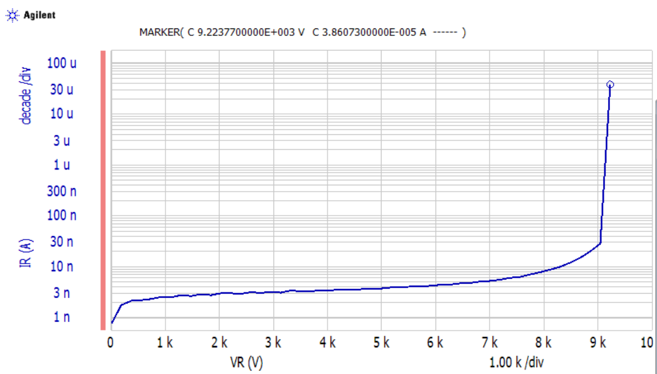
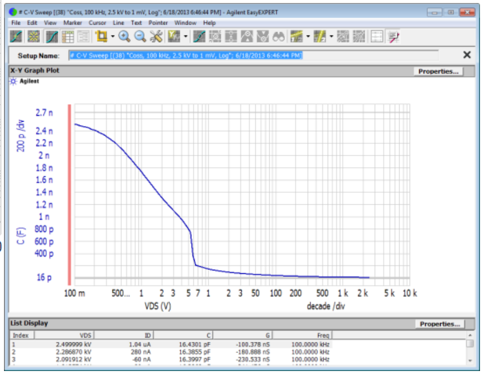
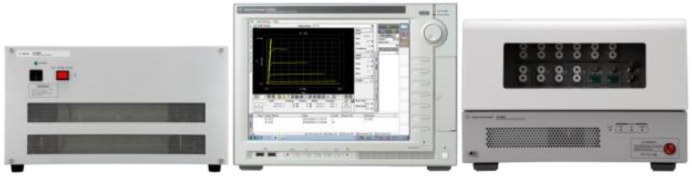
New Wide Band Gap High-Power Semiconductor Measurement Techniques

Accelerate your emerging material device development







Alan Wadsworth

Americas Market Development Manager

Semiconductor Test Division

July 31, 2013

Agilent Technologies

Agenda

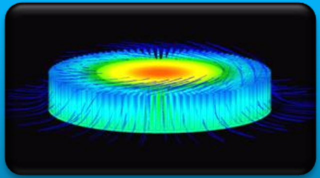
- Why Use WBG (wide band-gap) semiconductors?
- Evaluation challenges for WBG semiconductors
- WBG Evaluation example with the Agilent B1505A
  - SiC module evaluation
  - GaN power device evaluation
- High voltage capacitance measurement
- Summary

Why Use Wide Band-Gap (WBG) Semiconductors?

Requirements for modern power electronics:

Improved Conversion Efficiency

- Reduced losses (switching and conduction)
- Higher voltages & currents
- Higher frequency



Lighter Cooling Systems

- Higher operating temperatures

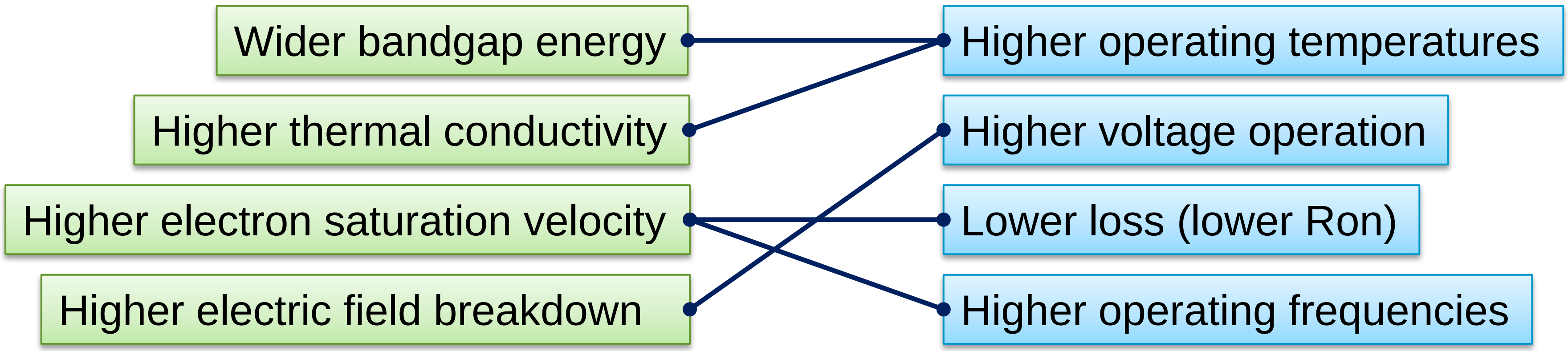
Reduced Volume and Weight

- Higher Integration

Physical Properties of WBG Power Devices

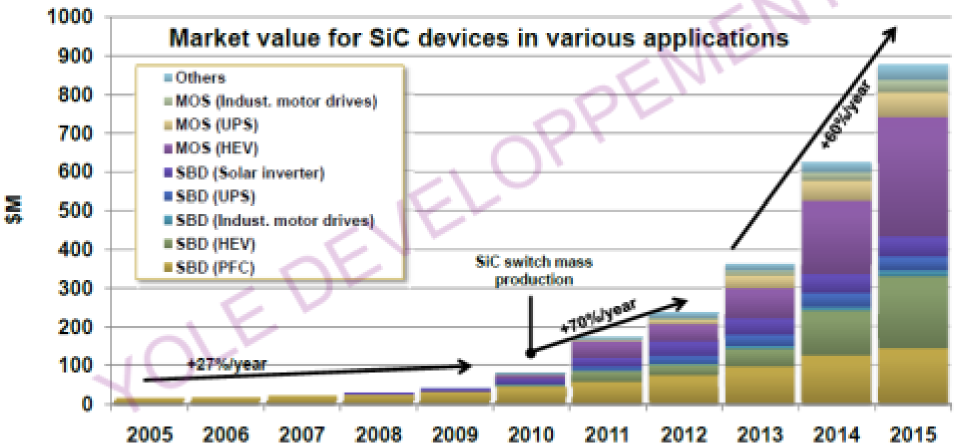
The superior electrical properties of WBG power devices offer significant performance improvements over that of conventional silicon devices.

	Band gap energy E_g (eV)	Thermal conductivity λ (W/cm-°K)	Electron saturation velocity V_{sat} ($\times 10^7$cm/s)	Electric field break-down E_c (kV/cm)
Si	1.12	1.5	1	300
GaN	3.39	1.3	2.2	3300
4H-SiC	3.26	4.9	2	2200
Diamond	5.45	22	2.7	5600



SiC/GaN Devices Comparison

<u>SiC devices</u>



Source: Yole Development, 2009

<u>GaN devices</u>

Source: Yole Development, 2012

◆4x better thermal conductivity than GaN
◆Higher current capability
◆Easy to develop normally off device
◆Difficult to create large diameter wafer because of micropipe defects.
◆Expensive wafer cost

◆2x the electron mobility of SiC
◆Micropipe-free material
◆GaN HEMT technology can be transferred from RF to power applications
◆GaN devices are less expensive than SiC
◆Exhibits current collapse phenomena
◆Difficult to develop normally OFF devices
◆Lateral devices are limited

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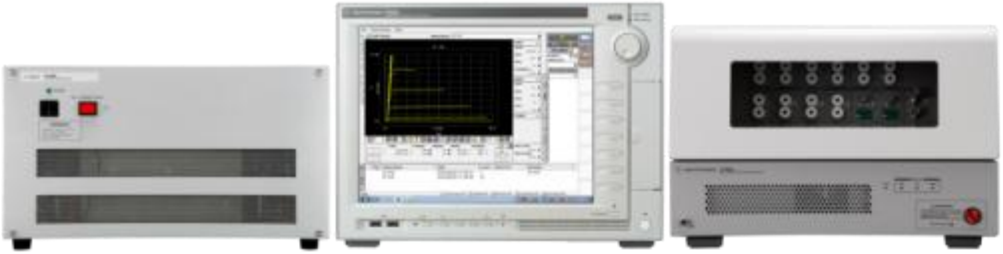
Evaluation Challenges for WBG Semiconductors

- Higher current force/measurement (>100 A)
- Higher voltage force/measurement (up to 10 kV)
- Accurate low on-resistance (Ron) measurement (sub-mΩ)
- Quantitative GaN current collapse effect evaluation
- Accurate device capacitance (Ciss, Coss etc) measurement

	SiC device	GaN device (on Silicon)
Power range	Several 100's kW	Few kW
Max Vb	10 kV	Few kV
Ron (per area)	<10 mΩ/cm^2	1 mΩ/cm^2

The Agilent B1505A Meets WBG Device Evaluation Challenges

- Current force/measure capability **up to 1500 A**
- Voltage force/measure capability **up to 10 kV**
- Accurate **sub-pA level** current measurement at high voltage bias
- **μΩ resistance** measurement capability at 100's of Amps
- Pulsed measurement capability **down to 10 μs**
- High voltage/high current fast switch option to characterize **GaN current collapse effect**
- **Capacitance measurement** at up to 3000 V of DC bias



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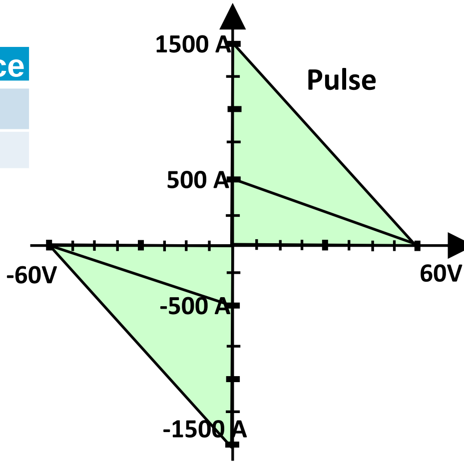
Equipment for SiC Module Evaluation

◆ Agilent B1505AP-H70 with 3kV / 1500A capabilities

N1265A Ultra High Current Expander/ Fixture(1500A)

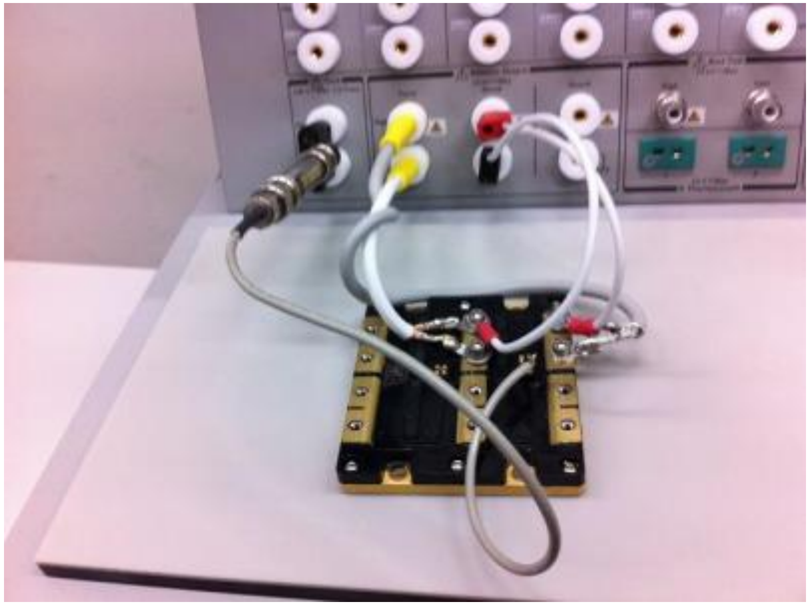
B1505A with HVSMU (3kV)

Output range	Output resistance
500 A	120 mΩ
1500 A	40 mΩ



	500 A range	1500 A range
Output	voltage pulse or current pulse	
Measurement	current or voltage	
Maximum current	±500 A	±1500 A
Maximum voltage	±60 V	
Output peak power	7.5 kW	22.5 kW
Pulse Period	10 μs~1 ms	
Current Measurement	500 μA to 500 A	2 mA to 1500 A
Voltage Measurement	100 μV to 60V	
Current accuracy	≦ 0.6%	≦ 0.8%

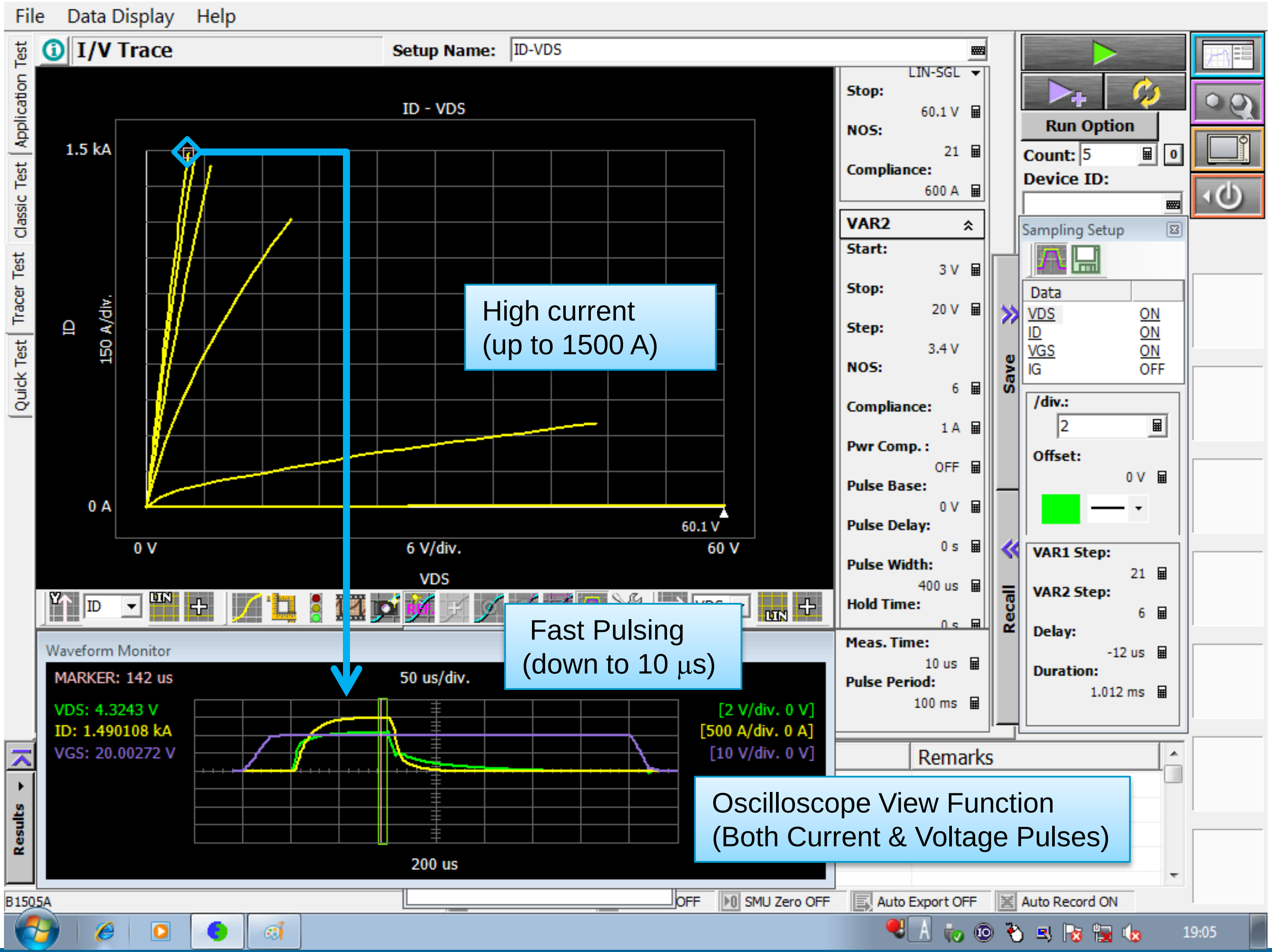
SiC module evaluation with the Agilent B1505A -
- SiC Trench MOS module Measurement results (1)



DUT: APEI/ROHM HT-2100 SiC Trench MOS module

High Current Characteristics: Id-Vds measurement

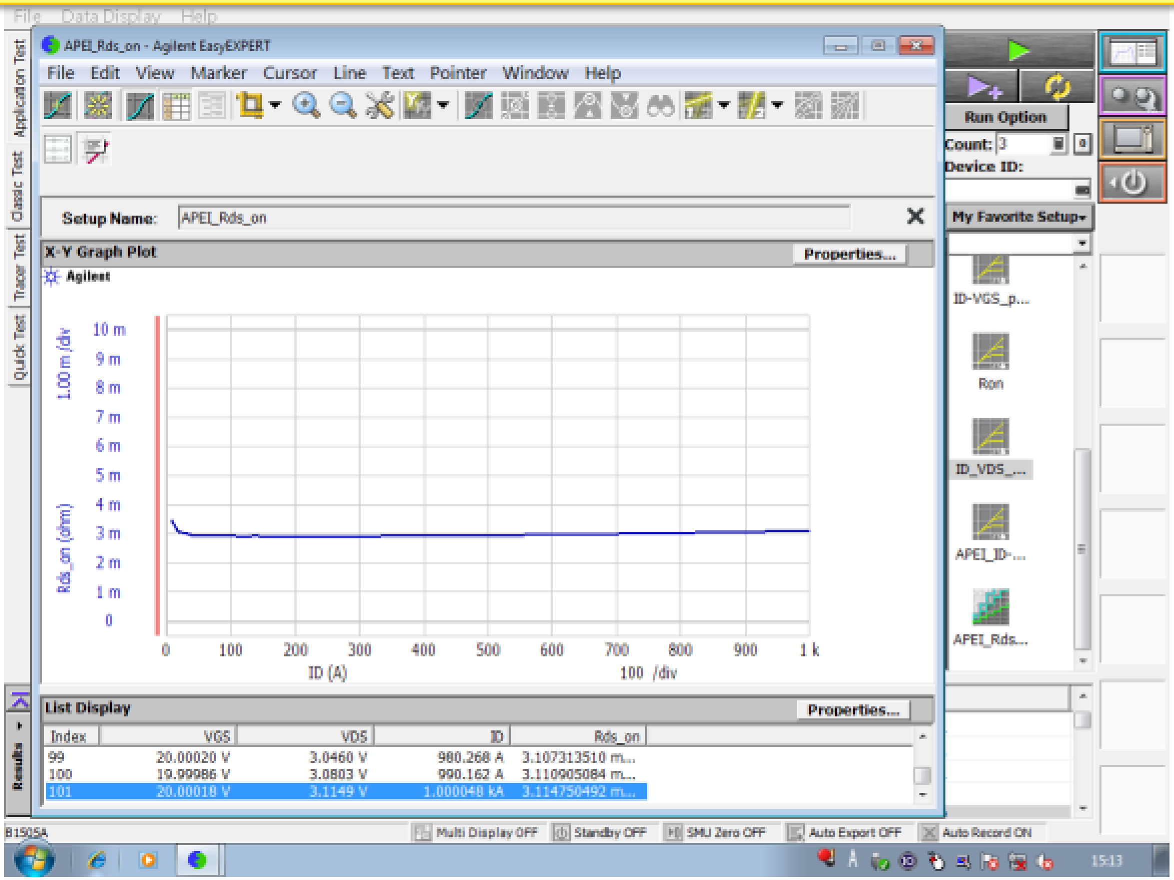
~ SiC Trench MOS module ~



On-resistance (Ron) measurement

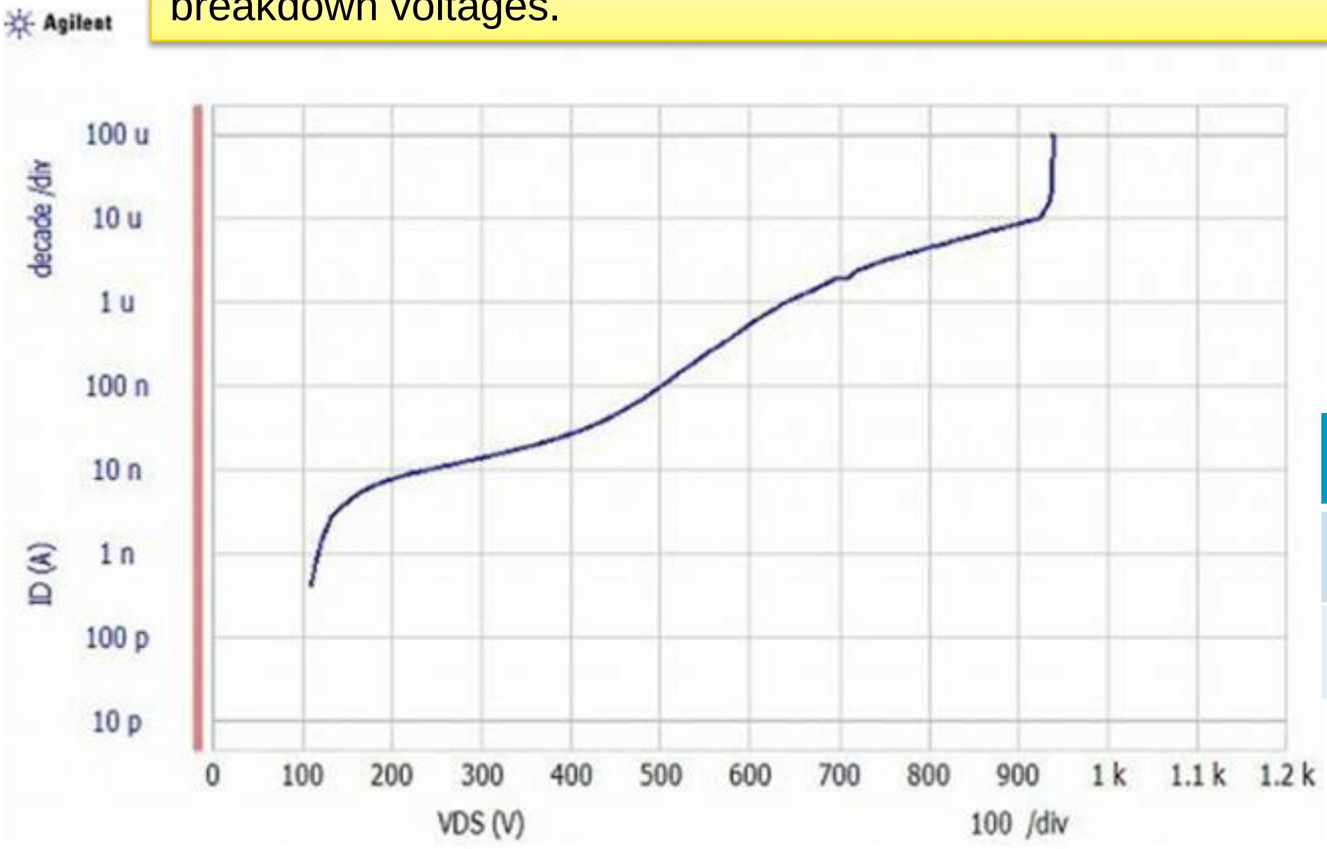
~ SiC Trench MOS module ~

Using the precision high current source, device on-resistance can be measured precisely with sub-milliohm resolution.
Note: Kelvin (4-wire) resistance measurement techniques need to be used.



Breakdown and leakage current measurement
~ SiC Trench MOS module ~

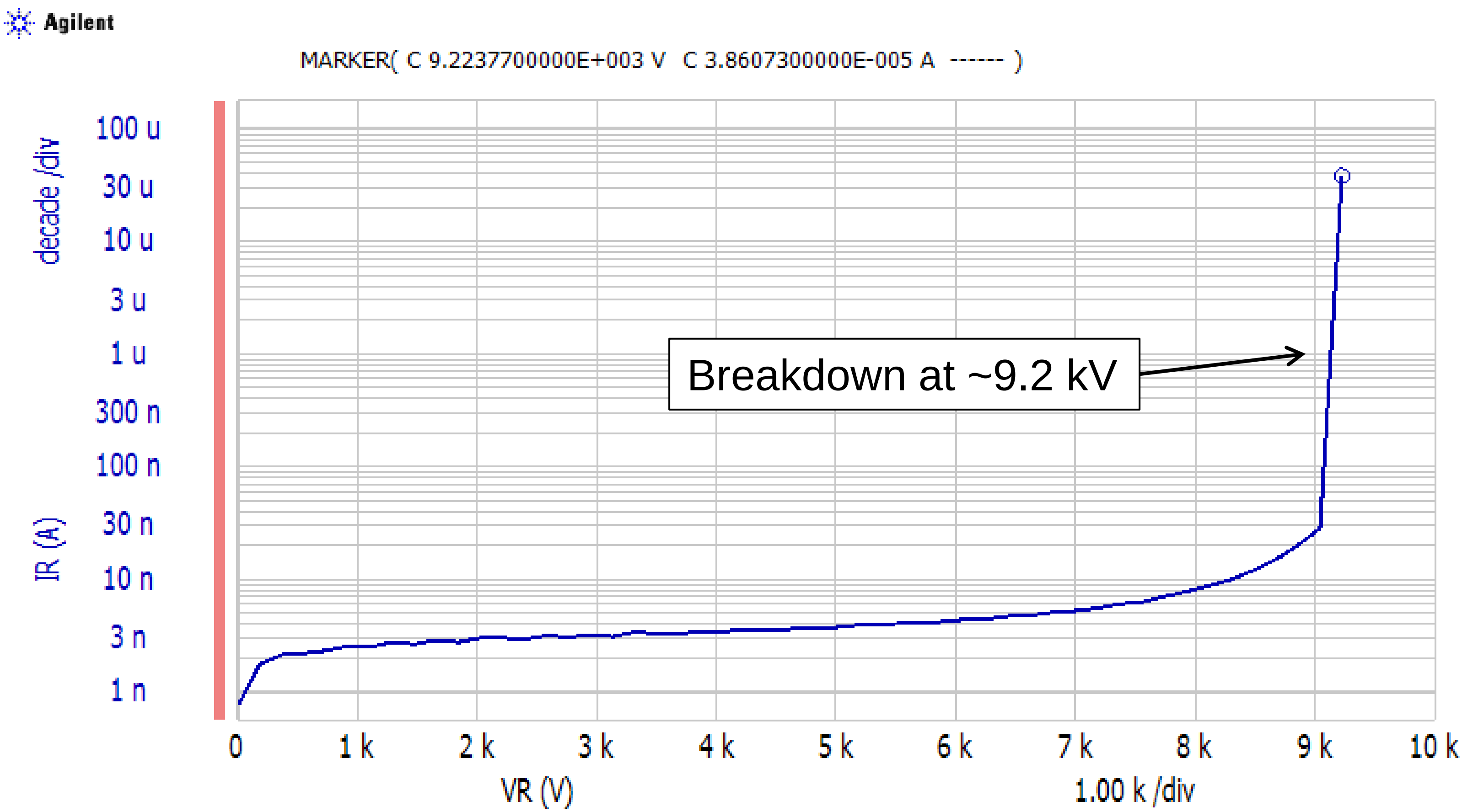
The B1505A can accurately measure small leakage currents for very large breakdown voltages.



	Max Voltage	Min. Current Resolution
B1513B HVSMU	3 kV	10 fA
N1268A UHVU	10 kV	10 pA

Measured by the B1513B HVSMU

Breakdown Measurements up to 10 kV



Using the ultra high-voltage unit (UHVU), breakdown voltages of up to 10 kV can be measured with resolution down to 10 pA.

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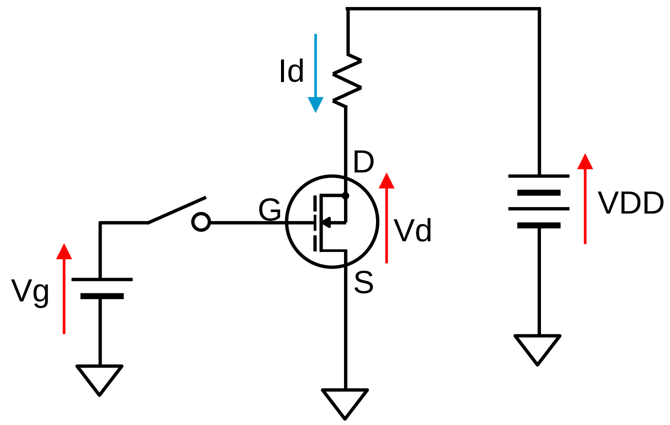
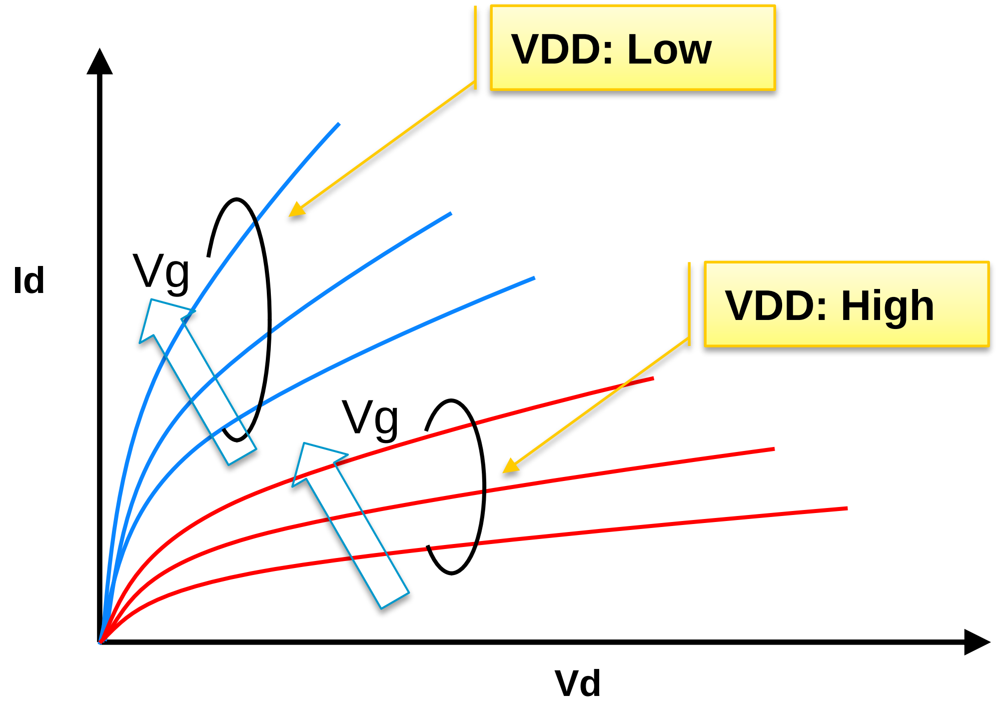
Key Issues Facing GaN Power Devices

- Lateral GaN devices:
  - Normally-on operation
    - Negative threshold voltage. Normally-off functionality is required for safety reasons.
  - Current collapse phenomenon
    - Drain current decreases after the application of high voltage stress.

- Vertical GaN devices:
  - Difficult to obtain high-quality, large-area wafer substrates at an affordable price

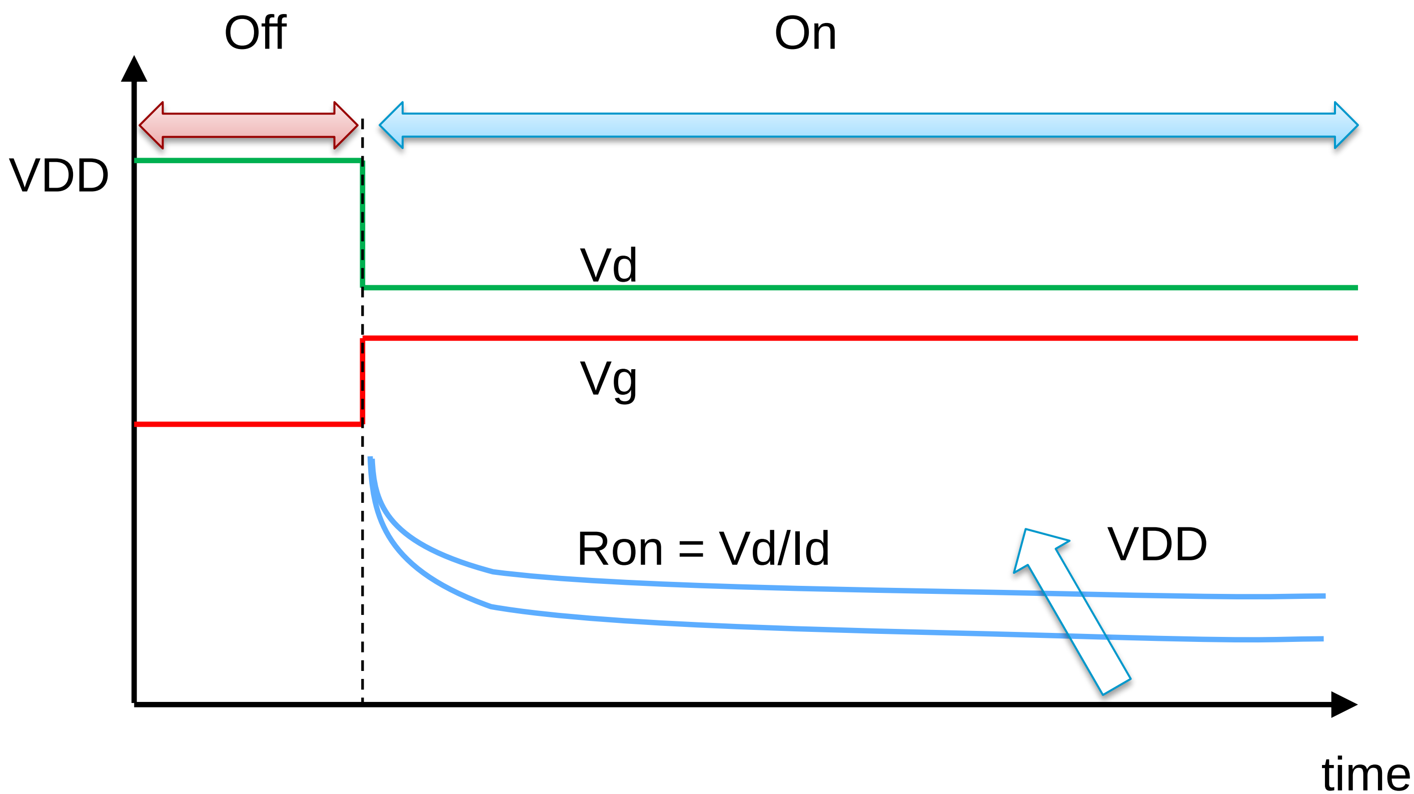
What is the "Current Collapse Effect" (GaN HEMTs)?





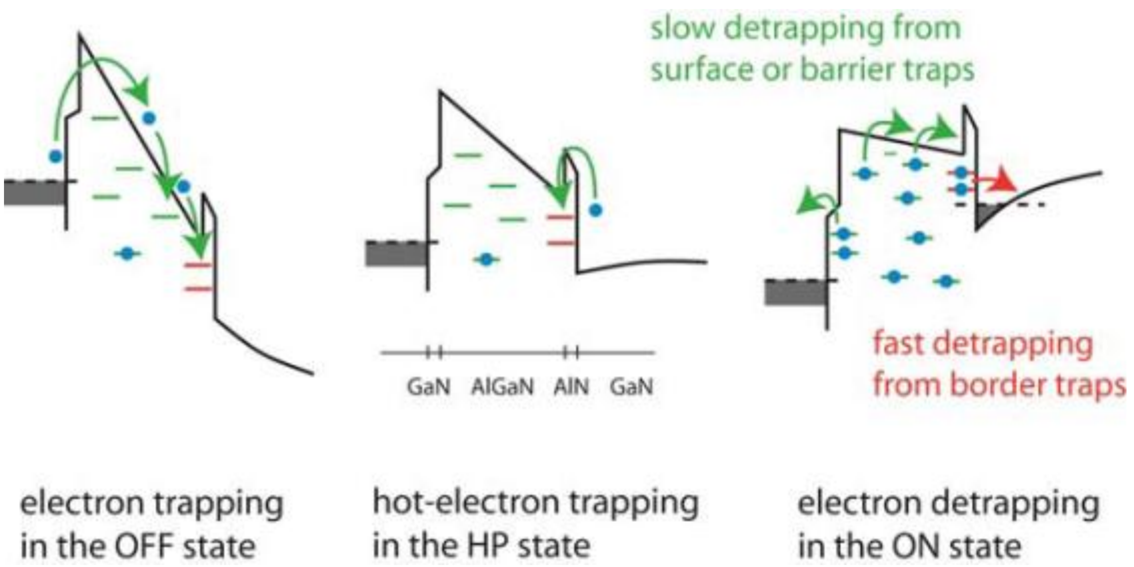
The drain current at higher VDD is less than at lower VDD?

"Dynamic On Resistance" (GaN HEMT)



- The On-resistance changes dynamically after changing from OFF-state to ON-state.
- The On-resistance depends on both VDD and the duration of the OFF-state.
- This phenomena is caused by the same mechanism as the current collapse phenomena observed when making basic current-voltage (IV) measurements.

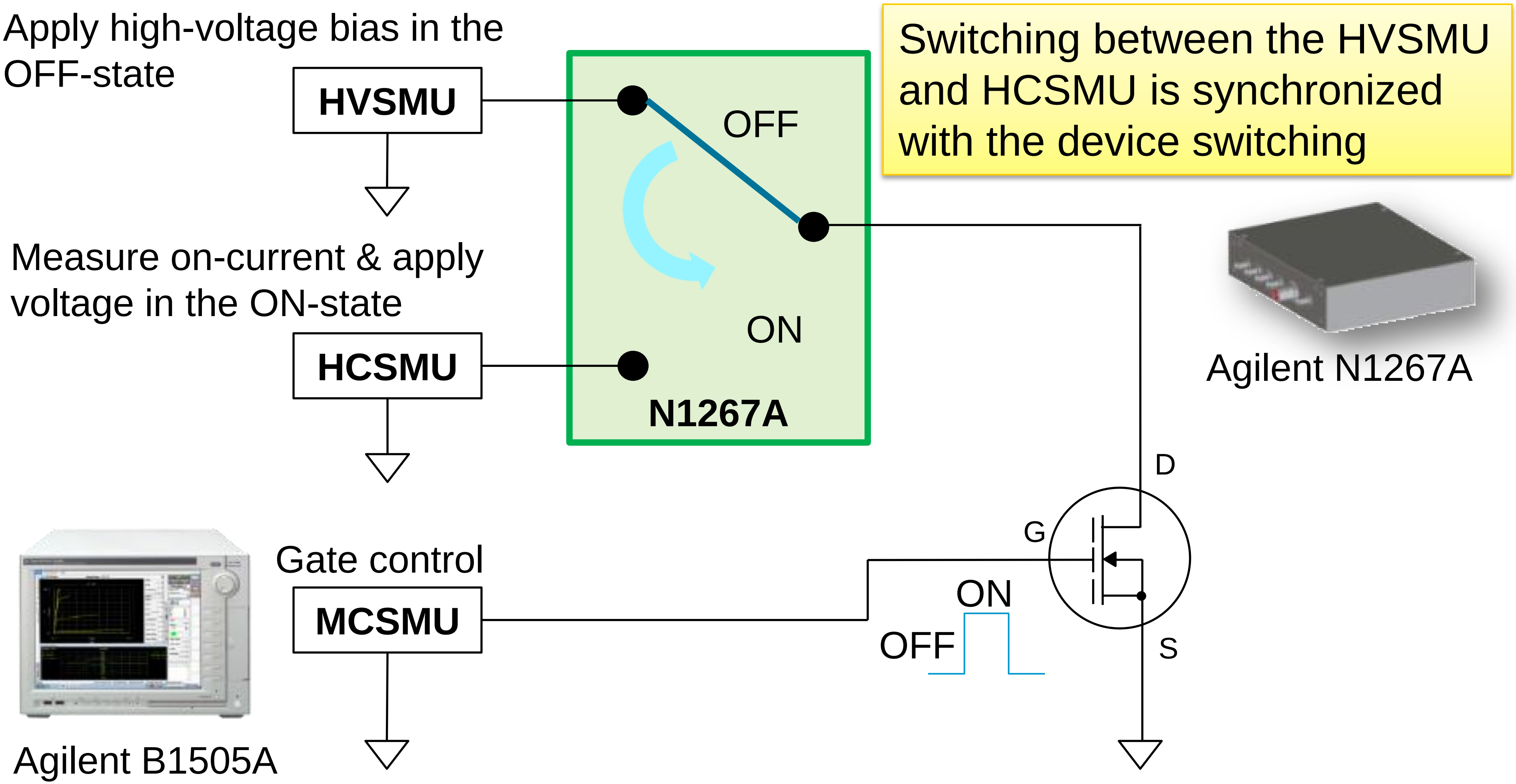
The Mechanism(s) of GaN Current Collapse



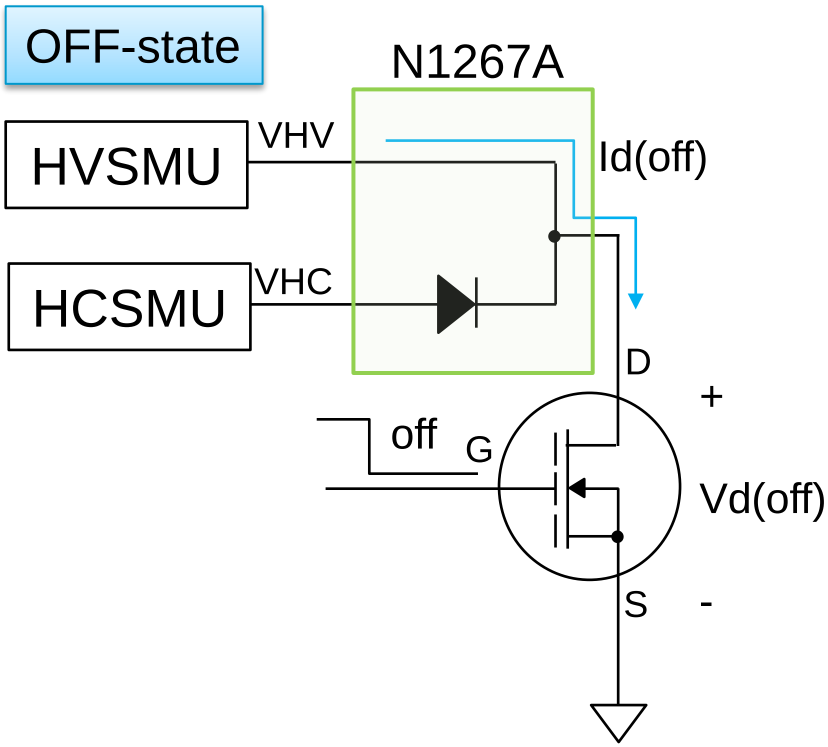
Donghyun Jin, et. al. "Mechanisms responsible for dynamic ON-resistance in GaN high-voltage HEMTs", Proc the 2012 24th ISPSD, pp 333-336

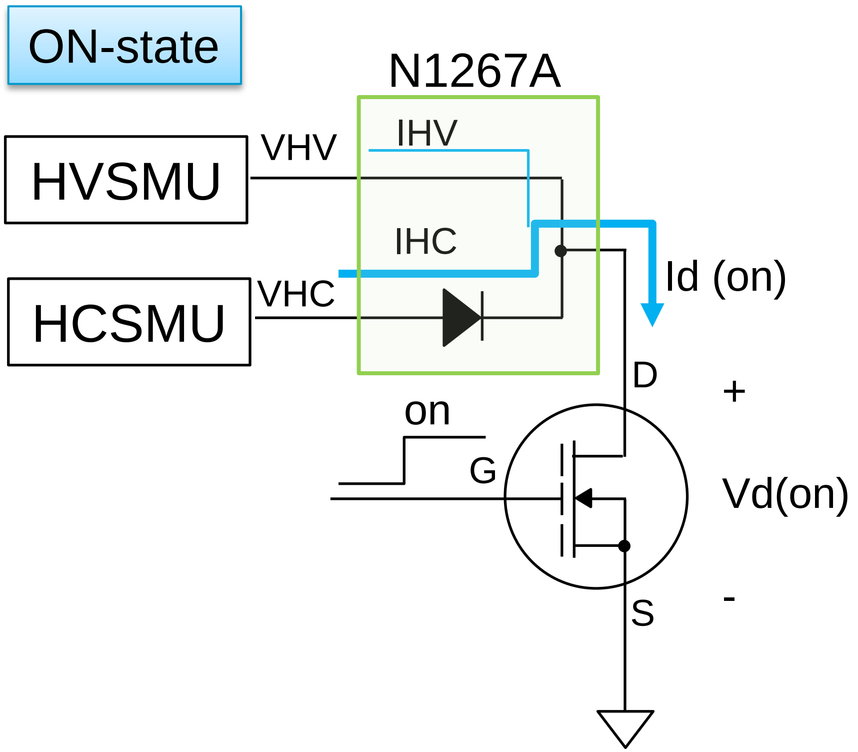
- Traps with various time constants may exist
- Fast response and slow response have to be measured
- Many researchers are currently working on techniques to reduce the current collapse effect

Agilent B1505A GaN Current Collapse solution using the N1267A Switch



Overview of N1267A Switch Operation





- The diode switch is reverse biased (off), so the HCSMU is disconnected from the device.
- Drain bias is applied by HVSMU.

- When the device is turned on, Id(on) starts to flow.
- The HVSMU's output voltage decreases because the Id(on) exceeds its maximum current.
- The diode switch is forward biased (on).
- The drain bias source is shifted to the HCSMU,
- The drain current Id(on) consists of the sum of the current from the HCSMU (IHC) and HVSMU (IHV).

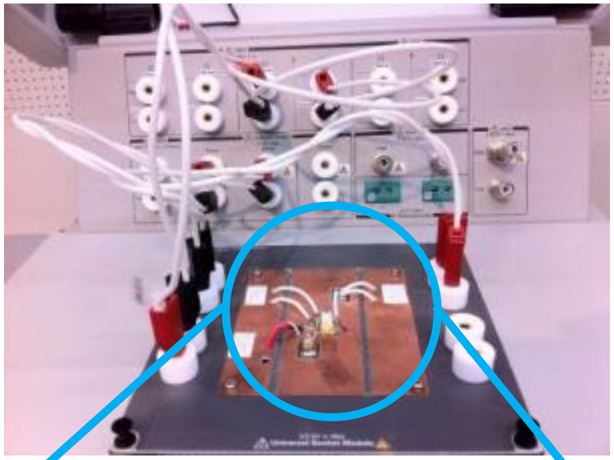
Key Features of B1505A GaN Current Collapse Measurement Solution

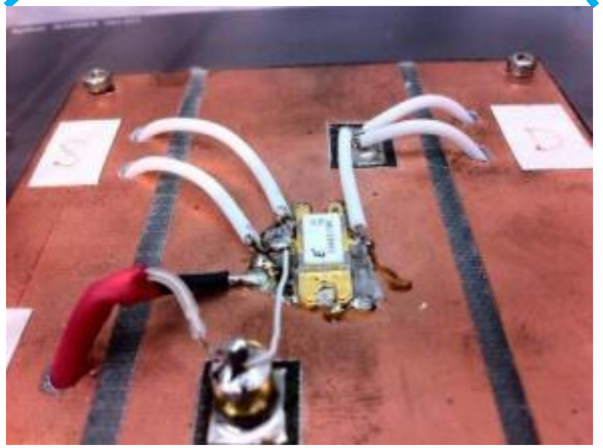
- Dynamic on-resistance measurement across both short and long time scales
  - 20 µs switching time from OFF-state to ON-state
  - High speed sampling (2 µs sampling rate)
  - Measure long term variations (log sampling mode)

- Wide voltage/current range with precise measurement
  - 3000 V OFF-state voltage stressing
  - 20 A ON-state drain current
  - Capture current variations with 6 digit resolution

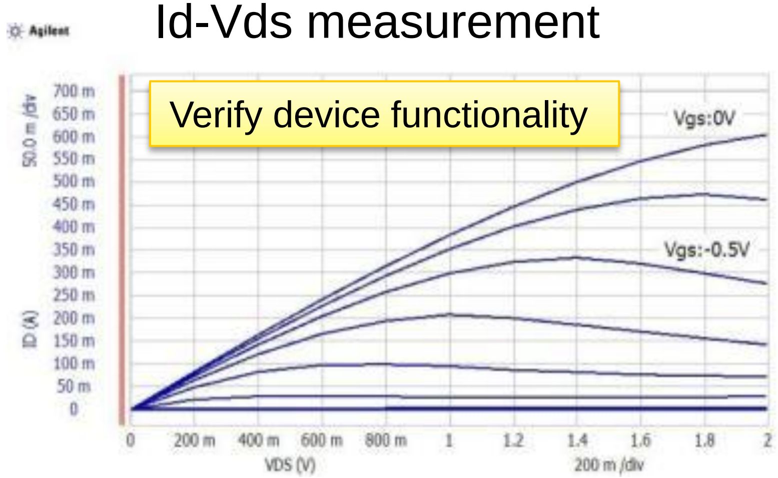
Static Characteristics Check

DUT: High Voltage-High Power GaN-HEMT
(EGNB010MK, Sumitomo Electric Device Innovation)

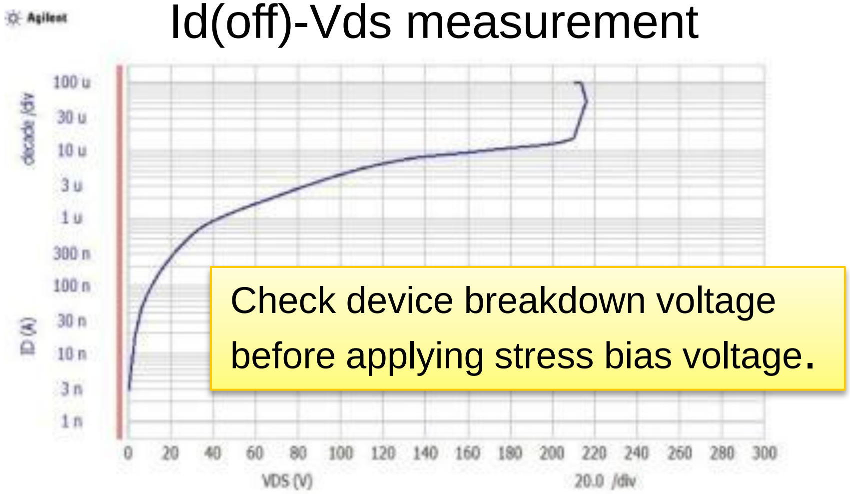




Id-Vds measurement



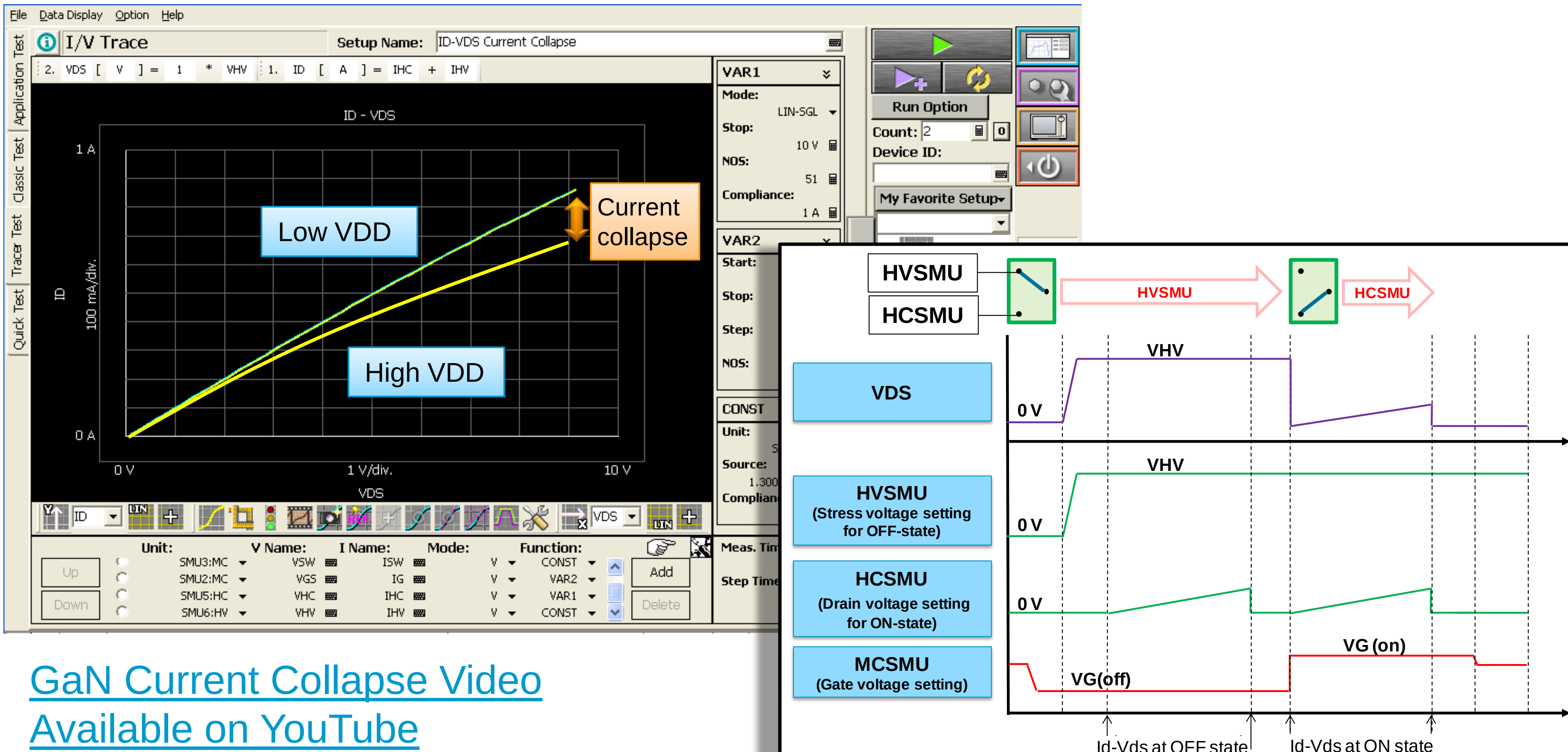
Id(off)-Vds measurement



Note: The static characteristics and GaN current collapse effect can be measured without the need to recable.

GaN Current Collapse measurement (using Tracer Test mode)

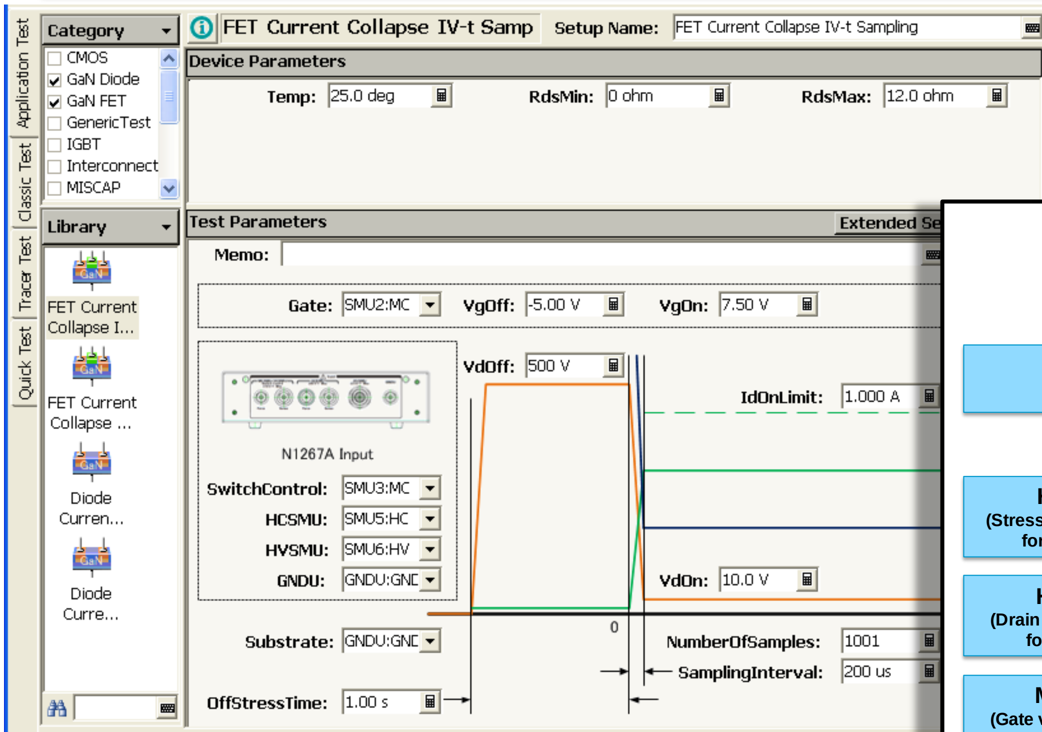
The overlay feature of the B1505A's tracer test mode permits easy graphical display of the current collapse effect

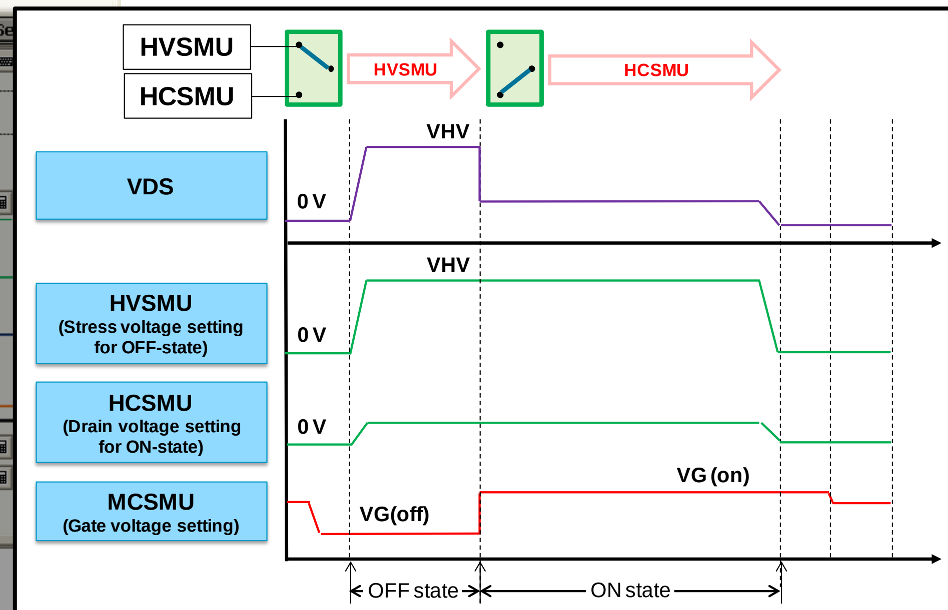


[GaN Current Collapse Video Available on YouTube]

Dynamic On-Resistance measurement
(using Application Test mode) - 1

EasyEXPERT software is furnished with pre-defined application tests for dynamic on-resistance measurement for both short and long time scales.



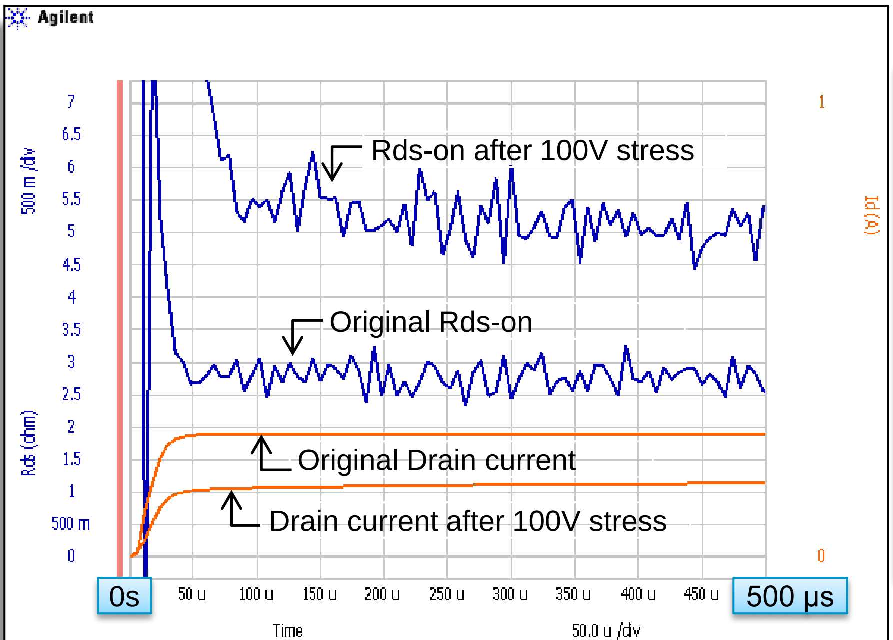


[GaN Dynamic R Measurement Available on YouTube]

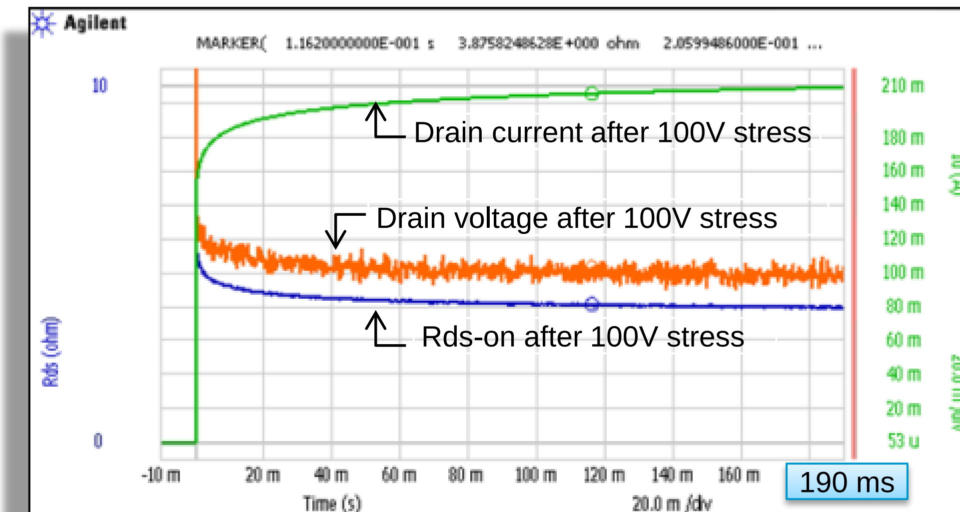
Dynamic On-Resistance measurement
(using Application Test mode) - 2

Both short term (<1 ms) and long term (>1 ms) GaN dynamic on-resistance tests can be done easily and quantitatively.

Short term (<1 ms)



Long term (>1 ms)



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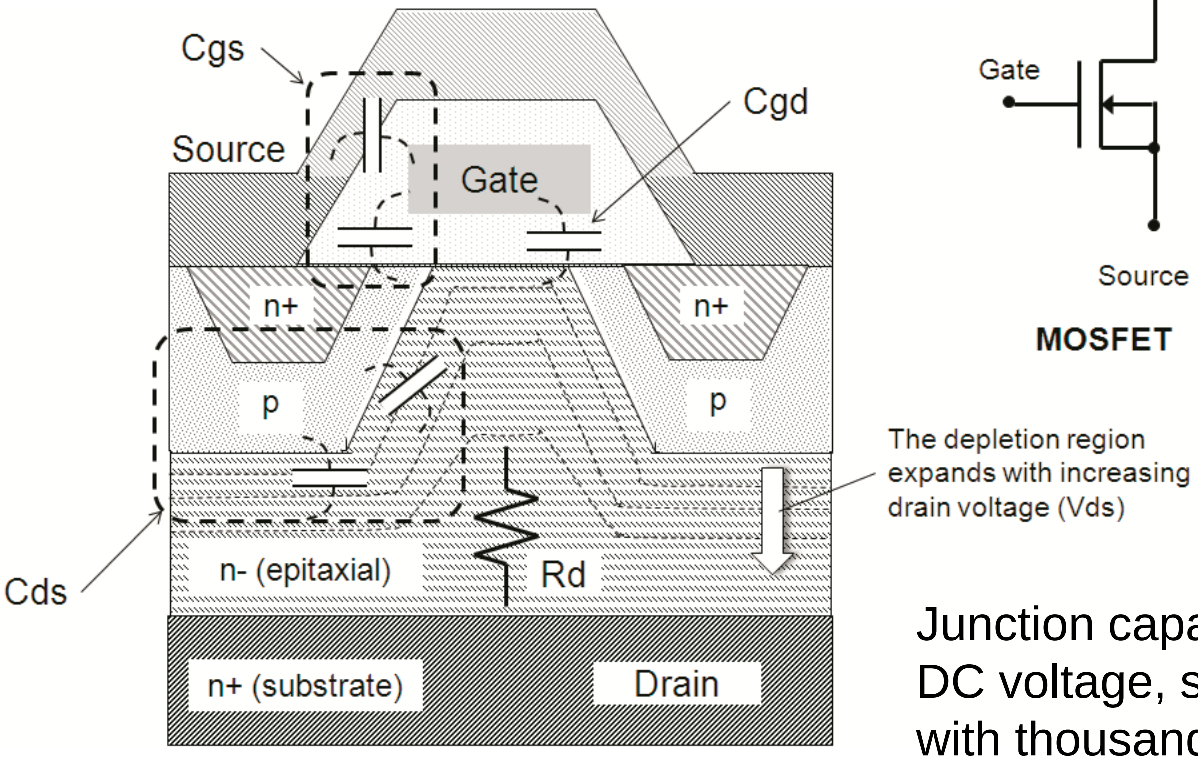
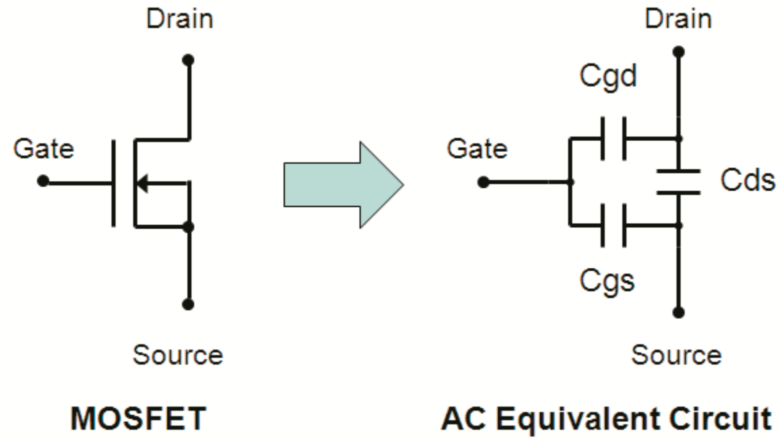
Power MOSFET Capacitance Measurement

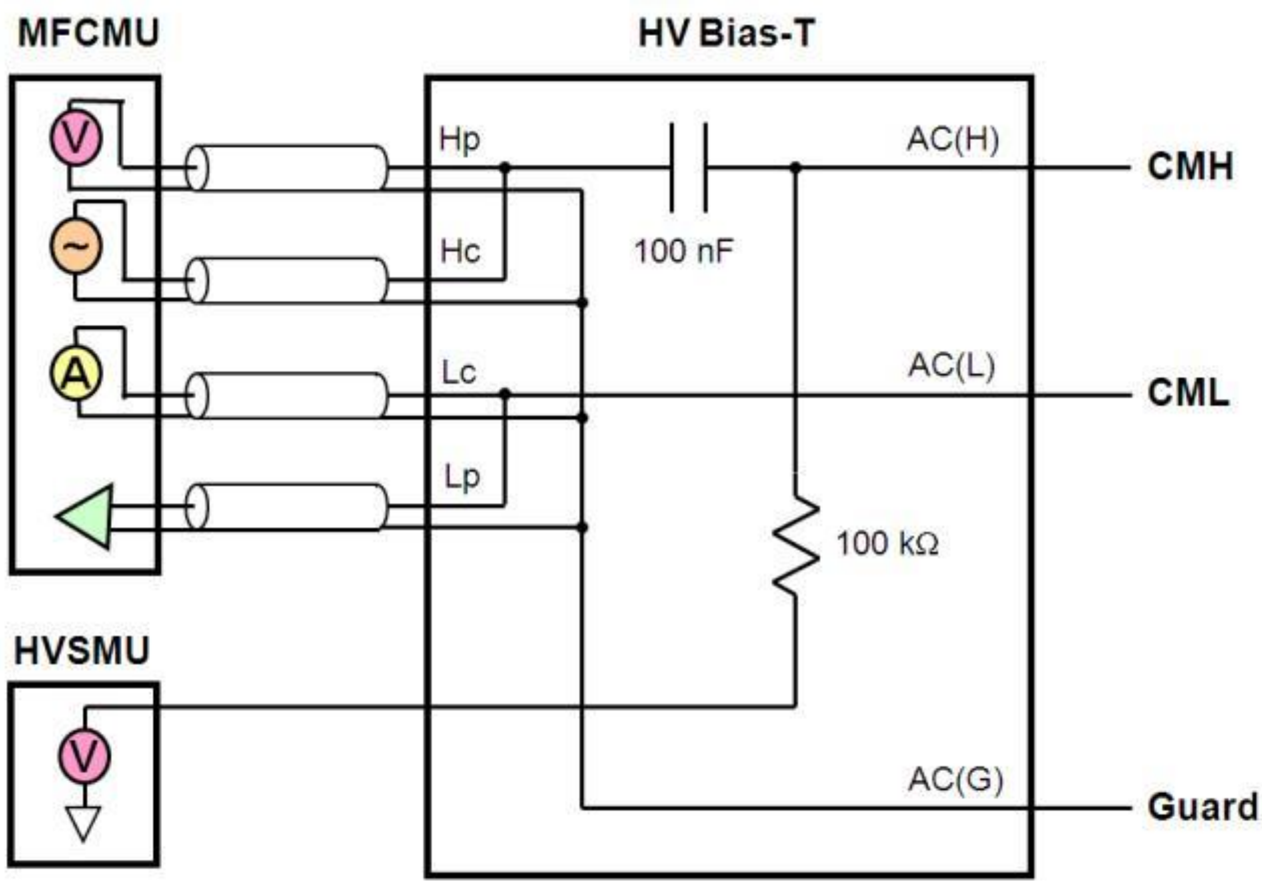




Junction capacitances vary with applied DC voltage, so you must measure them with thousands of volts of applied DC bias.

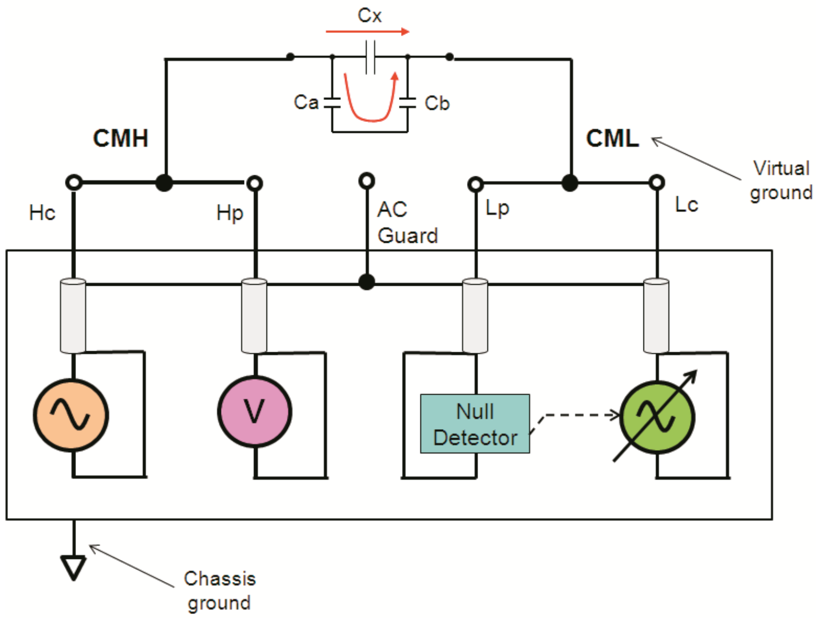
<u>Issue:</u> No off-the-shelf capacitance meter supports measurements with more than a few tens of volts of DC bias.

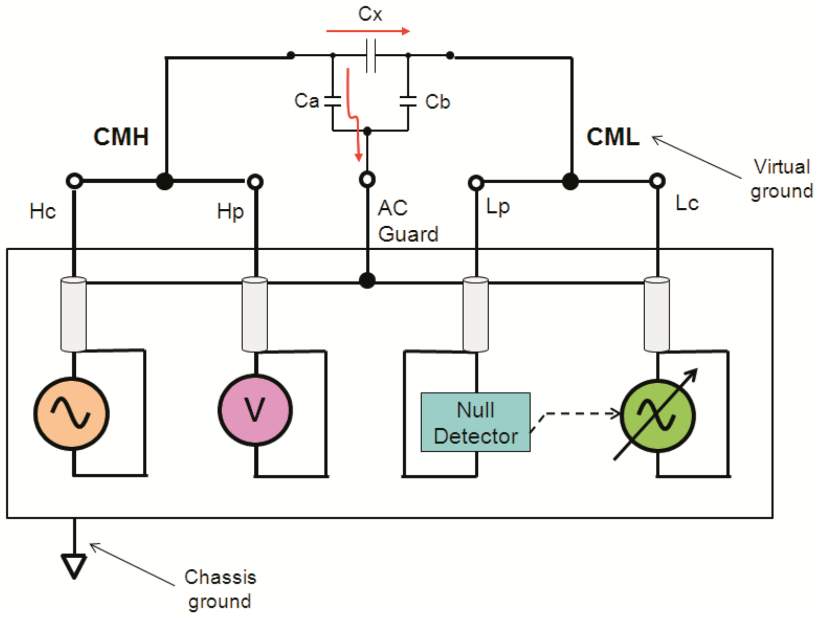
The B1505A High-Voltage Bias-T Supports Capacitance Measurement at 3 kV of DC Bias



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?

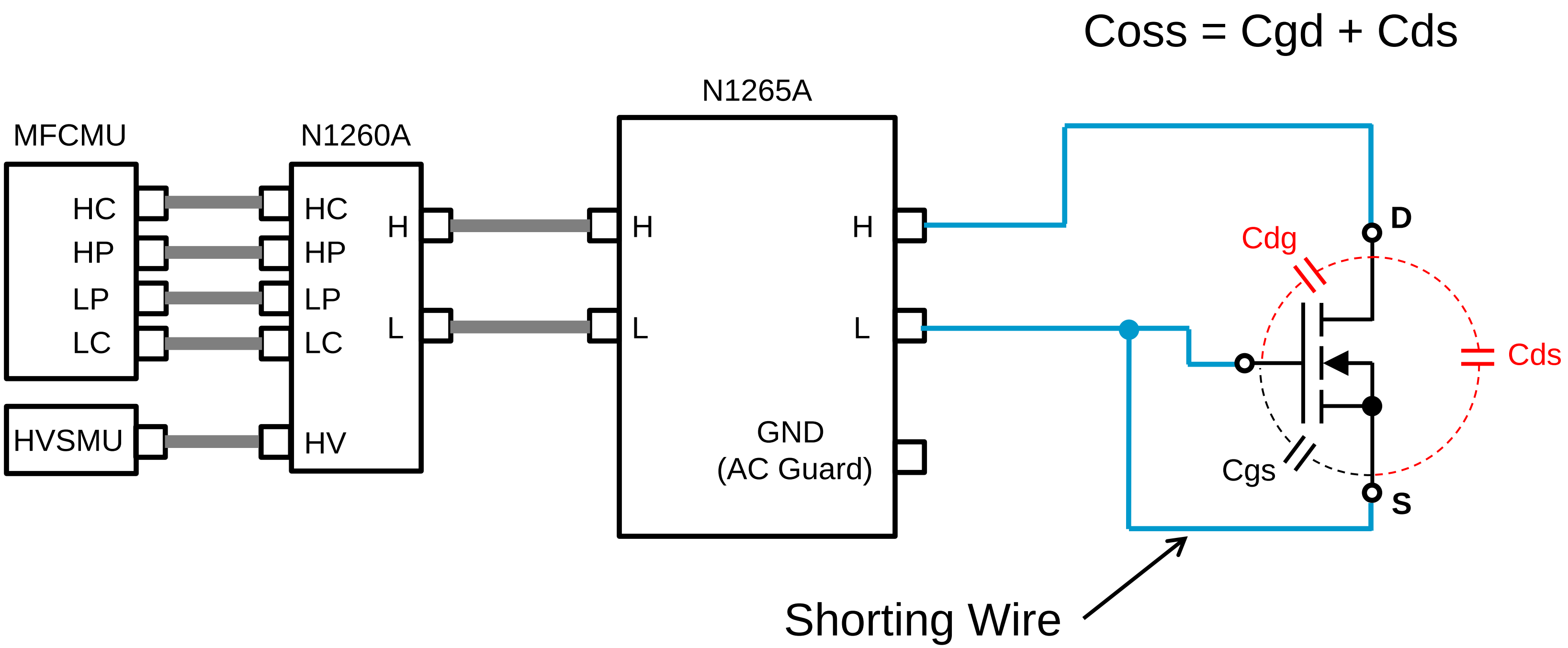




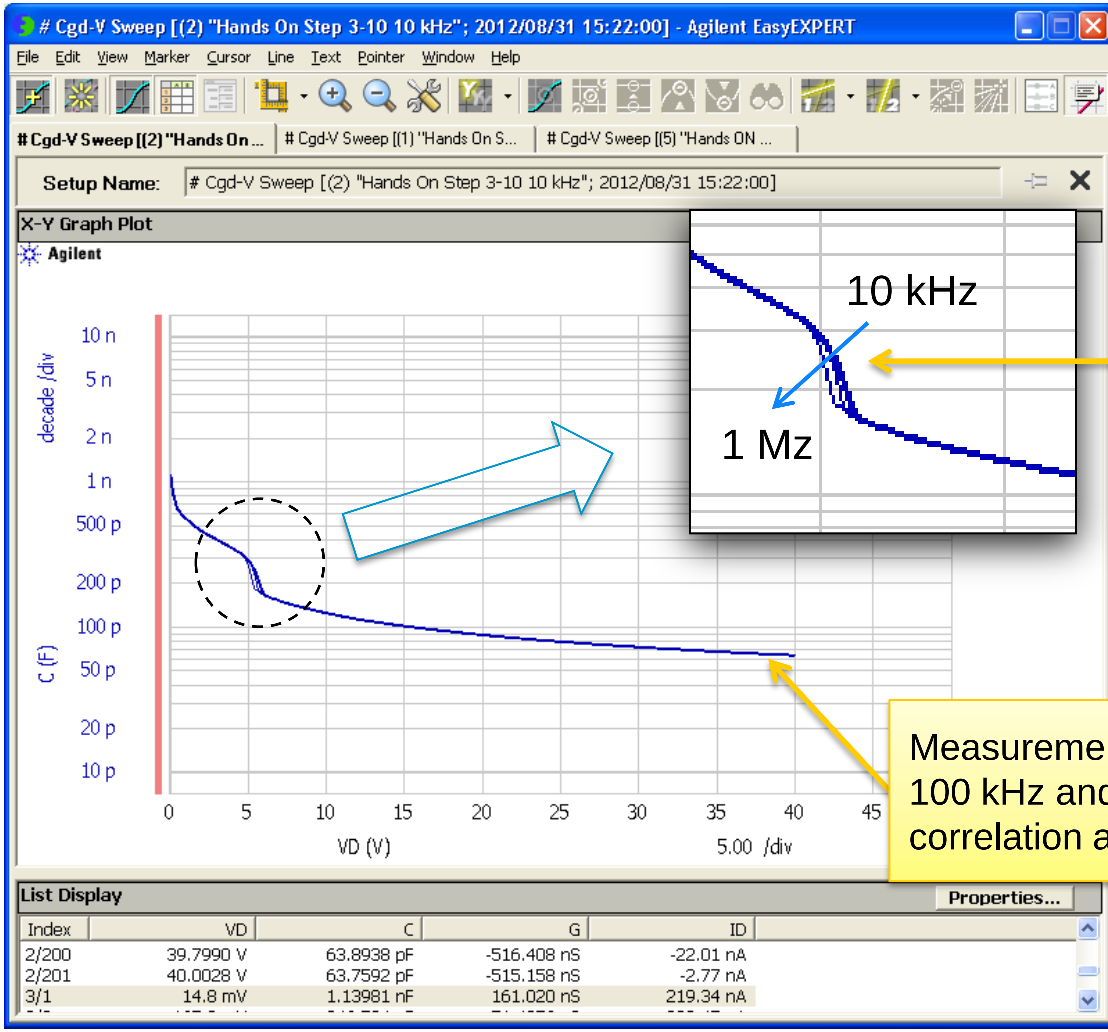
Problem: Some of the measured current passes through a parasitic path, which degrades measurement accuracy.

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

Configuration of Coss Measurement of Normally OFF Device



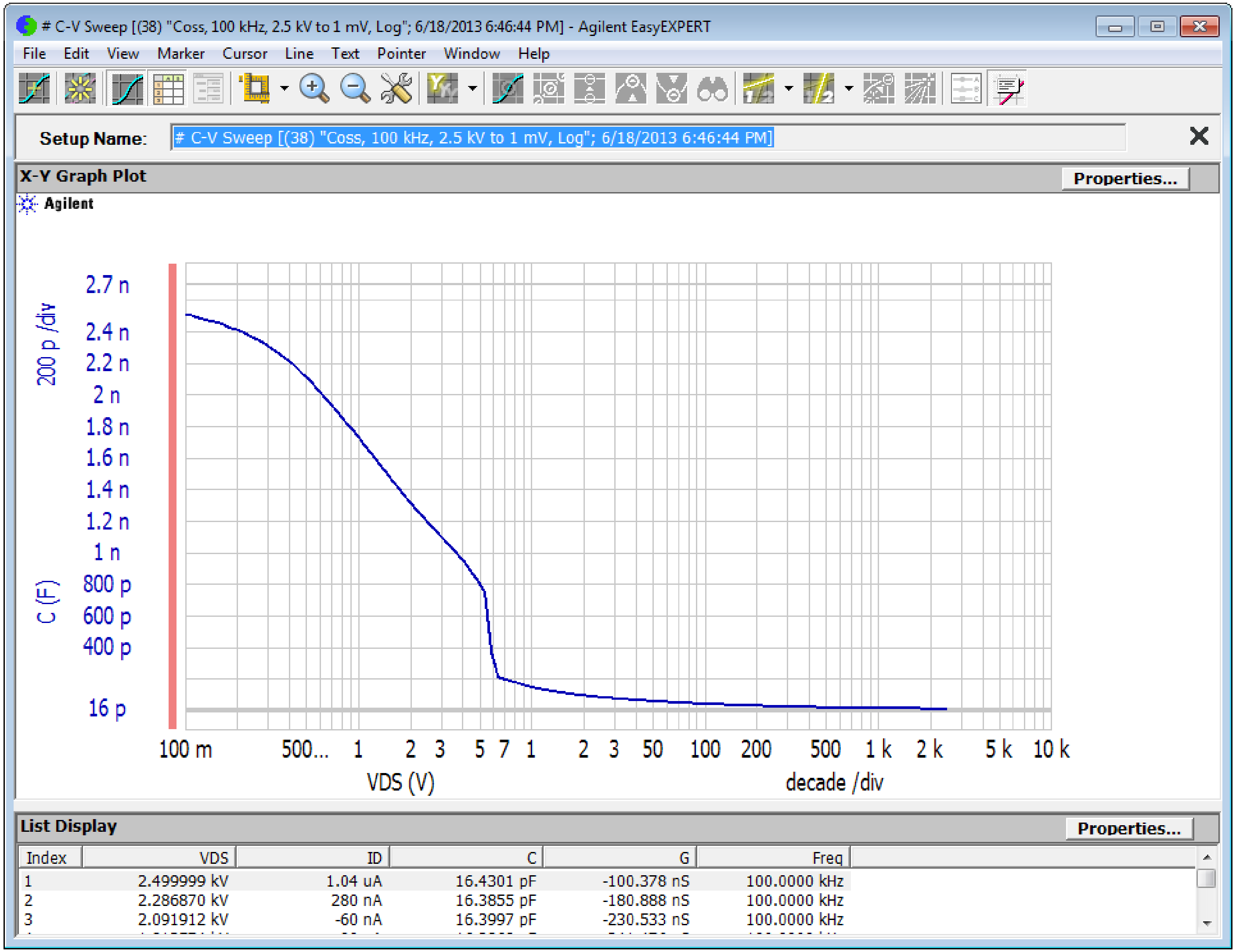
Coss Measurement Results - 1



Note: Some frequency dependence at this transition point was observed.

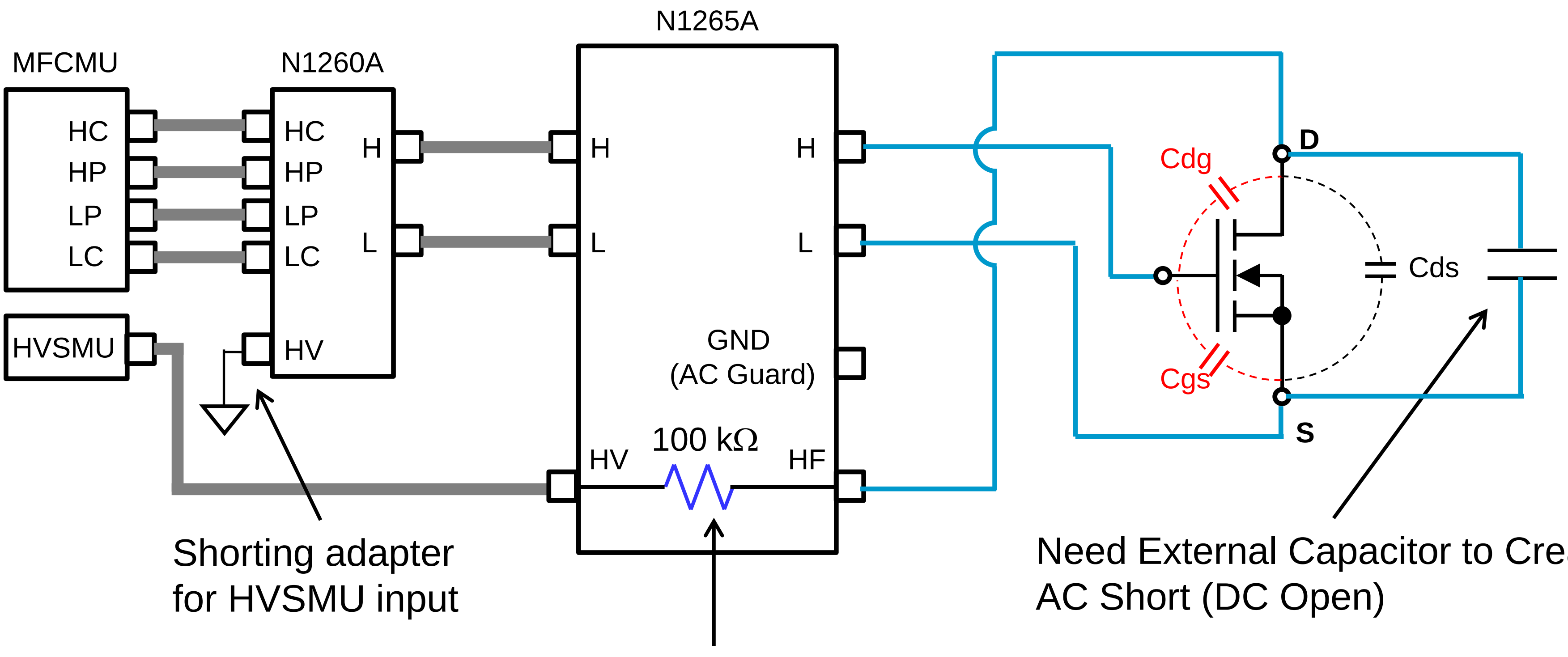
Measurement results at 10 kHz, 100 kHz and 1 MHz show good correlation across DC voltage

Coss Measurement Results - 2



Configuration of Ciss Measurement of Normally OFF Device

Ciss = Cgs + Cgd



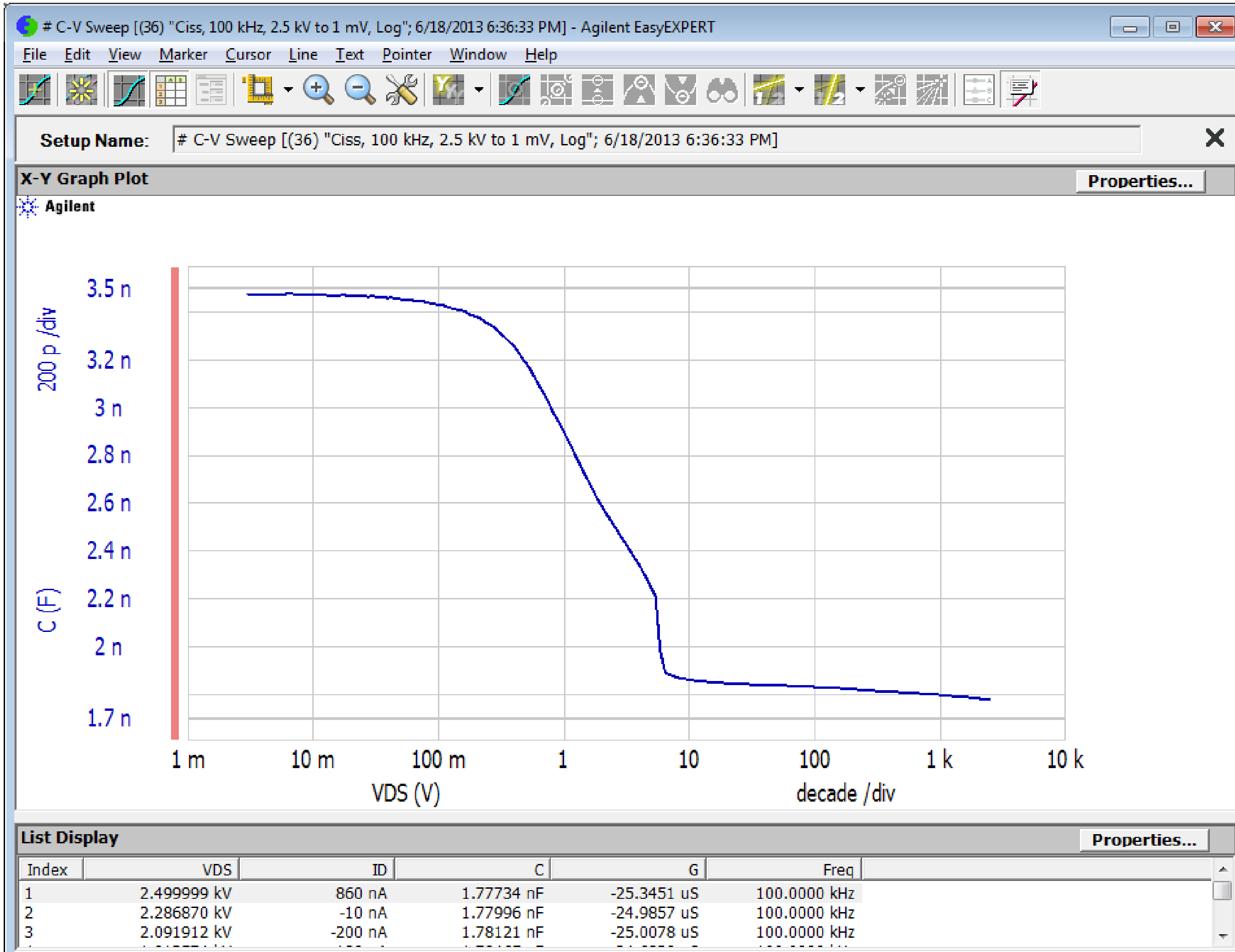
Shorting adapter for HVSMU input

Need AC blocking resistor. Can use series resistor from N1265A module selector unit. Need to set default path of module selector to HVSMU.

Need External Capacitor to Create AC Short (DC Open)

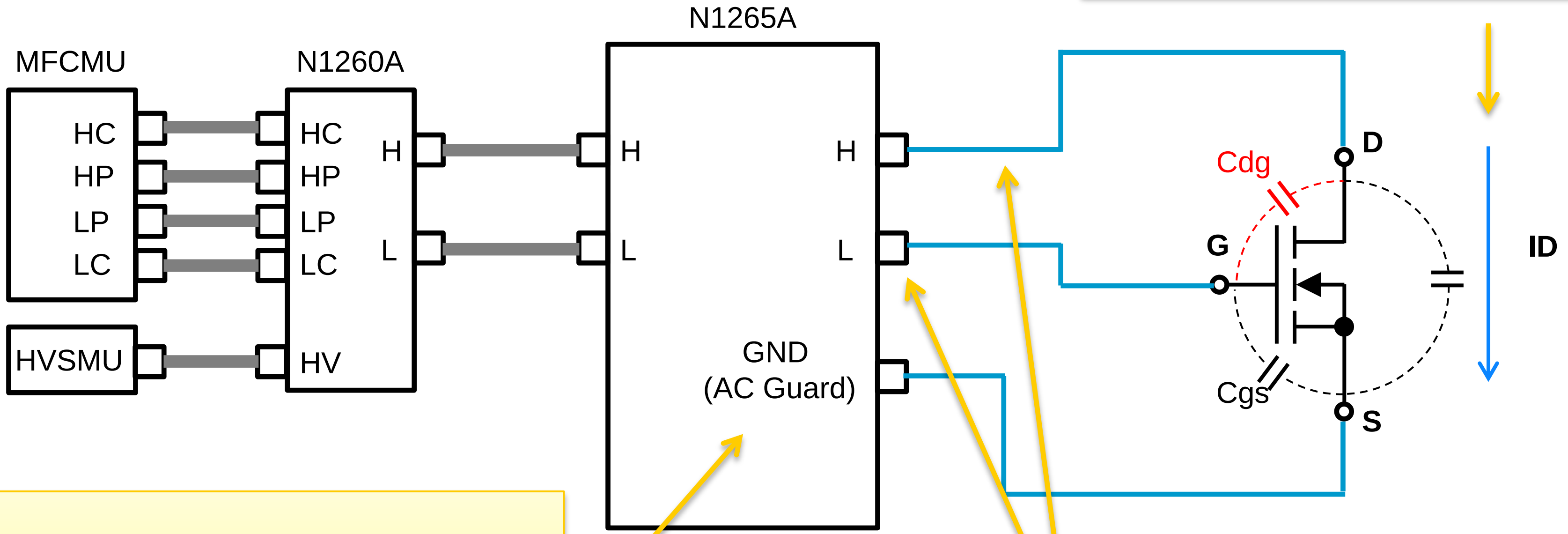
Z(AC block) >> Z(AC short)

Ciss Measurement Results



Issue: GaN HEMT Devices are Normally ON

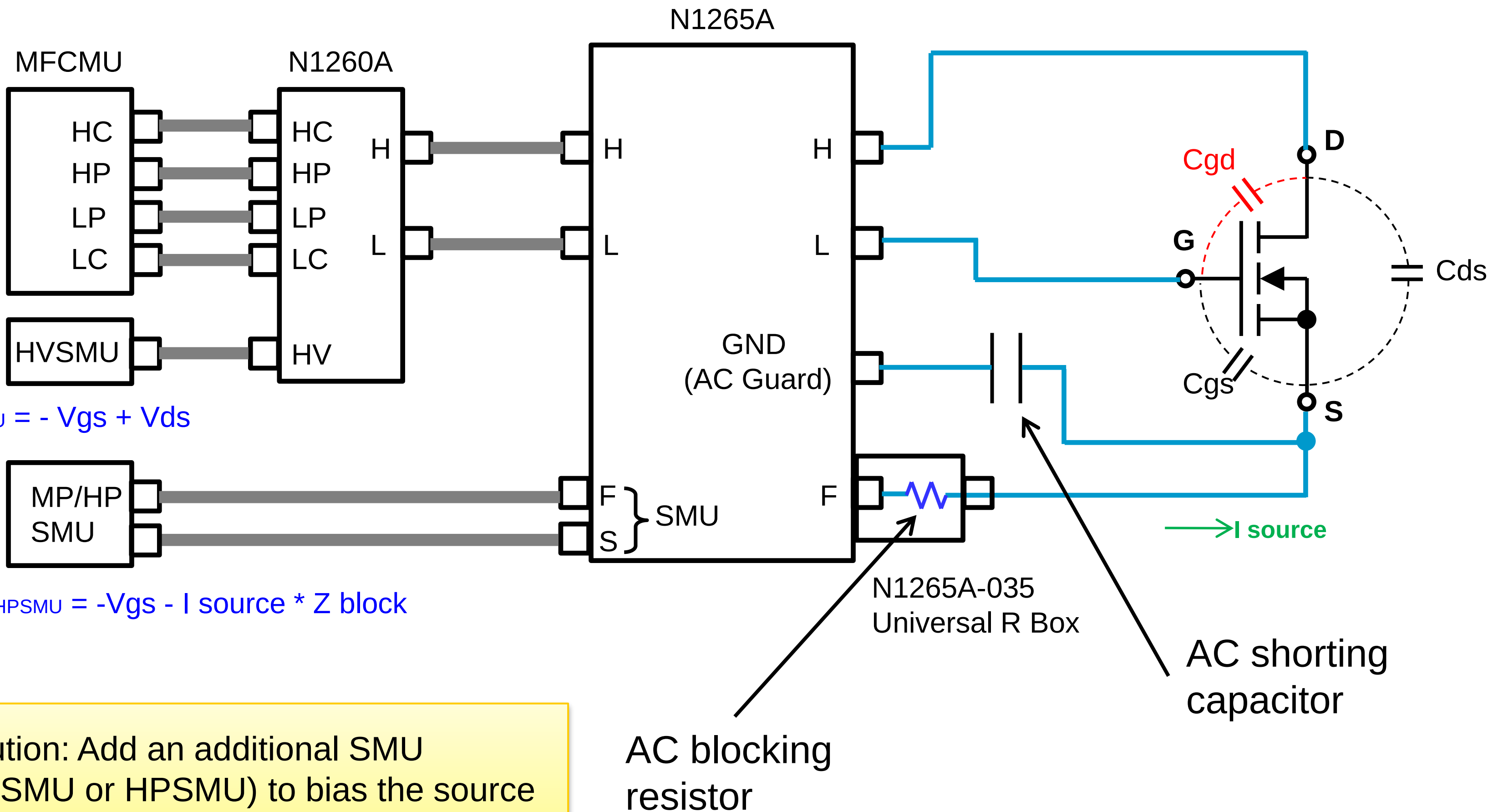
An HVSMU in series with a 100 kΩ resistor cannot supply current to an active FET.



This methodology cannot be used for normally ON devices because the gate terminal is connected to the CML terminal, which turns on a normally ON device.

Some method to simultaneously supply gate bias and drain bias while sweeping drain bias is required.

Cgd (Crss) Measurement of Normally ON Device



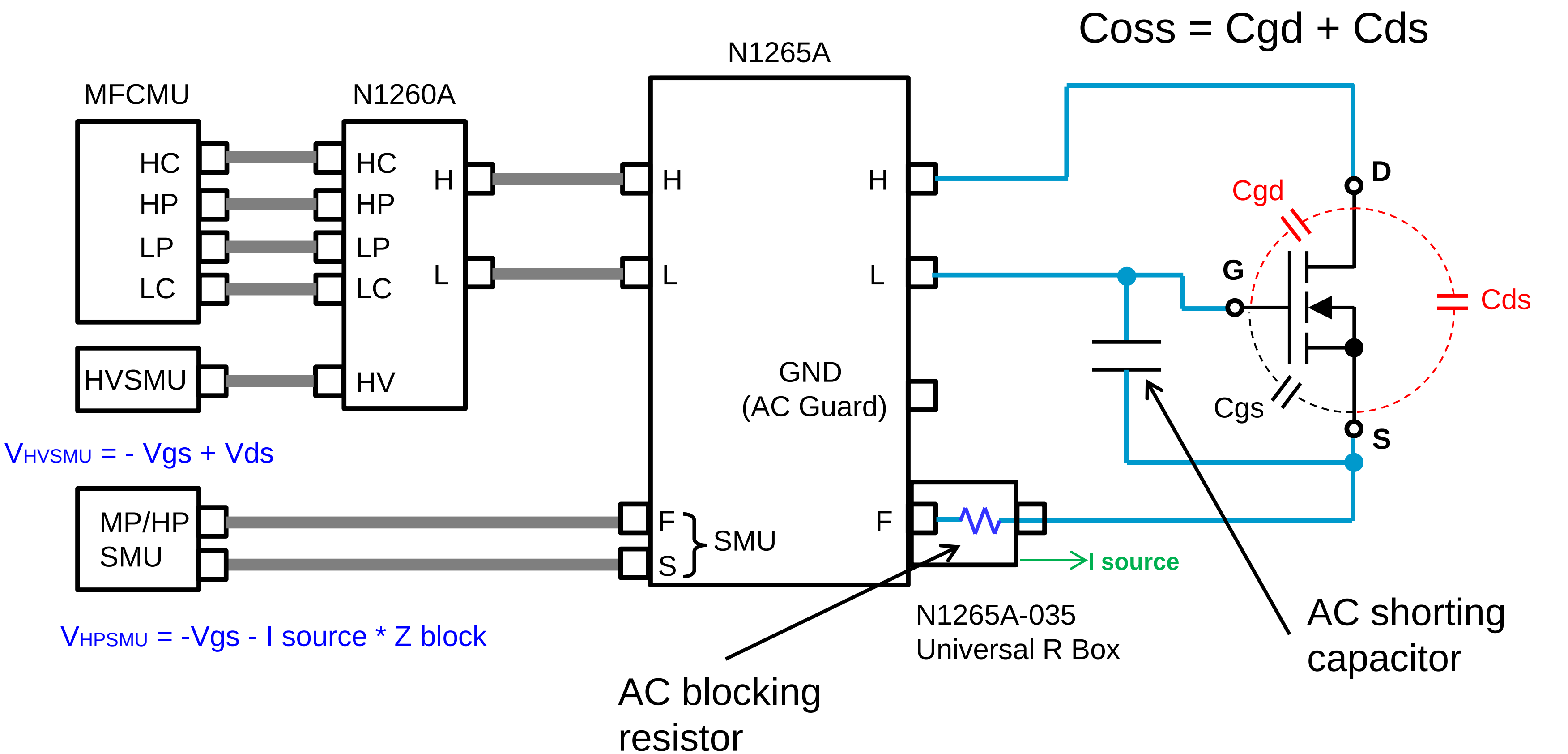
V_{HVSMU} = - Vgs + Vds

V_{HPSMU} = -Vgs - I source * Z block

Solution: Add an additional SMU (MPSMU or HPSMU) to bias the source terminal and keep the transistor off.

Z(AC block) >> Z(AC short)
C (AC short) >> Cgs

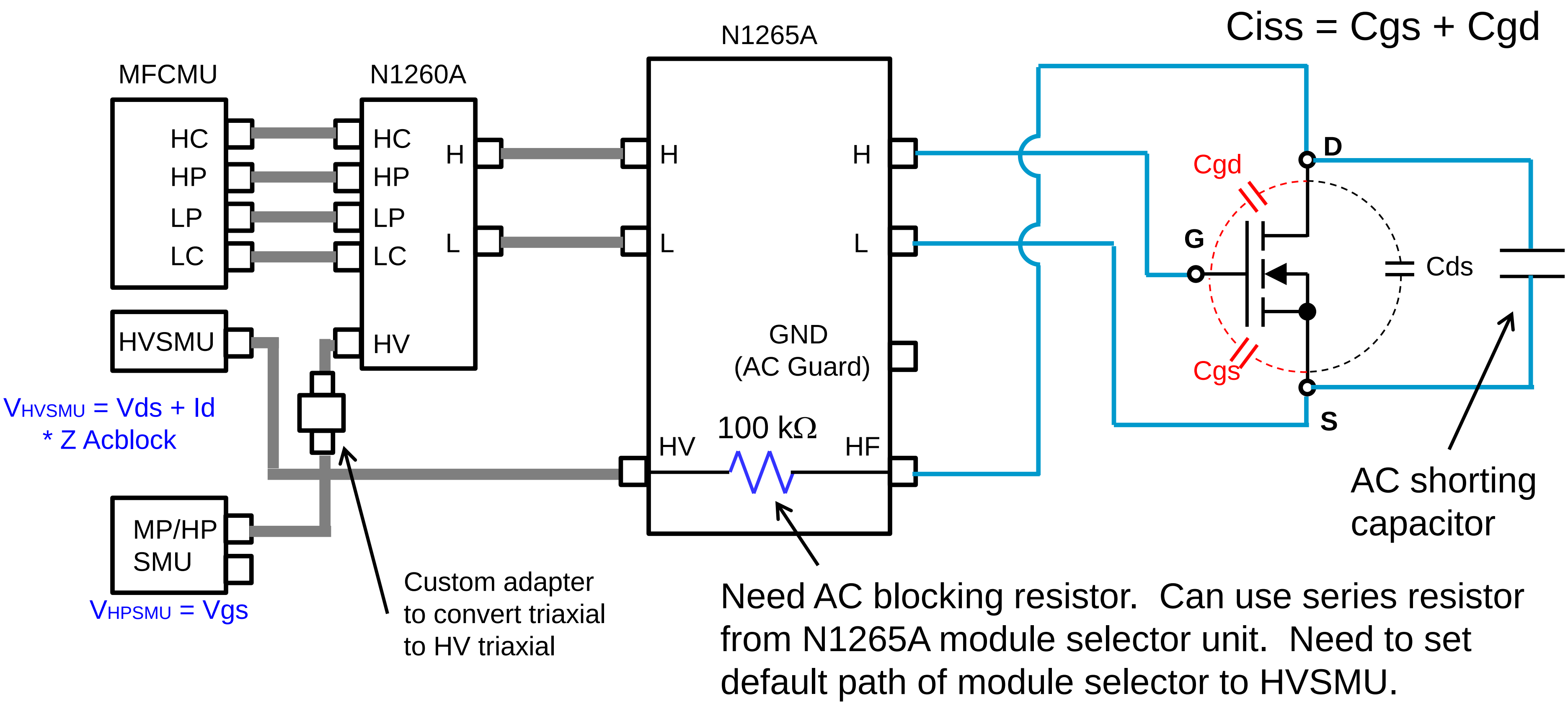
Coss Measurement for Normally ON Device



- The bias voltage needs to be applied in the correct order.
- Zgs/Zshort introduces frequency dependency.
- Large AC blocking resistor and AC shorting capacitor require long settling times.

Z(AC block) >> Z(AC short)

Ciss Measurement for Normally ON Device



- The bias voltage needs to be applied in the correct order.
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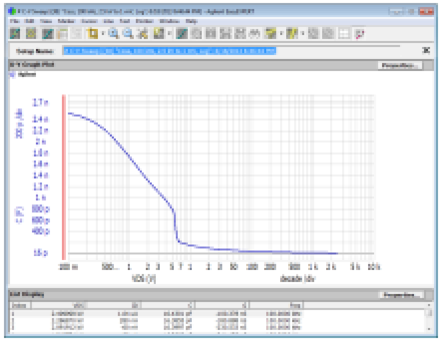
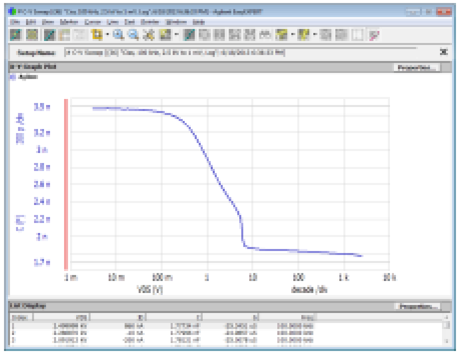
Z(AC block) >> Z(AC short)

Capacitance Measurement Summary





- Using the B1505A, capacitance measurement at up to 3 kV of DC bias is possible for both normally OFF and normally ON devices.
- For each device type and measurement, you need to understand the theory behind the measurement.
- Although not discussed in these slides, you do need to perform proper calibration (phase and open/short) before performing these measurements.

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Summary

The B1505A Power Device Analyzer can accurately characterize SiC and GaN devices

- Wide voltage/current range up to 1500A/10kV
- μΩ resistance measurement capability
- Pulsed measurement capability down to 10 μs
- Accurate sub-pA level current measurement at high voltage bias
- GaN current collapse measurement
- Capacitance measurement up to 3 kV of DC bias

Agilent B1505A Information

Agilent B1505A literature available for download from
www.agilent.com/find/b1505a

B1505A Data Sheet

Handbook

Application Notes


1500 A and 10 kV IGBT Characterization Using the Agilent B1505A

Application Note

B1505A Power Device Analyzer/Curve Tracer

Also, you can see more application videos at the Agilent B1505A Youtube channel:

http://www.youtube.com/user/agilentParaPwrAnalyz

Question & Answer Session

Thank you for your kind attention