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A Tektronix Company

# *Re-Inventing High Power Semiconductor Device Characterization*

## *Application Advice & Product Selection*



Reinventing High Power Semiconductor Device Characterization.....	2
Testing for Today's and Tomorrow's Devices .....	3
Building Blocks of Keithley High Power Offering .....	4
High Power Device Characterization with Parametric Curve Tracer Configurations .....	5
Characterize and Test High Voltage Electronics and Power Semiconductors .....	6
Get Unmatched Performance for Characterizing and Testing High Power, High Current Electronics .....	8
Software for High Power Device Characterization .....	10
System SourceMeter® SMU Instrument Selector Guide .....	11
Keithley Parametric Curve Tracer Configurations .....	12
For More Information .....	13










# Reinventing High Power Semiconductor Device Characterization

Green initiatives and energy efficiency standards worldwide have motivated engineers to find ways to design more efficient semiconductor devices and integrated circuits. High power semiconductor end applications are becoming increasingly demanding, requiring test instrumentation capable of characterizing significantly higher rated voltages and peak currents than ever before. Keithley offers a broad spectrum of tools, both hardware and software, for power device characterization.

## Demand for Higher Power Semi Devices Will Require Pushing Instrumentation to New Extremes

Many segments of the electronics industry, including the semiconductor industry, are focused on increasing energy efficiency, including boosting the efficiency of energy generation, transmission, and consumption. Power semiconductor devices are used as switches or blocking devices in such applications as motor control, voltage regulation and power conversion. New “greener” devices offer lower leakage, lower ON resistance, or both and create new requirements for test and measurement. [More ...](#)

	 UPSs	 High-End Power Supplies, Servers, etc.	 HEVEV	 Solar Panel Inverters	 Industrial Motors	 Wind Turbines	 Electronic Transmission, Rail Traction, Ships
<b>Main Devices</b>	FETs, IGBTs, Diodes	FETs, Diodes	FETs, IGBTs, Diodes	FETs, IGBTs, Diodes	FETs, IGBTs, Diodes	IGBTs, Diodes	IGBTs, Diodes
<b>Peak Current</b>	2A–100A	0.5A–10A	50A–200A	75A	3A–100A	>150A	>200A
<b>Rated Voltage</b>	600V–1200V	600V	650V–2000V	600V–1200V	600V–1200V	Today: 690V, Trend: 3kV–4kV	>5kV

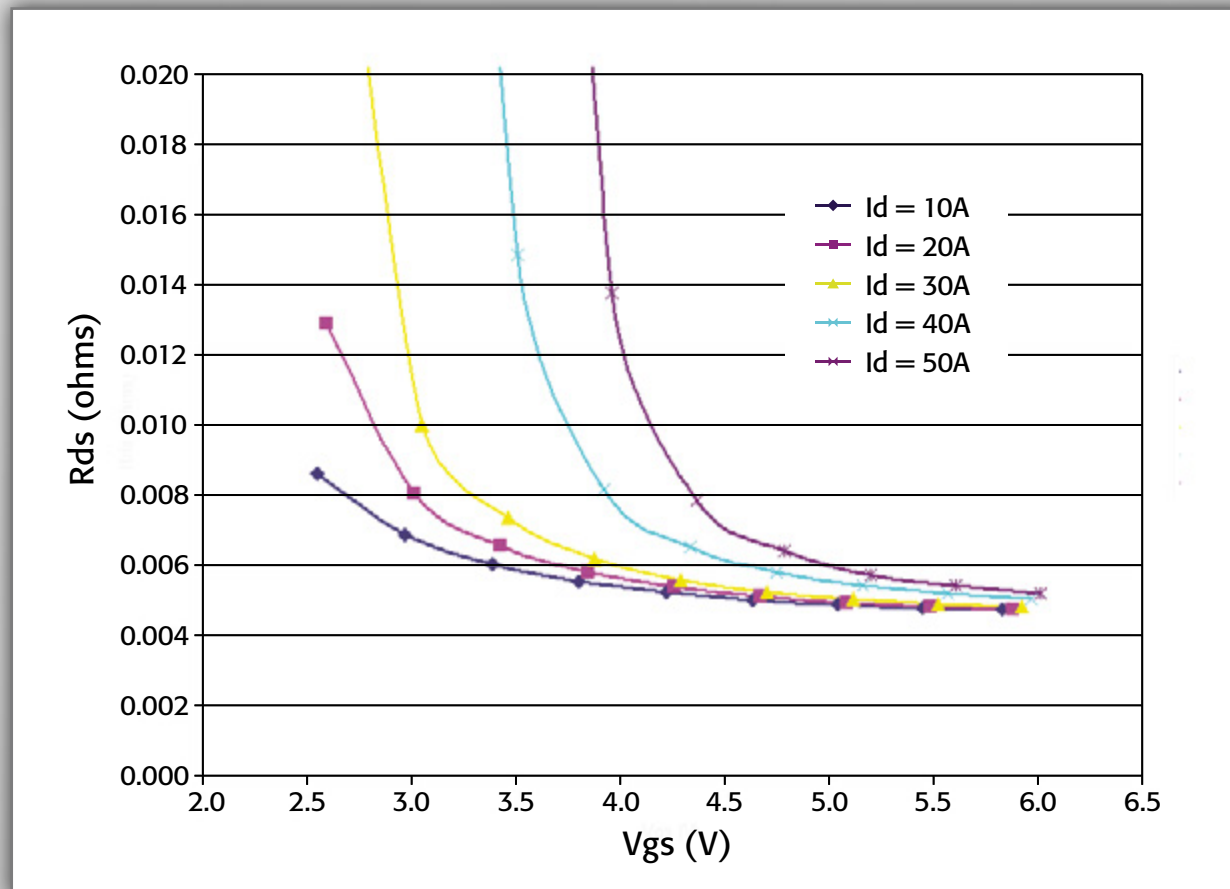
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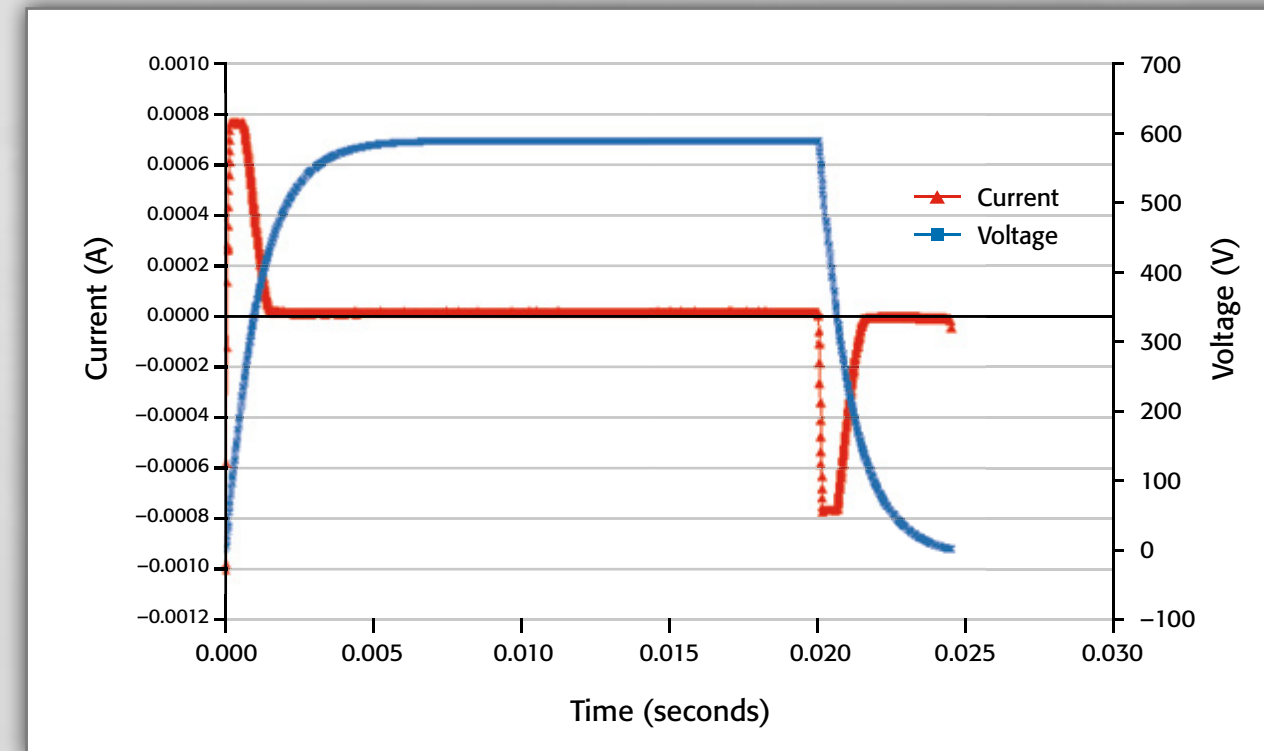
# Testing for Today's and Tomorrow's Devices

High power semiconductor end applications are becoming increasingly demanding, requiring test instrumentation capable of characterizing significantly higher rated voltages and peak currents than ever before. Even more significant, breakdown and leakage test are typically performed at 2–3 times the level of the rated or operating voltage. When the devices are in the ON state, they have to pass through tens or hundreds of amps with minimal loss; when they are OFF, they have to block thousands of volts with minimal leakage currents.

At the same time, semiconductor technology is being advanced so that it can operate at much higher levels of voltage, current, power, and frequency. This develops the need for integrating measurement modes for characterizing both transient and steady-state behavior, including rapidly changing thermal effects and capturing voltage and current transients simultaneously. Today's solutions need to be fast enough to capture and characterize transient behavior without the need to average multiple readings to produce an accurate result.



Low-level  $R_{ds}$  measurements to support next-generation devices



Full simultaneous characterization of both voltage and current to capture transient behavior

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# Building Blocks of Keithley's High Power Offering



- Model 2636B SourceMeter<sup>®</sup> SMU Instrument**
- Two independent SMU channels
  - Up to 200V, up to 10A pulsed
  - 0.1fA measurement resolution

- Model 2657A High Power Source Measurement Unit (SMU) Instrument**
- Up to 3000V, Up to 180W of power
  - 1fA measurement resolution
  - High speed and integrating ADCs

**Model 8010 Test Fixture:**  
Provides safe environment for testing at 3kV and at 100A

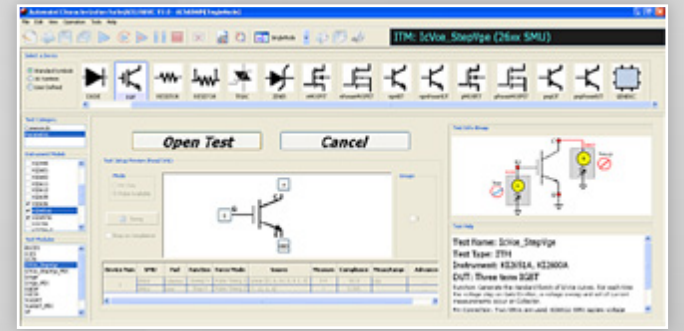


- Model 2651A High Power System SourceMeter Instrument**
- Up to 50A pulsed (up to 100A with 2 units)
  - Up to 2000W pulse / 200W DC power
  - Pulse widths from 100µs to DC
  - High speed and integrating ADCs

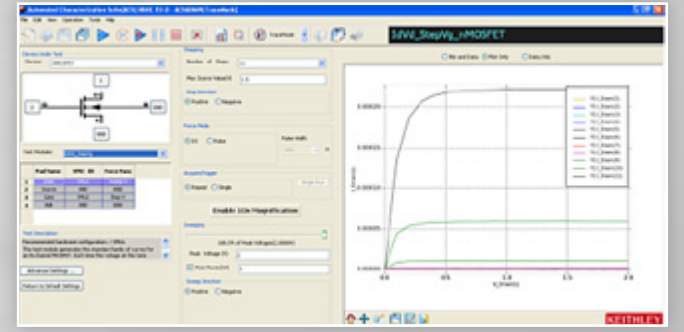
**TSP<sup>®</sup> Express:** Web-based plug & play I-V characterization and test software with simple spreadsheet and graphing functionality



**Parametric Curve Tracer software:**  
ACS Basic Edition

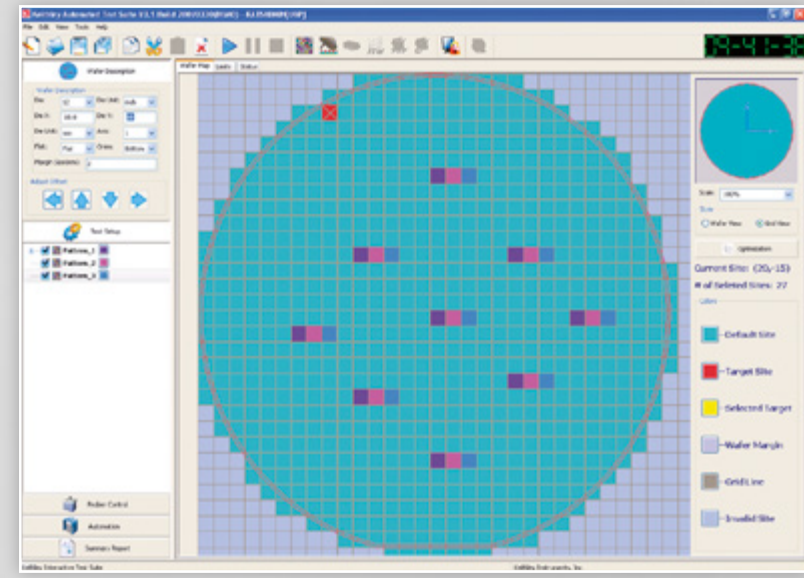


**Parametric Test Mode**



**Trace Mode**  
*For fast and simple single device testing!*

**Wafer-level software: ACS**



# High Power Device Characterization with Parametric Curve Tracer Configurations

Characterizing and testing today's high power semiconductor devices and components is placing a high demand on test equipment. Device design engineers need equipment that can support them throughout the complete lifecycle of a power device. Today, high power characterization systems are available in two main forms — complete turnkey systems and building blocks that must be configured by the user and completed with good software. Turnkey systems can be set up and running quickly, but they can be quite expensive and limited in the breadth of testing that can be performed.

**Keithley's Parametric Curve Tracer** configurations are complete solutions configured with a variety of high quality instruments, cables, test fixturing, and software. This building block approach offers the advantages of easy upgrading or modification to meet changing test needs. Additionally, these instruments and accessories can be used across different test system platforms, such as for reliability or device qualification testing.

Keithley's Parametric Curve Trace configurations include everything necessary for the characterization engineer to develop a complete test system quickly. The configurations supports both parametric and trace test modes, thus including the best of a curve tracer and a parameter analyzer.

■ [Download the Parametric Curve Tracer Configurations datasheet.](#)

## Key Facts

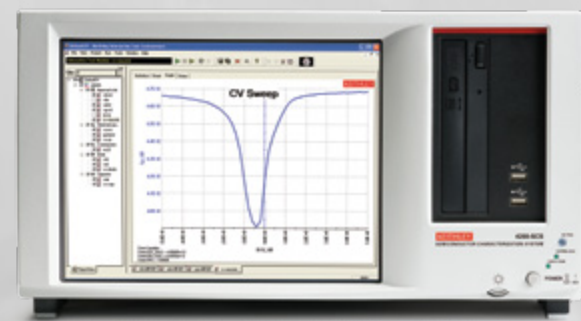
- Configurable power levels
  - From 200V to 3kV
  - From 1A to 100A
- Wide dynamic range
  - From  $\mu$ V to 3kV
  - From fA to 100A
- Capacitance-voltage measurement
- DC or pulsed I-V to 50 $\mu$ s
- Test management software includes both trace mode for real-time control and parametric mode for parameter extraction

## Applications

- Power semiconductor device characterization and testing
- Characterization of GaN and SiC, LDMOS, and other devices
- Reliability studies on power devices
- Incoming inspection and device qualification



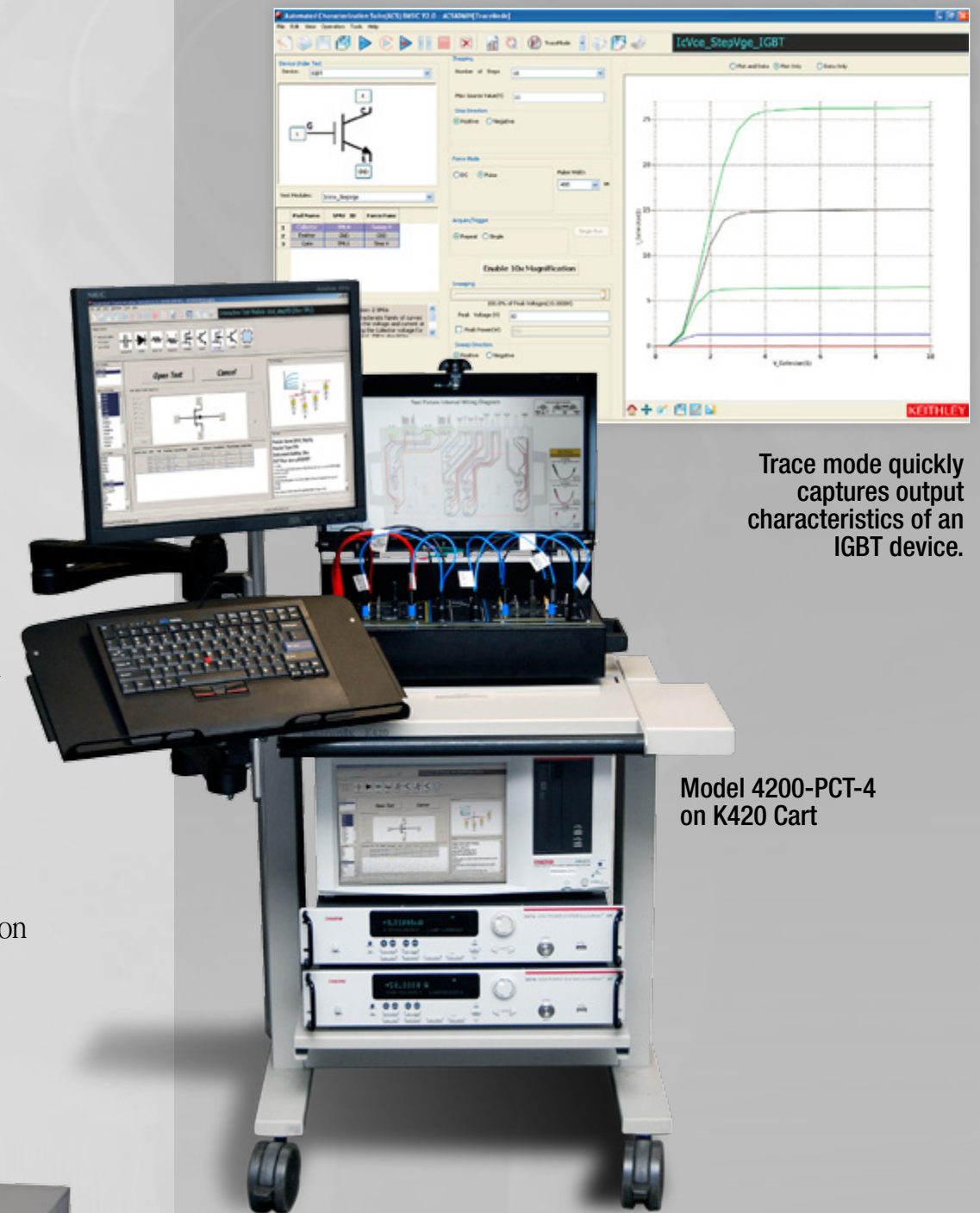
Curve Tracer



Parameter Analyzer



Parametric Curve Tracer



Model 4200-PCT-4 on K420 Cart

Trace mode quickly captures output characteristics of an IGBT device.

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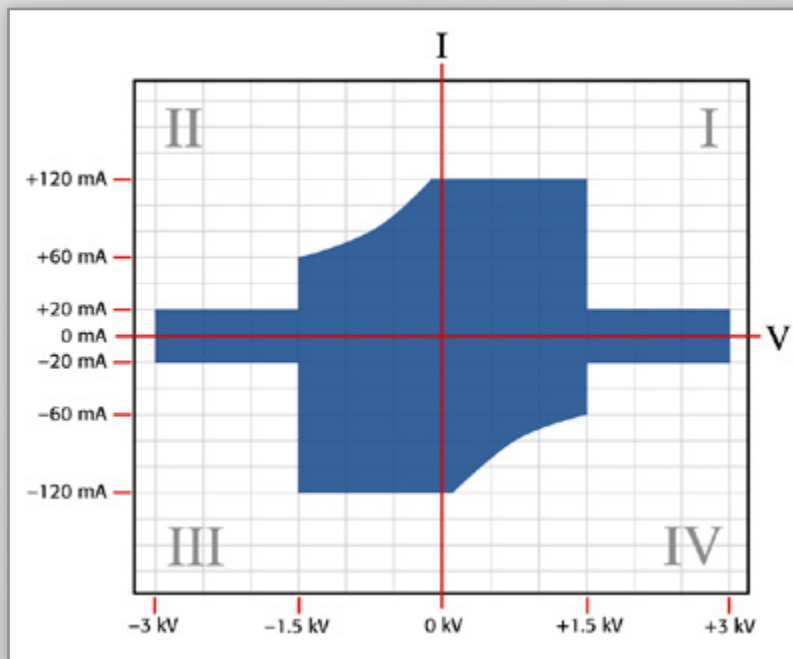
# Characterize and Test High Voltage Electronics and Power Semiconductors

The **Model 2657A High Power/High Voltage System SourceMeter® instrument** adds high voltage to Keithley's SourceMeter SMU instruments family of high speed, precision source measurement units. Suitable for R&D, production, and QA/FA, it:

- Sources or sinks up to 3000V @ 20mA or 1500V @ 120mA –able 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 2657A comes with dual 22-bit precision ADCs and dual 18-bit 1 $\mu$ s per point digitizers for high accuracy and high speed transient capture. Like other Series 2600A 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

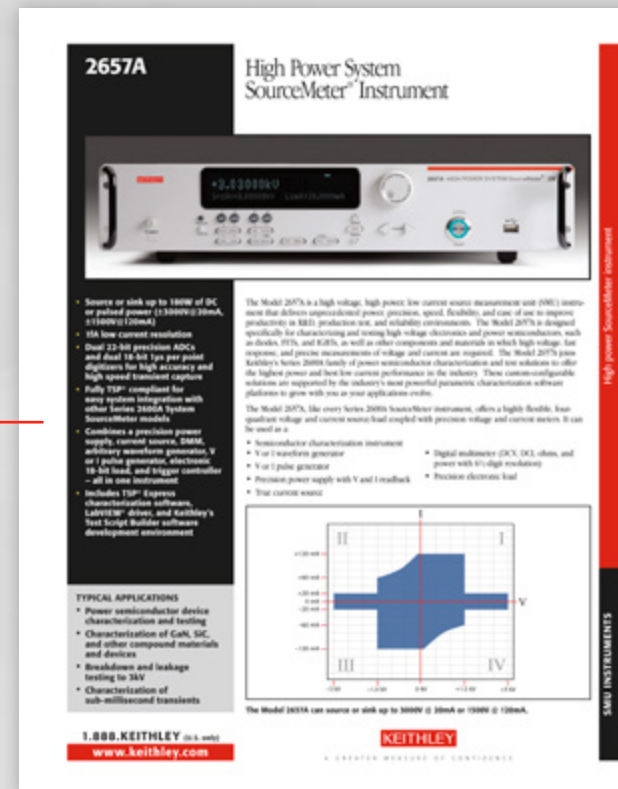


Keithley offers a broad spectrum of tools, both hardware and software, for power device characterization. A typical device test system could include the high voltage Model 2657A, one or two high current Model 2651A instruments, and up to three low power SMU instruments (other Series 2600A instruments 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 2600A instruments to form powerful multi-channel systems that rival the system speed of large ATE systems that cost tens of thousands of dollars more.

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 datasheet.



- 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 source measurement units (SMUs). The steps required to properly build these test systems are detailed in this new application note. [More...](#)



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

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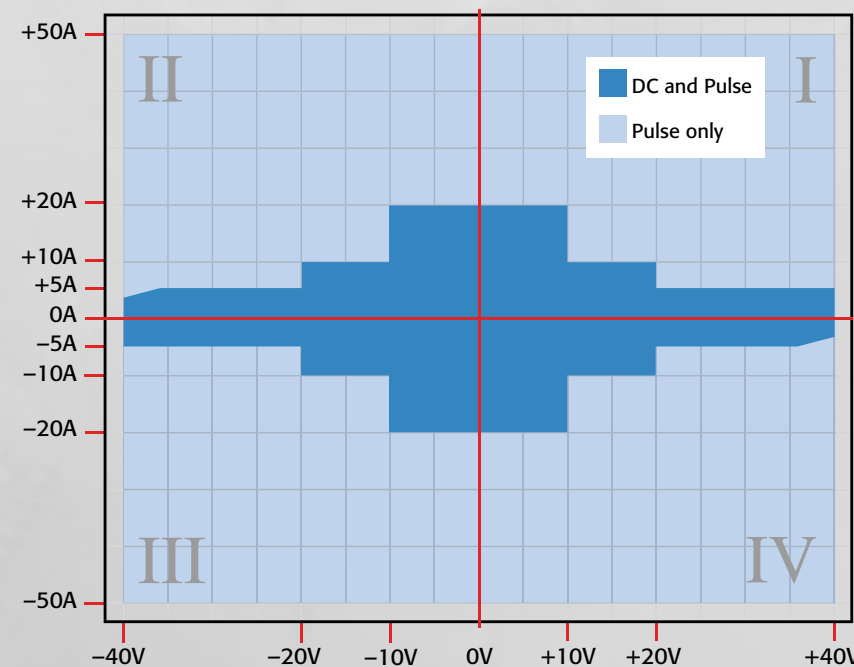
# Get Unmatched Performance for Characterizing and Testing High Power, High Current Electronics

Our new **Model 2651A High Power/High Current 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.

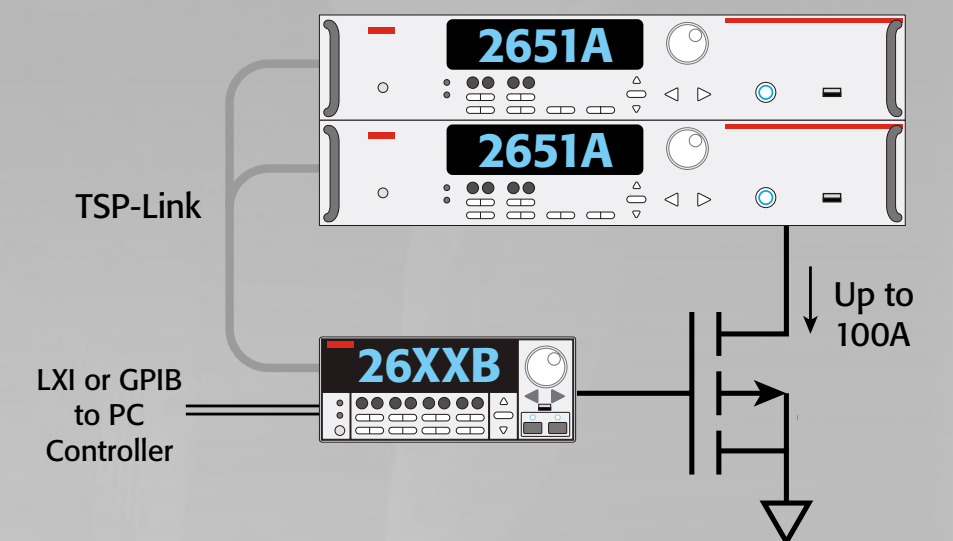


A single Model 2651A unit can source and sink up to  $\pm 40V$  and  $\pm 50A$ . Connect two units in parallel via the built-in TSP-Link expansion bus to extend the system's current range to 100A or connect them in series to expand the voltage range to 80V. The embedded Test Script Processor (TSP®) included 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 2600A instrument make it easy to link multiple Model 2651As and other Series 2600A 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 2600A 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 datasheet.](#)

- 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 2651A instrument.

**2651A High Power System SourceMeter® Instrument**

- Source or sink:
  - 2,000W of pulsed power (1,000 V, 100A)
  - 200W of DC power (1,000 V, 20A, 120V @ 1.6A, 1,000 V, 1A)
- Easily connect two units (in series or parallel) to source solutions up to 1,000 V or 200V
- 1µA resolution enables precise measurement of very low leakage currents
- 1µs per point (100ns), simultaneous 16-bit sampling, automatic characterization
- 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, load, arbitrary waveform generator, and 7 output channels with measurement, electronic load, and trigger controller—all in one instrument
- Includes TSP™ Express characterization software, LabVIEW™ driver, and Keithley's Test Builder software development environment

**APPLICATIONS**

- Power semiconductor, MOSFET, 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

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**Achieving Fast Pulse Measurements for Today's High Power Devices**

Green initiatives and energy efficiency standards worldwide have motivated engineers to find ways to design more efficient semiconductor devices and integrated circuits, and measuring the true state of these devices without the effects of self-heating is critical. Test instruments with only DC capabilities can deliver enough power to a device to cause heat dissipation that alters its characteristics. Pulsed characterization is a solution to this issue.

The use of a pulsed stimulus demands faster measurements. Traditional precision SMCs (source-measure-control) use integrating ADCs. Although it offers the advantage of high accuracy and excellent noise immunity, this ADC technology does not lend itself to high speed digitization or waveform capture. For applications that require these capabilities, Keithley's Model 2651A High Power SourceMeter® instrument also includes two high-speed ADCs for measuring current and voltage simultaneously. These ADCs use sampling technology similar to an oscilloscope and take snapshots of the signal over time. Each high-speed ADC in the Model 2651A samples at a rate of up to 100Ms with 16-bit resolution, which is much higher than the typical 4-bit resolution of an oscilloscope, resulting in more precise transient characterization in comparable bandwidths. Coupled with the ability to measure asynchronously from the source, this feature makes the Model 2651A ideal for many waveform capture and transient characterization applications.

**Using the Model 2651A for Fast Pulse Measurements**

Figure 1 illustrates some of the variables you can set to generate the pulses and the timing that best meets the needs of the devices being tested. Figure 2 illustrates five examples of pulsed signals and measurements that can be made with the Model 2651A.

Figure 1: Precisely specify a pulse using the Model 2651A.

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

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

Figure 2c: Digitizing the entire pulse.

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

Figure 2e: Triggering measurement to begin after the pulse.

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**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 Ohm resistances, require a unique combination of power and precision to be tested properly. A single Keithley Model 2651A is capable of sourcing up to 10A pulsed and measuring down to 1µA or less. For applications requiring even higher currents, the Model 2651A is capable of being combined to extend their operating range to 100A pulsed.

The high power Model 2651A is the newest addition to the Series 2650A 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 spectrum, 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 10A to 100A. When two units are connected in series, the voltage range is expanded from 40V to 80V. This built-in intelligence amplifies testing by enabling the units to be addressed as a single instrument, thus creating an industry best dynamic range (100A to 1µA). This capability enables you to test a much wider range of power semiconductor and other devices. (See example in Figure 1.)

**Theory**

Keithley'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 (100A) current source (10µs pulse width and 0.01 NPV) to test up to 100A of a power MOSFET device using two Model 2651A SourceMeter instruments connected in parallel.

**Keithley's NEW Model 2651A**  
High Power System SourceMeter® Instrument

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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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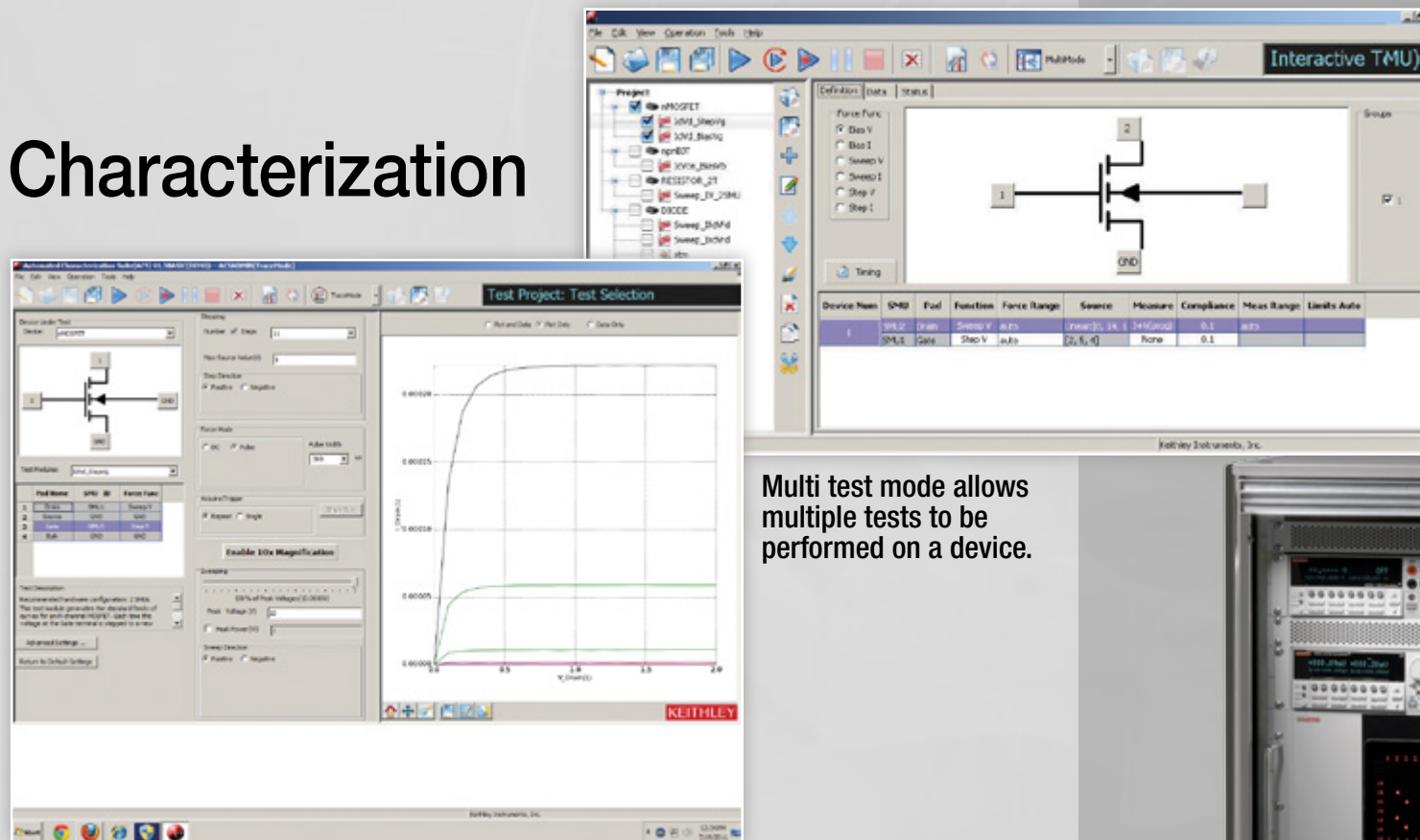
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# Software for High Power Device Characterization

Keithley's Automated Characterization Suite (ACS) Software combines with the high power, precision, speed, and flexibility of Keithley's Series 2600 High Power System SourceMeter<sup>®</sup> SMU instruments and Parametric Curve Tracer configurations to create a complete environment for high power semiconductor component characterization. Depending on your application, choose from ACS Basic Edition for single device testing or ACS Standard Edition for wafer-level, multi-DUT test automation or reliability analysis.

## ACS Basic Edition for Semiconductor Component and Discrete Devices

- Designed for discrete devices such as mosfets, BJTs, IGBTs, diodes, resistors, etc.
- Rich set of test libraries for fast and easy test setup without programming
- Built-in analysis tools for extracting parametric data
- Includes both interactive, real-time trace mode and parametric mode



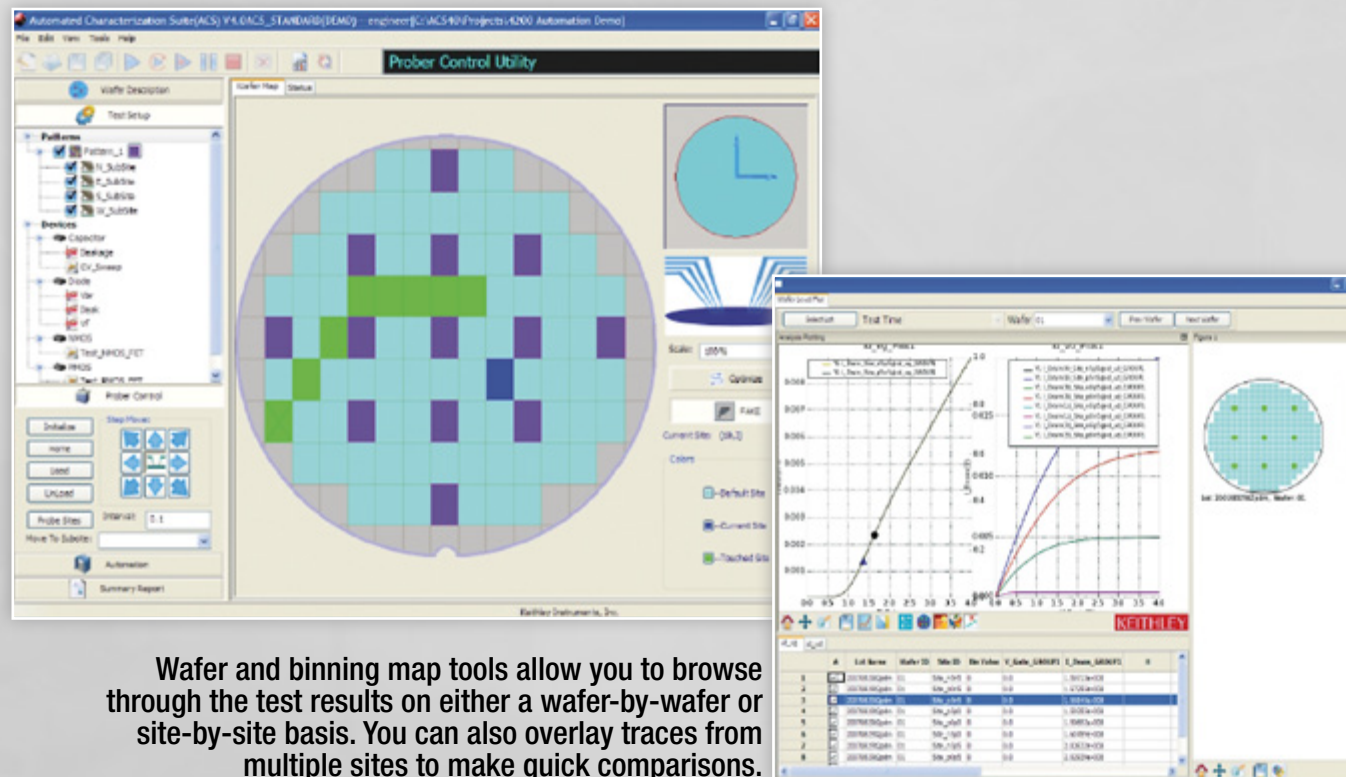
Multi test mode allows multiple tests to be performed on a device.

Trace mode supports interactive testing of a device.

## ACS Standard Edition for Characterization, Parametric Testing, Reliability Test, and Die Sort

- Supports a wide array of instruments and probers
- Develop and execute tests at the device, site, wafer, and cassette level
- Supports multiple SourceMeter<sup>®</sup> source

Interactive probe station control speeds and simplifies test development and debugging by combining interactive testing with manual probe station control.



Wafer and binning map tools allow you to browse through the test results on either a wafer-by-wafer or site-by-site basis. You can also overlay traces from multiple sites to make quick comparisons.



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# System SourceMeter® SMU Instruments



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/2363B)	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
Current Max / Min	105mA / 10aA	10.5A pulse / 100pA	1.05A / 10pA	5.25A/ 100pA	1.05A / 10pA
Voltage Max / Min	200V / 1uV	200V / 1uV	1100V / 1uV	100V / 1uV	200V / 1uV
Power	2W	1100W	22W	110W	22W
Max readings / sec	256	2,000	2,000	2,000	2,000
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
Connectors	Triax	Banana (front / rear)	Banana (front / rear)	Banana (front / rear)	Banana (front / rear)

# Keithley Parametric Curve Tracer Configurations



Model	2600-PCT-1	2600-PCT-2	2600-PCT-3	2600-PCT-4	4200-PCT-2	4200-PCT-3	4200-PCT-4	
<b>Type</b>	Entry Level	High Current	High Voltage	High Current and Voltage	High Current + C-V	High Voltage + C-V	High Current and Voltage + C-V	
<b>Collector/ Drain Supply</b>	<b>High Voltage Mode</b>	200V/10A	200V/10A	3KV/120mA	3KV/120mA	200V/1A	3KV/120mA	3KV/120mA
	<b>High Current Mode</b>	200V/10A	40V/50A	200V/10A	40V/50A	40V/50A	200V/1A	200V/1A
<b>Step Generator (Base/Gate supply)</b>	200V/10A	200V/10A	200V/10A	200V/10A	200V/1A	200V/1A	200V/1A	
<b>Typical Applications</b>	Incoming Inspection, FA, QA, Reliability, Design Qual, Product Dev.	Incoming Inspection, FA, QA, Reliability, Design Qual, Product Dev.	Incoming Inspection, FA, QA, Reliability, Design Qual, Product Dev.	Incoming Inspection, FA, QA, Reliability, Design Qual, Product Dev.	Data Sheet Generation, Modeling, General Characterization	Data Sheet Generation, Modeling, General Characterization	Data Sheet Generation, Modeling, General Characterization	
<b>Software</b>	ACS Basic Edition with Trace Mode and Parametric Mode, single and sequenced tests, sample power device libraries							
<b>Text Fixture</b>	Model 8010 High Power Device Test Fixture supports 3KV/100A Includes TO-220, TO-247, Axial, Custom sockets, sample demo parts (BJT, MOSFET, diode, etc.)							

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## Want to learn more about how Keithley is Re-Inventing High Power Semiconductor Device Characterization?



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

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

### Contact us by phone, fax, mail, or email:

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## A Greater Measure of Confidence

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