70th Anniversary

展望太克 榮耀70

2016太克科技

春季創新論壇

Tektronix

70th Anniversary
展望太克 榮耀70

Keithley Parametric Curve Tracer (PCT)

- For Power Device Characterization, Research and IQC

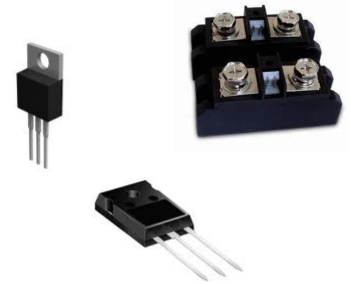
(應用於特性分析、故障分析及品質控制的高功率裝置測試解決方案)

Horace Chen, Sr. Technical Consultant

KEITHLEY
A Tektronix Company

Agenda

1. Keithley Solution Glance
2. Market Drivers and Power Design
3. Device Selection Verification
4. Parametric Curve Tracer
5. Conclusion



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Keithley and Tektronix: Where We Are Headed

A Tektronix Company

PRELIMINARY

Combined, Tektronix and Keithley are very strong

- Complementary products – the widest range in T&M
- Starting to leverage distribution channels
- Guided by ingenuity, precision, and simplicity

Tektronix and Keithley – From Nanovolts to Gigahertz.

吉時利儀器簡介

- 專精於高階電性量測儀器，擁有超過60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 ...

- 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

產品類別

DC/AC儀器和系統
- 專業儀器和系統
- 靈敏性量測
- 波形產生器
- 電流源
- 電壓源
- 數位多功能電錶
- 音頻分析儀
- 電源-電壓源(I-V)和量測(SMU)儀器
- 高速電源供應器

半導體測試系統和軟體
- 半導體參數分析儀
- 半導體開關系統
- 半導體電源量測單元(SMU)
- 半導體特性分析軟體
- 半導體可靠性測試方案
- 自動整合測試系統
- 半導體參數測試系統

配件
- IEEE-488/GPIB界面
- KPCI/KUSB
- 接頭/轉接器/工具
- 靜電計軟體
- 測試治具
- 測試導線和探針
- 觸發鏈結附件
- 觸發器附件
- 數據擷取器(DAQ)的DIN導軌固定套件
- 購物車
- 适配器，电缆和稳定工具箱
- 電腦配件
- 遠程前置放大器底座配件
- 手提儀器箱
- 掃描和開關選項
- 測試台套件
- 功率分配器
- 纜線
- 機架、機架安裝套件和機殼

數據擷取
- 多功能
- 類比輸出
- 數位I/O
- 計數器/定時器
- 數據記錄儀

開關系統
- 半導體/低漏電流
- 射頻/微波
- 多功能
- 整合式數位多功能電錶/開關

DC/AC儀器和系統 - 數位多功能電錶

高性能

- 七位半或八位半量測解析度
- 28位元A/D轉換器
- 其中一個檔位可量測1µV 到20V
- 靈敏度是所選檔位的1%
- 支援T/C或RTD的溫度測量

特定應用

- 六位半解析度
- 聲音頻帶品質量測（2015/16）
- 諧波量測和分析（2015/16）
- THD、THD+雜訊和SINAD量測（2015/16）
- 安全氣囊測試系統（2790）

廣泛用途

- 高精度六位半數位多功能電錶
- 量測電壓、電流和電阻
- 內建數學和量測函數
- 掃描卡選項（2000）
- 測試台和系統應用

數位多功能電錶/開關

- 整合數位多功能電錶、開關系統和/或數據記錄
- 六位半或七位半量測解析度
- 開關卡系列
- 高達200或576個通道
- LXI、乙太網路、GPIB、USB和/或數位I/O界面

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

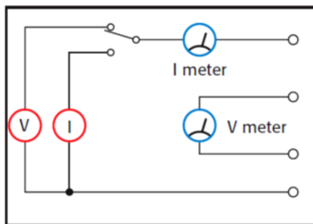
- 量測靈敏度達10aA、1μV
- 可選的脈衝功能
- 四至六位半解析度
- 電壓量測的輸入電阻達10^14/10^16歐姆
- 遠程前置放大器(6430)將線纜雜訊減至最小
- 測試粒子束、SET和超高電阻

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

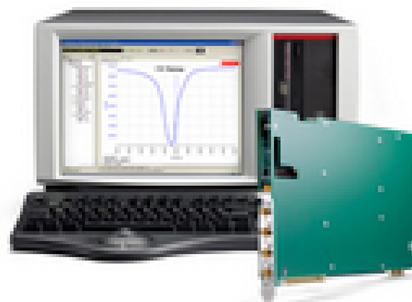


半導體測試系統和軟體 - 半導體參數分析儀

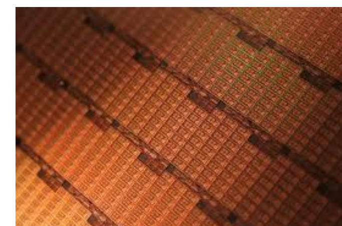
ACS基本版

- 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

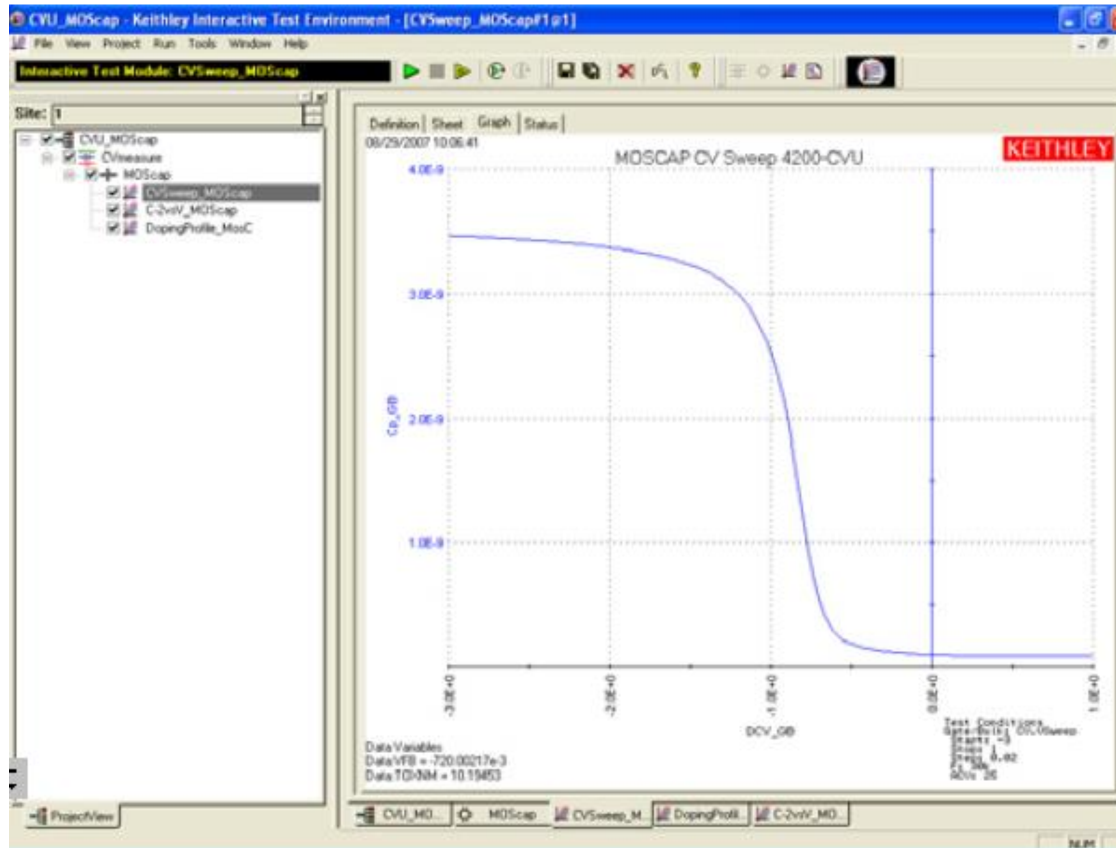
4200-SCS半導體參數分析儀

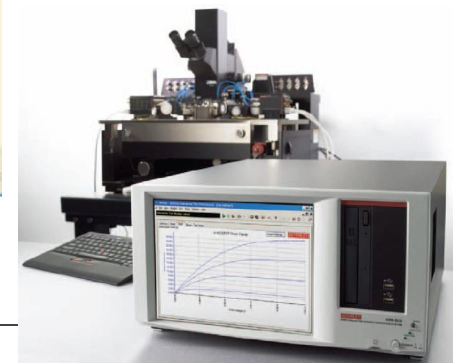


- 直覺式Windows人機使用界面
- 單儀器方案
- 具有I-V、C-V、脈衝產生功能以及脈衝I-V測試功能
- 包含支援各種技術的應用庫



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)

KEITHLEY

MOSFET Drain Family of Curves
DC (straight line) vs. Pulse i-V (dashed line)

Drain Current (A)

50.0E-3
40.0E-3
30.0E-3
20.0E-3
10.0E-3
0.0E+0

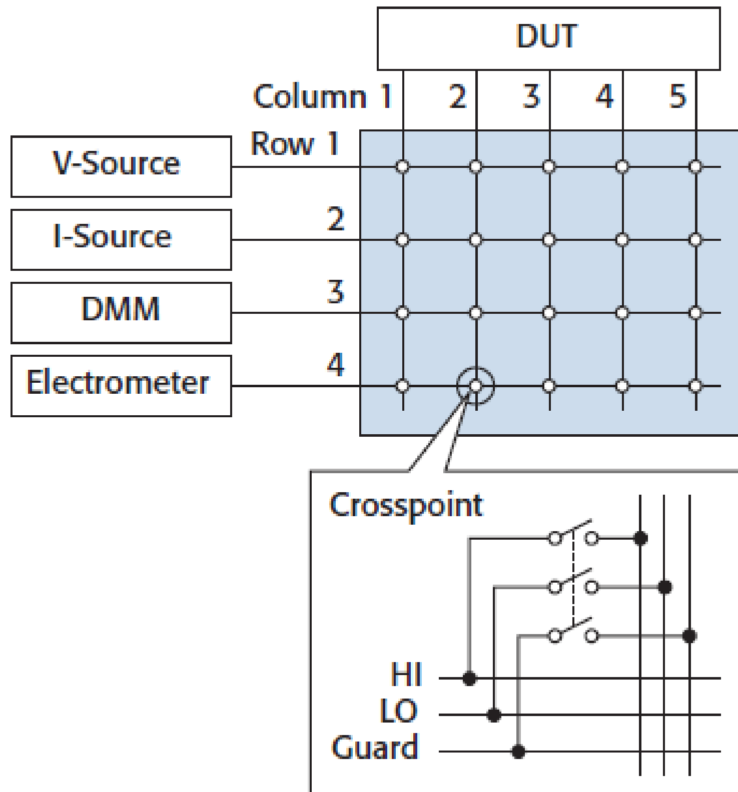
0.0E+0 1.0E+0 2.0E+0 3.0E+0 4.0E+0 5.0E+0 6.0E+0 7.0E+0 8.0E+0 9.0E+0 10.0E+0 11.0E+0 12.0E+0 13.0E+0 14.0E+0 15.0E+0 16.0E+0 17.0E+0

Drain Voltage (V)

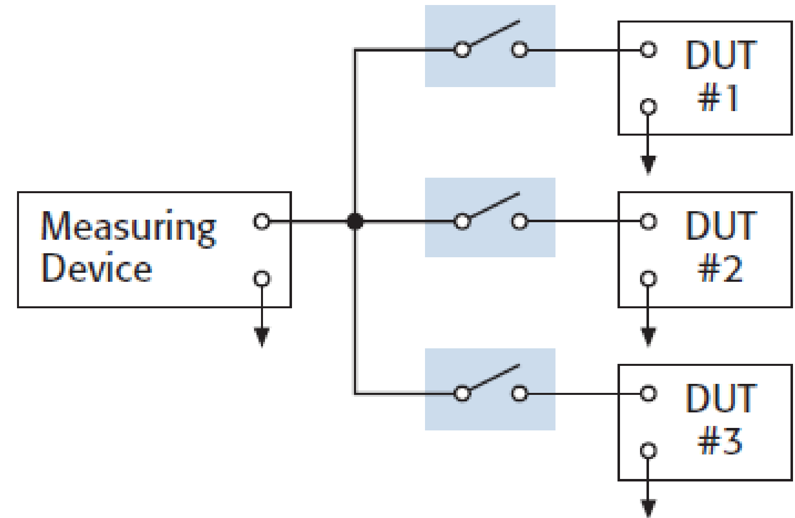
Pulsed I-V Curve
Current – dashed line
Voltage – straight line
time

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

半導體自動測試系統 (3-models) → Production, Lab

S530基礎

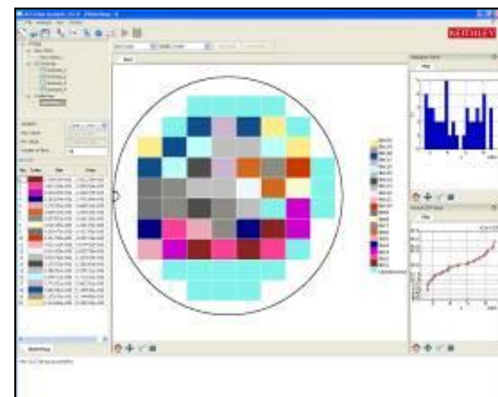
- 業界最高成本效益的自動參數測試儀
- 相容於常見的全自動探針系統
- 外部配線使探針界面的靈活性最大化
- 支援5英寸探針卡庫
- 成熟的儀器技術確保高量測精度和可重復性

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



Superior Technology for Parallel Measurement (30-day to 3-day or faster)

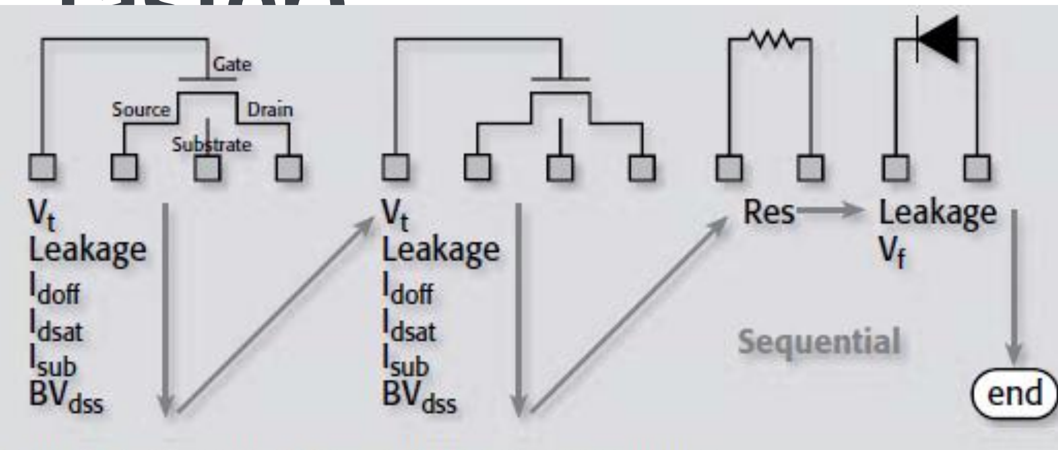


Figure 1-2. Schematic of a sequential mode test sequence.

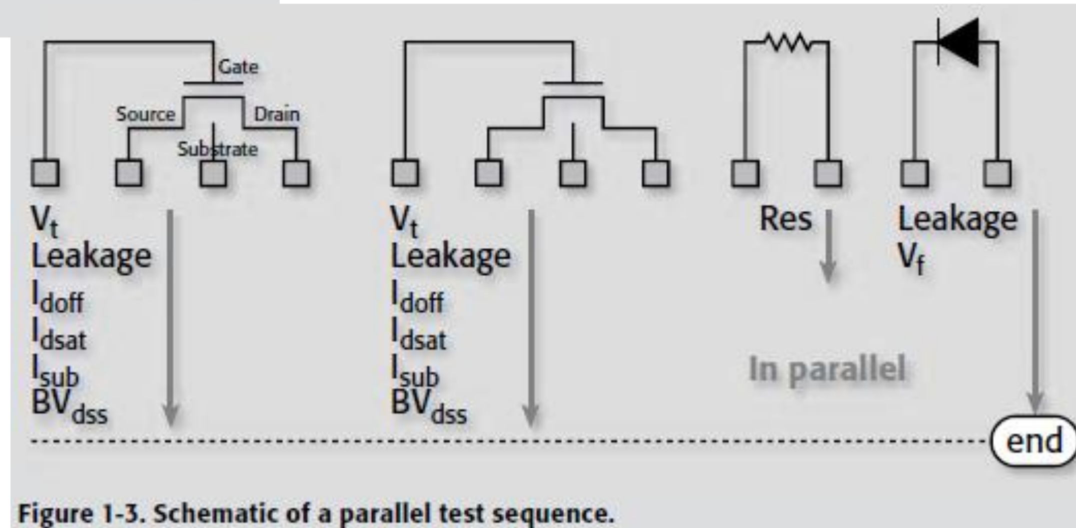


Figure 1-3. Schematic of a parallel test sequence.

半導體測試系統和軟體
- 半導體參數測試系統 (Cont')

ACS BASIC

Define wafer layout, reference die, test die, and choose from multiple test patterns via **Wafer Description.**

Test Setup provides an intuitive environment for test development of complex sequences, as well as parallel execution.

Prober control provides an interactive environment for both prober control and manual test execution.

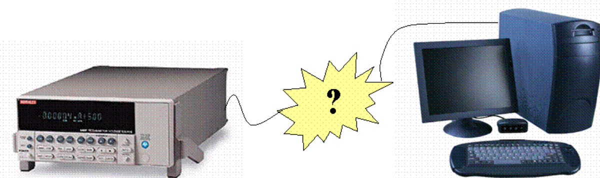
Automate an entire cassette of wafers or just a single wafer.

Summary report offers both a top level statistical analysis and ability to further scrutinize data for statistical variations.

Automated Characterization Suite (ACS)

常用配件
- IEEE-488/GPIB界面

PCI	IEEE纜線和轉接器	USB
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	單層屏障線 雙層屏障線 屏蔽轉接器 印表機轉接器	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 Demand Drivers

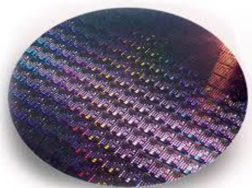
- **Green movement**
  - **Improved energy efficiency**
    - Motor drivers, power supplies, lighting (LEDs), IT (servers)
  - **Energy generation and management**
    - Alternate sources of energy such as solar and wind turbines
  - **Energy regulation policies**
    - Energy efficiency standards (voluntary 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



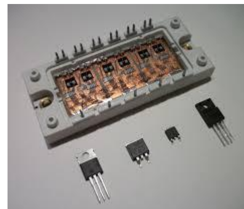
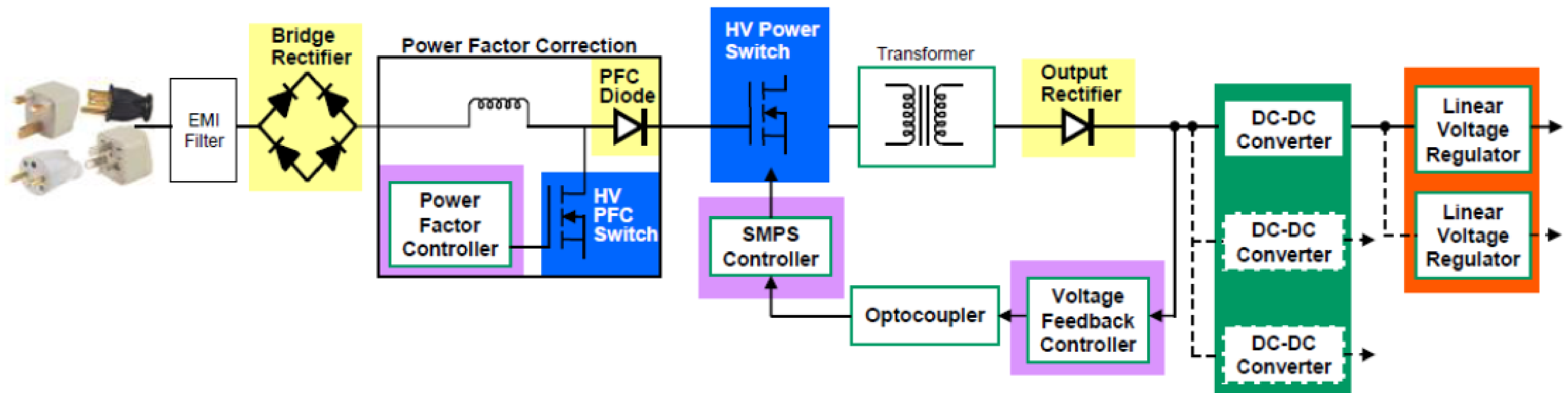


Diagram from On Semiconductor "Overview of Energy Efficient Solutions"

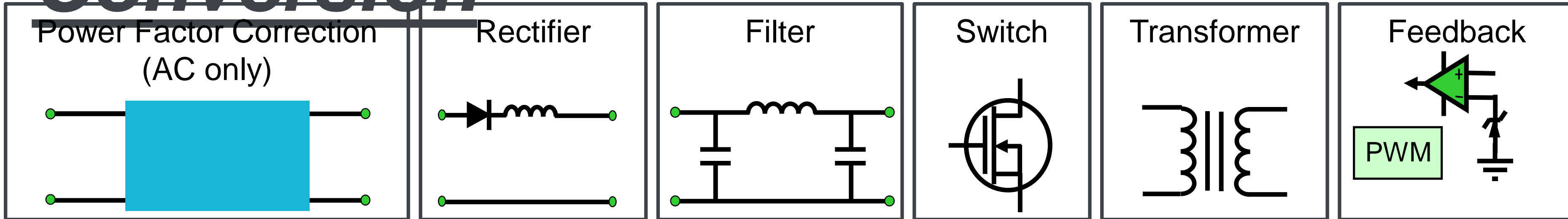
The typical role of power semiconductor devices in the switching power supply



- Semiconductor switches (e.g. MOSFETs) and diodes are largest determinants of switching power supply efficiency
  - Fuels increased interest in design and test of power semi devices
- Power supply designers evaluate components for their designs

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

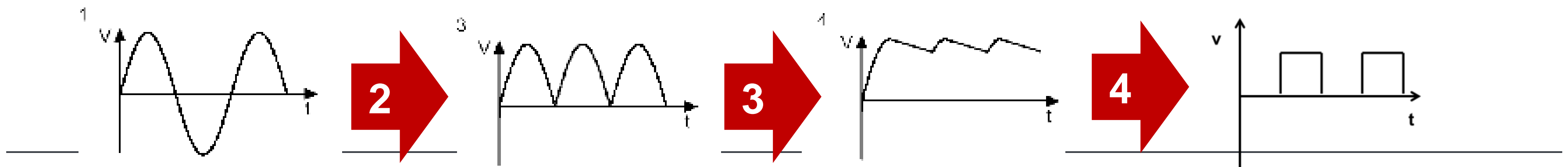
2. **Rectifier**: Converts sine or square wave to a pulsating wave

3. **Filter**: Smooth the wave to DC

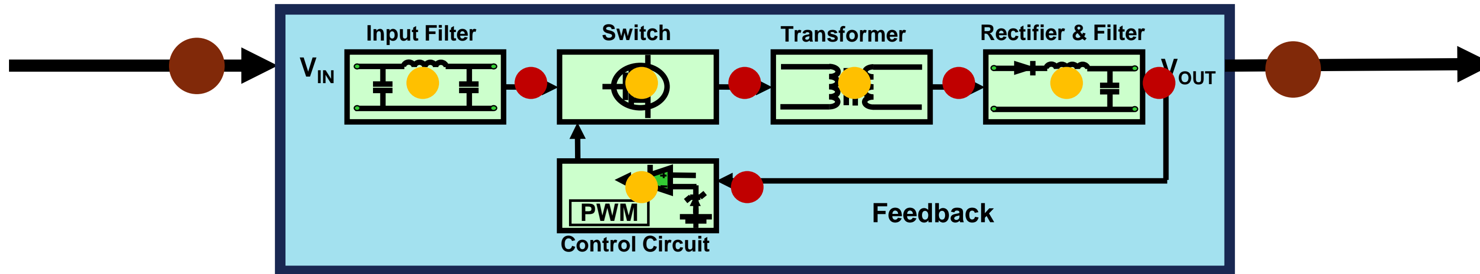
4. **Switch/Chopper**: Converts DC signal to a square wave

5. **Transformer**: Changes voltage level of the wave

6. **Feedback**: Adjusts output voltage to align with reference voltage



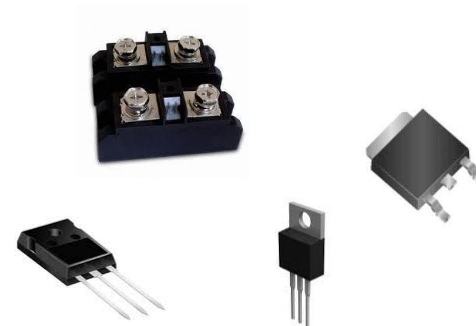
End-to-End Power Design Solutions



Keithley Parametric Curve Tracers and SourceMeter® SMU Instruments

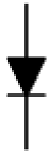
Tektronix Oscilloscopes and Power Probes

Tektronix Power Analyzers



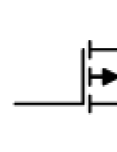
Typical Device Parameters

Diodes & Rectifiers



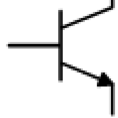
Forward Voltage (Vf)
Reverse Voltage (Vr)
Reverse Leakage (Ir)

MOSFETs & JFETs



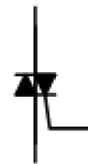
Family of Curves (Vds-Id)
Transfer characteristics (Vgs-Id)
On-resistance (Rdson)
Breakdown voltages (BVdss, BVdg)
Leakage Currents (Idss, Igss)

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)

Background on Power Semiconductor Devices

Power semiconductor devices are in all areas of energy modification

1. **AC to DC** (rectification): Happens almost every time an electrical device is plugged into a wall

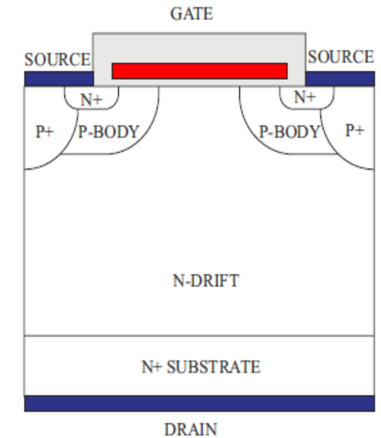
2. **DC to AC** (inversion): Motor control, transporting bulk power (DC from solar panel to supply AC power within a company or residence)

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

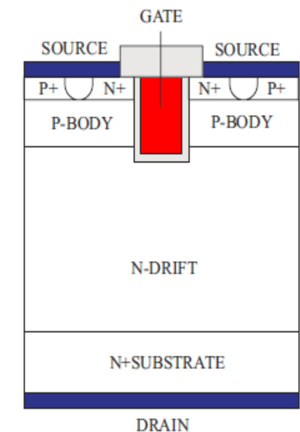
4. **AC to AC**: Changing voltage or frequency → light dimmer circuit

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。



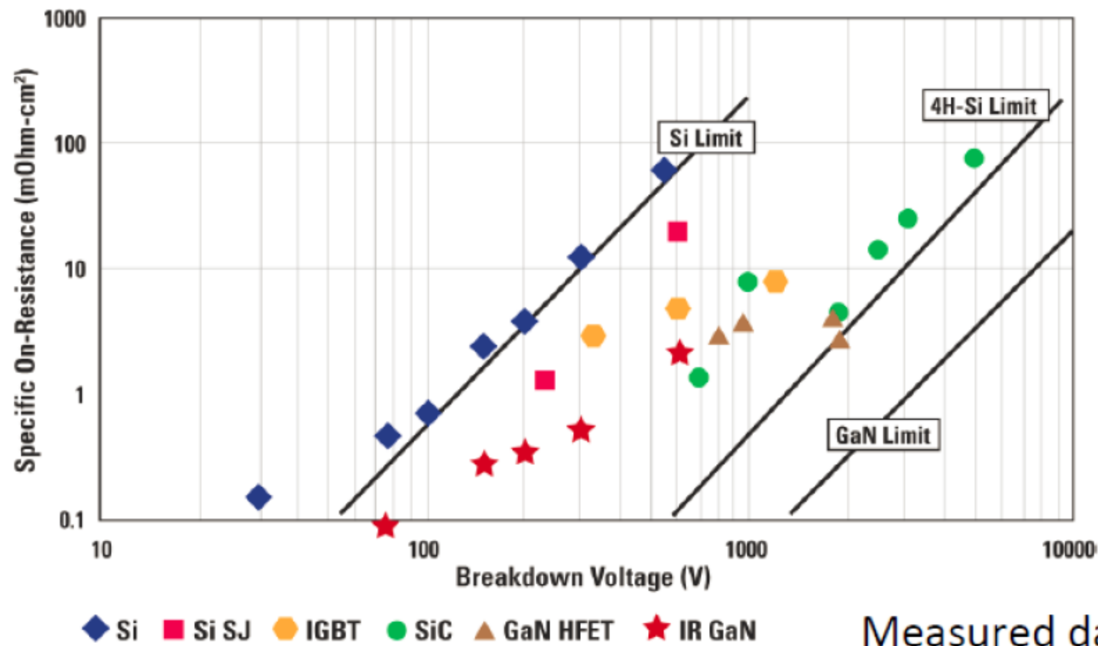
- **目前SiC的製程較GaN-on-Si困難**，主要是因為GaN在發光二極體(LED)與射頻(RF)元件的應用已行之有年，產業鏈與相關技術較為完整。

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

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

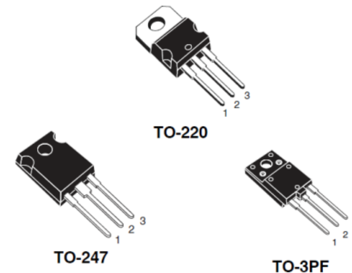
Agenda

1. Keithley Solution Glance
2. Market Drivers and Power Design
3. Device Selection Verification
4. Parametric Curve Tracer
5. Conclusion

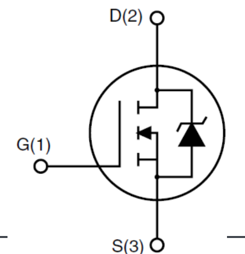
Typical Power MOSFET Datasheet
Static Characteristics

Table 5. **On /off states**

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$V_{(BR)DSS}$	Drain-source breakdown voltage	$I_D = 1$ mA, $V_{GS} = 0$	1500			V
I_{DSS}	Zero gate voltage drain current ($V_{GS} = 0$)	V_{DS} = Max rating V_{DS} = Max rating, T_C=125 °C			10 500	µA µA
I_{GSS}	Gate-body leakage current ($V_{DS} = 0$)	$V_{GS} = \pm 30$ V			± 100	nA
$V_{GS(th)}$	Gate threshold voltage	$V_{DS} = V_{GS}$, $I_D = 250$ µA	3	4	5	V
$R_{DS(on)}$	Static drain-source on resistance	$V_{GS} = 10$ V, $I_D = 1.3$ A		6	9	Ω



1. Pulsed: Pulse duration = 300 µs, duty cycle 1.5%

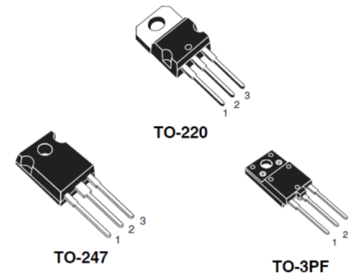


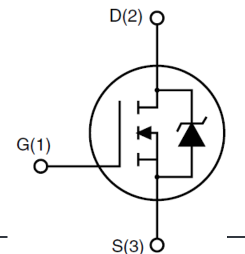
Source: ST Semiconductor.

Typical Power MOSFET Datasheet
Dynamic Characteristics

Table 6. Dynamic

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
g_{fs} (1)	Forward transconductance	V_{DS} = 30 V, I_D = 1.3 A	-	2.6	-	S
C_{iss} C_{oss} C_{rss}	Input capacitance Output capacitance Reverse transfer capacitance	V_{DS} = 25 V, f = 1 MHz, V_{GS} = 0	-	939 102 13.2	-	pF pF pF
$C_{oss\ eq.}$ (2)	Equivalent output capacitance	V_{DS}=0 to 1200 V, V_{GS} = 0	-	100	-	pF
R_g	Gate input resistance	f=1 MHz Gate DC Bias=0 Test signal level=20 mV open drain	-	4	-	Ω
Q_g Q_{gs} Q_{gd}	Total gate charge Gate-source charge Gate-drain charge	V_{DD} = 1200 V, I_D = 2.5 A, V_{GS} = 10 V *(see Figure 19)*	-	29.3 4.6 17	-	nC nC nC





Source: ST Semiconductor.

Typical Power MOSFET Datasheet
Switching Time, Output & Transfer

Table 7. Switching times

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$t_{d(on)}$	Turn-on delay time	V_{DD} = 750 V, I_D = 1.25 A, R_G = 4.7 Ω, V_{GS} = 10 V *(see Figure 18)*	-	24	-	ns
t_r	Rise time			47		ns
$t_{d(off)}$	Turn-off-delay time			45		ns
t_f	Fall time			61		ns

Figure 8. Output characteristics

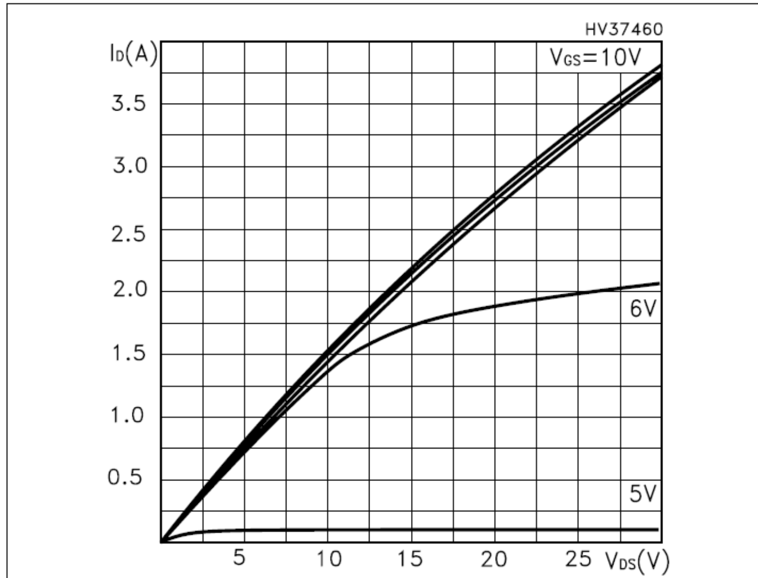
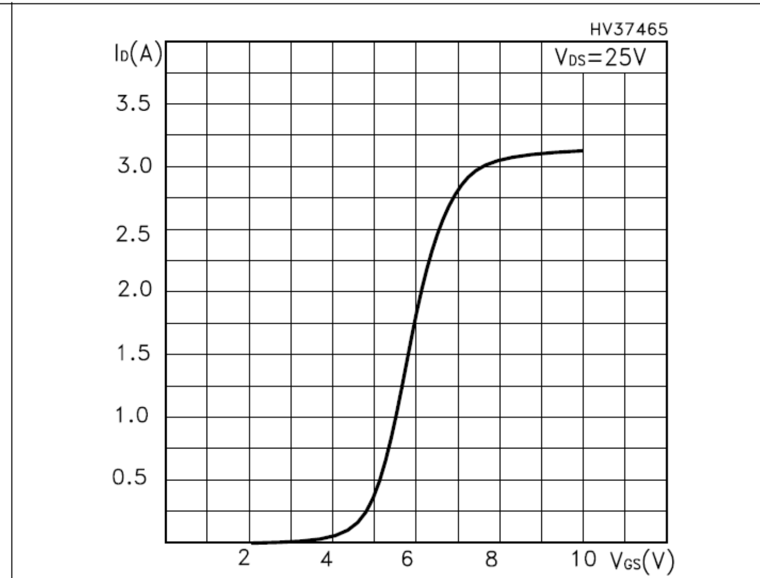
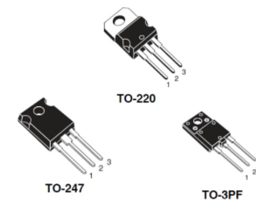
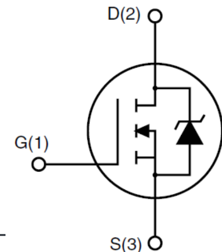


Figure 9. Transfer characteristics







Source: ST Semiconductor.

Typical Power MOSFET Datasheet

Safe Operating Area (SOA) & Thermal Impedance

Figure 4. Safe operating area for TO-220

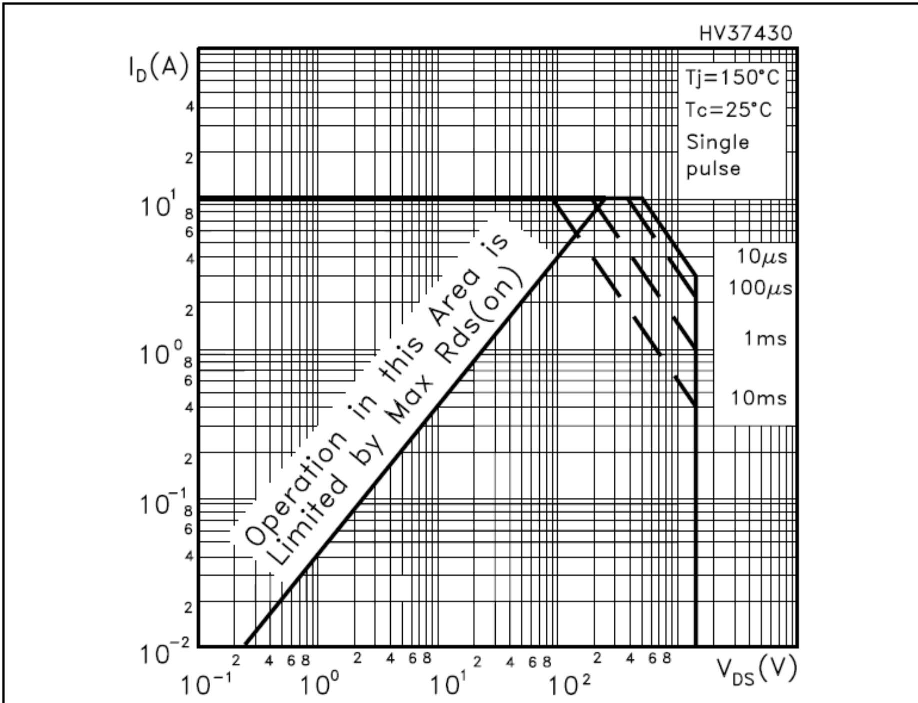
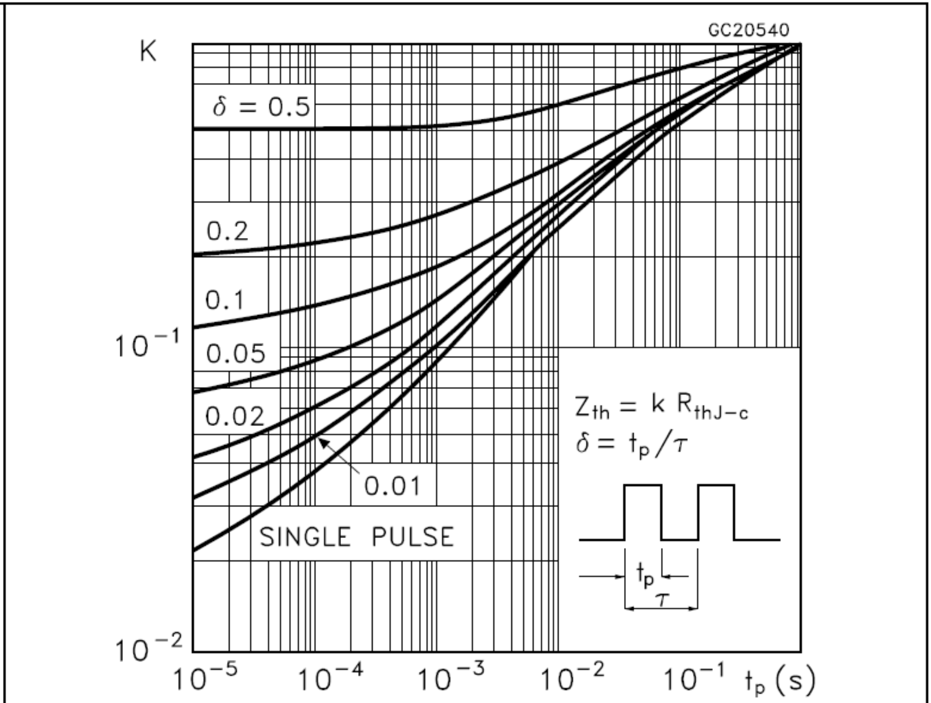
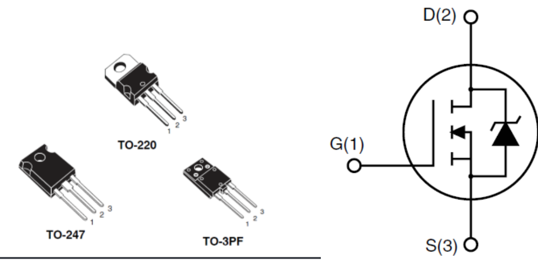


Figure 5. Thermal impedance for TO-220





Source: ST Semiconductor.

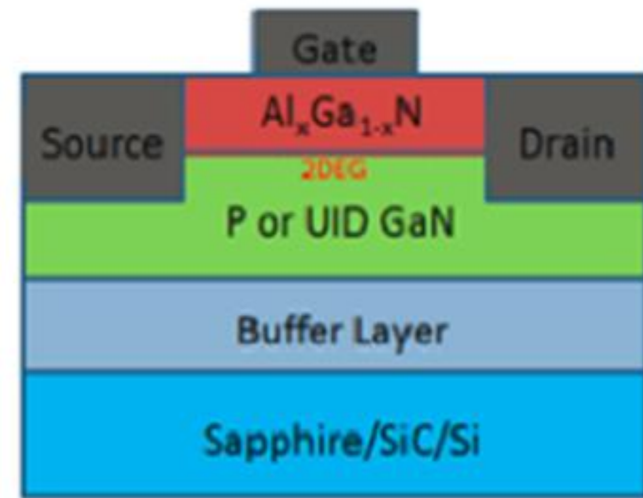
Next Generation Material for Power Device

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。

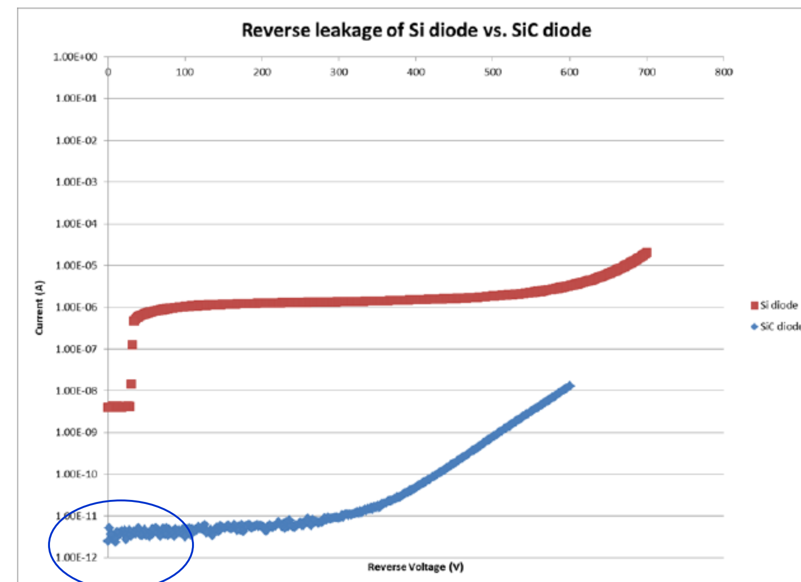


GaN HEMT structure

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

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

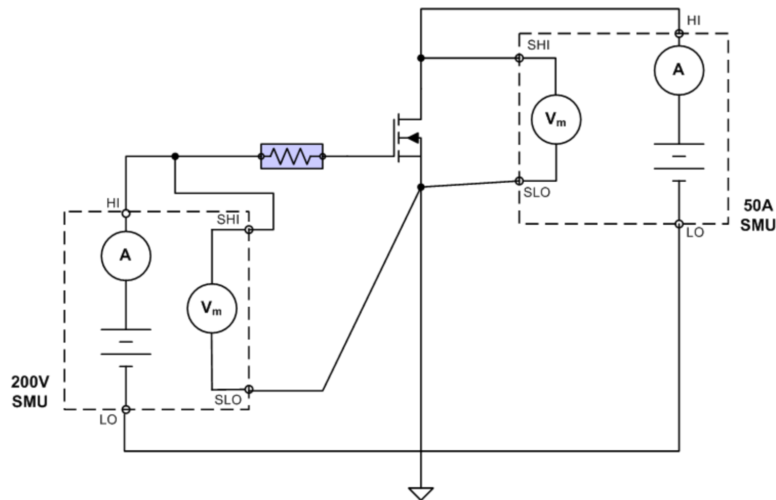
- Commonly performed at DC to achieve high accuracy leakage measurements (e.g., nA level)
- Very low leakage measurement capability required for new wide bandgap technologies (pA level; GaN, SiC)
- Test equipment must be capable of generating high voltages and measuring low currents
- Variety of tests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



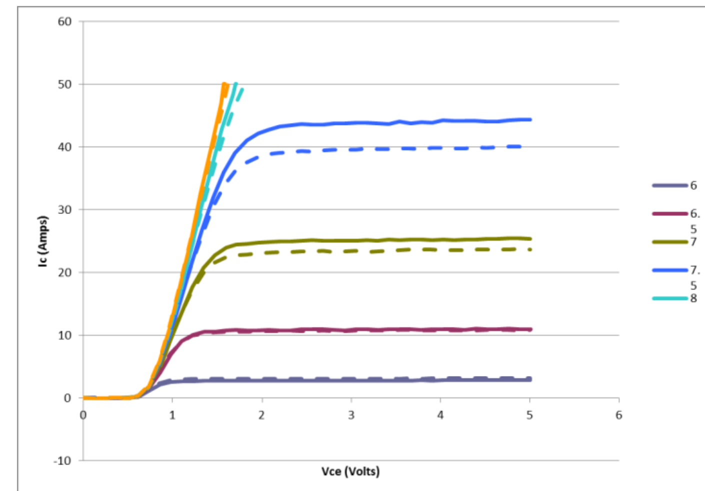
Example: MOSFET Transfer Characteristics

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

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



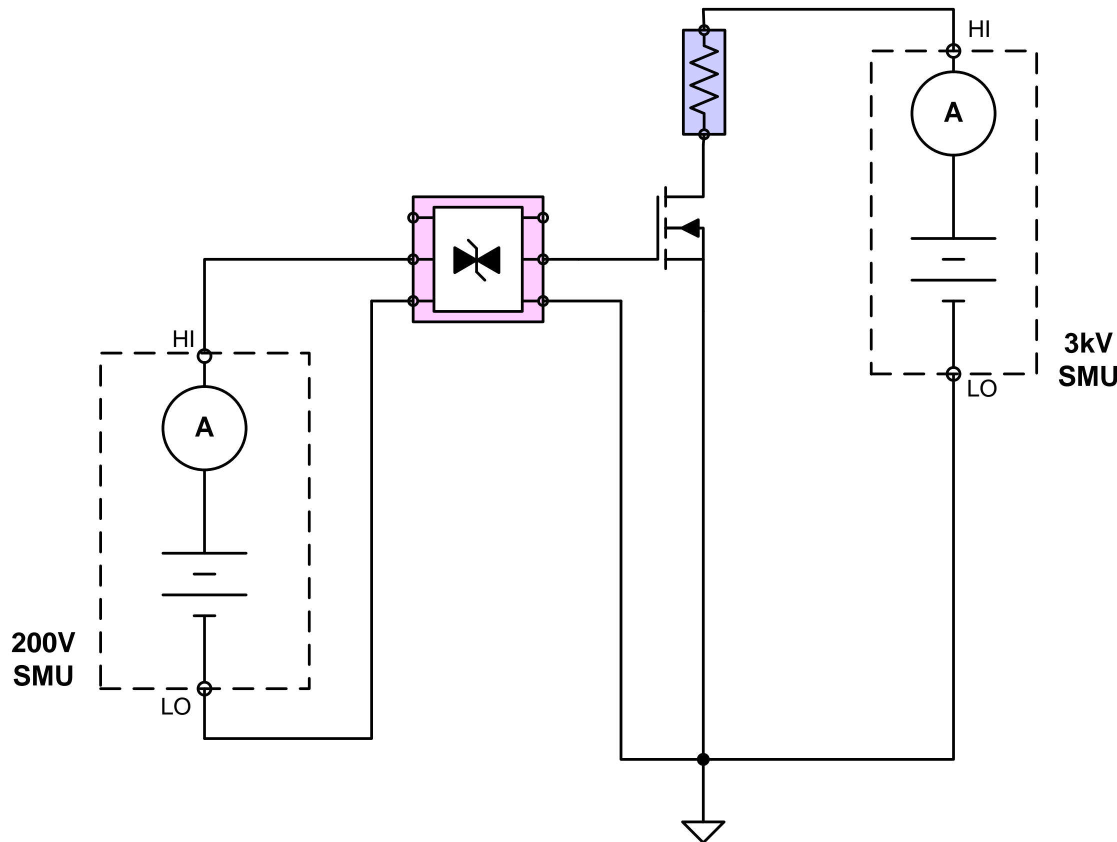
Test Configuration



Test Results

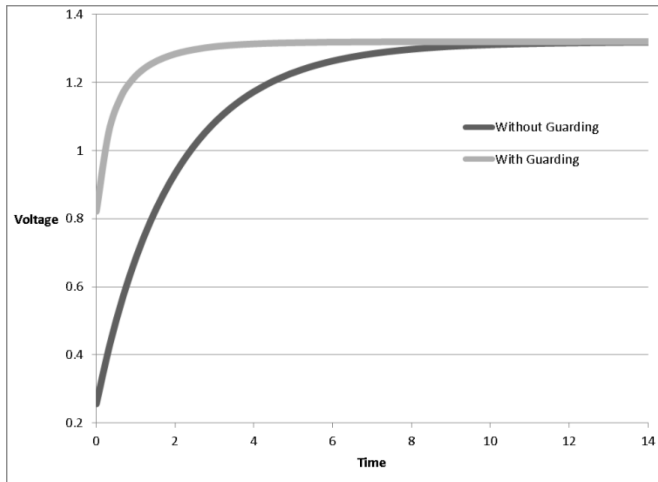
Electrical Model for Off-State testing

- 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:

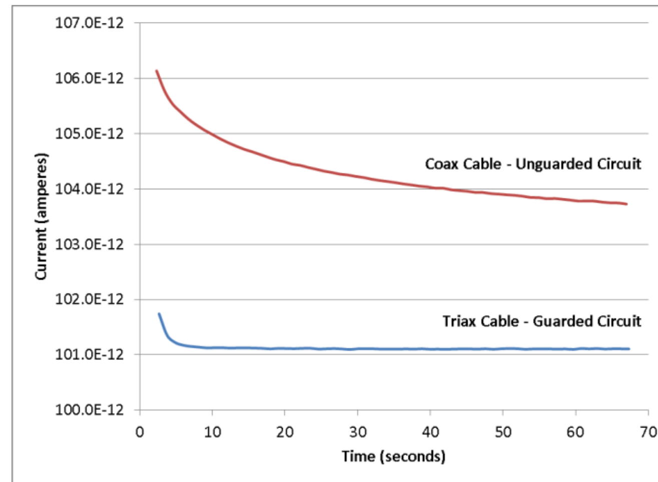


Optimizing Analog Measurements

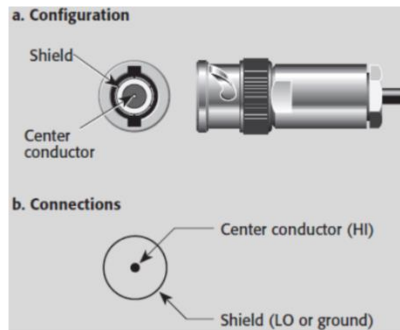
Coax Cabling vs. Triax Cabling



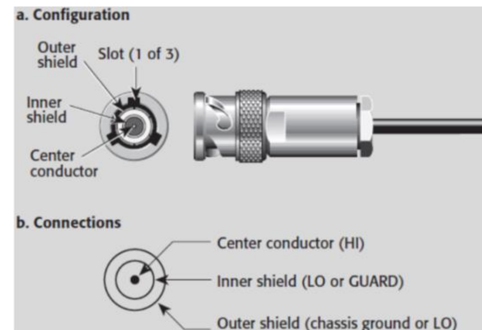
Sourcing Voltage



Measuring Current

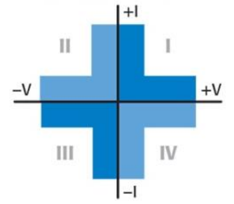


BNC Connector



Triaxial Connector

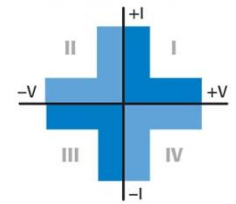
Optimizing Analog Measurements



Four quadrant source measure unit (SMU) technology:

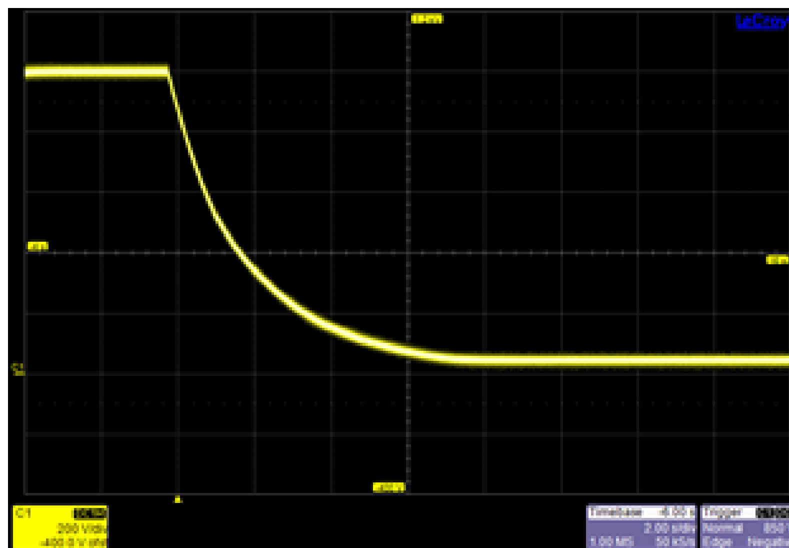
Note: Test data taken with Model 2657A’s built-in digitizer

Optimizing Analog Measurements



Four quadrant source measure unit (SMU) technology:

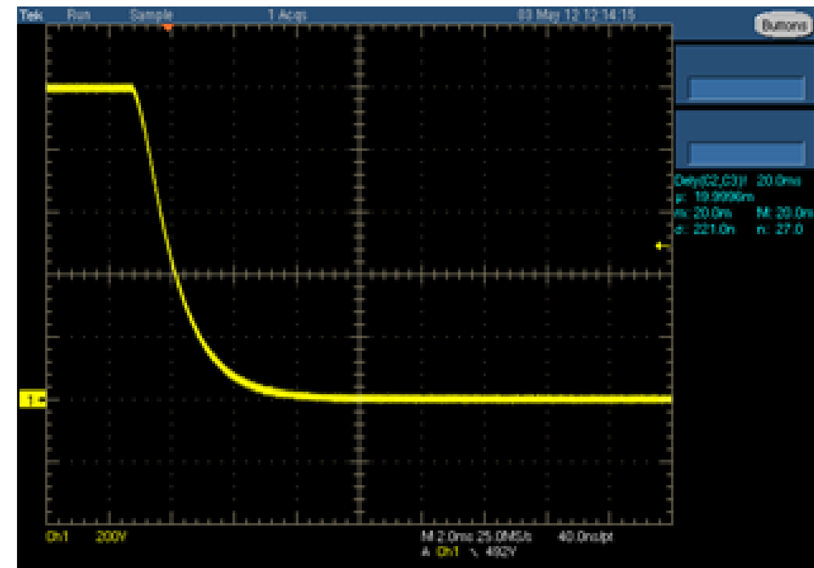
Charged a capacitor to 1000V. Then stepped voltage down to 0V. Scope used to capture capacitor discharge.



Using a Power Supply

Time scale = 2 sec / div

Total discharge time > 6sec



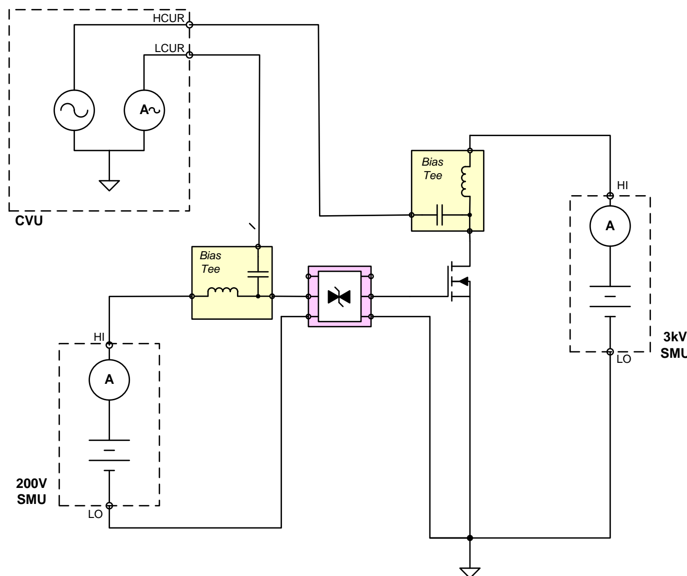
Using Model 2657A

Time scale = 2 msec / div

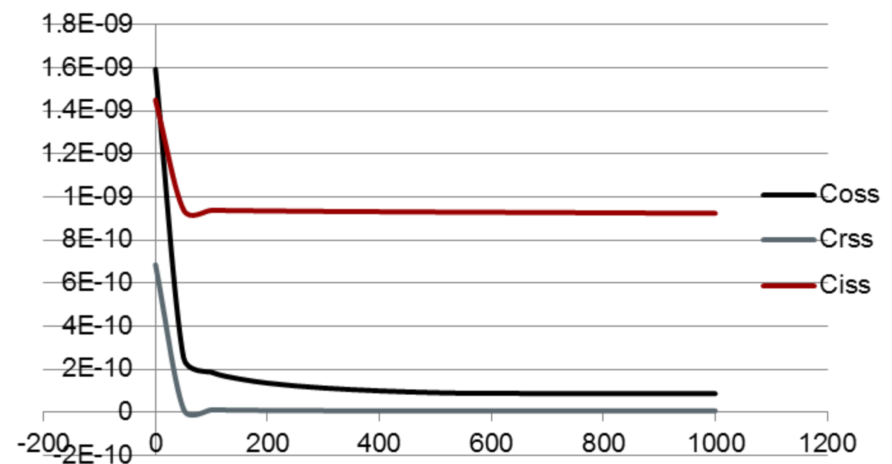
Total discharge time ~ 5msec

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 1000V

Agenda

1. Keithley Solution Glance
2. Market Drivers and Power Design
3. Device Selection Verification
4. Parametric Curve Tracer (PCT)
5. Conclusion

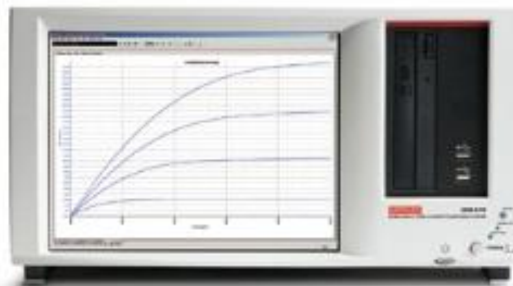
Keithley PCT

What is a Parametric Curve Tracer?

A configurable bench-top system for characterizing power devices

1. Comprehensive solution including instrume , test libraries, test fixture and/or prober interface
2. Supports both *Parametric* and *Trace* test m
3. Includes the best of a Curve Tracer and a P

+



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Keithley PCT
- What is a Parametric Curve Tracer?

1. World Class measurements to **3KV** and **100A**

2. Cost-effective (**Invest what you need**!)

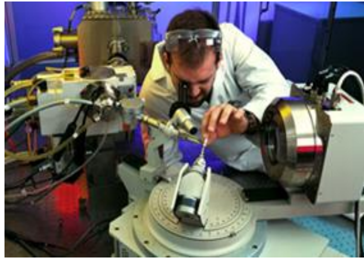
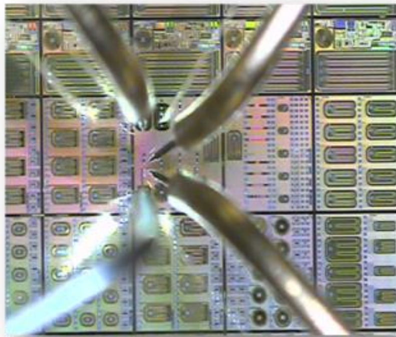
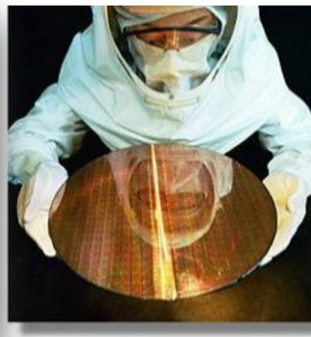
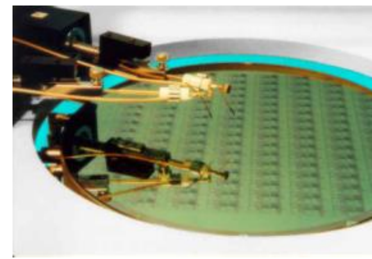
3. Easy field upgrades, scalable and re-configurable

Configuration Selector Guide

Model [1]		Collector/ Drain Supply [2]		Step Generator Base/Gate Supply	Auxiliary Supply
		High Voltage Mode	High Current Mode		
Low Power	2600-PCT-1B	200 V/10 A	200 V/10 A	200 V/10 A	N/A
High Current	2600-PCT-2B	200 V/10 A	40 V/50 A	200 V/10 A	200 V/10 A
High Voltage	2600-PCT-3B	3 kV/120 mA	200 V/10 A	200 V/10 A	200 V/10 A
High Current and High Voltage	2600-PCT-4B	3 kV/120 mA	40 V/50 A	200 V/10 A	200 V/10 A

1. Contact your Keithley field applications engineer for custom configurations.
2. Add a Model 2651A to increase high current mode to 50A or 100A.
3. PCT-CVU Multi-Frequency capacitance meter can be added to any configuration.

Semiconductor Test and PCT Configurations

Companies involved in:

Research &
Education Facilities

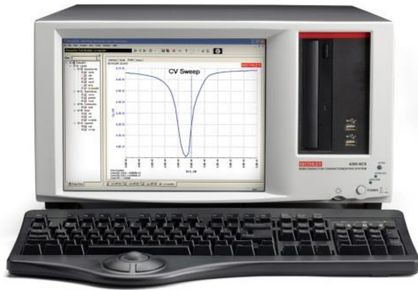
Integrated Circuits
Discrete & Power Components
Flat Panel Displays

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

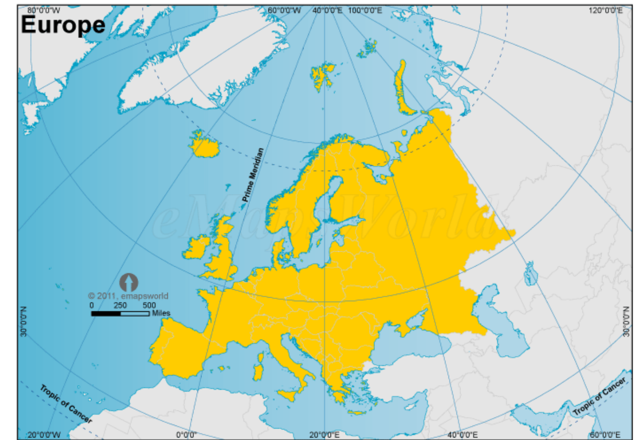
Target Customers & Apps for Parametric Curve Tracer

Semiconductor Test at Keithley from R&D, QA to Production

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 Customers

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



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

North America

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

Series 2400 SourceMeter

Series 2600 System SourceMeter

Series 265XA HP SourceMeter

Series 246X Touch SourceMeter

1989 1995 2005 2012 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

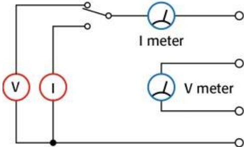
Current Source

Digital Multimeter

Electronic Load

Typical Equipment Rack for Device Testing

Which One Do You Want?



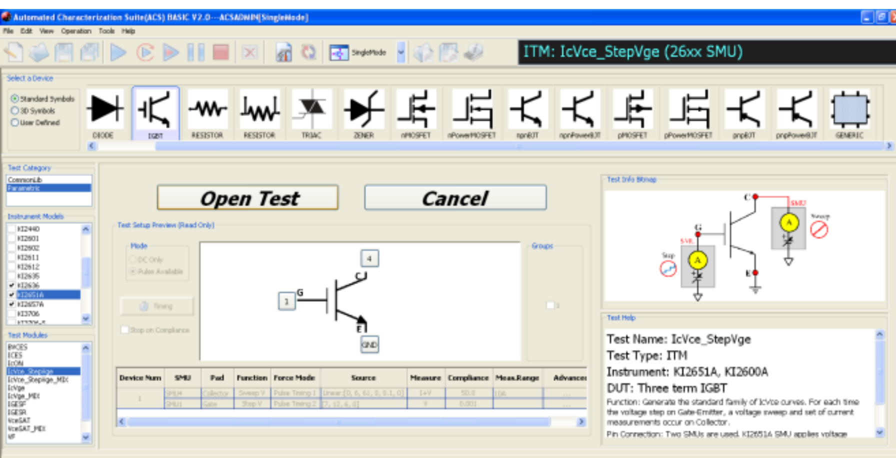
Well, it works.

It works well.

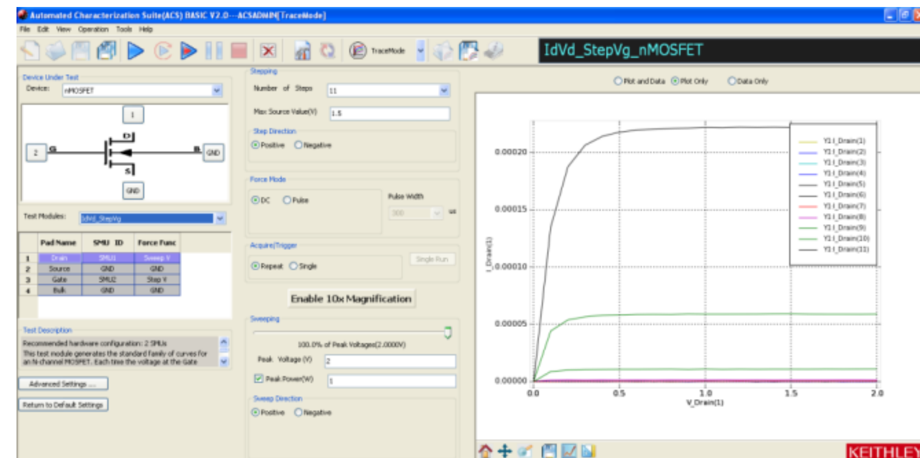
Parametric Curve Tracer software: ACS Basic

For fast and simple single device testing!

Over 400 Sample Libraries included



Parametric Test Mode



Trace Mode

Keithley PCT
What is Parametric Test Mode?

- Each test has clearly defined variables (e.g. start, stop, and step levels of sweep)
- Outputs precise digital data, which is necessary for I-V Curve and parameter extraction (e.g. I_D-V_G, I_D-V_D, V_T, R_{dsON}, gm)
- Operator controls test programmatically. Tests can run automatically without operator intervention.
- Common in
  - Device qualification
  - Process monitoring
  - Data sheet generation

Table 5. On /off states

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$V_{(BR)DSS}$	Drain-source breakdown voltage	I_D = 1 mA, V_{GS} = 0	1500			V
I_{DSS}	Zero gate voltage drain current (V_{GS} = 0)	V_{DS} = Max rating V_{DS} = Max rating, T_C=125 °C			10 500	µA µA
I_{GSS}	Gate-body leakage current (V_{DS} = 0)	V_{GS} = ± 30 V			± 100	nA
$V_{GS(th)}$	Gate threshold voltage	V_{DS} = V_{GS}, I_D = 250 µA	3	4	5	V
$R_{DS(on)}$	Static drain-source on resistance	V_{GS} = 10 V, I_D = 1.3 A		6	9	Ω

Parametric Test

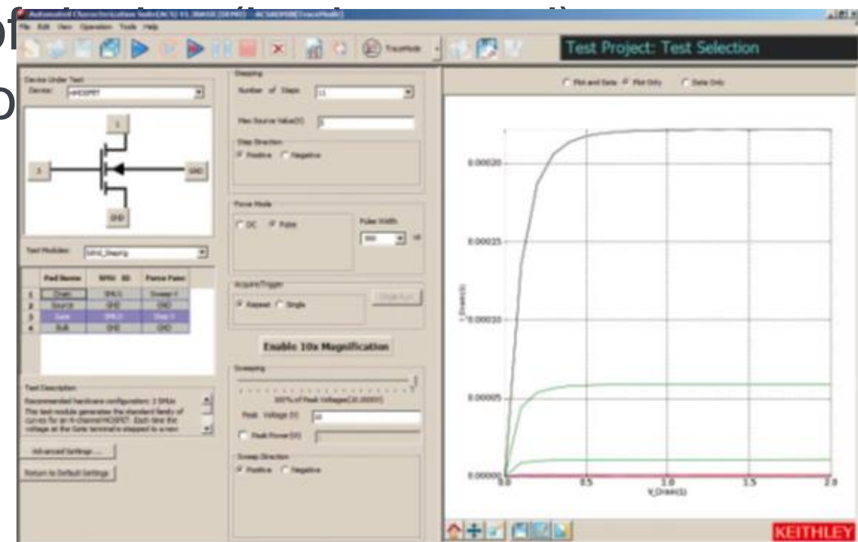
Keithley PCT Typical Power Transistor Parame

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.

Keithley PCT - What is Trace Test Mode?

- Generates rapid visual results of device characteristics
- Requires real-time operator control based upon visual inspection of test results (graph, plot)
  - The “knob” for the Tektronix curve tracer
  - The slider for the Keithley Parametric Curve Tracer
- Used to determine condition of
  boundaries of device (breakdo
- Common in
  - Device development
  - Failure analysis



Curve Tracer Test

Keithley Parametric Curve Tracer Demo
- Tr

Keithley Parametric Curve Tracer Demonstration - 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

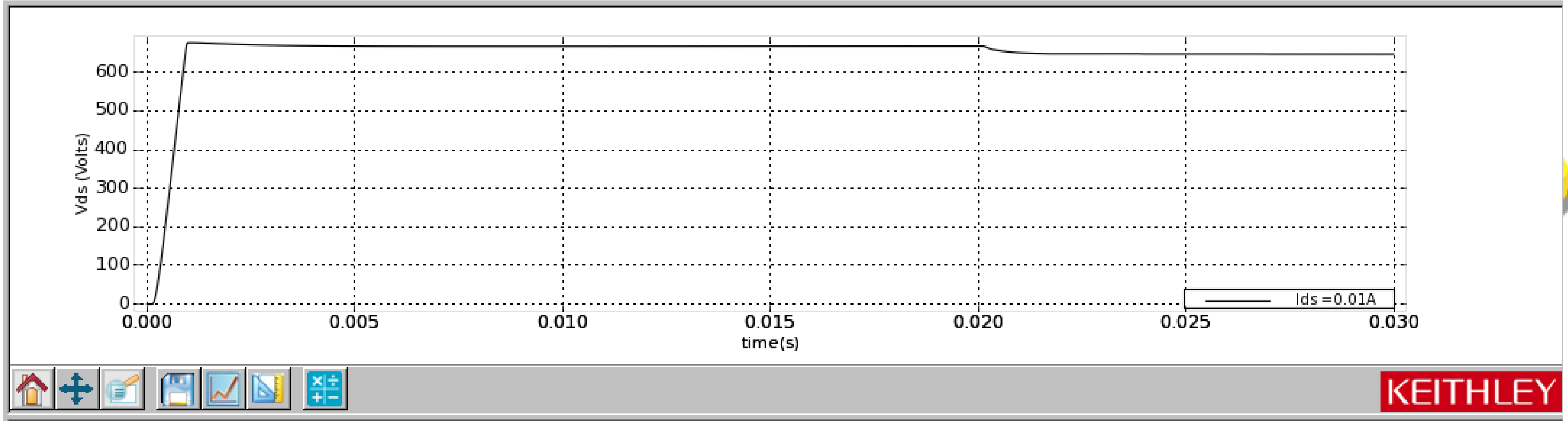
Characteristics		Symbol	Rating	Unit
Drain-source voltage		V_{DSS}	600	V
Gate-source voltage		V_{GSS}	±30	V
Drain current	DC (Note 1)	I_D	12	A
	Pulse (Note 1)	I_{DP}	24	

D: K2657A (Hi V; 3KV)

D: K2651A (Hi I; 50A Pulse)

G: K2635A (Hi P)

Keithley Parametric Curve Tracer Demonstration - **Parametric Mode** (Ex. V_{BRDSS}, Toshiba TK12A60U)



GROUP1

	A(X)	B(Y1)	C	D	E	F	G	H
1	time	V_Drain	I_Drain	BV				
2	1e-6	8.859171e-3	1.098364e-6	6.770494e+2				
3	8e-6	-3.451769e-2	3.181995e-7					
4	1.5e-5	-6.34356e-2	7.082818e-7					
5	2.2e-5	-4.897664e-2	9.033229e-7					
6	2.9e-5	-5.599783e-3	1.878529e-6					
7	3.6e-5	-2.005874e-2	-2.66924e-7					
8	4.3e-5	-3.451769e-2	2.07357e-6					
9	5e-5	2.331812e-2	-2.607418e-6					
10	5.7e-5	3.777708e-2	3.243817e-6					

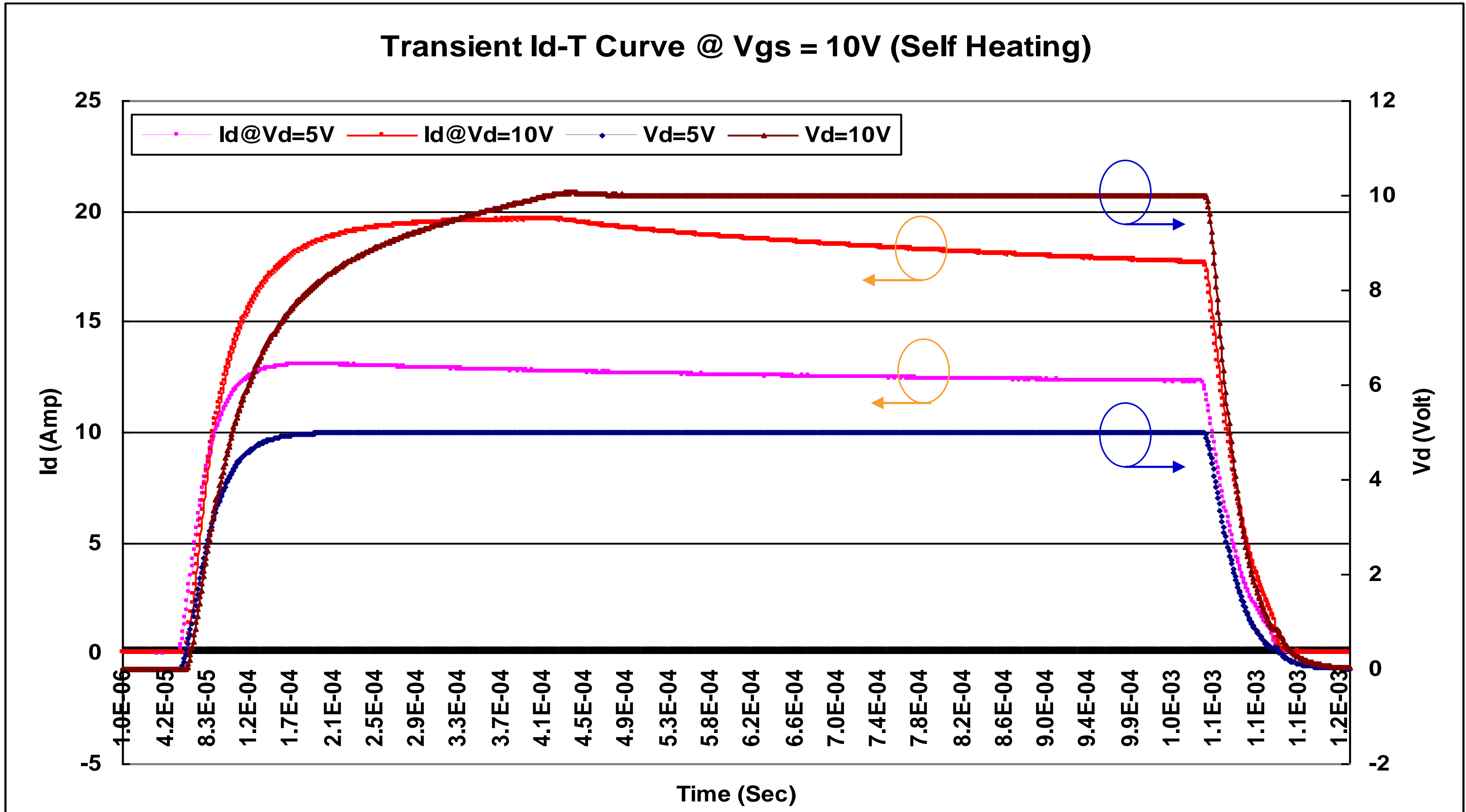
BVDSS

Automated Characterization Suite(ACS) BASIC V2.0(OFFLI

File Edit View Operation Tools Help

Project
- nPowerMOSFET_HI_Tests
  - IdVd_StepVg_Power
  - IdVg_StepVd_Power
  - RdsOn_SweepVg
- nPowerMOSFET_HV_Tests
  - BVDSS

Keithley Parametric Curve Tracer Demonstration → Transient IV (1us / point synchronous measure)



Series 2600B and 2650A SMUs

Model 2636B SMU

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

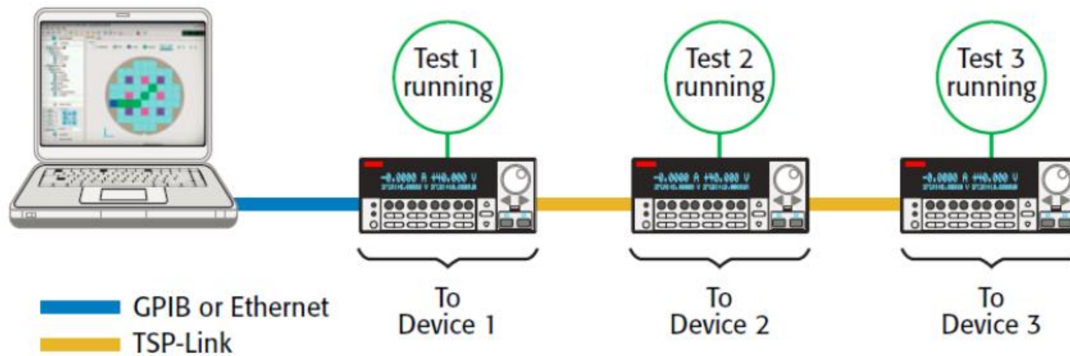
Model 2651A SMU

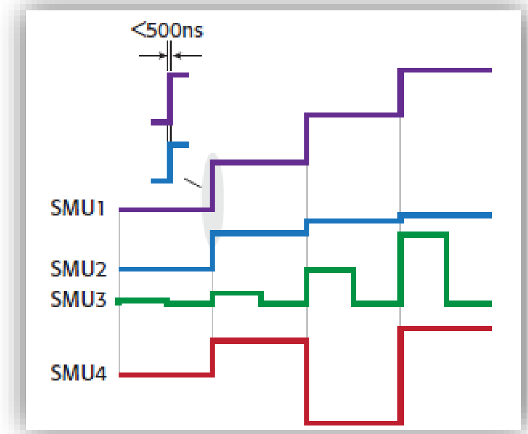
- Up to 50A pulsed (up to 100A with 2 units)
- Up to 2000W pulse / 200 W DC power
- Pulse widths from 100us to DC
- High speed and integrating ADCs

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

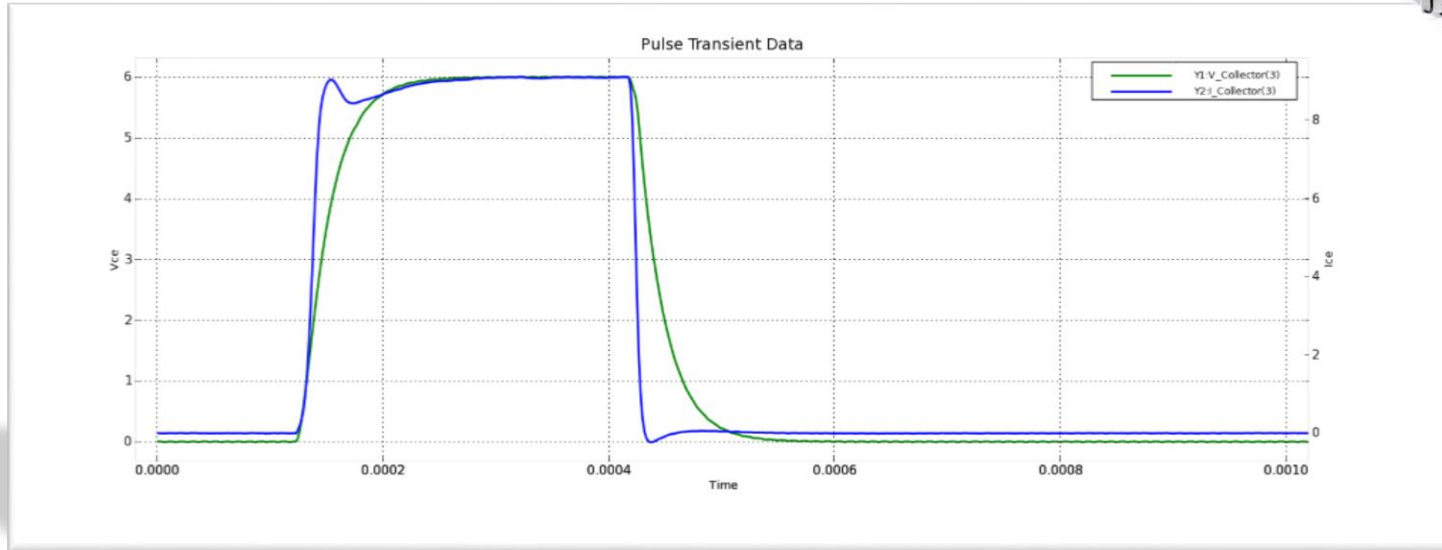
Series 2600B and 2650A SMUs – Flexibility and Speed





- 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 2650A ADCs



Integrating ADC

- 24-bit resolution
- Maximum reading rate = 20kHz
- Simultaneous voltage and current measurements ensured by dual ADCs
- Useful for high accuracy measurements

Fast ADC

- 18-bit resolution
- Maximum sample rate = 1 MHz
- Provide high speed measurements without external instruments
- Useful for transient characterization, especially pulse integrity inspection

Series 2650A Accessories for Optimal Performance

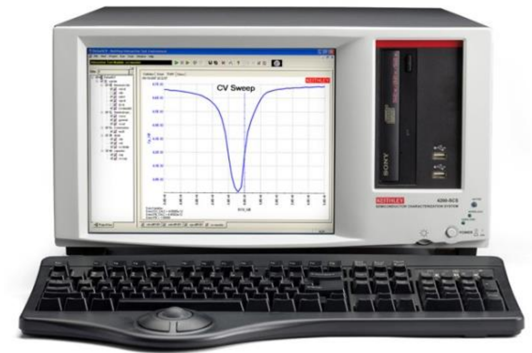
- **High Current**, Low Inductance, Low Resistance Cable
  - Custom design
  - Critical for achieving 100us pulses at **100A**
  - Supplied with Parametric Curve Tracer

- **High Voltage** Low Noise Triaxial Cable
  - Custom design
  - Critical for achieving guarded **pA-level** current measurements at **3kV**
  - Supplied with Parametric Curve Tracer

Model 4200-SCS Semiconductor Characterization System

- A an integrated semiconductor parameter analyzer that contains
  - Source-Measure Units (SMUs) – 200V, 1A
  - **Capacitance meters**
  - Ultra-Fast I-V and Pulse cards

This is the only reason to have 4200 in a parametric curve tracer

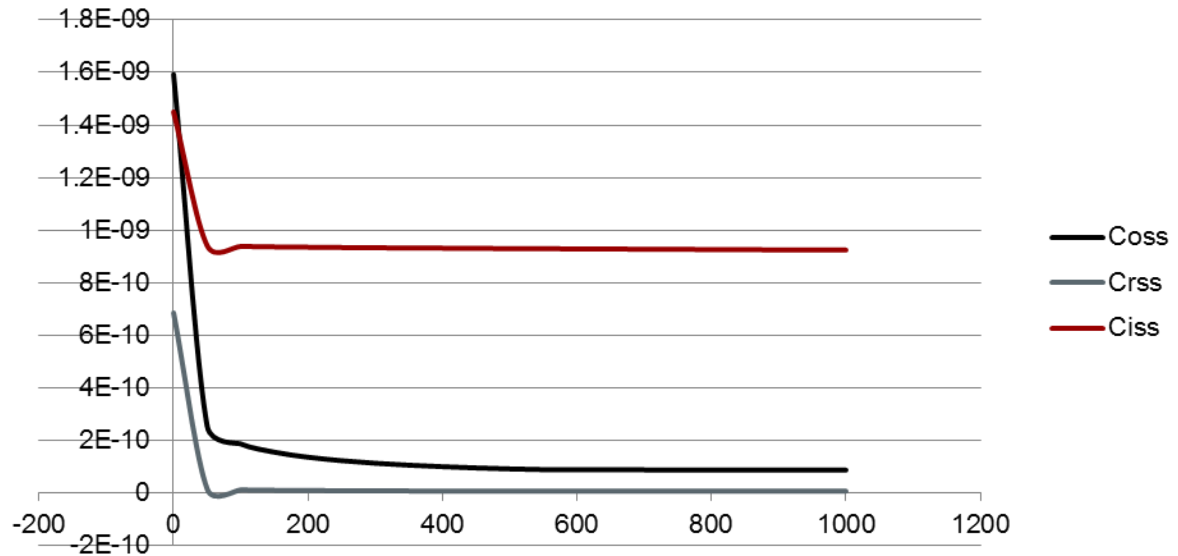


- Includes PC and Window-based, point-and-click GUI that enables the user to quickly and simply set up and run tests, and analyze data

- For more details on Keithley Model 4200, refer to KI201

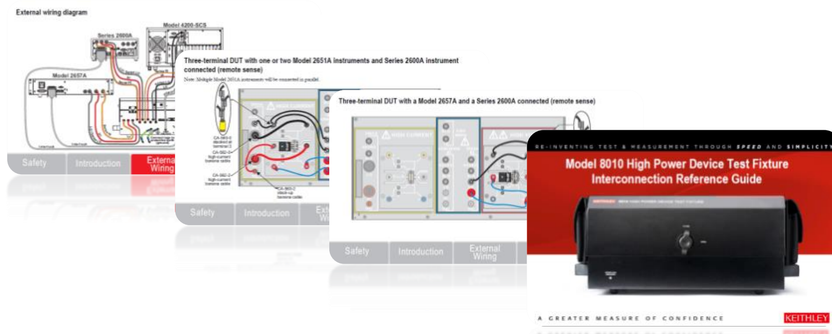
Add HV C-V capability with PCT-CVU Option

- 2,3 and 4 terminal C-V
- 10KHz to 2MHz
- Up to 3000V (HV-CV)
- Simplified interconnect



Example of Coss, Crss,Ciss on SiC FET

Package Level Test:
Model 8010 Test Fixture

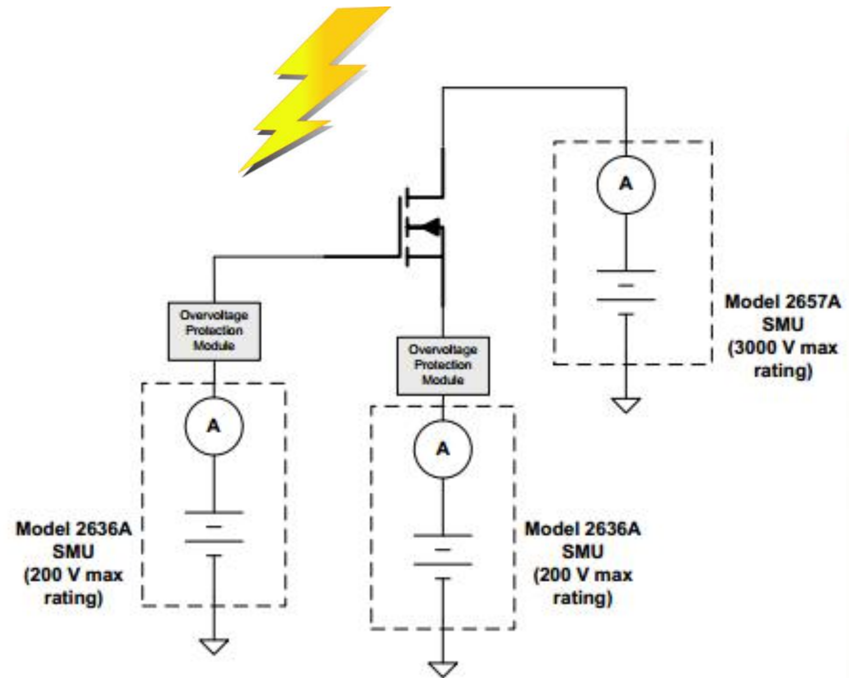


- Provides safe environment for testing at 3kV and at 100A
- Includes test sockets for TO-220 and TO-247 packages and custom devices.
- Easy to use banana connections
- Includes laminated, full-color connection guide

Protect Your Instrument if Device is Failed

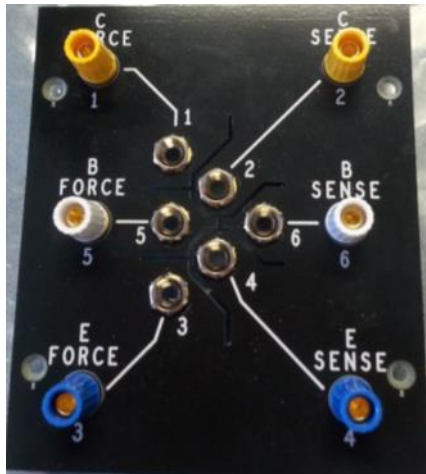
Overvoltage protection modules ensure that the lower voltage instrument is protected if device failure results

Model 2657A-PM-200
Protection Module



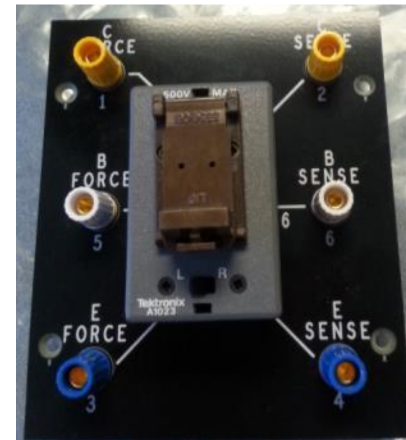
Note: K8010 test fixture is built in the protection module.

NEW!
Tektronix Curve Tracer Adapter Module



Model 8010-DTB-CT

Typical Tek module
that will fit into our Adapter



Our Adapter with a
Typical Tek module
plugged in

Makes Keithley Model 8010 compatible with all existing Tektronix curve tracer test modules

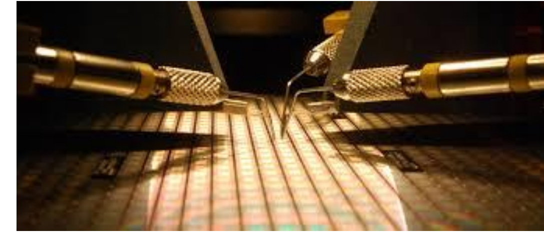
Wafer Level Test

Keithley Model 8020 High Power Interface Panel

- Solves complex interconnect cabling problems for probe stations and other test fixtures.
- Reduces set-up times
- Minimizes opportunities for connection errors
- Improves operator and test hardware protection
- Increases users' confidence in the accuracy of their results

Keithley PCT

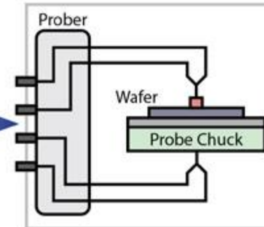
Wafer Level and Package Level Testing



WAFER LEVEL CHARACTERIZATION

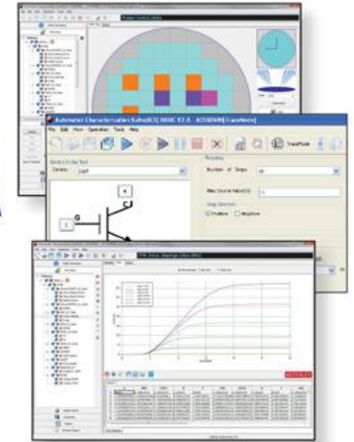
PCT CONFIGURATION
Model 2600-PCT-4

8020 High Power
Interface Panel



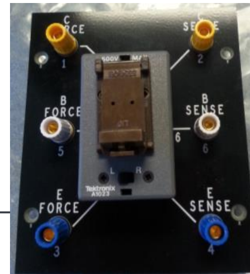
PROBE STATION

8010 High Power
Device Test Fixture



RESULTS!

PACKAGED PARTS CHARACTERIZATION



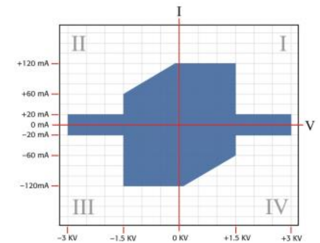
Agenda

1. Keithley Solution Glance
2. Market Drivers and Power Design
3. Device Selection Verification
4. Parametric Curve Tracer
5. Conclusion

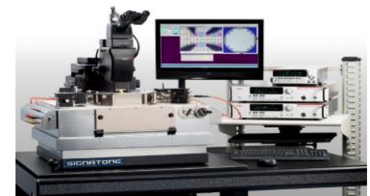
Conclusion

1. Keithley high power parametric curve tracer 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.

Thanks for your time ~