PRELIMINARY
DATA SHEET

Keysight PD1500A Dynamic Power Device Analyzer/Double Pulse Tester

Success in areas such as renewable energy and electric vehicles (EVs) depends on the ability to compete with longstanding traditional technologies. In search of competitive advantage, developers are looking for new approaches that can make major contributions to performance and efficiency.

Achieve reliable, repeatable characterization of wide-bandgap semiconductors

Introduction

Power converters are a key component enabling the electrification of the transportation, renewable energy and industrial markets. To facilitate needed advances in power converter design, new wide-bandgap (WBG) semiconductor technologies, based on silicon carbide (SiC) and gallium nitride (GaN), are being commercialized. WBG semiconductors provide major leaps in speed (10x to 100x faster than older designs), higher voltage and thermal operation, which in turn improve efficiency, reduce size and cost.

However, the resulting high-performance power converters are proving difficult to design due to many new challenges when characterizing WBG semiconductors. These difficulties delay the innovation of semiconductor manufacturers and engineers designing new converters.

Homegrown test systems have been the primary source for characterizing WBG semiconductors. Building these systems has been necessary because, to date, commercially available test systems have not been readily available. Unfortunately, it is difficult to produce reliable and repeatable measurement results with one-off testers. Unreliable results create additional obstacles for power-converter designers when correlating their measurements with the semiconductor's data sheets.

To enable consistent, reliable characterization of WBG semiconductors, Keysight created the PD1500A dynamic power device analyzer platform. Initially employing the Double Pulse Test (DPT) technique, it has been developed in close collaboration with semiconductor manufacturers and designers from energy and electric vehicle (EV) industries.

Reduce your time to market with the PD1500A

As an off-the-shelf measurement solution, the PD1500A delivers reliable, repeatable measurements of WBG semiconductors. The platform ensures user safety and protection of the system's measurement hardware.

The ability to ensure repeatable DPT results is built on Keysight's expertise in measurement science. Examples include innovations in high-frequency testing (gigahertz range), low leakage (femto-ampere range), and pulsed power (1,500 A current, 10 µs resolution). As a result, Keysight is uniquely positioned to help you overcome the challenges of dynamic power-semiconductor characterization.

Included with the PD1500A are standard measurement techniques such as probe compensation, offset adjustment, de-skewing, and common mode noise rejection. These techniques are utilized within an innovative measurement topology and layout. A semi-automated calibration routine (AutoCal) that corrects for system gain and offset errors was specifically developed for this system. The system also uses de-embedding techniques to compensate for inductive parasitics in the current shunt.

Overview: Established and emerging measurement methods

Fully characterizing a SiC- or GaN-based WBG device requires both static and dynamic measurements. Keysight's B1505A and B1506A power device analyzers excel at static measurements. The PD1500A has the needed flexibility to address a variety of dynamic measurements and the evolution of JEDEC standards as they take shape.

Static measurements: The following parameters are typically used to understand the static characteristics of a power device:

- Output characteristics
- On-resistance
- Threshold voltage
- Transconductance
- Junction, input, output and reverse transfer capacitance
- Breakdown voltage
- Gate charge

Static measurements: Power device analyzers

Keysight is the industry's *de facto* leader in static measurements, and the preferred solutions are the B1505A and B1506A power device analyzers.

The B1505A provides the broad and deep measurement capabilities needed by developers creating new semiconductor devices. The B1506A provides the core set of test functions more commonly needed by product designers when evaluating semiconductor devices for use in a power module.

www.keysight.com/find/B1505A

www.keysight.com/find/B1506A

Dynamic measurements: As JEDEC continues to define the dynamic testing of WBG devices, some standardized tests are starting to emerge. The DPT determines these key performance parameters:

- Turn-on characteristics
- Turn-off characteristics
- Dynamic on-resistance
- Dynamic current and voltage
- Switching characteristics
- Reverse recovery
- Gate charge
- Derived output characteristics

Ruggedness testing: Since WBG devices operate with high voltages and at high temperatures, characterizing ruggedness is necessary. The key measurements determined by short-circuit testing and avalanche testing include:

- Short-circuit conduction time
- Short-circuit energy
- Avalanche energy

Take a closer look

The remainder of this brochure provides deeper dives into Keysight's measurement solutions, including essential product specifications, and the relevant measurement techniques.

Dynamic power converter design challenges

Semiconductor and power engineering teams are in a tenuous position. The market forces them to quickly develop and ship reliable products, while needing to overcome changing technology, unreliable measurements in a hazardous test environment. In the absence of commercial characterization solutions, most engineering teams have been forced to develop their own solutions. Some of their key challenges are listed below.

- Improving efficiency has resulted in higher frequency switching converters. Accounting for the high-frequency energy is important in both characterizing power semiconductors and in modeling and simulating them in power converter designs. This additional complication challenges the traditional power designer.
- The combination of increased frequency and higher power affects the reliability of the measurements. It is often hard to distinguish whether the measured signal is the device characteristic or the parasitic characteristic of the measurement setup.
- Operating with greater voltage (> 1000 V) and current (> 100 A) levels leads to a more hazardous test environment. Design and test engineers need to use extra precaution when working with lethal power levels.
- The process for making WBG semiconductors is still maturing and is not as well studied as Si-based semiconductors. The resulting unproven reliability makes it difficult for many designers to commit to WBG devices for their designs. This isn't stopping some designers from using these new devices for mission critical applications such as renewable energy and EV's.
- Characterization and test standards are under development and will soon drive a common methodology for testing WBG devices.

JC-70 Wide Bandgap Power Electronic Conversion Semiconductors

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

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

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

As a result of the challenges above, WBG device manufacturers struggle to consistently characterize their devices. Data sheets often provide specifications defined more narrowly than the breadth of a specific application (e.g., temperature). These specifications are often typical and not guaranteed. As a result, power-converter designers often end up characterizing the semiconductors themselves, augmenting the manufacturer's provided specifications. Obviously, new approaches are needed for characterizing, modeling and simulating power semiconductors and their respective converter designs.

Dynamic Power Device Characterization

As various JEDEC committees address standardization of WBG device characterization, the DPT technique has become the standard for determining performance parameters of power semiconductors.

DPT Operation

The measurement process proceeds as follows:

- S1 is closed, enabling the high-voltage supply to charge C1 (DC-link capacitor) and C2 (blocking capacitor).
- S1 is opened and T2 is turned on, enabling C1 to charge inductor L. Pulse length is used to determine I_D threshold.
- T2 is then turned off, enabling turn-off characteristics to be determined for T2. I_D is maintained through the free-wheeling body diode in T1.
- T2 is turned on again to determine turn-on characteristics of T2.

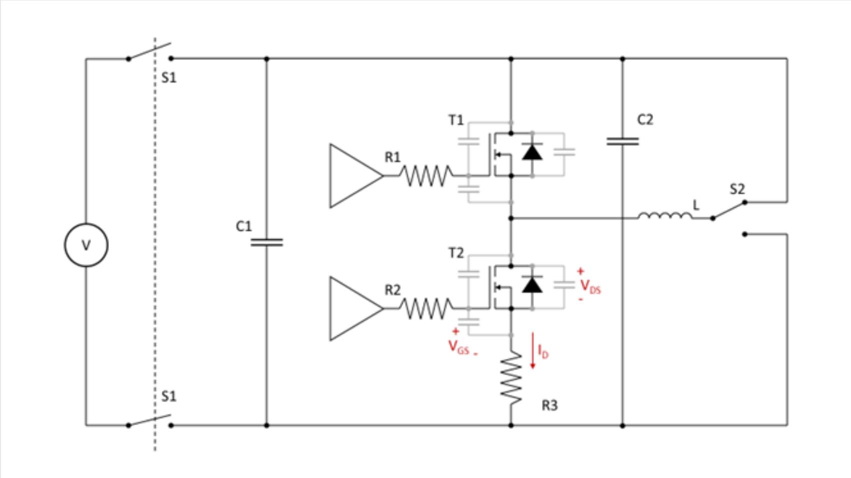


Figure 1 - Basic DPT Setup

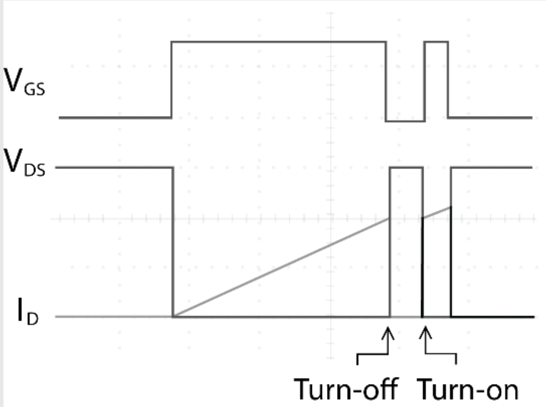


Figure 2 - Basic DPT Waveforms

DPT Parameters

Group	Parameters	Description	Associated Standards
Turn-On Characteristics	$t_{d(on)}$, t_r, t_{on}, $e_{(on)}$, dv/dt, di/dt	Characterizes how quickly the transistor can turn on, the maximum di/dt and dv/dt, and the resulting energy loss. Contributes to switching loss characteristic.	FET – IEC 60747-9 IGBT - 60747-8
Turn-Off Characteristics	$t_{d(off)}$, t_f, t_{off}, $e_{(off)}$, dv/dt, di/dt	Characterizes how quickly the transistor can turn off, the maximum di/dt and dv/dt, and the resulting energy loss. Contributes to switching loss characteristic.	FET – IEC 60747-9 IGBT - 60747-8
Switching Characteristics	I_d vs. t, V_{ds}, vs. t, V_{gs} vs. t, I_g vs. t, Clamped V_{ds} vs. t, e vs. t, I_d vs V_{ds} (switching locus)	These time-based parameters are waveforms retrieved directly from the oscilloscope. The I_d vs V_{ds} (switching locus) are derived from the waveforms.	
Reverse Recovery	t_{rr}, Q_{rr}, E_{rr}, I_{rr}, I_d vs. t	Characterization of reverse recovery of body diode in vertical FETs. Provides additional timing information regarding how quickly the transistor can switch between on and off.	IEC 60747-8
Gate Charge	V_g vs. Q_g, (Q_{gs}(th), Q_{gs}(pl), Q_{gd})	The voltage and the current of the gate are measured during a double pulse turn-on operation. The charge on the gate during different gate voltage transitions is characterized. This parameter is used to determine the driving loss of the transistor.	IEC 60747-8 IEC 60474-9
Derived Output Characteristics	I_d vs. V_g, I_d vs. V_d	Provides basic transfer characteristics for the semiconductor.	

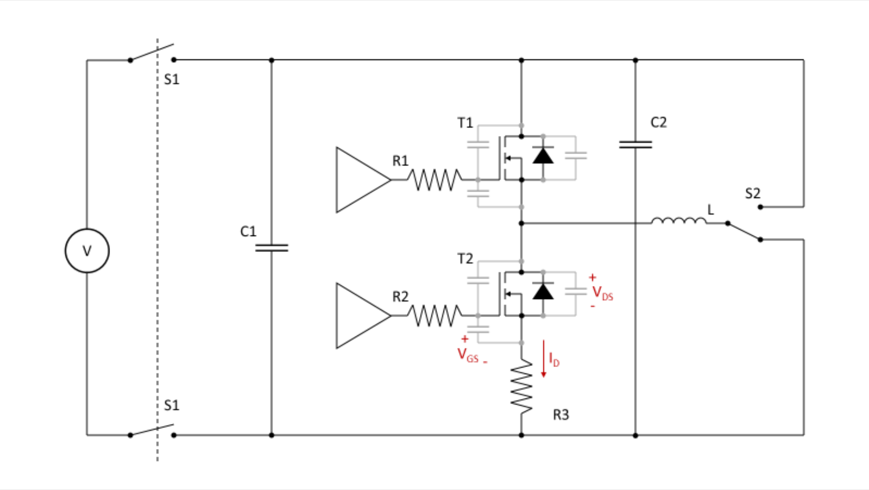


Figure 3 - Basic Reverse Recovery Test Configuration (T2 Body Diode – DUT)

Reverse recovery is also measured using a double pulse, but the load inductor is now switched across T2 and T1 is used to charge the inductor. After T1 is turned off, the body diode in T2 conducts. When T1 is turned on again, the reverse recovery of T2 can be measured.

Repeatable, Reliable Measurements

Common Measurement Practice

Keysight's PD1500A uses many common measurement practices. Some attenuation probe errors are eliminated by compensating the passive probes and adjusting the offset of the differential probe as recommended. Care was taken to minimize parasitic capacitance and inductance when laying out the DPT setup in the fixture. In order to correlate the timing of each measurement probe, de-skew is also implemented.

AutoCal

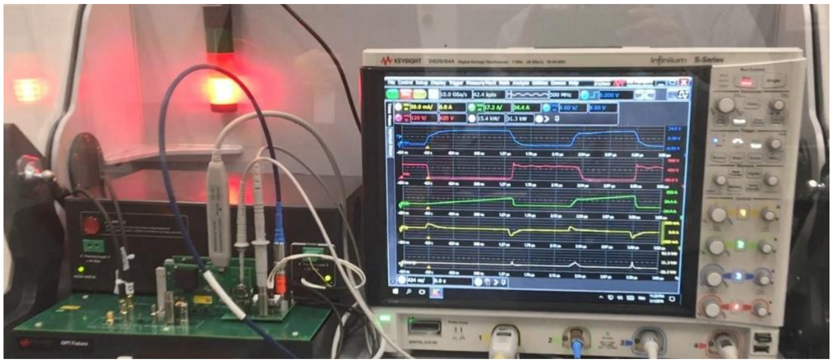
Gain and offset errors for each oscilloscope channel/probe can often lead to errors in the DPT waveforms, which will impact the extracted parameters. The PD1500A incorporates an automatic calibration technique that uses a known-good accurate, internal system voltage standard to measure and characterize each oscilloscope channel. Gain and offset errors are compensated for to provide more accurate and repeatable DPT waveforms.

De-embedding

Current shunts often have poor bandwidth and inconsistent performance from shunt to shunt. Keysight characterized a popular coaxial shunt with a network analyzer and found a wide variability in bandwidth, from ~25 MHz to 300 MHz. This variability significantly impacts dynamic testing of higher-speed WBG power devices. With the current de-embedding technique, the transfer function is measured for each current shunt that is used for I_D measurements. This data is entered into the oscilloscope, which basically applies the inverse of the shunt's transfer function to the output signal measured in order to flatten the response across the bandwidth of interest. This method increases the accuracy of I_D measurements, resulting in a more accurate extraction of DPT parameters.

Safe Test Environment

Your safety is critical when testing power semiconductors. Keysight designed multiple safety features into the PD1500A to enhance your safety. The test environment is covered by a transparent hood, protecting the user from contacting high voltages. When > 42V is energized, the hood is locked and the red light is illuminated.



For further protection, the PD1500A provides an Emergency Off Operation (EMO) button to disconnect high voltages when pressed.

Expandable Power Device Platform

The initial PD1500A introduction focuses on performance testing such as DPT for Si and SiC discrete devices (1.2 kV and 200 A maximum). However, the PD1500A platform was developed with modularity in mind, enabling expansion of its capabilities as needs and standards develop.

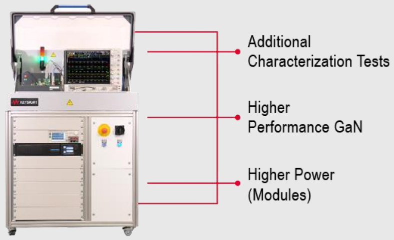


Figure 4 - Expandable PD1500A Platform

Additional Characterization Tests

Ruggedness tests (short circuit and avalanche) are planned to be added to the platform soon. As the JEDEC JC-70 standard evolves, we will continue enhance the suite of characterization tests.

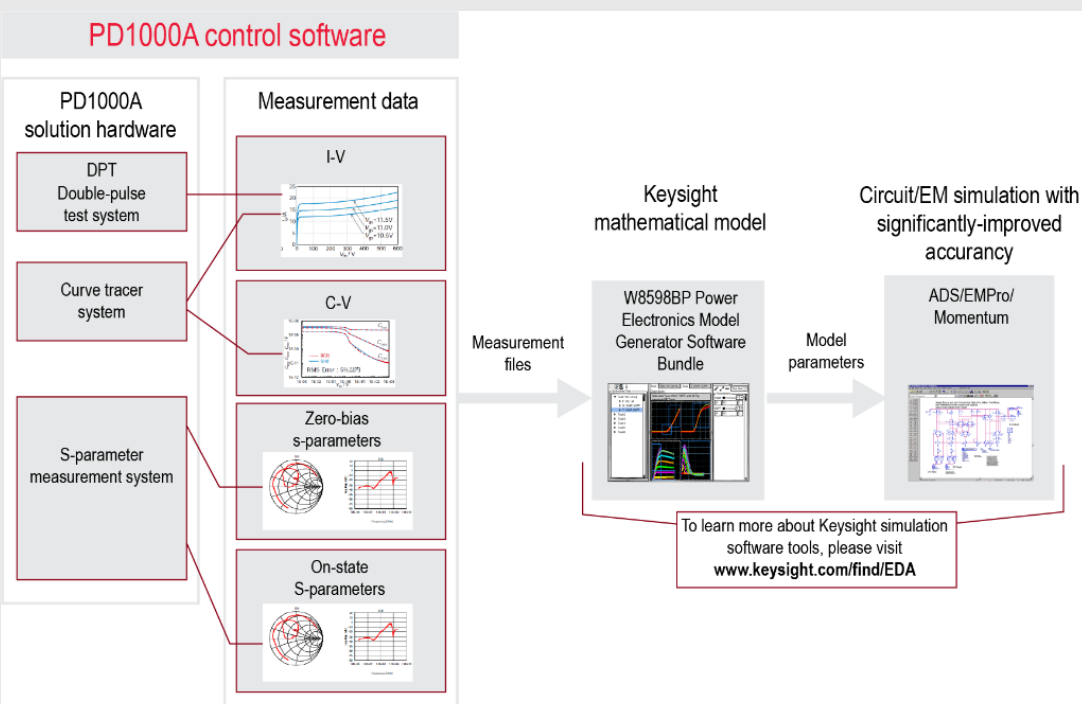
Higher Performance GaN Characterization

The higher switching speeds of GaN make it particularly challenging to test. Therefore, new enhancements focussed on fixturing and an increased performance will be developed for GaN discrete devices.

Higher Power Module Testing

Many developers purchase modules (2x, 4x, 6x, etc.) for their power converter designs instead of discrete devices. Higher power module testing capability for power converter applications such as the EV market will be added.

PD1000A Power Device Measurement System for Advanced Modeling



Key Features

- Easily create models you can trust for any WBG device with real measurements right on your bench*
- Exclusive WBG device modeling results in accurate simulations of EMI, in-rush, overshoots, switching time, etc.
- Easily identify causes of EM noise in simulation, before the design is finalized
- Complete, one-vendor solution of hardware, software, consulting and support services worldwide

Please reference the PD1000A Power Device Measurement System for Advanced Modeling Solution Brochure (5992-2700EN) for more information.

PD1500A Overview and Basic Operation

The PD1500A is designed to be modular, allowing for a variety of devices (SiC, IGBTs, Si MOSFETs and soon GaN), different characterization tests (DPT and soon short circuit and avalanche), different power levels (> 1.2 kV, > 200A), and module test. The initial system provides complete DPT characterization and parameter extraction for Si- and SiC-based power semiconductors, supporting maximum power operation at 1.2 kV and 200 A.

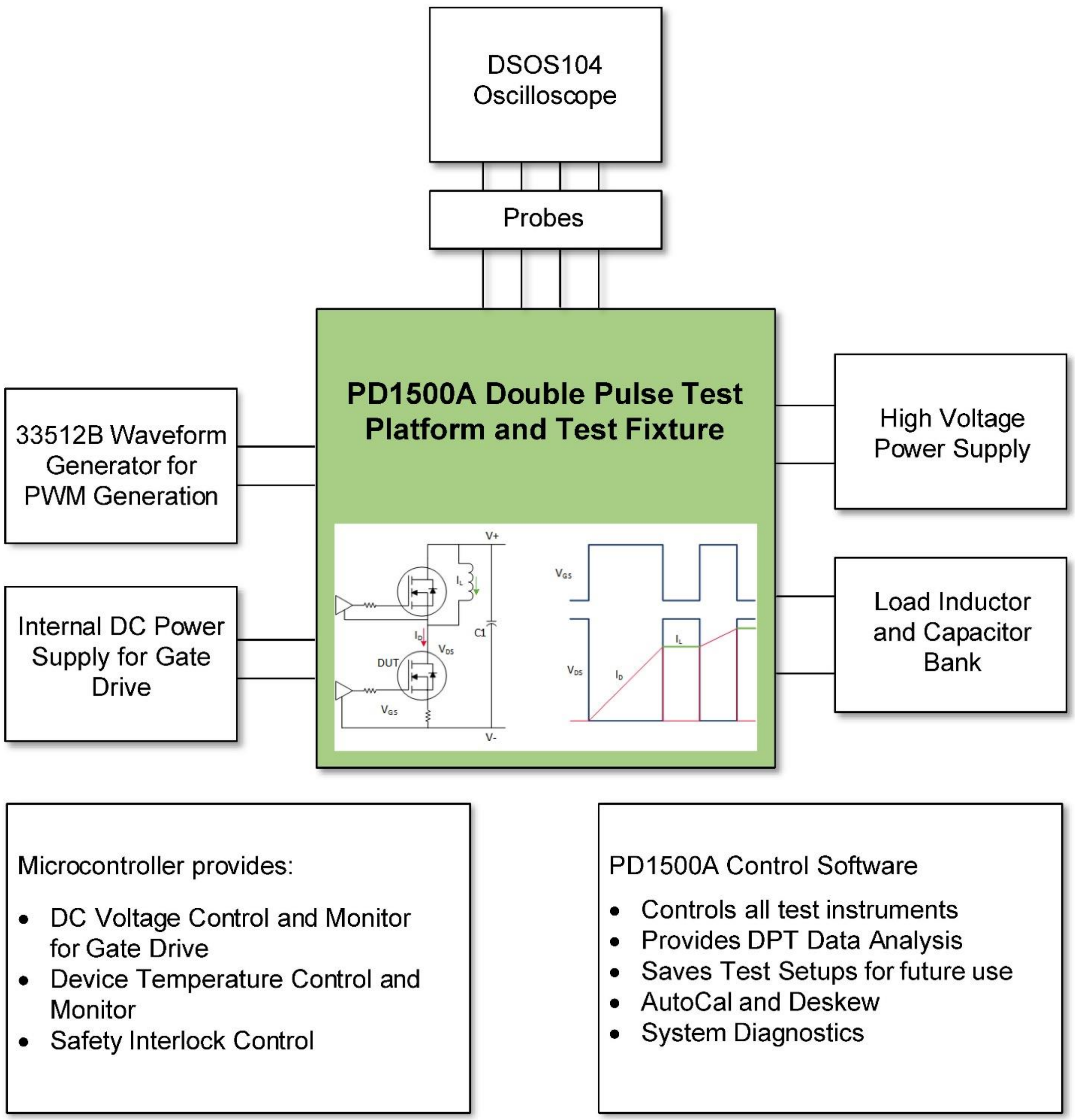


Figure 6 - PD1500A Block Diagram

The PD1500A fixture allows TO-247 or SMD packages to interface with the system. Connections for de-skew and AutoCal are readily available. When high-current and module testing is included, the system will scale to the appropriate size for the DC-link capacitor and load inductors. When high performance GaN testing is included, integration of the gate drivers, clamp circuit, DC–link capacitors and load inductors will be integrated into a single PCA.

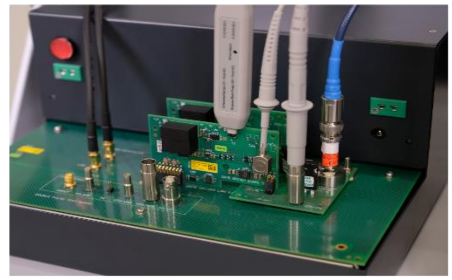


Figure 7 - PD1500A Fixture

Temperature Test

The PD1500A enables testing of characteristics over a temperature range (ambient temperature to 150˚C). A small heater is connected directly to the DUT for maximum heat conduction. The temperature is monitored (K-type thermocouple) and controlled by an internal microcontroller. A second K-type thermocouple and jack are provided on the test fixture for external monitoring.

User Configuration, Control and Analysis

The PD1500A is controlled with a simple and flexible graphical user interface. It provides test setup, execution, DPT display and data logging. Both the raw waveform and the extracted parameters are available from the local database. A simple semi-automated sequence is shown below.

1. Insert DUTs on the test module
2. Attach heater and thermocouple (if used)
3. Assemble test modules (DUT, clamp, gate driver modules) onto test fixture
4. Connect probes to test modules
5. Set up test parameters in the control software
6. Press "Start"
7. Repeat steps 4 and 5 for reverse recovery diode test or other tests

Figure 8 - Example PD1500A User Interface

Specifications

Tested Parameters

Test	Parameter / Characteristics	Symbol
Double Pulse Test/Clamp	Turn on delay time	td(on)
	Turn on rise time	tr
	Turn on time	ton
	Turn on energy	e(on)
	Turn off delay time	td(off)
	Turn off rise time	tf
	Turn off time	toff
	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
		e vs. t
	Switching locus	Id vs Vds
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	Total gate charge	Qg
	Threshold gate charge	Qgs(th)
	Plateau gate charge	Qgs(pl)
	Gate drain charge	Qgd
	Gate charge curve	Vgs vs. t
Multiple Tests	Derived output characteristics	Id vs. Vd

NOTE: Based on IEC 60474 and JESD24 standards

General Specifications

Category	Type			Item	Specification
Electrical	General			Sample Rate	10 Gsa/s
				Sampling Accuracy	12 ppb + 75 ppb/year
				Deskew Accuracy	200 ps (estimated)
	Drain/ Collector Channel	DC	Source	Max. Voltage / current	1200V[1] / 200A
				Min Voltage / current	50V[2], 10A[2]
				Voltage Programming Resolution	23mV
			Measure	Voltage Accuracy	2% of range (estimated)
				Current Accuracy	4% of range (estimated)
		AC	Measure	Voltage/current BW	500MHz / 400MHz
				Min V, I Transition Time	2 ns, 2.5 ns
				Voltage Edge time	< 10 ns (depends on DUT response and Rg)
	Gate	DC	Source	High Level Max/Min Voltage	29V / 12V
				Low Level Max/Min Voltage	0V / -10V
				Voltage Resolution	0.1V
				Max Current	10A (sink and source)
			Measure	Voltage Accuracy	2% of range (estimated)
				Current Accuracy	4% of range (estimated)
		AC	Source	Timing Resolution / Accuracy	100 ps / 200 ps
				Max Pulse Width (1st Pulse)	100 µs
				Max Pulse Width (2nd Pulse)	10 µs
				Max Off-Time between 1st and 2nd Pulse	25 µs
				Min Pulse Width (1st Pulse)	1 µs[3]
				Min Pulse Width (2nd Pulse)	200 ns
				Min Off-Time between 1st and 2nd Pulse	200 ns
			Measure	Voltage / current BW	500 MHz / 800 MHz
				Min Voltage Transition Time	2 ns
				Min Current Transition Time	1.25 ns
	Modular Components			Load Inductors	120 µH
					16.7 µH
				DC-Link Capacitor	800 µF

[1] Maximum supply voltage 1.2 kV; capable of characterizing 650 V, 1.2 kV, and 1.7 kV-rated devices

[2] Voltage can be less than 50V but the current is limited by the energy in capacitor (800uF) (Energy=(1/2)*CV^2)

[3] Smaller Values may be possible but are not recommended and tested

General Specifications (cont.)

Category	Type		Item	Specification
DUT			MOSFET, IGBT	
			Silicon and SiC	
			TO-247 (3pin), D2PAK7	
			Temperature Control	Room temperature[4] to 150˚C
System	Mechanical	Safety Enclosure	Size	90 cm (W) x 65 cm (D) x 160 cm (H)
			Weight	150 kg
		DPT Fixture	Size	32cm (W) x 25cm (D) x 16cm (H)
	Environmental		Operating Temperature	20˚C to 30˚C
			Operating Humidity	50 to 80 % RH
	Power		AC Input Power	200 to 240 V, ± 10% 50/60 Hz
	System Protection & Safety		Emergency Off switch (EMO)	
			Oscilloscope protection (Clamp output)	~+/-15V
		Safety Hood	Maximum energy in the system	6J
			Hood Lock	> 42 V present
			Open hood detection (disconnect HV & discharge DC-Link Capacitor)	
			Over temperature Shutdown	(at > ~50˚C)

[4] From 20˚C to 30˚C

For more information, please go to www.keysight.com/find/PD1500A.

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