Keysight PD1500A Dynamic Power Device Analyzer/ Double-Pulse Tester

Provides detailed information to install, configure, and use the PD1000A Control Software for PD1500A Double-Pulse Test characterization measurements.
Manual applies to PD1000A Control Software version 2021.624 and later, Test Fixture Firmware version A.02.04 and later.

KEYSIGHT TECHNOLOGIES

Control Software Guide

Notices

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www.keysight.com/find/PD1500A

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General

Do not use these instruments in any manner not specified by the manufacturer. The protective features of these instruments must not be impaired if it is used in a manner specified in the operation instructions.

Before Applying Power

Verify that all safety precautions are taken. Make all connections to the instruments before applying power. Note the external markings described under "Safety Symbols".

Ground the Instrument

Keysight instruments are provided with a grounding-type power plug. The instruments must be connected to an electrical ground to minimize shock hazard. The ground pin must be firmly connected to an electrical ground (safety ground) terminal at the power outlet. Any interruption of the protective (grounding) conductor or disconnection of the protective earth terminal will cause a potential shock hazard that could result in personal injury.

Unless otherwise noted in the specifications, these instruments or system is intended for indoor use in an installation category II, pollution degree 2 environment per IEC 61010-1 and 664 respectively. They are designed to operate at a maximum relative humidity of 50% to 80% at 30 °C or less (noncondensing). These instruments or system are designed to operate at altitudes up to 3000 meters, and at temperatures between 20 and 30 °C.

Do Not Operate in an Explosive Atmosphere Do not operate in the presence of flammable gases or fumes.

Do Not Operate Near Flammable Liquids

Do not operate the instruments in the presence of flammable liquids or near containers of such liquids.

Cleaning

Clean the outside of the Keysight instruments with a soft, lint-free, slightly dampened cloth. Do not use detergent or chemical solvents.

Do Not Remove Instrument Cover

Only qualified, service-trained personnel who are aware of the hazards involved should remove instrument covers. Always disconnect the power cable and any external circuits before removing the instrument cover.

Keep away from live circuits

Operating personnel must not remove equipment covers or shields. Procedures involving the removal of covers and shields are for use by service-trained personnel only. Under certain conditions, dangerous voltages may exist even with the equipment switched off. To avoid dangerous electrical shock, DO NOT perform procedures involving cover or shield removal unless you are qualified to do so.

DO NOT operate damaged equipment

Whenever it is possible that the safety protection features built into these instruments have been impaired, either through physical damage, excessive moisture, or any other reason, REMOVE POWER and do not use the instrument until safe operation can be verified by service-trained personnel. If necessary, return the product to a Keysight Technologies Sales and Service Office for service and repair to ensure the safety features are maintained.

DO NOT block the primary disconnect

The primary disconnect device is the appliance connector/power cord when an instrument used by itself, but when installed into a rack or system the disconnect may be impaired and must be considered part of the installation.

Do Not Modify the Instrument

Do not install substitute parts or perform any unauthorized modification to the product. Return the product to a Keysight Sales and Service Office to ensure that safety features are maintained.

In Case of Damage

Instruments that appear damaged or defective should be made inoperative and secured against unintended operation until they can be repaired by qualified service personnel.

Measurement Limits

The Truevolt Series DMMs provide protection circuitry to prevent damage to the instrument and to protect against the danger of electric shock, provided the Measurement Limits are not exceeded. To ensure safe operation of the instrument, do not exceed the Measurement Limits shown on the front and rear panel.

The DMMs comply with EN/IEC 61326-2-1, for sensitive test and measurement equipment.

When subjected to transient radiated and/or conducted electromagnetic phenomena, the DMMs may have temporary loss of function or performance which is self-recovering. Recovery may take longer than 10 seconds.

When subjected to continuously present electromagnetic phenomena, some degradation of performance may occur.

Safety and Regulatory Symbols

CAUTION

A CAUTION denotes a hazard. It calls attention to an operating procedure or practice that, if not correctly performed or adhered to, could result in damage to the product or loss of important data. Do not proceed beyond a CAUTION notice until the indicated conditions are fully understood and met.

WARNING

A WARNING denotes a hazard. It calls attention to an operating procedure or practice, that, if not correctly performed or adhered to, could result in personal injury or death. Do not proceed beyond a WARNING notice until the indicated conditions are fully understood and met.

Products display the following:


Refer to manual for additional safety information.


Earth Ground.


Chassis Ground.


Alternating Current (AC).


Direct Current (DC).


Standby Power. Unit is not completely disconnected from AC mains when power switch is in standby position


Indicates that antistatic precautions should be taken.


DANGER:
High Voltage


Hot Surface; DO NOT Touch!

The CE marking is a registered trademark of the European Community (if accompanied by a year, it is the year when the design was proven). It indicates that the product complies with all relevant EU directives.

The Regulatory Compliance Mark (RCM) is a registered trademark of the Australian Communications and Media Authority.

The CSA mark is a registered trademark of the Canadian Standards Association and indicates compliance to the standards laid out by them. Refer to the product Declaration of Conformity for details.

Waste Electrical and Electronic Equipment (WEEE) Directive 2002/96/EC

This WEEE symbol indicates separate collection for electrical and electronic equipment, mandated under EU law as of August 13, 2005. All electric and electronic equipment are required to be separated from normal waste for disposal. Cable or components and sub-assemblies contained within a product are typically not marked.

To return unwanted products, contact your local Keysight office for more information.

South Korean Certification (KC) mark. It includes the marking's identifier code.

A 급 기기 (업무용 방송통신기자재)
이 기기는 업무용 (A 급) 전자파적합기
기로서 판 매자 또는 사용자는 이 점을 주
의하시기 바라 며 , 가정외의 지역에서
사용하는 것을 목적으 로 합니다.

This symbol represents the time period during which no hazardous or toxic substance elements are expected to leak or deteriorate during normal use. Forty years is the expected useful life of this product.

Universal recycling symbol. This symbol indicates compliance with the China standard GB 18455-2001 as required by the China RoHS regulations for paper/fiberboard packaging.

Safety Warnings

The following warnings and cautions are applicable to the Double-Pulse Test Rack and Safety Enclosure. Observe all safety precautions and warnings.

Grounding

This product has not been evaluated for connection to an IT power system, an AC distribution system having no direct connection to earth (ground), according to EN60950.

WARNING **This is a safety class I product and has a protective earthing (grounding) terminal. There must be an un-interruptible safety earth ground from the main power source to the product's input wiring terminals, power cord, or supplied cord set. Whenever it is likely that the protection has been impaired, disconnect the power cord until the ground has been restored.**

Leakage Current

WARNING **Due to the instruments installed in this cabinet, there is a risk of leakage current (> 3.5 mA). Reliable ground circuit continuity is required for safe operation of this product. To reduce the risk of electrical shock, an earth (ground) connection is essential before connecting the AC power mains. Never operate the system with the ground connector disconnected. Use a permanent safety ground connection (described in PD1500A System Installation Guide Chapter 1) or a plug meeting the IEC 60309 (CEE plug) requirements.**

Power Limitations

CAUTION **To reduce the risk of overload, do not load any single PDU with more than a maximum of 16 Amperes. In addition, do not load a single NEMA 5-15 or IEC-320 receptacle with more than 15 Amperes.**

Accessories

CAUTION **This product is designed for use with specific electrical accessories (i.e., PDUs, fans, oscilloscope & probes, high voltage cables, etc.). The use of any other accessory is not recommended or supported.**

Intended Use of Equipment

The Keysight Double-Pulse Test Rack and Safety Enclosure and Test Fixtures, along with the recommended accessories, are intended to be used for the PD1500A Dynamic Power Device Analyzer/Double-Pulse Tester.

WARNING

HIGH VOLTAGE
is used in the operation of this equipment.

LETHAL VOLTAGE on CONTACT
may be present at measurement terminals if you fail to implement all safety precautions.

- When the RED light on the light tower is on inside the Double-Pulse Test Rack and Safety Enclosure, lethal voltage (±1000 V dc/pulse) may appear at measurement terminals.
- Never attempt to defeat the safety interlock function of the Safety Hood.
- Do not operate the system unless another person is around the work space who is familiar with system operation and hazards or administering first aid.
- Potential voltages less than ±500 V may cause death under certain conditions. Therefore, adequate preventive measures must be taken at all times!

Safety Summary

The following general safety precautions must be observed during all phases of operation, service, and repair of this system. Failure to comply with these precautions or with specific warnings elsewhere in this manual may impair the protections provided by the system. In addition, it violates safety standards of design, manufacture, and intended use of the system. Keysight Technologies assumes no liability for customer's failure to comply with these requirements.

Product manuals are available on the Web. Go to www.keysight.com/find/PD1500A for all documentation.

WARNING

Hazardous voltage: System maximum output voltage may appear at the measurement terminals inside the Safety Hood. Never attempt to bypass the safety interlock and features of the PD1500A Double-Pulse Test Solution Rack and Safety Enclosure. To avoid contact with extremely high voltages, the rack cabinet must be operated with all side, front, and rear panels in place and the Safety Hood must remain closed. There are no user-serviceable parts inside.

Do not intentionally modify the interlock function of the Safety Hood. While the high voltage indicator is lit, dangerous voltage or residual charge may appear on the measurement terminals.

CAUTION

Some of the material in the safety enclosure can generate static electricity. Take care if you are using ESD sensitive devices in its vicinity.

NOTE

Do not use this system in any manner not specified by the manufacturer. The protective features of this system may be impaired if it is used in a manner not specified in the operation instructions. This system is an INDOOR USE product only.

This system complies with INSTALLATION CATEGORY II for mains input and INSTALLATION CATEGORY I for measurement input terminals, and POLLUTION DEGREE 2 defined in IEC 61010-1.

If an system is marked CAT I (IEC Measurement Category I), or it is not marked with a measurement category, its measurement terminals must not be connected to line-voltage mains.

Safety of any system incorporating the equipment is the responsibility of the assembler of the system.

DANGEROUS PROCEDURE WARNINGS

- Warnings shall be complied. Procedures throughout in this manual prevent you from potential hazardous situations. The instructions contained in the warnings must be followed.

BEFORE APPLYING POWER

- Verify that all safety precautions are taken. Make all connections to the system before applying power. Note the system's external markings described under “Safety and Regulatory Symbols”.

GROUND THE RACK

- This is Safety Class I system. To minimize shock hazard, the Rack and Safety Enclosure must be connected to an electrical ground. The power terminal and the power cable must meet International Electrotechnical Commission (IEC) safety standards.

DO NOT OPERATE IN AN EXPLOSIVE ATMOSPHERE

- Do not operate the system in the presence of flammable gases or fumes. Operation of any electrical instrument in such an environment constitutes a definite safety hazard.

DO NOT REMOVE COVERS

- No operator serviceable parts inside. Refer servicing to qualified personnel. To prevent electrical shock do not remove covers.

IN CASE OF DAMAGE

- Instruments, probes or cables that appear damaged or defective should be made inoperative and secured against unintended operation until they can be repaired by qualified service personnel. Return the product to a Keysight Technologies sales or service office for service and repair to ensure that safety features are maintained.

USE ONLY THE SPECIFIC ACCESSORIES

- Specified accessories satisfy the requirements for specific characteristics for using the instruments and the Rack and Safety Enclosure.

CLEANING

- Disconnect the power from the rack before cleaning the Rack and Safety Enclosure. Use only a damp cloth to clean the surfaces of the Rack and Safety Enclosure.

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1 Index

1 Introduction

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. Refer to the *PD1000A Control Software Help* file for detailed information regarding using the Control Software.

NOTE

The PD1500A Double-Pulse Test software is one part of the PD1000A Power Device Measurement System for Advanced Modeling Control Software.

IMPORTANT: This version of the Software Guide applies to and describes features present in PD1000A Control Software version 2021.624 and later. Refer to the software **Settings > About** for the software version.

IMPORTANT: PD1000A Software version 2021.624 and later, requires Test Fixture firmware version A.02.04. Refer to “Hardware Configuration: Hardware Tab” on page 40 to determine the firmware version of your Test Fixture. Contact our local Keysight AE for updated firmware if necessary.

Keysight’s PD1500A Double-Pulse Test (DPT) System uses a common test circuit for characterizing power transistors. It enables the analysis of turn-on and turn-off characteristics for supply voltages up to 1200 VDC and currents to 200 A.

The DPT system measures farther out in the I-V curve than standard IV/CV device characterization (such as the PD1000A tests with the Keysight B1505A or B1506A). For Wide Band Gap (WBG) devices, this means behavior at higher voltage and current operating points can be accurately characterized. It can also be used as a verification tool for the simulation results by showing the actual switching curves.

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WARNING

Never attempt to disable, bypass or obstruct the hood latch or any of the safety switches. High voltage and current are present when running a Double-Pulse or Reverse Recovery test.

Double-Pulse Test Overview

The PD1500A Double-Pulse Test (DPT) system consists of multiple instruments including the Keysight DSOS104A Oscilloscope, 33512B Waveform Generator, a high voltage power supply, custom test fixture, etc. All instruments are integrated into a test system and controlled from the PD1500A Control Software. Both switching characterization (including reverse recovery) and derivation of high power IV curves necessary for characterization are supported.

Figure 1shows a simplified schematic for the DPT tester. Two power transistors are configured in a totem-pole configuration (also called a “half-bridge”). The low-side transistor is the actual device under test or DUT. For DPT operation the body-diode of the high-side transistor is mandatory.

Calibration for the DPT system is done through software using tools provided as part of the system. Each individual Keysight test instrument in the PD1500A must be calibrated annually at a Keysight Service Center. Similarly, the coaxial Shunt must be characterized annually.

During the DPT test, the four primary quantities of interest are the Drain-Source Voltage (V_{DS}), the Drain Current (I_D), the Gate-Source Voltage (V_{GS}) and the Gate Current (I_G). It is very difficult to measure the Drain current. Therefore, the Source current is measured instead. In the DPT system this is done by integrating a 10 mΩ or optional 100 mΩ Coaxial Shunt Resistor between the DUT transistor source lead and V-. The voltage across this shunt resistor becomes the measure for the current.

For FET devices, measurements are defined according to IEC 60747-8
For IGBT devices, measurements are defined according to IEC 60747-9

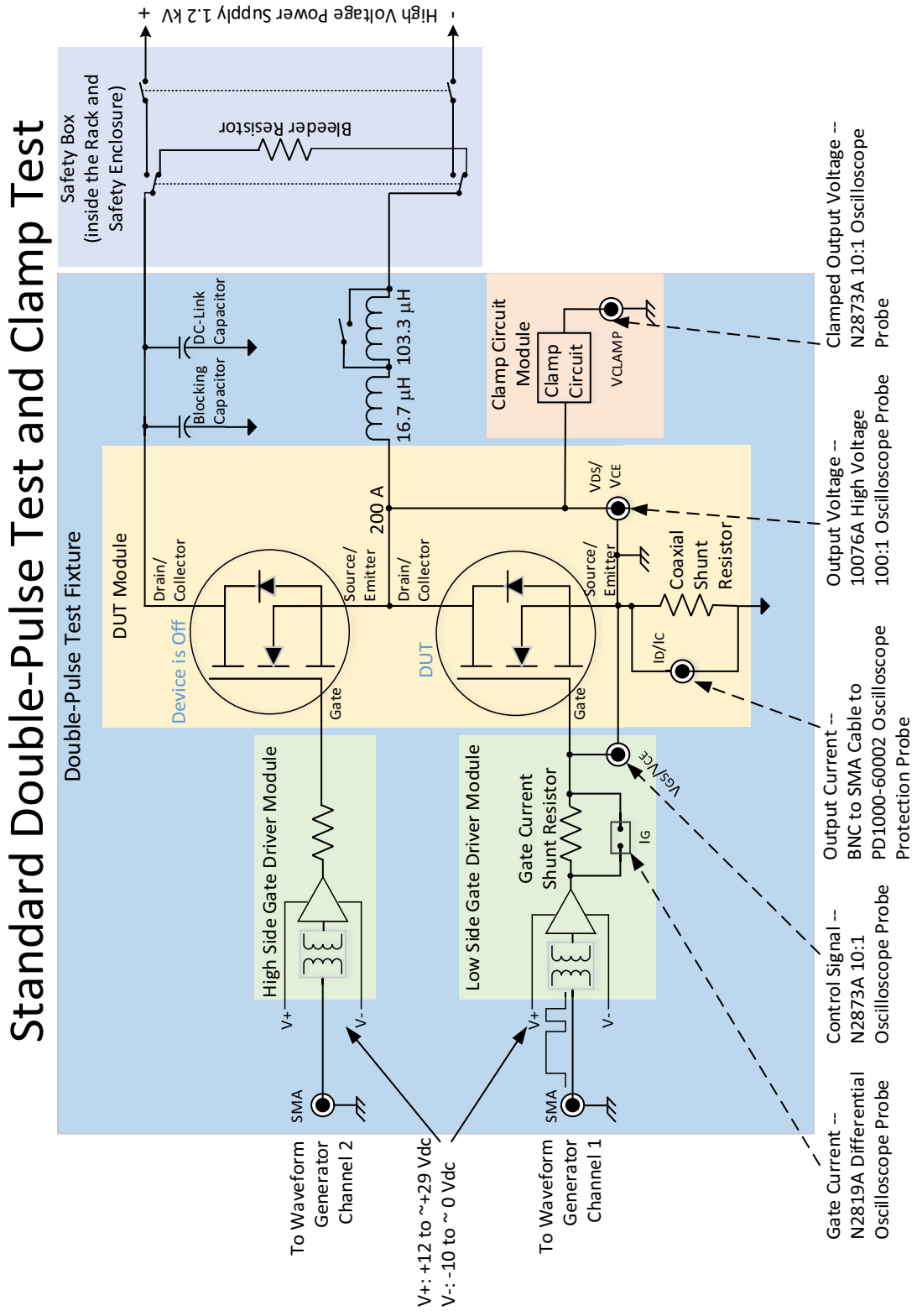

Figure 1 Simplified DPT Test Circuit

Test Equipment and Accessories Used in the PD1500A

The PD1500A Double-Pulse Test Solution includes several test instruments. These test instruments should have been installed by a Keysight-trained Application Engineer.

For actual testing of Si/SiC devices, you need the following:

- PD1500A Test Rack and Safety Enclosure with installed test equipment
- PD1000-68701 DPT Test Fixture
- Optional device test modules:
  - -- PD1000-60901 DUT module for TO-247-3 device package
  - -- PD1000-60902 DUT module for TO-247-4 device package
  - -- PD1000-62401 DUT module for D^2PAK7 device package
  - -- PD1000-66505 Clamp Circuit module for Si/SiC devices
  - -- Isolated Low-Side Gate Drive Modules for Si/SiC devices
    PD1000-66540 No Gate Resistor installed on module
    PD1000-66542 0 Ω Gate Resistor installed on module
    PD1000-66544 10 Ω Gate Resistor installed on module
    PD1000-66546 100 Ω Gate Resistor installed on module
  - -- Isolated High-Side Gate Drive Modules for Si/SiC devices
    PD1000-66541 No Gate Resistor installed on module
    PD1000-66543 0 Ω Gate Resistor installed on module
    PD1000-66545 10 Ω Gate Resistor installed on module
    PD1000-66547 100 Ω Gate Resistor installed on module
- Cables and Oscilloscope Probes
  - -- PD1000-61901 Characterized 10 mΩ Coaxial Shunt Resistor (an optional PD1000-61902 Characterized 100 mΩ Coaxial Shunt is available)
  - -- N2873A 10:1 Oscilloscope Probe (quantity 4 supplied with DSOS104 Oscilloscope)
  - -- 10076C 100:1 High Voltage Oscilloscope Probe
  - -- N2819A Differential Oscilloscope Probe, 10:1, 800 MHz
  - -- PD1000-60002 Oscilloscope Protection Probe
  - -- 8121-2816 BNC to SMA Cable 1 Meter (to go from Oscilloscope Protection Probe to Coaxial Shunt)

The PD1000A Control Software automates almost all of the measurement process and creates multiple device characterization or analysis files. The PD1500A Double-Pulse Test software is part of the PD1000A Control Software.

PD1500A Double-Pulse Test Documentation

Each test instrument comes complete with its own documentation. The Country-specific power cord and other cables or accessories may be discarded. All necessary power cords and cables are included in the DPT system Rack and Safety Enclosure. For detailed information about any of the test instruments, refer to the documentation provided with the instrument.

- **PD1500A Control Software Guide:** Provides detailed information to install, configure, and use the PD1000A Control Software for the PD1500A DPT system. PN: PD1500-90001
- **PD1500A Rack and Safety Enclosure Operation Guide:** Provides detailed information to operate and maintain the PD1500 Test Rack and Safety Enclosure. PN: PD1500-90003
- **PD1500A Si/SiC Test Fixture User Guide:** Provides detailed information to install and use the Double-Pulse Test Modules for testing Si/SiC devices in the DPT Test Fixture. PN: PD1500-90004
- **PD1500A System Installation Guide:** Provides detailed information for Keysight personnel to install the Double-Pulse Rack and Safety Enclosure at a customer's site. PN: PD1500-90002

Documentation and software are available at: www.keysight.com/find/PD1500A

Instrument documentation, data sheets, firmware updates, software updates, specifications, and more can be found on the product web pages listed below.

www.keysight.com/find/PD1000A (for Control Software, and PD1000A general information)

www.keysight.com/find/DSOS104A 4-Channel Oscilloscope

www.keysight.com/find/33512B Waveform Generator, 2-Ch with ARB

www.keysight.com/find/B2902A Precision Source/Measurement Unit

www.Heinzinger.com High Voltage Power Supply Model EVO

NOTE Adobe Reader is required to view PDF files. It is available free at: https://get.adobe.com/reader.

Host Computer System Requirements

Table 1 Host Controller Hardware and Software Requirements

Operating System	Requirement
OS versions:	Windows 10, 32-bit and 64-bit.
Processor Speed:	1 GHz 32-bit (x86), 1 GHz 64-bit (x64), Itanium64 not supported
Computer memory:	1 GB minimum
Available hard disk space[1]:	1.5 GB available hard disk space, includes: 1 GB available for Microsoft .NET Framework 4.5.2 100 MB for Keysight IO Libraries Suite
Video:	Screen resolution -- Full HD (1920x1080) at 100%. Support for DirectX 9 graphics with 128 MB graphics memory recommended

1. Because of the installation procedure, less memory may be required for operation than is required for installation.

System Installation and Support

The PD1500A system should be installed by a qualified Keysight Application Engineer. Contact your local Keysight Sales and Service office for information regarding the installation. Refer to the individual instrument documentation and help files provided with your system for warranty and support information. Hardware support (repairs and calibration) is provided separately for each of the individual test instruments in the system.

NOTE

In general, you should turn off the PD1500A system when it will not be used for long periods of time. This prevents a problem with the Heinzinger HV power supply. If the system has been left on and cannot communicate with the HV power supply, do the following:

1. Shut down the PD1500A DPT system.
2. Disconnect the PD1500A from the ac power socket.
3. Wait a few minutes.
4. Reconnect the PD1500A system to the ac power socket.
5. Turn on the PD1500A.

2 Software Installation

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Download PD1000A Control Software page 22

NOTE Keysight IO Libraries is required to configure and control the system test instruments from the PD1000A Control Software. It is free software and available at: www.keysight.com/find/iosuite

Install Software on Host PC

To communicate with the PD1500A test equipment, Keysight I/O Libraries Suite must be installed on your host computer. IO Libraries Suite is a collection of libraries and utilities that enable you to connect your instruments to the host computer and run programs on the computer that interact with the instruments. The IO Libraries Suite is used with all Keysight instruments

Install Keysight IO Libraries Suite on your Host PC

Download the latest version from: www.keysight.com/find/iosuite. Always install IO Libraries Suite before installing any instrument Drive or software. Use the latest version of the IO Libraries Suite.

Download PD1000A Control Software

PD1000A Control Software for PD1000 Series of Power Device Modeling and Characterization Solutions. This is the software that controls the test equipment to make the characterization measurements. The PD1000A Control Software may be downloaded from Keysight at any time. Download the software from either of the following websites: www.keysight.com/find/PD1000A or www.keysight.com/find/PD1500A.

Refer to the *PD1000A Control Software* help file for detailed information on using the PD1500A Control Software.

NOTE The PD1500A Double-Pulse Test software is part of the *PD1000A Control Software for PD1000 Series of Power Device Modeling and Characterization Solutions*. Install the PD1000A Control Software to control the PD1500A DPT hardware.

Software Licensing

Software licenses are required for the following PD1000A/PD1500A features:

License ID	Description	Notes
PD1010B	PD1000A On-State/Off-State S-Parameter Test	Replaces eh PD1010A. Not required for PD1500A Double-Pule Test.
PD1020A	Double-Pulse Test Control	A perpetual fixed license for DPT test software. This license enables the software on the host controller PC the license is originally assigned to; without a time limit. License checked when starting a Double-Pulse Test.

License ID	Description	Notes
PD1021A	Double-Pulse Test Offline Mode Also requires the *D9010BSEO* and *D9010ASIO* Infiniium Offline software to be installed and licensed.	License checked when opening the context menu in the Measurement History. If no license is present, the "Run Extractions..." in the Measurement History context menu is disabled.
PD1030A	GaN Test Features	License checked when starting a Double-Pulse Test with a GaN device selected.

NOTE

You must install the Keysight PathWave License Manager software on your host controller PC (if it was not previously installed by other Keysight software).
Keysight PathWave License Manager.

The PathWave License Manager does not use the PCSERNO host ID. You must use the "Computer Ethernet Address Host." Choose a host ID that corresponds to your PC's permanent network card. This is easiest to identify when your PC is disconnected from all other networking interfaces, e.g., docking stations for laptops, etc.

All aspects of the PD1000A Control Software can be installed and used for 30 days without a license. However, after 30 days a permanent software license is required to continue running On State/Off State S-Parameter tests and DPT tests. For software and licensing information, go to:
www.keysight/com/find/PD1500A.

3 Set-up the Double-Pulse Test for Si/SiC Devices

In this Chapter:

Test Circuit Diagrams page 25
Test Fixture Modules for Si/SiC Devices page 28
General Double-Pulse Test Setup page 29
Connect Oscilloscope Probes to Oscilloscope page 30
Connect Probes to the Double-Pulse Test Modules page 32
Using the N2787A 3D Probe Positioner page 34
Connect the 10076C High Voltage Probe page 35

For detailed information on set up and using the Double-Pulse Test Solution Si/SiC Test Fixture, refer to the *PD1500A Si/SiC Test Fixture Installation and Use Guide*.

For detailed information on using the PD1500A Double-Pulse Test Rack and Safety Enclosure, refer to the *PD1500A Test Rack and Safety Enclosure Operation Guide*.

Test Circuit Diagrams

The following simplified schematics illustrate the overall PD1500A Double-Pulse Test (DPT) test procedure and the oscilloscope probe connection points. The names used on the oscilloscope connection points match the names used in the *DPT Control Software Hardware Configuration* setup dialog.

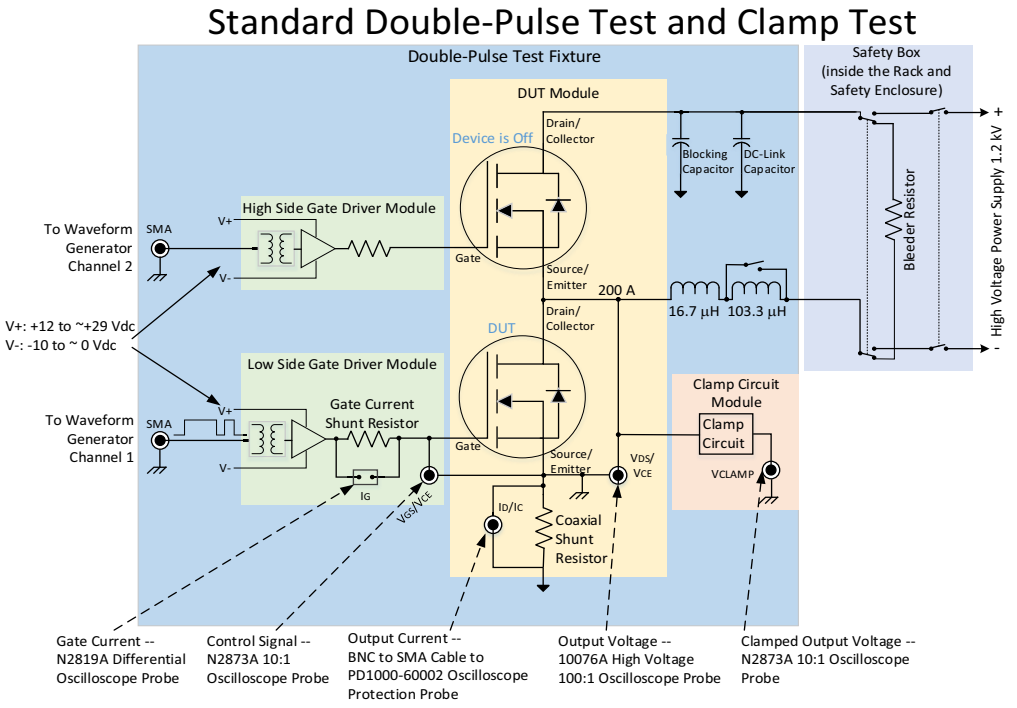


Figure 2 Double-Pulse Test Switching Characteristics Simplified Circuit Diagram

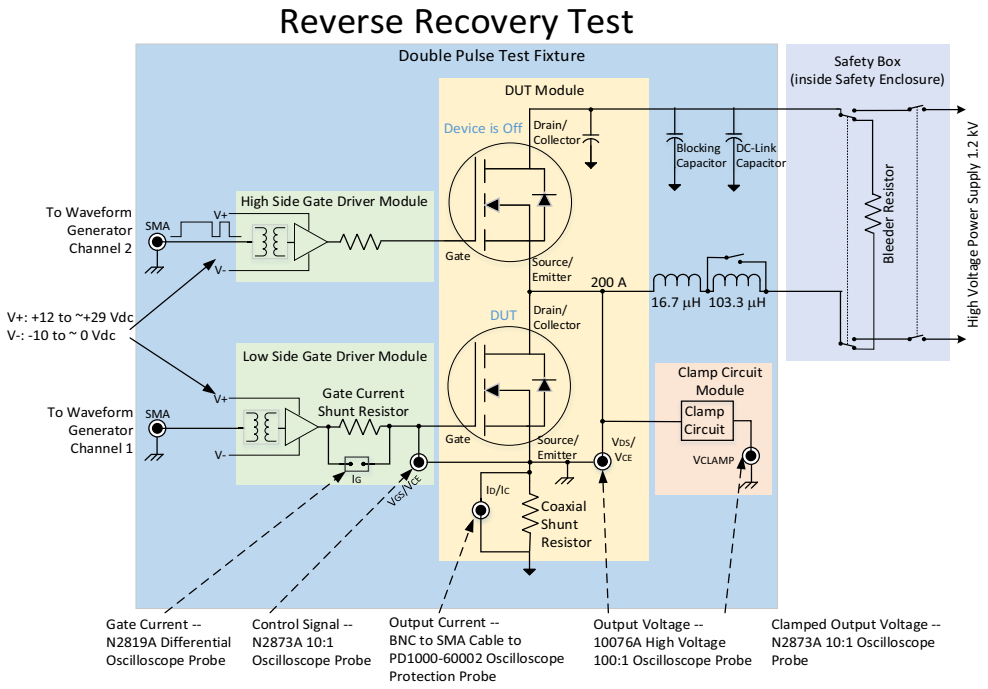


Figure 3 Double-Pulse Test Diode Reverse Recovery Test Simplified Circuit Diagram

The internal inductor is selected automatically based on device test current and voltage specified for the test. If the specified Drain Source current (I_{DS}) is less than (0.06125 x Applied Voltage) then the inductance is 16.7 μH + 103.3 μH = 120 μH. If the current is greater than (0.06125 x Applied Voltage) then the inductance is 16.7 μH.

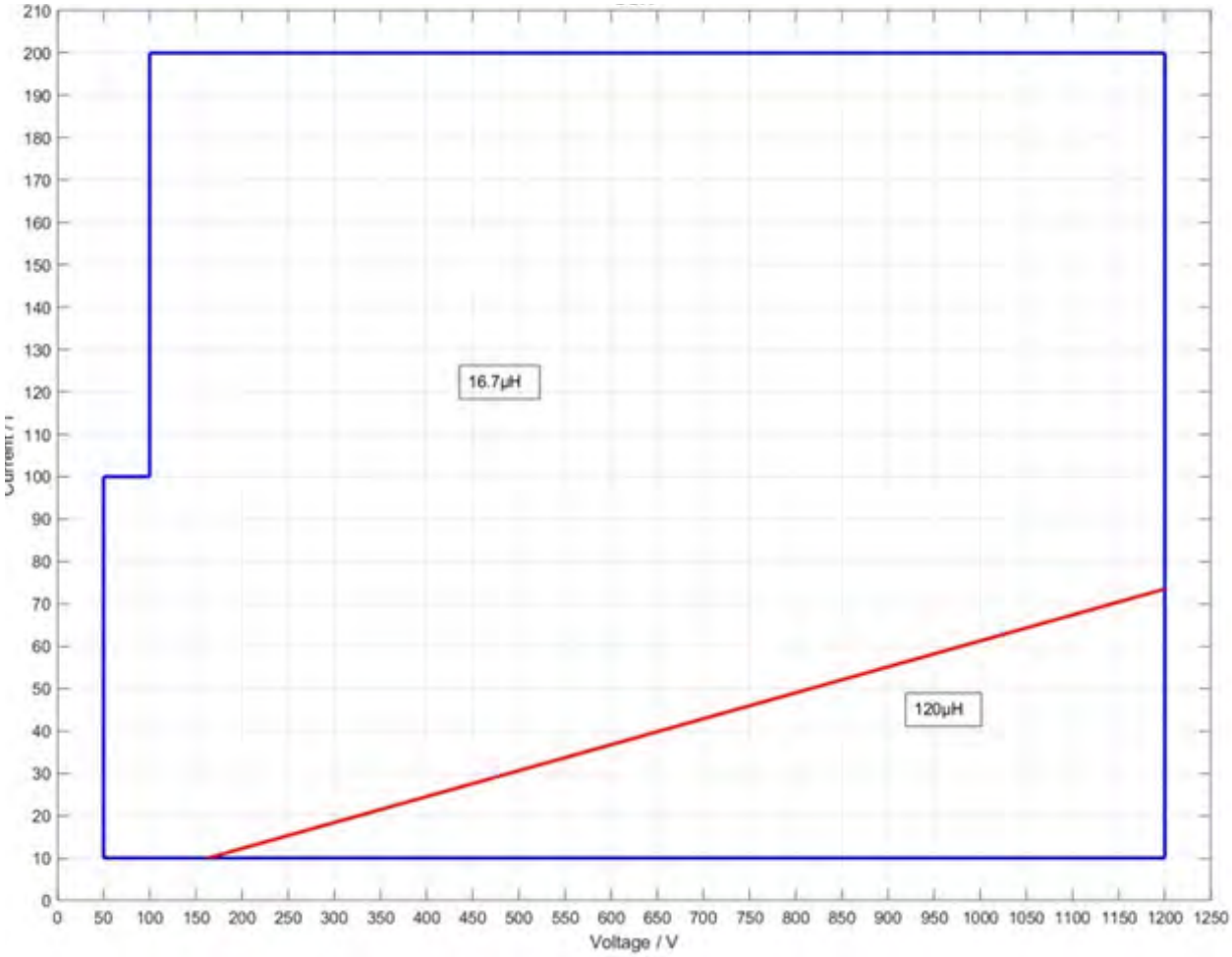


Figure 4 PD1500A Double-Pulse Test Inductor Operating Range

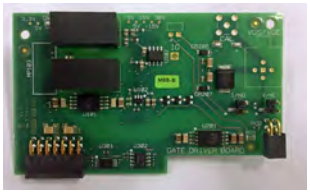
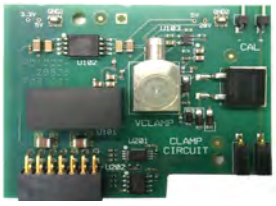
When charging the inductor during the first pulse, the voltage across the DC-Link capacitor drops slightly. This is known as the “Droop.” For currents up to 100 A, there is enough energy stored in the capacitor so that the voltage drops no more than 5%. For currents up to 200 A the drop may be as large as 10%.

There are four capacitor banks:

800 μF for 50 to 200 Vdc tests,
144 μF for 200 t 400 Vdc
36 μF for 400 to 880 Vdc
12 μF for 880 to 1200 Vdc

Test Fixture Modules for Si/SiC Devices

The following table lists optional modules for the PD1000-68701 Test Fixture:

Description	Photos below are representative, what you receive may be slightly different.
Isolated Low-Side Gate Drive Modules PD1000-66540 No Gate Resistor installed on module[1] PD1000-66542 0 Ω (2x 0 Ω) Gate Resistor PD1000-66544 10 Ω (2x 4.99 Ω) Gate Resistor PD1000-66546 100 Ω (2x 50 Ω) Gate Resistor	
Isolated High-Side Gate Drive Modules PD1000-66541 No Gate Resistor installed on module[1] PD1000-66543 0 Ω (2x 0 Ω) Gate Resistor PD1000-66545 10 Ω (2x 4.99 Ω) Gate Resistor PD1000-66547 100 Ω (2x 50 Ω) Gate Resistor	
Clamp Module PD1000-66505	
DUT Module for TO-247 3-pin devices PD1000-60901 DUT Module for TO-247 4-pin devices PD1000-60902	
DUT Module for D^{2}PAK 7-pin (TO-263) devices PD1000-62401	
PD1000-61901 mΩ Coaxial Shunt Resistor Optional PD1000-61902 100 mΩ Coaxial Shunt Resistor to be installed on either the TO-247 or the D^{2}PAK DUT module.	
PD1000-62001 Device heater with integrated type K thermocouple, device clamp	

1 See Si/SiC Test Fixture Guide for custom gate resistor installation instructions. After installation, module requires calibration.

General Double-Pulse Test Setup

Click on the following screen for a short video showing how to install the DPT Test Modules. Note, after the movie starts, right click and select **Full Screen Multimedia** to enlarge the video.

Connect Oscilloscope Probes to Oscilloscope

1 Attach the probe connector to the desired oscilloscope channel.

2 Connect the probe to the appropriate DPT Test Module.

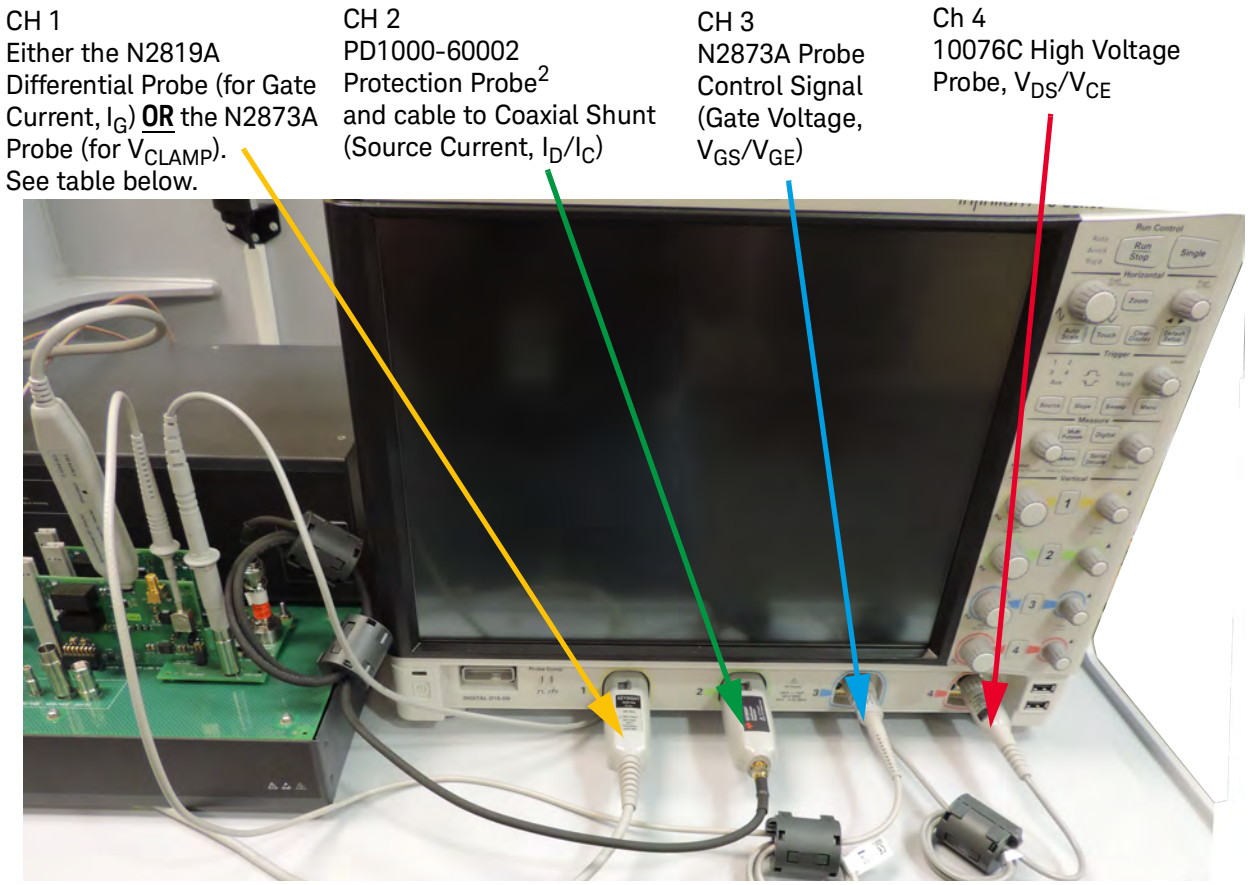


Figure 5 Oscilloscope Probe Connections

Oscilloscope Channel	Color	Oscilloscope Probe	Used to Measure	Connects to Test Module
1[1]	Yellow	N2819A Differential Probe	Gate Current, I_G	Gate Driver Module
		Standard N2873A Probe	Clamp voltage, V_{CLAMP}	Clamp Module
2	Green	PD1000-60002 Protection Probe and cable to Coaxial Shunt[2]	Source Current, I_D/I_C	Coaxial Shunt on DUT Module
3	Blue	Standard N2873A Probe	Gate Voltage, V_{GS}/V_{GE}	Gate Driver Module
4	Red	High Voltage 10076C Probe	Drain/Collector Voltage, V_{DS}/V_{CE}	DUT Module

1 Only one of these two probes should be used in a DPT test. The N2819A Differential Probe is used when measuring Gate Current and Gate Charge. The standard N2873A probe is used with the Clamp Test Module to measure V_{CLAMP}.

2 Use the 0.56 N-m (5 lb-in) 5/16 in. SMA Break-over torque wrench (provided with the PD1500A system) to tighten the SMA cable connector to the PD1000-60002 Protection Probe. Failure to do so might cause extensive ringing in the DPT measurements. See appendix for details.

NOTE

The oscilloscope channels and colors shown above are recommended. You may choose different channels. All examples and screen captures shown in the DPT documentation use this configuration. The colors on the PD1000A Control Software screen match the DSOS104 Oscilloscope probe channel number colors: i.e., Channel 1/I_G or V_{CLAMP} is yellow, Channel 2/I_{DS} is green, Channel 3/V_{GS} is blue, and Channel 4/V_{DS} is red.

CAUTION

Do not exceed the maximum input voltage rating on the oscilloscope.

The maximum input voltage for the 50 Ω input impedance setting is ±5 V.

The maximum input voltage for the 1 MΩ input impedance setting is 30 V_{rms} or ±40 V_{max} (DC + V_{peak}).

Probing technology allows for testing of higher voltages; the N2873A 10:1 probe supports 300 V_{rms} or ±400 V_{max} (DC + V_{peak}). No transient over voltage allowed.

CAUTION

When measuring voltage over 30 V, use a 10:1 probe.

CAUTION

When a probe, adapter, or cable is attached to the oscilloscope, the oscilloscope's channel input circuits can be damaged by ESD. Avoid applying static discharges to anything connected to the oscilloscope. Ensure the oscilloscope is properly earth-grounded to prevent buildup of static charge. Wear a wrist strap or heel strap.

CAUTION

Loose cables can hold electrostatic charges. The free end of a cable touching a charged surface can cause oscilloscope input damage. Before connecting any cable to an oscilloscope input, short the center and outer conductors of the cable together to ground momentarily. Alternately, connect to a 50 Ω termination adapter to discharge the cables.

CAUTION

All Oscilloscope probes (except the N2819A Differential Probe) must have the common mode chokes installed on the probe cables.

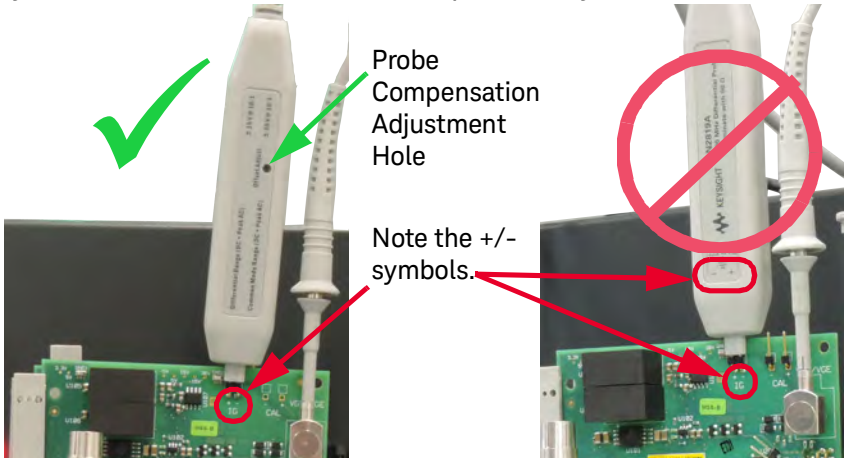
Connect Probes to the Double-Pulse Test Modules

Refer to Figure 6 below. Oscilloscope probes connect to the Test Fixture Modules as follows:

- The DUT Module uses the following oscilloscope probes:
  - -- BNC to SMA cable from the Coaxial Shunt Resistor (**I_D/I_C**) to the PD1000-60002 Oscilloscope Protection Probe.
  - -- 10076A High Voltage, 100:1 Probe to the **V_{DS}/V_{CE}** probe socket.
- The Low Side Gate Driver Module has two oscilloscope probe connections (see Figure 6 below):
  - -- N2873A 10:1 Probe connects to the **V_{GS}/V_{CE}** probe socket
  - -- N2819A Differential Probe connects to the **I_G** probe socket terminals
- Optionally, if the Clamp Circuit Test Module is used:
  - -- Do not install the N2819A Differential Probe on the **I_G** probe socket terminals of the Low Side Gate Driver Module.
  - -- Attach N2873A 10:1 probe to the V_{CLAMP} socket on the Clamp Module.

CAUTION

IMPORTANT: When installing the N2819A Differential oscilloscope probe on the I_G pins on the Low Side Gate Driver Module, the Probe Compensation Adjustment hole **must** face outward. The Keysight logo must face toward the module. Verify with the +/- symbols on the module and on the probe body.



NOTE

If you use the Clamp Circuit Module, do not install the N2819A Differential Probe. Instead, install one N2873A 10:1 Oscilloscope Probe connected to the Clamp Test Module (**V_{CLAMP}**) probe socket.

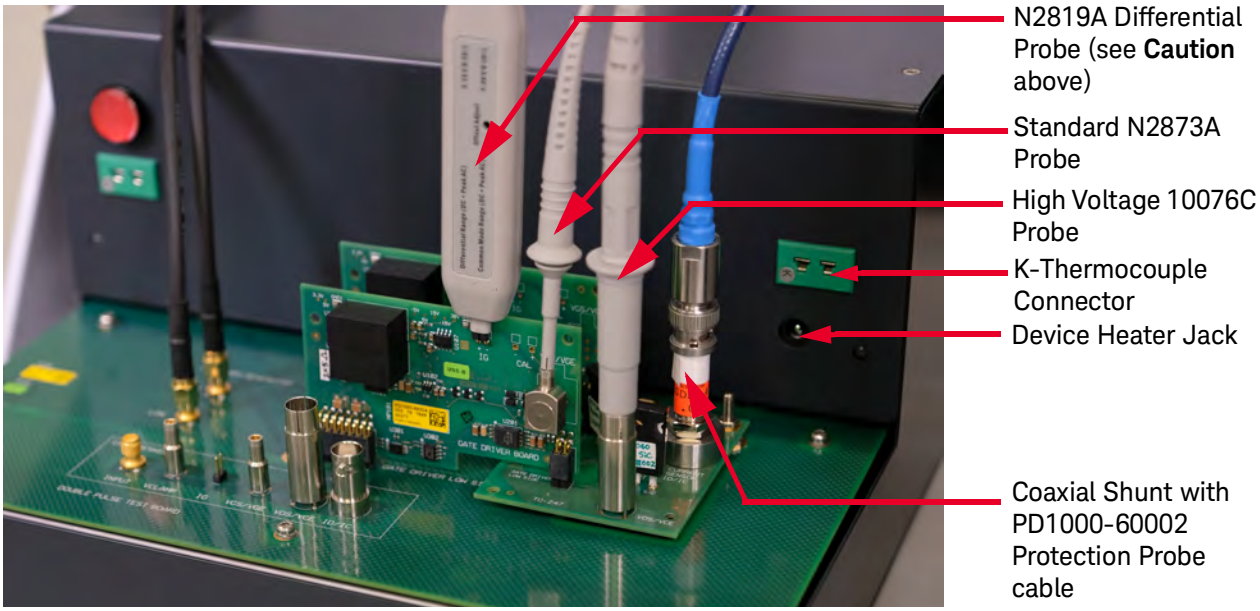


Figure 6 Connecting Oscilloscope Probes to the Test Modules (Clamp Circuit Module not shown)

Using the N2787A 3D Probe Positioner

The N2787A Probe Positioner was included to hold the N2819A Differential Probe in place.

1. Place the positioner base of the N2787A on top of the Test Fixture.
2. Tighten the jaws around the N2819A Differential Probe.
3. Move the probe into place on the I_G pins of the Gate Drive Module.
4. Tighten the Central Positioning Knob of the Probe Positioner.

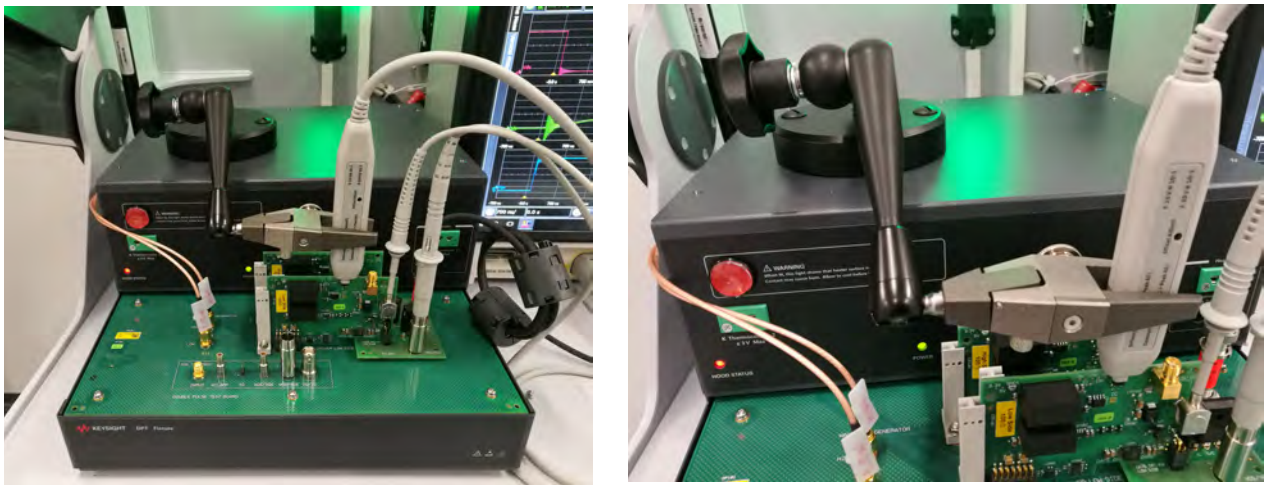


Figure 7 Using the N2787A 3D Probe Positioner

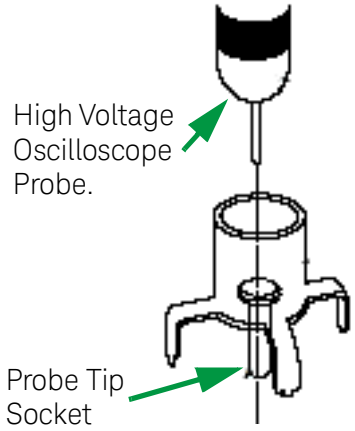
Connect the 10076C High Voltage Probe

Take extra care when inserting the 10076C High Voltage Probe in the probe socket on the DUT module or in the Deskew socket. While it is not difficult, you must ensure the probe tip is fully inserted in the socket center pin.

CAUTION

When inserting the 10076C High Voltage probe into the socket on the DUT module or the Deskew socket, make certain that the probe tip goes into the socket center pin. The shoulder of the probe should rest against the top of the socket.

The probe tip must be inserted all the way into the tip socket.



4 Double-Pulse Test Device Characterization Tests

In this Chapter:

Testing GaN Devices page 37
Run the PD1000A Control Software page 38
Configure Common Settings page 38
Hardware Configuration: Hardware Tab page 40
Hardware Configuration: Oscilloscope Tab page 46
Hardware Configuration: Extractions Tab page 47
Hardware Configuration: Calibration Tab page 48
Measurement Preparation – Calibration & Compensation page 49
Oscilloscope Probe Compensation page 49
DPT System Calibration page 49
Oscilloscope Probe Deskew page 49
Coaxial Current Shunt De-embedding page 49
Standard Double-Pulse Characterization Test page 50
Clamped Double-Pulse Test page 51
DPT Reverse Recovery Test page 53
Set Double-Pulse Test Parameters page 54
Run the Characterization Test page 63
Results Tab page 65
Measurement History Tab page 66
Frequently Asked Questions page 70

Testing GaN Devices

This chapter is primarily concerned with testing Si or SiC devices using the standard PD1500A Si/SiC device Test Fixture and test modules. If you will be testing GaN devices, either HEMT, GIT or Cascode, contact your local Keysight Application Engineer for help in designing a customized test board for the PD1500A Test Solution and user documentation.

NOTE **A software license is required to use the PD1000A software to test GaN devices on the PD1500A Test Solution.**

Run the PD1000A Control Software

NOTE For specified system accuracy, allow all of the instruments in the Double-Pulse Test Rack and Safety Enclosure to warm up for a minimum of one hour (60 minutes) before running any DPT tests.

1 From the Host PC's Windows **Start** button, select:
Keysight > Keysight PD1000A Control.

2 In the PD1000A Control Software, select **Double-Pulse Measurement Control**.

NOTE **IMPORTANT**. VISA addresses for all of the Double-Pulse Test test instruments (DSOS104 Oscilloscope, Waveform Generator, Test Fixture, etc.) must be established before configuring and running the DPT tests.

Configure Common Settings

Click on the **Settings** icon at the top of the screen.

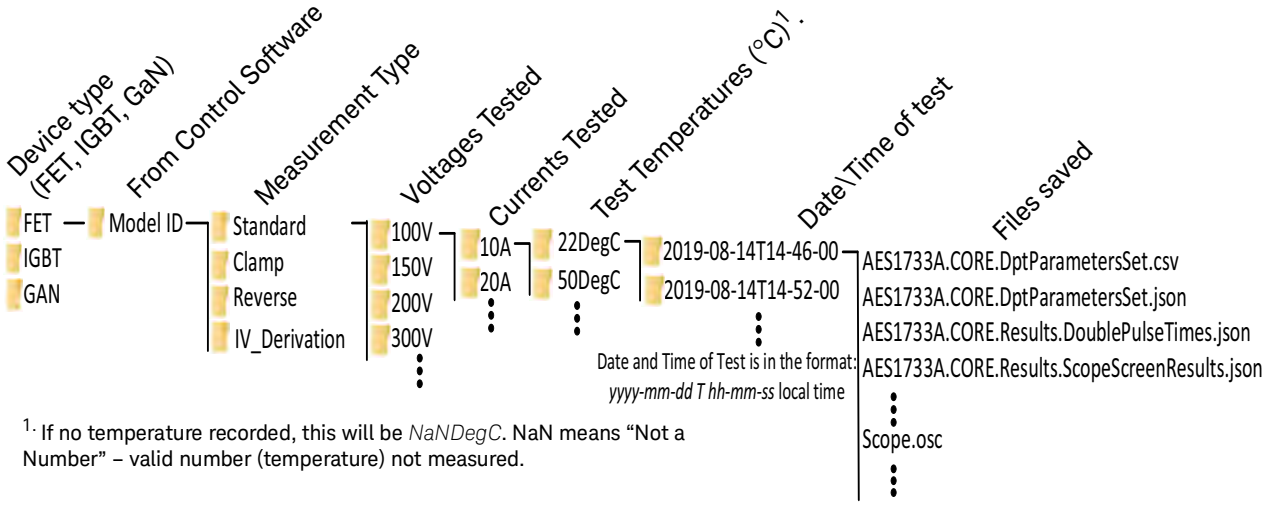
Global Settings This opens the Global Settings dialog.

- **Debug Mode:** Check this box to cause the system to send a SCPI *SYST:ERR?* command after each command to identify any errors in the system measurements. Use the **IO Monitor** utility in the IO Libraries Suite to monitor communication between the host PC and the DPT system test instruments and to view the error messages. Uncheck the box for best speed.
- **Output Directory:** Enter the complete file path for where you want to save the measured data. For example:
  C:\Users\PD1500A\DPT_Tests\....

  Characterization data is saved with the following folder structure:

Device > Model ID > Meas. Type > Voltages Tested > Currents Tested > Temperatures Tested > Date\Time > Test Data Files

For example:



Hardware Configuration for Double-Pulse Measurement Control: Allows you to specify instrument connections, Probe Setup, Shunt settings and more. See "Hardware Configuration: Hardware Tab" on page 40 for detailed information.This menu has three tabs:

- **Hardware:** See "Hardware Configuration: Hardware Tab" on page 40.
- **Oscilloscope:** See "Hardware Configuration: Oscilloscope Tab" on page 46.
- **Extractions:** See "Hardware Configuration: Extractions Tab" on page 47
- **Calibration:** See "Hardware Configuration: Calibration Tab" on page 48.

Load Settings from File: Opens a Windows Explorer dialog to the folder specified in **Global Settings > Output** Directory. This allows you to reload saved DPT test settings into the Control Software.

Save Settings to File: Opens a Windows Explorer dialog to the folder specified in **Global Settings > Output** Directory. Settings files are saved as .kts files.

Calibration & Compensation: Runs the complete DPT system calibration procedure; including oscilloscope probe compensation. Refer to "Double-Pulse Test Solution Calibration for Si/SiC Modules," starting on page 79 or the *PD1000A Control Software Help File* for additional information. Follow all instructions.

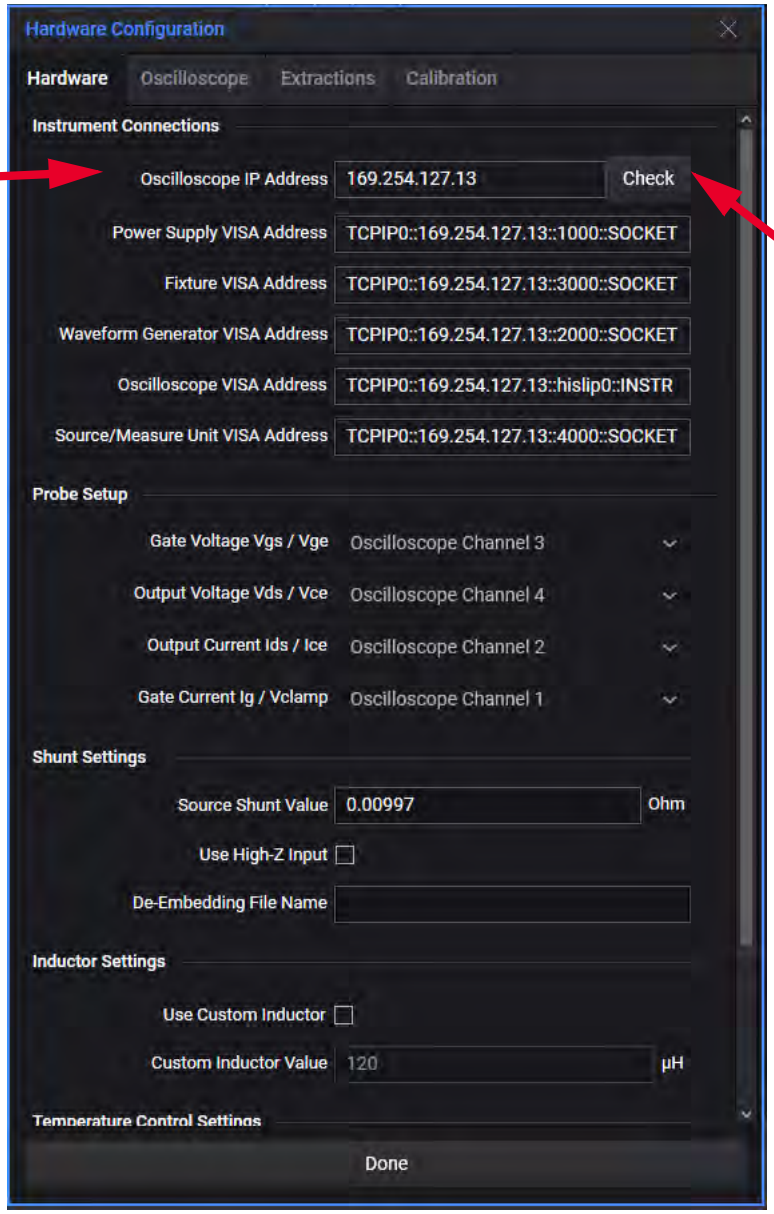
Show Oscilloscope Screen: This displays the oscilloscope display from the last measurement. Click the image to open a printer-friendly image.

About: Displays a screen showing the Control Software version.

Hardware Configuration: Hardware Tab

Selecting the **Instrument Configuration Hardware** tab opens the following dialog.

1. Enter the oscilloscope's IP Address.



2. Click the **Check** Button to verify communication with test instruments. See **NOTE** on next page

Figure 8 Double-Pulse Test Hardware Configuration Screen

NOTE

IMPORTANT: If you are using a laptop computer, turn the Wireless Network Connection off in the laptop before connecting to the PD1500A system.

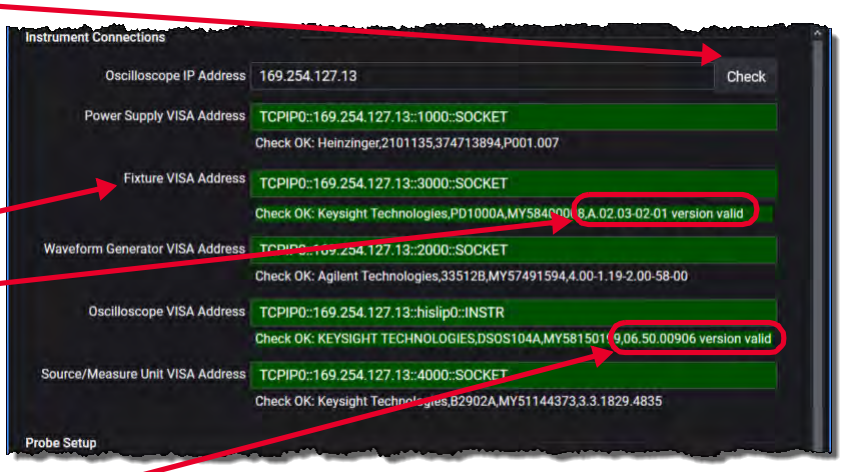
NOTE

Click the **Check** button to verify that the Control software can communicate with all of the DPT system instruments. It sends a SCPI **IDN?* command to each instrument and expects the correct identification string from each instrument. After a few moments, all of the addresses should update and turn green:

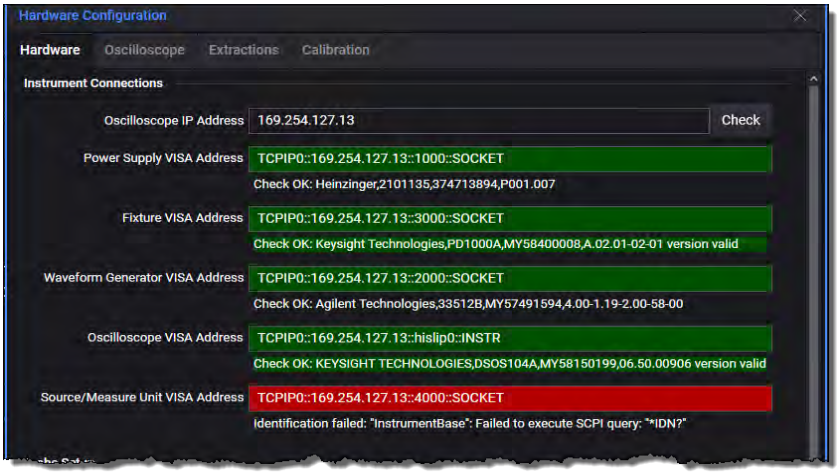
Check Button used to verify communication with test instruments.

Fixture VISA Address shows the firmware version of the PD1500A Test Fixture. In this example, it is A.02.03-02-01.

Oscilloscope Firmware Version. See Note on next page.



If any or all of them are red, it indicates a failure to communicate with that instrument or an invalid firmware version.



IMPORTANT: If you are using a laptop computer, turn the Wireless Network Connection off in the laptop before connecting to the PD1500A system.

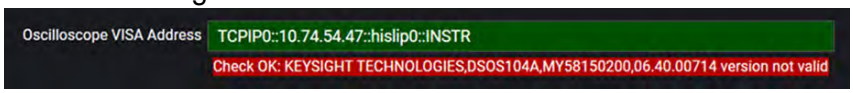
Instrument Connections

Instrument VISA addresses should be automatically populated during the initial PD1500A Installation.

- **Oscilloscope IP Address:** Enter the IP address of the DSOS Oscilloscope. This was initially entered by the Keysight Application Engineer when the PD1500A system was installed. If the system is moved or the IP address changes, you must enter the new IP Address:
  - **a** On the DSOS 104 Oscilloscope, touch the **Utilities** soft key at the top of the screen.
  - **b** Touch **Remote**.
  - **c** Locate the **Web Interface** field. Do **NOT** use the 192.168.25.2 address. Use the other address as the **Oscilloscope IP Address**.
- **Power Supply VISA Address:** Shows the VISA address of the Henizinger EVO Power supply.
- **Fixture VISA Address:** Shows the VISA address of the DPT Test Fixture. This address is fixed and cannot be changed. After clicking the **Check** button, the Test Fixture VISA Address shows the firmware version of the PD1500A Test Fixture.
- **Waveform Generator VISA Address:** Shows the VISA address of the 33512 Waveform Generator.
- **Oscilloscope VISA Address:** Shows the VISA address of the DSOS104A Oscilloscope.

NOTE

DSOS Oscilloscope Software Version. If the **Check** returns a note such as the following:



you may need to upgrade your oscilloscope software. Do not use version 06.60.00403. Version 06.50.xxxxx and all previous versions have been tested and work without problems.

- **Source/Measure Unit VISA Address:** Shows the VISA Address of the B2902A Source/Measure Unit. The B2902A is used for system calibration only. Double-Pulse tests will run without error if this address field is red.

Probe Setup

Refer to "Connect Oscilloscope Probes to Oscilloscope" on page 30 for an explanation of the various probe locations.

- **Gate Voltage V_{GS}/V_{GE}:** Specify oscilloscope channel (default: Channel 3) for the Control Signal measurement. This is the Gate Voltage measured on the Low-Side Gate Drive Module by the N2873A 10:1 Oscilloscope Probe.
- **Output Voltage V_{DS}/V_{CE}:** Specify oscilloscope channel (default: Channel 4) for the Output Voltage measurement. This is the Source Voltage measured on the DUT Module with the 10076C 100:1 High Voltage Probe.
- **Output Current I_{DS}/I_{CE}:** Specify oscilloscope channel (default: Channel 2) for Output Current measurement. This is the current measured across the Coaxial Shunt Resistor with the PD1000-60002 Oscilloscope Probe.
- **Gate Current I_G/V_{CLAMP}:** Specify oscilloscope channel (default: Channel 1) for Gate current measurement I_G or the V_{CLAMP} measurement. I_G is the current measured across the Gate Current Shunt Resistor (Low-Side Gate Drive Module) with the N2819A Differential Probe[a]. V_{CLAMP} is the Clamped Output Voltage measured with an N2873A 10:1 Oscilloscope Probe. **NOTE:** V_{CLAMP} tests require use of the Clamp Circuit Module (PD1000-66505).

NOTE For the Clamp DPT test, use the Clamp Circuit Module and do not install the N2819A Differential Probe. Install one N2873A 10:1 Oscilloscope Probe (Channel 1) that connects to the Clamp Circuit Module (V_{CLAMP}) probe socket. Do not exceed 400 Volts V_{DS} or V_{CE}.

Shunt Settings

- **Source Shunt Value:** Enter value, in Ohms, of the Coaxial Shunt Resistor. This value is printed on the shunt label. The default/nominal value for the Keysight PD1000-61901 Shunt is 0.01 Ω.
- **Use High-Z Input** (checkbox): Leave the box unchecked when using the Coaxial Current Shunt with the PD1000-60002 Oscilloscope Protection Probe. Check the box if you are not using the PD1000-60002 Oscilloscope Protection Probe and the top of the Coaxial Shunt connects directly to the oscilloscope (High Z input).

a Due to limitations of the N2819A Differential Probe, occasional dropouts may lead to incorrect results in I_G current measurements. This can affect Gate Charge measurements. These dropouts occur only during measurements of very high current changes in the PD1500A system; for example when a small value inductor large currents and a very fast DUT.

- **De-embedding File Name:** Enter the de-embedding file name. For example, *MY584xxxx.tf2* (where "xxxx" is the shunt's serial number). The file should be installed in the DSOS104A oscilloscope in the folder: *C:\Users\Public\Documents\Infiniium\Filters*.

NOTE On the DSOS104 Oscilloscope, the file path will show as: *C:\Users\Public\Public Documents\Infiniium\Filters.* However, this is an alias path. Use the path: *C:\Users\Public\Documents\Infiniium\Filters* in the Shunt Settings De-embedding File path in the Control Software.

Inductor Settings

With software version 2020.820 (and later) you have the option to use the standard, internal inductor (internal to the PD1500A Test Fixture) or an external, custom inductor. To use the internal inductor, leave the checkbox unchecked. If you choose to use an external inductor, check the **Use Custom Inductor** checkbox and enter the value of the inductor, in microHenrys (μH), in the **Custom Inductor Value** field. Recommended range of inductors is from 16.7 μH to 120 μH.

Refer to *PD1500A Using an External Inductor (PD1500-90006)* for detailed information about selecting or constructing, and installing a custom, external inductor on the PD1500A Test Fixture DUT module.

CAUTION **When using an external inductor, the internal inductor must be disconnected. Automatic switching between standard double-pulse test and reverse recovery test is not be possible with an external inductor.**

Temperature Control Settings

See Appendix A for a detailed description about using the device heater with the Double-Pulse Test Control Software.

- **Tolerance:** Specify a range (±) around the specified temperature for triggering the DPT measurement. For example, if you specify making a DPT measurement at 50 °C and a 1 °C Tolerance, then the measurement is triggered somewhere between 49 °C and 51 °C.
- **Settling Time:** Specify a time period (in seconds) to wait after the DUT reaches the specified temperature (withing the specified range) before triggering the DPT measurement.
- **Temperature Control Timeout:** Specify the maximum time period (in seconds) to wait for the device to reach the specified temperature before triggering the measurement. If the device does not reach the specified temperature within this time period, the DPT test aborts.

For example, to go from ambient temperature (~25 °C) to 100 °C with a 2 °C Tolerance may take up to 60 seconds.To go from Ambient to 100 °C with a 1 °C Tolerance may take up to 90 seconds.

For more information on using the device heater, see “Using the Device Heater” on page 97.

Hardware Configuration: Oscilloscope Tab

Selecting the **Instrument Configuration: Oscilloscope** tab opens the following dialog. This dialog can be used to configure the double-pulse test oscilloscope before running the DPT test.

NOTE Normally, the default settings are best. For detailed explanations of this tab and the various fields, refer to the PD1000A Help file; see *Hardware Configuration: Oscilloscope Tab* and *Parameter Extraction Techniques*.

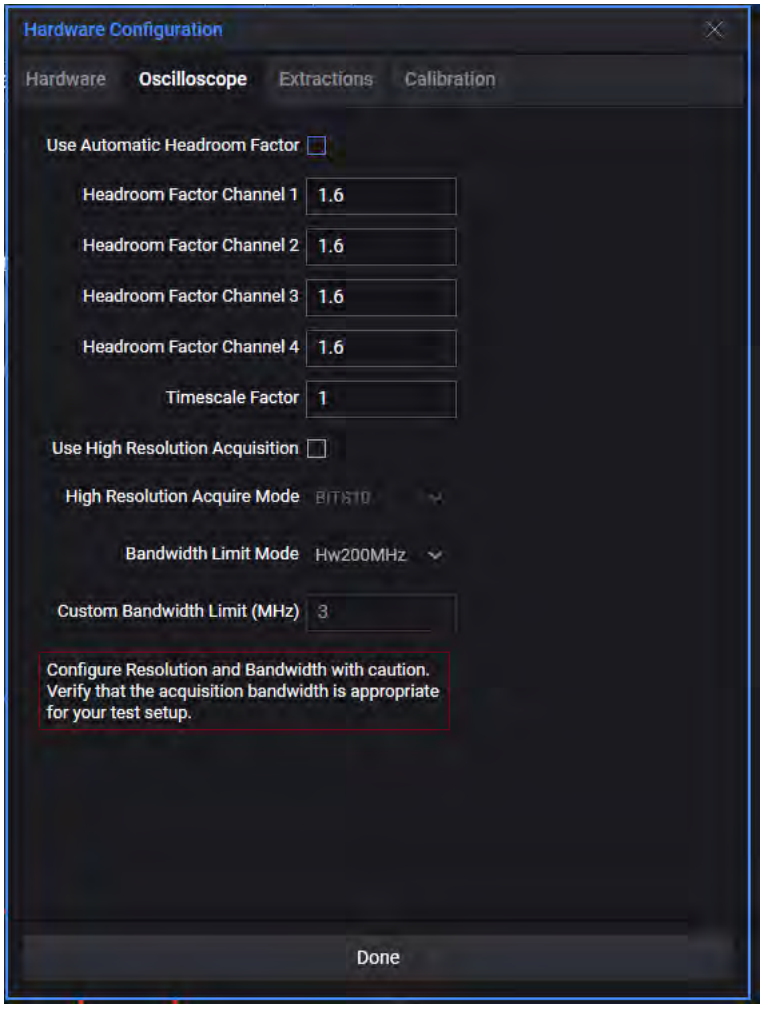


Figure 9 Hardware Configuration Oscilloscope Tab Screen

NOTE For complete description of each field, refer to the PD1000A Help file; see *Hardware Configuration: Oscilloscope Tab.*

Hardware Configuration: Extractions Tab

The top part of the **Hardware Configuration > Extractions** tab, Parameter Extraction Settings, refers only to testing IGBT devices, They have no effect on FET or GaN device testing. The bottom half, IV Derivation Settings refer to settings in the oscilloscope for FET devices.

Vcc Turn On Level and Icm Turn Off Level are used to calculate the Total Turn On Switching Energy and the Total Turn Off Switching Energy. Typically these levels are at 2% of V_{CE} and I_{CE}, but sometimes the curve of V_{CE} / I_{CE} doesn't goes down to 2%.

The I_D Turn Off Level for Switching Locus is used to calculate the Tail Time and this Tail Time is used for Switching Locus of Turn Off.

Current Smoothing Number and Integration End Time Threshold are used in the Reverse Recovery test.

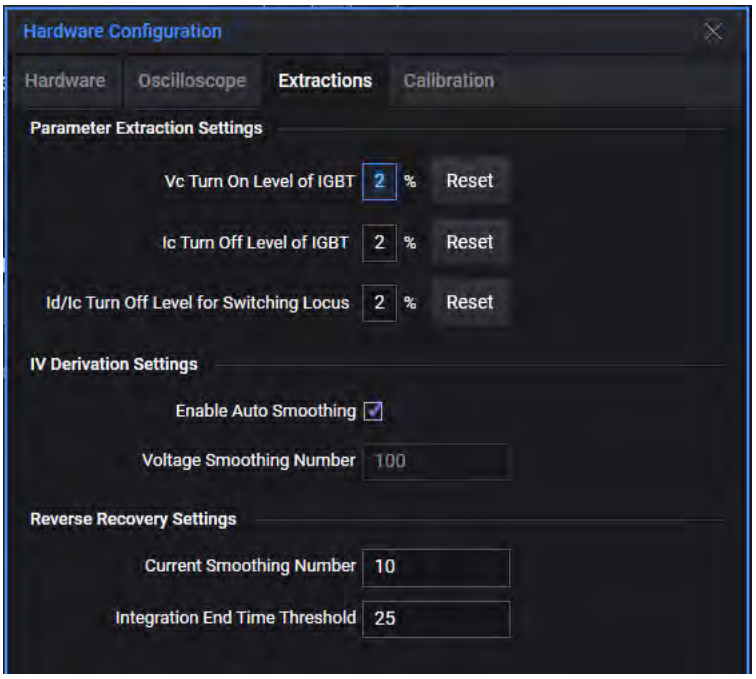


Figure 10 Hardware Configuration Extractions Tab Screen

NOTE For complete description of each field, refer to the PD1000A Help file; see *Hardware Configuration: Extractions Tab*

Hardware Configuration: Calibration Tab

NOTE Click the **Read Calibration** button at the bottom of the screen to read the stored calibration values.

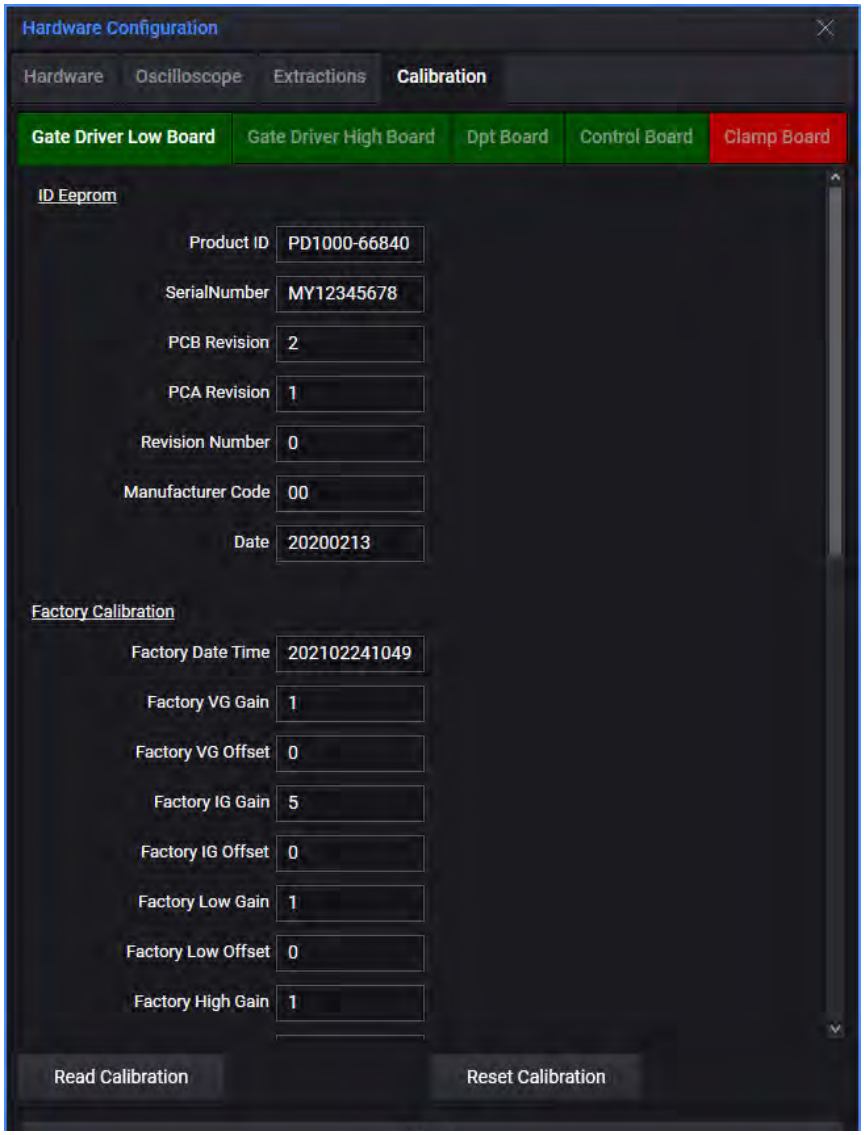


Figure 11 Hardware Configuration Calibration Tab Screen Showing Gate Drive Low Board. The Clamp Board is not installed.

NOTE For complete descriptions of each subtab and fields, refer to the PD1000A Help file; see *Hardware Configuration: Calibration Tab*

Measurement Preparation – Calibration & Compensation

Oscilloscope probe compensation, Deskew, and De-embedding are steps that the Double-Pulse Test (DPT) system operator should perform periodically to achieve the most accurate measurements. System Calibration is a formal calibration procedure. For accurate DPT measurements, it is very important to calibrate the DPT system to insure that all delays are equivalent. Refer to "Double-Pulse Test Solution Calibration for Si/SiC Modules" on page 79 for detailed information.

NOTE **It is not necessary to set the oscilloscope probe compensation, or run Deskew before each DPT test. However, a complete calibration should be performed when the ambient temperature changes more than ±5 °C or when any change is made to the DPT system.**

Oscilloscope Probe Compensation

Prior to running Deskew, system calibration, or DPT tests, the oscilloscope probes must be adjusted for low frequency compensation. The 10076C and N2873A passive probes have built-in compensation RC divider networks. The N2819A Active Differential Probe also requires offset compensation.

DPT System Calibration

System calibration is a formal calibration of the DPT system. For detailed instructions, refer to the *PD1500A online help file*.

Oscilloscope Probe Deskew

Deskew is a process of applying a square wave from the Waveform Generator to all four channels of the oscilloscope simultaneously. The DPT Control Software measures the time difference between channels relative to Channel 1 and sends a command to the oscilloscope to automatically calculate and set the channel-to-channel skew factor. Deskew should be performed anytime the ambient temperature changes ±5 °C.

Coaxial Current Shunt De-embedding

The Coaxial Shunt should be characterized annually and its transfer file (.t2f) installed in the DSOS104 Oscilloscope. This provides frequency compensation correction for the shunt. Coaxial Shunt De-embedding is applied to the oscilloscope channel you specify for the **Output Current**.

Standard Double-Pulse Characterization Test

A Standard Double-Pulse Test is a common method for characterizing WBG power transistors. In general, it characterizes the turn-on and turn-off behavior for different supply voltages and different current levels. Two power transistors are configured in a totem-pole configuration (also called a half-bridge configuration). The Low-Side transistor is referred to as the Device Under Test (DUT). For proper operation, the body diode of the High-Side transistor is mandatory and is also used for the Reverse Recovery test.

Use these Double-Pulse Test Modules and Oscilloscope Probes

The Standard DPT test uses the following test modules and probes:

- Any Keysight Low-Side and matching High-Side Gate Drive Module.
- Either the PD1000-60901 DUT Module for TO-247 3-pin devices, PD1000-60902 DUT Module for TO-247 4-pin devices, or the PD1000-62401 DUT Module for D^{2}PAK (TO-263) SMD devices.
- N2819A 10:1 Differential Oscilloscope Probe to measure Gate Current, I_G.
- PD1000-60002 Protection Probe for measuring I_D.
- N2873 10:1 Standard Oscilloscope Probe for measuring V_{GS} on the Low-Side Gate Drive Module.
- 10076C 100:1 High Voltage Probe for measuring V_{DS} on the DUT Module.
- **IMPORTANT**: Remove the PD1000-66505 Clamp Module. Cycle power on the test system if necessary.

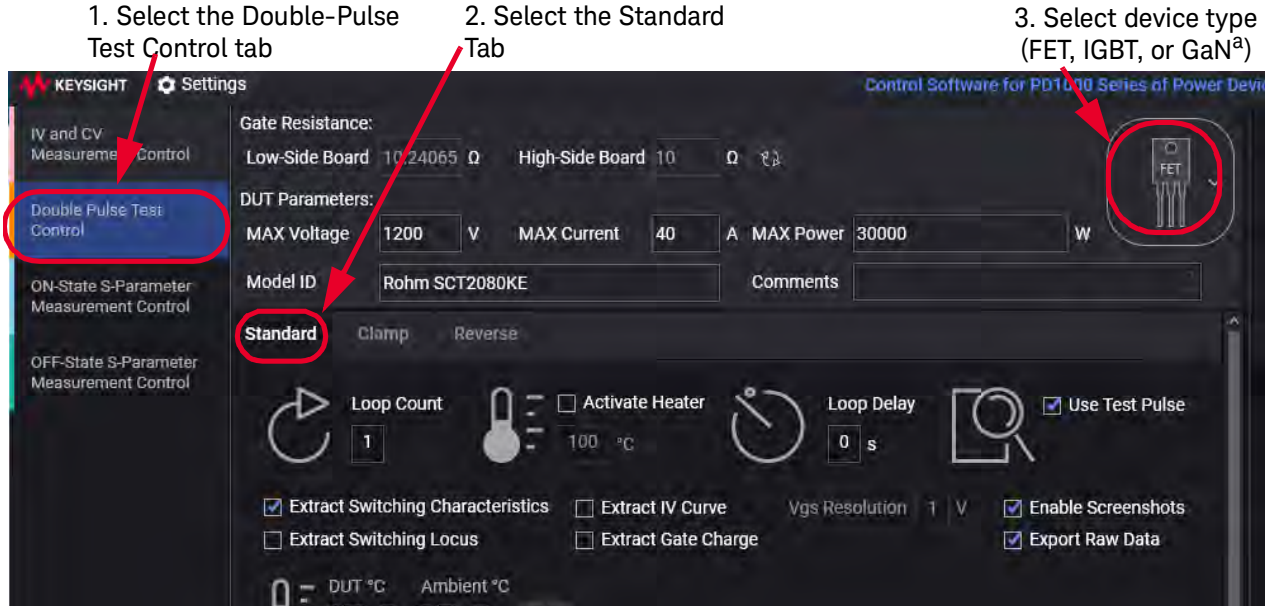


Figure 12 PD1000A Control Software Screen for Standard Double-Pulse Test

[a] GaN devices require a special DUT Test Board and a software license. Contact Keysight for information.

Clamped Double-Pulse Test

The DPT Clamp Test is the same as the Standard test but uses the Clamp Circuit module (PD1000-66505). For accurate $R_{DS(on)}$ measurements the clamping circuit limits the applied voltage level to the oscilloscope probe while the DUT is turned off. This way an oscilloscope probe with a lower divider ratio (10:1) can be used for accurately measuring V_{DS} while the transistor is turned on.

Use these Double-Pulse Test Modules and Oscilloscope Probes

This Clamped DPT test uses the following test modules and probes:

- Any Low-Side and High-Side Gate Drive Module.
- Either the PD1000-60901 DUT Module for TO-247 3-pin devices, PD1000-60902 DUT Module for TO-247 4-pin devices, or the PD1000-62401 DUT Module for D^2PAK (TO-263) SMD devices.
- PD1000-66505 Clamp Circuit Module. Use only when running the Clamp test; otherwise remove it.
- 10076C 100:1 High Voltage Probe for measuring V_{DS} on the DUT Module.
- PD1000-60002 Protection Probe for measuring I_D.
- N2873 10:1 Standard Oscilloscope Probe for measuring V_{GS} on the Low-Side Gate Drive Module.
- N2873 10:1 Standard Oscilloscope Probe for measuring V_{DS} on the Clamp Circuit Module.

The Clamp Circuit Module provides the following:

- Clamps voltage to levels suitable for using the N2873A 10:1 passive probe.
- Characterized systematic errors so that they can be taken into account.
- Quantified achievable accuracy.

CAUTION **The maximum V_{DS} or V_{CE} test voltage that may be applied to the Clamp Circuit Module is 400 V. This for both IGBT (V_{CE}) and FET (V_{DS}) devices.**

NOTE **When installing or removing the PD1000-66505 Clamp Module, you must cycle power on the PD1500A test system in order for the change to be discovered.**

For detailed information about the Clamp Circuit Module and its use, refer to the *PD1500A DPT Si/SiC Test Fixture and Modules Installation and Use Guide*.

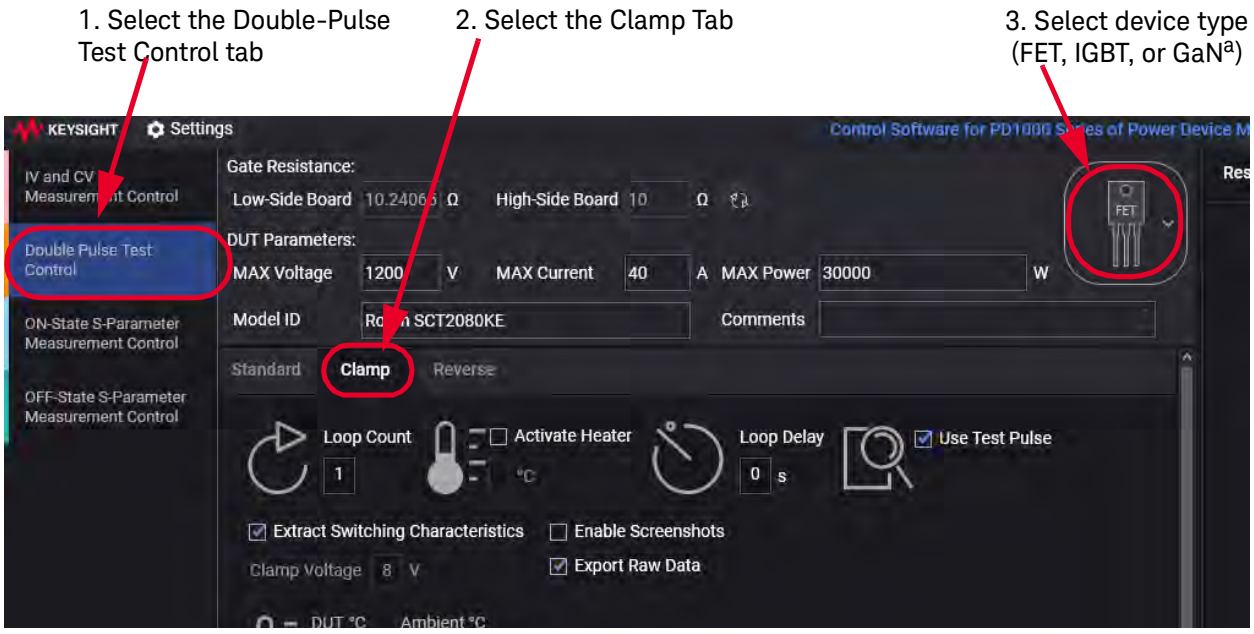


Figure 13 PD1000A Control Software Screen for Clamp Double-Pulse Test

CAUTION The maximum test voltage that may be applied to the Clamp Circuit Module is 400 V. This for both IGBT and FET devices.

[a] GaN devices require a special DUT Test Board and a software license. Contact Keysight for information.

DPT Reverse Recovery Test

Reverse Recovery tests characterize the body diode in the DUT device on the DUT Test Module. If a diode is conducting in a forward direction and immediately switched to a reverse bias condition, the diode continues to conduct in the reverse bias state for a very short time as the forward voltage bleeds off. The current through the diode is fairly large in the reverse direction during this small recovery time.

After the carriers are flushed and the diode is acting as a normal blocking device in the reverse bias condition, the current flow drops to normal leakage levels.

Use these Double-Pulse Test Modules and Oscilloscope Probes

This Reverse Recovery DPT test uses the following test modules and probes:

- Any Keysight Low-Side and matching High-Side Gate Drive Module.
- Either the PD1000-60901 DUT Module for TO-247 3-pin devices, PD1000-60902 DUT Module for TO-247 4-pin devices, or the PD1000-62401 DUT Module for D^2PAK (TO-263) SMD devices.
- N2819A 10:1 Differential Oscilloscope Probe to measure Gate Current, I_G.
- PD1000-60002 Protection Probe for measuring I_D.
- N2873 10:1 Standard Oscilloscope Probe for measuring V_{GS} on the Low-Side Gate Drive Module.
- 10076C 100:1 High Voltage Probe for measuring V_{DS} on the DUT Module.
- **IMPORTANT**: Remove the PD1000-66505 Clamp Module. Cycle power if necessary.

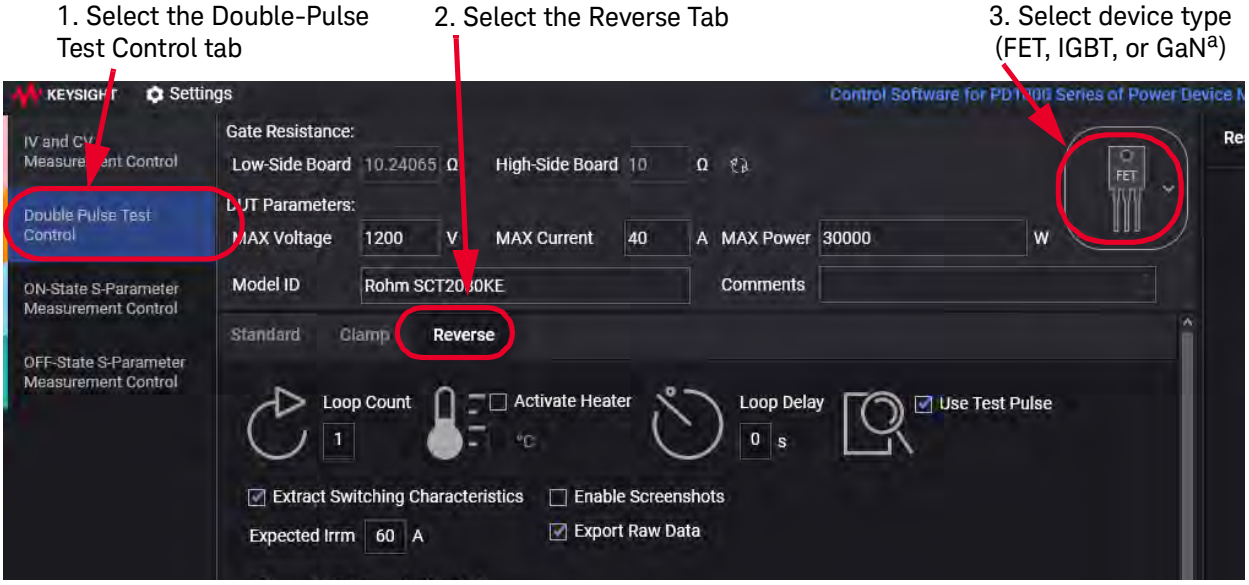


Figure 14 PD1000A Control Software Screen for Reverse Recovery Test

[a] GaN devices require a special DUT Test Board and a software license. Contact Keysight for information.

Set Double-Pulse Test Parameters

Most DUT test parameters can be obtained from the DUT data sheet.

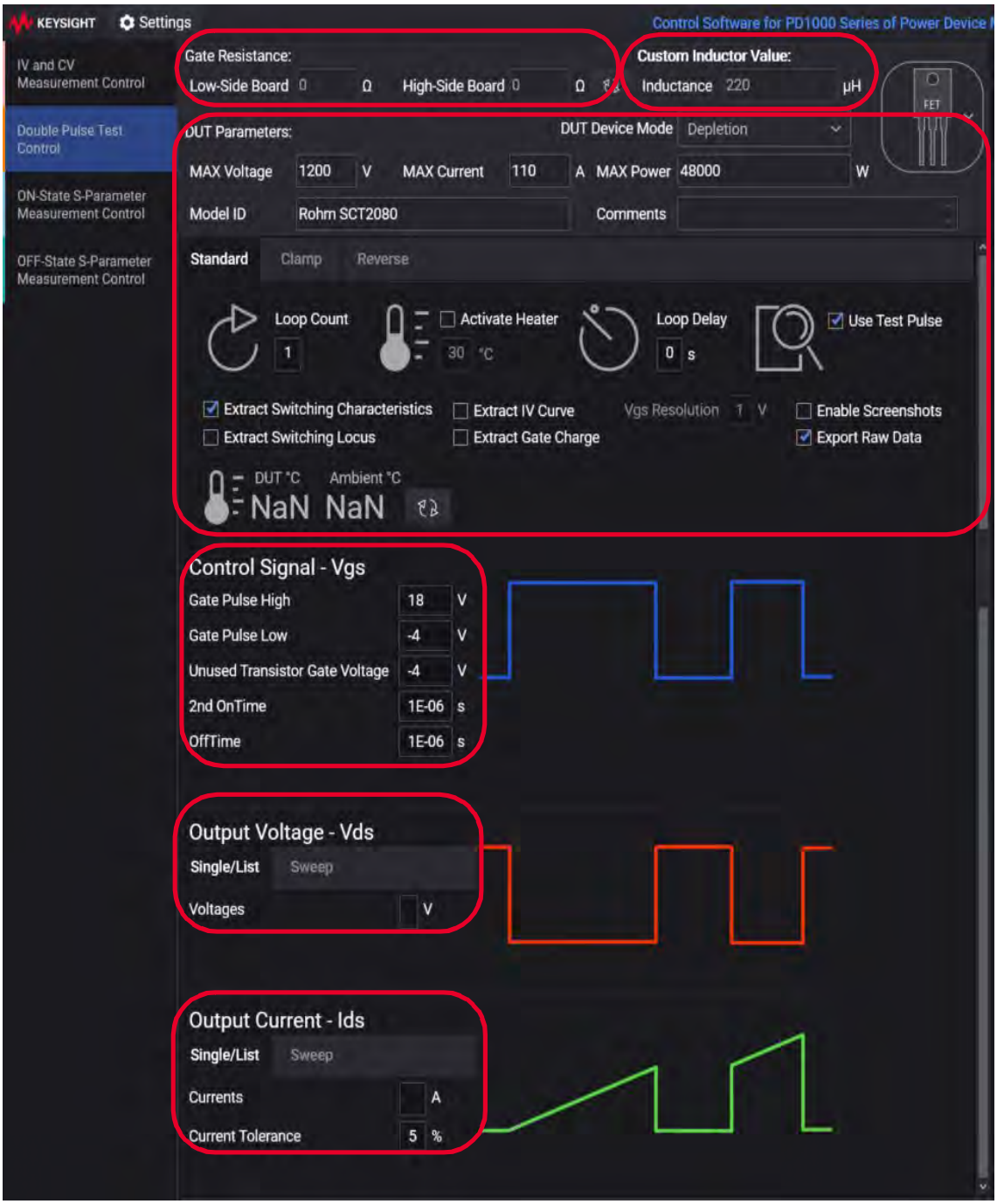


Figure 15 DPT Test Parameters

Gate Resistance:

All of the Keysight Gate Drive Modules have two series resistors for the Gate Resistor. Both resistors are the same value. For example, the PD1000-66544 10 Ω Gate Drive Module has two 4.99 Ω resistors in series for the 9.98 Ω RG. The Control Software reads the value of one of the two Gate resistors from the Low-Side Gate Drive module and displays the value here. For the Low-Side gate resistance, the actual measured/calibrated value is displayed; for the High-Side gate resistance, only the nominal value is displayed.

Remember, both the High-Side and Low-Side Gate Drive modules should have gate resistors, RG, of the same resistance.

For Gate Drive modules with no installed gate resistor (the PD1000-66540 and -66541 modules), R_G is measured during system calibration which must be done prior to running Double-Pulse tests.

NOTE Click the refresh button ( ) next to the Gate Resistance to force the software to read the current gate resistor value. Do this when you first start the Control Software and anytime you change the Gate Drive Modules. This also ensures the resistor has not failed.

Custom Inductor Value:

- **Inductance:** With software version 2020.820 (and later) you have the option to use the standard, internal inductor (internal to the PD1500A Test Fixture) or an external, custom inductor. Custom Inductor Value appears only if you have specified using a custom inductor in the **Hardware Configuration > Inductor Settings** dialog. See “Inductor Settings” on page 44.

  If you are using an external inductor, enter the value of the inductor in the Hardware Setting screen. The value appears in the **Custom Inductor Value > Inductance** field.

  Refer to the *PD1500A Using an External Inductor (PD1500-90006)* for detailed information about selecting (or designing your own) and installing an external inductor on the PD1500A Test Fixture DUT module.

CAUTION When using an external inductor, the internal inductor must be disconnected. Automatic switching between Standard and Clamp double-pulse tests and Reverse Recovery test is not be possible with an external inductor.

DUT Parameters

- **DUT Device Mode:** Select either Enhancement Mode (normally off device) or Depletion Mode (normally on device) for GaN or regular FETs. Refer to device data sheet. Default is Enhancement Mode.
- **MAX Voltage:** Specify the maximum voltage (V_{DSS} or V_{CES}) that may be applied across the device (Drain to Source or Collector to Emitter). Obtain value from the device data sheet.
- **MAX Current:** Specify the maximum current (I_D or I_C) that may be used to test the DUT (Drain to Source or Collector to Emitter). Obtain value from the device data sheet.
- **MAX Power:** Specify the maximum power that may be applied to the DUT. This value is generally not specified on the device data sheet.

NOTE

As a general guideline, the typical operating voltage for a FET or IGBT is much lower than the Maximum Rated voltage (V_{DSS} or V_{CES}). The following examples are typical and not hard rules:

V_{DSS} Rating:	Typical Operating Voltage:
600 V	400 V
1200 V	600 V
1700 V	900 V

- **Model ID:** A text field to enter the model or device type of the DUT, or any other text information you want to record. Characters not legal for file paths (e.g., \, /, ?, <, >, ...) are replaced by the character "_". If nothing is entered, the word "*Unknown*" is used.
- **Comments:** Allows you to enter comments such as test details or DUT details. Comments are saved as part of the Measurement History and in the Parameters Results page.
- **Device Type** (Drop-down menu item)**:** Select either FET, IGBT, or GaN for the device to be tested (DUT).

NOTE

IMPORTANT: Testing GaN devices require a special DUT Test Board and a license for the control software. Contact your local Keysight Application Engineer for availability and information.

NOTE

GaN devices have different system limits than FET or IGBT devices. GaN devices are limited to:

Maximum System Voltage ≥ 500 V
Minimum System Current: ≥ 1 A
Maximum System Current ≥ 100 A

- **Loop Count:** Specify number of times to repeat the DPT test with the current parameter settings. See Note, "**Looping or Sweeping Multiple DPT Tests**" below.
- **Activate Heater:** Turns the heater circuit on or off. Remember to set the Temperature Control Settings in the Hardware Configuration Menu (see "Temperature Control Settings" on page 44). See Appendix B for a detailed description about using the device heater with the Double-Pulse Test Control Software.
  - **Temperatures:** Enter a single value or a semicolon (;) delimited list of temperatures to heat the device to when running the DPT tests. 175 °C[b] Maximum. This box is grayed-out unless **Activate Heater** is checked. See Note, "**Looping or Sweeping Multiple DPT Tests"** below.

NOTE Heater temperatures between 150 °C and 175 °C are valid only for TO-247 device packages. Do not use temperatures above 150 °C for D^2PAK or GaN devices.

- **Loop delay:** Specify the delay time (in seconds) for the DPT test to idle before running each DPT test in a loop. This time allows the device to cool if you use the heater. See Note, "**Looping or Sweeping Multiple DPT Tests"** below.

NOTE **Looping or Sweeping Multiple DPT Tests.** When running multiple tests on a device, loops are nested:

```
Loop Count {
    Temperature {
        Multiple List or Sweep Voltage Values (VDS) {
            Multiple List or Sweep Current Values (IDS)
            }
        }
    }
```

That is, all "Sweep Current Values" are tested before incrementing the "Sweep Voltage Value". All "Sweep Voltage Values" are tested before incrementing "Temperature". All "Temperatures" are tested before incrementing "Loop Count". When looping DPT tests, all measurement data is saved in the directory specified in the **Settings > Global Settings** menu.

b Requires Software version 2020.820 or later. Ambient to +175 °C for TO-247 device packages only; ambient to +150 °C for SMD devices.

- **Use Test Pulse** (checkbox): When checked, click **Start** to run a low voltage/low current Double-Pulse Test (50 V_{DS}) before the actual measurement begins. This verifies that the DUT is functional and has not been destroyed. Note, because of the low voltage/low current, the I_G and I_{DS} measurements will appear noisy on the oscilloscope. If the Test Pulse measurement succeeds, the complete test runs at full voltage and current. The Test Pulse is available only in Standard Test mode, not for Clamp and Reverse measurements.
- **Extract Switching Characteristics:** (checkbox) If not checked, only the *Extract Gate Charge, Enable Screenshots,* and *Export Raw Data* check boxes are available.
  - **Extract IV Curve** (checkbox, available only in Standard DPT Test): This checkbox is grayed-out (not available) unless the **Extract Characteristics** box is checked. If checked, the complete I/V derivation is extracted and saved. If a Gate Drive Module with a gate resistor (R_G) 10 Ω or greater was used in the DPT test, then the Gate Charge data is displayed. **Note**: 100 Ω Gate Resistor (R_G) is recommended for IV derivation.
  - **Vgs Resolution:** This field is grayed-out (not available) unless the **Extract IV Curve** box is checked. Enter a single value to be is used for the extraction of the IV curves.
  - **Extract Switching Locus:** Switching locus represents the voltage and current combination (I_D / V_{DS}) along turn-on and turn-off. It is generally used to make sure the locus is within the Safe Operating Area (SOA) of a device. Fro more information, see "*Parameter Extraction Techniques*" in the PD1000A software online help file.
- **Extract Gate Charge:** (available only in Standard DPT Test) Extracts and plots Gate Charge information. Accurate Gate Charge measurements require a high gate resistor (R_G) value; typically 100 Ω or greater.
- **Enable Screenshots:** Allows user to enable/disable the system automatically taking oscilloscope screen captures during a DPT test. Screen captures are stored in the test subfolder.
  - When disabled (default setting), the only screen captures taken are the *Summary.png* and the *PulseAdjustment.png*.
  - Disabling can shorten the Standard DPT test time.
  - Enabling screen captures allows for easier test debugging.
- **Export Raw Data:** When checked, it enables the export of raw curve data from the oscilloscope. When unchecked, the "Oscilloscope Capture" is not displayed or saved and can decrease the Double-Pulse Test time.
- **Clamp Voltage:** (available only in Clamp DPT Test). Clamp voltage is fixed at 8 V_{DC} and cannot be changed.

- **Expected Irrm:** (available only in Reverse DPT Test). Maximum Reverse Recovery Current of a fast or ultrafast diode; such as often used in switch-mode power supplies). Enter the maximum current the body diode is rated for.
- **DUT °C:** Indicates the temperature of the DUT if the Heater/Thermocouple assembly is connected to the Test Fixture. If the Heater/Thermocouple assembly is not connected to the test fixture or if **Activate Heater** is not selected, **NaN** (Not a Number) is shown.
- **Ambient °C**: Indicated the ambient temperature inside the Safety Hood enclosure. Sources for the temperature readings are three internal fixture sensors and scope temperature reading to make sure it is not overheating.

Click the **Refresh** button () to read the current temperatures. See Appendix B for a detailed description about using the device heater with the Double-Pulse Test Control Software.

Measurement Parameters for Standard, Clamp, and Reverse Tests

Control Signal (Gate Voltage (V_{GS} or V_{GE})):

- **Gate Pulse High:** A single voltage level for the turn-on Gate Pulse. For the *Standard* and *Clamp* tests, this is for the Low-Side device (DUT). For the *Reverse Recovery* test, this is for the High-Side device. Minimum value for the Gate Pulse High = +13 V. Maximum value = +29 V. The difference between Gate Pulse High and Gate Pulse Low must be less than 30 V.
- **Gate Pulse Low:** The voltage level of the Gate Pulse; used to ensure the DUT is fully turned off. Minimum value = -10 V. Maximum value = 0 V.

NOTE The maximum difference between Gate Pulse High and Gate Pulse Low must not exceed 30 V.

- **Unused Transistor Gate Voltage:** This sets the Gate Voltage for the device *not* being tested. For the *Standard* and *Clamp* tests, this is the High-Side device (DUT).
- **2nd On Time:** Enter the time, in microseconds, when the DUT is turned on a second time (and V_{DS} is minimum). For example, 2 microseconds is expressed as “2E-6”. Minimum 200 nS, Maximum 10 μS.
- **Off Time:** Enter the time, in microseconds, between when the DUT is turned off (and V_{DS} is maximum) and when the DUT is turned on a second time. For example, 2 microseconds is expressed as “2E-6”. Minimum 200 nS, Maximum 10 μS.

NOTE Keep **2nd On Time** and **Off Time** as short as possible. IGBT and some other slow devices may require longer times. The pulse width must be long enough that the transistor turns fully on (e.g., > 1 μS). However, the pulse width must not be too long, otherwise, the measurement will be influenced by self-heating of the transistor. 200 nS is the minimum time.

Output Voltage (V_{ds} or V_{ce}):

The Double-Pulse Test can either test at a single V_{DS}/V_{CE} Output Voltage, a list of semicolon-separated Output Voltages, Output Voltages or sweep a series with multiple V_{DS}/V_{CE} Output Voltages.

NOTE

GaN devices have different system limits than FET or IGBT devices. GaN devices are limited to:

Maximum System Voltage ≥ 500 V
Minimum System Current: ≥ 1 A
Maximum System Current ≥ 100 A

CAUTION

The maximum test voltage that may be applied to the Clamp Circuit Module is 400 V. This for both IGBT and FET devices.

- **Single/List or Sweep tabs:** If Single/List tab is selected, then run test with a single voltage or a semicolon (;) delimited list of voltages (e.g., 50; 100; 200; ...).
  If **Sweep** is selected, then enter the starting voltage, the ending voltage, and the number of points (voltages) to test. See note below: **Sweeping Voltage Example**.
- Minimum Voltage = 50 V, Maximum Voltage = 1200 VDC.
- **# of Points:** Sets the number of voltage steps between Start and Stop for sweeping.

NOTE

Sweeping Voltage Example: As a sweep example, suppose you want to run Double-Pulse Tests at the following V_{DS}/V_{CE} voltages: 100, 150, 200, 250, 300, 350, 400 Volts.

- Check the **Sweep** tab.
- Set **Start** to: *100*.
- Set **Stop** to: *400*,
- Set the **# of Points** to: *7*. This sets the Step Size to 50 V.
- Then click **Start** to run the test.

Also, see the **Looping or Sweeping Multiple DPT Tests** Note on page 57.

Output Current (I_{ds} or I_{ce}):

The Double-Pulse Test can either test at a single I_{DS} or I_{CE} Output Current, a semi-colon-separated list of currents or sweep with multiple I_{DS} or I_{CE} Output Currents.

- **Single/List or Sweep tabs:** If Single/List tab is selected, then run test with a single current or a semicolon (;) delimited list of currents (e.g., 20; 35; 50; ...).
  If **Sweep** is selected, then enter the starting current, the ending current, and the number of points (currents) to test. See note below: **Sweeping Current Example**.
- Minimum current = 10 A[c], Maximum current = 200 A.
- **# of Points:** Sets the number of current steps between Start and Stop for sweeping.

NOTE

Sweeping Current Example: As a sweep example, suppose you want to run Double-Pulse Tests at the following I_{DS} or I_{CE} currents: 10, 15, 20, 25, 30, 35, 40 Amps.

- Check the **Sweep Current** box.
- Set **Single/Start** current at *10*.
- Set the **Stop** current at *40*,
- Set the **# of Points** at *7*. This sets the Step Current to 5.00 A.
- Then click **Start** to run the test.

Also, see the **Looping or Sweeping Multiple DPT Tests** Note on page 57.

- **Current Tolerance %:** Specify a Tolerance value used is setting the pulse width to obtain current values. For example, if you specify a current of 40 A and a tolerance of 5% then the actual current used in the test will be between 38 and 42 A. Value must be greater than zero (0).

c Values less than 10 A are possible but have not been tested. Current is limited by the energy in the capacitor.

Run the Characterization Test

After selecting the type of test (Standard, Clamp, or Reverse Recovery) setting the test parameters:

1. Click the **Start** button (START) to start a measurement or a loop of measurements.
   – Stop an active measurement by clicking the **Stop** (STOP) button.
2. The DPT Control Software calculates the amount of energy that it needs to store in the inductor for the complete test and sets the width of the first pulse accordingly.
3. Watch the Progress details just above the START button.
4. After the test runs, and if **Enable Screenshots** is checked, the Oscilloscope Capture plot and other test data appear in the software display (right side of the display) on the host PC.

Figure 16 Sample Double-Pulse Test Plot for a FET Device

Test result data is automatically stored in the file specified in the **Global Settings > Output Directory** (see “Configure Common Settings” on page 38).

NOTE If a Gate Drive Module with a gate resistor (R_G) equal to or greater than 10 Ω was used in the DPT test, then the Gate Charge data is calculated and available. If R_G is 0 Ohms. then the gate current cannot be measured.

NOTE Waveforms from the PD1500A Double-Pulse Tests system are different from waveforms shown in various test standards. This is because of issues such as gate plateau, ringing due to parasitic inductances and capacitances, voltage drop due to stray inductances, overshoot, etc.

After a successfully completed test (or loop or sweep of tests). The right side of the screen displays the test results. The **Results Tab** shows the results of the most recent DPT test or the results of a test selected from the **Measurement History**.

Results Tab

Depending on the type of test (Standard, Clamp, or Reverse Recovery) and the extractions selected (Extract Switching Characteristics, Extract Switching Locus, Enable Screenshots, etc), the Results Tab shows the measured or calculated results of the DPT test. These results include an oscilloscope capture, Gate Charge, Test Parameters, etc.

Figure 17 Sample Oscilloscope Capture from the Results Tab

Selected Result

Shows the measured or calculated results of the DPT test. Note that you can select one or more tests from the Measurement History tab, right click, select **Load Measurement(s)...** to open the Results tab. Then click on the **Selected Result** down arrow to select one of the test results.

Selected Extractions

Provides a list of the **Run Extraction(s)** you have performed. You can do multiple extractions on one file; this list allows you to switch between the extractions.

Comment Field on each Results Page

Comments fields at the bottom of each Results page (Oscilloscope Capture, Gate Charge, Signal Levels and Time, etc.) are automatically saved.

Measurement History Tab

Starting with PD1000A Control Software version 2021.624, all tests are recorded and available in a Measurement History.

Measurement History Columns

System State Column

C	Test completed without errors.
E	Errors occurred during the test execution or data extraction. Error messages are recorded in the Measurement History.
A	Test aborted by user, message recorded in Measurement History.
	No icons means that the selected test was done on a previous version of the PD1000A Control software. These are not available for **Run Extraction(s)...**.

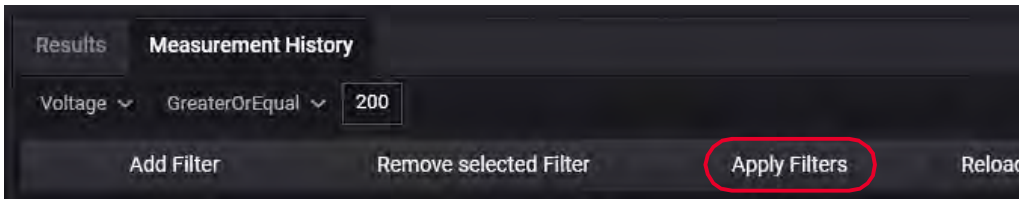
The other columns in the Measurement History table are taken directly from the main test parameter screen.

You can reorder the columns by holding the left mouse key down on a column head and sliding it to the position you want.

Using Filters

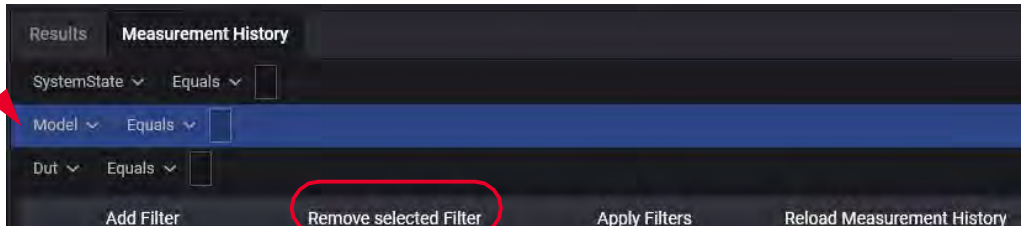
1. Click the **Add Filter** tab.This adds a filter menu to the screen. Click the down arrow to open the list of filter types; scroll down for the complete list.
2. Click the down arrow next to **Equals** to select the type of filter to use.
3. Enter the parameter in the blank field.
4. Click **Apply Filters**.

For example, if you want a list of all measurements made at 200 volts or greater:



To remove a filter from the list, select the filter to remove (click at the far left, the filter is highlighted when it is selected). Then click **Remove selected Filter**.

Click here to highlight a filter to remove



Reload Measurement History

This reloads the complete Measurement History. For example, after you delete one or more files or set and apply filters, then remove the filters, click **Reload Measurement History** to get the complete list of tests.

Additional Features of the Measurement History

Click on any test to highlight it; right click to open the Context menu. Use the *Shift* or *Ctrl* keys to select multiple tests.

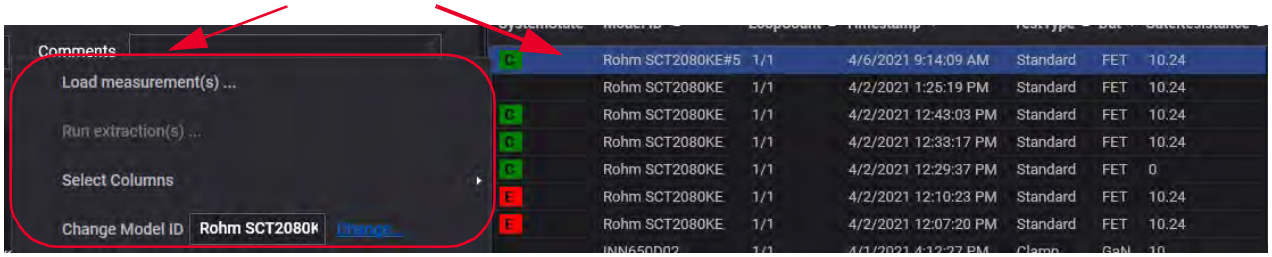


Figure 18 Measurement History Context Menu

Load Measurement(s)...

Select one or more tests from the Measurement History tab, right click to open the context menu, select **Load Measurement(s)...** to open the **Results** tab. Then click on the **Selected Result** down arrow to select one of the test results.

Run Extraction(s)...

Run Extraction(s)... allows you to open previous DPT measurement results in the Infiniium Offline PC-Based Oscilloscope Analysis Software. For example, you may want to expand the Turn-On / Turn-Off switching times on the oscilloscope display or change the IEC 10%/90% measurement points[d]. The Offline software allows you to view, analyze, share, and document previously captured DPT measurements.

To run extractions, the Infiniium Oscilloscope Offline software must be running first; **Run Extraction(s)...** does not open or start the Infiniium Oscilloscope software. Only one instance of the Infiniium can run at a time.

NOTE

Run Extraction(s)... requires the PD1000A Control Software PD1021A license **AND** the Keysight Infiniium Offline Software (*infiniium D9010ASIO* and *D9010BSEO)* license has everything required) is to be installed and licensed on the host PC. If the PD1021A license is not installed, **Run Extraction(s)...** is disabled.

Run Extraction(s)... is available only for Double-Pulse Tests run with control software version 2021.624 (or later)

To use **Run Extraction(s)...**:

1. Start the Infiniium Oscilloscope Offline software on the same PC as the PD1000A Control software.
2. In **Measurement History** view, right click on the DPT test you want to analyze.
3. Click on **Run Extraction(s)...**.
4. The PD1000A Control software reruns the analysis and transfers the measurement results to the Offline software.

A list of extractions you performed is available in the **Results** tab under **Selected Extractions**. You can do multiple extractions on one file; this list allows you to switch between the extractions.

It is beyond the scope of this manual to describe how to use the Infiniium Offline PC-Based Oscilloscope Analysis Software. Refer to the Offline Software help file.

d For FET devices, measurements are defined according to IEC 60747-8
For IGBT devices, measurements are defined according to IEC 60747-9

Select Columns

This allows you to select and add/delete columns from the Measurement History view.

Change Model ID

The Model ID is part of the Output Directory path (see "Global Settings" on page 38) for saving test measurement data. Changing the **Model ID** moves the measurement on the hard disk to a new measurement path.

Right click the test that you want to change the Model ID. The context menu opens with the model ID of the test you selected. Type in the new Model ID and click **Change...**. The control software creates a new folder with the new **Model ID** name.

Delete a Measurement from the Measurement History

To delete a test from the Measurement History, delete the measurement from the output folder. The next time the Measurement History is loaded (or click **Reload Measurement History**) the test does not appear in the Measurement History.

Frequently Asked Questions

Can I set the di/dt rate?

The di/dt rate is used primarily for Reverse Recover tests.The rate can be controlled in two ways:

a You can increase V_{GS} to have a faster di/dt or decrease V_{GS} for a slower di/dt.

b You can increase the gate resistor value on the High-Side Gate Drive module to decrease the di/dt or decrease the gate drive resistor value on the High-Side Gate Drive module to increase the di/dt.

By controlling these two parameters, you can tune the di/dt for Reverse Recovery to match the data sheet.

How do I change the Gate Drive Resistor (R_G)?

The PD1500A DPT system provides different Gate Drive Modules, each with a different value Gate Drive Resistor:

- Isolated Low-Side Gate Drive Modules for Si/SiC devices.
  - -- PD1000-66540 No Gate Resistor installed on module for users to install their own gate Drive resistors. See the *PD1500A Si/SiC Test Fixture User Guide* for detailed information.
  - -- PD1000-66542 0 Ω (2x 0 Ω) Gate Resistor installed on module.
  - -- PD1000-66544 10 Ω (2x 4.99 Ω) Gate Resistor installed on module.
  - -- PD1000-66546 100 Ω (2x 50 Ω) Gate Resistor installed on module.
- Isolated High-Side Gate Drive Modules for Si/SiC devices.
  - -- PD1000-66541 No Gate Resistor installed on module for users to install their own gate Drive resistors. See the PD1500A Test Fixture User Guide for detailed information.
  - -- PD1000-66543 0 Ω (2x 0 Ω) Gate Resistor installed on module.
  - -- PD1000-66545 10 Ω (2x 4.99 Ω) Gate Resistor installed on module.
  - -- PD1000-66547 100 Ω (2x 50 Ω) Gate Resistor installed on module.

NOTE Refer to the *PD1500A Si/SiC Test Fixture and Modules Installation and Use Guide* for information on selecting and installing custom gate resistors.

How are general electrical characteristics measured: General FET characteristics, such as V_F, I_R, and C are measured with the PD1000A system using the Keysight B1505A or B1506A. Reverse Recovery parameters are measured with the PD1500A Double-Pulse Test Solution.

What is the stray Inductance in the power loop circuits? approximately 38 nH.

How is system discharge accomplished? Automatically, through a bleed resistor in the test fixture.

High Voltage Detection? In the Rack and Safety Enclosure, there is a voltage detection circuit that works with the interlock system. Additionally, the Heinzinger High Voltage Power Supply (HVPS) displays the output voltage.

A PD1500A System Specifications

All PD1500A documentation and individual instrument documentation are available on-line. Refer to the individual Keysight instrument data sheets, user guides and help files for detailed specifications, operation, and use instructions as well as specific warranty and support information.

www.keysight.com/find/PD1500A (for general product information including the PD1500 A data sheet, PD1000A Control Software, etc.)

www.keysight.com/find/DSOS104A High Definition Oscilloscope
For the full list of specifications and characteristics, see the Data Sheet, literature number 5991-3904, at:
(http://literature.cdn.keysight.com/litweb/pdf/5991-3904EN.pdf)

www.keysight.com/find/33512B Waveform Generator.
For the full list of specifications and characteristics, see the Data Sheet, literature number 5992-2572, at:
(http://literature.cdn.keysight.com/litweb/pdf/5992-2572EN.pdf)

www.keysight.com/find/B2902A Precision Source/Measure Unit
For the full list of specifications and characteristics, see the Data Sheet, literature number 5990-7009, at:
(http://literature.cdn.keysight.com/litweb/pdf/5990-7009EN.pdf).

www.heinzinger EVO High Voltage Power Supply

Tested Parameters[a,b]		
Test	Parameter/Characteristics	Symbol
Double-Pulse Test/Clamp	Turn-on delay time	td(on)
	Turn-off delay time	td(off)
	Rise time	tr
	Fall time	tf
	Turn-on time	ton
	Turn-off time	toff
	Turn-on energy	e(on)
	Turn-off energy	e(off)
	di/dt	di/dt
	dv/dt	dv/dt
	On-resistance	Rds(on)
	Switching Characteristics	Id vs. t
		Vds vs. t
		Vgs vs. t
		Ig vs. t
		Clamped Vds vs. t
	Switching locus	Id vs. Vds[c]
Reverse Recovery	Reverse recovery time	trr
	Reverse recovery charge	Qrr
	Reverse recovery energy	Err
	Maximum reverse recovery current	Irr
	Reverse recovery current characteristics	Id vs. t
Gate Charge[d]	Total gate charge	Qg
	Plateau gate charge	Qgs(pl)
	Gate drain charge	Qgd
	Gate charge curve	Vgs vs. t
Multiple Tests	Derived output characteristics	Id vs. Vd[3]

a Based on IEC 60747 and JESD24 Standards.

b Long off time leads to significant inductor current. This leads to limitations of parameter extraction.

c Quality of the characteristic depends on the cleanliness of measured switching characteristics.

d Gate Charge parameter extraction requires gate current monitoring. The quality of gate charge parameters depends on smoothness of measured curve. High Gate Resistance (e.g., 100 Ohms or larger) is recommended.

Specifications					
Category	**Type**			**Item**	**Specification**
Electrical	General			Sample Rate	10 Gsa/s
				Sampling Accuracy	12 ppb + 75 ppb/year
				Deskew Accuracy	200 ps (typical)
	Drain/ Collector Channel	DC	Source	Maximum Voltage	1200 V[a]
				Minimum Voltage	50 V
				Maximum Current	200 A[b]
				Minimum Current	10 A
				Voltage Programming Resolution	23 mV
			Measure	Voltage Accuracy	2% of range (typical)
				Current Accuracy	4% of range (typical)
		AC	Measure	Voltage Probe Bandwidth	500 MHz
				Current Shunt Bandwidth	400 MHz (typical)
				Voltage transition time	<10 ns (depends on DUT response and Rg)
	Gate	DC	Source	High Level Max / Min Voltage	29 V / 13 V
				Low Level Max / Min Voltage	0 V / -10 V
				Voltage Resolution	< 0.1 V (typical)
				Maximum Current	10 A (sink and source)
			Measure	Voltage Accuracy	2% of range (typical)
				Current Accuracy	4% of range (typical)
		AC	Source	Timing Resolution / Accuracy	100 ps / 200 ps
				Typical 1st pulse width	1 to 60 μs
				Minimum Pulse width (1st Pulse)	1 μs
				Maximum Off-Time between 1st and 2nd Pulse	25 μs[c]
				Minimum Off-Time between 1st and 2nd Pulse	200 ns[d]
				Maximum Pulse Width (2nd Pulse)	10 μs
				Minimum Pulse Width (2nd Pulse)	200 ns[e]
			Measure	Voltage Probe Bandwidth	500 MHz
				Current Probe Bandwidth	800 MHz

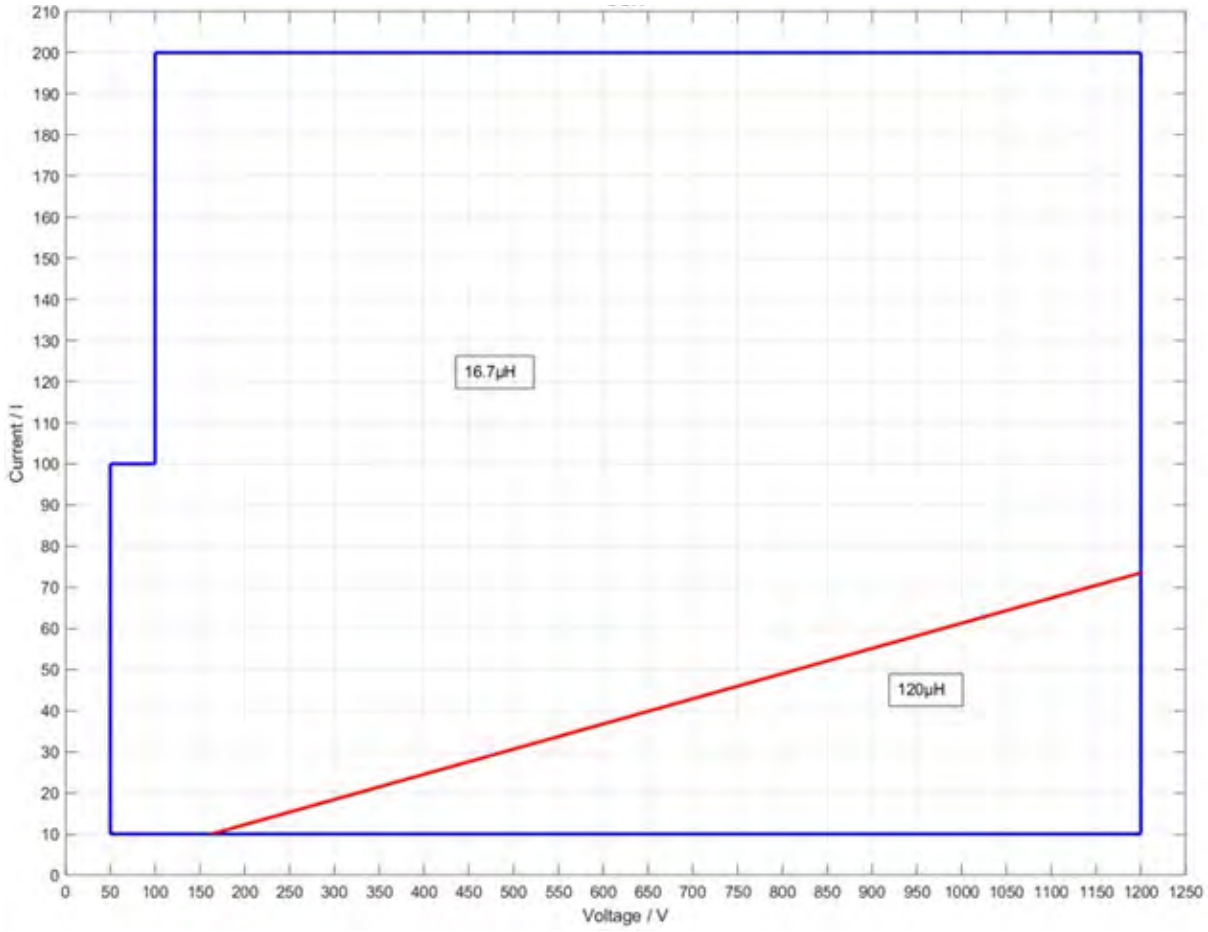
a Maximum supply voltage 1.2 kV; capable of characterizing 650 V, 1.2 kV, and 1.7 kV rated devices; Clamp circuit limits max voltage to 400 V

b 200 A is the maximum system current; limited test voltage (see graph on next page)

c Large values for Off-Time lead to significant loss of inductor current. This leads to limitations of parameter extraction.

d Smaller values may be possible but are not recommended or tested.

e Second pulse width must be selected so that the maximum system current is not exceeded



Specifications (continued)			
Electrical	Modular Components	Load Inductors	120 µH (typical)
			16.7 µH (typical)
		DC-Link Capacitor	800 µF (typical) at ≤ 200 V
			144 µF (typical) at > 200 V to ≤ 400 V
			36 µF (typical) at > 400 V to ≤ 880 V
			12 µF (typical) at > 880 V
DUT	Discreet Devices	MOSFET, IGBT	
		Silicon and SiC	
		TO-247-3, TO-247-4, D2PAK7 Devices	
Temperature Control		Heater	Ambient temperature to 175 °C[a]

a TO-247 devices only; D2PAK devices limited to 150 °C.

General Specifications (continued)				
Category	**Type**		**Item**	**Specification**
System	Mechanical	Safety Enclosure	Size -- safety hood closed	92 cm (W) x 72 cm (D) x 151cm (H)
			Size -- safety hood open	92 cm (W) x 87 cm (D) x 168cm (H)
			Weight - enclosure only	120.5 kg
			Weight - complete system	162.0
		SiC Fixture	Size	32 cm (W) x 25 cm (D) x 16 cm (H)
			Weight	5.3 kg
	Environmental		Operating Temperature	20 °C to 30 °C
			Operating Humidity	50 to 70 % RH, non-condensing
			Operating Altitude	up to 3000 m
			Warm-up Time	1 hour
			Storage Temperature	0 °C to 40 °C
	Line Power		Voltage	200 to 240 Vac, ±10%, 50/60 Hz
			Power Consumption	600 VA
	Protection and Safety		Emergency Off Switch (EMO)	
			Oscilloscope Protection (Clamp Output)	±15 V (typical)
		Safety Hood	Maximum Energy in the System	16 J (typical)
			Hood Lock	> 42 V (typical)[a]
			Open Hood Detection	High-voltage disconnect, DC-Link capacitor discharged
			Over Temperature Shutdown	> 50 °C (typical)
Interfaces	LAN			10/100/1000 Base T Ethernet

a Safety hood cannot be opened at voltages > 42 V present in the system.

How to use this Specification Chapter

This document contains technical specifications for all manufacturing versions of thePD1500A Dynamic Power Device Analyzer/Double-Pulse Tester. Specifications published in the data sheet apply only to the currently shipping version of the equipment.

If a specification only applies to a certain manufacturing version of the equipment, it is indicated in this document. Such changes are usually designated by a serial number break. For example, you might see a table indicating the specification for equipment with "**Serial Number TW51150212 and earlier**" accompanied with another column with **"Serial Number TW51160201 and later.**" indicating that the equipment with serial number TW51160201 and greater use the new specification.

Technical Specification and Characteristics

- **Specifications** describe the warranted performance and include guard bands to account for the expected statistical performance distribution, measurement uncertainties, and changes in performance due to environmental conditions. All specifications and characteristics apply over the operating environment outlined in the "Environmental and Regulatory" section. In addition, the following conditions must be met:
  - -- All instruments are within their calibration cycle.
  - -- All instruments have been stored for a minimum of 1 hour within the operating temperature range prior to turn-on and after a 60-minute warm-up period.
- **Characteristics** describe product performance that is useful in the application of the product, but that is not covered by the product warranty. Characteristics are often referred to as Typical or Nominal values.
- **Typical** describes expected performance of an average unit when operated over a 20 to 30 °C temperature range. Typical performance is not warranted. All instruments must be within their calibration cycle .
- **Nominal** describes representative performance that is useful in the application of the product when operated over a 20 °C to 30 °C temperature range. Nominal performance is not warranted.

Additional information

- Any graphs contain measured data from multiple units at room temperature and are representative of product performance within the controlled temperature range unless otherwise noted.
- The data contained in this document is subject to change.

B Double-Pulse Test Solution Calibration for Si/SiC Modules

In this Chapter:

GaN Test Board Calibration page 80
Set/Verify AC Line Frequency & Date/Time on B2902A page 80
Begin Calibration & Compensation page 80
- Low Frequency Compensation for the 10076C and N2873A Probes page 81
- Offset Compensation for the N2819A Differential Probe page 82

System Calibration Procedure (Autocal) page 84
- Gate Voltage Calibration – V_{GS}/V_{GE} Probe page 85
- Gate Voltage Source Calibration – V_{GS} Output page 86
- Gate Current Calibration – I_G Probe page 87
- Gate Resistance Calibration – R_G page 88
- High Voltage Probe Calibration – V_{DS}/V_{CE} Probe page 89
- Clamp Circuit Probe Calibration – V_{CLAMP} Probe page 90
- PD1000-60002 Protection Probe Calibration – I_D/I_C page 91

Coaxial Shunt Resistor Characterization page 92
Oscilloscope Probe Deskew page 93
- Connect Probes to Deskew Fixture page 93

IMPORTANT – Calibration Information:

Several calibration-related procedures should be performed: anytime changes are made to the PD1500A system or anytime the ambient temperature changes more than ±5 °C.

- **Oscilloscope Probe Compensation.**
- **System Calibration.**
- **Oscilloscope Probe Deskew.**
- **Coaxial Shunt Resistor Characterization & De-embedding. Characterization should be performed annually.**

Additionally, a complete Service Calibration is required annually for the DSOS104 oscilloscope, 33512B Waveform Generator, and the B2902A Precision Source/Measure Unit test instruments. The Coaxial Shunt should be characterized annually.

GaN Test Board Calibration

This chapter describes the Si/SiC Test Module calibration. Contact your local Keysight Application Engineer for information regarding calibration for your specific GaN Test Board.

Set/Verify AC Line Frequency & Date/Time on B2902A

The Keysight B2902A Source Measure Unit (SMU) is used for the system calibration. Its factory default line frequency is set to 50 Hz. For specified accuracy, the line frequency must be changed to 60 Hz in those countries with a 60 Hz line frequency. To change the line frequency, press the following keys:

- For setting to 50 Hz: **More > System > PLC > 50 Hz**
- For setting to 60 Hz: **More > System > PLC > 60 Hz**

Optionally, set the Date and Time on the B2902A SMU, press the following:

System > Info > Date/Time

Begin Calibration & Compensation

1. Turn on the PD1500A Test System and allow it to warm-up for one hour.
2. Install the gate Drive modules that you will use in the Double-Pulse tests. The Gate Drive resistor (R_G) is measured as part of the calibration and its value stored in an EEPROM on the module.
3. Remove the oscilloscope probes from the DPT test fixture and test modules. Do not remove them from the oscilloscope. Probes are re-installed as required for the calibration.
4. From the **Settings** drop-down menu select **Calibration & Compensation**.
5. Follow all on-screen instructions.

Calibration and Compensation includes the following steps:

1. Oscilloscope Probe Compensation
2. Gate Voltage Calibration - VGS/VGE Probe
3. Gate Voltage Source Calibration – VGS Output
4. Gate Current Calibration - IG Probe
5. Gate Resistance Calibration - RG
6. High Voltage Probe Calibration – V_{DS}/V_{CE} Probe
7. Clamp Circuit Probe Calibration – V_{CLAMP} Probe
8. PD1000-60002 Protection Probe Calibration – ID/IC
9. Oscilloscope Probe De-Skew

Oscilloscope Probe Compensation

As the first step calibrating the Double-Pulse Test system, the oscilloscope probes must be adjusted for low frequency compensation. For this, the 10076C and N2873A passive probes have built-in compensation RC divider networks. The N2819A Active Differential Probe requires offset compensation.

NOTE **Allow the oscilloscope and probes to warm up at ambient temperature for a minimum of 60 minutes (1 hour) before performing the adjustment.**

Required Equipment

All equipment required for compensation and calibration were provided with the PD1500A test system. This includes:

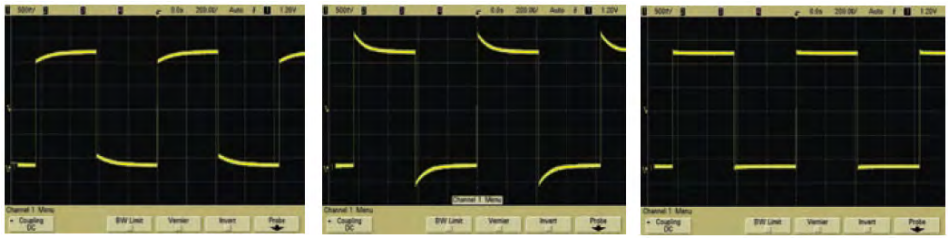
- Spring hook and ground clips for passive oscilloscope probes.
- 5 cm Extension Leads and either Pincer or Micro IC clips for the N2819A Differential probe.
- Low Frequency Compensation trimmer/adjustment tools (small non-metallic screwdriver).

Low Frequency Compensation for the 10076C and N2873A Probes

The Infiniium S-Series Oscilloscopes have a square wave reference signal available on the front panel to use for compensating the passive probes. Attach the spring hook and ground clip to the probe and then the square wave reference terminal.

1. Refer to the N2873A Probe User Guide for instructions. A general description and procedure can also be found on page 5 (Hint #3) of the Keysight 8 Hints for Better Scope Probing.
2. Connect the probe to the oscilloscope's front-panel calibration output (a square wave label is seen near this output).
3. Use the supplied trimmer tool to adjust the Low Frequency compensation to an optimum square wave response as shown below.

4 Adjust so that the square wave on the oscilloscope screen looks square.



Under Compensated Over Compensated Optimum

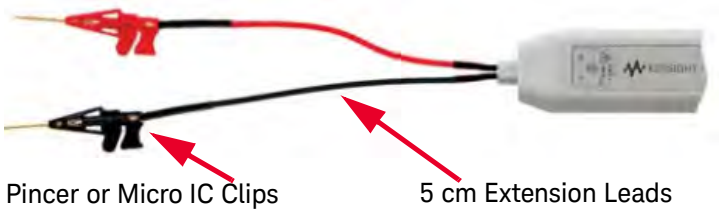
NOTE Due to the 100:1 divider of the 10076C High Voltage Probe, the signal will appear to be very noisy. Therefore, it is beneficial to enable averaging in the **Setup > Acquisition** menu for suppressing this noise. Setting the number of averages to 16 will result in a clean signal.

Offset Compensation for the N2819A Differential Probe

The N2819A Active Differential Probe also requires offset compensation. This is described below and in the N2818/9A Differential Probe User Guide. Use the trimmer tool supplied with the probe to perform the offset zero calibration.

1 Connect the probe to an oscilloscope channel input.

2 Using the probe's 5 cm Extension Leads and the Pincer or Micro IC Clip connection accessories, short the + and - inputs together.



3 Press **Control** > **Autoscale** on the oscilloscope.

4 Press the channel button for the probe and set the oscilloscope channel to DC Coupled mode.

5 Set the oscilloscope to **Averaging** mode (**Setup** > **Acquisition...** > **Averaging Enabled**, x8 or higher) to reduce oscilloscope noise, if needed.

6 Set the vertical scale of the oscilloscope to 100 mV/div.

7 Using the offset adjustment tool that comes with the probe, adjust the probe offset voltage to zero volts.

In the Compensation & Calibration section of the Control Software, software, click the **Skip** button when you have completed the probe compensation.

System Calibration Procedure (Autocal)

CAUTION Follow all on-screen instructions. Damage to the Test Modules is possible if instructions are not followed.

CAUTION **IMPORTANT:** After calibration and before running any Double-Pulse Test, make certain the Low-Side Gate Drive Modules have the V/NC jumper installed and the I/NO jumper removed. Remove all cables from the B2902A SMU.

Calibration requires the B2902A Precision Source/Measure Unit (SMU) and the following cables/adapters:

- 1251-2277 Banana to BNC Adapter, quantity 1. Used with 2- and 4- wire measurements.
- 8121-2816 BNC to SMA Cable, 1 m, 50 Ω, quantity 1. Used with 2- and 4-wire measurements.
- U1168B Standard Probe Kit, quantity 1. Used with Gate Resistance and the Clamp Module 4-wire calibration measurements.
- 2.54 mm jumpers (a package of 10 was provided with the DPT system).

Requirements

- Perform the Oscilloscope Probe Offset Compensation as the first step in the calibration.
- Unless instructed, both High-Side and Low-Side transistors should be removed from the DUT module (if possible).
- Install both High-Side and Low-Side Gate Drive modules, with the same resistance value (R_G) on the Test Fixture.
- The PD1000-66805 Clamp Module is required only for the Clamp Module calibration procedure.
- Perform the oscilloscope probe Deskew as the last calibration step.

NOTE All test instruments must be warmed up for at least 60 minutes at ambient temperature before starting the calibration procedure. Failure to allow warm up may result in inaccurate calibration.

Gate Voltage Calibration – V_{GS}/V_{GE} Probe

Hardware Setup:

- Remove the I/NO Jumper on the Low-Side Gate Drive Module.
- Remove the V/NC Jumper on the Low-Side Gate Drive Module.
- Connect the N2873A V_{GS}/V_{GE} Gate Voltage Probe to the Low-Side Gate Drive Module.
- Connect the BNC to Banana Adapter to the BNC to SMA calibration cable.
- Connect the SMA end of the cable to the SMA connector on the Low-Side Gate Drive Module.
- Connect the banana plug cable to Channel 1 Force terminals of the B2902A SMU (2-wire measurement).
- The Safety Enclosure hood may be left open.

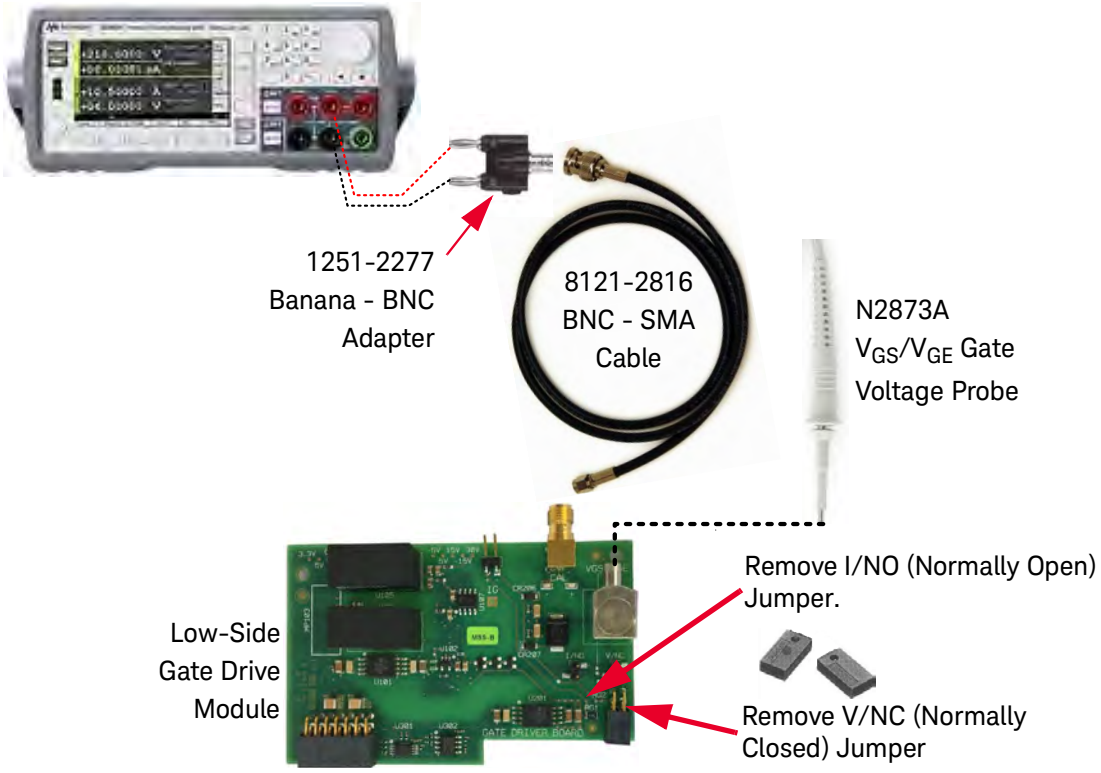


Figure 19 Setup for Gate Voltage Calibration

Procedure:

After setting up the hardware as described above, click **Start** to perform the calibration and continue to the Gate Voltage Source Calibration.

NOTE A strip of 10 header jumpers (Keysight part number 1258-0225) were supplied with your PD1500A for use during calibration.

Gate Voltage Source Calibration – V_{GS} Output

Hardware Setup: Refer to Figure 20 below.

- Remove the I/NO Jumper on the Low-Side Gate Drive Module.
- Install the V/NC Jumper on the Low-Side Gate Drive Module.
- Connect the BNC to Banana Adapter to the BNC to SMA calibration cable.
- Connect the banana plug cable to Channel 1 Force terminals of the B2902A SMU (2-wire measurement)
- Connect the SMA end of the cable to the SMA connector on the Low-Side Gate Drive Module.
- The Safety Enclosure hood may be left open.

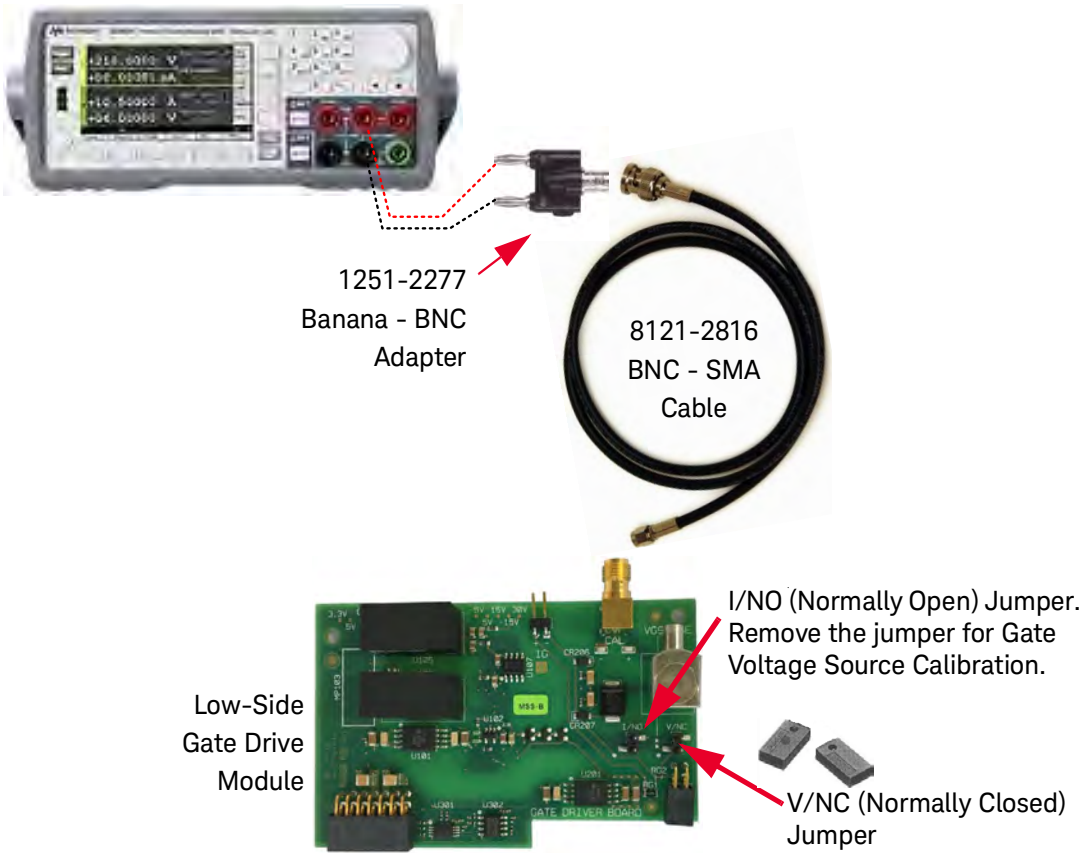


Figure 20 Setup for Gate Voltage Calibration

Procedure:

After setting up the hardware as described above, click **Start** to perform the calibration and continue to the Gate Current Calibration.

NOTE A strip of 10 header jumpers (Keysight part number 1258-0225) were supplied with your PD1500A for use during calibration.

Gate Current Calibration – I_G Probe

Hardware Setup: Refer to Figure 21 below.

- Install the I/NO Jumper on the Low-Side Gate Drive Module.
- Install the V/NC Jumper on the Low-Side Gate Drive Module.
- Connect the N2819A Differential Oscilloscope Probe to the I_G pins on the on the Low-Side Gate Drive Module. Carefully observe polarity when installing probe.
- Connect the U1168B Calibration Cable between the Channel 1 Force terminals of the B2902A SMU (2-wire measurement) and the + and - CAL eyelet terminals on the Low-Side Gate Drive Module.
- The Safety Enclosure hood may be left open.

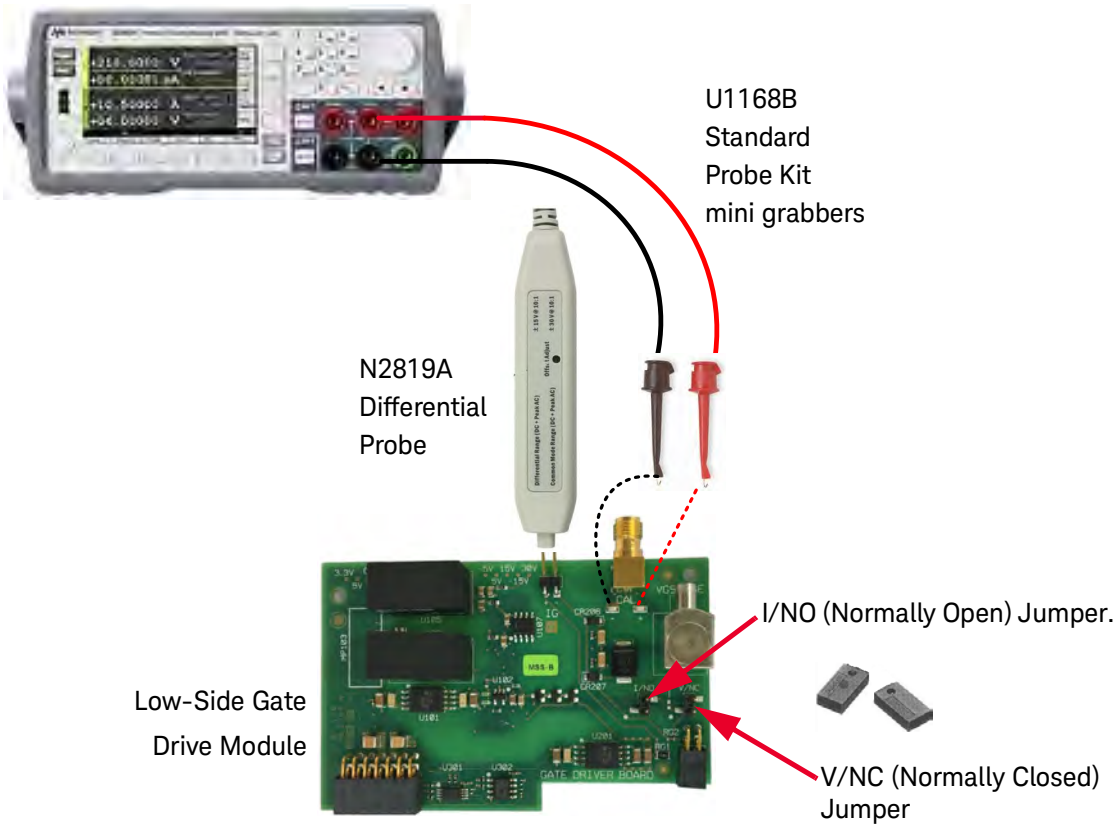


Figure 21 Setup for Gate Current Calibration

Procedure:

After setting up the hardware as described above, click **Start** to perform the calibration and continue to the Gate Resistance Calibration.

NOTE **A strip of 10 header jumpers (Keysight part number 1258-0225) were supplied with your PD1500A for use during calibration.**

Gate Resistance Calibration – R_G

This step is required when installing custom gate resistors on the High-Side and Low-Side Gate Drive modules.

Hardware Setup: See Figure 22 below.

- Install the I/NO Jumper on the Low-Side Gate Drive Module.
- Install the V/NC Jumper on the Low-Side Gate Drive Module.
- Refer to Figure 22 below. Install both calibration cables to connect the B2902A SMU to the Low-Side Gate Drive module.
- The Safety Enclosure hood may be left open.

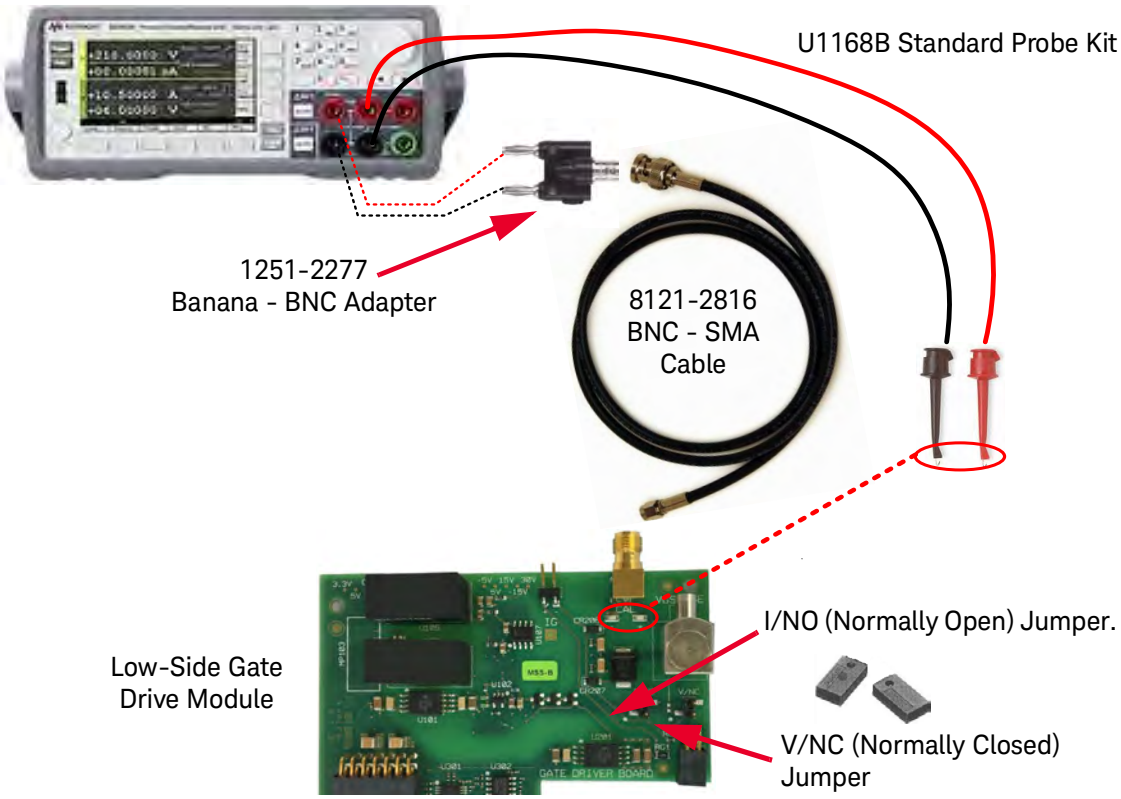


Figure 22 Setup for the Gate Resistance Calibration 4-Wire Measurements

Procedure:

After setting up the hardware as described above, click **Start** to perform the calibration and continue to the High Voltage Probe Calibration.

CAUTION **IMPORTANT:** After the R_G Calibration, the I/NO jumper must be removed from the Low-Side Gate Drive Module.

NOTE There is no calibration for the 0Ω Gate Drive modules or the High-Side Gate Drive modules.

High Voltage Probe Calibration – V_{DS}/V_{CE} Probe

Hardware Setup:

- Install a PD1000-66843 High-Side Gate Drive Module (0 Ω Gate Resistor)
- Install a 1200 V FET (for example, the SCT2080KE FET supplied with the PD1500A) in the High-Side position of the DUT module.
- Remove any FET in the Low-Side position of the DUT Module.
- Remove (do not install) the Low-Side Gate Drive Module.
- Connect the 10076C High Voltage Probe to the DUT Module.
- Remove all other cables and oscilloscope probes.

CAUTION **Safety Enclosure hood must be closed for this test.**

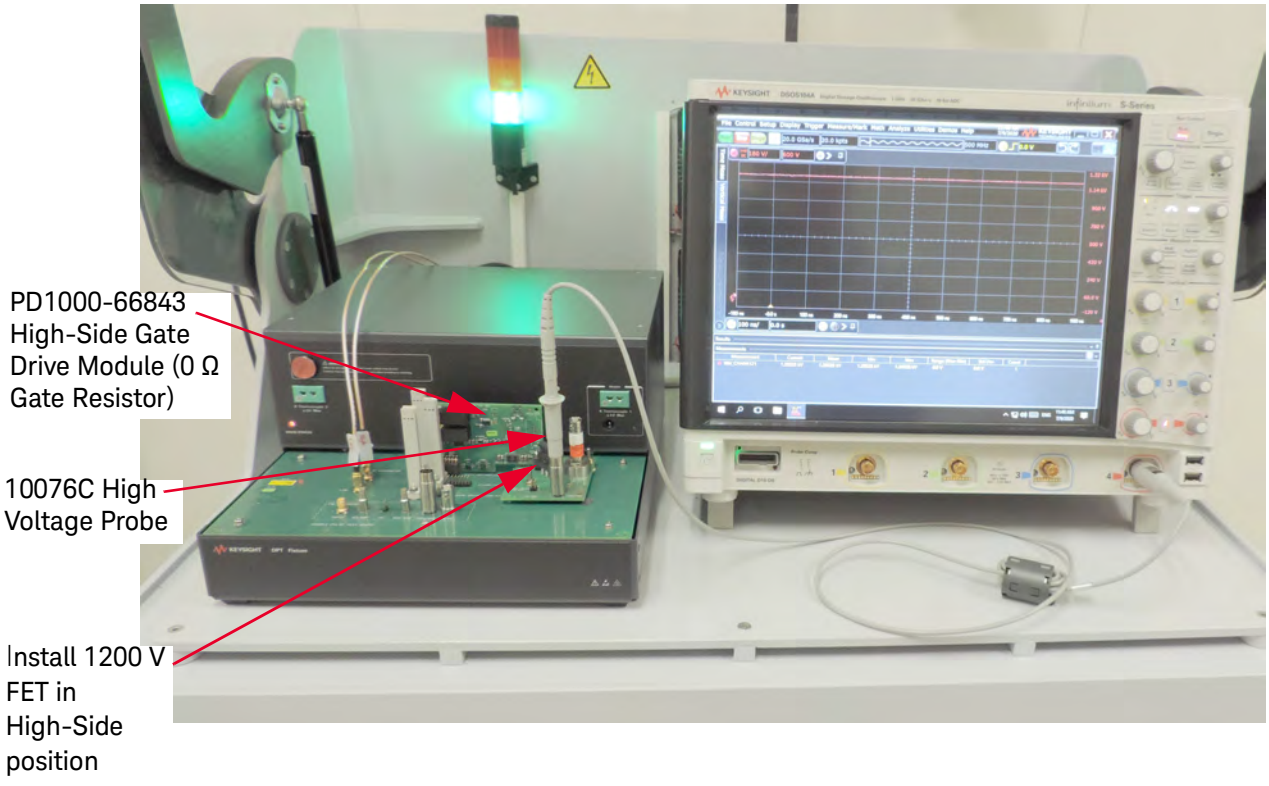


Figure 23 Setup for High Voltage Probe Calibration

Procedure:

After setting up the hardware as described above, click **Start** to perform the calibration.

Clamp Circuit Probe Calibration – V_{CLAMP} Probe

Hardware Setup: See Figure 24 below.

- Install the PD1000-66805 Clamp Circuit Module in the PD1500A Test Fixture. If you are not using or calibrating the Clamp Module, press the **Skip** button to skip this step and proceed to the Protection Probe Calibration.
- Connect the N2873A V_{GS}/V_{GE} Clamp Voltage Probe to the top of the Clamp Circuit Module.
- Using the U1168B Standard Probe Kit, connect banana plugs to Channel 1, Force output of the B2902A SMU.
- On the other end of the test cables, attach two mini clips (one red, one black).
- Connect the mini clips to the **CAL** pins on the Clamp Circuit Module.
- The Safety Enclosure hood may be left open.

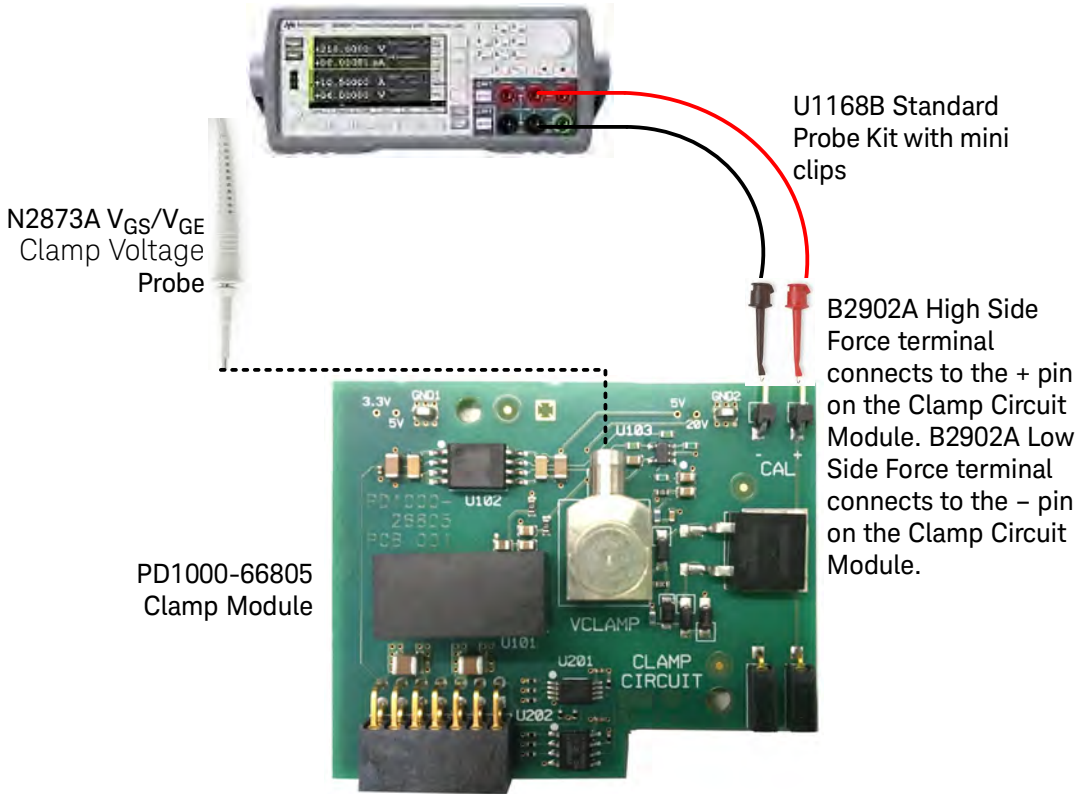


Figure 24 Setup for Clamp Circuit Probe Calibration

Procedure:

After setting up the hardware as described above, click **Start** to perform the calibration and then continue to the next step.

PD1000-60002 Protection Probe Calibration – I_D/I_C

Hardware Setup: Refer to Figure 25 below.

- Connect the PD1000-60002 Protection Probe to the Oscilloscope Channel 2.
- Connect the BNC to Banana Adapter to the BNC to SMA cable.
- Connect the SMA end of the cable to the SMA connector on the PD1000-60002 Protection Probe. Use the 0.56 N-m (5 lb-in) 5/16 in. SMA Break-over torque wrench (provided with the PD1500A system) to tighten the cable to the PD1000-60002 Protection Probe.
- Connect the banana plug cable to Channel 1 Force terminals of the B2902A SMU (2-wire measurement).
- The Safety Enclosure hood may be left open for this calibration step.

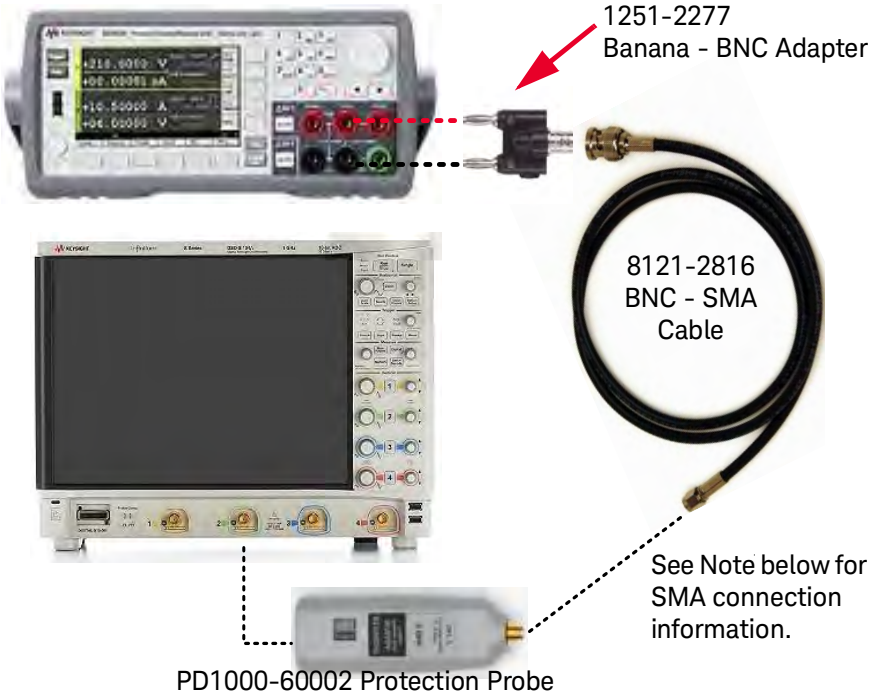


Figure 25 PD1000-60002 Protection Probe Calibration Setup

Procedure:

After setting up the hardware as described above, click **Start** to perform the calibration and then continue to the next step.

NOTE Use the 0.56 N-m (5 lb-in) 5/16 in. SMA Break-over torque wrench (provided with the PD1500A system) to tighten the cable to the PD1000-60002 Protection Probe. Failure to do so might cause extensive ringing in the DPT measurements. See appendix for SMA connector care and connection information.

Coaxial Shunt Resistor Characterization

There is no separate calibration for the PD1000-61901 10 mΩ and the PD1000-61902 100 mΩ Coaxial Shunt Resistors. The De-embedding characterization file installed in the DSOS104 Oscilloscope provides the necessary accuracy.

NOTE The PD1000-61901 Coaxial Shunt Resistor should be removed from the DUT Test Module and shipped to a Keysight Service Center for characterization. This should be done annually.

After the shunt is characterized, Keysight will return the shunt to you. This provides the latest characterization .tf2 file. Download the file from the *Keysight Infoline* website and install it in the DSOS104 oscilloscope.

Install the De-Embedding Transfer File on the DSOS104 Oscilloscope

1 From the temporary location where you unzipped the de-embedding file, copy the .tf2 file to the DSOS104 Oscilloscope. Place it in the folder: *C:\Users\ Public\Documents\Infiniium\Filters*.

NOTE On the DSOS104 Oscilloscope, the file path will show as: *C:\Users\Public\Public Documents\Infiniium\Filters*. However, this is an alias path. Use the path: *C:\Users\Public\Documents\Infiniium\Filters* in the Shunt Settings De-embedding File path in the Control Software.

2 In the PD1000A Control Software, type the .tf2 file name into the **Double-Pulse Measurement Control > Settings > Instrument Configuration > De-embedding File** field. For new PD1500A systems, the de-embedding file was installed in the DSOS104 oscilloscope at the factory with the file name:
MY5840xxxx.tf2

where xxxx is the serial number labeled on the shunt itself.

NOTE The oscilloscope channel you specify for the **Output Current** ID/IC in the DPT Control Software Hardware Configuration screen is the channel that the Coaxial Shunt De-embedding is applied to.

Oscilloscope Probe Deskew

Connect Probes to Deskew Fixture

After the Oscilloscope Probe Compensation and System Calibration, the last step is to run Deskew. Deskew has the greatest impact on both On and Off Delay times and hence affects the total Switching Time. Both On and Off Switching Energies are also affected.

Hardware Setup

Because the oscilloscope has only four input channels and the DPT test fixture uses only four oscilloscope probes at a time, then only four probes may be deskewed at one time. Typically, either the N2819A Differential Probe (for measuring I_G) or the N2873A (V_{CLAMP}) probe are used in a DPT test; rarely are they both used at the same time. Deskew the probes that you will be using in your test. Figure 27 below shows the typical configuration for Deskewing the oscilloscope probes.

1. Locate the Deskew oscilloscope probe connectors on the main Test Fixture. See Figure 26 below.
2. Remove the SMA cable from the Low Side SMA connector on the Test Fixture and connect it to the **Cal (Deskew) Input** SMA connector.

Connect Low-Side (Channel 1) of Waveform Generator to Cal (Deskew) Input

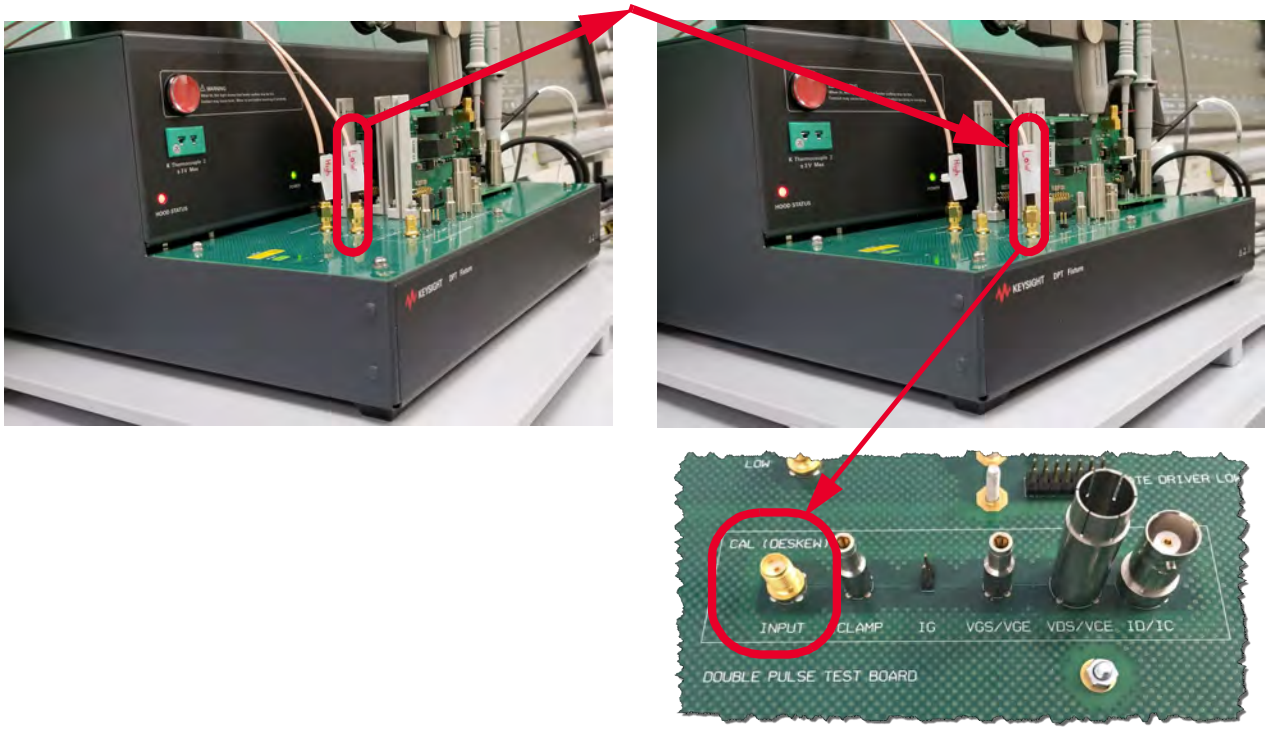


Figure 26 33512B Function Generator Connected to Deskew Fixture

3 Connect the oscilloscope probes to the Deskew section of the Test Fixture.

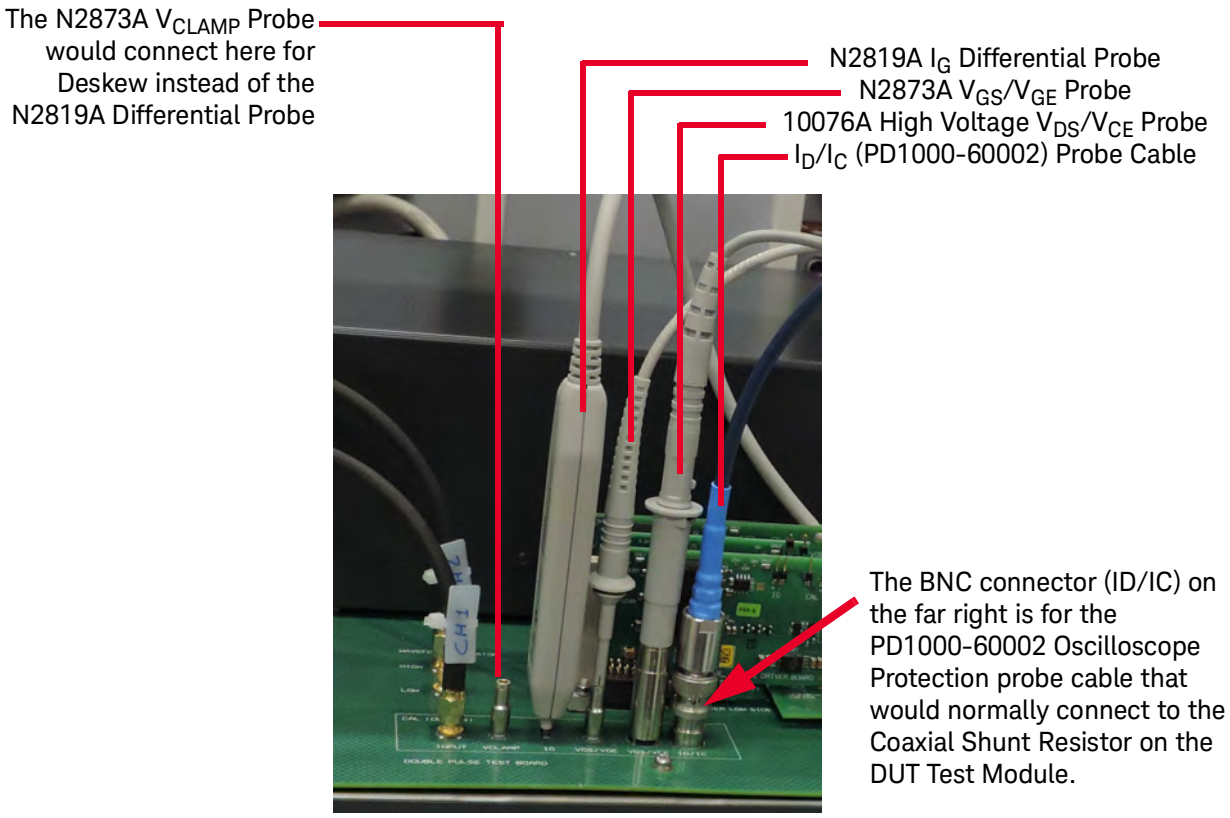


Figure 27 Oscilloscope Probes Connected to Deskew Fixture

NOTE **IMPORTANT:** The N2918A Differential Probe must face to the left; the Keysight logo must face toward the **V_{CLAMP} probe** connector.

Procedure:

1. After setting up the oscilloscope probes in the Deskew fixture, click **Start** to perform Deskew calibration.
2. When complete, return the oscilloscope probes to the appropriate connectors on the DUT and Test Modules.
3. Return the SMA cable from the **Cal (Deskew) Input** SMA connector to the **Low Side** SMA connector on the Test Fixture.

CAUTION **IMPORTANT: After calibration and before running any Double-Pulse Test, make certain the Low-Side Gate Drive Modules have the V/NC jumper installed and the I/NO jumper removed. Remove all cables from the B2902A SMU.**

This concludes the **Compensation and Calibration** procedure.

C Using the Device Heater

PD1000-62001
Device Heater with
Integrated Type K
Thermocouple shown
with Clamp

When making a Double-Pulse Test measurement with the Device Heater activated and a valid temperature specified, the Control Software automatically initiates the measurement when the heater reaches the specified temperature. However, there are several details to consider:

- DUT temperature affects the following: T_{on} transition time, T_{on} and Turn off delay time, Turn on dv/dt, Turn on and Turn off di/dt,
- Are the heater and thermocouple properly connected to the DUT?
- Are the heater and thermocouple connected to the Test Fixture?
- Is the heater activated in the PD1000A DPT Control Software?
- You may want the heater to settle at the specified temperature before initiating the DPT measurement. Don't forget that the heater needs to heat a large thermal mass including the DUT itself and the aluminum clamp.
- After the heater reaches the specified temperature, it may take a few seconds for the internal die of the device itself to reach that temperature.
- What happens if the heater fails to achieve the specified temperature?

This appendix explains how the device heating system and various temperature settings in the Control Software work together.

NOTE Use of the heater/thermocouple is optional. However, they must be connected to the Test Fixture before powering-up the PD1500A system.

NOTE Heater temperatures between 150 °C and 175 °C[1] are valid only for TO-247 device packages. Do not use temperatures above 150 °C for D^2PAK devices.

1 Requires PD1000A Control Software version 2020.820 or later and Test Fixture Firmware A.01.03 or later. Ambient to +175 °C is for TO-247 device packages only; ambient to +150 °C for SMD devices.

CAUTION

Hot Surface; DO NOT Touch! When the PD1500A device heater is used to heat the DUT, it becomes very hot. Do not touch the heater, clamp, or DUT. Do not allow flammable material (such as paper) to come into contact with the heater while it is hot.

CAUTION

Inspect the Heater assembly before every use. If the assembly shows any sign of wear or is cracked, discard it immediately and obtain a replacement. The metal clamp contacts the FET Drain or IGBT Collector; if the heater assembly is damaged, it may contact the metal clamp and apply a very high voltage to the heater circuitry causing damage.

Adding Kapton (polyimide) Tape to TO-247-3 and -4 Devices

Keysight recommends wrapping one layer of Kapton (polyimide) tape (for example, Keysight part number 0460-3128, 0.75 inch wide, 2.7 mil thick) around the TO-247 device before attaching the heater bracket.

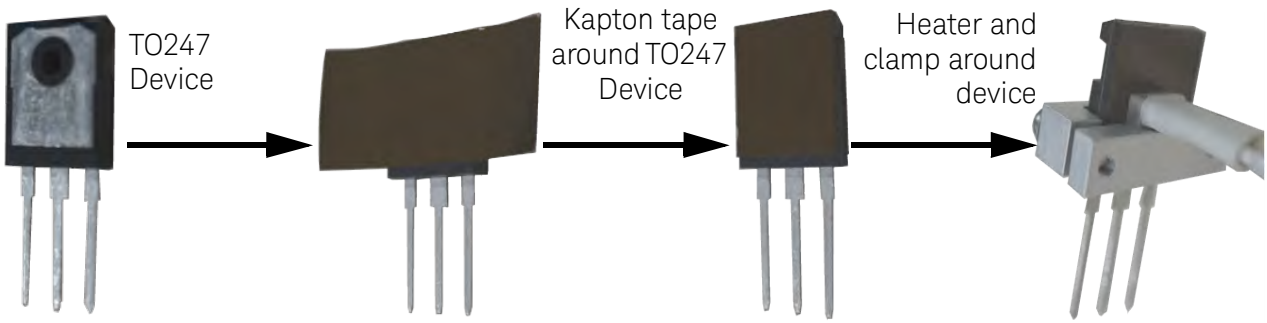


Figure 28 Adding Kapton Tape to a TO-247 Device

Device Heater Theory of Operation

If the device heater operated in a pure vacuum, the heating curve would be a simple straight line -- you apply a certain amount of energy to the heater and it heats to the desired temperature. But in a real-world test system, there are more issues involved. The heater heats not only itself, but also the DUT, the aluminum clamp, plus a small amount of heat is lost to the air.

Therefore, a control circuit applies energy to the heater, monitors its temperature (via a K-type thermocouple) and tries to regulate at the desired temperature. In the PD1500A, the temperature is sampled approximately 10 times per second. The heater itself has a theoretical capacity to heat itself at a rate up to 175 °C per second. In 1/10 of a second then, the heater can raise its temperature approximately
15 °C. So, if you set a small temperature increase, let's say 10 °C, then in 1/10 of a second, the heater can overshoot your desired temperature by 5 °C. Again, it is slightly less than that because heat is transferred to the device, the clamp, surrounding air, etc.

The heater has no capacity to actively "cool" a device; it can only provide heat. Therefore, to lower the temperature, the system must allow the heater to cool and allow the heat to dissipate. This may take a few minutes.

If you set a large temperature change, for example, from 22 °C to 150 °C, then it may take several seconds to arrive at the desired temperature. Again, there is the possibility of slight temperature overshoot.

Figure 30 below shows the fields in the Hardware Configuration used to set the Temperature Tolerance and Settling Time. In Figure 30**, Desired Temperature** is set in the main screen of the DPT control software. Several temperatures may be set with a semicolon list (for example, *25;50;100;150*).

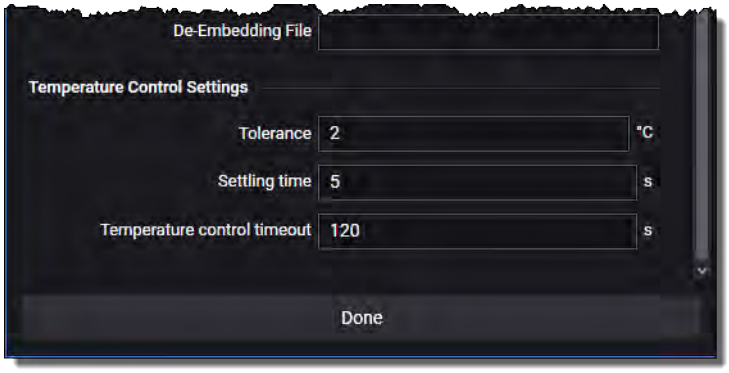


Figure 29 Hardware Configuration Temperature Control Settings

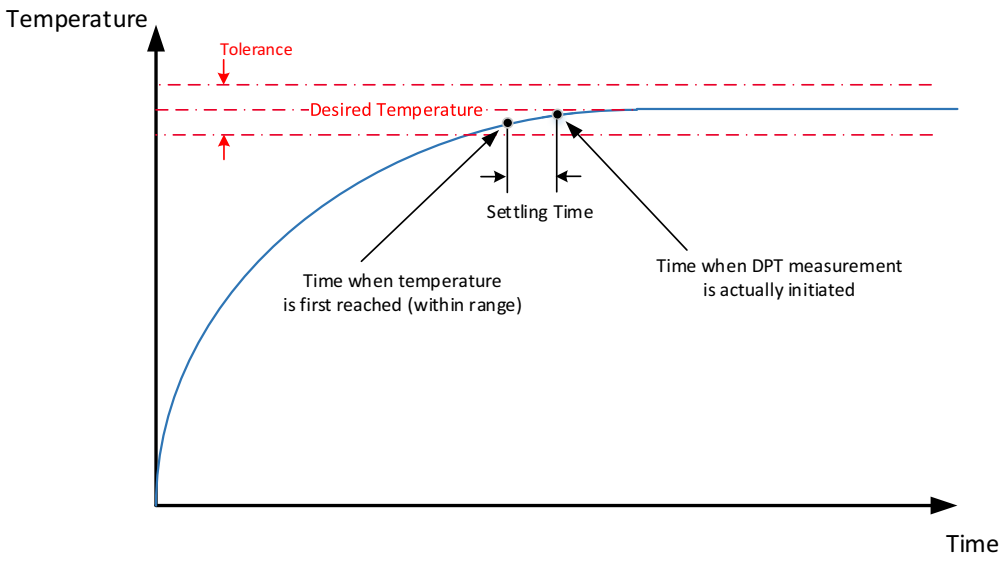


Figure 30 PD1500A Device Heater Timing

Heater Stability

The following table lists typical (not guaranteed) temperature deviation after the specified time. **Settings > Hardware Configuration > Tolerance** set to 2 °C.

Specified Temperature	Temp. after 30 seconds	Temp after 1 min.	Temp after 2 min.	Temp after 5 min.	Delta after 5 minutes
TO-247 Devices					
30 °C	29.67 °C	29.71 °C	29.73 °C	29.73 °C	-0.27 °C
50 °C	49.47 °C	49.50 °C	49.51 °C	49.51 °C	-0.49 °C
100 °C	99.06 °C	99.10 °C	99.12 °C	99.15 °C	-0.96 °C
150 °C	148.72 °C	148.76 °C	145.75 °C	148.79 °C	-1.21 °C
D2PAK-7 Devices					
30 °C	31.30 °C	29.80 °C	29.81 °C	29.81 °C	-0.19 °C
50 °C	49.52 °C	49.56 °C	49.28 °C	49.58 °C	-0.42 °C
100 °C	99.23 °C	99.22 °C	99.23 °C	99.23 °C	-0.77 °C
150 °C	148.93 °C	148.91 °C	148.91 °C	148.94 °C	-1.06 °C

Using the Device Heater

There are two parts to configuring the PD1500A Device Heater:

- Configuring the Temperature Control Settings
- Activating the Heater and specifying Temperatures to test the DUT

NOTE If you want to use the heater and thermocouple, they must be connected to the Test Fixture before powering-up the PD1500A system.

Configuring Temperature Control Settings (Hardware Configuration)

In the **Settings > Hardware Configuration** for Double-Pulse Test Control menu, set the following:

- **Tolerance:** Specify a range (±) around the specified temperature for triggering the DPT measurement. For example, if you specify making a DPT measurement at 100 °C and a 1 °C Tolerance, then the measurement is triggered somewhere between 99 °C and 101 °C.

- **Settling Time:** Specify a time period (in seconds) to wait after the heater reaches the specified temperature (within the specified Tolerance) before triggering the DPT measurement.
- **Temperature Control Timeout:** Specify the maximum time period (in seconds) to wait for the device to reach the specified temperature before triggering the measurement. If the device does not reach the specified temperature within this time period, the Double-Pulse Test aborts.

For example, to go from ambient temperature (~25 °C) to 100 °C with a 2 °C Tolerance may take up to 60 seconds.To go from Ambient to 100 °C with a 1 °C Tolerance may take up to 90 seconds.

Activating the Heater and Setting Test Temperatures

- **Activate Heater:** Turns the heater circuit on or off.
- **Temperatures:** Enter a single value or a semicolon (;) delimited list of temperatures to heat the device to when running the DPT tests. This box is grayed-out unless **Activate Heater** is checked.

NOTE When the heater/DUT temperature exceeds approximately 50 °C, the large red light on the Test Fixture turns on.

Table 2 lists several examples and expected results when using the PD1500A Heater and Thermocouple. It assumes the following test conditions:

- Gate High Voltage: 18 V
- Gate Low Voltage: -2 V
- V_{DS}: 300 V
- I_D: 10 A
- Tolerance: 20%
- Temperature Range: 1 °C
- Temperature Timeout: 30 S.

Table 2 Measurements Using Heater and Thermocouple

Temperature(s) Specified (in PD1000A Software)	Heater Activated (in PD1000A Software)	Thermocouple Connected to Test Fixture	Heater Connected to Test Fixture	Expected Result
50 °C	YES	YES	YES	Test runs normally at a temperature between 49 °C and 51°C. Temperature is recorded.
50;60 °C	YES	YES	YES	Both tests run normally at temperature: First test between 49 °C and 51°C. Second test between 59 °C and 61°C. Temperatures are recorded.
50 °C	NO	YES	YES	Test runs normally but with no heating. Device temperature is recorded.
50 °C	NO	YES	NO	Test runs normally but with no heating. Device temperature is recorded.
50 °C	NO	NO	NO	Test runs normally but with no heating. No temperature (NaN[1]) is recorded.
50 °C	YES	NO	NO	Test aborts with the error message, "*Failed to read temperature. Is a thermocouple connected?*"
50 °C	YES	YES	NO	Test aborts with the error message, "*The heater did not respond. Is the heater connected?*"
50 °C	YES	NO	YES	Test aborts with the error message, "*Failed to read temperature. Is a thermocouple connected?*"

[1]NaN means "Not a Number" – valid number (temperature) is missing.

D Update Test Fixture Firmware

Use the following procedure to update the firmware in the PD1500A Double-Pulse Test Solution Test Fixture. To prepare for this procedure, you must first download the firmware update (*.upd) file and the Keysight Firmware Update Utility to your local PC drive.

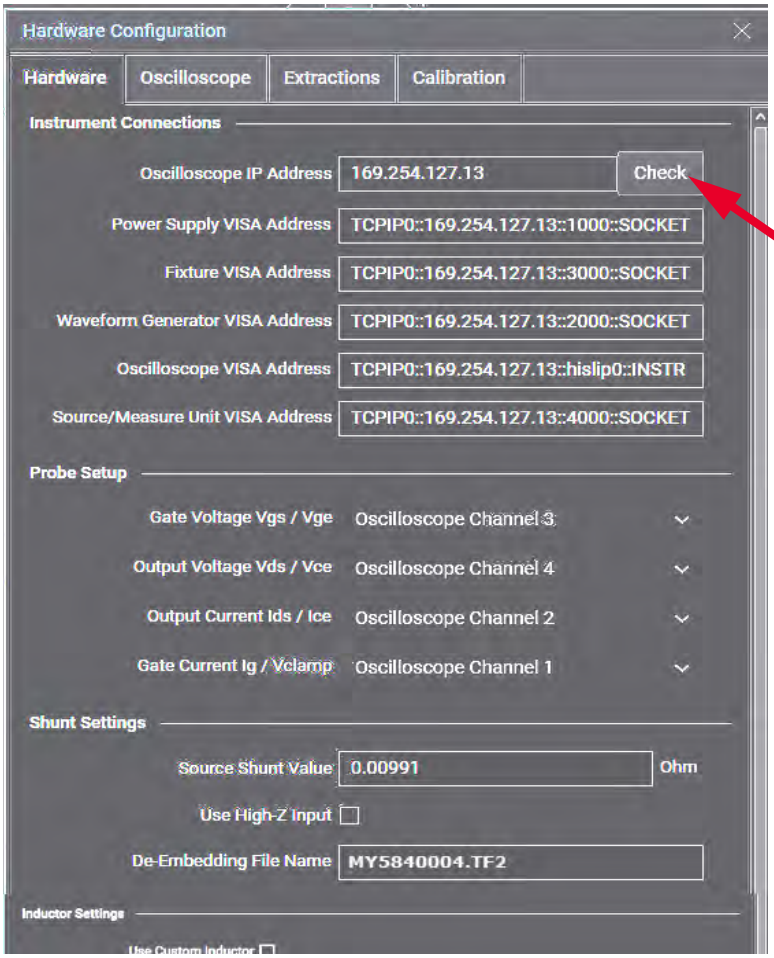
CAUTION Be sure to execute the Firmware Update procedure only under conditions or reliable power and I/O connectivity to the Test Fixture. For example, do not update the firmware with an intermittent LAN connection, a loose power cord, or during a thunderstorm that may interrupt power. Loss of power or connectivity may cause the firmware update to fail, possibly leading to instrument inoperability.

NOTE **IMPORTANT:** If you are using a laptop computer, turn the Wireless Network Connection off in the laptop before attempting to connect to the PD1500A system.

Identify Current Version of Test Fixture Firmware

In the PD1000A Control Software:

1. Select the **Double-Pulse Test Control** tab.
2. Click on the **Settings** icon at the top of the screen.
3. Select Hardware Configuration for Double-Pulse Test Control.
4. Select the **Hardware Configuration > Hardware** tab opens the following dialog.

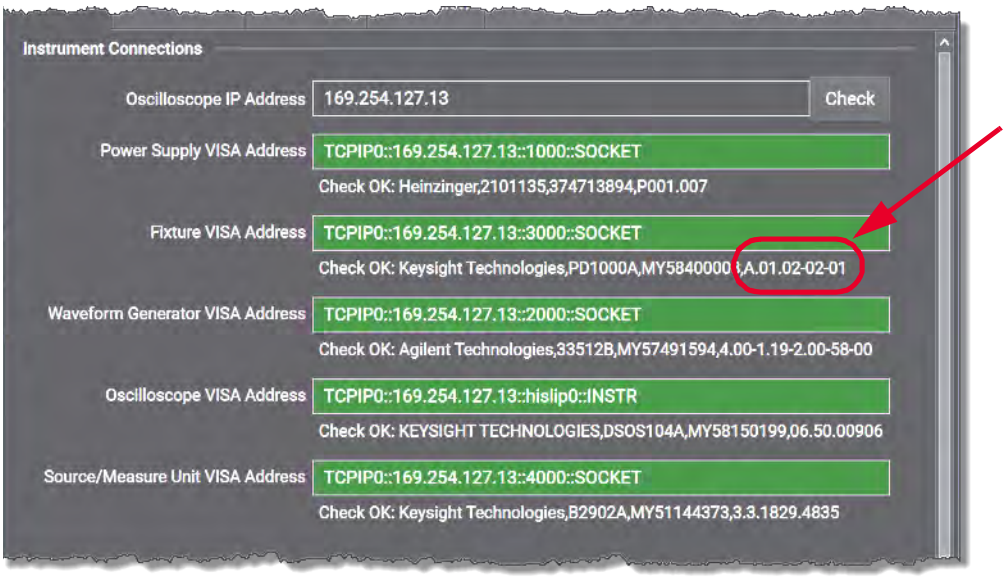


Check Button used to verify communication with test instruments.

Figure 31 Double-Pulse Test Hardware Configuration Screen

5 Click the **Check** button to verify that the Control software can communicate with all of the DPT system instruments. After a few moments, all of the

addresses should turn green and the Test Fixture serial number and firmware code appears:



If any or all of them are red, it indicates a failure to communicate.

When pressing the **Check** button ***IDN?** is sent to all the test instruments in the DPT system. If this is successful the instrument address turns green. Additionally, for the DPT Test Fixture the complete ***IDN?** response appears. This includes the serial number and circuit board revision codes.

The full identification string documentation for the ***IDN?** response format is:

Keysight Technologies,PD1000A,<serial number>,<revision codes>

A typical return is:

Keysight Technologies,PD1000A,USP600R295,A.XX.YY-01-02

where the revision codes are in the form:

A.XX = major firmware revision
.YY = minor firmware revision
01 = control board id
02 = dpt board id

Firmware Update Process

When firmware updates become available, the update and an installation utility will be available at: www.keysight.com/find/PD1500Afirmware.

1 Install the *Keysight Firmware Update Utility* on your PC.

2 Download the latest firmware version to the host PC. Save the firmware file to a temporary location on the host PC. The firmware file name will be in the form: *SAKEXX_rev_A_xx_yy.upd*.

3 Run the *Keysight Firmware Update Utility*. .

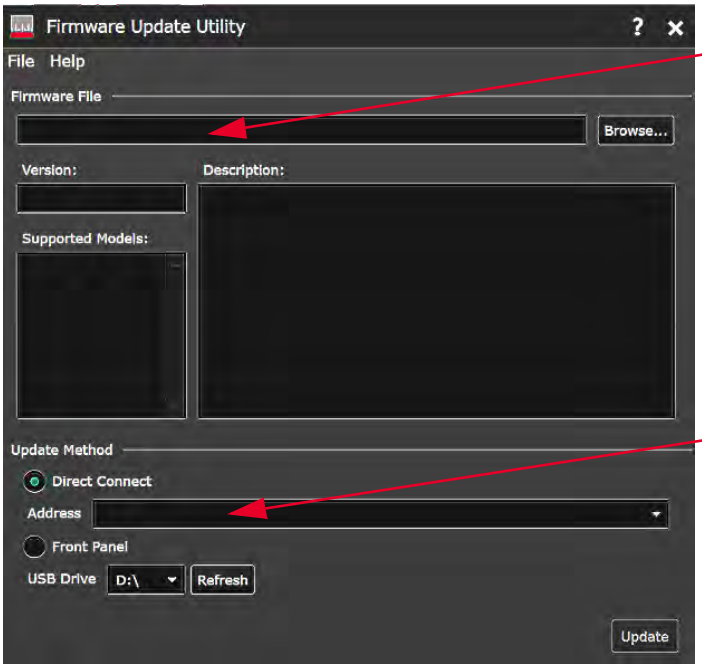
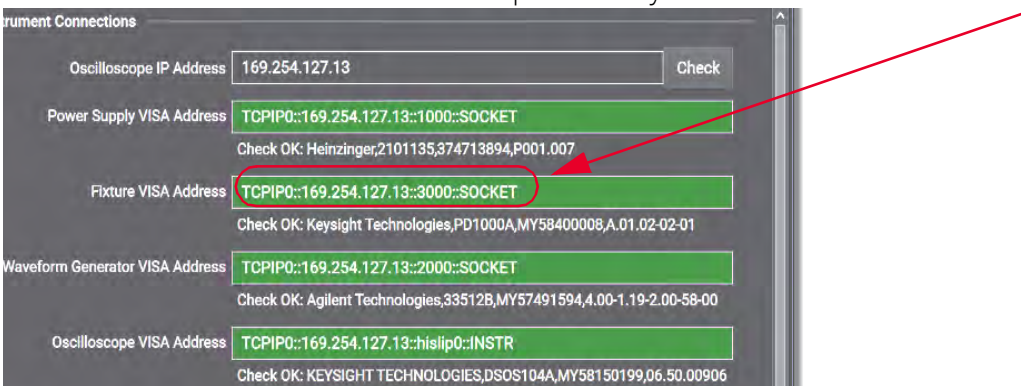


Figure 32 Keysight Firmware Update Utility

4 Use the Browse button in the utility to browse to the location where you save the new firmware file. Select the file.

5 Copy the Fixture VISA address from the **Hardware Configuration > Hardware** tab. Paste it into the *Address* field in the update utility.



6 Click the **Update** button.

When the utility finishes updating the firmware, the Test Fixture automatically reboots.

E SMA Connectors

Good connections are essential for accurate calibrations and measurements and require a skilled operator. The most common cause of measurement error is poor connections. The following information is for use when connecting the two Waveform Generator cables to the DPT Test Fixture and when connecting the BNC-SMA cable to the PD1000-60002 Protection Probe. IMPORTANT: proper connection can help prevent ringing during a DPT test.

SMA connectors mate with 2.92 and 3.5 mm connectors. However, a damaged SMA connector, or a used SMA connector with a slightly bent pin can destroy a 2.92 or 3.5 mm connector. In SMA connectors, the center pin connects first, before the threads. If an SMA pin is bent or off-center for any reason, then the pin will make contact with the 2.92/3.5 mm female contacts which are unsupported as an air dielectric is used, and the female contact may be pushed out of place.

1. Ground yourself and all devices. Wear a grounded wrist strap and work on a grounded, conductive table mat.
2. Visually inspect the connectors. If necessary, clean the connectors.
3. Carefully align the connectors. As you make the actual connection, be sure the connectors align perfectly.
4. Push the connectors straight together. Do not twist or screw the connectors together.
5. Engage the connector nut (of the connector with the retracted sleeve) over the threads of the other connector (the connector with the extended sleeve). Turn only the connector nut. Let the connector nut pull the two connectors straight together.
6. Do not over tighten this connection. A connection in which the outer conductors make gentle contact at all points on both mating surfaces is sufficient. Very light finger pressure is enough to accomplish this.
7. Make sure the connectors are properly supported. Relieve any side pressure on the connection from long or heavy devices or cables.
8. Torque the connection according to the procedures described below.

Final Connection Using a Torque Wrench

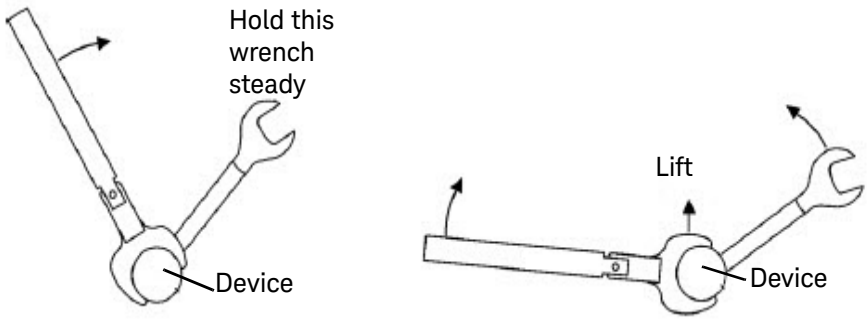
Using a torque wrench guarantees the connection is not too tight, preventing possible connector damage. It also guarantees that all connections are equally tight. Prevent the rotation of anything other than the connector nut that you are tightening.

Use a Keysight 8710-1582, 0.56N-m (5 lb-in) 5/16 inch break-over torque wrench to make a final connection. A Torque wrench is supplied as part of the PD1500A Accessory Kit.

Figure 33 Keysight 8710-1582 SMA Torque Wrench

NOTE The Keysight 8710-1582, 5 lb-in Torque Wrench is a precision instrument and should be treated and maintained like a measuring instrument.

1. Turn the connector nut. This may be possible to do by hand if one of the connectors is fixed (as on a test port). However, it is recommended that you use a second open-end wrench to keep the body of the device from turning.
2. Position both wrenches within 90 degrees of each other before applying force. Wrenches opposing each other (greater than 90 degrees apart) will cause a lifting action that can misalign and stress the connections of the device involved. This is especially true when several devices are connected together. Refer to the following figure.



Correct method
(reduces lift on connection)

Incorrect method
(too much lift on connection)

Figure 34 Wrench Positions

3 Hold the torque wrench lightly, at the end of the handle only (beyond the groove). See the following figure.

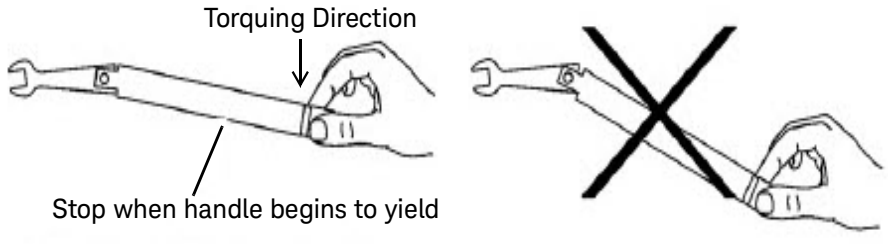


Figure 35 Using the Torque Wrench

4 Apply force downward to the wrench handle. This applies torque to the connection through the wrench. Do not hold the wrench so tightly that you push the handle straight down along its length rather than pivoting it, otherwise you apply an unknown amount of torque.

CAUTION **You don't have to fully break the handle of the torque wrench to reach the specified torque; doing so can cause the handle to kick back and loosen the connection. Any give at all in the handle is sufficient torque.**

5 Tighten the connection just to the torque wrench break point. The wrench handle gives way at its internal pivot point. Do not tighten the connection further.

Separating Connections

To avoid lateral (bending) force on the connector mating plane surfaces, always support the devices and connections.

CAUTION **Do not turn the device body. Only turn the connector nut. Damage to the center conductor can occur if the device body is twisted.**

1 Use an open-end wrench or spanner wrench to prevent the device body from turning.

2 Use another open-end wrench or the torque wrench to loosen the connector nut.

3 Complete the separation by hand, turning only the connector nut.

4 Pull the connectors straight apart without twisting, rocking, or bending.

Inspect and Clean Connectors

Clean connector interfaces prolong connector life and produce more accurate and repeatable measurements. When using SMA female connectors, pay special attention to the contact fingers on the female center conductor. These can be bent or broken, and damage to them is not always easy to see. A connector with damaged contact fingers will not make good electrical contact and must be repaired or replaced.

Inspect each connector to make sure that no particles or residue are present.

Connector Cleaning

WARNING **Always use protective eye-wear when using compressed air or nitrogen.**

WARNING **Keep isopropyl alcohol away from heat, sparks, and flame. Store in a tightly closed container. Isopropyl alcohol is extremely flammable. In case of fire, use alcohol foam, dry chemical, or carbon dioxide; water may be ineffective.**

Use isopropyl alcohol with adequate ventilation and avoid contact with eyes, skin, and clothing. It causes skin irritation, may cause eye damage, and is harmful if swallowed or inhaled. It may be harmful if absorbed through the skin.

Wash thoroughly after handling. In case of spill, soak up with sand or earth. Flush spill area with water.

Dispose of isopropyl alcohol in accordance with all applicable federal, state, and local environmental regulation.

- Use compressed air to loosen particles on the connector mating plane surfaces.
- Apply a small amount of isopropyl alcohol to a lint-free swab. Clean the connector threads. Let the alcohol evaporate, then blow the threads dry with a gentle stream of clean, low-pressure compressed air or nitrogen. Always completely dry a connector before you reassemble or use it.

F Measurement Tips and Troubleshooting

This appendix provides simple PD1500a troubleshooting procedures and checks.

- Do a complete visual inspection.
- Make certain that the Safety Enclosure Hood is closed and **LOCKED**!

  -- The **Hood Status** light on the Test Fixture should be green.
- Make certain that the test modules (DUT module, both High-Side and Low-Side Gate Drive modules, and the Clamp Circuit module [if used]) are properly installed. For example, if no current is drawn but the Heinzinger power supply front panel indicates the correct voltage for the test, then verify that the Low-Side Gate module is properly installed; the 4 pin header may not be properly connected to the DUT Module.
- If you are using a laptop as the host PC, make certain the wireless connection is turned off in the laptop.
- Ensure hardware is properly set up with all of the test instruments, 'scope probes, etc.
- If possible, run each of the DPT system Calibration & Compensation steps.
- Heater not detected. Use of the heater/thermocouple is optional. However, they must be connected to the Test Fixture before powering-on the PD1500A system. Reboot the PD15000A if the heater is not detected.

NOTE Waveforms from the PD1500A Double-Pulse Tests system are different from waveforms shown in various test standards. This is because of issues such as gate plateau, ringing due to parasitic inductances and capacitances, voltage drop due to stray inductances, overshoot, etc.

Typical Problems

1. Running the Double-Pulse Test but the oscilloscope does not show waveforms.
   - Check the Keysight 33512B Waveform Generator for errors, it may not be sending the proper output signals.
   - Ensure the waveform generator cable are connected correctly to the Test Fixture. For Example, ensure the Low Side is not connected to the Deskew connection.
   - Try different Gate Drive modules.
2. No High voltage shown on Heinzinger Power Supply front panel.
   - Check the Heinzinger PS front panel display. Is the supply in current limiting? DUT may be shorted.
   - Check 10076C High Voltage Probe and ensure it is properly, completely inserted in the DUT Module probe holder.
3. Little or no gate voltage shown on screen.
   - Check the N2873A probe and connection to the Low-Side Gate Drive Module and ‘scope.
   - Ensure that only the V/NC jumper is installed on the Low-Side Gate Drive module. The I/NO jumper must be removed.

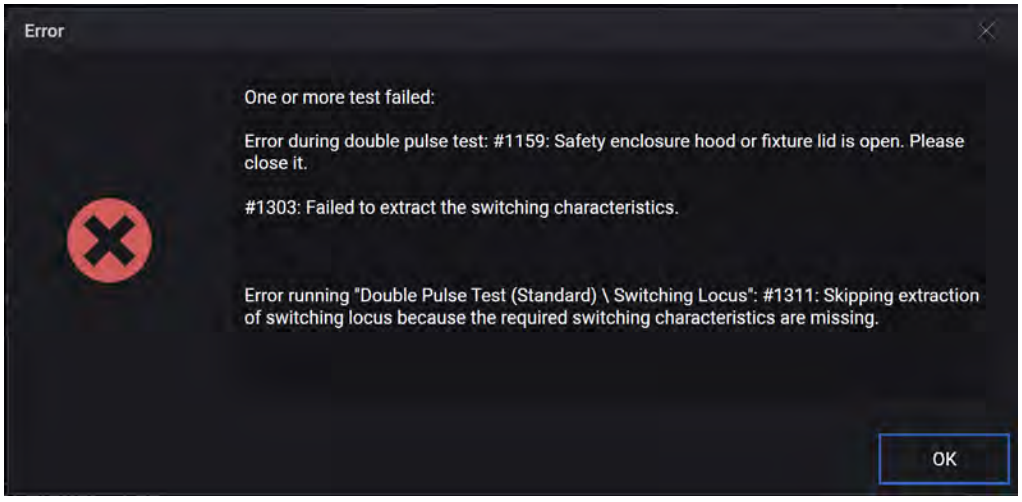
Error Messages

Problem: Error Message Occurs

Test finished with errors: voltage charge failed
Voltage reached x V for target voltage y V.

- Make certain the safety hood is closed and **LOCKED**!
- Check the **Hood Status** light on the Test Fixture -- it should be green.

Problem: Error Message Occurs



Solution: You are attempting to run a DPT but the Safety Hood is not closed and locked. Use the key provided with the PD1500A to lock the safety hood.

Problem: No Drain-Source Current (I_{DS}) with sufficient Gate Drive (V_{GS}) voltage and supply voltage (V_{DS})

Solution: The most likely problem is that the Low-Side Gate Drive Module is not properly installed on the Test Fixture. Verify that the module is properly installed and retest. If this does not solve the problem, the DUT may have failed.

Problem: Error Message -- One or more extractions failed

Solution: The Gate Drive Voltage (V_{GS}) must be at least 13 V.

Problem: Error Message -- Failed to Generate IV Derivation

Solution: For the IV derivation use 100 Ω Gate Drive Modules to do the extraction properly.

Check the screen captures to make sure that the DUT is fully turned on by making the on time big enough.

It is also very important that the signal (mainly V_{GS}) does not have too much noise. In Settings > Measurements there is an IV Derivation section. Enable “Auto smoothing” to make sure the signal is smooth enough for IV derivation.

Problem: Drain Voltage (V_{DS}) goes negative and then very high

Consider the following oscilloscope screen captures. You can see that the Drain Voltage (V_{DS}) goes negative (approximately -40 V) when the DUT is turned ON, and then V_{DS} shoots very high (approximately 1.56 kV).

Adjusting the Drain current (I_D) did not resolve the problem.

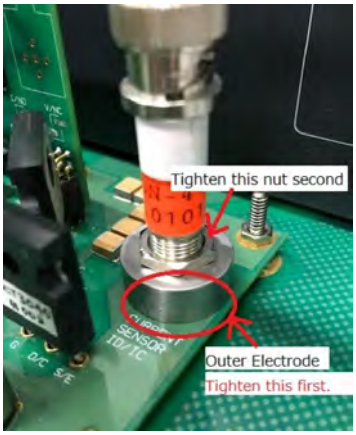
Solution: Coaxial Shunt not properly installed. The shunt bushing was not tight against the copper pad on the DUT Module. See *PD1500A Test Fixture Guide* or *PD1500A System Installation Guide*.

Problem: Loose Shunt Resistor Connection

Because connection to current shunt port is done many times, the connection of outer conductor of shunt to the ground tends to get loose over time. This loose connection makes undesirable measurement results.

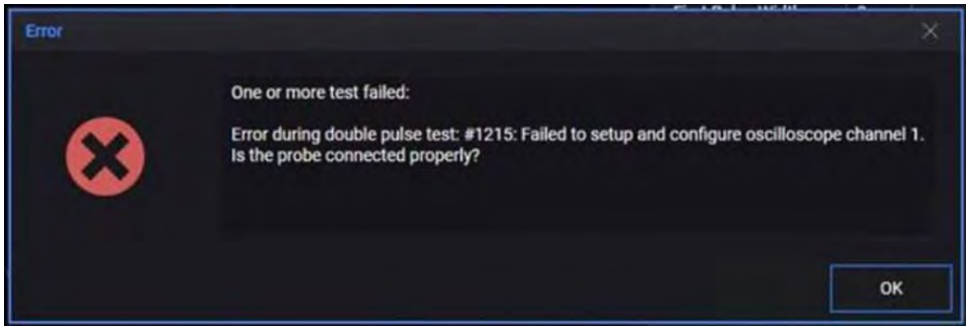
Another typical faulty measurement result is for I_D to increase very rapidly exceeding the scale of scope.

I_D (green trace) increases too rapidly

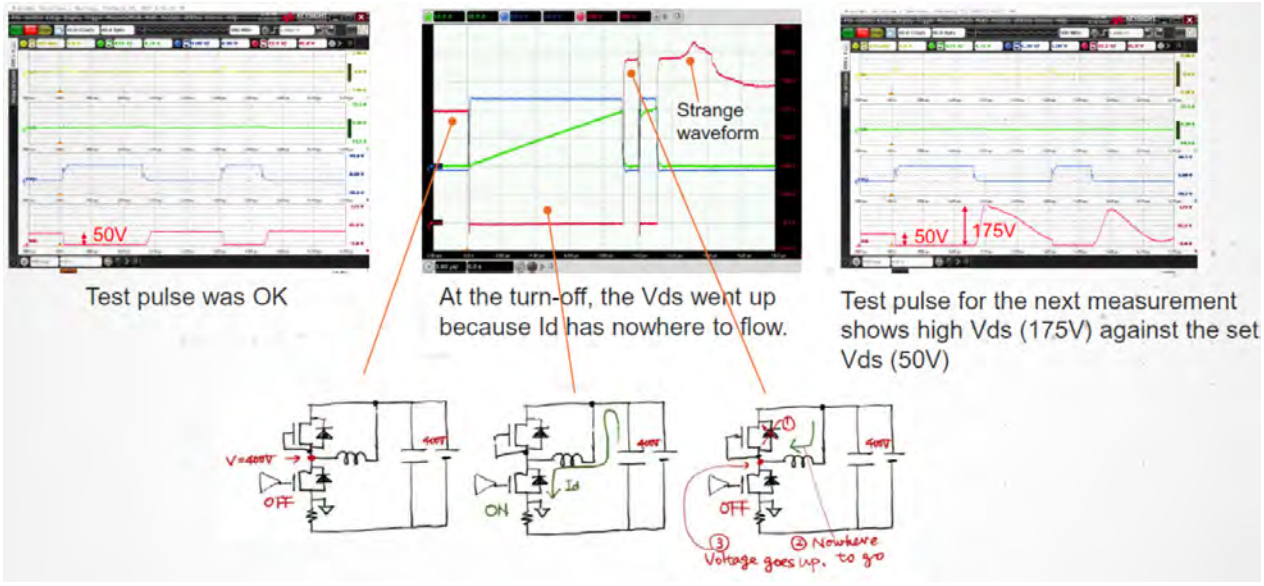


Problem: Error related to Oscilloscope Channel 1

This error happens when 'clamp' tab is accidentally selected when a differential probe (N2819A) is attached to CH1.



Problem: High-Side Device is Broken

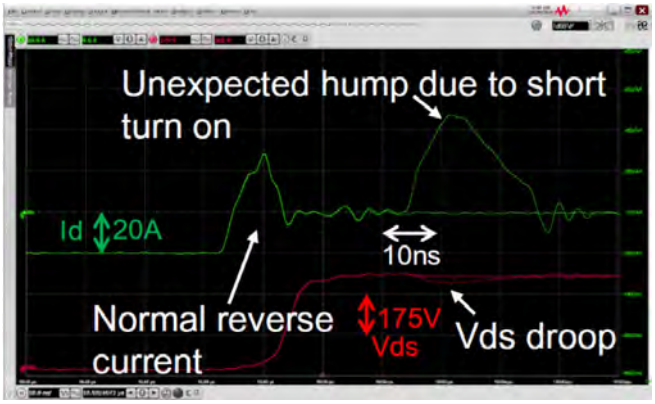


For GaN Devices

Problem: On Reverse Recovery, Avoiding Unnecessary “Hump”

Strange phenomena observed when performing reverse recovery of GaN HEMT. There are 2 humps after the reverse current as shown below.

This hump happens with small dip on V_{DS}. If the graph is superimposed on the successful results, it is caused by unexpected turn on or false turn-on of the DUT.



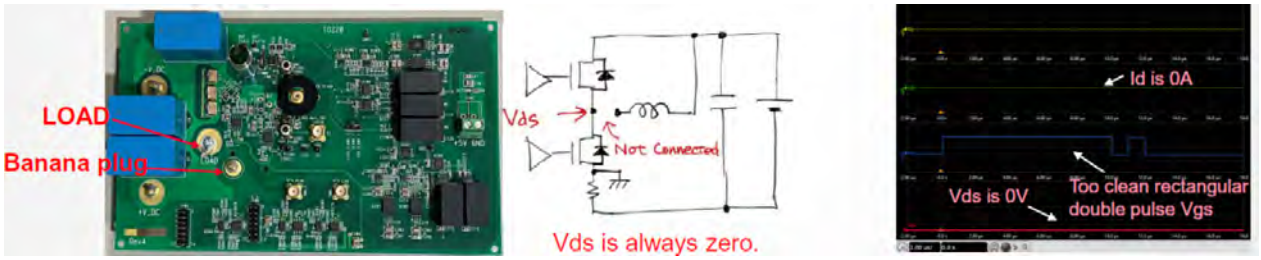
To avoid this problem, apply negative voltage to the DUT in order to make sure the (low-side) DUT is off throughout the test and not affected by parasitic turn on.

Problem: Inductor Not Connected Properly

Observed phenomena:

- V_{DS} doesn't ramp up and it is shown 0 V on the scope screen throughout the test
- V_{GS} shows too clean double pulse trace on the scope
- Heinzinger shows intended voltage with 0 mA
- Red Tower light in the enclosure illuminates

- Potential cause or actual case
  - When using external inductor, the inductor is not connected to load port but the following banana plug which is floating electrically.
  - Hand made inductor was disconnected at the joint because enamel was not removed when soldering.

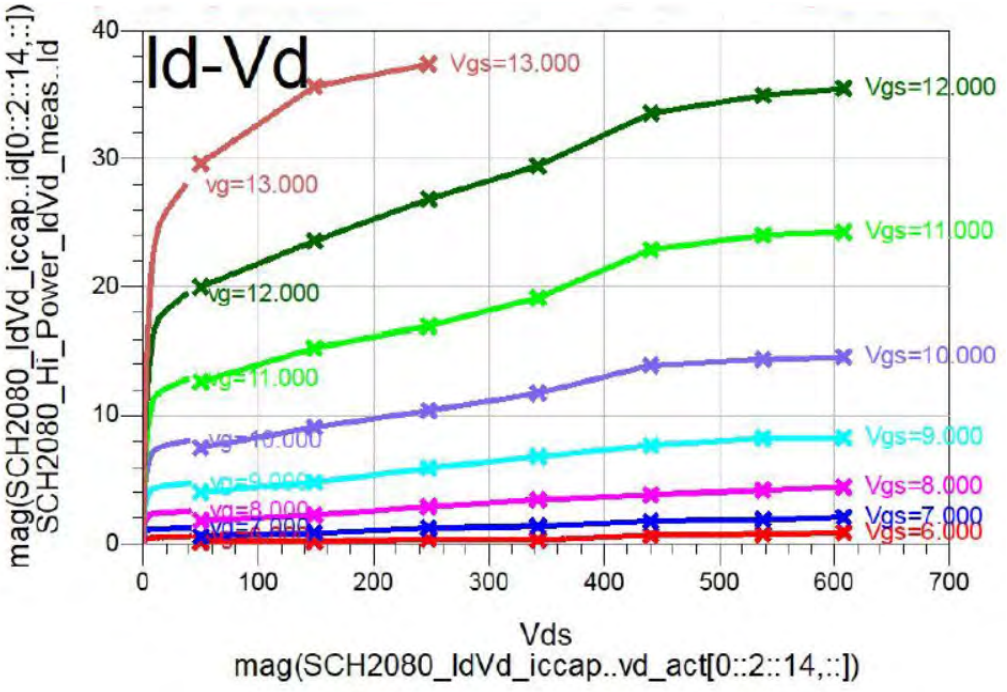


A Technique to Create an Accurate High-Power IV Curve

In the graph below, the low voltage region was measured by B1506A and the high voltage region was measured by PD1500A. The following technique was used to put them together to create an accurate high-power IV curve.

- Use the same DUT for B1506A and PD1500A.
- Use a large R_G (e.g. 100Ω).
- Set V_{GS} low to less than 0 V (e.g. V_{GS} = -2 V to +18 V).
- Set I_D as large as possible (e.g. I_D = 40 A).
- V_{DS} step should be reasonably large (e.g. 50 V to 650 V with 100 V step).
- Note that inductor change can cause discontinuity in the graph. It is generally best to use an external inductor.
- Set OFF pulse width long enough so that the V_{DS} ringing is settled and V_{GS} comes back to V_{GS} low.
- Set 2nd ON pulse width long enough for V_{GS} to reach a large enough value. Use a large inductive load (e.g. 470 μH) to avoid I_D reaching too high value.

PD1500A and IC-CAP (B1506A)



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