2016 Keithley熱門應用技術論壇

Tektronix

“Solving Today’s Power Semiconductor Challenges”

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A Tektronix Company

Agenda

“SOLVING TODAY’S POWER SEMICONDUCTOR CHALLENGES”

1. Keithley Instrument Introduction
2. Market Drivers and Challenges for Power SEMI.
3. Keithley Parametric Curve Tracer for Power SEMI.
4. Reliability Solutions (TDDB, Activation Energy, etc.)
5. Conclusion

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Keithley Instrument Intro.

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吉時利儀器簡介

- 專精於高階電性量測儀器，擁有超過70年以上的研發經驗
  - 為全球專業的電子製造商提供高準確度用於產品測試、過程監控、產品發展和研究的各種測量解決方案。
  - 針對各產業特性開發解決方案。例如: 半導體、光電、平面顯示器、通訊、電腦週邊、汽車 …

Texas Instruments

- 總部位於美國Ohio州Cleveland市，全球有超過100個銷售服務據點
  - 台灣、日本、韓國、中國大陸、新加坡、美國、英國、德國 …
  - 各地分公司擁有完整維修與技術諮詢能力

- 不斷創新與突破
  - 多次諾貝爾獎得主，使用Keithley儀器量測發表研究成果而獲將獎

Keithley's Low-Level Instrumentation

Sensitive Measurements Beyond the DMM

DMM

Keithley Electrometers

- *High Resistance*
- *Low DC Current*
- *DC Voltage*
- *Charge*

Keithley Picoammeters

- *Low DC Current*

Keithley Nanovoltmeter

- *Low DC Voltage*
- *Low Resistance (w/ 622X Source)*

Atto	– Femto	– Pico	– Nano	– Micro	– Milli	1	Kilo	– Mega	– Giga	– Tera	– Peta
10^{-18}	10^{-15}	10^{-12}	10^{-9}	10^{-6}	10^{-3}	10^{0}	10^{3}	10^{6}	10^{9}	10^{12}	10^{15}

Keithley's Low-Level, Instruments

Keithley Electrometers

- *High Resistance*
- *Low DC Current*
- *DC Voltage*
- *Charge*

6514

6517B
+ V Source

6430
Most
Sensitive

Keithley Picoammeters

- *Low DC Current*

6485
1 channel

6487
+ V source

6482
2 channel

Keithley Nanovoltmeter and Current Sources

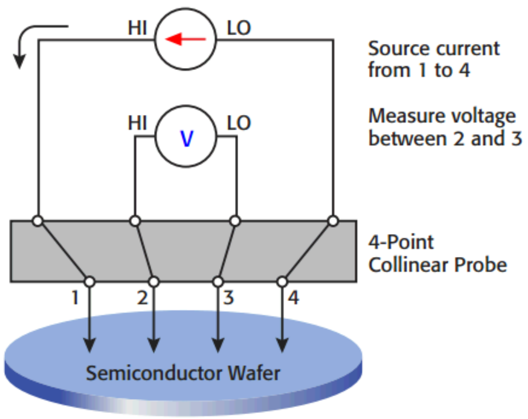
- *Low DC Voltage*
- *Low Resistance (w/ 622xSource)*

2182A
nV

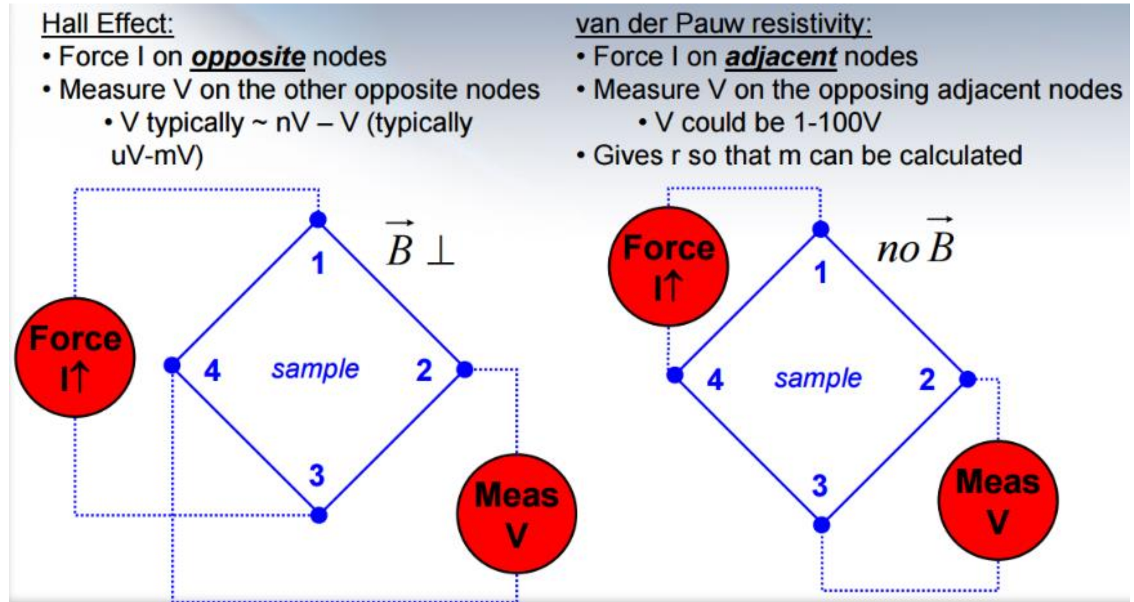
6220, 6221
Current Sources

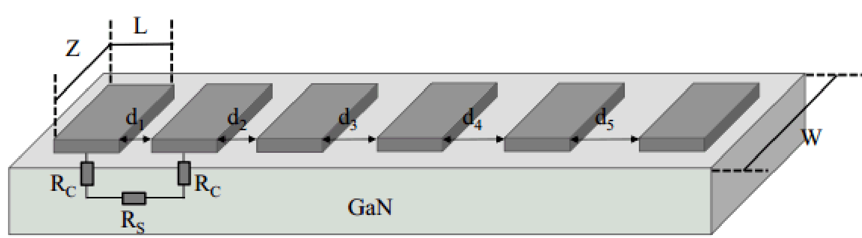
Atto	Femto	Pico	Nano	Micro	Milli	1	Kilo	Mega	Giga	Tera	Peta
10^{-18}	10^{-15}	10^{-12}	10^{-9}	10^{-6}	10^{-3}	10^{0}	10^{3}	10^{6}	10^{9}	10^{12}	10^{15}

Typical Applications in Semiconductor



Sheet Resistivity: Four-point probe





Contact Resistance: TLM

DC/AC儀器和系統
- 電源量測儀器 (SMU)

通用/中等功率

- 高穩定DC電源加上五位半多功能電錶
- 範圍包括1pA到10A、1μV 到200V
- 用於快速PASS/FAIL測試的內建比較器
- 可選的接觸檢查功能
- 特性分析和生產測試應用

低電流

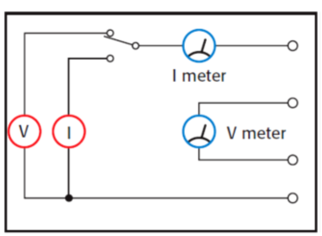
- 量測靈敏度達10aA、1μV
- 可選的脈衝功能
- 四至六位半解析度
- 電壓量測的輸入電阻達10^14/10^16歐姆
- 遠程前置放大器(6430)將線纜雜訊減至最小
- 測試粒子束、SET和超高電阻

高電流

- 最大電流範圍達5.25A
- 可選的每通道10A脈衝模式
- 30 至 1100W 功率輸出
- 精確時序和同步
- 並聯測試功能（2600系列)
- 測試高功率元件和IDDQ

高電壓

- 最大電壓檔位1100V
- 浮動輸出電壓高達±250V
- 四到五位半解析度
- 客戶自定掃描程序
- 測試電壓係數和高電壓元件

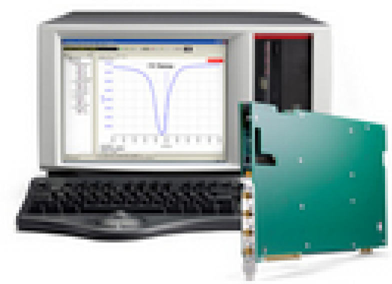


半導體測試系統和軟體
- 半導體參數分析儀

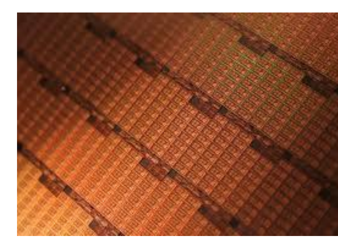
ACS基本版

- 半導體元件特性分析
- 失效分析
- 易於適應新技術應用
- 上百個標準元件測試庫
- 支援吉時利全系列數位電源電錶和更多設備

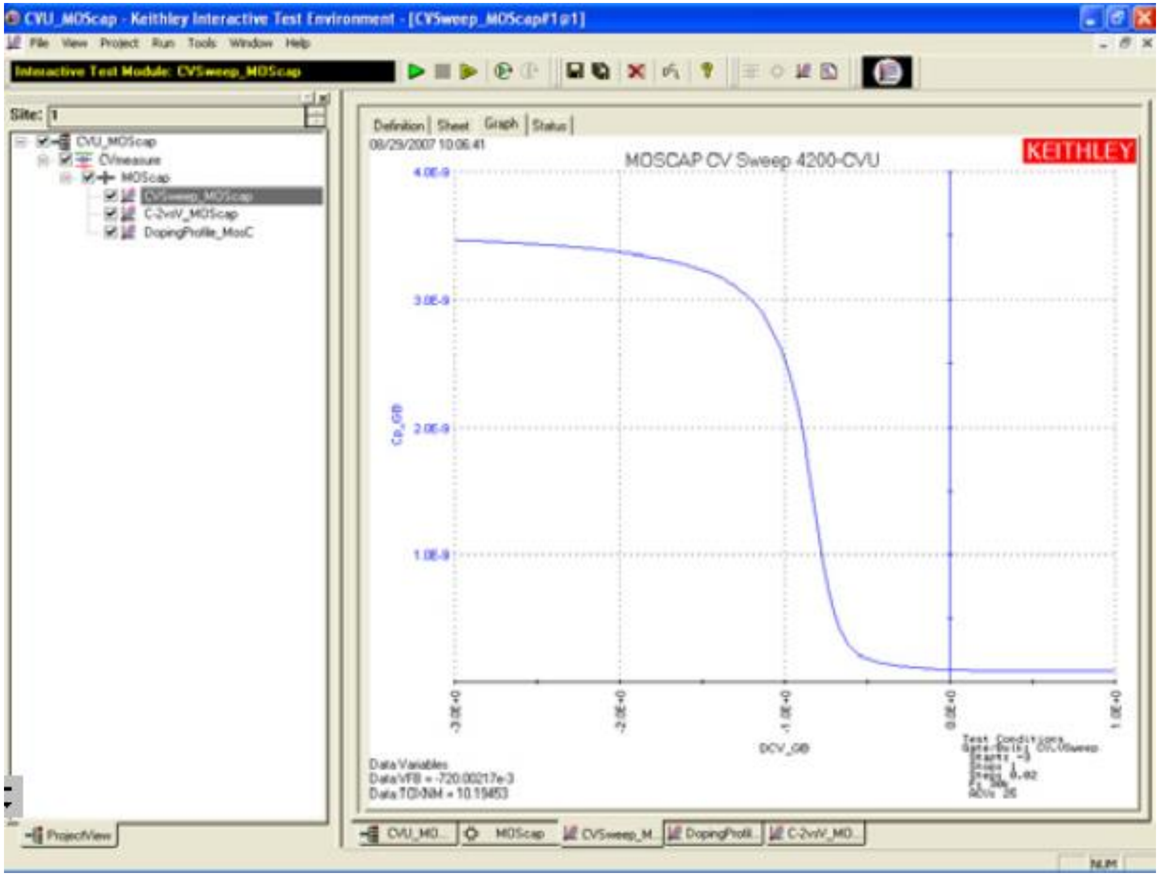
4200-SCS半導體參數分析儀



- 直覺式Windows人機使用界面
- 單儀器方案
- 具有I-V、C-V、脈衝產生功能以及脈衝I-V測試功能
- 包含支援各種技術的應用庫

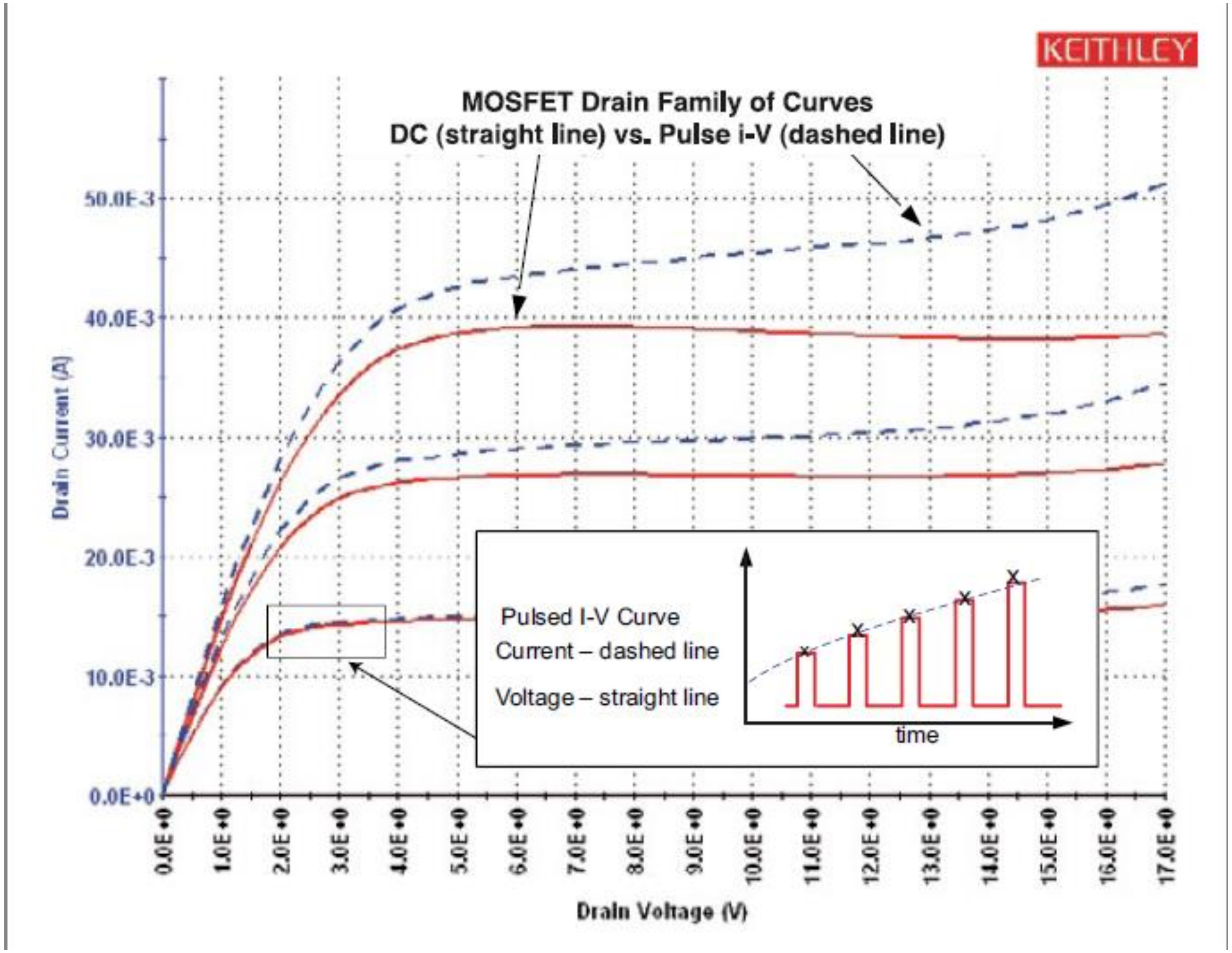


半導體參數分析儀 (K4200)
- Capacitance Voltage Unit (CVU)



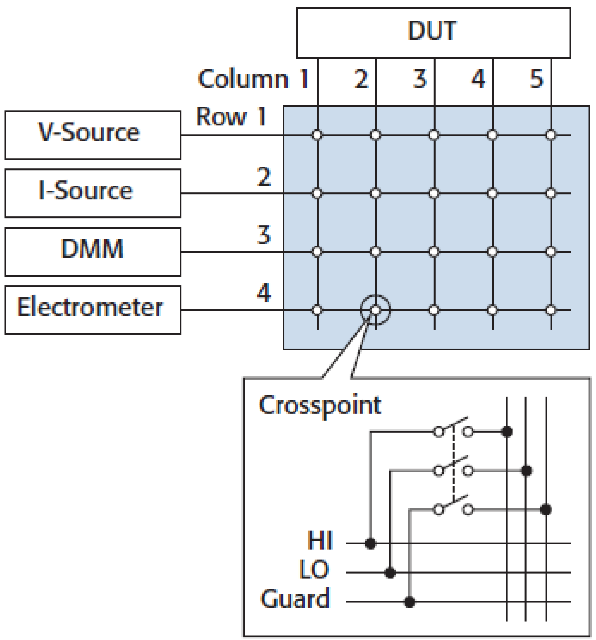
半導體參數分析儀 (K4200)

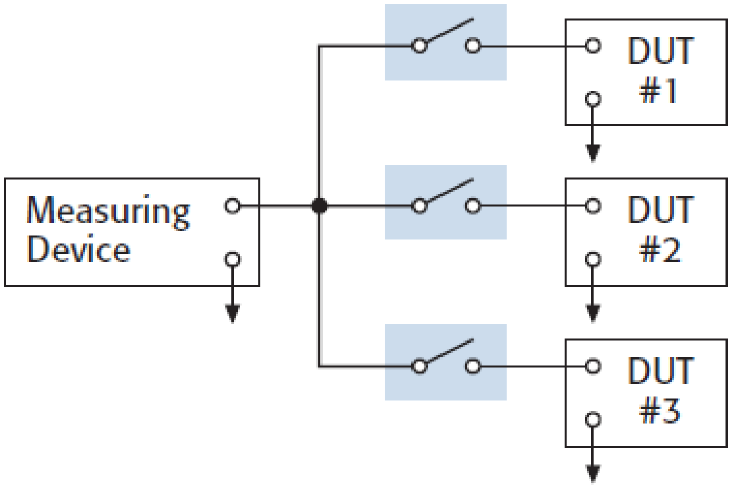
- Ultra High Speed Pulse Measure Unit (PMU; ns Level)



Self-heating effects on MOSFET

半導體測試系統和軟體
- 半導體開關系統 (K2700, K3706A, K707B)





Matrix System

Mux System

半導體測試系統和軟體
- 半導體自動參數測試系統

S530基礎

- 業界最高成本效益的自動參數測試儀
- 相容於常見的全自動探針系統
- 外部配線使探針界面的靈活性最大化
- 支援5英寸探針卡庫
- 成熟的儀器技術確保高量測精度和可重復性

S530低電流特性

- pA電流量測功能
- 低漏電流量測完整性
- 20W SMU最高可提供1A電流和200V電壓
- 可配置多達8個SMU和60個接腳
- 可選的轉接器擴展探針具有漏電流抑制能力
- 相容於常見的全自動探針系統
- C-V量測高達1MHz

S530高電壓特性

- 最高可提供10mA下1000V的電壓源
- 支援高壓漏電流和崩潰測試
- 低漏電流量測完整性
- 具有pA電流量測功能
- 20W SMU最高可提供1A電流和200V電壓
- 可配置最多7個SMU和32個接腳
- 可選的轉接器擴展探針具有漏電流抑制能力
- 相容於常見的全自動探針系統
- C-V量測高達1MHz

半導體測試系統和軟體
- 半導體自動參數測試系統 (Cont')

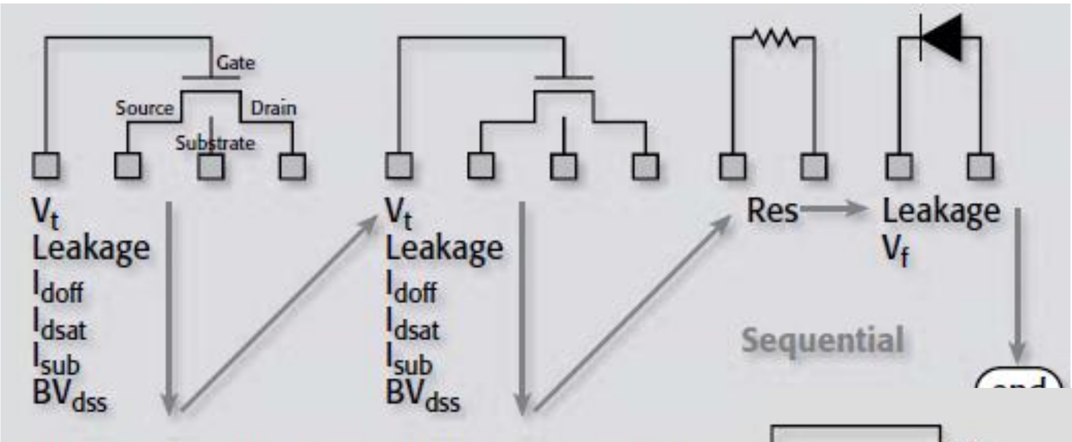


Figure 1-2. Schematic of a sequential mode test sequence.

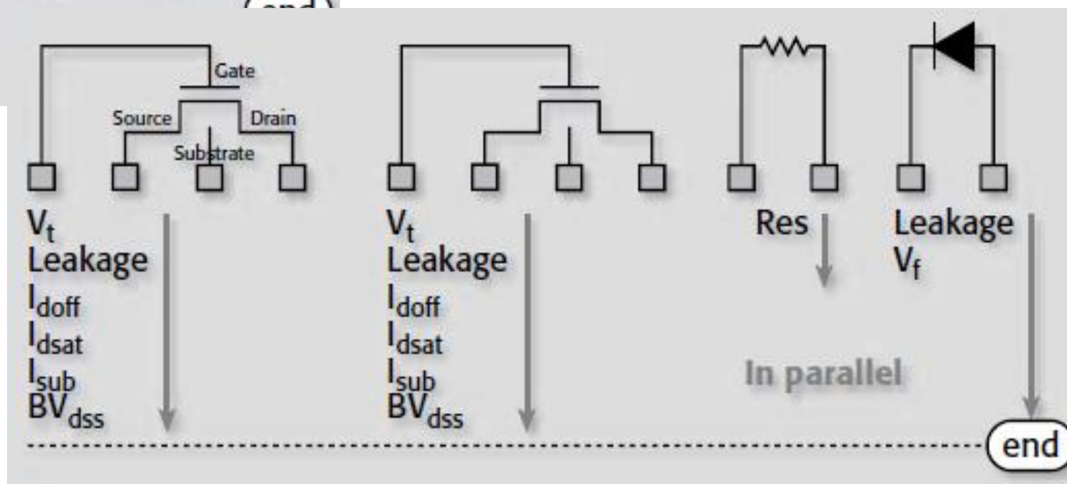
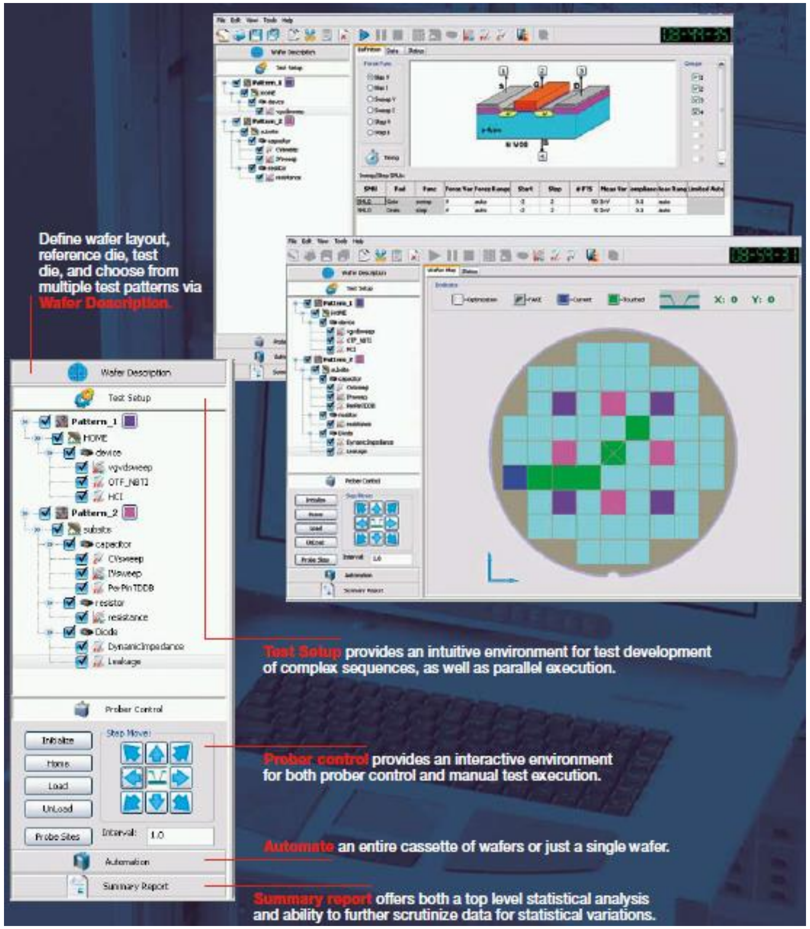


Figure 1-3. Schematic of a parallel test sequence.

半導體測試系統和軟體
- 半導體參數測試系統 (Cont')

ACS BASIC



Automated Characterization Suite (ACS)

常用配件
- IEEE-488/GPIB界面

PCI

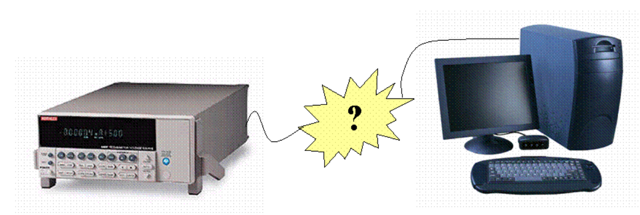
GPIB到PCI界面
33位元/33MHz
最高可控制14台設備
支援3.3V和5V
長達2m的連接長度

IEEE纜線和轉接器

單層屏障線
雙層屏障線
屏蔽轉接器
印表機轉接器

USB

GPIB到USB界面
1.8MB/s 速度
最高可控制14台設備
支援3.3V和5V
無需外接電源



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Market Drivers & Challenges

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Market Drivers

- **Green movement**
  - Improved energy efficiency
    - Motor drivers, power supplies, lighting (LEDs), IT (servers)
  - Energy generation and management
    - Alternate sources of energy such as solar and wind turbines
  - Energy regulation policies
    - Energy efficiency standards (voluntary and mandatory), Power Factor Correction (PFC) policies
- Increasing use of electronics in transportation industry
  - Power control elements in all vehicles
  - Critical for HEV/EV

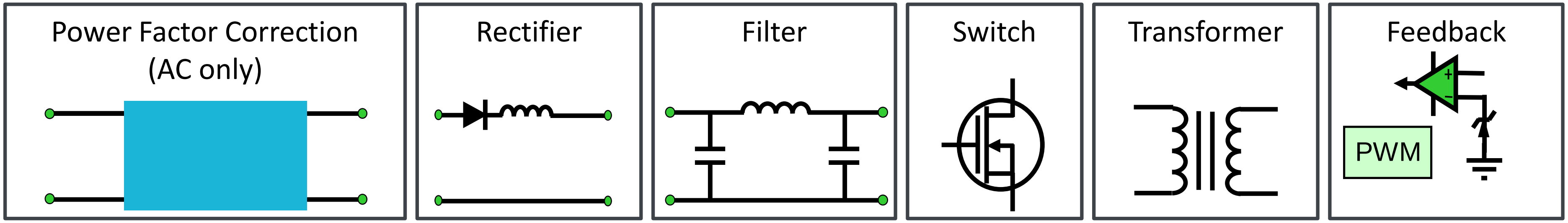
Power semiconductor devices are critical to all of the above!

So how does this relate to semiconductor devices?

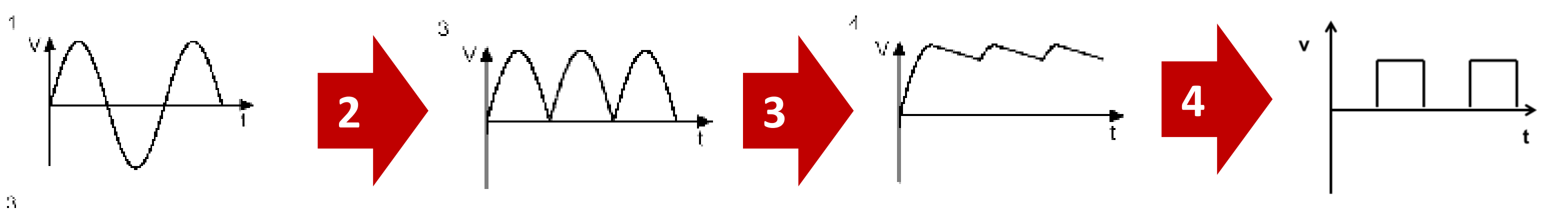
- Opportunities for energy efficiency improvement exist in products we interact with daily.
- **One of the most common products is the switch mode power supply (SMPS).**
- SMPS are more efficient and lighter weight than linear power supplies
  - Still, the SMPS accounts for >10% total system weight of PC. Making a more efficient SMPS will produce a lighter end product.
  - Still, lots of power is wasted in SMPS. Average desktop PC is only 50% efficient.

Diagram from On Semiconductor "Overview of Energy Efficient Solutions"

Similar Building Blocks for ***all Power Conversion***

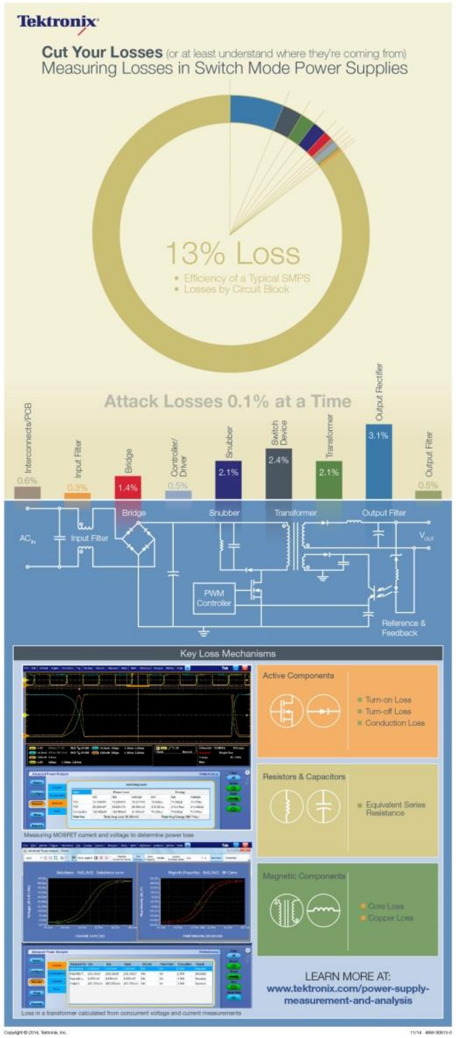


1. **Power Factor Correction**: Aligns voltage and current phase to make power delivery most efficient and minimize loss from the grid
2. **Rectifier**: Converts sine or square wave to a pulsating wave
3. **Filter**: Smooths the wave to DC
4. **Switch/Chopper**: Converts DC signal to a square wave
5. **Transformer**: Changes voltage level of the wave
6. **Feedback**: Adjusts output voltage to align with reference voltage

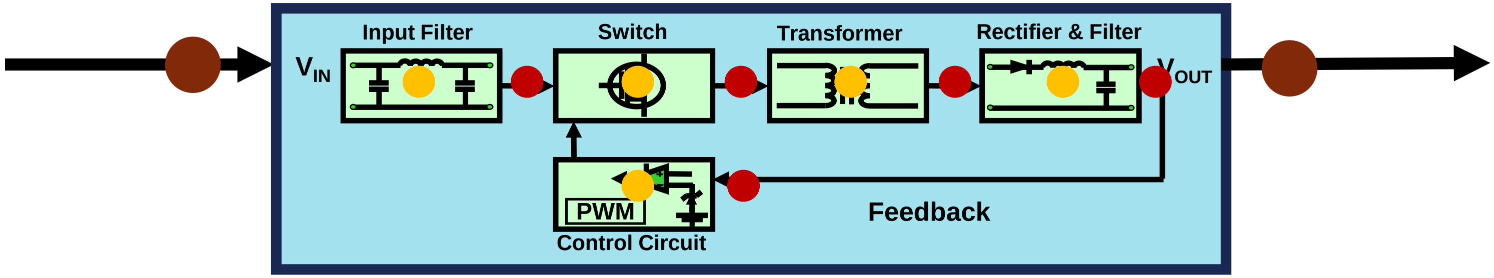


Improving Power Conversion Efficiency and Consumption

- How does a designer improve power conversion efficiency? 0.1% at a time!
  1. Choose **active components** with **minimal losses (e.g. Power Semiconductors)**
  2. Measure input and output power (P_{out}/P_{in})
  3. Measure losses and compare to expected results for **each component**
  4. Try **component changes** to see if losses decrease
  5. Try **circuit topology changes** to see if efficiency improves
  6. **Repeat** and **improve** the process many times for until specifications are met



End-to-End Power Design Solutions



Keithley Parametric Curve Tracers and SourceMeter® SMU Instruments

Tektronix Oscilloscopes and Power Probes

Tektronix Power Analyzers

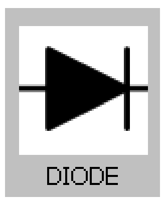
Device Evaluation & Selection

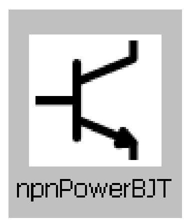
Design Troubleshooting

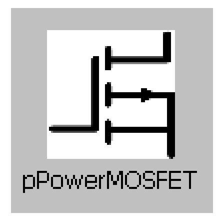
Final Design Testing & Compliance

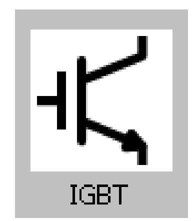
Power Semiconductor Devices - Overview

- The driving factors for lots of interest in power semiconductor performance improvements
- Role of semiconductor components in the switching power supply
  - **Diode**
  - **BJT**
  - **MOSFET**
  - **IGBT**



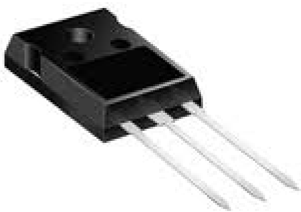


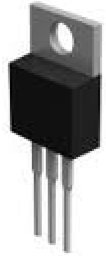




- Role of advanced materials in improving power semiconductor device performance

Power Semiconductor Devices - Background





Power semiconductor devices are in all areas of energy modification

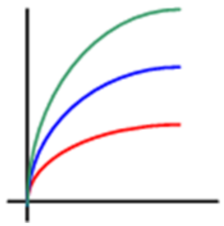
•AC to DC conversion (rectification): Happens almost every time an electrical device is plugged into a wall

•DC to AC conversion (inversion): Motor control, transporting bulk power (DC from solar panel to supply AC power within a company or residence)

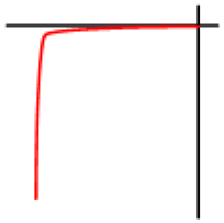
•DC to DC: Used for voltage regulation. Used often in mobile devices

•AC to AC: Changing voltage or frequency → light dimmer circuit

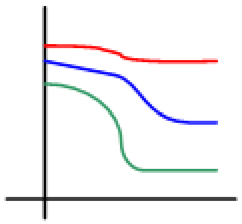
Power Semiconductor Device Testing



ON-State



OFF-State

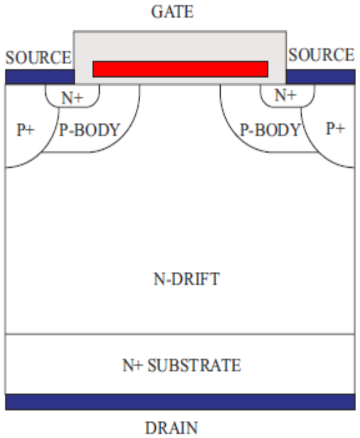


Capacitance-Voltage (C-V)

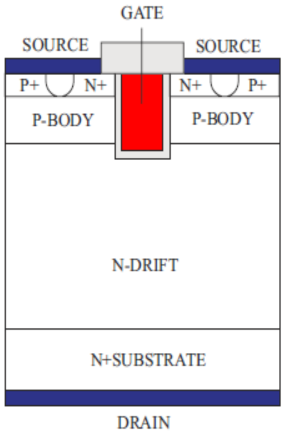
- Involves a variety of measurements
  - On-State
  - Off-State
  - Capacitance-Voltage (C-V)
  - Dynamic
- Requires voltage and current bias, and voltage and current measurements to fully characterize device

Next Generation Material for Power Device → Silicon Carbide (SiC) Power FET

- 碳化矽(SiC)、矽(Si)和氮化鎵(GaN)的熱傳導能力分別為1.5, 5以及2　Watts/ cm K；故SiC比Si和GaN擁有**更優異的熱傳導力**，使SiC在此特性上，很適合於高功率領域之應用。



- 由於SiC比Si有更高的操作溫度，故其元件**可以在更高接面溫度下作業**；同時可以在超過正常操作溫度下，維持低的導通電阻(R_{DSon})和元件的漏電電流。

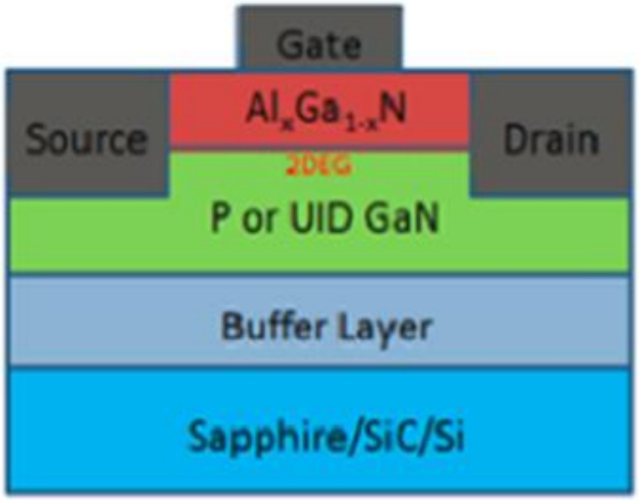


- **目前SiC的製程較GaN-on-Si困難**，主要是因為GaN在發光二極體(LED)與射頻(RF)元件的應用已行之有年，產業鏈與相關技術較為完整。

Diagrams from "High Temperature Electronics in Europe" report, Chapter 7 "High Voltage SiC Devices" by T. Paul Chow. Downloaded from http://itri2.org .

Next Generation Material for Power Device → Gallium Nitride (GaN) Power FET

- 氮化鎵(GaN)比Si和SiC有**更高的電子遷移能力，此特性具有更低的導通電阻，故可以最小化功率元件使用時之傳導損失(conduction loss)**。另外GaN可以在多種的基板上製作 。
- GaN為側向結構元件，有更快的開關切換速度，故十分適合於RF方面的應用；但側向元件先天上的崩潰電壓和元件製造的密度會較垂直型元件差一些。
- **2DEG (Two-Dimensional Electron Gas)為二維電子氣，具有更高速的電子遷移能力**，故非常亦適合高速功率元件驅動之應用。



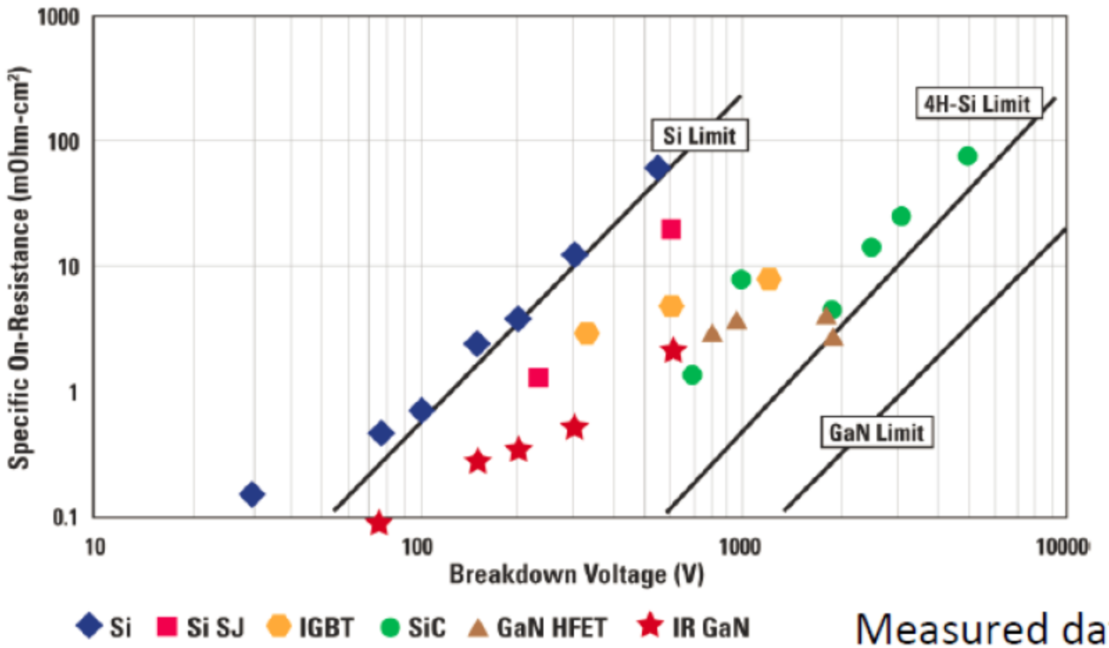
GaN HEMT structure

Diagram from "GaN Based FETS for Power Switching Apps" by Thomas Marron of Renesselaer Polytechnic Institute. Downloaded from http://homepages.rpi.edu/~sawyes/ .

SiC vs. GaN vs. Si Comparison

Materials Property	Si	SiC-4H	GaN
Band Gap (eV)	1.1	3.2	3.4
Critical Field 10^6 V/cm	.3	3	3.5
Electron Mobility (cm^2/V-sec)	1450	900	2000
Electron Saturation Velocity (10^6 cm/sec)	10	22	25
Thermal Conductivity (Watts/cm^2 K)	1.5	5	1.3

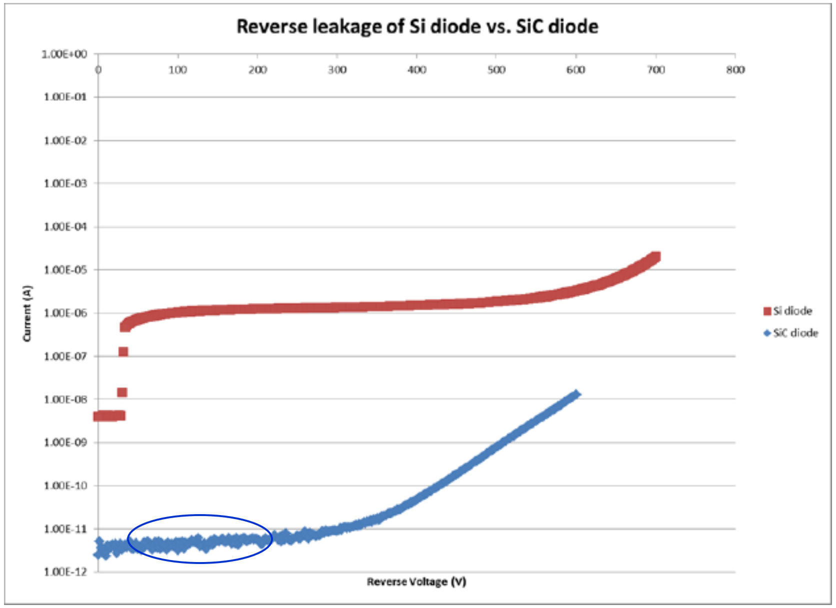
Comparison of R_{on} for Si, SiC, and GaN



Measured data

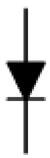
Si Diode vs. Wide Band Gap Device (SiC Diode) Comparison: Off-State Characterization

- Commonly performed at DC to achieve high accuracy leakage measurements
- Very low leakage measurement capability required for new wide bandgap technologies (GaN, SiC)
- Test equipment must be capable of generating high voltages and measuring low currents
- Variety of tests dictates both voltage and current source control



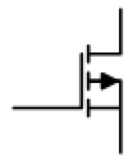
Typical Device Parameters

Diodes & Rectifiers



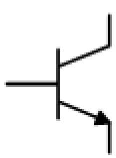
Forward Voltage (Vf)
Reverse Voltage (Vr)
Reverse Leakage (Ir)

MOSFETs & JFETs



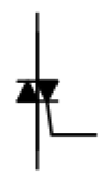
Family of Curves (Vds-Id)
Transfer characteristics (Vgs-Id)
On-resistance (Rdson)
Breakdown voltages (BVdss, BVdg)
Leakage Currents (Idss, Igss)

Bipolar transistors & IGBTs



Saturation Voltage (Vcesat)
Family of curves (Vce-Ic)
Breakdown voltages (Vceo, Vebo, Vcbo)
Leakage Currents (Iceo, Ices, Iebo)
DC Current Gain (hfe)

Triacs & SCRs etc.



Blocking voltages (Vdrm, Vrrm)
Leakage currents: (Idrm, Irrm)
Holding current (I_H)
Latching current (I_L)

Example: IGBT Transfer Characteristics

Source Meters can directly measure all MOSFET/IGBT parameters easily and automatically.

This allows for better device models, device matching, failure analysis, counterfeit component detection.

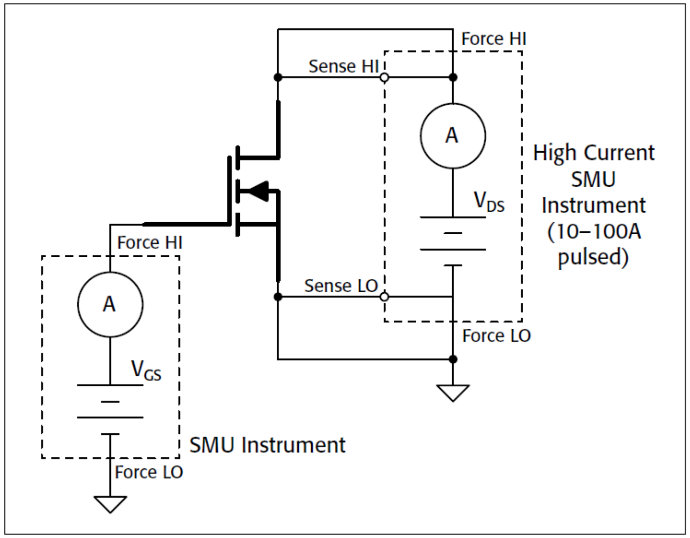


Figure 2. Typical SMU configuration for ON-state characterization of power devices.

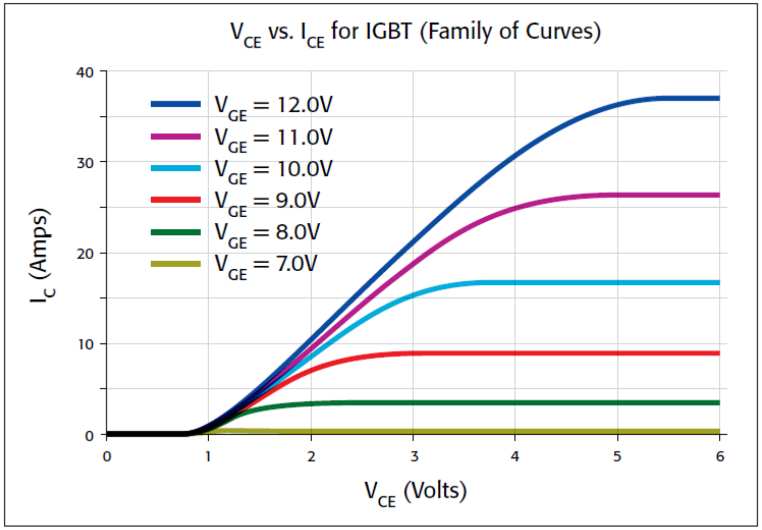


Figure 3. Measured output characteristics for commercially available IGBT.

Test Configuration

Test Results

Example: IGBT Transfer Characteristics (Sync Transient IV)

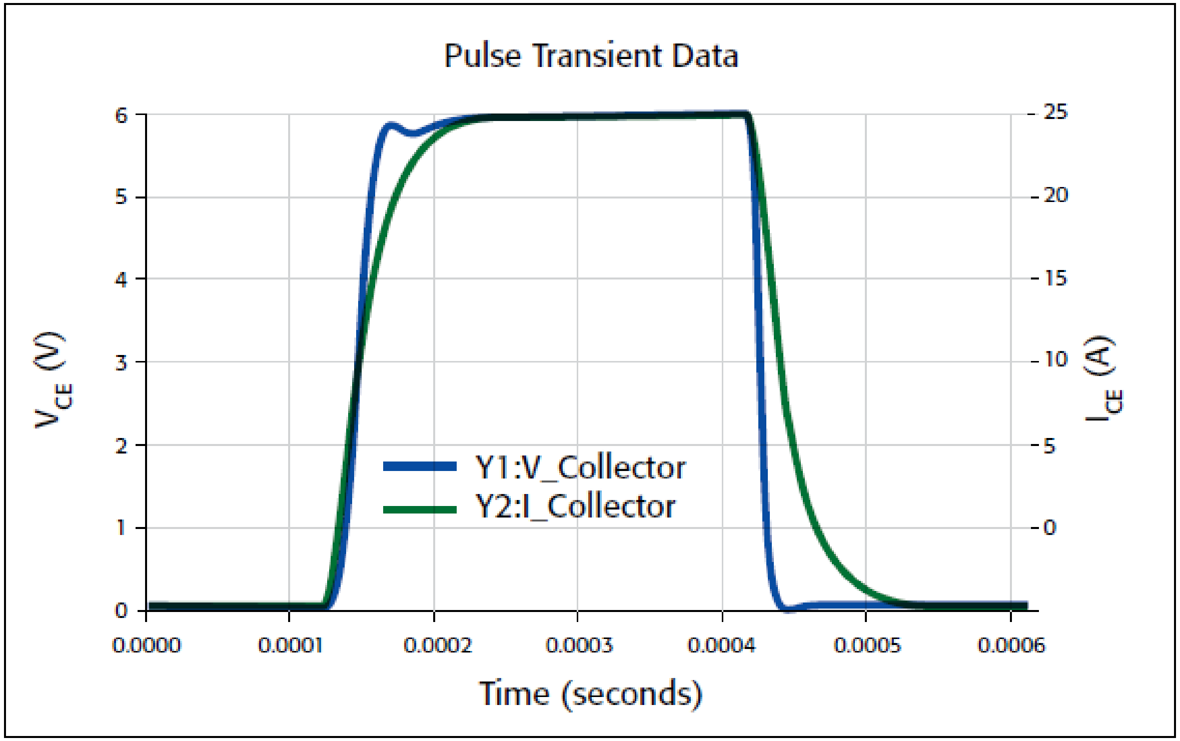


Figure 4. Pulse transient data of collector voltage and current vs. time for an IGBT.

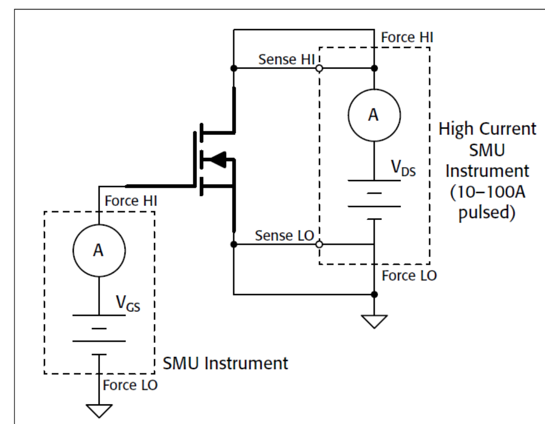
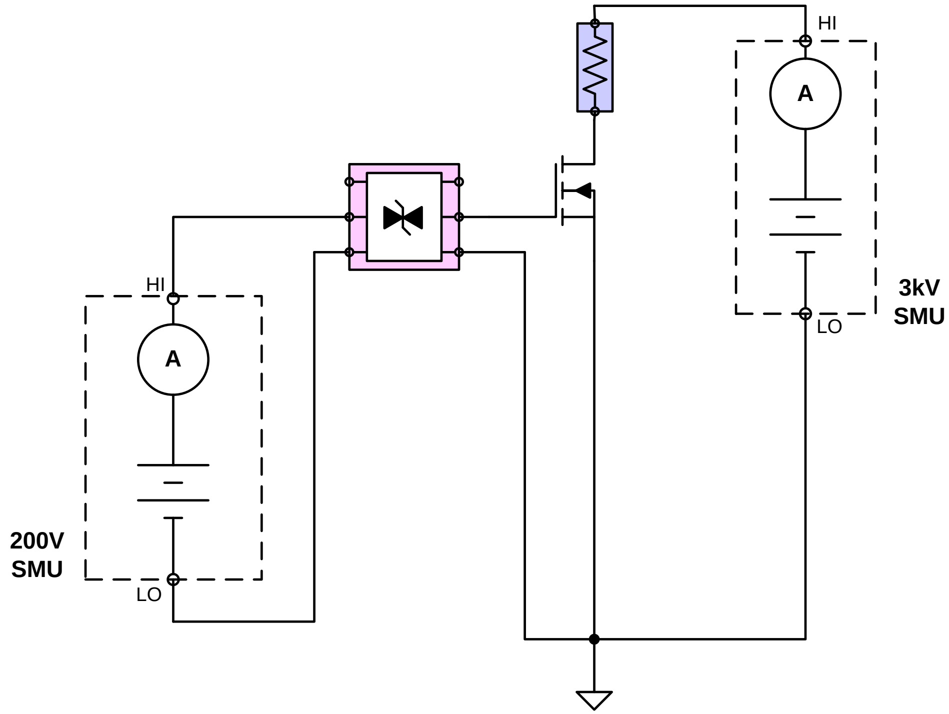


Figure 2. Typical SMU configuration for ON-state characterization of power devices.

Electrical Model for Off-State testing

- Off-State testing is generally thought of as a high voltage test. High resistance means very small current needs to be measured. A simplified electrical model might look like:



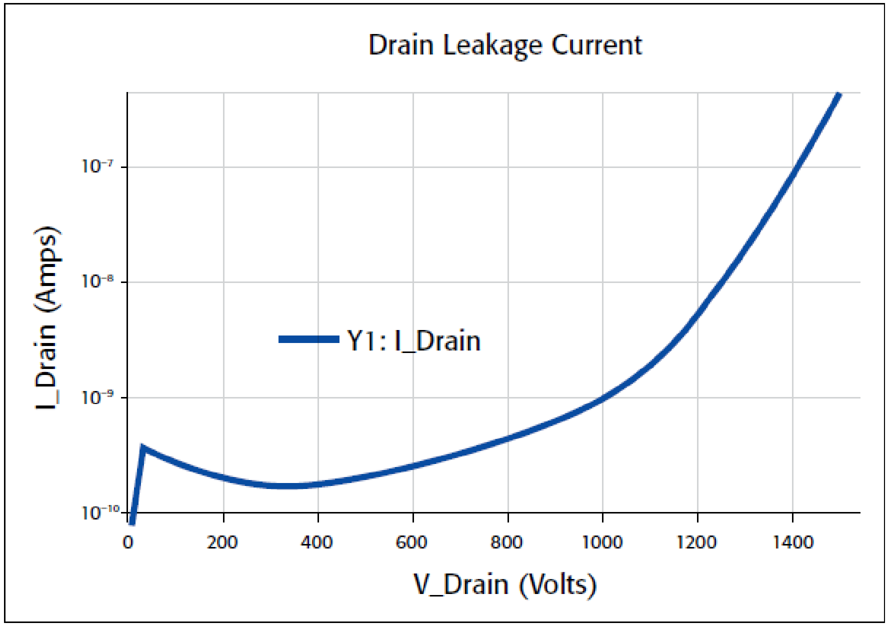


Figure 8. A look at the drain leakage current as the drain voltage is swept while the transistor is in the OFF state.

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Guard Technology for Low Leakage Current (e.g., pA level @ 3KV)

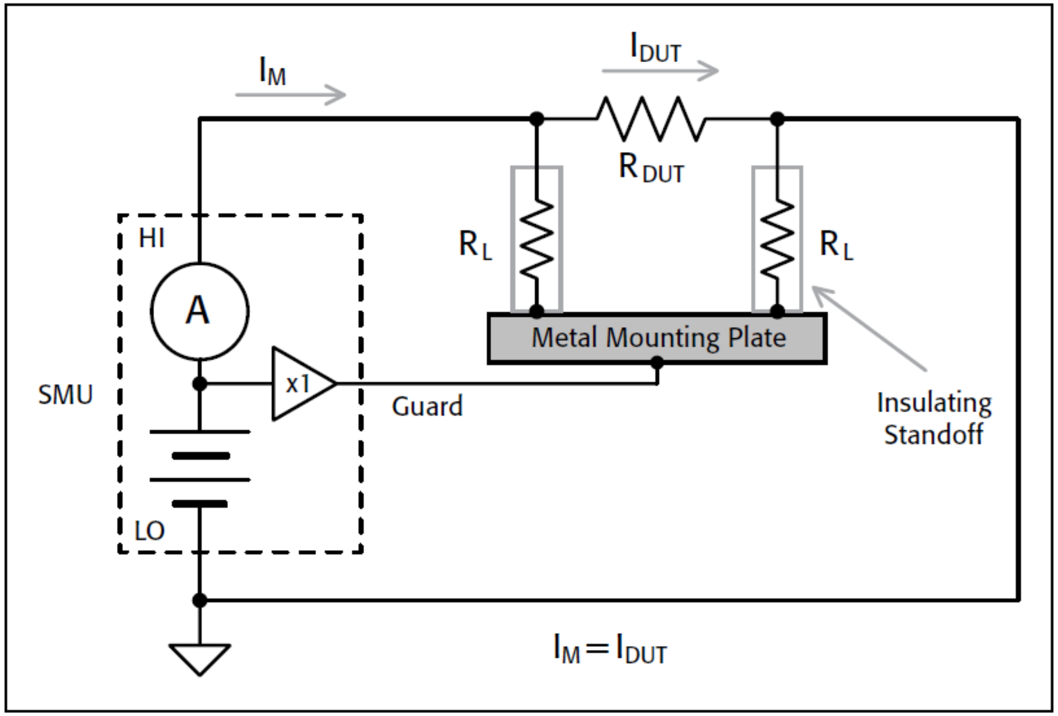
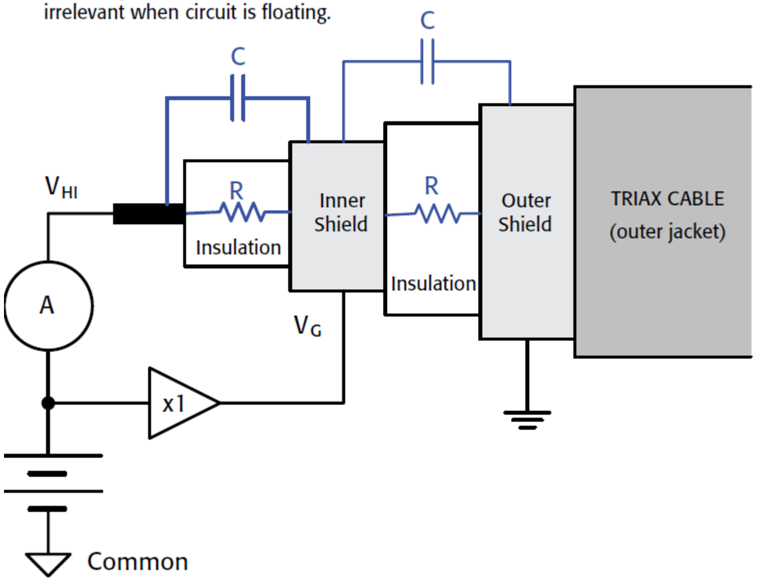


Figure 5. Guard is used to reduce leakage currents by reducing the voltage across the insulators in the circuit to nearly 0V. Any remaining leakage is routed away from the HI terminal where the measurement occurs.

Note: Capacitance of second insulator is irrelevant when circuit is floating.



Electrical Model for R_{dsON} testing

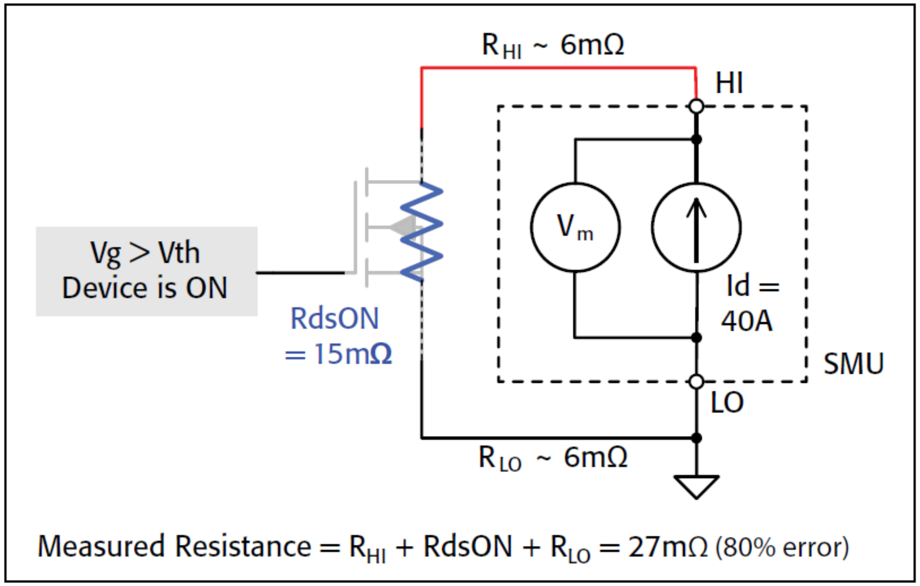


Figure 2. Resistance of test leads is large relative to the DUT resistance. Because the voltage measurement is made at the instrument's output terminals in a two-wire configuration, the measurement includes the sum of the test lead resistance and the DUT resistance.

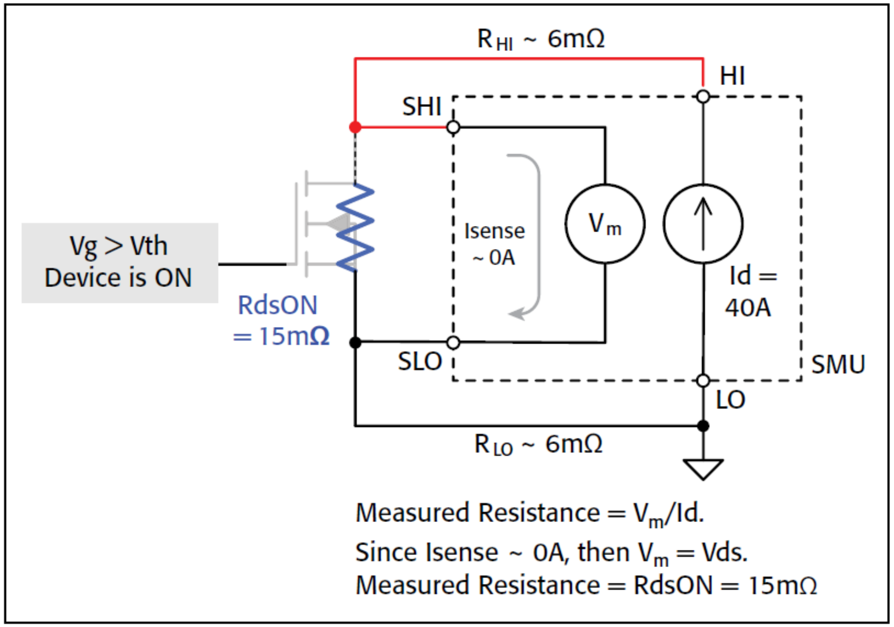
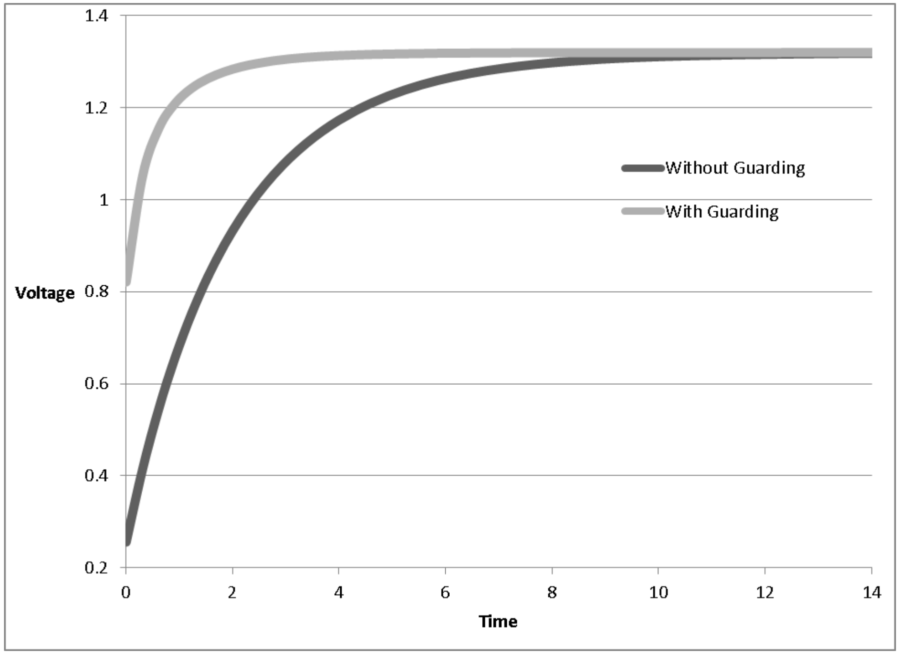


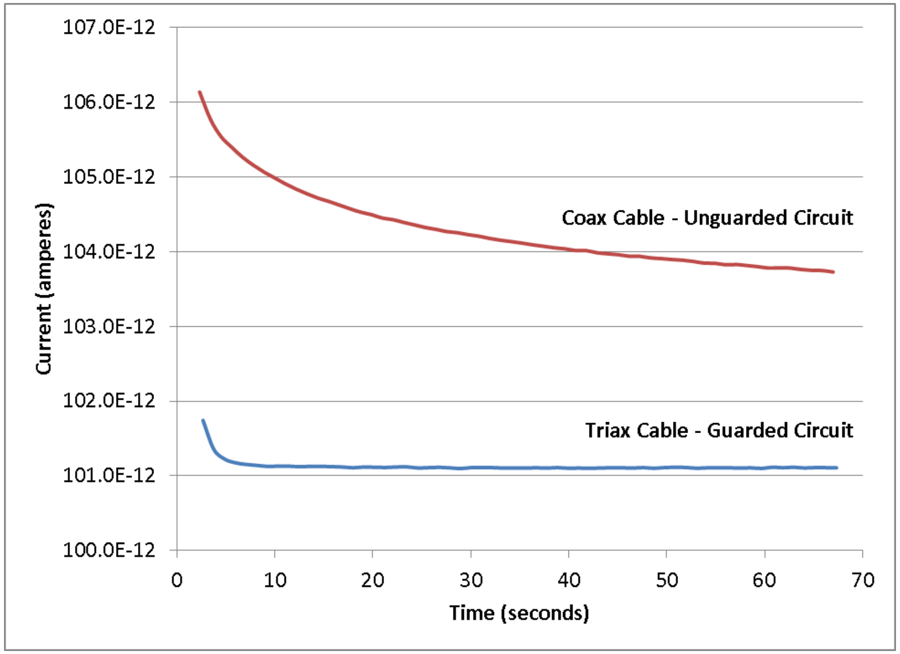
Figure 3. Use separate test leads to connect the device to the instrument's sense terminals. In this way, the voltage measured is only that across the device. The resulting resistance measurement will be a true measurement of the DUT resistance.

Optimizing Analog Measurements

Triax Cabling vs. Coax



Sourcing Voltage



Measuring Current

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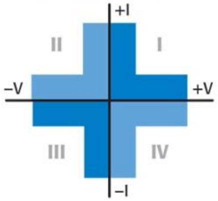
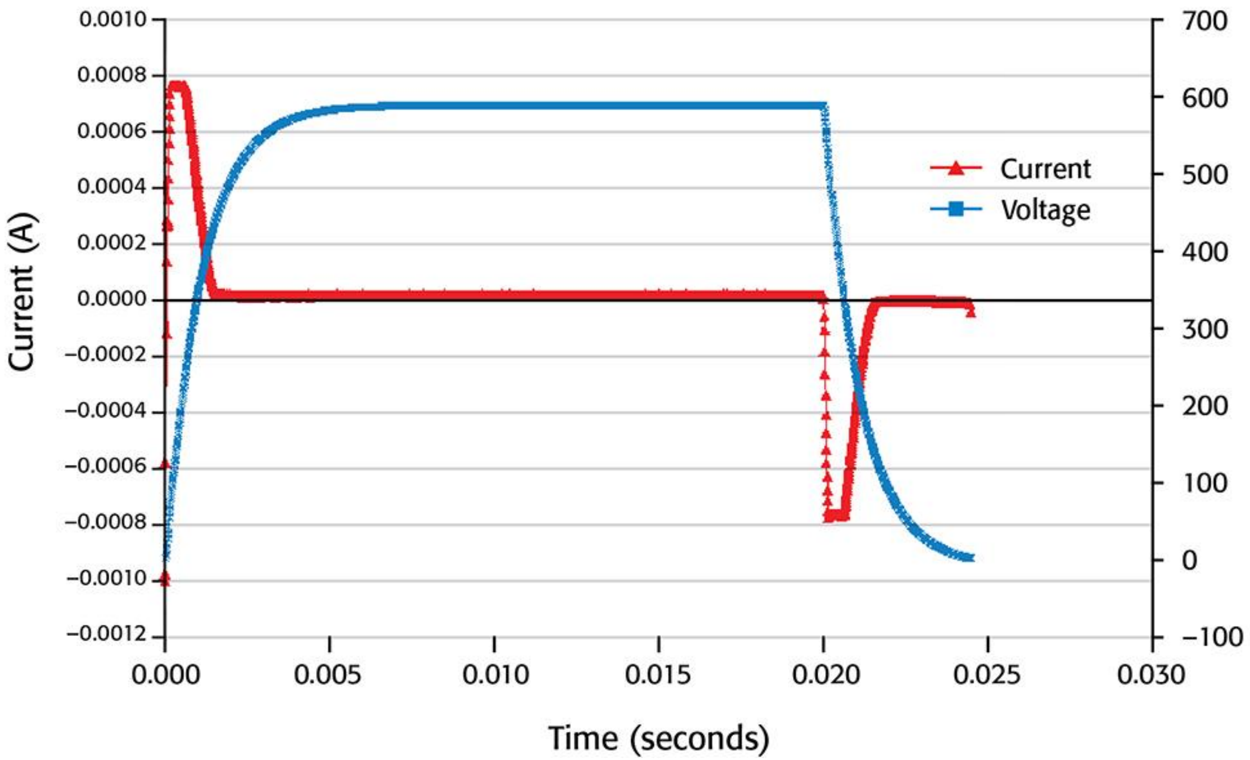
Optimizing Analog Measurements

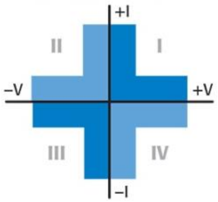


Four quadrant source measure unit (SMU) technology:



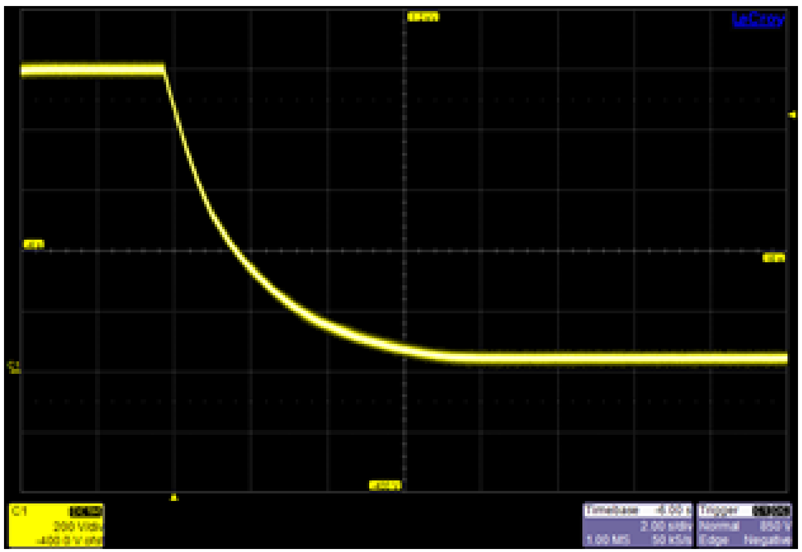
Note: Test data taken with Model 2657A's built-in digitizer

Optimizing Analog Measurements



Four quadrant source measure unit (SMU) technology:

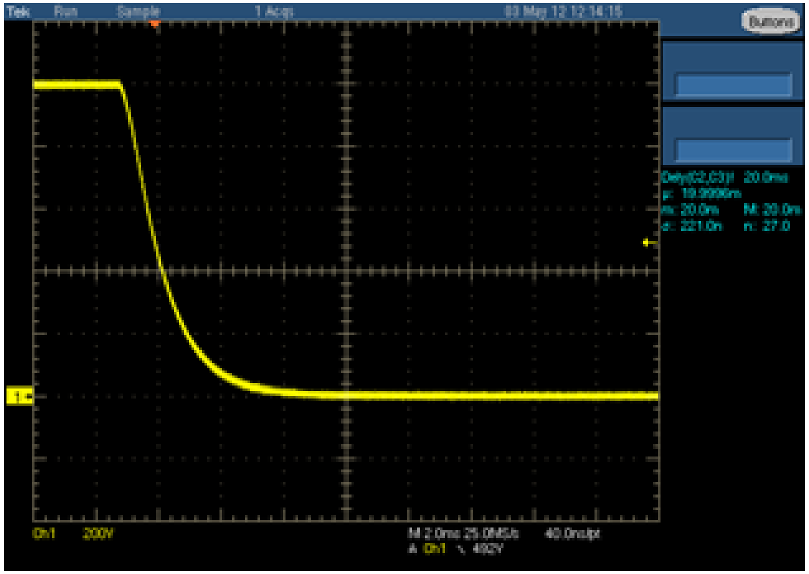
Charged a capacitor to 1000V. Then stepped voltage down to 0V. Scope used to capture capacitor discharge.



Using a Power Supply

Time scale = 2 sec / div

Total discharge time > 6sec



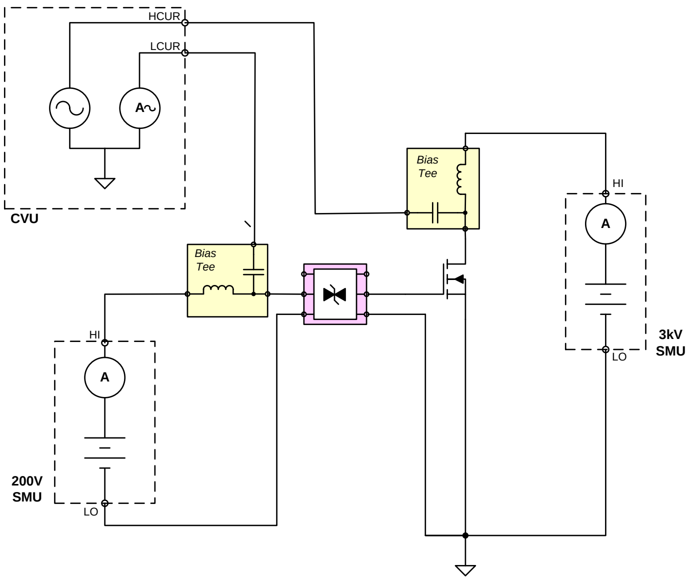
Using Model 2657A

Time scale = 2 msec / div

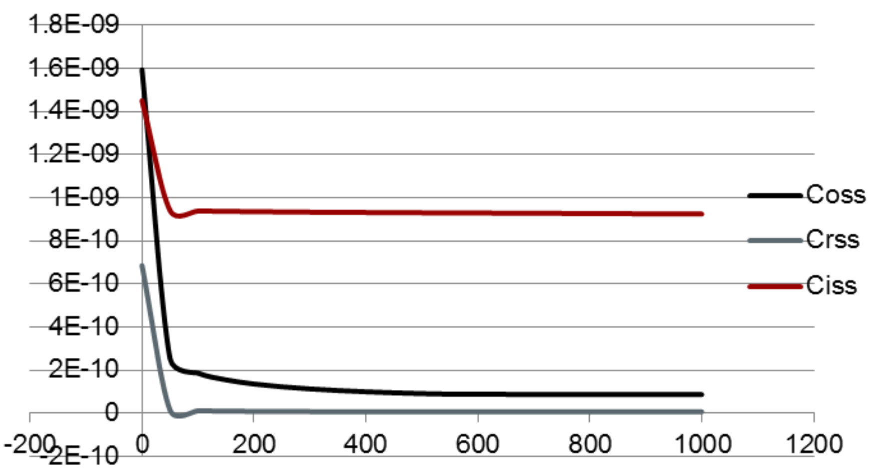
Total discharge time ~ 5msec

Example: Capacitance-Voltage Device Characterization

- High efficiency design of DC-DC and AC-DC converters requires detailed knowledge of all parasitic capacitance in the power transistors
- As the voltage on the transistor varies from zero to 3KV, the capacitance can change by many orders of magnitude
- Manufacturers typically specify capacitance to 10s of volts



C-V Test Configuration



Coss, Crss,Ciss on a SiC FET to 1KV

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Tektronix

Parametric Curve Tracer (PCT) Overview

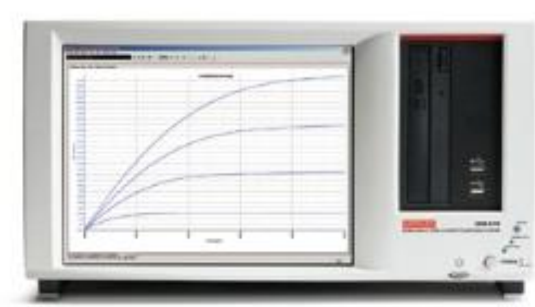
KEITHLEY

What is a Parametric Curve Tracer?

A configurable bench-top system for characterizing power devices

- Comprehensive solution including instruments, cables, software, test libraries, test fixture and/or prober interface
- Supports both *Parametric* and *Trace* test modes
- Includes the best of a Curve Tracer and a Parameter Analyzer

+



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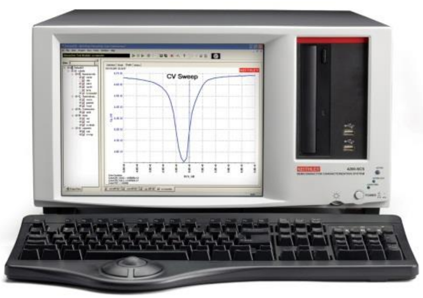
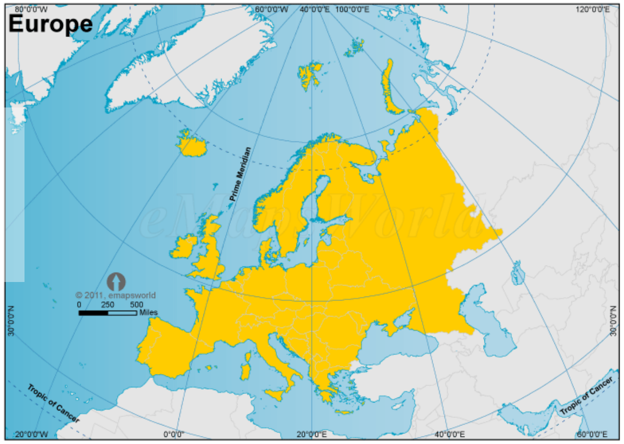
Semiconductor Test using Keithley

4200-SCS	Parametric Curve Tracer	S530, S500 & ACS
		
Semiconductor characterization system, single box solution with integrated test software	High power and highly flexible parametric curve tracer configurations with test software	Automated semiconductor device characterization and parametric test systems and software

Example of Parametric Curve Tracer

AIST, Denso, Fuji Electric, Hitachi, Mitsubishi Electric, Renesas, Rohm, Toshiba, Toyota



ABB, Azzurro, Bosch, Fraunhofer Institute, IMEC, Infineon, NXP, Semikron, ST Micro, Vishay,

Cree, EPC, Fairchild, GE Global Research, GeneSiC, International Rectifier (IRF), IXYS, Linear Technology, Microsemi, National Semi, OnSemi, RFMD, SemiSouth, TI, Transphorm, numerous universities and national labs

Keithley's Leadership in SMU Technology

Series 23x SMUs

1989

Series 2400 SourceMeter

1995

Series 2600 System SourceMeter

2005

Series 265XA HP SourceMeter

2012

Series 246X Touch SourceMeter

2015

- **20 patents issued for SMU-specific technology**
- **Numerous industry awards, including *R&D*100, *T&MW*, and more**
- **Thousands and thousands of customers**
- **Serving Semiconductor, Electronic Components, Optoelectronics, Automotive, Mil/Aero, Medical, Research & Education, and many more industries**

S500 and S530 Parametric Test Systems

Common Instruments for Semiconductor Device Testing?

Picoammeter

Power Supply

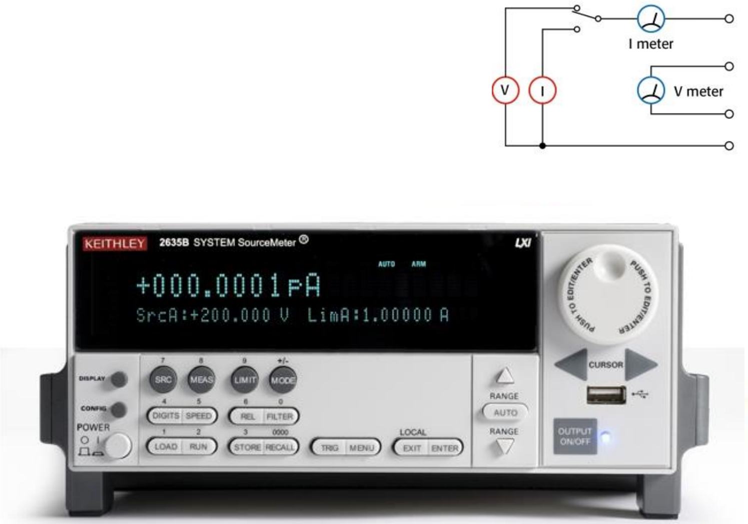
Current Source

Digital Multimeter

Electronic Load

Typical Equipment Rack for Device Testing

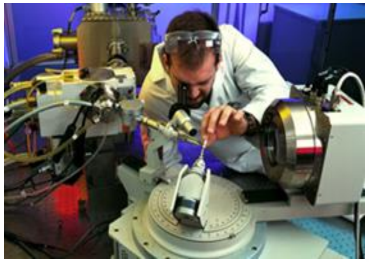
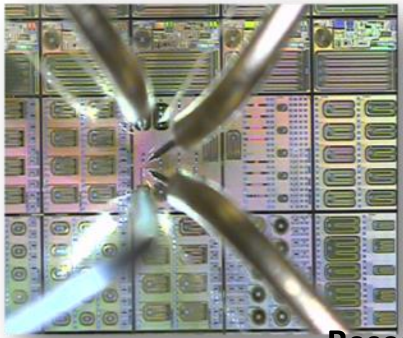
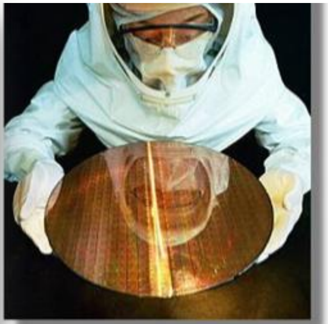
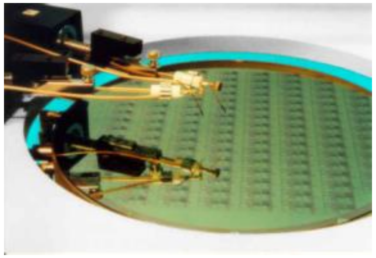
Which One Do You Want?



Well, it works.

It works well.

Semiconductor Test and the Parametric Curve Trace configurations


Research/technology involved in:

Research & Education Facilities

Integrated Circuits
Discrete & Power Components
Flat Panel Displays

Electronic Systems Manufacturers.
Consumers of discrete & power components)

- **Materials & Novel Device Research**
- **Device Development & Characterization**
- **Reliability Analysis**
- **Process Control Monitoring (PCM)**
- **Functional (Die Sort) Test**
- **Failure Analysis**
- **Incoming Inspection**

Target Customers & Apps for Parametric Curve Tracer

What's PCT (Parametric Curve Tracer)?

2600-PCT-xB

Ordering Information

2600-PCT-1B Low Power
2600-PCT-2B High Current
2600-PCT-3B High Voltage
2600-PCT-4B High Voltage and High Current

Accessories Supplied

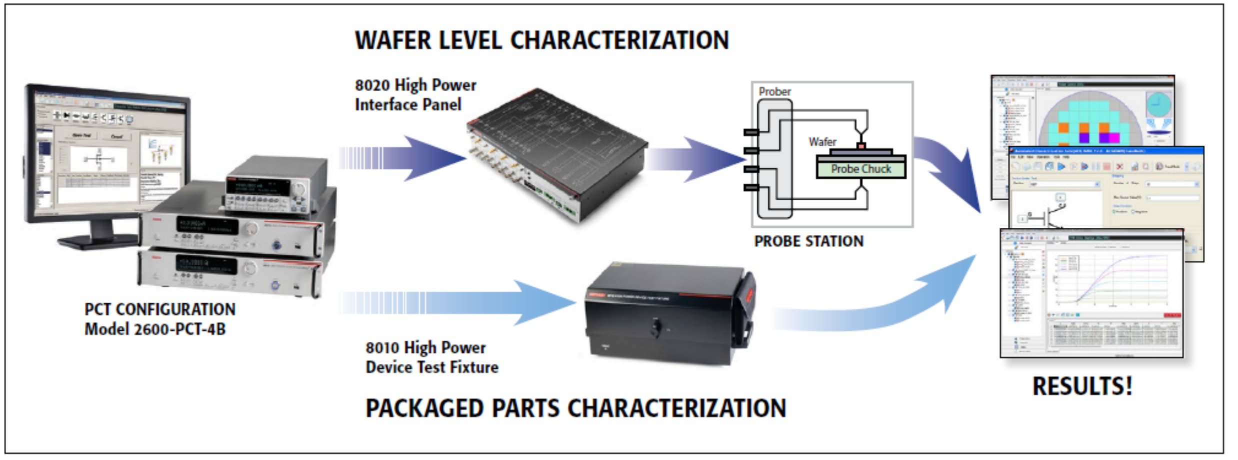
ACS Basic Component Test Software

KUSB-488B USB to GPIB Adapter

All cables and adapters for connecting to the 8010 Test Fixture or 8020 High Power Interface Panel

Note: PC and monitor not included; user must supply a Windows XP/7 PC with a USB port.

Parametric Curve Tracer Configurations



Keithley's Parametric Curve Trace configurations support both package part and wafer level testing.

Keithley's Parametric Curve Trace configurations are complete characterization tools that include the key elements necessary for power device characterization. The measurement channels consist of Keithley SourceMeter® Source Measure Unit (SMU) Instruments and an optional Multi-frequency capacitance-voltage (C-V) meter. The dynamic range and accuracy of these instruments is orders of magnitude beyond what a traditional curve tracer could offer.

PCT: Accessories Supplied (標配)

2600-PCT-xB

Ordering Information

2600-PCT-1B	Low Power
2600-PCT-2B	High Current
2600-PCT-3B	High Voltage
2600-PCT-4B	High Voltage and High Current

Accessories Supplied

ACS Basic Component Test Software

KUSB-488B USB to GPIB Adapter

All cables and adapters for connecting to the 8010 Test Fixture or 8020 High Power Interface Panel

Note: PC and monitor not included; user must supply a Windows XP/7 PC with a USB port.

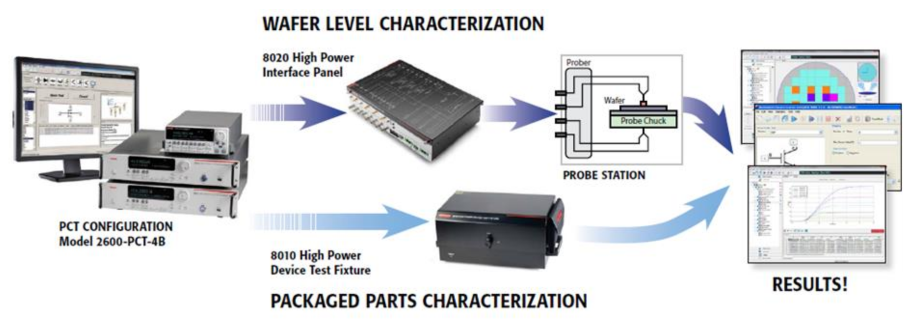
Accessories Available (選配)

ACCESSORIES AVAILABLE

2651A	High Power System SourceMeter (adds 50A to any system, max 100A)
2657A	High Power System SourceMeter (adds 3kV to any system, max of one unit per system)
K420	Workbench Cart Mobile cart for smaller PCT configurations
K475	Workstation Tower Mobile cart for all PCT configurations
PCT-CVU	Multi-frequency Capacitance-voltage (C-V) Meter
70161-MSA	Keyboard/Monitor Arm for K420 and K475 Carts
8020	High Power Interface Panel: Ideal for connecting to probe stations
8010	High Power Device Test Fixture

8010 OPTIONS

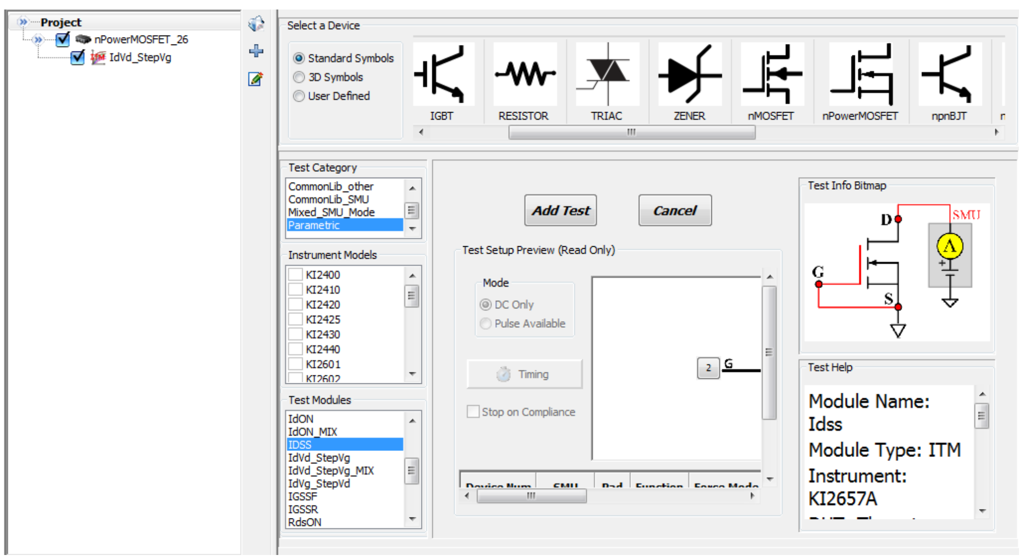
CVU-3K-KIT	Bias Tee kit for up to 3kV C-V
CVU-200-KIT	Bias Tee kit for up to 400V C-V
8010-CTB	Customizable Test Board
8010-DTB	Device Test Board with TO-247 socket
8010-DTB-220	Device Test Board with TO-220 socket
8010-DTB-CT	Device Test Board compatible with Tek curve tracer sockets

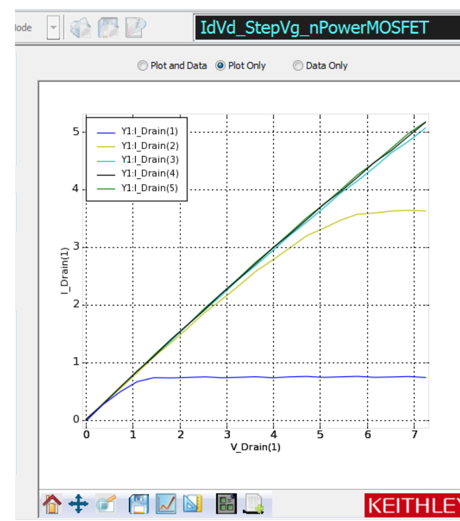


Power Semi Test Software

ACS BASIC, ACS

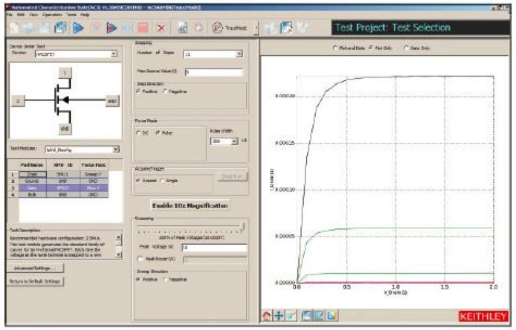
- ACS Software is the “glue” that brings all of the instruments together to make a solution
  - Supports Series 2400, 2600, and 4200 SMUs
- Includes hundreds of built-in device test libraries





Keithley PCT
- What is a Parametric Curve Tracer?

A configurable benchtop system for characterizing power devices



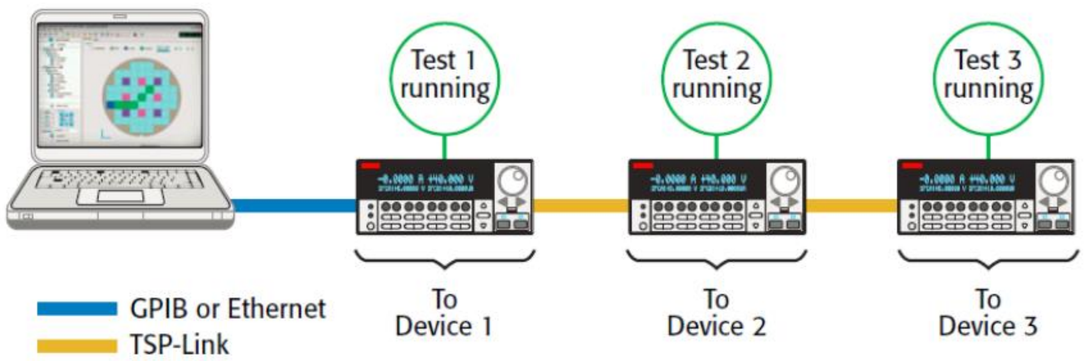
- Comprehensive solution including instruments, cables, test fixture, software, test libraries, and sample devices
- World Class measurements to **3KV** and **100A**
- Cost-effective
- Easy field upgrades, scalable and re-configurable
- Supports both *Parametric* and *Trace* test modes

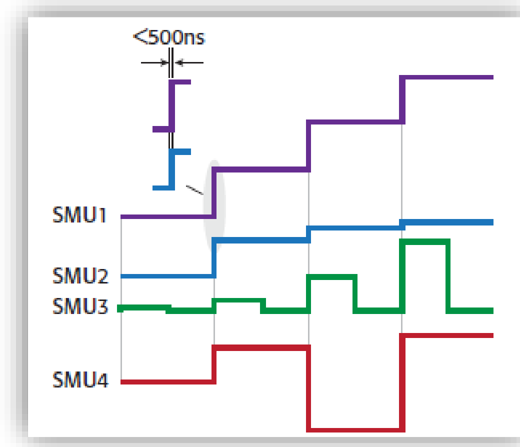
Keithley Parametric Curve Tracer Configurations

Model 2600-PCT-4

Model 4200-PCT-4 on K420 Cart

Series 2600B and 2650A SMUs – Flexibility and Speed





- Each SMU is a completely independent instrument
  - Can be used alone or as a component of a larger system
- Virtual backplane (TSP-Link) includes enhanced communication and triggering features
  - Nearly simultaneous synchronization between instruments on the backplane

Series 2600B and 2650A SMUs

Model 2636B SMU

- Two independent SMU channels
- Up to 200V
- Up to 10A pulsed
- 0.1fA measurement resolution

Model 2651A SMU

- Up to 50A pulsed (up to 100A with 2 units)
- Up to 2000W pulse / 200 W DC power
- Pulse widths from 100us to DC
- High speed and integrating ADCs

Model 2657A SMU

- Up to 3000V, Up to 180W of power
- 4-Quadrant operation (source and sink power)
- 1fA measurement resolution
- High speed and integrating ADCs

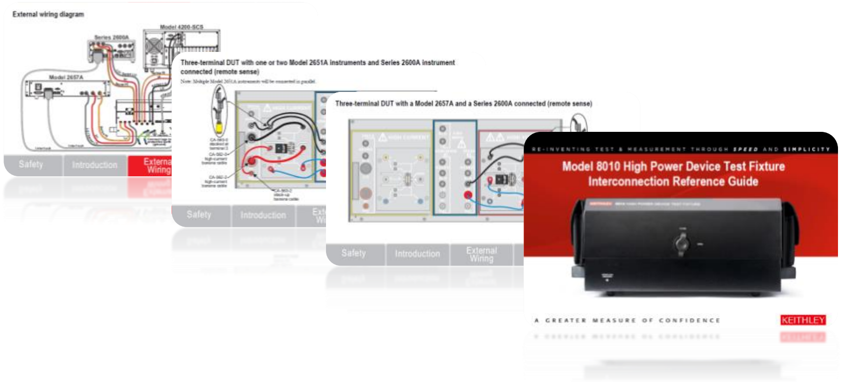
Typical Power Transistor Parameters

Parameter	Symbol	Test Method [1]	Maximum Range	Typical Best Resolution	Typical Accuracy
Breakdown Voltage	Bvdss, Bvceo	Id–Vd or Id (pulse)	±3000 V [2]	100 µV, 10 fA	0.05% rdg + 0.05% rng
On-State Current (DC)	Vdson, Vcesat, Vf	Id–Vd	±20 A [4] , Optional: ±40 A [4]	100 nA, 1 µV	0.05% rdg + 0.05% rng
On-State Current (Pulse)	Vdson, Vcesat, Vf	Id–Vd	±50 A [4], Optional: ±100 A [4]	100 µA, 1 µV	0.05% rdg + 0.05% rng
Drain/Collector Leakage Current	Idss, Ir/Icbo, Iceo	Id–Vd	±20 mA @ 3000 [2, 5]	10 fA, 1 µV	0.2% rdg + 1% rng
Gate/Base Leakage Current	Igss, Ib	Ig–Vg	±1 A or, ±10 A Pulsed [3]	10 fA, 1 µV	0.2% rdg + 1% rng
On-State Threshold Voltage or Cutoff Voltage	Vth, Vf, Vbeon, Vcesat	Id–Vg	±200 V [3]	10 fA, 1 µV	0.2% rdg + 0.5% rng
Forward Transfer Admittance or Forward Transconductance	|yfs| Gfs, Hfe, gain	Vd–Id @ Vds	1 ms ~ 1000 s [6]	1 pA, 1 µV	1%
On-State Resistance	RDS(on), Vcesat	Vd–Vg @ Id	<100 µΩ [7]	10 µΩ, 1 µV	1%
Input Capacitance	Ciss	C–V 100 kHz	10 nF [8] ±200 V	10 fF, 10 µV	Better than 1% at C<10 nF
Output Capacitance	Coss	C–V 100 kHz	10 nF [8] ±200 V	10 fF, 10 µV	Better than 1% at C<10 nF
Reverse Transfer Capacitance	Crss	C–V 100 kHz	10 nF [8] ±200 V	10 fF, 10 µV	Better than 1% at C<10 nF

1. Test method used for extracting the parameter. Only typical MOSFET listed, but similar method for other devices.
2. Model 2657A High Power System SourceMeter® SMU Instrument.
3. Model 2636A SourceMeter SMU Instrument or Model 4210-SMU.
4. Model 2651A High Power System SourceMeter SMU Instrument or optional dual Model 2651A High Power System SourceMeter SMU Instruments.
5. Maximum 20mA at 3000V, 120mA at 1500V.
6. Typical extracted capability (Example: 1mA/1V ~ 1A/1mV).
7. Typical extracted capability (Example: 1mV/10A).
8. Max. ±200VDC (±400VDC differential) bias with 4210-CVU and 4200-CVU-PWR.

Model 8010 Test Fixture

- Provides safe environment for testing at 3kV and at 100A
- Includes test sockets for TO-220 and TO-247 packages and custom devices.
- Easy to use banana connections
- Includes laminated, full-color connection guide

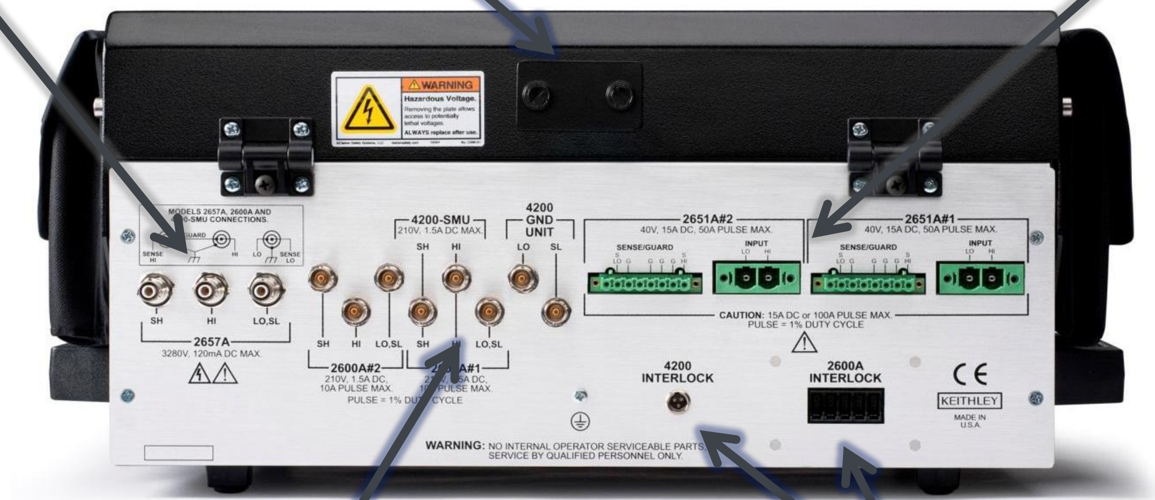


Connections to the Model 8010 Test Fixture

Connect one Model 2657A for **3kV** and **low current (pA)** testing

Access port for routing external instrumentation (scope probes, thermocouples)

Connect two Model 2651As in parallel for **100A** pulsed testing



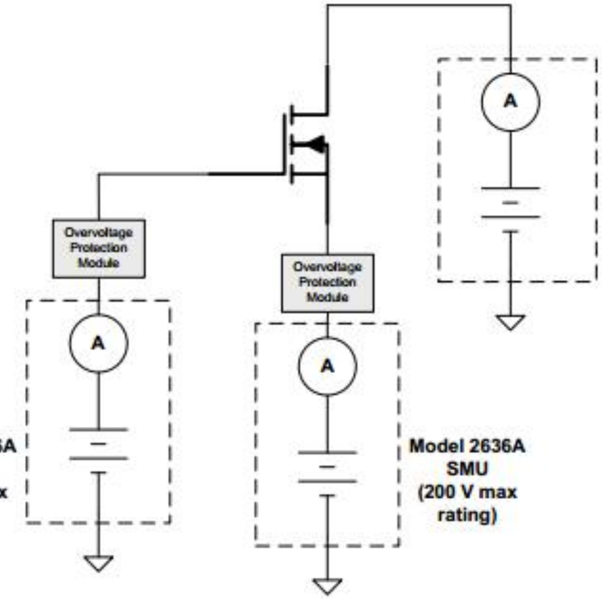
Connect up to two Model 2636Bs or Model 4200 SMUs for 200V and low current (pA) testing

Connections to SMU interlocks. Disables high voltage outputs of SMUs when test fixture is opened.

Protect Your Instrument if Device Is Failed

Overvoltage protection modules ensure that the lower voltage instrument is protected if device failure results

Model 2657A-PM-200
Protection Module

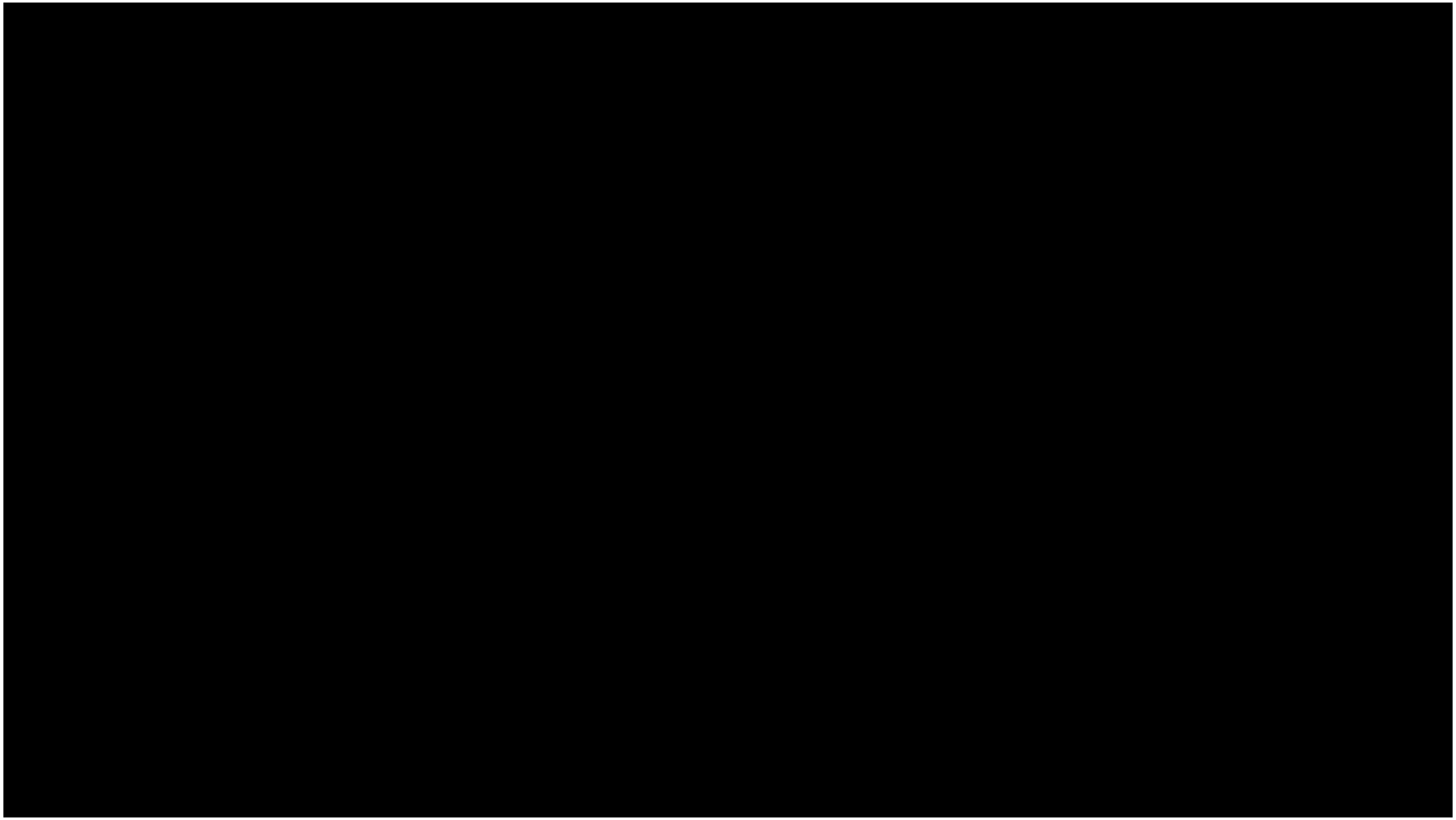


Note: K8010 test fixture is built in the protection module.

K2651A: Pulse 100A Demo

K2657A+K8010: Breakdown Test

K8020: Prober Integration



Keithley Parametric Curve Tracer Demo

- Parametric Mode (Toshiba TK12A60U)

Electrical Characteristics (Ta = 25°C)

Characteristics	Symbol	Test Condition	Min	Typ.	Max	Unit
Gate leakage current	I_{GSS}	V_{GS} = ±30 V, V_{DS} = 0 V	—	—	±1	μA
Drain cut-off current	I_{DSS}	V_{DS} = 600 V, V_{GS} = 0 V	—	—	100	μA
Drain-source breakdown voltage	$V_{(BR)\ DSS}$	I_D = 10 mA, V_{GS} = 0 V	600	—	—	V
Gate threshold voltage	V_{th}	V_{DS} = 10 V, I_D = 1 mA	3.0	—	5.0	V
Drain-source ON-resistance	$R_{DS\ (ON)}$	V_{GS} = 10 V, I_D = 6 A	—	0.36	0.4	Ω
Forward transfer admittance	$\|Y_{fs}\|$	V_{DS} = 10 V, I_D = 6 A	2.0	7.0	—	S

Characteristics		Symbol	Rating	Unit
Drain-source voltage		V_{DSS}	600	V
Gate-source voltage		V_{GSS}	±30	V
Drain current	DC (Note 1)	I_D	12	A
	Pulse (Note 1)	I_{DP}	24	

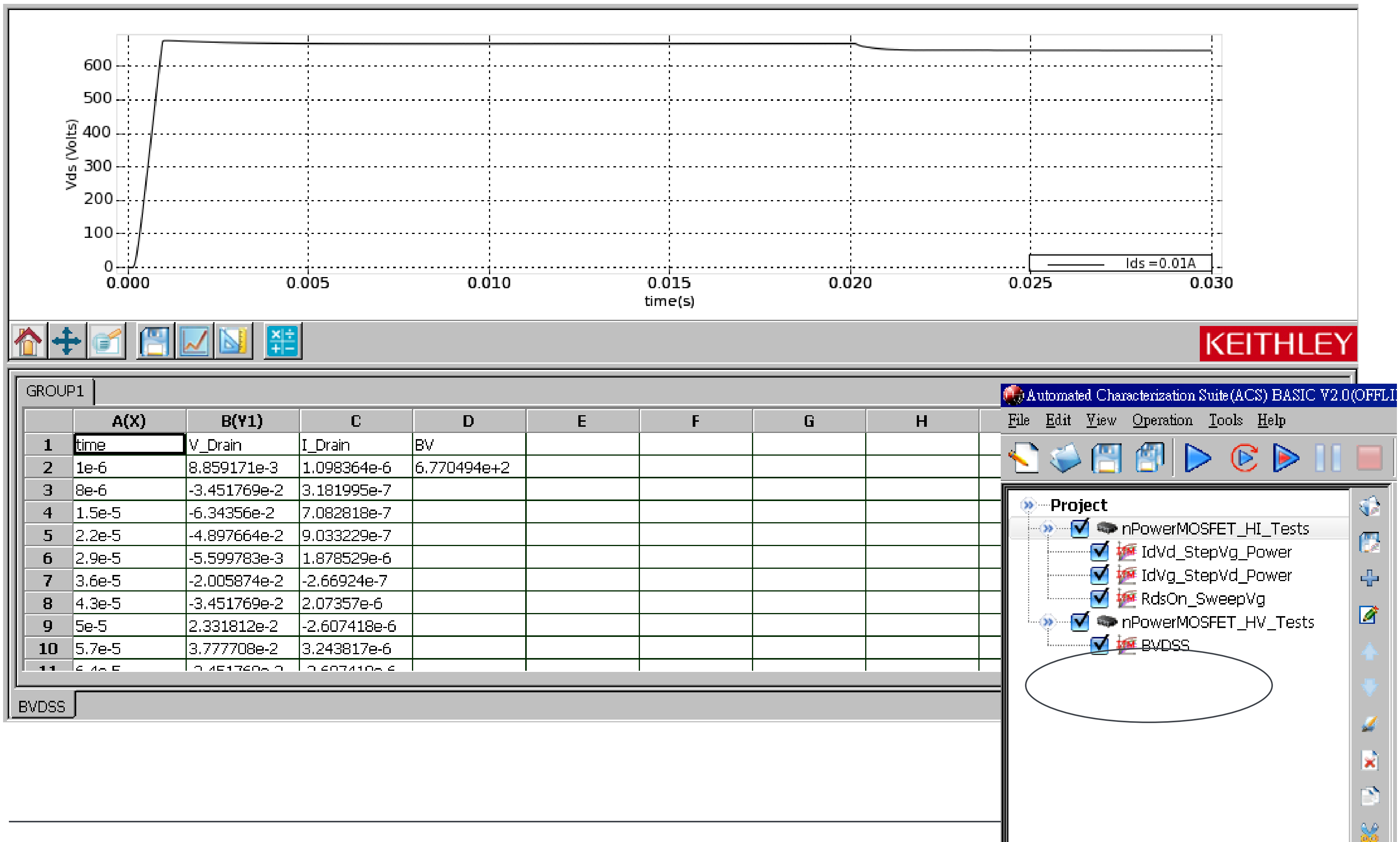
D: K2657A (Hi V; 3KV)

D: K2651A (Hi I; 50A Pulse)

G: K2635A (Hi P)

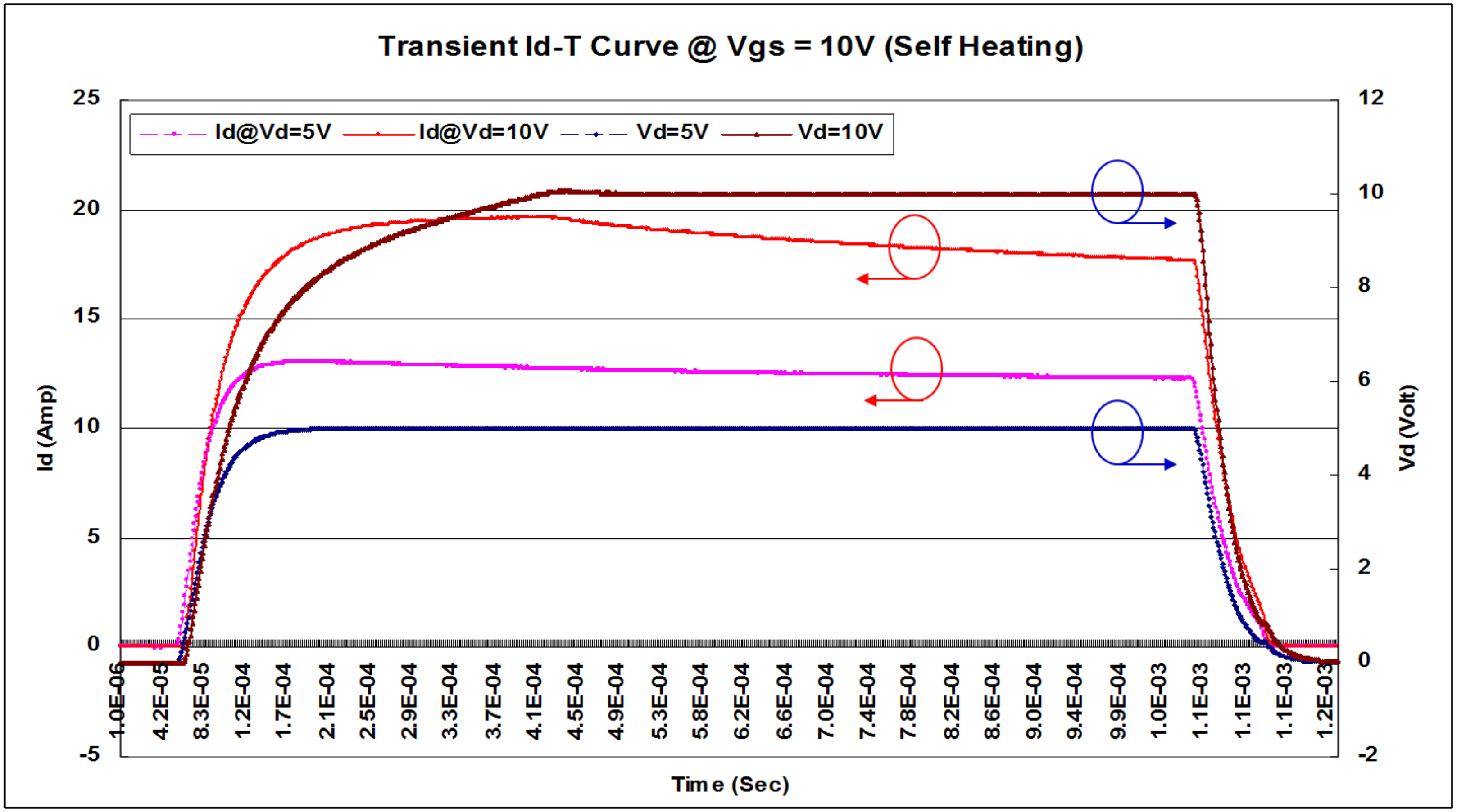
Keithley PCT Demo

- Parametric Mode (Ex. V_{BRDSS}, Toshiba TK12A60U)

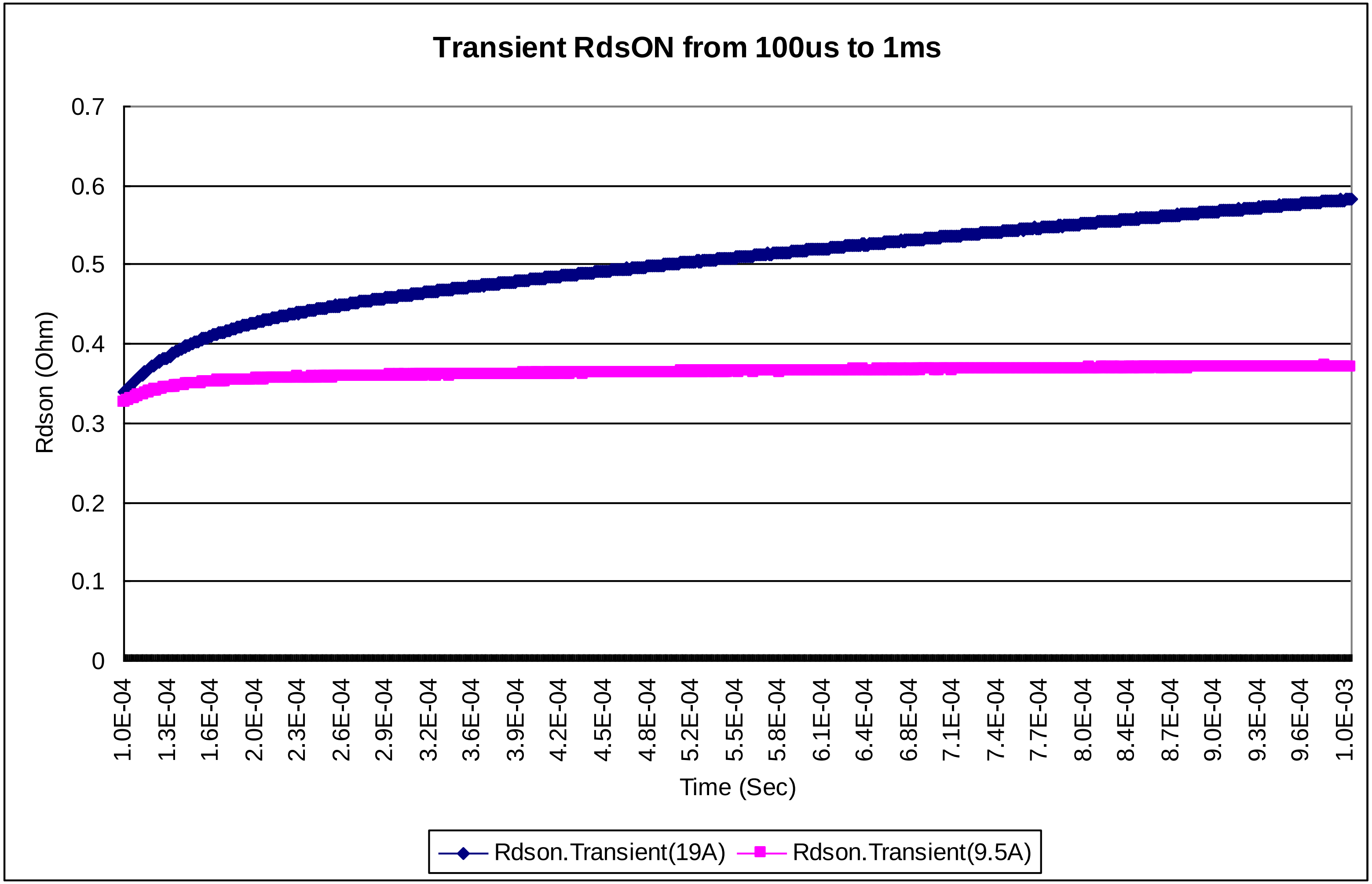


Keithley PCT Demo

→ Transient IV (1us / point synchronous measure)

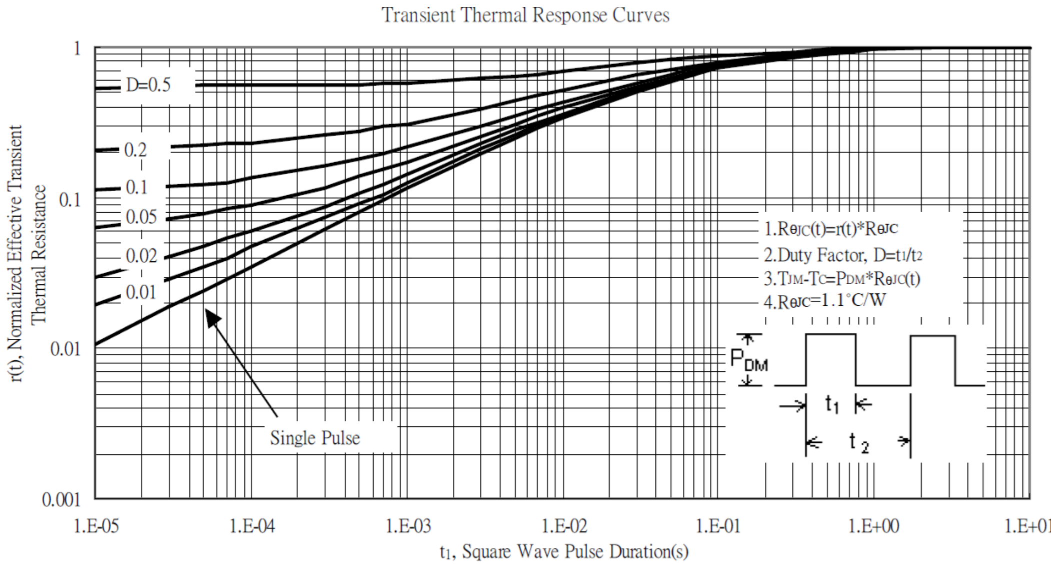


Transient $R_{DS(ON)}$-T Curve by Self Heating
→ Typical: 0.36Ω, Max:0.4Ω

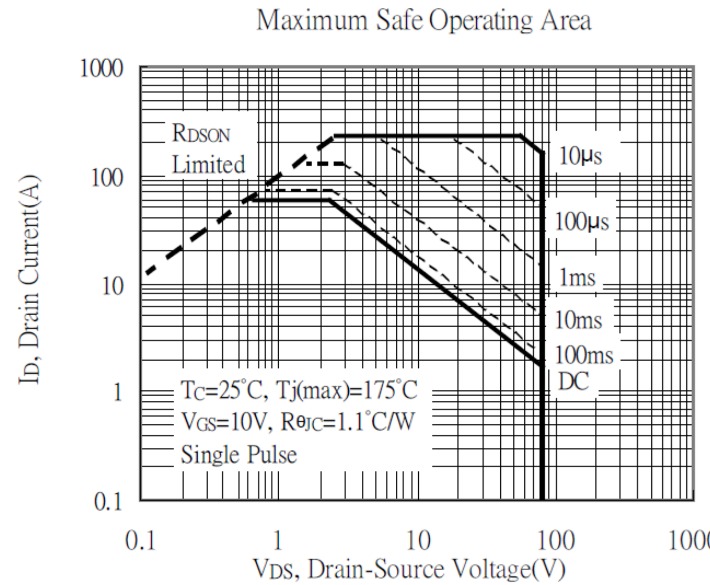


電子元件的規格表 (thermal data)

- Transient thermal impedance(Z_{thjc})



- SOA

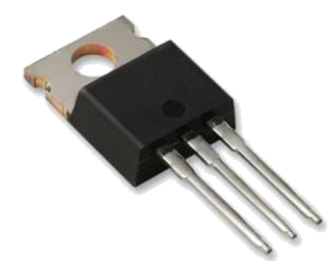


- $R_{\theta JC}$ (junction-to-case thermal resistance)

Thermal Data

Parameter	Symbol	Value	Unit
Thermal Resistance, Junction-to-case, max	$R_{\theta JC}$	1.1	°C/W
Thermal Resistance, Junction-to-ambient, max (Note 2)	$R_{\theta JA}$	60	

Note : 1.The power dissipation P_D is based on $T_{J(MAX)}$=175°C, using junction-to-case thermal resistance, and is more useful in setting the upper dissipation limit for cases where additional heatsinking is used.



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Reliability Solution Overview

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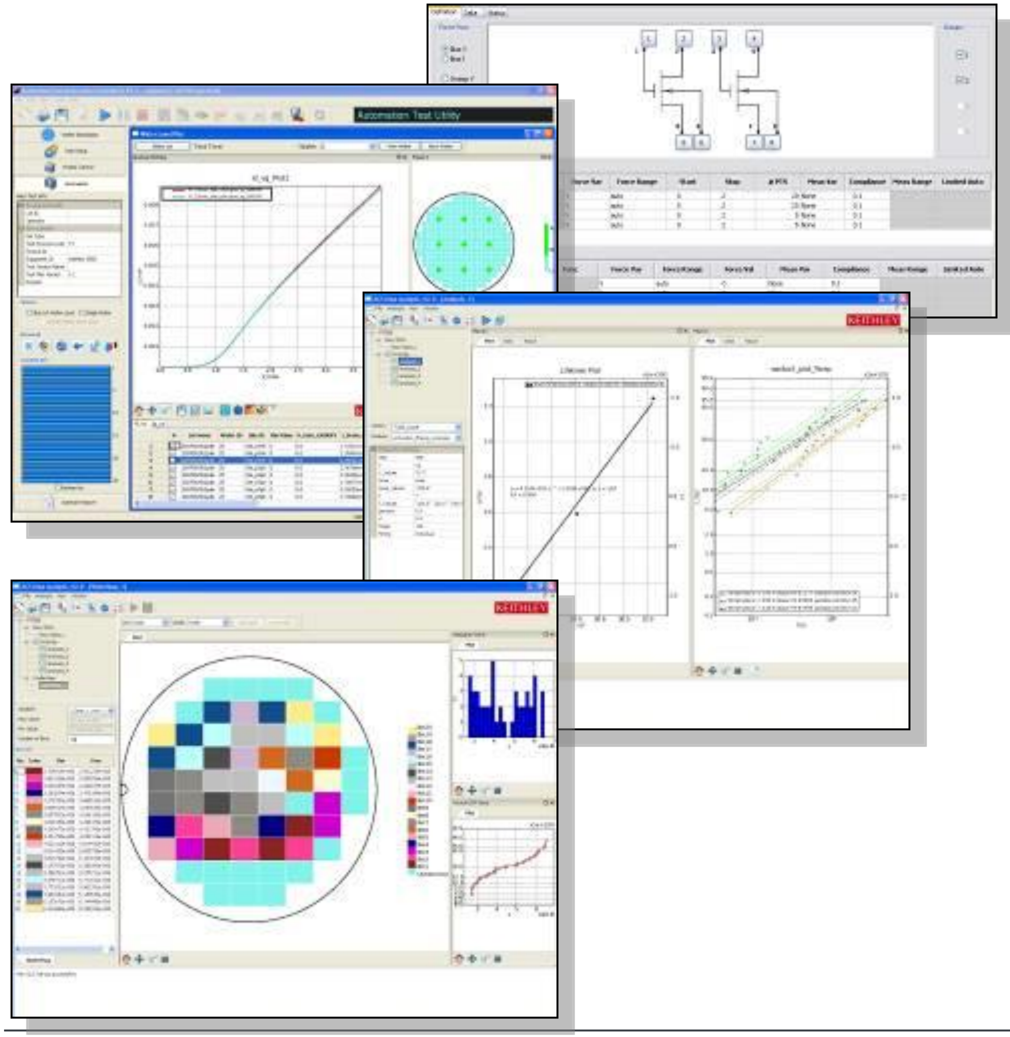
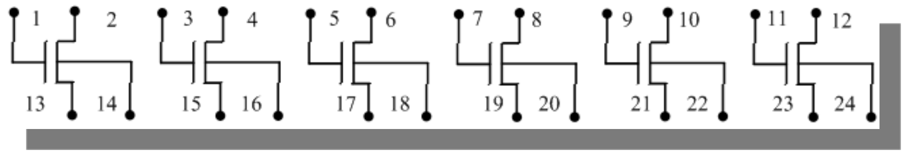
Automation: ACS-2600-RTM

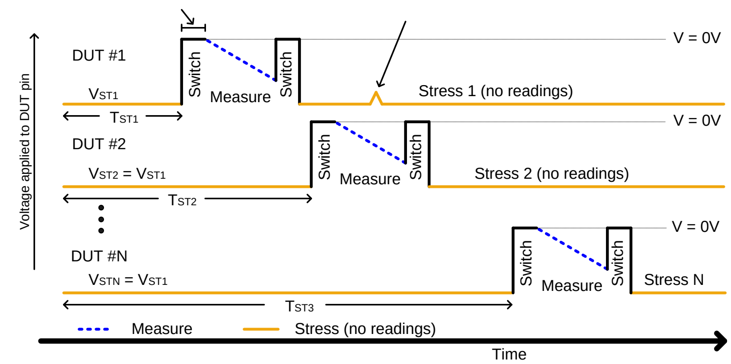


- **Easy parallel WLR setup.**
- Cassette- and wafer-level automation.
- Database.
- **Data analysis(KDAT)**

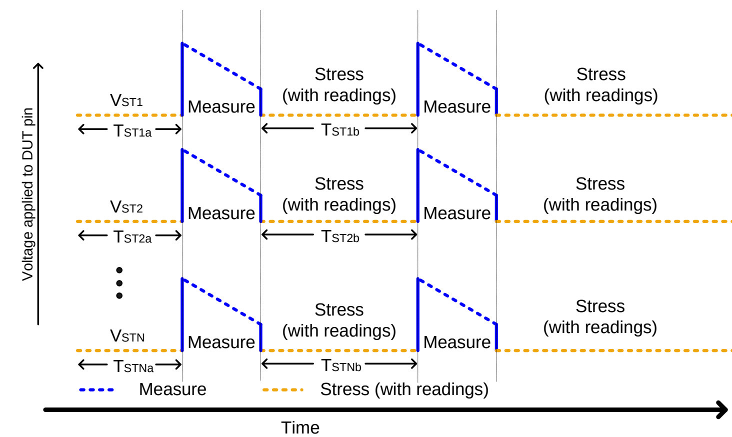
Truly parallel system-2600 RTM



- **Traditional parallel stress – sequential measure**
  - Difficult to control stress timing
  - transient events cannot be captured
  - Relaxation between stress and measure
  - Cannot cover cases that current source required. (EM test)



- **ACS Truly parallel system (SMU per pin)**
  - Tight control of stress timing
  - No missed transient events
  - **No relaxation between stress and test !**
  - No GPIB communication time cost during test, because of 2600 SMU unique capacity that embedded script running inside.



Benefit of ACS-2600-RTM

- High throughput
  - Up to 32 devices truly parallel test(Gate Oxide), 16 devices device reliability test(HCI, NBTI)
- Simple
  - SMU-per-pin architecture.
  - Truly parallel test. The embedded TSP script runs in 2600 instrument not PC, so each device test is completely independent and maintains own timing.
  - Completely systemization configuration, contains rack, PCA.
  - Completely upgrade solution, adapt to future application
- Flexible
  - System configuration from single SMU to 32 SMUs for different requirement
  - LXI or GPIB communication
  - Flexible test algorithm to handle different application, such as high power device test, NBTI recover affection.

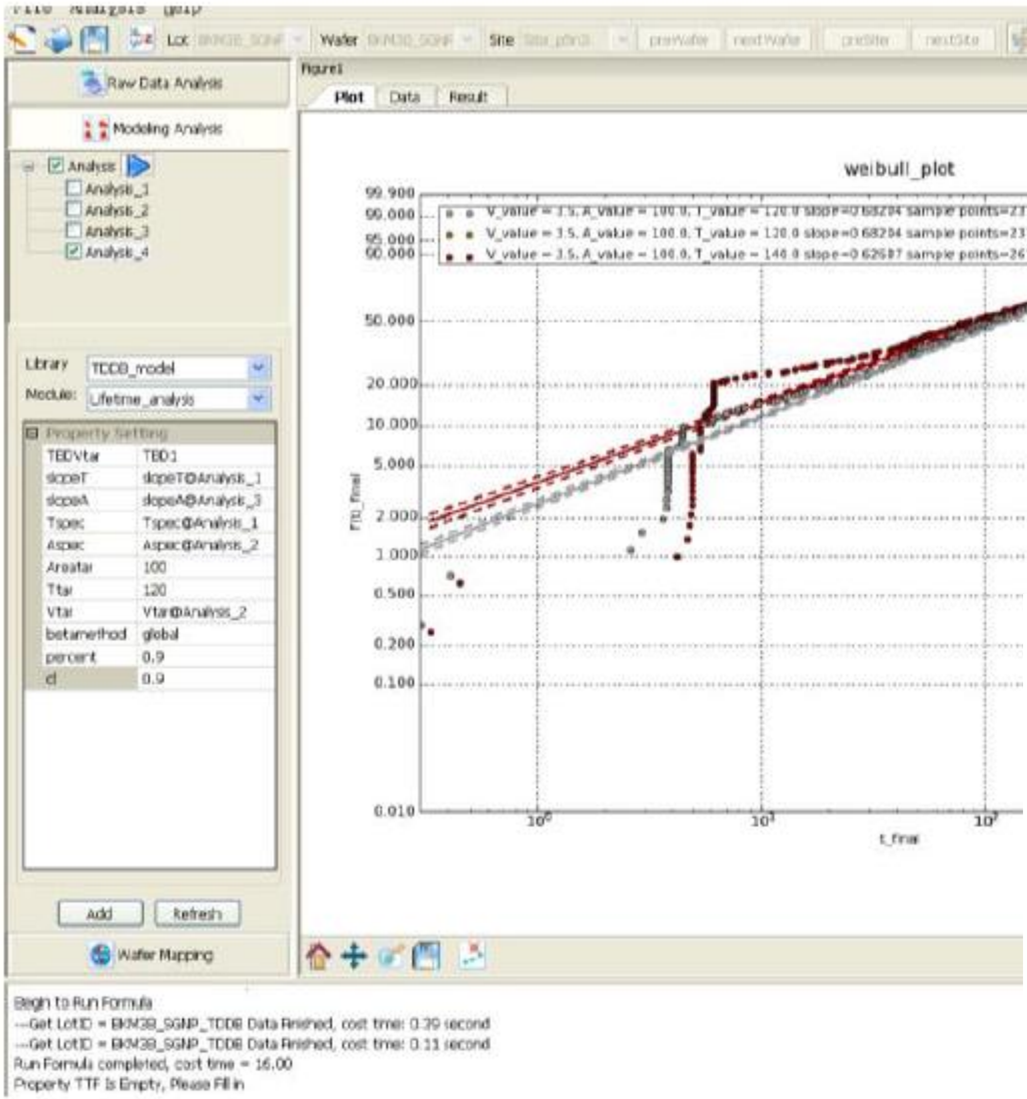
Reliability Test
KDAT : Modeling Analysis Library for WLR

Modeling analysis library

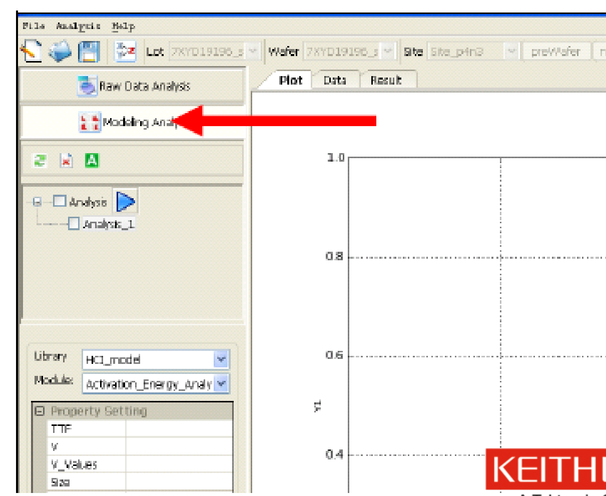
Library	Modules
HCI_model	Activation_Energy_Analysis, Voltage_acceleration, TTF_VS_IdsatFirst, Size_acceleration, Lifetime_single, Lifetime_analysis
NBTI_model	Multi_fit
Stress_migration	Plot, Summary
WLR_model	TDDB_model, EM_model, HCI_model
TDDB_model	Activation_Energy_Analysis, TBD_VS_IgFirst, Voltage_acceleration, Area_acceleration, Lifetime_single, Distribution_plot, Lifetime_analysis.
VRamp_model	VBD_Distribution, I_Distribution

Reliability Test

KDAT Example 1: TDDB Life Time Prediction

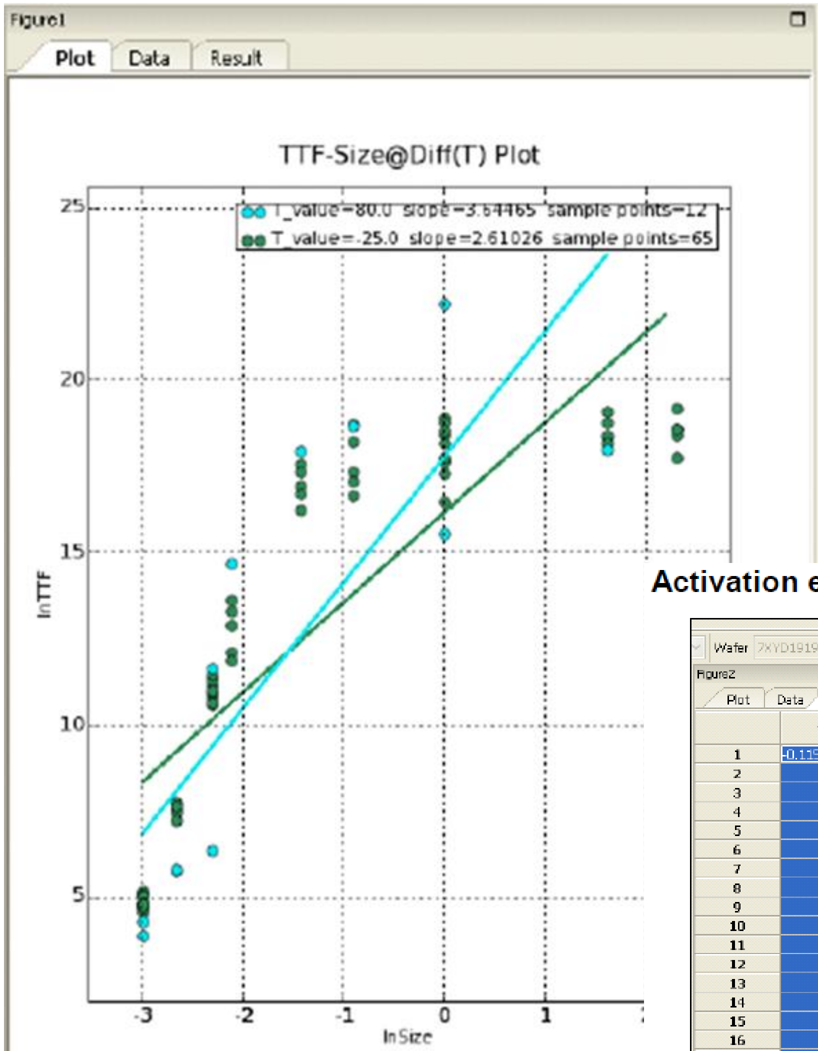


Modeling analysis window



Reliability Test

KDAT Ex 2: Activation Energy (E_A) Analysis, HCI



Activation energy analysis Results tab

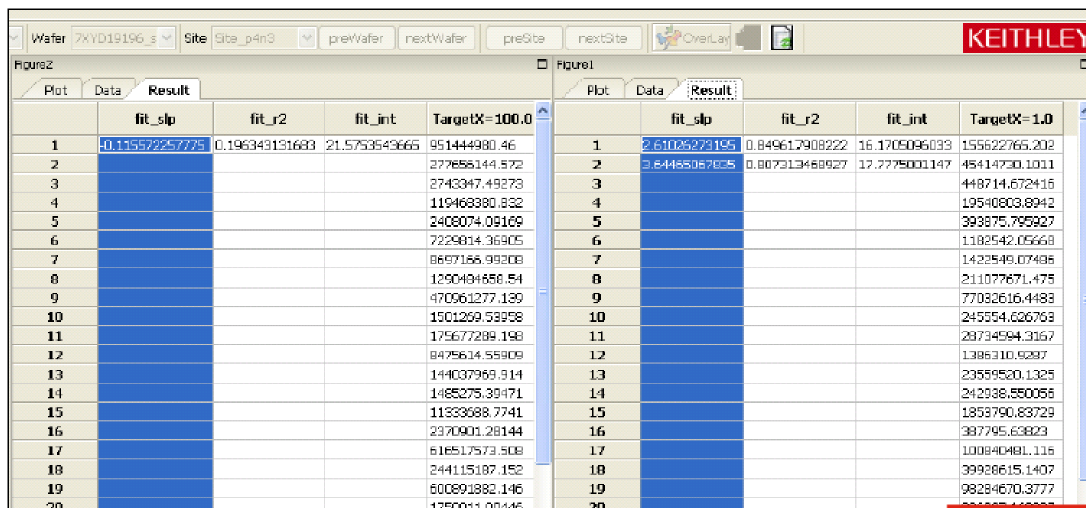


Figure2 — Result

	fit_slp	fit_r2	fit_int	TargetX=100.0
1	-0.115572257775	0.196343131683	21.5753543665	951444980.46
2				277656144.572
3				2743347.49273
4				119468380.832
5				2408074.09169
6				7229814.36905
7				8697166.99208
8				1290484658.54
9				470961277.139
10				1501269.53958
11				175677289.198
12				8475614.55909
13				144037969.914
14				1485275.39471
15				11333688.7741
16				2370901.28144
17				616517573.508
18				244115187.152
19				600891882.146
20				1750911.09446

Figure1 — Result

	fit_slp	fit_r2	fit_int	TargetX=1.0
1	2.61026273195	0.849617908222	16.1705096033	155622765.202
2	3.64465067835	0.807313468927	17.7775001147	45414730.1011
3				448714.672416
4				19540803.8942
5				393875.795927
6				1182542.05668
7				1422549.07486
8				211077671.475
9				77032616.4483
10				245554.626763
11				28734594.3167
12				1386310.9287
13				23559520.1325
14				242938.550056
15				1853790.83729
16				387795.63823
17				100840481.116
18				39928615.1407
19				98284670.3777
20				[illegible]

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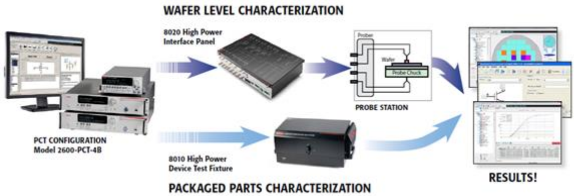
Conclusion

Conclusion

1. Keithley PCT provides the most flexible, economical, upgradable and accurate for high power device characterization (Si, SiC, GaN, etc).

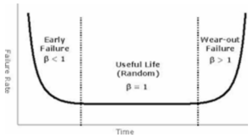


2. The max voltage up to 3KV @ 20mA and the max current up to 100A @ 40V with parallel connection.



3. Superior low current ability which can achieve pA level measurement under high voltage

4. Available accessories are ready for further customized prober or test fixture integration.



5. GaN based power device is attractive; however, several highlighted issues (current collapse, lifetime, thermal dissipation, etc.) need to be improved and solved ASAP.

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Thanks for your time ~

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