Next Generation Curve Tracing & Measurement Tips for Power Device

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Agenda

– Conventional Analog Curve Tracer & Measurement Challenges

– Next Generation Curve Tracing & Measurement Tips for Power Device

- Next Generation Measurement Requirements
- Tips for Precision IV Characterizations
- Tips for CV, Qg & Current Collapse Measurement
- Measurement Impact from Temperature and Small Pulse Width.
- Compliance Setting & Waveform Inspection

– Keysight Solutions on High Power Curve Tracing

What is a Conventional Analog Curve Tracer?

The conventional analog curve tracer has two main signal sources:

- A collector supply to sweep bias on the collector and
- A step generator to sweep the bias on the base terminal.

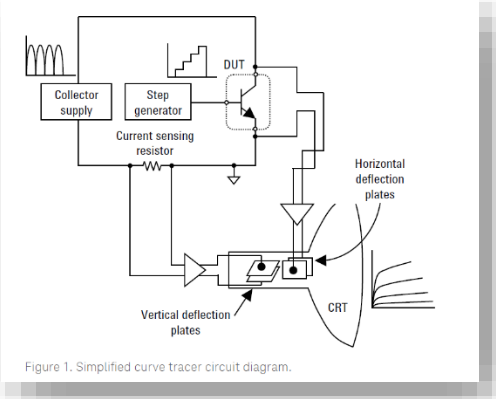
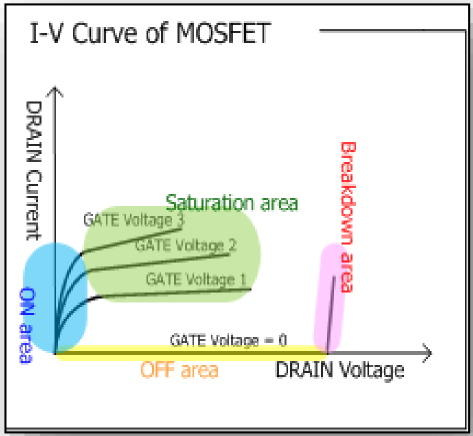


Figure 1. Simplified curve tracer circuit diagram.

In a traditional curve tracer, a cathode ray tube (CRT) is used to display the IV curve. The voltage applied to the collector terminal is used to detect an electron beam horizontally and voltage across a shunt resistor (to measure collector current) is used to detect it vertically.



Normally curve tracer is use to perform I-V curve measurement for various semiconductor device like IGBTs, MOSFETs, Transistors, Diodes, etc.

Measurement example like:

- Resistor curve
- Diode curve (forward or reverse bias)
- Transistor curve (Ic-Vce)
- MOSFET / FET curve (Id-Vds, Breakdown, saturation area)

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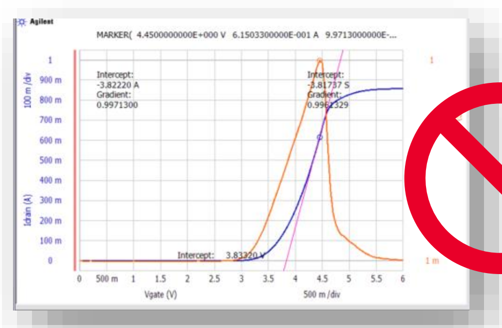
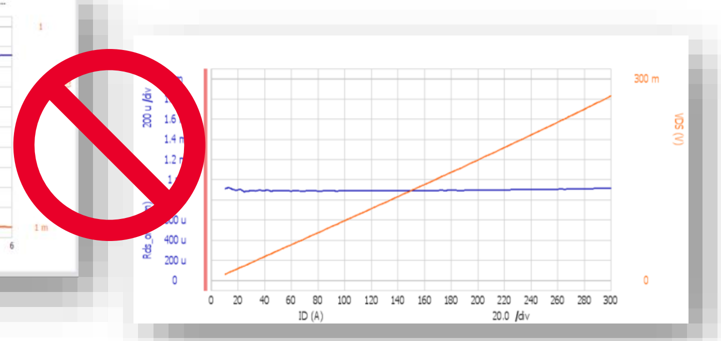
Measurement Challenges using Conventional Analog Curve Tracer

1. Unable to measure transfer characteristic (Like Id-Vg, gm, Vth and On resistance) accurately.
2. Difficult to manage measurement data (like curve comparison).
3. No compliance feature to avoid damaging the device.
4. Unable to measure CV or Qg for advance power device.

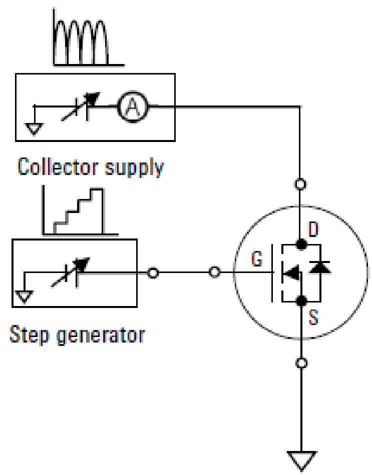


Id-Vg



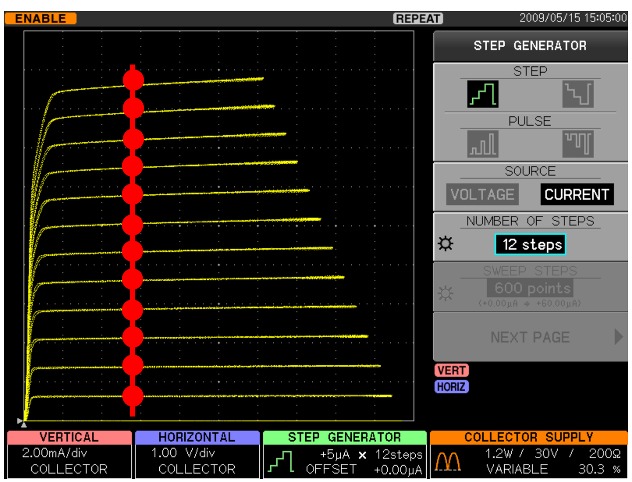
On-resistance

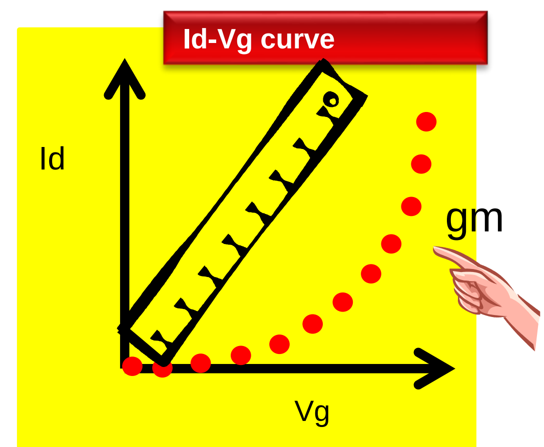
It is not easy to extracting Id-Vg, gm and Vth Using a Traditional Curve Tracer



Issues:

1. Curve tracer has ~ 20 steps maximum; insufficient for accurate gm & Vth measurement
2. Extremely tedious to make this measurement; no easy way to automate it

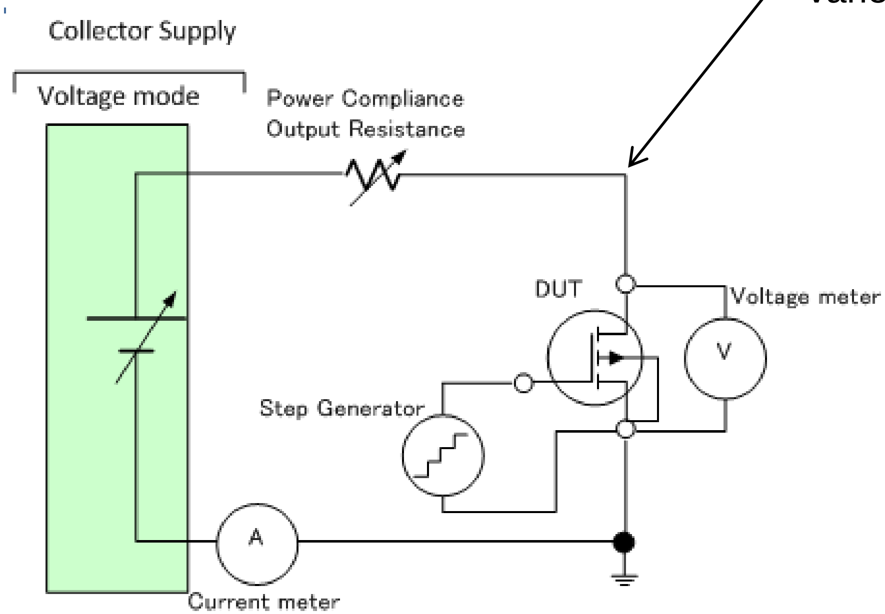


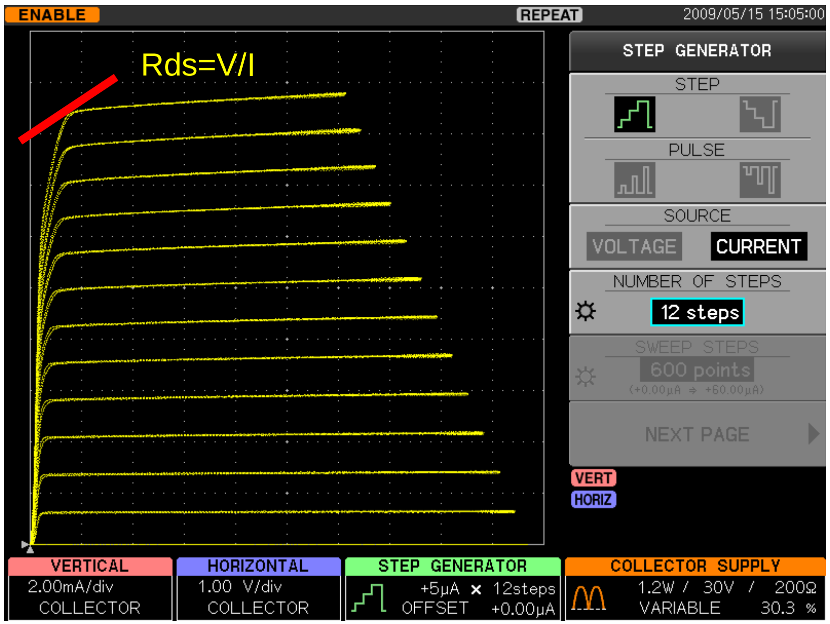


It is not easy to measuring On Resistance Using a Traditional Curve Tracer

Curve Tracer Measurement:

Actual drain voltage varies with current.





→**The on resistance obtained from the Id-Vd curve gradient is not accurate, because the applied voltage at the drain is not constant.**

Next Generation Curve Tracing & Measurement Tips for Power Device

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Next Generation of Curve Tracing

Able to Measure Complete Static Characteristic

- New curve tracer should be able to measure complete static characteristic like Ig-Vg, Vth, Igss… and also Transfer characteristic like Vge-Ic / Vge-Vce.

Meet future power device measurement requirements

- WBG material (GaN / SiC) will improve the switching frequency in order to achieve higher energy efficiency.
- With higher switching frequency, CV and Qg characteristic become important parameters that need to be evaluated.

Support automotive / mission critical requirements

- Mission critical operation like the automotive/ military, required detail measurement of the device.
- Measurement under different temperatures, smallest pulse width is critical to reveal the actual characteristic of the device.

Effective and Efficiency measurement

- Compliance features is require to make effective measurement without damaging the device.
- Waveform inspection / Oscilloscope view is critical to ensure smallest pulse width and yet obtain the measurement accurately.

Next Generation of Curve Tracing

Able to Measure Complete Static Characteristic

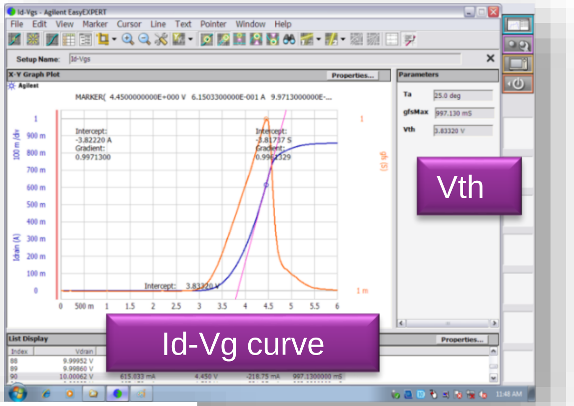
- New curve tracer should be able to measure complete static characteristic like Ig-Vg, Vth, Igss… and also Transfer characteristic like Vge-Ic / Vge-Vce.

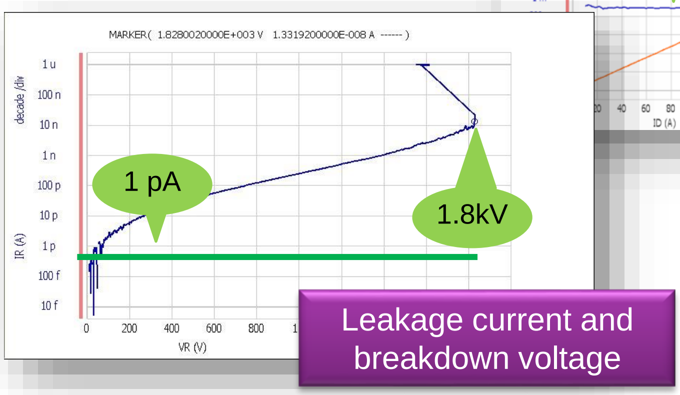
- SMU Technologies to measure complete static characteristics
- Tips on Power MOSFET IV Measurement

Measure complete static characteristics

➢ Using SMU technology, <u>complete static characteristics</u> of power device can be measured easily.

Static characteristics		
	Threshold voltage	V(th),Vge(th)
	Transfer Characteristics	Id-Vgs, Ic-Vge, gfs
	On resistance	Rds-on. Vce(sat)
	Gate leakage current	Igss, Iges
	Output leakage current	Idss, Ices
	Output Characteristics	Id-Vds, Ic-Vce
	Breakdown voltage	BVds, BVces

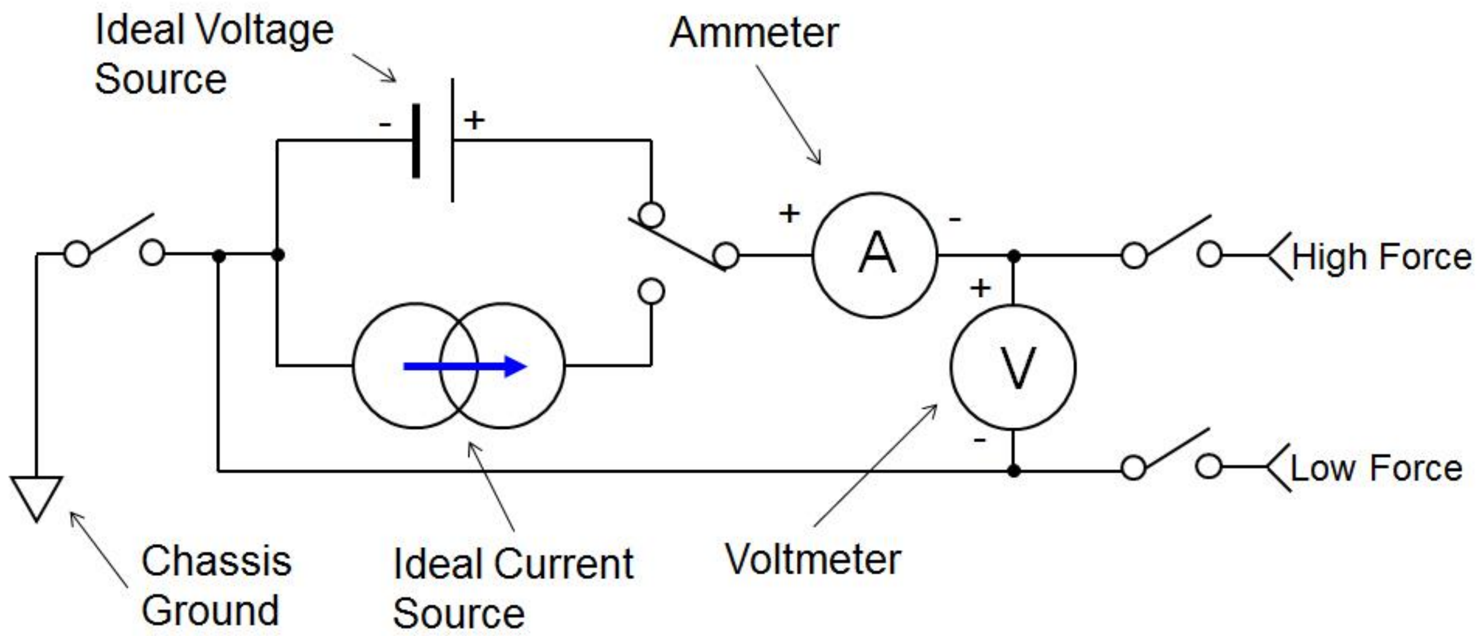




What is a Source/Measure Unit (SMU)?

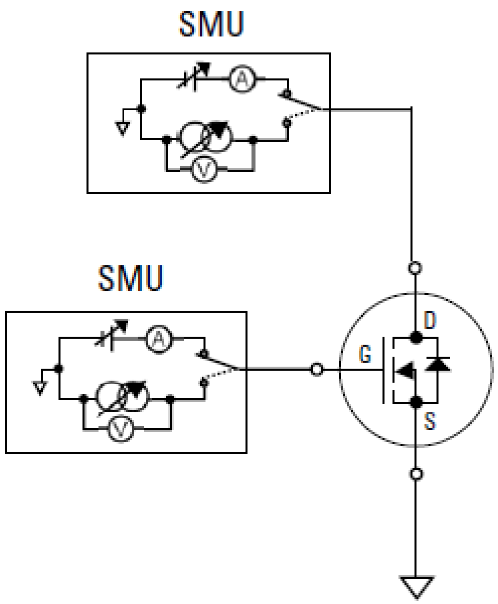
An SMU integrates the following capabilities:

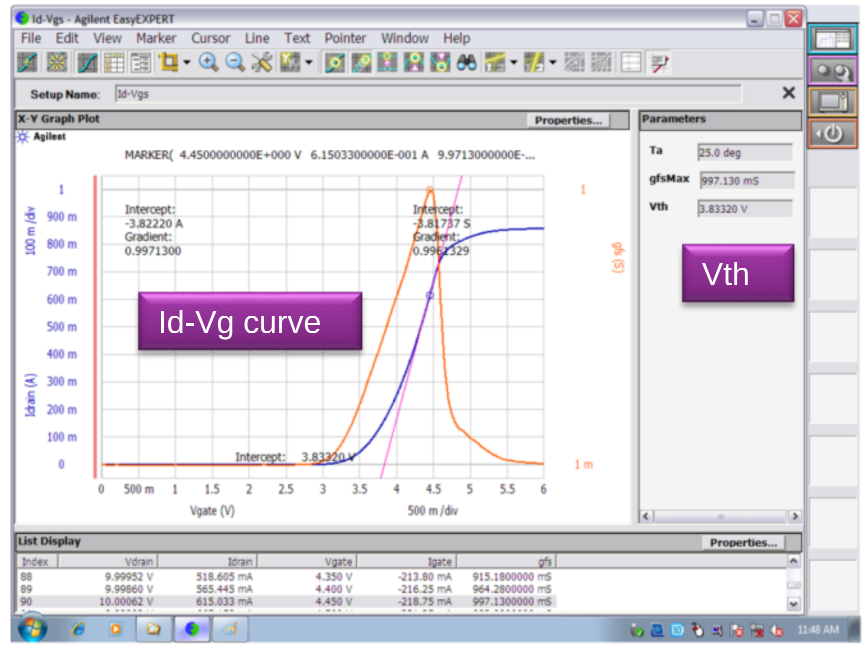
- Four-quadrant voltage source
- Four-quadrant current source
- Voltage Meter
- Current Meter



Source/Measure Unit Technology is Much Better for Doing Id-Vg, gm and Vth Measurement

SMU Architecture





Advantages of SMU-based Measurement:

1. Id-Vg curve is very easy to make
2. Using built-in auto analysis functions, it is easy to extract threshold voltage (Vth)

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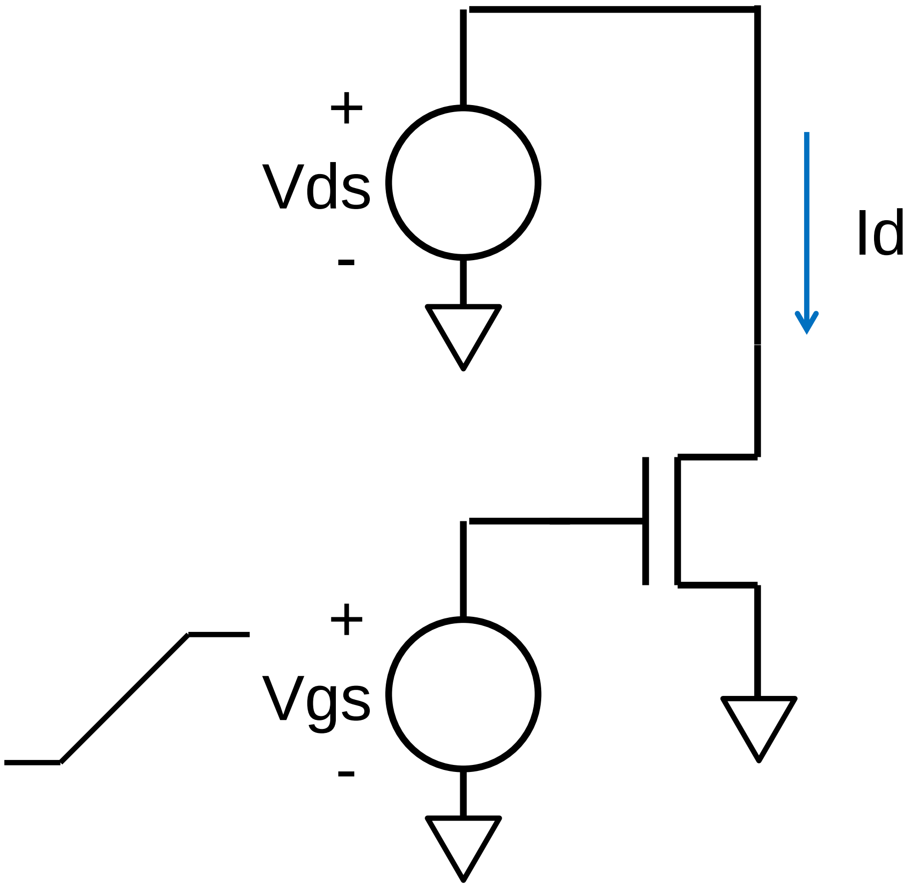
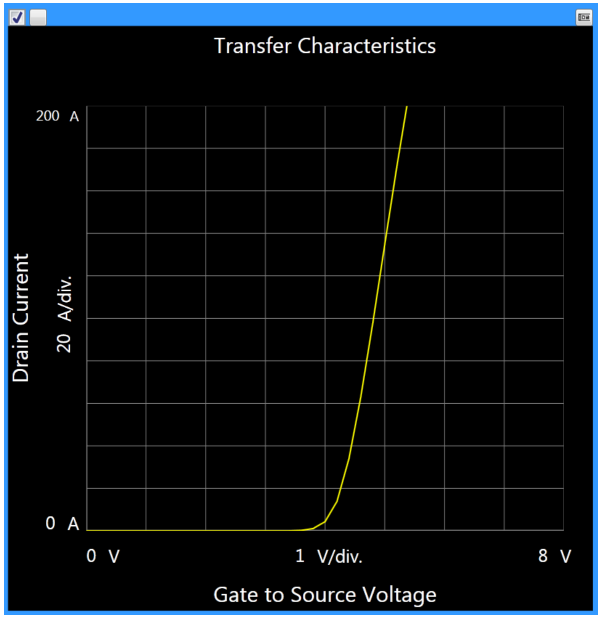
MOSFET Transistor IV Measurement Basics – 1

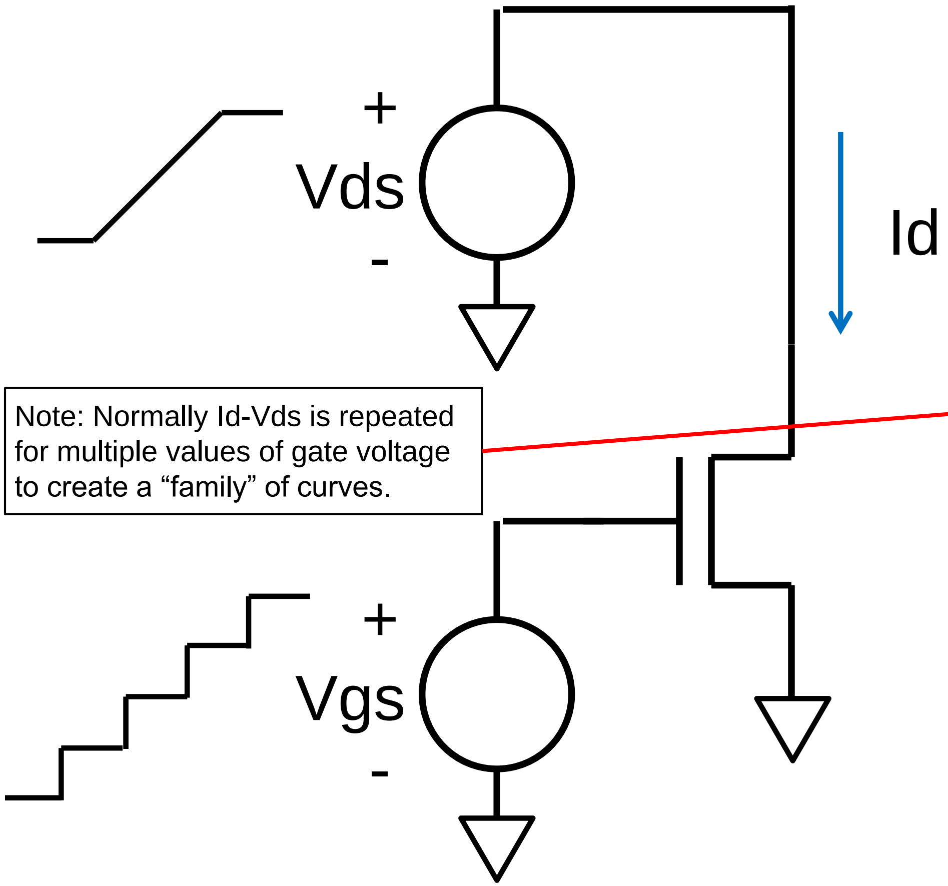


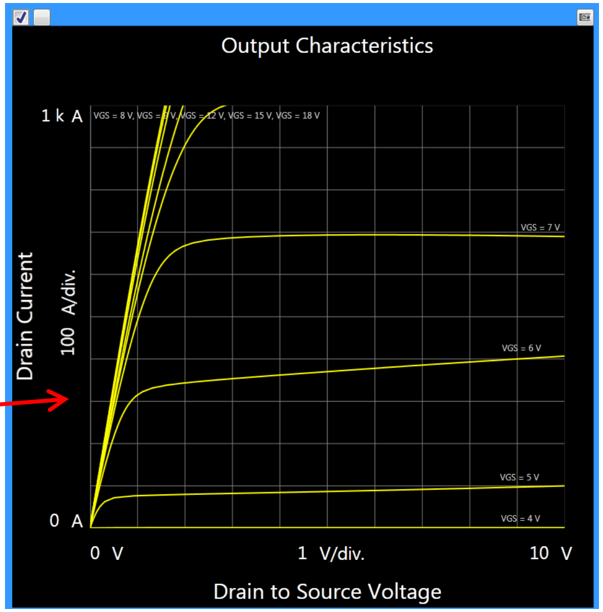


Id vs. Vgs

Id vs. Vgs – Sweep the voltage applied to the gate (with a fixed drain voltage) and measure the drain current as a function of gate to source voltage.

MOSFET Transistor IV Measurement Basics – 2

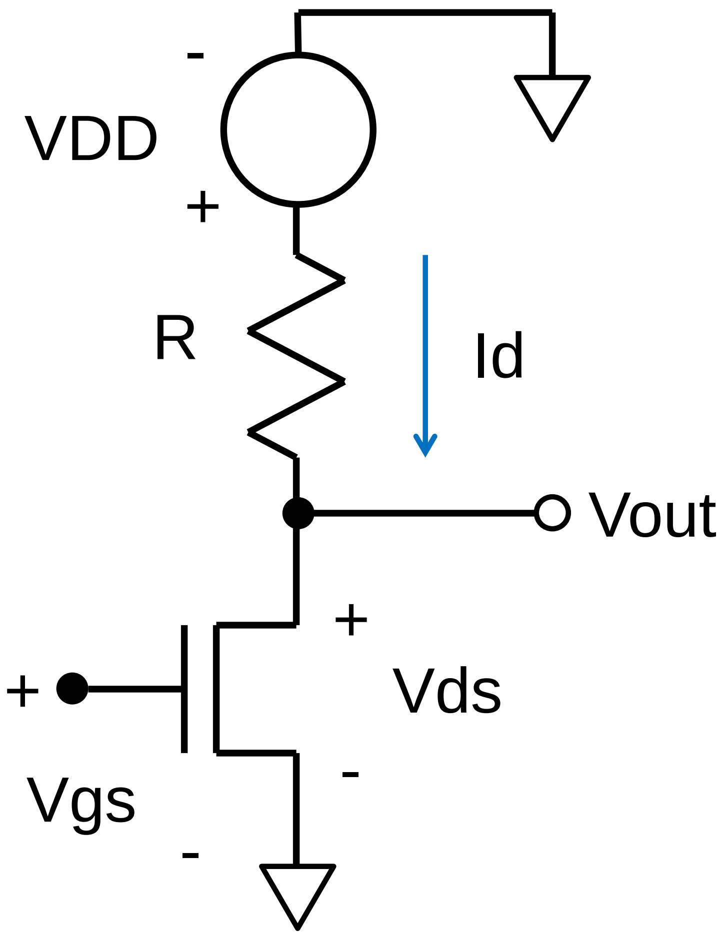


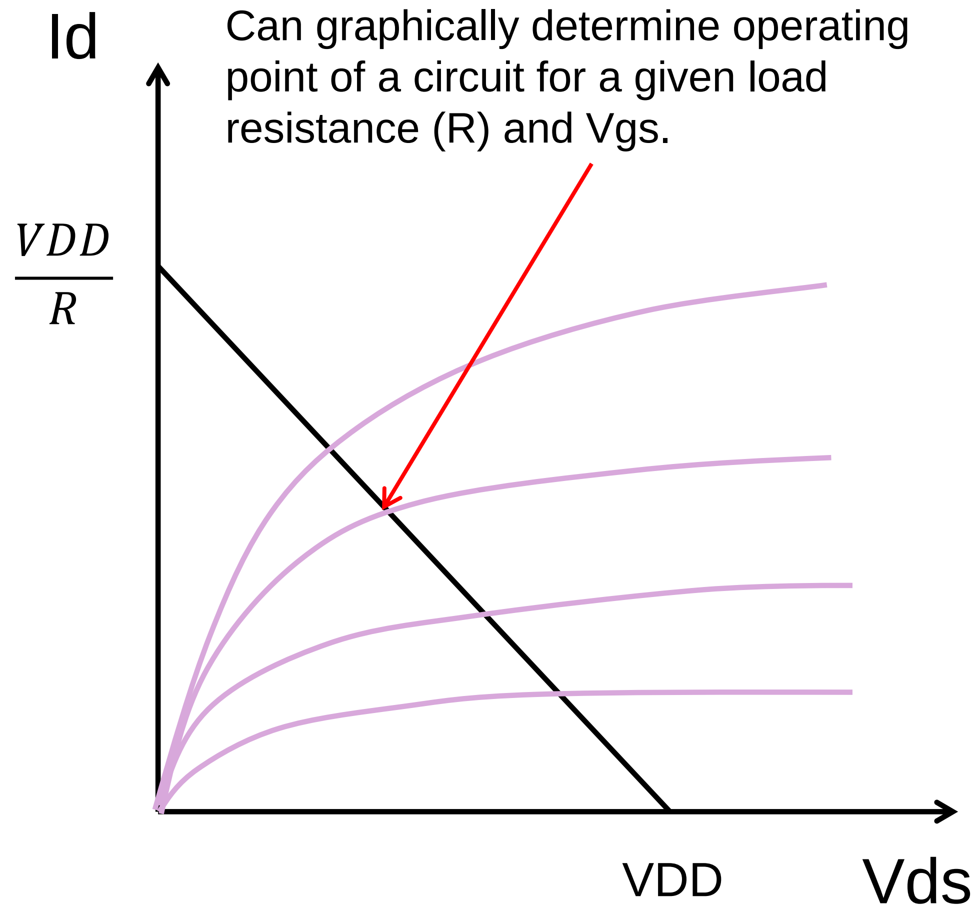


Id vs. Vds

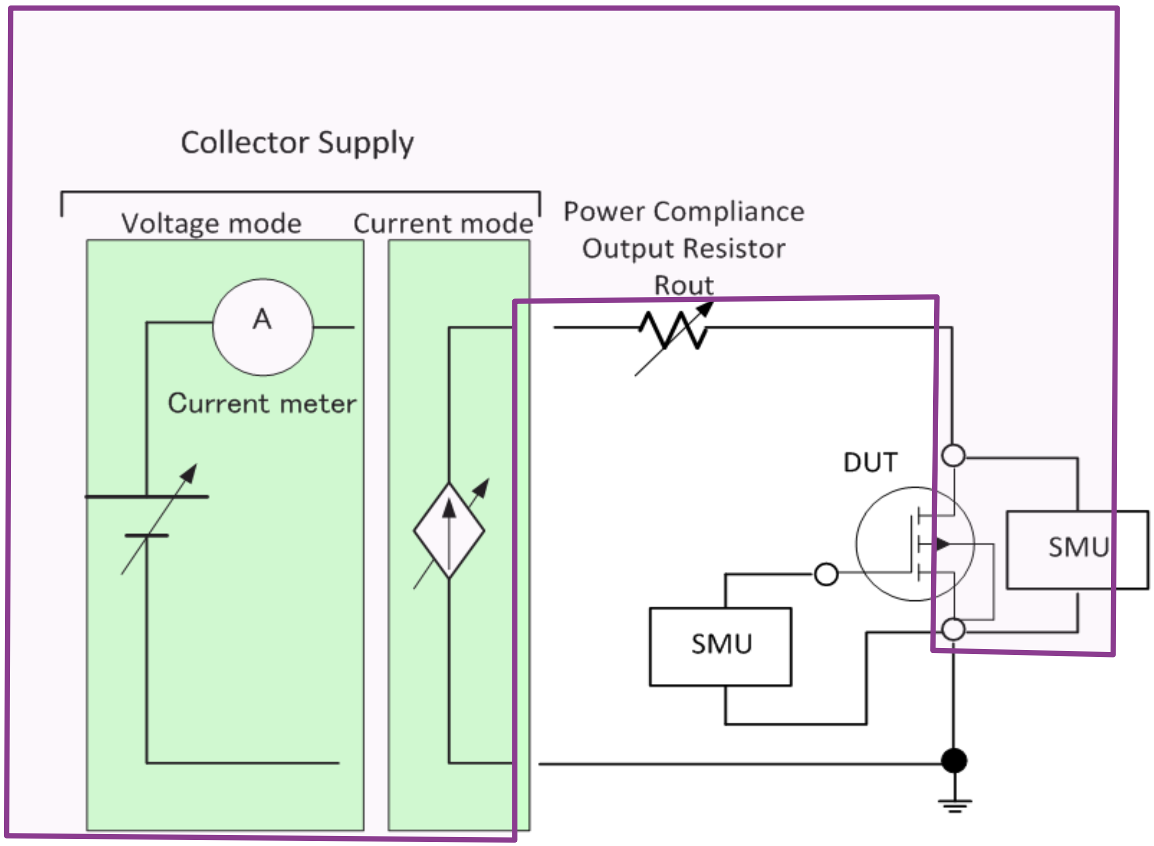
Id vs. Vds – Sweep the voltage applied to the drain (with a fixed gate voltage) and measure the drain current as a function of drain to source voltage.

Why is Id-Vds an Important Curve?





It is Better to Measure On Resistance by Forcing Current



Ultra-High Current Unit

Advantages:

1. Eliminate uncertainty as to actual current flowing into drain.
2. Precision voltage measurement capability support sub-milliohm measurement resolution

Next Generation of Curve Tracing

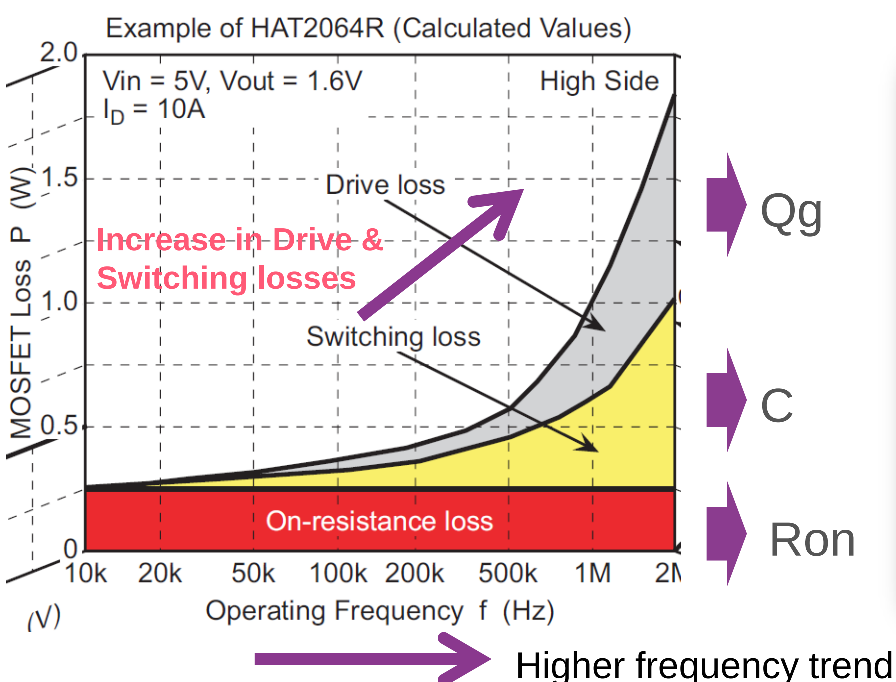
Meet future power device measurement requirements

- WBG material (GaN / SiC) will improve the switching frequency in order to achieve higher energy efficiency.
- With higher switching frequency, CV and Qg characteristic become important parameters that need to be evaluated.

- Capacitance Measurement
- Gate Charge Measurement
- GaN Current Collapse measurement

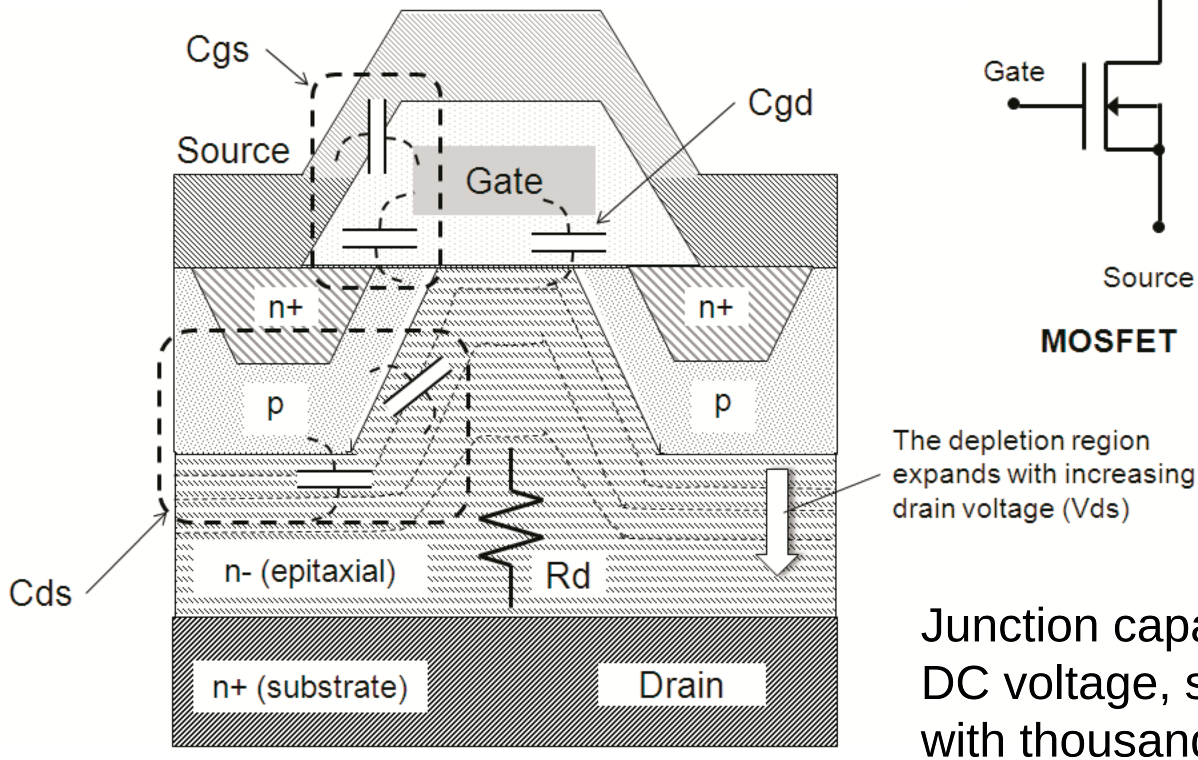
Gate Charge and Capacitance Measurement are Needed for Higher Switching Frequency

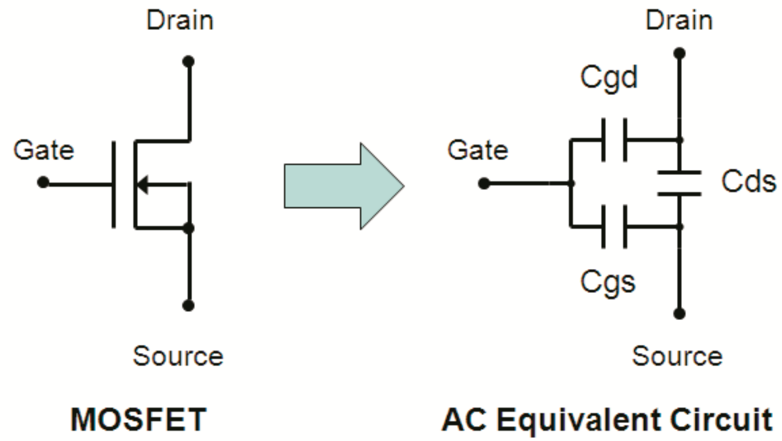
Energy efficiency is high priority for modern power device.
Switching and driving loss are increased as switching frequency goes up in order to make the equipment smaller.
Evaluate gate charge and device capacitances are necessaries.



Gate charge (Qg) and device capacitances (Ciss, Coss, Crss) evaluation is essential for power loss estimation

Power MOSFET Capacitance Measurement

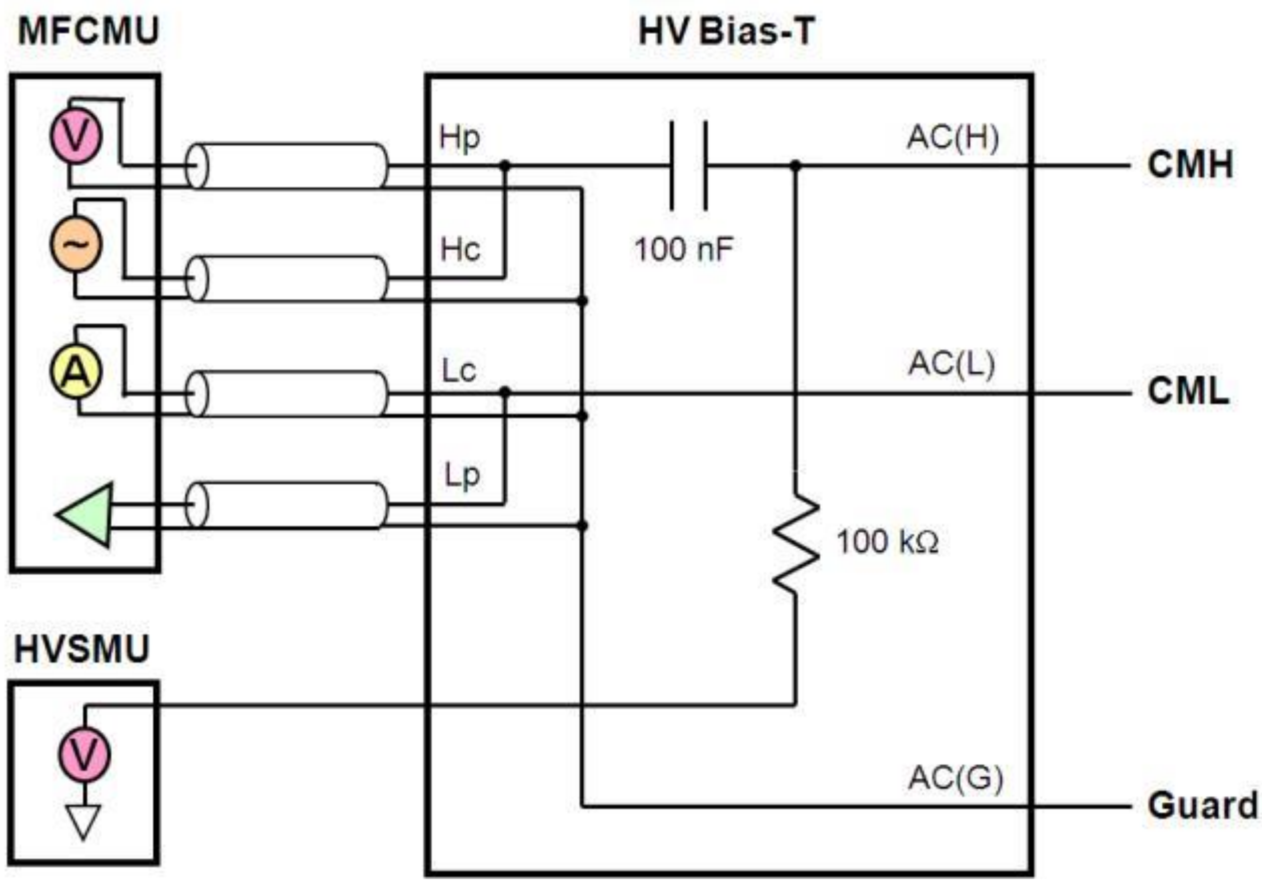




Junction capacitances vary with applied DC voltage, so you must measure them with thousands of volts of applied DC bias.

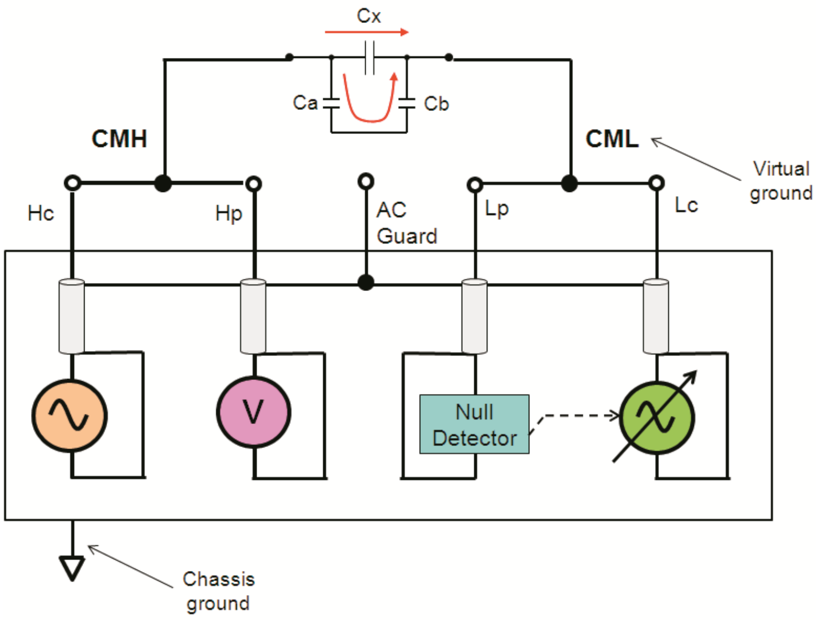
__Issue:__ No off-the-shelf capacitance meter supports measurements with more than a few tens of volts of DC bias.

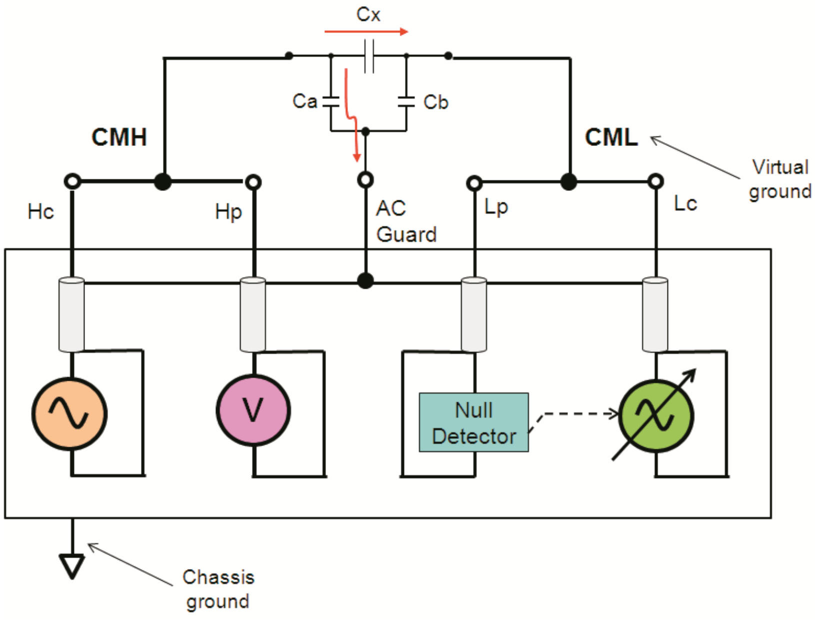
High-Voltage Bias-T Measures Capacitance at 3 kV



DC bias can be at thousands of volts while the AC signal is in the tens of millivolts.

Why is There a Separate Output for the AC Guard?



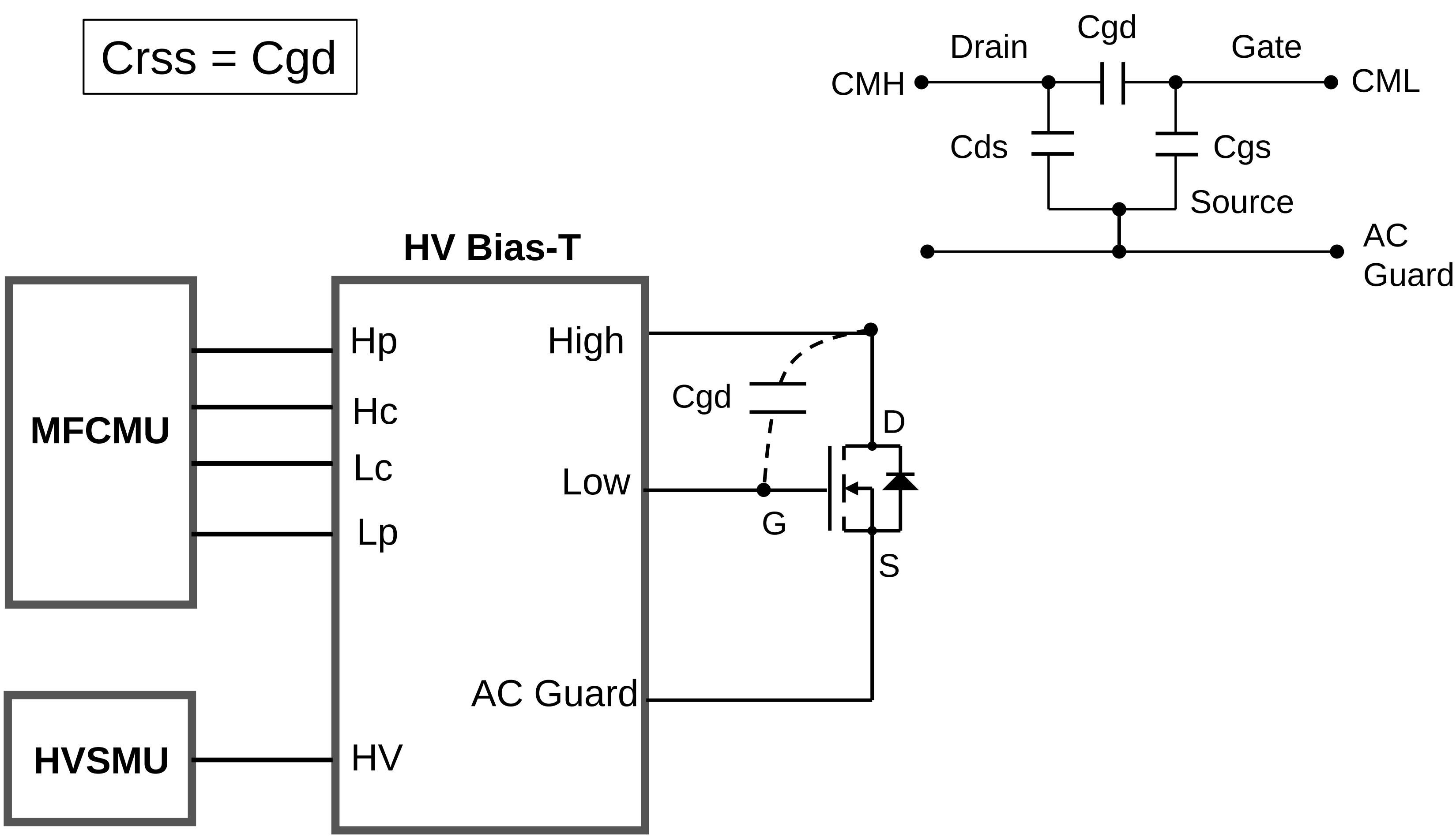


Problem: Some of the measured current passes through a parasitic path, which degrades measurement accuracy.

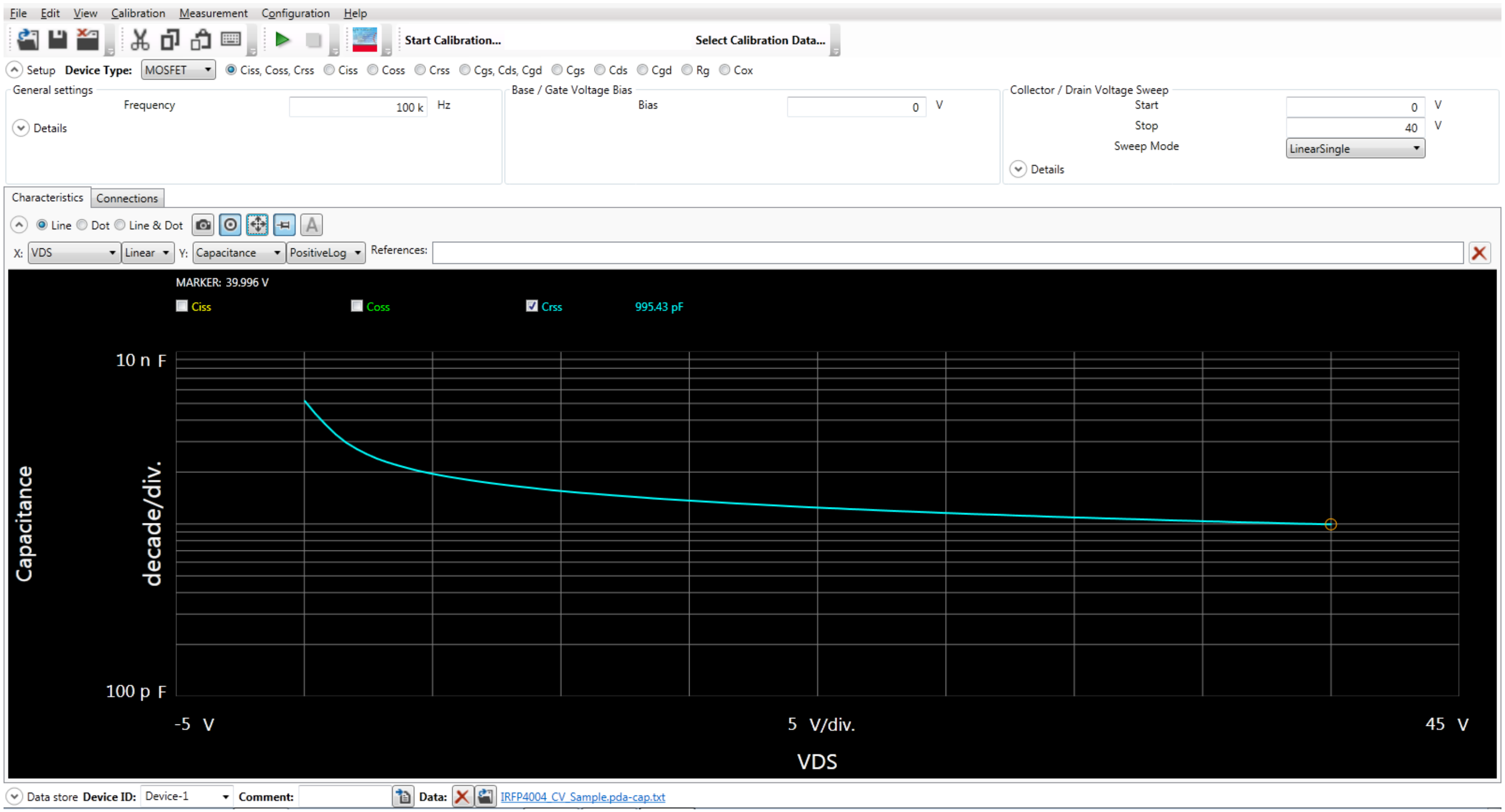
Solution: Use the AC guard to provide an alternative current path that keeps the parasitic current from going into the measurement node.

Typical Crss Measurement Configuration of Normally OFF Device

Crss = Cgd

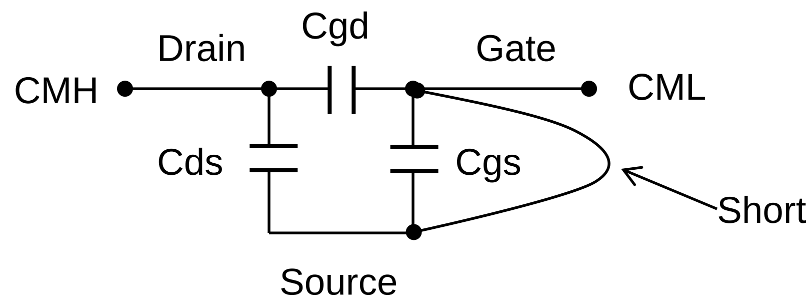


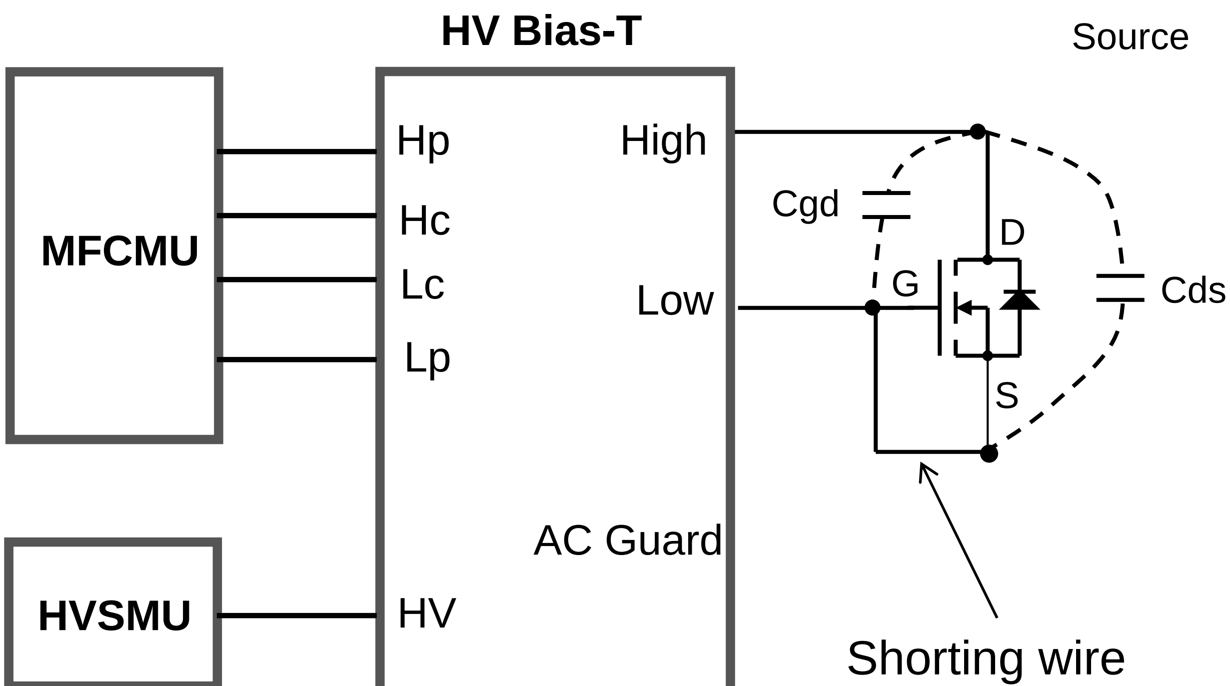
Typical Crss Measurement Results



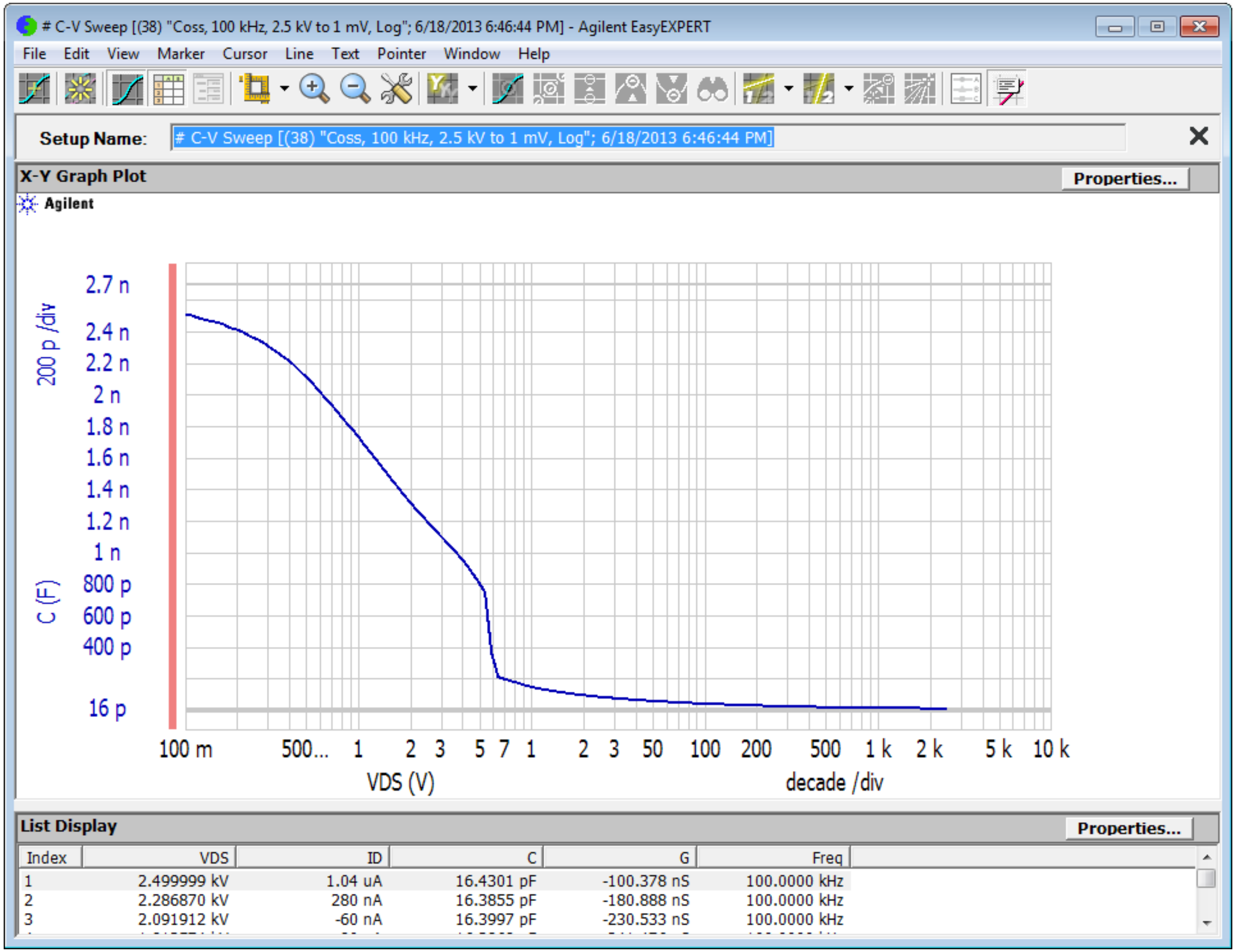
Configuration of Coss Measurement of Normally OFF Device

Coss = Cgd + Cds





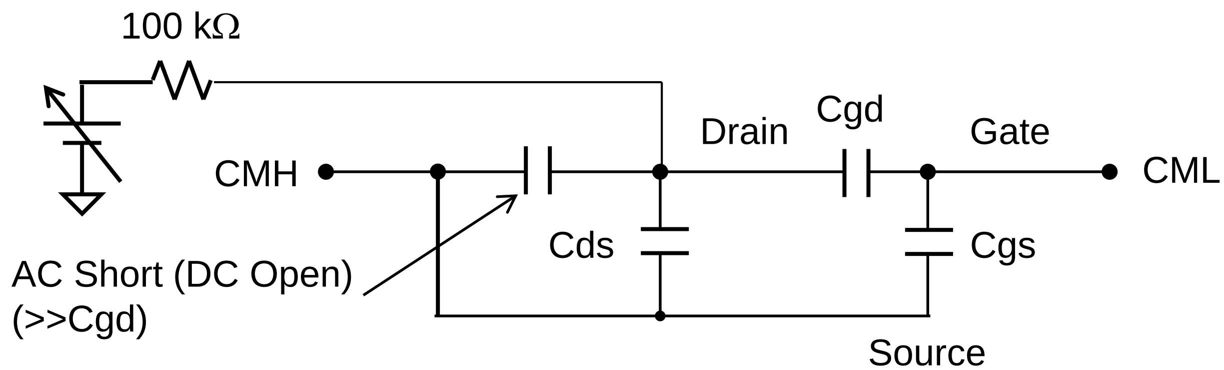
Typical Coss Measurement Results

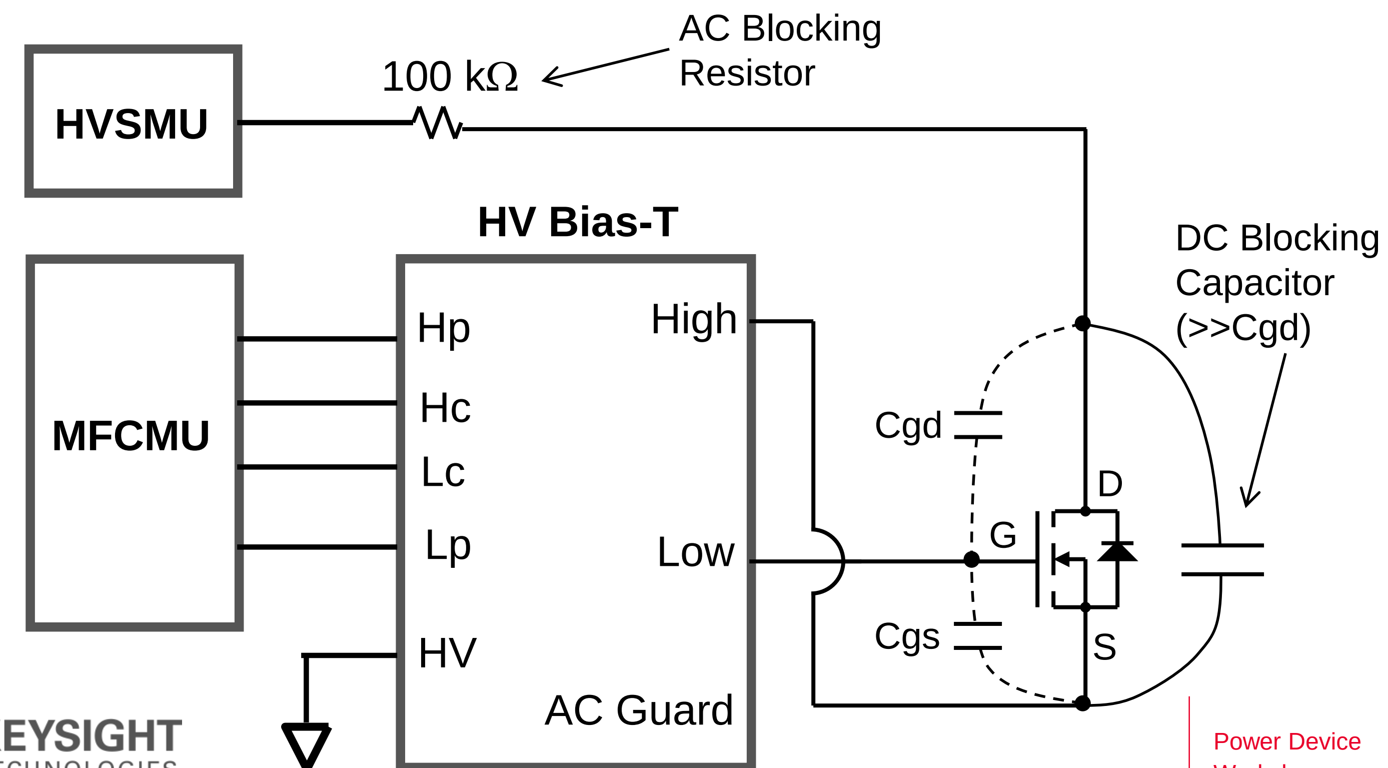


Index	VDS	ID	C	G	Freq
1	2.499999 kV	1.04 uA	16.4301 pF	-100.378 nS	100.0000 kHz
2	2.286870 kV	280 nA	16.3855 pF	-180.888 nS	100.0000 kHz
3	2.091912 kV	-60 nA	16.3997 pF	-230.533 nS	100.0000 kHz

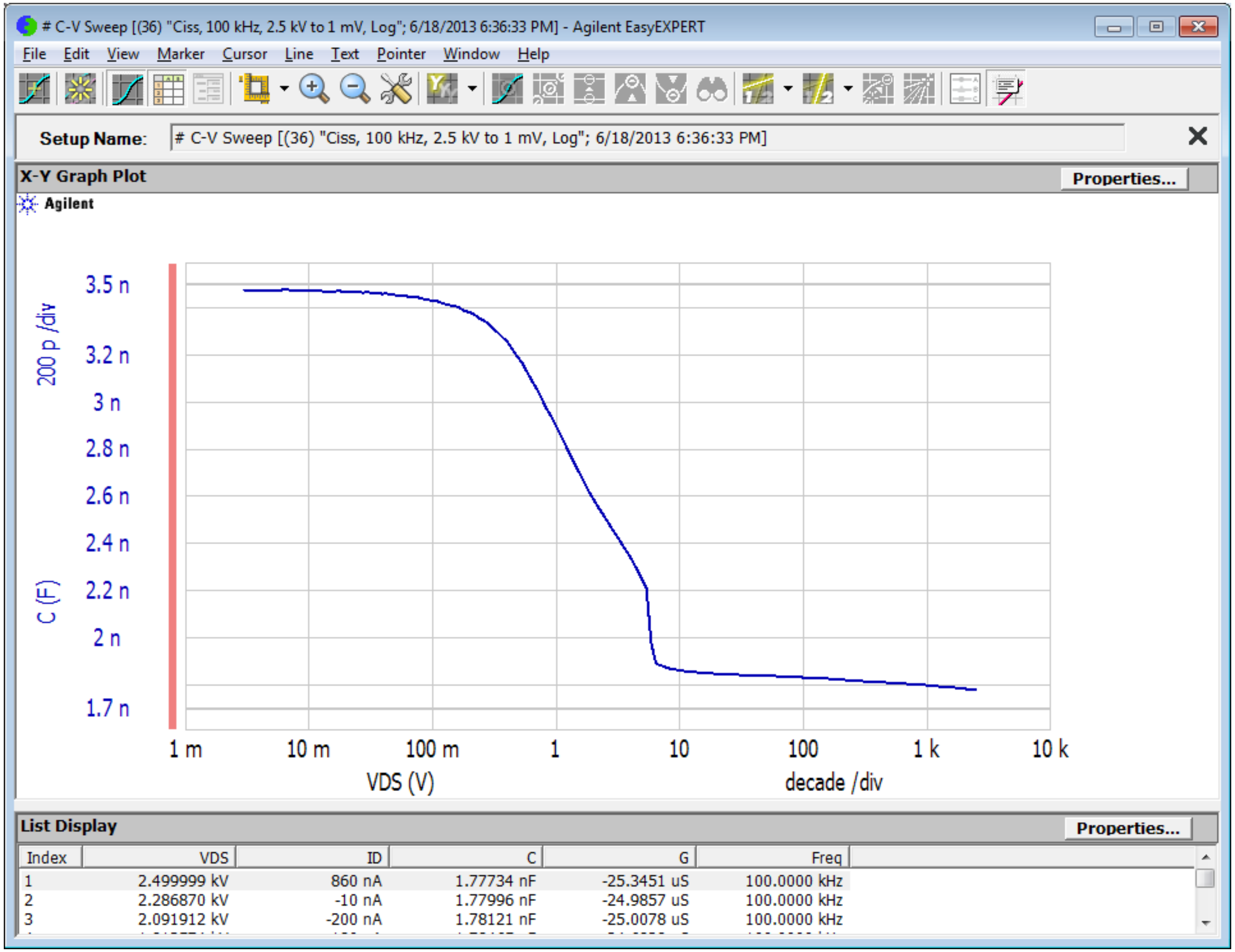
Configuration of Ciss Measurement of Normally OFF Device

Ciss = Cgs + Cgd





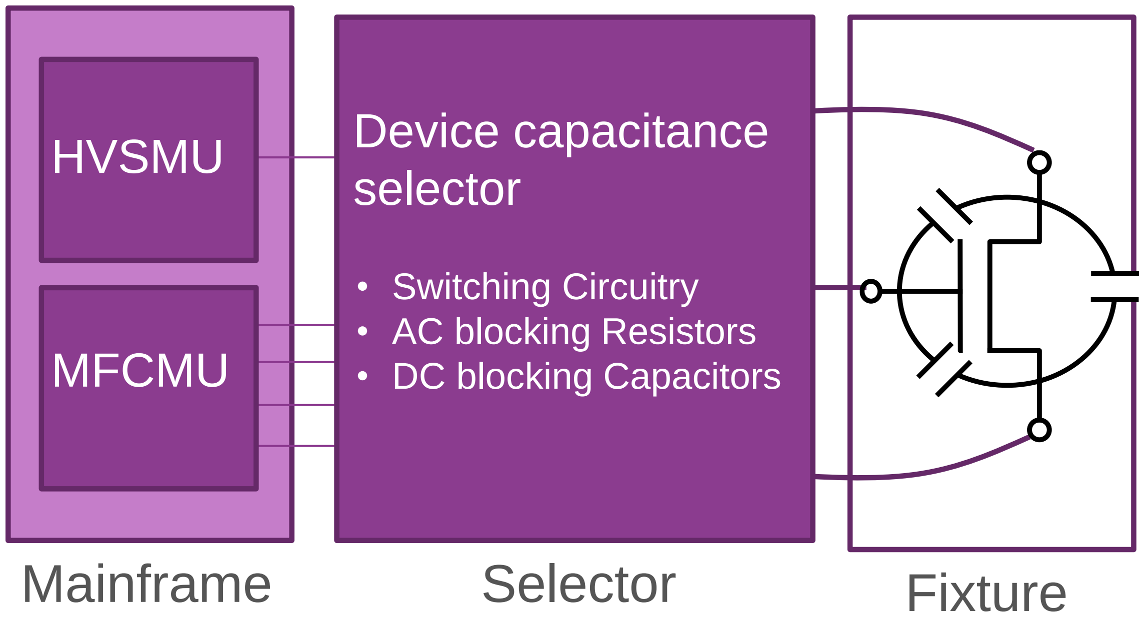
Typical Ciss Measurement Results



Accurate Capacitance Measurement on Power Devices is Extremely Difficult!

- Each capacitance measurement requires some manual re-wiring of the test setup.
- The connections for each measurement can be quite complicated & require external components.
- Especially difficult to measure “normally on” devices.
- No easy way to automate Ciss, Coss and Crss measurement.
- A deep understanding of measurement theory is needed to get valid results.

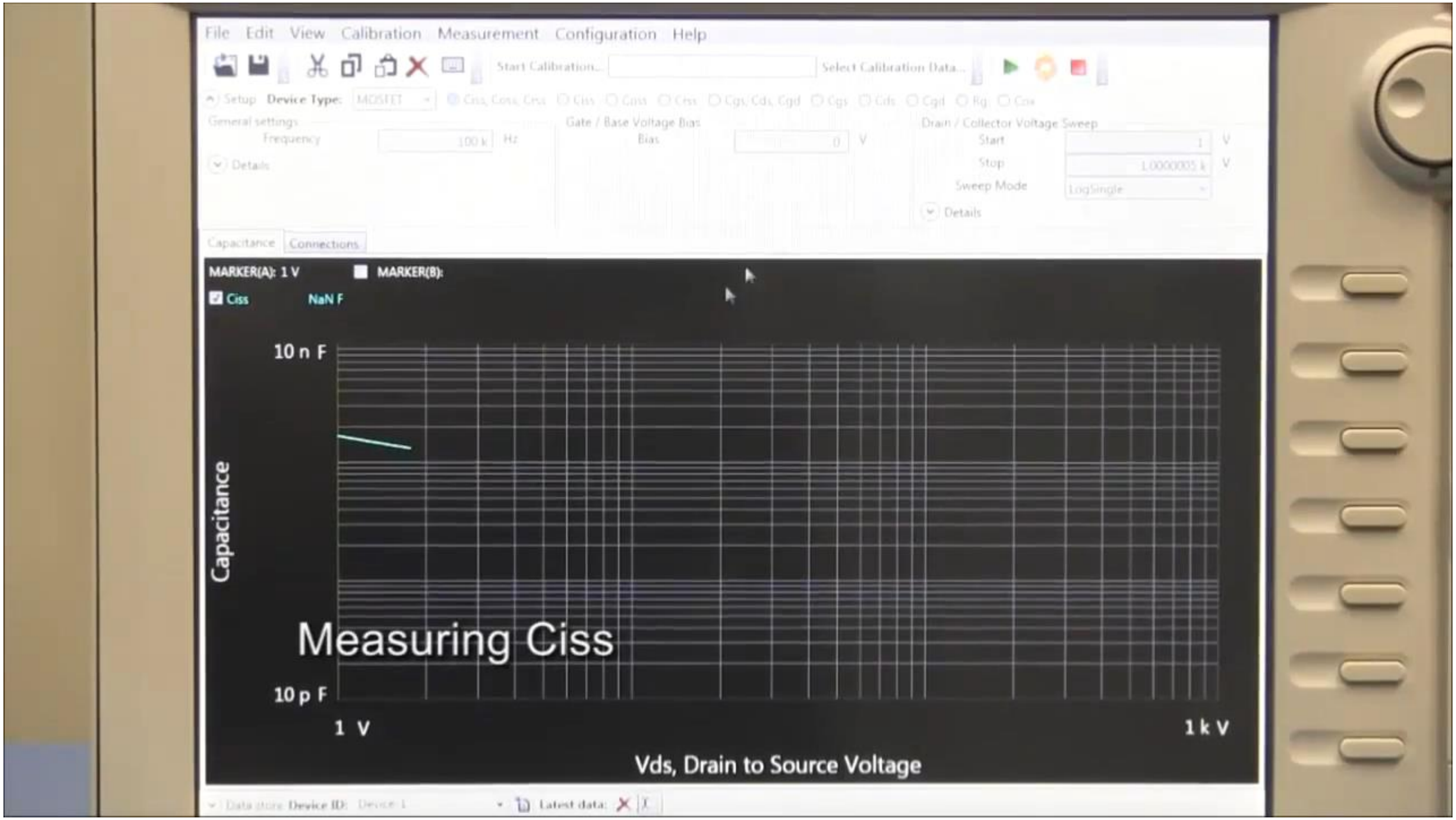
Keysight B1506A/07A Provide an Innovative Solution that Eliminates Capacitance Measurement Complexity



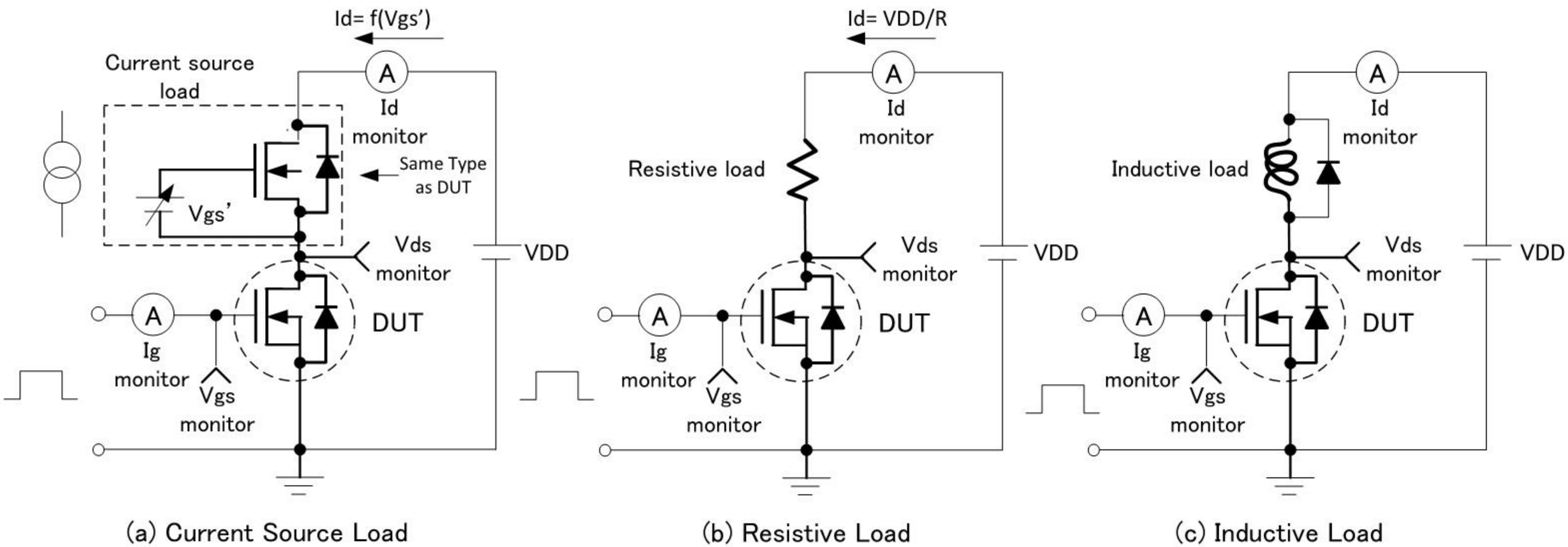
- ❖ Device capacitance selector supports more than 20 measurement configurations
- ❖ Can measure capacitance with up to 3 kV bias on the drain or collector
- ❖ Uses appropriate AC guarding as well as verified compensation techniques
- ❖ Can characterize "normally-on" devices such as GaN FET or SiC JFET
- ❖ Also able to perform gate resistance (Rg) measurements

Typical B1506A/07A Capacitance Measurements

Very complicated measurements now made easy (w/out changing cables).



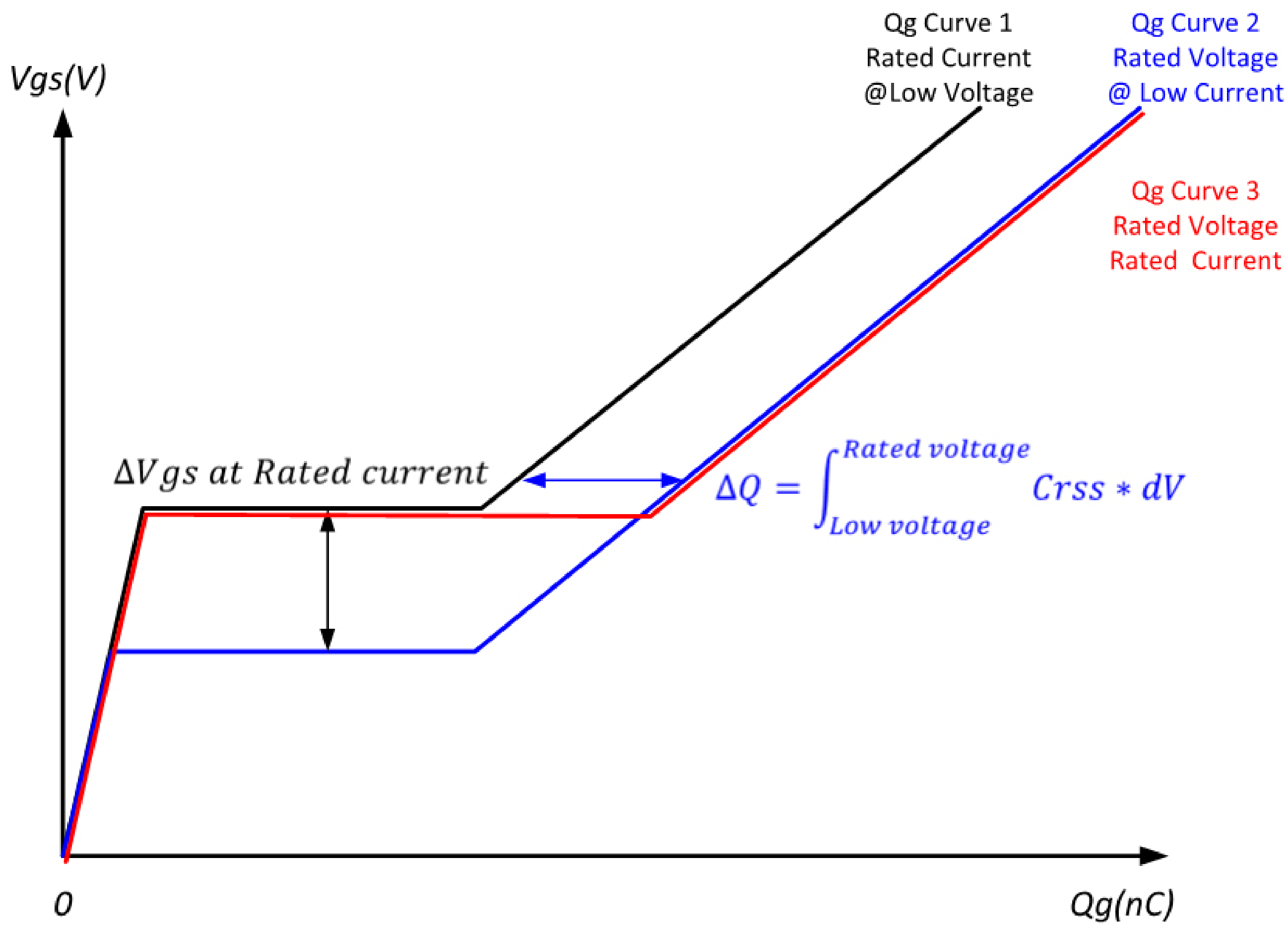
Conventional Gate Charge (Qg) Measurement Circuits



Key Challenges:

- Obtaining a power supply stable enough to provide accurate time-dependent output voltage and current.
- Designing a gate drive circuit that can accurately measure time-dependent current and voltage.

Improved Qg Measurement Technique

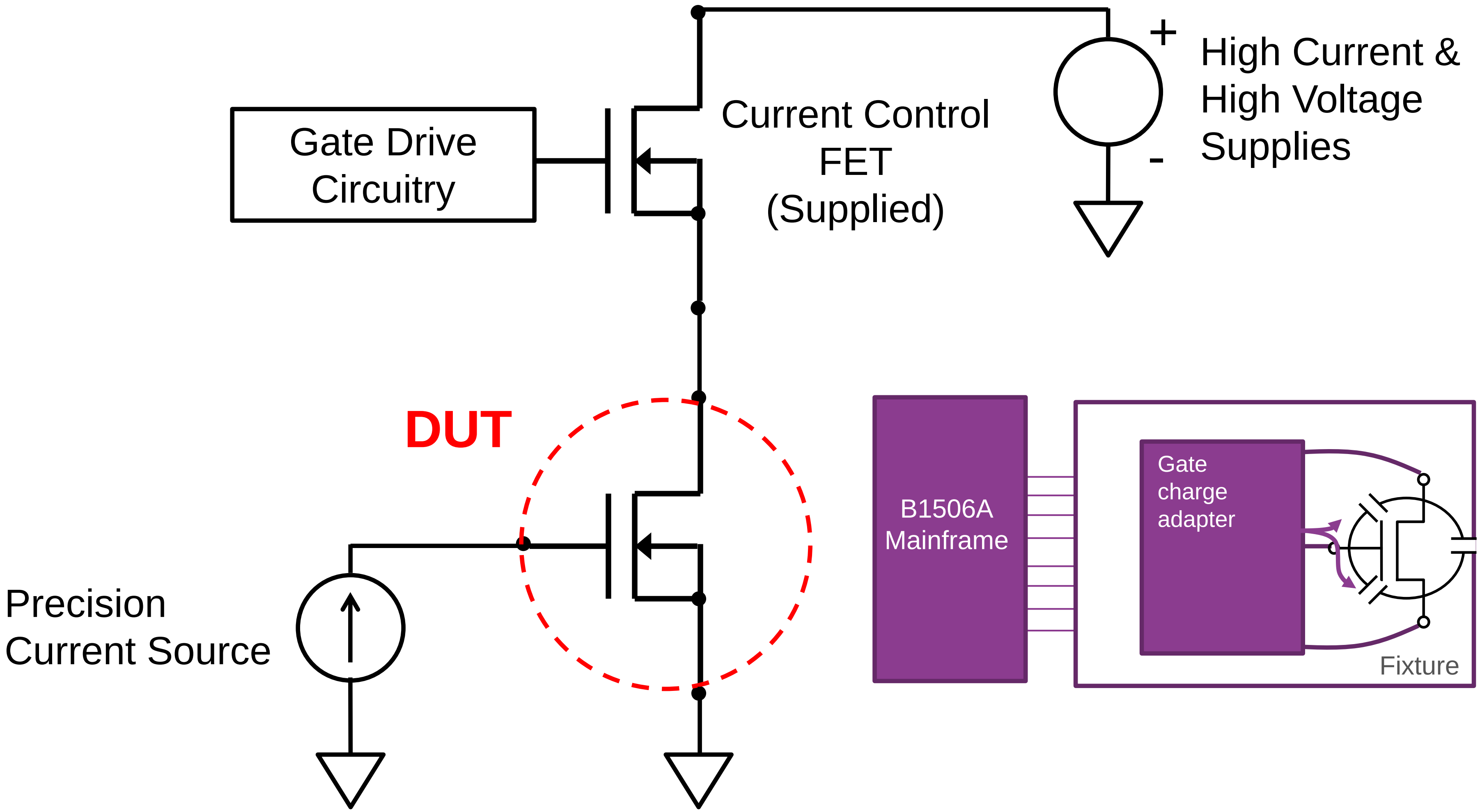


The Gate Charge Test Setup

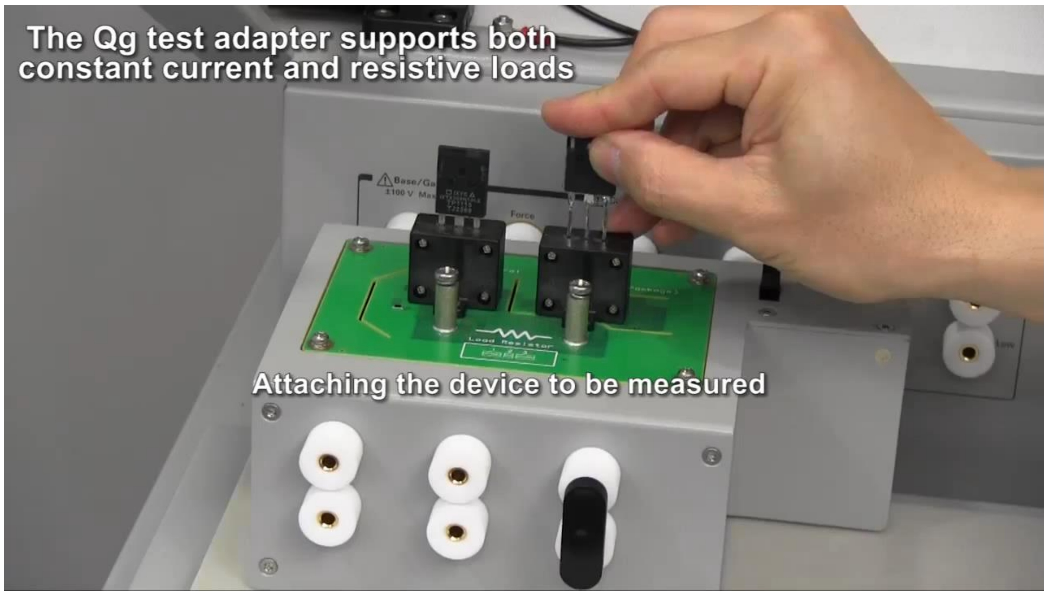
The standard 3-pin B1506A test fixture can do all measurements **<u>except</u>** for gate charge.

The B1506A will prompt you to insert the gate charge test fixture before starting the gate charge measurement.

Overview of New Gate Charge Measurement Technique



Advantages of New Gate Charge Solution



- Supports all power devices up to 3 kV, breaking the 60 V limit of commercially available Q_g test equipment
- Easily evaluate Q_g characteristics of high current and high voltage devices such as IGBT modules
- Q_g characteristics along with other measured parameters can be used to automatically calculate power losses

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Next Generation of Curve Tracing

Support automotive / mission critical requirements

- Mission critical operation like the automotive/ military, required detail measurement of the device.
- Measurement under different temperatures, smallest pulse width is critical to reveal the actual characteristic of the device.

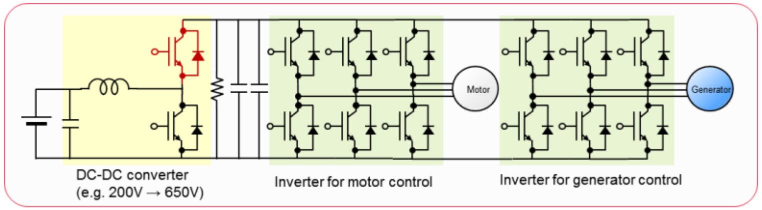
Device Characterization under Different Temperatures

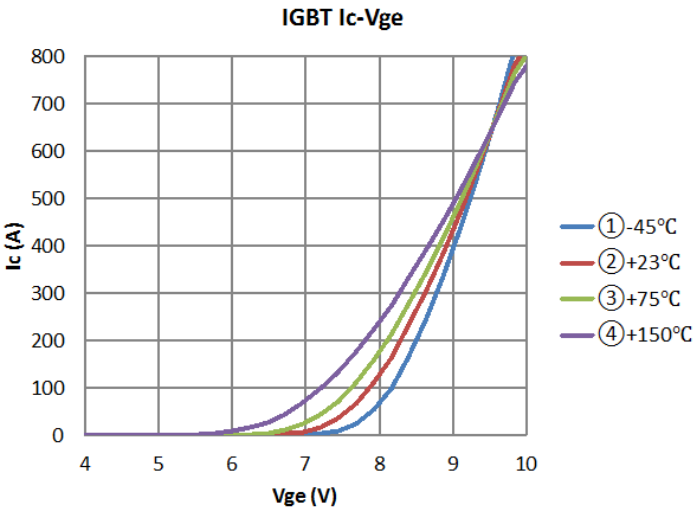
Self Heating Issue & Pulse Measurement

Safe & Fast Temperature Dependence Measurement for Automotive Market

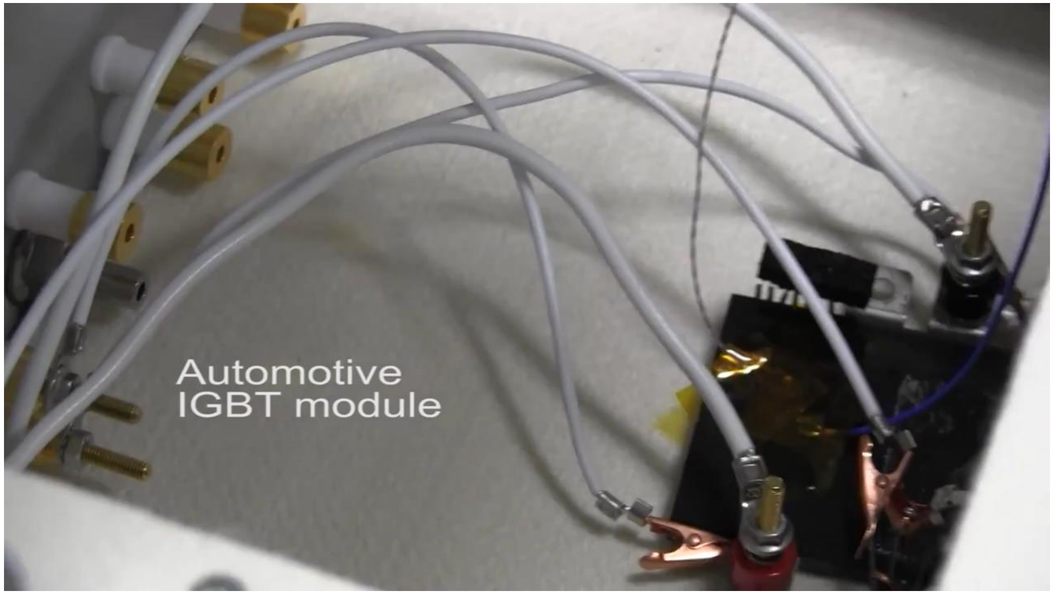
Power Device Characteristic Change according to Temperature

IGBT used in Power Train





Device characteristics across temperature taken by automatic temperature dependent test with Thermostream



Temperature dependence measurement is critical for automotive application
(eg. like the IGBT used in Power Train (Power Control Unit) for EV /HEV).

Power Device Self-Heating Issues

For BJTs:

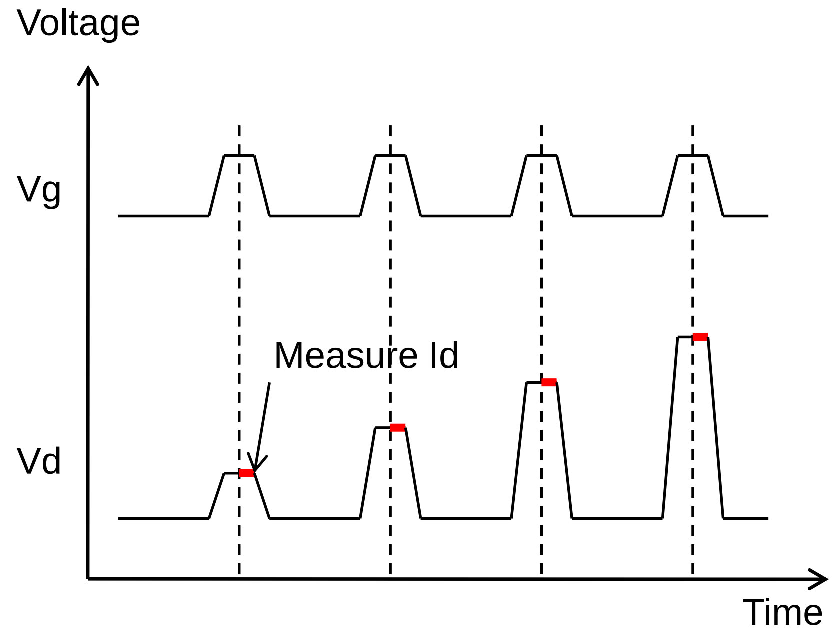
1. Collector current (Ic) at bias Vce consumes power (Ic x Vce).
2. Power dissipation increases the C-B junction temperature, which generates more minority carriers.
3. More minority carriers in-turn increases the collector current (Ic).
4. This increases the power dissipation, which in-turn increases the C-B junction temperature.
5. Eventually, the C-B or E-B junction reaches "thermal destruction*".

For MOSFETs:

1. Drain current (Id) at bias Vds consumes power (Id x Vds).
2. As the channel temperature increases, the channel resistance also increases (negative temperature coefficient). This decreases the drain current.
3. In other words, the on-resistance Rds(on) increases.
4. However, power dissipation concentrates at the pinch-off point in the channel. This can also cause "thermal destruction*".

*Aka "thermal runaway" 열폭주

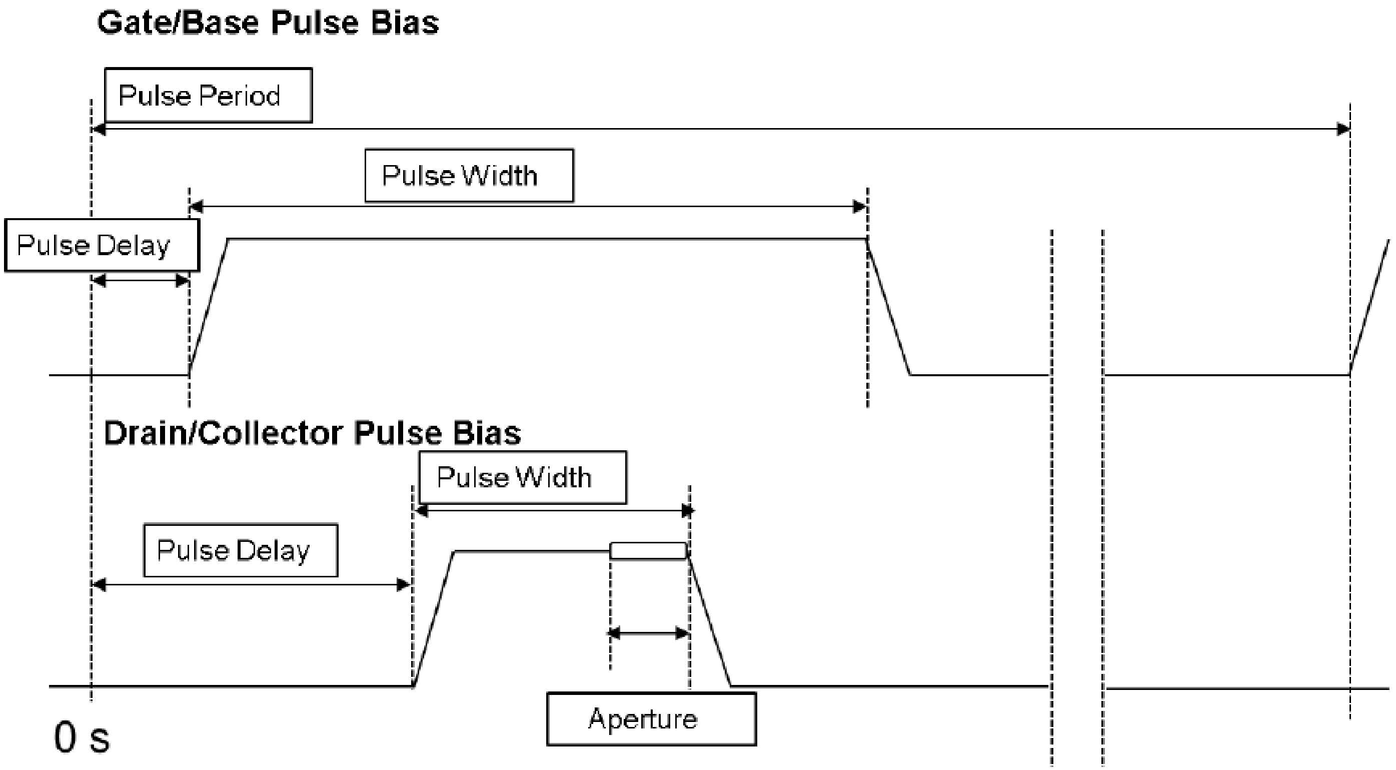
Making Pulsed Measurements – (1)



Pulsed Id-Vd measurements

High power measurements on power devices must be pulsed in order to prevent device self-heating from distorting the measurement results (or damaging the device!).

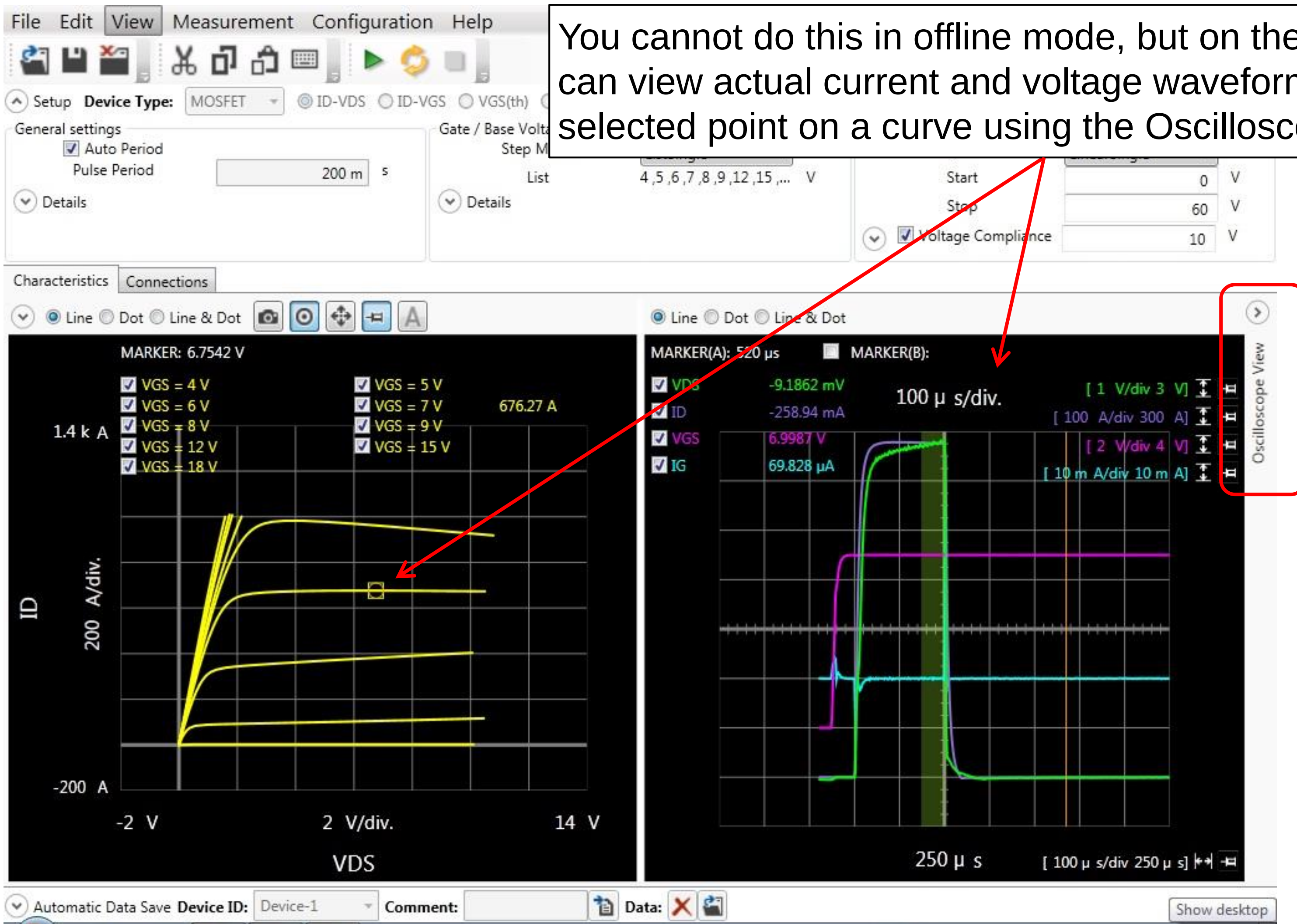
Making Pulsed Measurements – (2)



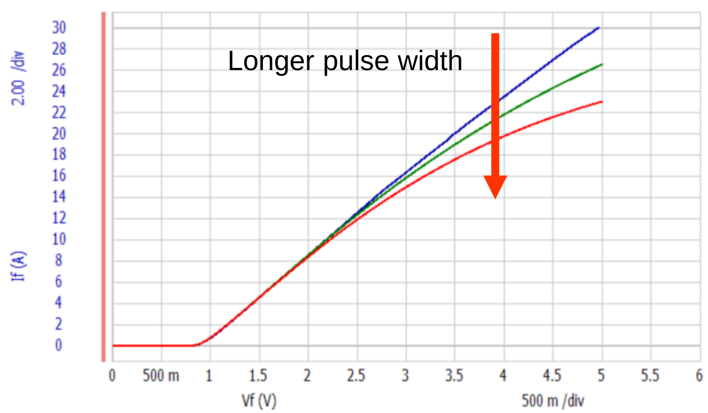
This slide shows the basic waveform timing diagram for the gate/base and drain/collector pulses.

Making Pulsed Measurements – (3)

You cannot do this in offline mode, but on the B1506A you can view actual current and voltage waveforms at any selected point on a curve using the Oscilloscope view.

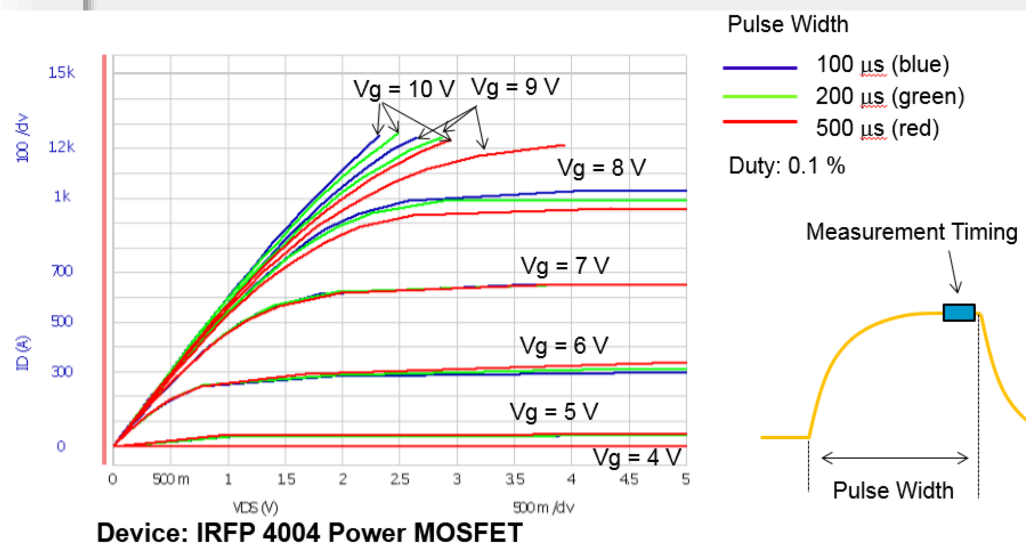


Small Pulse Width Measurement



- Pulsed measurements with **<50 µs pulse widths** required to avoid device self heating (especially for medium current at high voltage bias)

Device self-heating distorts data and prevents accurate device characterization when pulses are too long.



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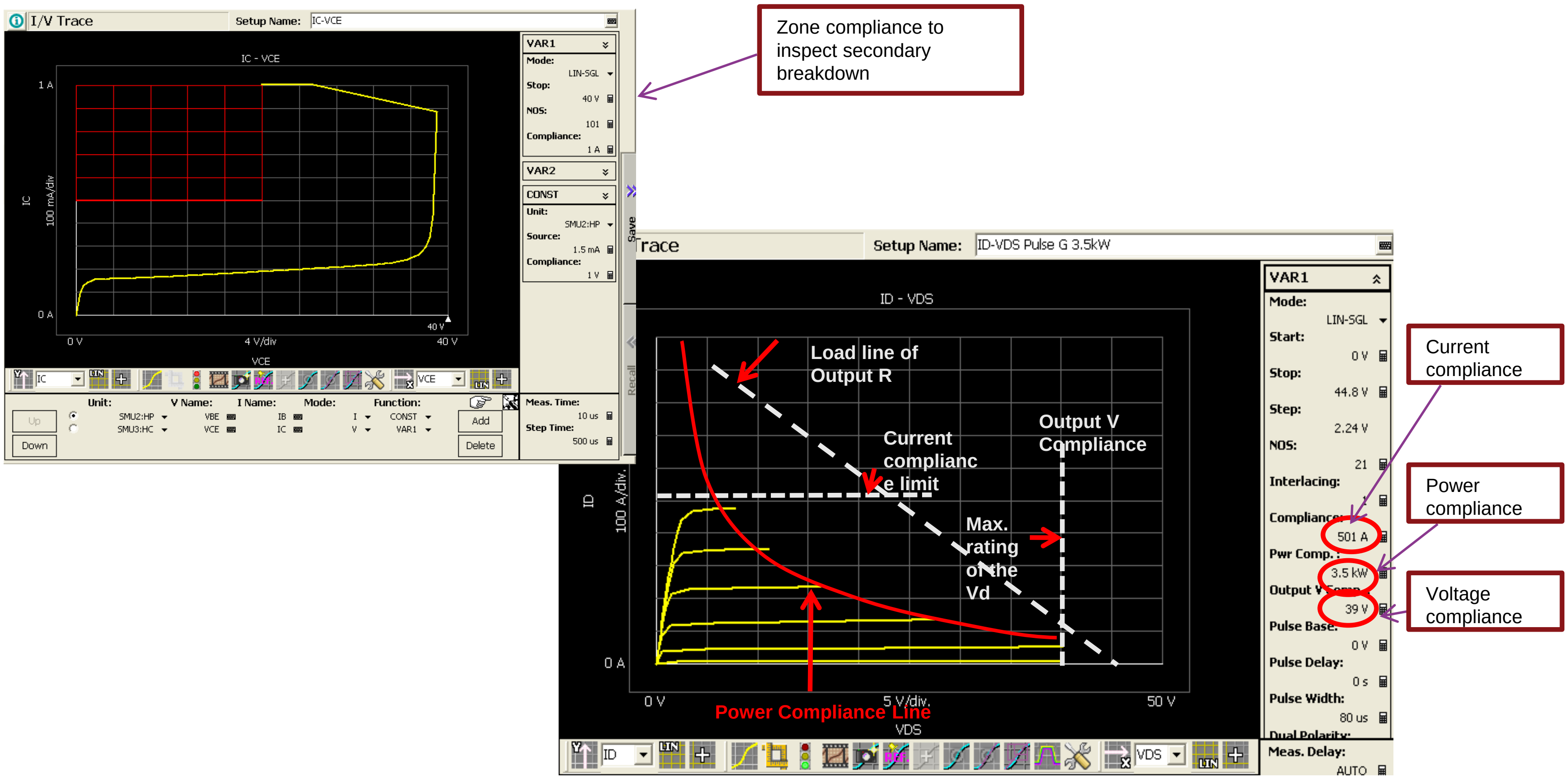
Next Generation of Curve Tracing

Effective and Efficiency measurement

- Compliance features is require to make effective measurement without damaging the device.
- Waveform inspection / Oscilloscope view is critical to ensure smallest pulse width and yet obtain the measurement accurately.

- Compliance features to avoid damaging the device
- Oscilloscope view to check the waveform

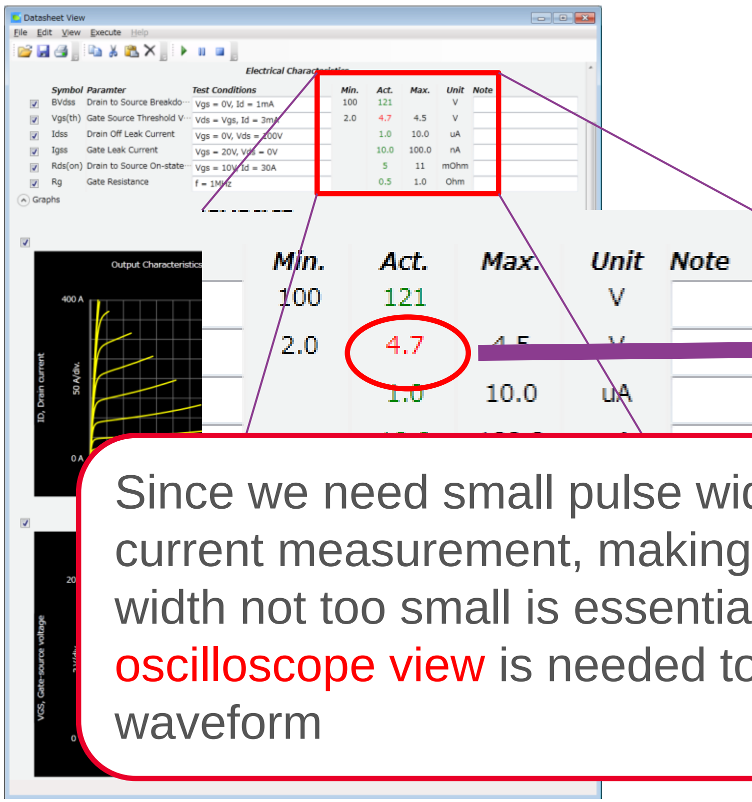
Compliance features to avoid damaging the device

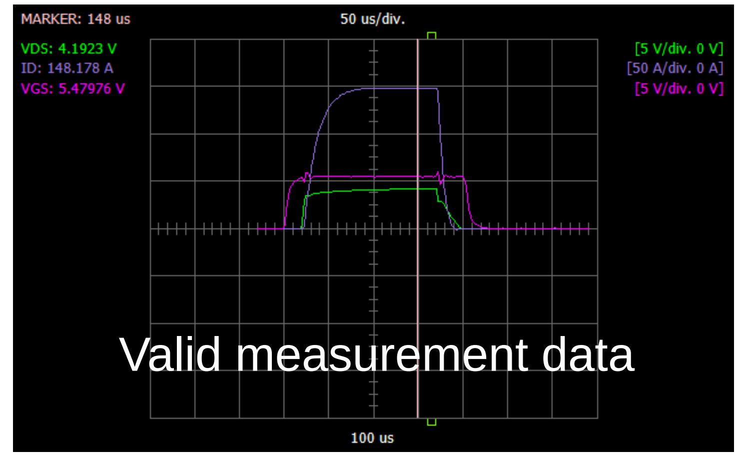


- ✓ Due to series resistance, equipments cannot know actual values before measurement.
- ✓ Software compliance skip rest of sweep once measured value over those limitations

KEYSIGHT TECHNOLOGIES

Oscilloscope View Allows Visual Verification of Pulsed Measurement Waveforms (Voltage & Current)





Since we need small pulse width for high current measurement, making the pulse width not too small is essential. Hence, oscilloscope view is needed to check the waveform

Keysight Solutions on High Power Curve Tracing

Total Solutions on Power Device Characterization

For R&D that need flexibility & comprehensive measurement

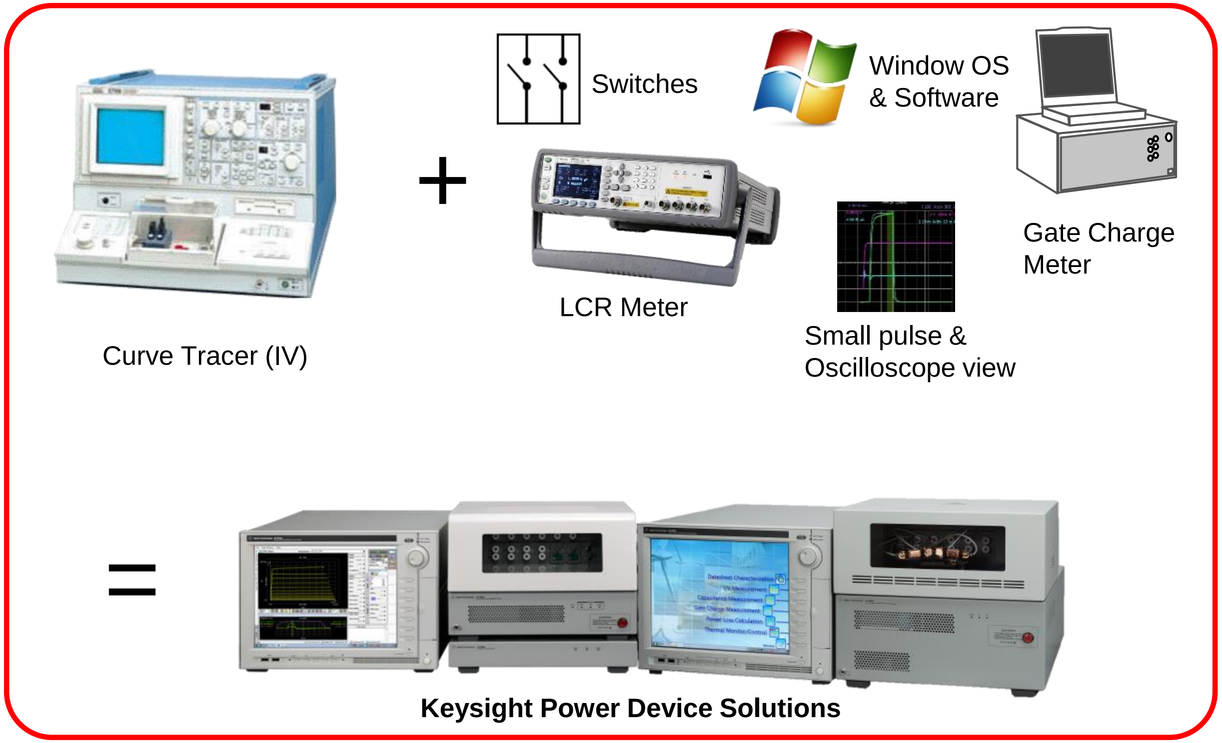
For FA & QA that need Speed & Accurate measurement

		B1505A	B1506A
Wide Coverage	Max Voltage	10kV	3kV
	Max Current	1.5kA	1.5kA
High Accuracy	Accurate Volatge (uV) / Current (fA) measurement	O	O
	Accurate On Resistance (uΩ) Measurement	O	O
	Small Pulse width (10uS)	O	O
	Accurate Capacitance Measurement	O	O
	Accurate Qg Measurement	O	O
Additional Features for WBG material	Thermal Solutions (Thermal Plat / Thermostream)	O	O
	GaN Current Collapse Measurement	O	
	5 / 6 Terminal Measurement (Intelligent IGBT)	O	
High Effective & Efficient Measurement	Current/Voltage/Power Compliance	O	O
	Oscilloscope view	O	O
	Support Wafer Level Testing	O	
	Build in Window base Test Application software	O	O
	Datasheet mode & one click measurement		O

KEYSIGHT TECHNOLOGIES

The B1505A / B1506A is more than just a Digital Curve Tracer

- **Measure complete static characteristic**
- **Meet future power device measurement requirements**
- **Support automotive / mission critical requirements**
- **Effective and Efficiency measurement**



Keysight Power Device Solutions meet your **current and future needs**

KEYSIGHT TECHNOLOGIES

Question & Answer Session

KEYSIGHT TECHNOLOGIES

Thank you for your kind attention