using expensive, high power programmable power supplies for PV cell characterization. The Model 2420 offers 10pV resolution on the 2V range, which is sufficient to measure the I-V curve of any single junction cell. The 20V range offers adequate resolution (100pV) for multi-junction cells and small arrays, where the open circuit voltage may exceed 2V. The Model 2420's low current measuring capability, with 10pA maximum resolution on the 1mA current range, is sufficient for virtually all dark I-V applications.

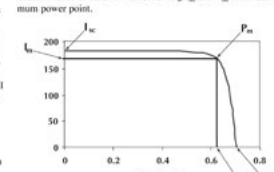
Test Description

A PV cell may be represented by the equivalent circuit model shown in Figure 1, consisting of a photon current source (I_L), a diode, a series resistance (r_s), and a shunt resistance (r_{sh}).



Forward Bias I-V (Illuminated)

This test involves generating the forward biased I-V curve between the two points ($V_1 = 0, I_1 = I_{sc}$) and ($V_2 = V_{oc}, I_2 = 0$). The parameters V_{oc} and I_{sc} can be directly determined from the curve and V_{oc} , V_{oc} , P_m , and η are easily calculated. Additional analytical techniques may be used to determine r_s and r_{sh} .



Application Note Series

Diode Production Testing with Series 2400 SourceMeter® Instruments

Introduction

Performing single-point pass/fail DC tests on packaged diodes is critical to ensure compliance with manufacturers' specifications and to identify and weed out defective devices before they are shipped. Most types of diodes undergo at least three basic DC parametric tests during this final inspection process: the Forward Voltage Test (V_f), Breakdown Voltage Test (V_b), and Leakage Current Test (I_L). While the reliability of these tests is essential to ensuring product quality, it's equally important that they be conducted quickly to maintain high production throughput.

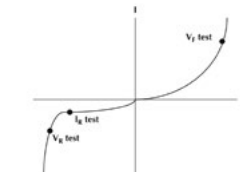
Usually, several instruments are required to make these tests, such as a DMM, voltage source, and current source. However, as the number of instruments in the test system increases, the slower the overall measurement process becomes, reducing test throughput.

A system configured with a separate DMM and sources takes up substantially more rack space than a system built with all these functions in one unit. In addition to higher equipment costs, three separate instruments also mean there are three sets of commands to learn, complicating system programming and maintenance. Using multiple instruments and sources also makes trigger timing more complex and increases triggering uncertainty. Coordination of the connections of separate instruments also extends increasing the amount of bus traffic.

Two example programs for this application are available from Keithley's Web site. See the "Example Programs" section in this application note for more details on how to obtain copies of these programs.

Test Descriptions

Figure 1 illustrates the test points for each of the tests described.



Polarity Test

The polarity test is designed to determine the orientation of the diode safely and quickly prior to completing functional tests on the device. The breakdown characteristics of the diode are used to generate an indication of the diode's polarity in one of two ways. A positive current can be sourced through the diode 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. Alternatively, 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 between these two methods for polarity testing depends primarily on the overall structure of the test program.



Click on the video above - Learn how to use saved setups with the Series 2400 SourceMeter Instrument Family.

Want assistance, a quote, or to place an order? Contact us online.

Join the discussion on our application forum.

When you need the lowest noise and drift specifications available, choose the Model 6430 SMU instrument

The **Model 6430 Sub-Femtoamp Remote SourceMeter instrument** offers you sensitivity, noise, and input resistance specifications superior to an electrometer's. It also offers the lowest noise (just 400aA p-p) and best long-term stability of any instrument available.

- Measures current, voltage, and resistance
- 0.4fA-p noise
- $>10^{16}\Omega$ input resistance on voltage measurements
- $6\frac{1}{2}$ -digit resolution
- Up to 2000 source/measure readings/second
- Programmable digital I/O and GPIB interfaces for fast component characterization or selection

The Model 6430's Remote PreAmp provides a very sensitive bi-directional amplifier with sensitive feedback elements for measuring or sourcing currents at the DUT. The amplified signals the Remote PreAmp produces are not subject to cable noise as they are carried to the controlling mainframe. This architecture makes the Model 6430 the most sensitive current measurement instrument on the market.

Model 6430 Applications

- Low current measurements
 - Particle beam experiments, including precision mass spectrometry
 - Single-electron tunneling and other quantum experiments
- High resistance measurements
 - Research on insulators, dielectrics, polymers, etc.
 - Precise measurements of high resistances
- Four-terminal low resistance measurements
- Semiconductor research and characterization
 - Measuring sub-femtoamp gate currents
 - Characterizing sub-threshold I-V curves
 - Characterizing probe performance
- Component testing
 - Development labs
 - Production facilities



Want to learn more?

- [Download the Model 6430 data sheet.](#)

- [Learn how to make high resistance measurements. Click here.](#)
 - Learn how to apply the Model 6430 to both constant voltage and constant current techniques for resistance measurement.

- Want assistance, a quote, or to place an order?
[Contact us online.](#)
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SourceMeter® SMU instruments selector guide



Feature	2651A / 2657A High Current / High Voltage	2634B / 2635B / 2636B Low Current	2602B / 2612B Dual Channel	2601B / 2611B Single Channel	2604B / 2614B Dual Channel Benchtop
# of Channels	1 (optional expansion to 32 via TSP-Link®)	1 – 2 (optional expansion to 64 via TSP Link for 2635B/2636B)	2 (optional expansion to 64 via TSP-Link)	1 (optional expansion to 32 via TSP-Link)	2
Current Max / Min	2651A: 50A pulse/100fA 2657A: 120mA/1fA	2634B: 10A pulse/1fA 2636B, 2635B: 10A pulse/0.1fA	10A pulse/100fA	10A pulse/100fA	10A pulse/100 fA
Voltage Max / Min	2651A: 40V/100nV 2657A: 3,000V/100nV	200V/100nV	40V/100nV for 2602B 200V/100nV for 2612B	40V/100nV for 2601B 200V/100nV for 2611B	40V/100nV for 2604B 200V/100nV for 2614B
System-Level Automation	Digital I/O, TSP-Link, Contact Check	Digital I/O, TSP-Link, Contact Check (not available on 2634B)	Digital I/O, TSP-Link, Contact Check	Digital I/O, TSP-Link, Contact Check	N/A
Max readings / sec	38,500 1µSec/pt., 18-bit digitizer	20,000	20,000	20,000	20,000
Computer Interface	GPIB, LAN (LXI), RS-232	GPIB, LAN (LXI), RS-232, USB	GPIB, LAN (LXI), RS-232, USB	GPIB, LAN (LXI), RS-232, USB	GPIB, LAN (LXI), RS-232, USB
Connectors/Cabling	2651A: Screw terminal, adaptors for banana 2657A: HV triax, SHV	Triax	Screw terminal, adaptors for banana or triax	Screw terminal, adaptors for banana or triax	Screw terminal, adaptors for banana or triax



Feature	6430 Low I SourceMeter	2430 High Power SourceMeter Instrument	2410 High V SourceMeter Instrument	2420 / 2425 / 2440 High I SourceMeter Instruments	2400 / 2401 Low Power SourceMeter Instruments	2450 Advanced Touchscreen SourceMeter Instruments
Current Max / Min	105mA / 10aA	10.5A pulse / 100pA	1.05A / 10pA	5.25A/ 100pA	1.05A / 10pA	1.05A/10fA
Voltage Max / Min	200V / 1uV	200V / 1uV	1100V / 1uV	100V / 1uV	200V / 1uV	200V/10nV
Power	2W	1100W	22W	110W	22W	20W
Max readings / sec	256	2,000	2,000	2,000	2,000	3,100
Interface	GPIB, RS-232, Digital I/O, Trigger Link Trigger Bus	GPIB, RS-232, Digital I/O, Trigger Link Trigger Bus	GPIB, RS-232, Digital I/O, Trigger Link Trigger Bus	GPIB, RS-232, Digital I/O, Trigger Link Trigger Bus	GPIB, RS-232, Digital I/O, Trigger Link Trigger Bus	GPIB, USB 2.0, LAN/LXI, Digital I/O, TSP-Link
Connectors	Triax	Banana (front / rear)	Banana (front / rear)	Banana (front / rear)	Banana (front / rear)	Banana (front) Triax (rear)

Want to learn more about applications for Keithley's growing family of SMU instruments?



Keithley Instruments hosts an online applications forum to encourage idea exchange and discussions among users. [Join the conversation today.](#)

To learn more about how Keithley's high performance SMU instruments can enhance the productivity of your test and measurement applications, contact your local Keithley representative or [ask us a question online.](#)

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