Power Device Testing

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1 Introduction

In recent years, with the growing demand in industrial control markets, new energy vehicle markets, and renewable energy power generation sectors, the related demand for power devices has been continuously increasing, accompanied by gradually higher performance requirements. Power devices are a significant branch of semiconductor devices, primarily used for high-voltage and high-current power conversion and control, capable of handling substantial power.

Power devices currently mainly include the following types:

1. **Diode:** Utilizes its unidirectional conductivity for circuit rectification and voltage regulation.
2. **Transistor:** Typical transistors include Bipolar Junction Transistors (BJTs) and Field-Effect Transistors (FETs), widely used in amplifiers, audio amplifiers, power regulators, etc., for power amplification and switching circuits.
3. **Thyristor:** Includes Silicon Controlled Rectifiers (SCRs), Triode for Alternating Current (TRIACs), Gate Turn-Off Thyristors (GTOs), used in AC voltage regulation and controlled rectification.
4. **MOSFET:** A unipolar device characterized by fast switching speed, low drive power, and high input impedance. Suitable for high-frequency applications, commonly used in high-frequency switching power supplies, DC-DC converters, motor drives, and other scenarios requiring high switching speeds.
5. **Insulated Gate Bipolar Transistor (IGBT):** A composite device formed by combining a MOSFET and a BJT. It combines the high input impedance of a MOSFET with the low conduction voltage drop of a BJT, while also possessing strong voltage withstand capability. Suitable for high-voltage applications and widely used in power electronics.
6. **New Silicon Carbide (SiC) and Gallium Nitride (GaN) Power Devices:** Power devices made from new wide-bandgap semiconductor materials, featuring high voltage withstand, low on-resistance, high switching frequency, and high-temperature tolerance. Widely used in new energy vehicles, charging piles, solar inverters, industrial power supplies, etc. Among these, electric vehicles are the most important application scenario for new power devices under the trend of high-voltage fast charging. The application of 800V SiC platforms is also driving the development of SiC power devices.

2 Difficulties and Challenges

MOSFETs and IGBTs are finding increasingly widespread applications across various fields. How to effectively test the related parameters of MOSFETs and IGBTs is a problem that troubles many engineers. The processes involved in IGBT turn-on and turn-off are complex, posing challenges for accurately measuring and analyzing their switching characteristics. Simultaneously, determining the Safe Operating Area (SOA) of an IGBT requires consideration of multiple factors such as voltage, current, and time. Measurements are also susceptible to the influence of parasitic parameters. Parasitic inductances and capacitances present in device packaging and test circuits can significantly affect results in high-frequency and high-speed switching tests, leading to signal distortion and measurement errors. Furthermore, the fast switching speed of MOSFETs and IGBTs necessitates high-precision test equipment and fast response times for dynamic characteristic testing, making the selection of appropriate measurement instruments particularly important.

In the testing of these power devices, various measurement instruments and equipment need to work in coordination to better characterize device parameters. Common test items for power devices include the following aspects:

1. **Static Parameter Tests:**
   - **On-Resistance (Rds(on)):** For devices like MOSFETs, measures the resistance between drain and source in the on-state.
   - **Threshold Voltage (Vth):** The gate voltage at which the device begins to conduct.
   - **Breakdown Voltage (BV):** Measures the maximum voltage the device can withstand, such as Drain-Source Breakdown Voltage (BVDSS) or Gate-Source Breakdown Voltage (BVGSS).
   - **Leakage Current (Idss, Igss):** Measures the drain-source leakage current or gate-source leakage current under specified conditions.
2. **Dynamic Parameter Tests:**
   - **Switching Times (ton, toff):** Measures the time for the device to switch from on to off or vice versa.
   - **Switching Delay Times (td(on), td(off)):** In the power device switching process, the time interval between the start of applying/removing the control signal and the beginning of device turn-on/turn-off.
   - **Switching Losses (Eon, Eoff):** Measures voltage and current during switching to calculate the energy loss of the device during turn-on and turn-off.
   - **Current Rise and Fall Times (tr, tf):** Time taken for the current under test to rise from 10% to 90% or fall from 90% to 10% of its rated value.
   - **Reverse Recovery Time (trr):** Measures the time for current to recover to zero when switching from forward conduction to reverse blocking.
3. **Safe Operating Area (SOA) Test:**
   - Determines the device's safe operating area. Tests under what voltage and current combinations the power device can operate normally, ensuring that in practical applications, the device's operating voltage and current do not exceed safe limits, preventing overheating, breakdown, or other damage.

The above are only some of the common test items for power devices. In actual testing, based on the device's own characteristics, test equipment must be prepared and test circuits built to test various parameters of the device.

3 Solution

3.1 Double Pulse Test (DPT)

The Double Pulse Test is a common method for measuring dynamic parameters of MOSFETs and IGBTs. This test can better evaluate power device characteristics, assess switching losses, voltage/current peak values, parasitic parameters, etc., to understand product long-term reliability and facilitate subsequent product optimization. The test requires two voltage pulses with different widths. The first pulse establishes the initial state, preheats the circuit to bring other components to a relatively stable operating temperature, reducing the impact of temperature variations on test results. It also builds up a certain current in the circuit's inductor, creating conditions for the second pulse test. The second pulse is used to test the dynamic characteristics of the power device. At this point, an oscilloscope and differential probes are used to measure the voltage and current parameters during device switching. The turn-off process is observed at the falling edge of the first pulse, and the turn-on process is observed at the rising edge of the second pulse. A simplified DPT circuit is shown in Figure 1.

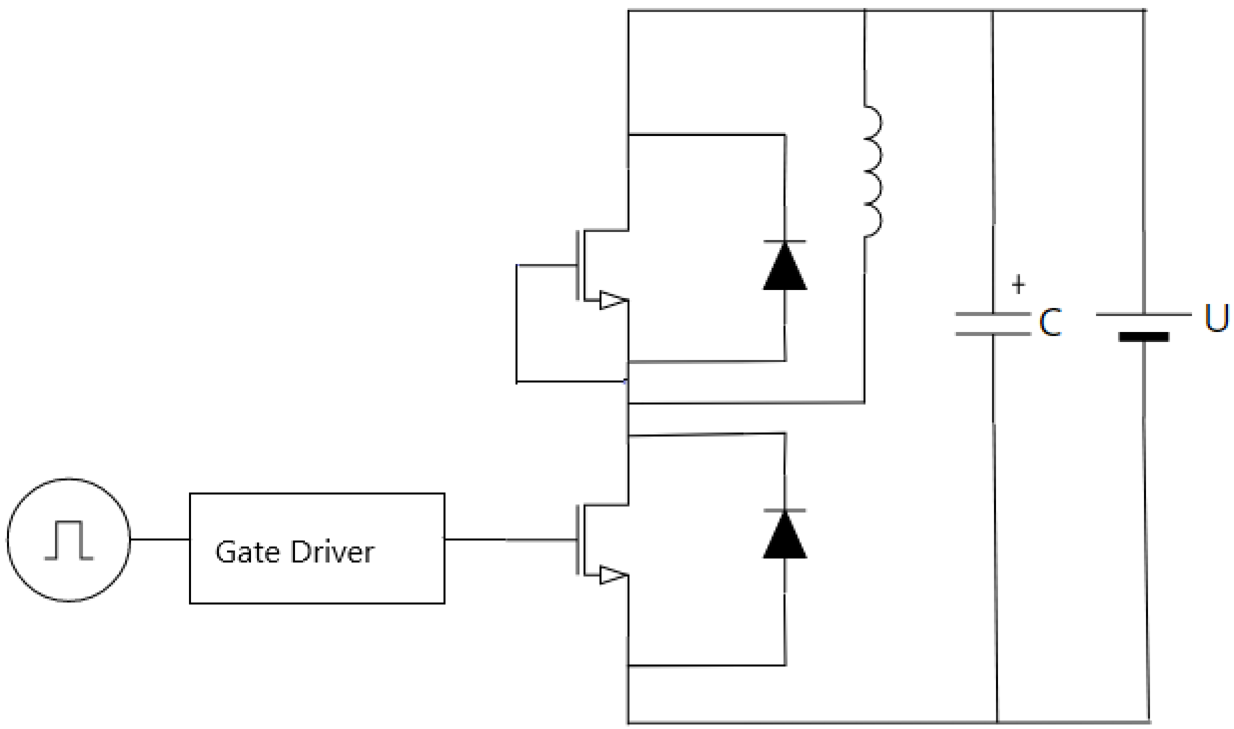


Figure 1 Simplified Example of a Double Pulse Test Circuit

DPT is typically performed in a half-bridge configuration. To reduce the influence of factors like electromagnetic interference during testing, a full-bridge structure can be used. In the half-bridge, the upper switch (high-side) is kept constantly off and is paralleled with an inductor. A double pulse is sent to the gate of the lower switch (low-side), and the voltage Vce across the lower switch and the collector current Ic are measured. Various parameters of the power device are tested during the brief switching transients driven by the double pulses. The basic waveforms in a DPT are shown in Figure 2.

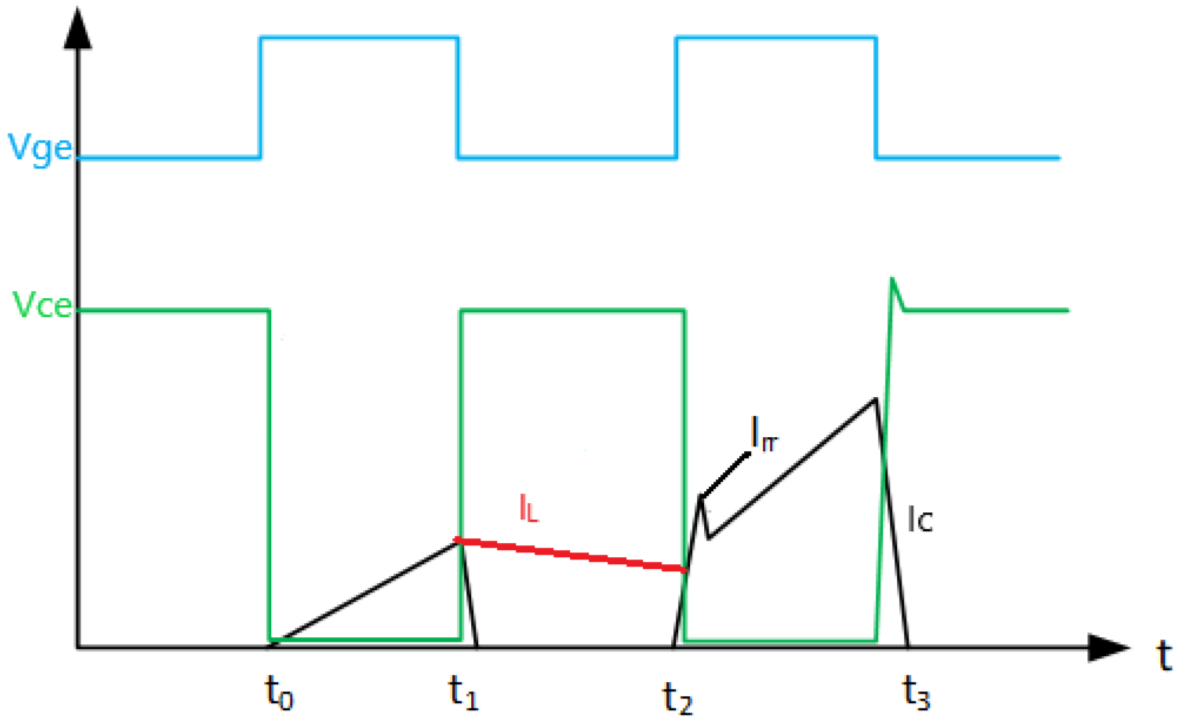


Figure 2 Example of Basic Waveforms in Double Pulse Test

In the figure, the blue waveform is the double pulse sent to the gate, the green waveform is the voltage Vce across the lower switch, and the black waveform is the measured collector current Ic of the lower switch.

At time t0, the first gate pulse arrives. The lower IGBT enters saturation and turns on. Voltage is applied across the inductor, causing the inductor current to rise linearly. The current value is determined by the voltage and inductance. With both fixed, a longer first pulse duration results in a higher current.

At time t1, the first pulse ends, and the lower switch turns off. The inductor current freewheels through the diode of the upper switch, decaying slowly. If a current probe is placed at the emitter of the lower switch, this freewheeling current will not be observed.

At time t2, the second pulse arrives, turning on the lower switch again. The freewheeling diode enters reverse recovery. The reverse recovery current also flows through the lower IGBT, captured as a momentary current spike by a current probe at the collector of the lower switch.

At time t3, the second pulse ends, and the lower switch turns off. With high current and the presence of stray inductance, a voltage spike occurs.

The steps above constitute the complete DPT process. Parameters such as IGBT reverse recovery time, rise time, fall time, etc., can be measured. Some measurable parameters are indicated in Figure 3. The switching loss parameters can be calculated using the oscilloscope's math functions, by integrating the product of the voltage and current signals over specified time intervals. The integration interval for turn-on loss is from 10% of the gate voltage rise to Vce falling to 2%. The interval for turn-off loss is from the gate voltage falling to 90% to the current dropping to 2%.

Switching Characteristic, Inductive Load

Parameter	Symbol	Conditions	Value min.	Value typ.	Value max.	Unit
IGBT Characteristic, at T_{vj} = 25°C						
Turn-on delay time	$t_{d(on)}$	T_{vj} = 25°C, V_{CC} = 600V, I_C = 25.0A, V_{GE} = 0.0/15.0V, $R_{G(on)}$ = 23.0Ω, $R_{G(off)}$ = 23.0Ω, $L\sigma$ = 80nH, $C\sigma$ = 67pF $L\sigma$, $C\sigma$ from Fig. E Energy losses include "tail" and diode reverse recovery.	-	27	-	ns
Rise time	t_r		-	41	-	ns
Turn-off delay time	$t_{d(off)}$		-	277	-	ns
Fall time	t_f		-	17	-	ns
Turn-on energy	E_{on}		-	1.80	-	mJ
Turn-off energy	E_{off}		-	0.85	-	mJ
Total switching energy	E_{ts}		-	2.65	-	mJ

Figure 3 Some Measurable Parameters in Double Pulse Test

This specific pulse sequence can be edited and generated in mathematical software, adjusting pulse parameters, and then imported into an arbitrary waveform generator (AWG) for output. This method is cumbersome and inconvenient for parameter adjustment. SIGLENT's SDG1000X Plus series and others have built-in double pulse waveform settings. The signal source interface intuitively displays the characteristics of the output double pulse waveform and allows for easier setup of parameters like pulse width. The interface is user-friendly and provides clear guidance, saving engineers' time and allowing them to focus more on power device testing, debugging, and problem-solving. The relevant multi-pulse setup interface is shown in Figure 4.

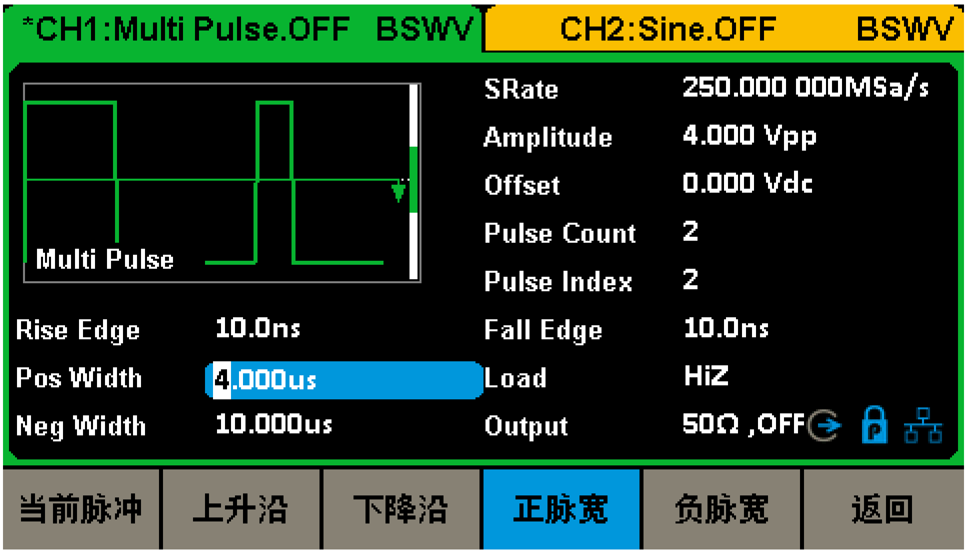
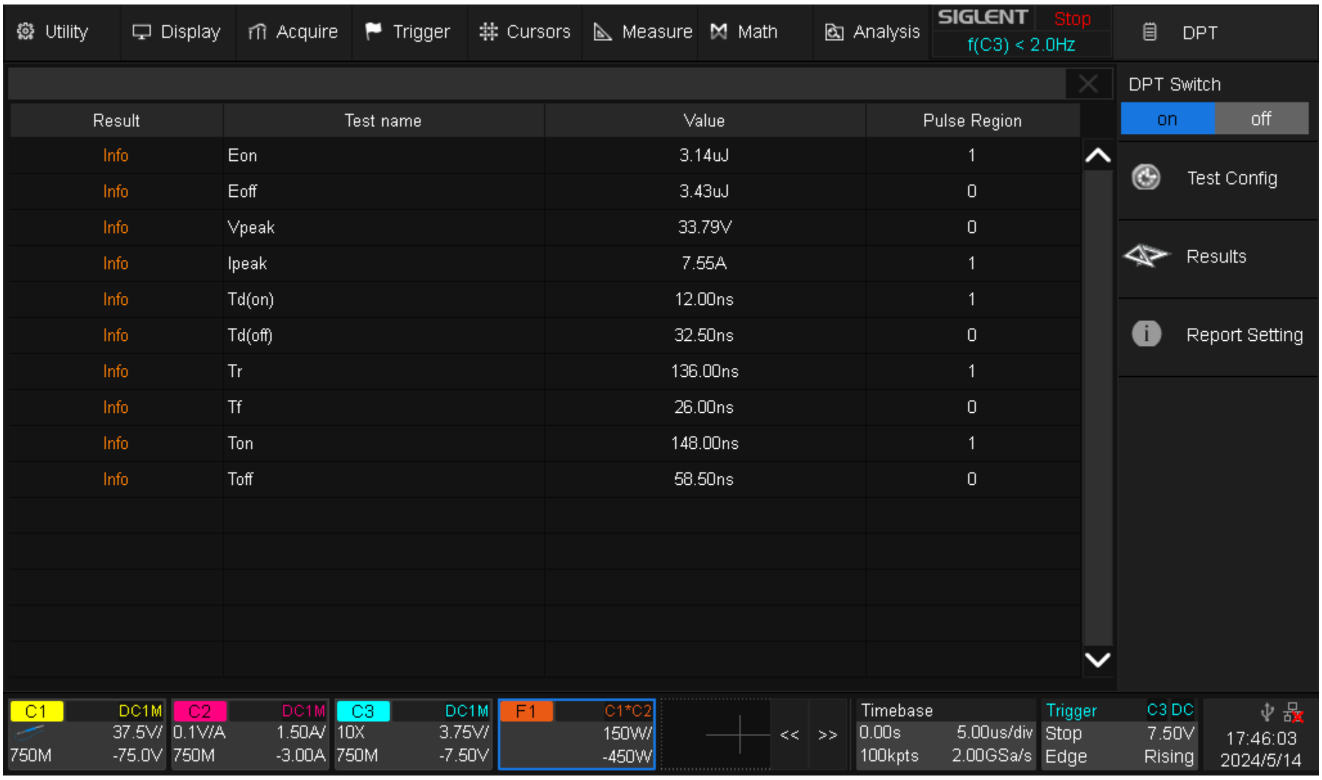


Figure 4 Multi-Pulse Output Setup Interface on Signal Source

In the multi-pulse interface, users can select the number of pulses and amplitude, and set the rise/fall times and positive/negative pulse widths for each pulse. The interface is concise with clear operational logic.

SIGLENT also provides test software for DPT on oscilloscopes. The DPT software can reduce manual operations, effectively shortening test time. The software provides test result ranges based on JEDEC/IEC standards and also supports user-defined parameters. After testing, results are displayed intuitively and can be exported.

Figure 5 Example of Actual Test Waveform from DPT Software



Result	Test name	Value	Pulse Region
Info	Eon	3.14uJ	1
Info	Eoff	3.43uJ	0
Info	Vpeak	33.79V	0
Info	Ipeak	7.55A	1
Info	Td(on)	12.00ns	1
Info	Td(off)	32.50ns	0
Info	Tr	136.00ns	1
Info	Tf	26.00ns	0
Info	Ton	148.00ns	1
Info	Toff	58.50ns	0

Figure 6 Test Result Display Interface

3.2 Power Analysis

The power analysis software option for oscilloscopes helps users quickly analyze switch-mode power supply efficiency and reliability. It supports a wide variety of measurements and analyses, including Switching Loss, Slew Rate, Modulation Analysis, and Safe Operating Area (SOA), which correspond to MOSFET-related parameter tests. Each test item provides detailed connection guides and prompt diagrams for user reference. Taking switching loss as an example, the related connection instructions are shown in Figure 7, which indicates probe point selection, probe equipment choice, correct probing direction, and configuration methods.

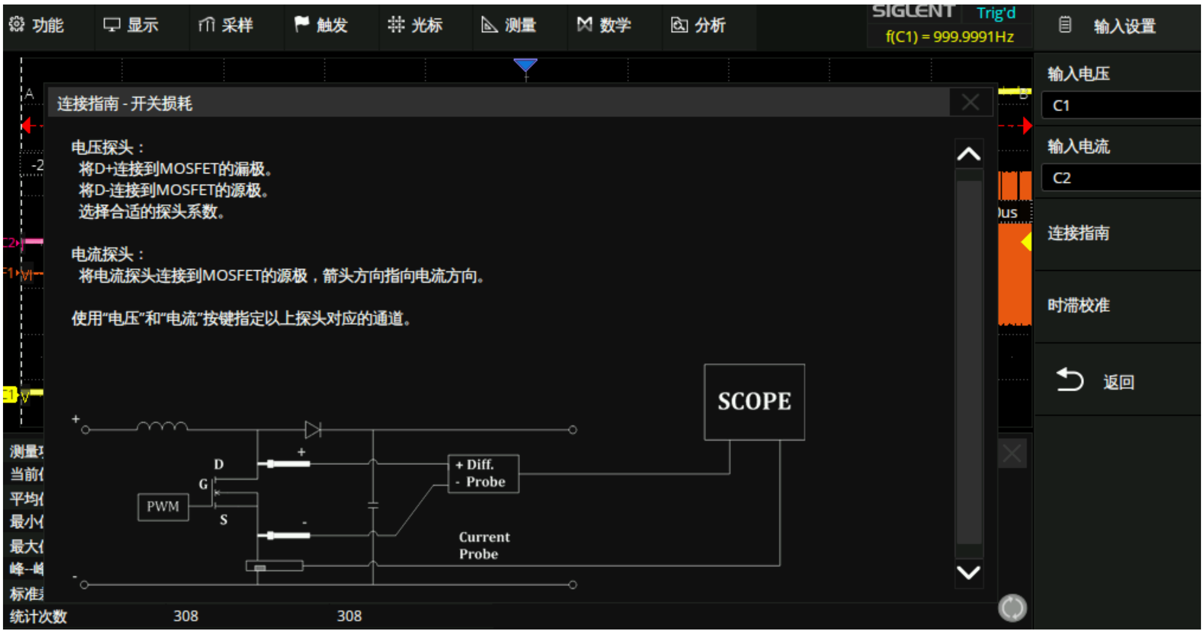


Figure 7 Connection Guide Illustration

During measurement, relatively small timing skews can cause significant switching loss measurement errors, especially during the turn-on phase when voltage is near zero and the non-conduction phase when current is near zero. Deskew calibration can correct oscilloscope or probe time delays and should be performed once before testing and re-run whenever any part of the hardware setup changes.

The Safe Operating Area (SOA) function within power analysis can automatically generate an SOA based on voltage, current, and power limit parameters set in the configuration menu. It also determines if the stress on the MOSFET exceeds the SOA, helping designers quickly identify problems or potential risks in the circuit. Figures 8 and 9 are examples of testing the electrical stress on a MOSFET and using SOA to determine if the stress is safe.

Figure 8 Voltage and Current Waveforms on MOSFET During Power-up

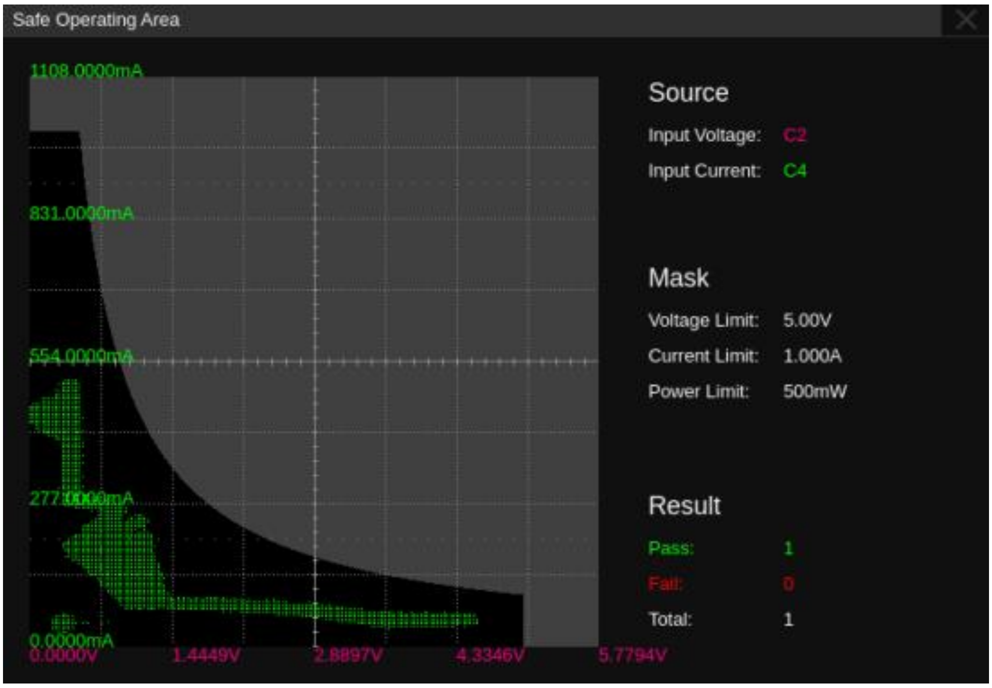


Figure 9 Test Panel for SOA Testing on a MOSFET

4 Summary

SIGLENT provides solutions for power device testing. The Double Pulse Test is the primary method for measuring dynamic parameters of power devices, capable of accurately characterizing device performance. Constructing double pulses for testing and measuring related parameters have consistently been challenging for many engineers. SIGLENT's

SDG1000X Plus Arbitrary Waveform Generator offers a multi-pulse construction method directly selectable in the waveform interface, providing users with a fast and convenient pulse signal editing experience. Simultaneously, the DPT application on oscilloscopes enables convenient testing of parameters in DPT, reducing test time and providing intuitive test reports. Additionally, the Power Analysis option on oscilloscopes provides measurements for MOSFET-related parameters and Safe Operating Area, facilitating user engagement in power device testing.

关于鼎阳

鼎阳科技（SIGLENT）是通用电子测试测量仪器领域的行业领军企业，A股上市公司。

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