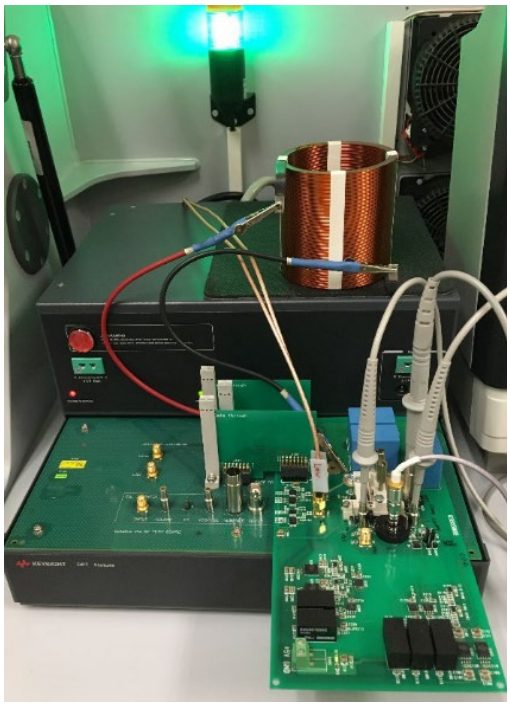


TECHNICAL OVERVIEW

Customized GaN Solutions for Double-Pulse Test

Leveraging the PD1500A Dynamic Power Device Analyzer for GaN power device characterization



Achieve repeatable, reliable characterization of GaN power semiconductors with Keysight's customized, proprietary GaN test boards.

HEMT, Cascode, GIT and vertical GaN technologies

Sub 5 nH power loop inductance

Customized to your specific GaN test needs

KEYSIGHT TECHNOLOGIES

Introduction

Keysight Technologies introduced the PD1500A dynamic power device analyzer and Double-Pulse Tester (DPT) in 2019 to address wide bandgap (WBG) dynamic test and characterization requirements. Before then, commercially available dynamic power device test systems were developed for slower silicon (Si) power FETs, focusing on resistive switching techniques. Unfortunately, they are inadequate for characterizing the faster switching speeds and edge rates of WBG devices, which forced power semiconductor manufacturers and power device designers to develop custom characterization solutions.

Because there are many factors (e.g., inductive switching, power loop parasitics, gate driver design, etc.) that affect dynamic parameter results, testing of these WBG devices evolved into a situation where power device manufacturers and consumers can't easily compare their results.



Figure 1. PD1500A dynamic power device analyzer and double-pulse tester.

The major objective of the PD1500A is to provide repeatable and reliable characterization results for WBG devices. Whether it is from person-to-person or system-to-system, one achieves a consistent comparison of different power devices allowing you to determine the best power device for your design. The initial PD1500A introduction in 2019 was focused on Si FETs, IGBTs, and SiC FETs. Its modular architecture minimized the need for customization of the test solution. Since introduction the PD1500A has demonstrated repeatable and reliable results for these power semiconductors.

GaN FET Test Challenges

Because GaN FET switching speeds and edge rates are up to 10 times faster than SiC, additional challenges are encountered when designing a DPT system that provides repeatable and reliable characterization results.

- **Variety of device designs and form factors** – The industry is still developing different topologies and approaches to maximize the benefit of GaN power devices. Therefore, there is less standardization in devices, requiring more customized designs. Figure 2 shows the main GaN device types that are being developed at the time of this publishing.

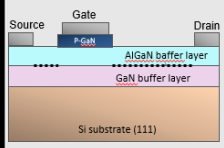
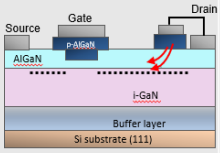
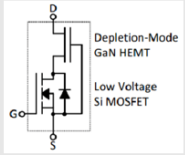
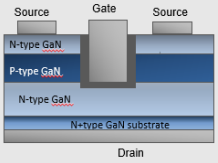
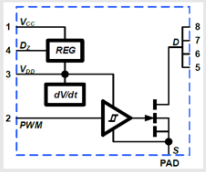
	HEMT (High Electron Mobility Transistor)	GIT (Gate Injection Transistor)	Cascode GaN	Vertical GaN	GaN Power IC
Advantage	• Very fast switching	• Very fast switching • Less current collapse	• SiO_2 gate is stable • Wider Vgs swing	• Vertical structure allows higher voltage and higher current	• Easy to use in actual circuit
Disadvantage	• Low Vth • Not robust • Current collapse	• Difficult to use due to its special structure & unique gate drive	• Much slower than HEMT or GIT • Prone to oscillations	• Very difficult to manufacture (Commercially not available yet.) • Slower than HEMT or GIT	• Not easy to manufacture
Typical specs	• Vds max: 650V or 100V, 200V • Vgs drive: 0V to 6V • Id max: 3A to 80A	• Vds max: 600V • Vgs drive: Fixed (-5V to 5V) • Id max: 10A to 30A	• Vds max: 650V • Vgs drive: 0V to 10V-12V • Id max: 10 to 40A	• Vds max: 1.2kV or higher • Vgs drive: 0V to 10V? • Id max: 20A to 400A?	• Vds max: 650V • Drive voltage: 6V • Id max: 24A
Structure					
Typ. package	SMD	SMD	TO-220, SMD	SMD	SMD

Figure 2. Main GaN device types.

- **Stable DPT operation** – Minimizing power loop and gate loop inductance is even more critical for the high-frequency energy in the GaN switching waveforms. Otherwise, you can easily have excessive ringing causing HV oscillation, which frequently leads to the destruction of the device or damage to the test system (Figure 3).

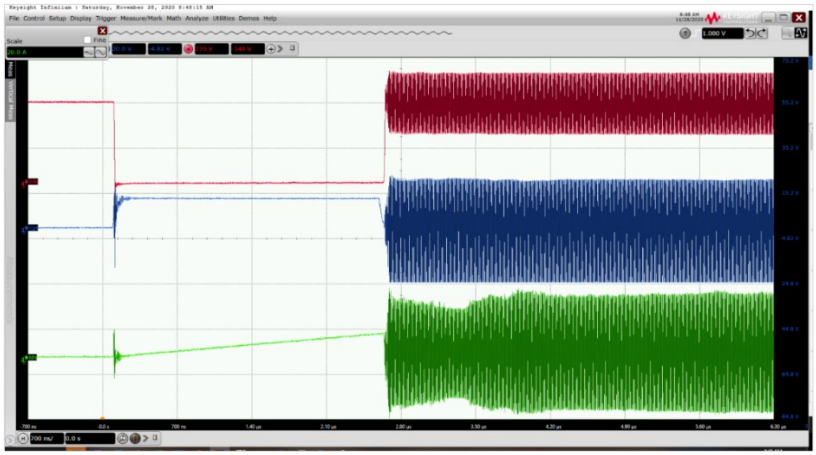


Figure 3. Device oscillation at turn-off event.

- **High bandwidth, low parasitic current measurements** – Because of GaN's high-frequency energy in the switching waveforms, it is important to have a higher frequency and a lower parasitic current measurement capability.
- **Dynamic $R_{ds(on)}$/Current Collapse** – Unlike Si and SiC power device, GaN FET has dynamic $R_{ds(on)}$ characteristics due to a charge trapping phenomenon within the crystal/dielectric film or the interface between the dielectric and the semiconductor layer.
- **DUT connection to system** – The GaN FET connection to the test system is also a parasitic that must be minimized. Soldering the device is ideal from a parasitic perspective but is difficult to use and time-consuming when testing many devices.

Minimizing Fixture Parasitics

As mentioned earlier, the PD1500A's modular architecture with its separate DUT board, gate driver boards, DC-Link capacitors, and automated load inductors allow configurable solutions for Si, IGBT, and SiC with minimal customization. However, the design has too many parasitics in the fixture for effectively testing GaN devices. It is critical to minimize the power loop, gate loop, and even the DC-Link loop inductance to enable repeatable and reliable measurements (see Figure 4, from 'Overcoming Challenges Characterizing High-Speed Power Semiconductors', Bodo's Power Systems®, April 2020, pages 36-39, www.bodospower.com).

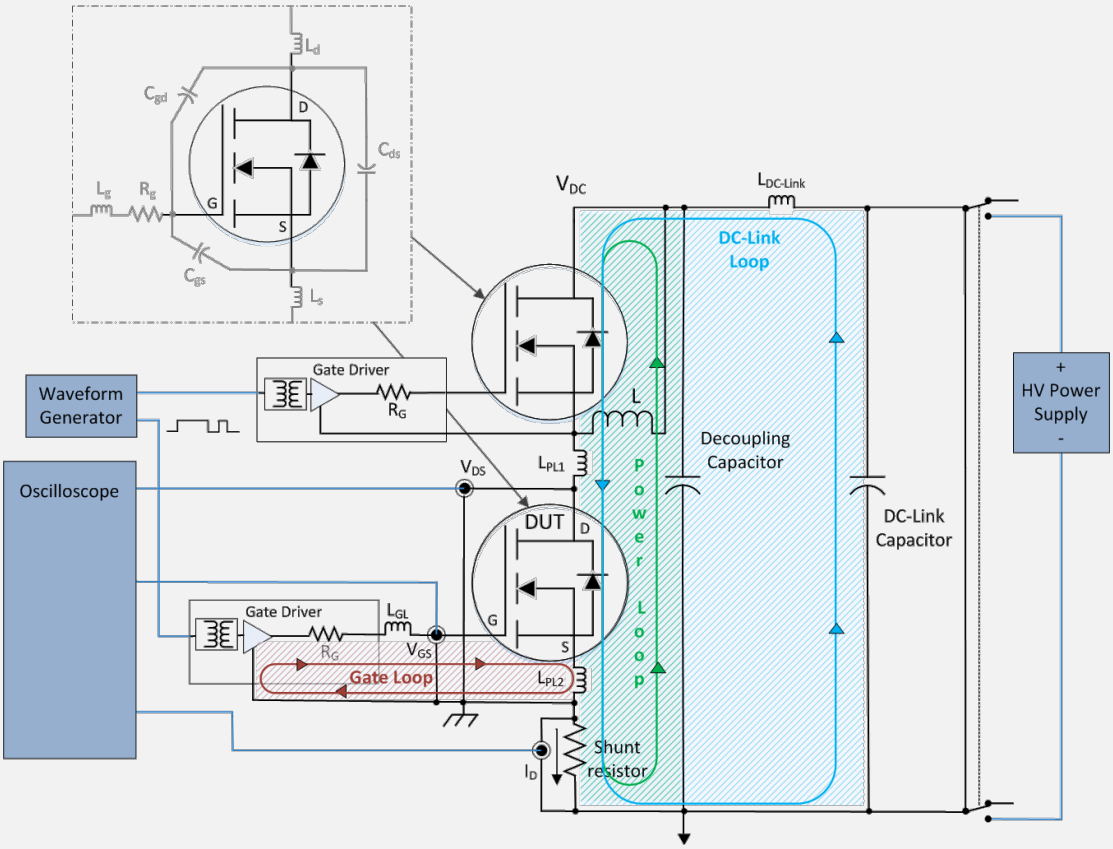


Figure 4. Double-pulse test circuit, including fixture and device parasitics.

To enable GaN testing with the PD1500A, Keysight leverages the PD1500A system architecture including, instrumentation, probes, safety system, automated control software, autocalibration routines, and the existing fixture, combined with customized test boards for different GaN device configurations. The customized GaN test board includes the DC-link and decoupling capacitors, custom gate drivers, clamp circuit ($R_{ds(on)}$), probe connections, and auto-calibration constants. Placing all these DPT components on a single board enables much smaller loop areas (i.e., inductance), required for GaN device testing. After removing the standard PD1500A gate driver boards and DUT board, the customized GaN test board connects directly to the fixture using the same connections as the PD1500A standard DUT boards (Figure 5).

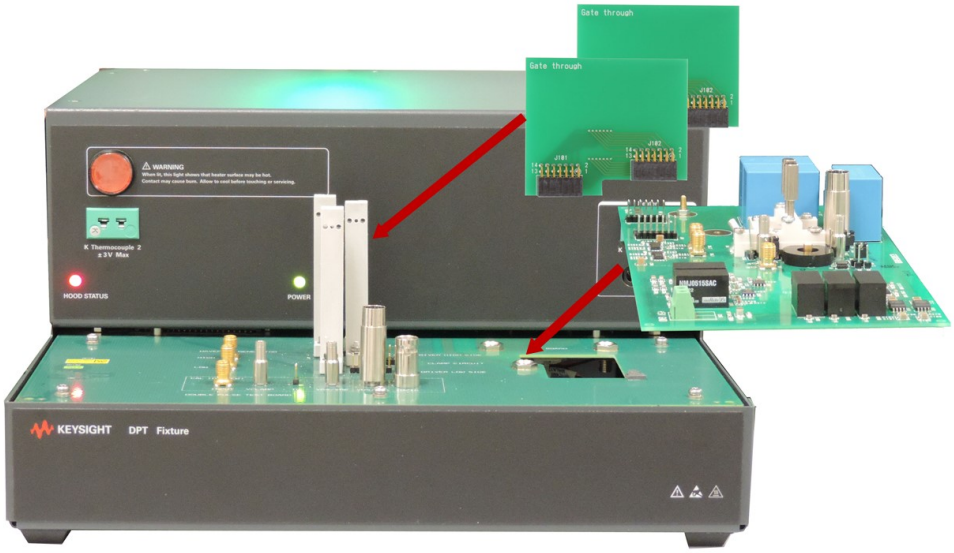


Figure 5. Customized GaN test board and PD1500A DPT fixture.

The load inductor is not included on the customized GaN test board. The PD1500A system was updated to allow external, customer supplied, load inductors to provide more flexibility in determining initial pulse widths and current ramping speeds. External load inductors are typically used with the customized GaN test board. For more details on how to choose or make your own load inductor reference the PD1500A External Inductors Guide, P/N: PD1500-90006.

Developing the DPT circuit on a single board reduces parasitics for the power, gate, and DC-link loops because one can locate components very close to each other. But there are other challenges to overcome to enable repeatable and reliable GaN FET measurements. Measurement probes, DUT connectors, and other measurement science complications must be considered when laying out the DPT circuit on the test board.

Keysight spent years investing in measurement science innovations to develop ‘Repeatable and Reliable GaN Characterization’ (R^2GC) technologies for our DPT reference design. These R^2GC technologies enabled us to provide industry-leading, commercially available power loop inductance (< 5 nH). Please note, GaN test board designs are custom, results will vary depending on the specific requirements and design for each board. Figure 6 shows the ‘turn-on’ waveforms from a customized eHEMT GaN test board to extract the approximate power loop inductance.

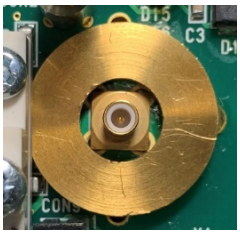


Figure 6. Power loop inductance analysis (eHEMT – 400V, 60A: Power loop inductance = V_{droop} /di/dt = 22.667A/5.145 GA/s = 4.41 nH).

Repeatable & Reliable GaN Characterization (R^2GC) Technologies

What are Keysight's R^2GC innovations?

- **Current sensor** – Keysight has a patent pending on this technology, enabling extremely low insertion inductance (S_{21}) with high bandwidth. Figure 7 shows a comparison of Keysight's R^2GC current sensor technology to the industry standard Pearson Probe capability. The R^2GC current sensor obviously has a higher frequency content (high BW) allowing the true characteristics of the device to be characterized.



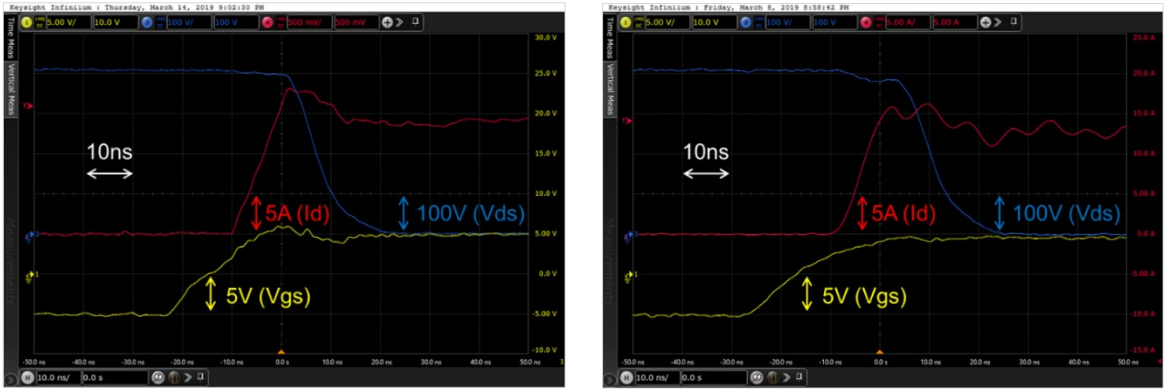
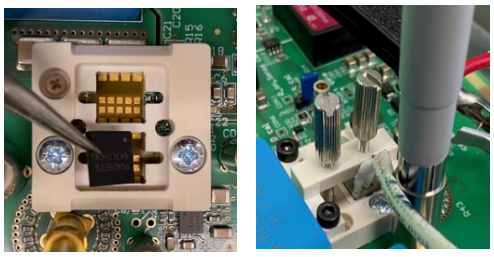


Figure 7. Keysight's R^2GC current sensor (left), Pearson Probe wideband current monitor (right).

- **Power device connection** – To further minimize parasitic loop inductance, we invested in a solderless power device connection technology that allows the flexibility to change power devices (DUT) without soldering, with parasitic performance equivalent to soldering. Additionally, Keysight's R^2GC solderless connection technology also allows temperature testing of GaN devices from room temperature to 150 ˚C.



- **Gate resistors (R_g)** – Exchanging gate resistors is common practice when deciding on just the right amount of dampening for standard DPT tests, gate charge (Q_g) measurements, and dynamic $R_{ds(on)}$ measurements. However, R_g is in the gate loop (Figure 4), where any parasitics will impact the control of switching the GaN FET. Similar to the DUT connection approach, Keysight developed an R^2GC replaceable R_g technology that allows changing gate resistors without de-soldering and soldering, providing equivalent performance to soldering R_g (Figure 8).

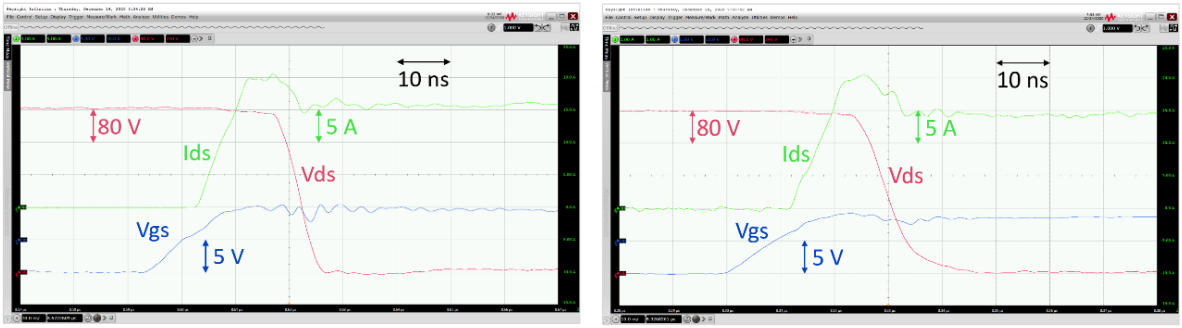


Figure 8. Keysight R^2GC replaceable Rg = 1Ω (left), soldered Rg = 1Ω (right).

Dynamic $R_{ds(on)}$ – The current collapse phenomenon is a hot topic for the GaN device manufacturers and users. It was the first test method standard that the JEDEC JC-70.1 committee released for GaN eHEMT devices (JEP173, January 2019; https://www.jedec.org/standards-documents/docs/jep173). Following the recommendations within this standard, Keysight engineered a fast R^2GC clamp circuit, enabling a high resolution 10:1 probe for measuring $V_{ds(on)}$ (see Figure 9). The clamped $V_{ds(on)}$ signal settles in 50 to 200 ns. GaN test board designs are custom, results will vary depending on the specific requirements and design for each board.

JC-70 Wide Bandgap Power Electronic Conversion Semiconductors

The JEDEC standards recognized the need to provide WBG standards for the power semiconductor industry.

In September of 2017, the JC-70 Wide Bandgap Power Electronic Conversion Semiconductor committee was formed for both GaN JC-70.1 and SiC JC-70.2

Each section has three task groups, focusing on Reliability and Qualification Procedures, Datasheet Elements and Parameters, and Test and Characterization Methods. Keysight is actively participating in developing these standards.

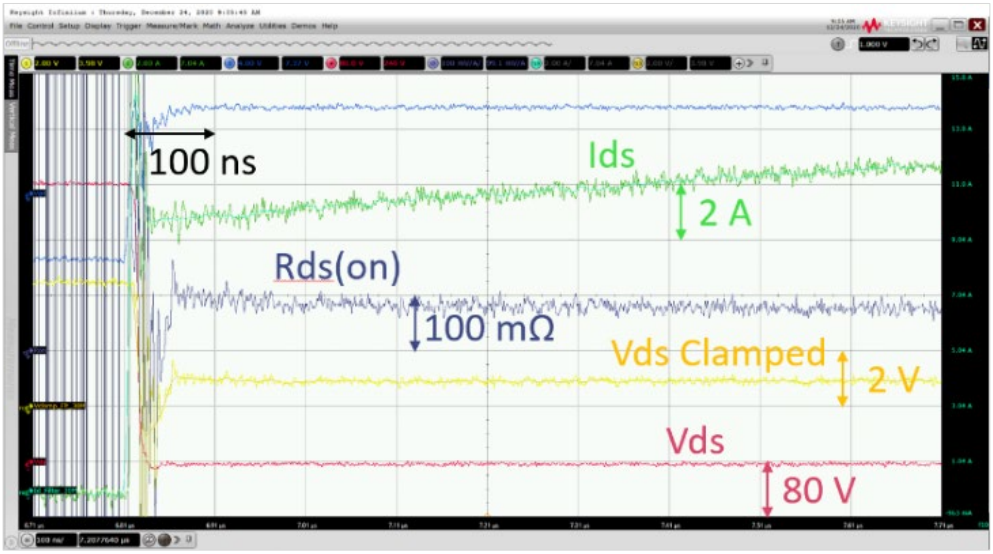


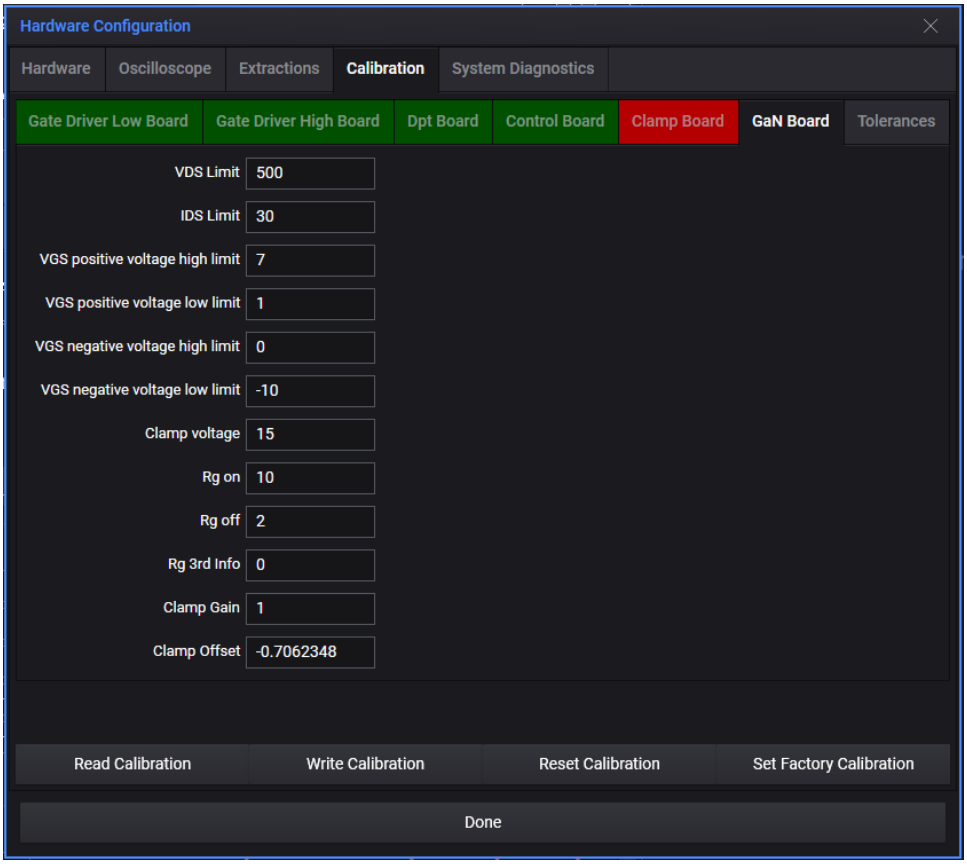
Figure 9. Rds(on) (clamped Vds) measurement using R^2GC technology.

Leveraging the standard PD1500A Dynamic Power Device Analyzer/Double-Pulse Tester and a customized GaN test board, Keysight's R^2GC technologies enable repeatable and reliable GaN FET characterization.

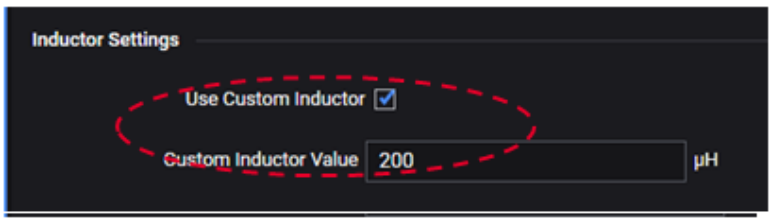
PD1500A Software

Using the PD1500A software to test customized GaN test boards is easy. Just a few simple steps are needed to set up a customized GaN test board.

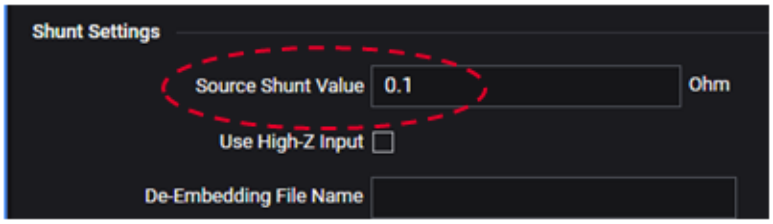
- Setup the initial GaN board parameters in the hardware configuration menu



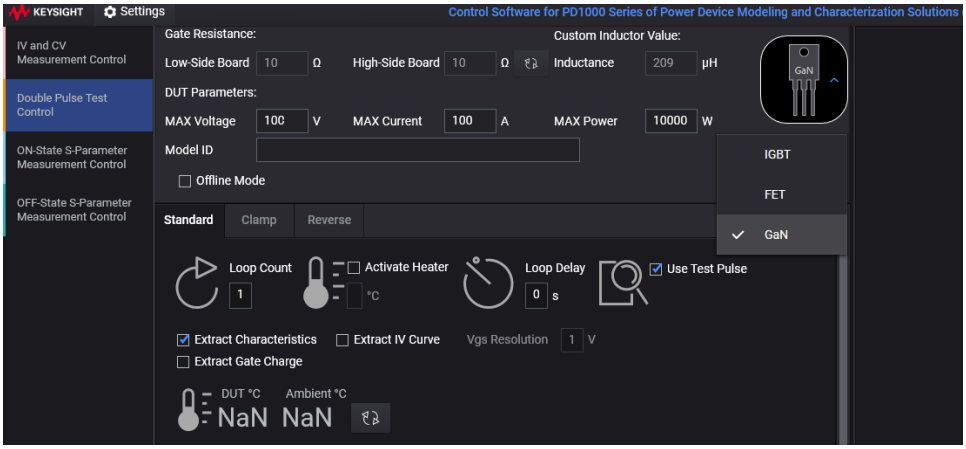
- Setup the desired external inductor, specifying the inductor value.



- Setup the R^{2}GC current sensor



- Then simply select the GaN device in the menu and you are ready to configure the test!



Tested Parameters

Please refer to the PD1500A Series – Dynamic Power Device Analyzer/Double-Pulse Tester data sheet (P/N 5992-3942EN) for a comprehensive list of tested parameters. Each GaN test board is custom, so specific parameters tested may vary. However, typically the customized GaN board can test all the parameters listed, with a few comments noted below.

- Reverse Recovery testing is available for GaN devices but is not always performed. Some GaN devices don't have a body diode (e.g. eHEMT). Customized GaN boards are capable of testing reverse recovery parameters.
- Unlike Si and SiC devices, $R_{ds(on)}$ is a dynamic parameter for GaN devices. For Si and SiC devices, $R_{ds(on)}$ is typically measured with a B1505/6A Power Device Analyzer to obtain an accurate static measurement. However, for GaN devices a customized board with Keysight's R^2GC clamp circuit is the preferred method for measuring dynamic $R_{ds(on)}$.

Customized GaN Test Board Measurement Capabilities

Each GaN test board is custom, so specific system and measurement capabilities will vary. Additionally, there are some system limitations for the customized GaN test boards compared to the standard PD1500A for Si and SiC. Please refer to the PD1500A Series – Dynamic Power Device Analyzer/Double-Pulse Tester data sheet (P/N 5992-3942EN) for a comprehensive list of specifications. The system limitations and measurement capabilities for the customized GaN test boards that differ from the standard PD1500A are listed below.

- **Drain Channel - DC - Source - Max Current** = 80A for current designs. (Additional design/testing planned to provide higher currents)
- **Drain Channel – DC – Source – Min Current** = 1A
- **Gate – DC – Source** items are all custom depending on the test board design
- **Gate – AC – Source** items are all custom depending on the test board design
- **Electrical – Modular Components** items are all custom depending on the test board design
- **DUT – Discrete Device** items are GaN eHEMT, GaN GIT, GaN Cascode & vertical GaN
- **DUT – Discrete Device** packages are custom depending on the test board design
- **System – Safety Hood – Maximum Energy in the system** is custom depending on DC-Link Capacitor design

For more information on the PD1500A Dynamic Power Device Analyzer Solution

Visit www.keysight.com/find/PD1500A

PD1500A Series Dynamic Power Device Analyzer/Double-Pulse Tester Data Sheet

Achieve repeatable, reliable characterization of wide-bandgap semiconductors. (5992-3942EN)

PD1500A Dynamic Power Device Analyzer/Double-Pulse Tester - Control Software Guide

This guide provides complete software installation, configuration, and operation information for the PD1500A Dynamic Power Device Analyzer/Double-Pulse Tester (or DPT System) Control Software. (PD1500-90001).

Learn more at: www.keysight.com

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KEYSIGHT TECHNOLOGIES

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