Double Pulse Test DEMO Fixture

TF1000D

产品说明书

Product User Manual

Preface

Warning

To safely use this equipment:

Please be aware that TF1000D contains a 1000V High Voltage Power Supply, and there could be a 1000V DC voltage in internal circuit and the output connector when TF1000D is operating. **To ensure the personal safety of users, please strictly follow the safety precautions below, and operate according tot he instruction below.** CYBERTEK will not be responsible for any issue caused by violating the safety precautions.

- **When there's DC high voltage in the internal circuit and output connector, the LCD screen on TF1000D will display the value of the voltage. Any attempt of wiring is strictly prohibited when the voltage is over 36V.**
- **When there's DC high voltage in the internal circuit and output connector, the Red High Voltage Indicator Light on TF1000D will be on when the voltage is over 36V. Any attempt of wiring is strictly prohibited when this light is on.**
- **Users must turn off the high voltage power supply through operating the touch screen, and wait until the power supply discharges so that the voltage drops lower than 36V (the Red High Voltage Indicator Light will be off at this point) before attempting to connect or remove the current/voltage probe.**
- **TF1000D is high voltage equipment. Users are not allowed to disassemble or repair it on their own. Or there could be serious safety problem.**
- **TF1000D is high voltage equipment. Users need to have a basic understanding to the electric devices, and must operate strictly according to this instruction manual.**

1. Summary

TF1000D is a **portable double pulse tester** that integrates complete core components such as **high voltage power supply, power inductor, double pulse signal generator, UI control interface**, etc.

- TF1000D is designed with a portable connector for current/voltage probe. It can easily and accurately read the test waveform of the power half bridge topology structure and transmit to the oscilloscope of the user. Engineers no longer need to configure additional peripheral instruments and meters.
- TF1000D is designed to help engineers to measure the dynamic performance of TO-247-3L/TO-247-4L packaged SiC MOSFET . Its main circuit includes the main circuit loop and the driving circuit. Due to the overall low stray inductance circuit design, when the MOSFET quickly turns on and off and reaches 500V/15ns (dv/dt up to 33KV/us), the waveform oscillation at both ends of the device can still be controlled at an extremely low level, making it easy to accurately measure and calculate the dynamic parameters of the tested SiC MOSFET device.
- The upper PCB zone of TF1000D is integrated with the connectors for different types of current/voltage probe. Connectors are all designed and laid out according to the requirements of precise measurement in order to fully utilize the performance of the probes. For high voltage differential probe, we installed customized 4mm banana socket which can achieve low distortion measurement and acquisition of 500MHz high-speed voltage signals while reducing waveform oscillation. For high frequency current acquisition: Two of our company's latest bolt type coaxial current shunt have been set up to detect the high-speed current waveforms of the upper and lower MOSFET, respectively. These shunts can be installed or removed easily with bare hand, or replaced with shunts of different resistance value.

This equipment is able to switch the hardware circuit connections of different test project (DUT device switch characteristics/reverse recovery characteristics) in the double pulse experiment through the visual UI software control interface in front. When setting up the software, the drivers of the upper/lower bridge arms, internal relays, and the connection positions of the air core inductors will be synchronously configured. Engineers can quickly and accurately switch settings and avoid incorrect settings.

The dimensions of TF1000D is just 214*193*123mm, which is easy to carry and DEMO.

2. Double Pulse Test Briefing

Double Pulse Test is a testing method for measuring and evaluating the dynamic switching performance and indicator parameters of power semiconductor devices. It applies an inductive load switching circuit based on a half bridge structure. Power electronics R&D engineers and testing engineers will use double pulse testing to measure the following types of switch parameters:

- **Turn-on parameter:**

Turn-on delay$T_{D(ON)}$, rise time T_R, turn-on loss E_{ON}, transient voltage and current change rate $dv/dt_{(ON)}$ and $di/dt_{(ON)}$

- **Turn-off parameter**

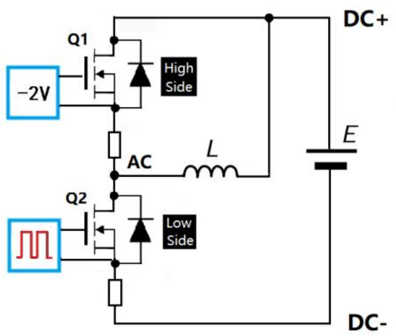
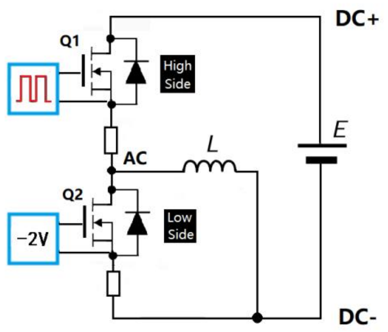
Turn-off delay $T_{D(OFF)}$, fall time T_F,turn-off loss E_{OFF}, transient voltage and current change rate $dv/dt_{(OFF)}$ and $di/dt_{(OFF)}$

- **Reverse recovery parameters:**

Reverse recovery time T_{RR}, reverse recovery current I_{RR}, reverse recovery charge Q_{RR}, reverse recovery energy E_{REC}, reverse recovery peak voltage $V_{RR\ Peak}$.

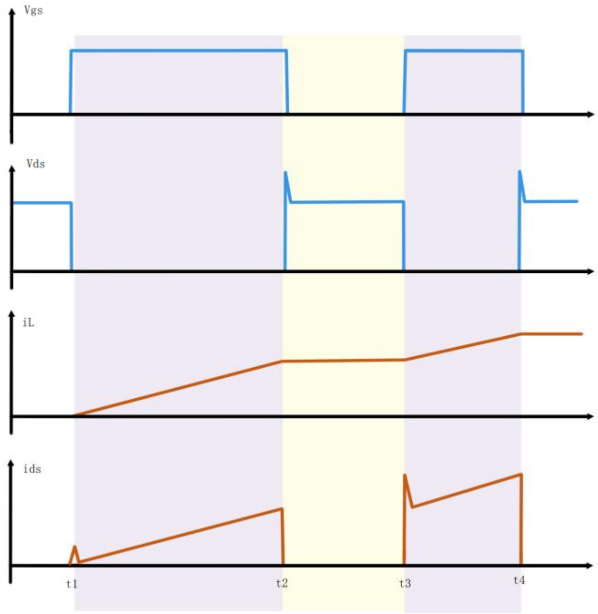
Double pulse testing method: Based on a half bridge topology, the device under test is located on the High Side (referred to as the upper tube) and the Low Side (referred to as the lower tube), respectively. A set of (two consecutive) driving pulse signals is emitted to the gate of one MOSFET/IGBT, and a turn off signal (zero or negative voltage) is continuously applied to the other MOSFET/IGBT during the testing process. This method is not only easy to operate, but also does not require continuous application of gate pulse signals to control MOSFET/IGBT to turn on and off repeatedly. Therefore, the switching losses of the upper/lower tubes will not continue to occur, avoiding the situation where the component heats up and affects the test results.

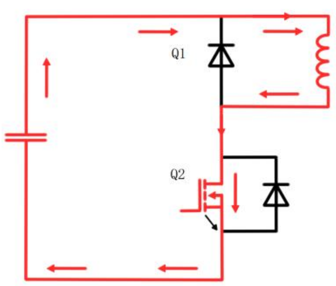
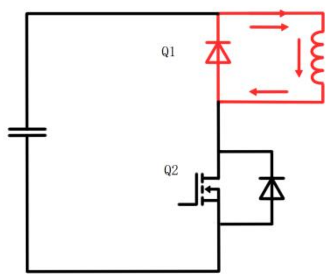
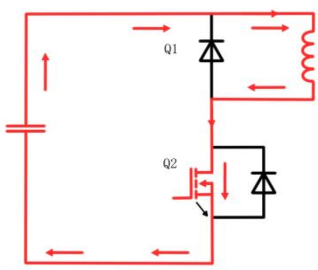
The double pulse testing method only requires the application of two pulse signals to obtain the dynamic switching characteristic parameters of MOSFET/IGBT under specified current and voltage conditions. The V_{GS} I_{DS} V_{DS} waveforms of the upper/lower transistor devices at turn off and turn on times can be measured and retained for analysis and evaluation. Using the most commonly used testing method as an example: based on a complete half bridge circuit, to measure all dynamic parameters of one side of the device, it is necessary to configure and test two different circuit connections separately.

	Driving lower tube Q2 mode	**Driving upper tube Q1 mode**
Main circuit	The air core inductor is connected in parallel between the midpoint of the half bridge circuit (on the upper side of the D electrode of lower tube Q2 in the figure) and the power supply DC+	The air core inductor is connected in parallel between the midpoint of the half bridge circuit (on the upper side of the D electrode of lower tube Q2 in the figure) and DC -
		
Control method	Q1 off, equivalent to a diode	Q1 applies a double pulse signal to turn on and off
	Q2 applies a double pulse signal to turn on and off	Q2 off, equivalent to a diode
Test result	Q1's body diode dynamic parameters (reverse characteristics)	Q1’s dynamic characteristics parameter (open and close)
	Q2’s dynamic characteristics parameter (open and close)	Q2's body diode dynamic parameters (reverse characteristics)
Method characteristics	Q2 is at low potential and does not require floating measurement	Q1 is at high potential and must be applied with floating measurement
Suitable target	Single MOSFET and half bridge module	Half bridge module and multiple phase full bridge module

3. Principle analysis for double pulse testing

Taking the double pulse test driven by the lower tube mode as an example, the analysis principle is as follows:



t1-t2 (The first pulse cycle)	t2-t3 (Pulse interval)	t3-t4 (The second pulse cycle)
The bus bar capacitor is subjected to high voltage, and Q1 remains off at all times. After Q2 conducts, the current and inductor current increase linearly from zero until reaching the target current value	Q2 is turned off, but due to the presence of the inductor, the current cannot suddenly change. Therefore, the current is converted to Q1 and the inductor forms a freewheeling loop, and the inductor current slowly and slightly decreases	Q2 is reopened, and the current flows back to Q2. The Q2 current continues to rise, and the inductor current continues to increase
		
The peak current of Id at time t1 is caused by the stray capacitance of the air core inductor L		The peak current of Id at time t3 is the reverse recovery current of Q1 diode
	At time t2, the Vds peak is the product of the DC bus stray inductance Ls and the di/dt of the Id current	At time t4, the Vds peak is the product of the DC bus stray inductance Ls and the di/dt of the Id current

Example: The following table shows some dynamic parameters of Wolfspeed's SiC half bridge module CAB006M12GM3:

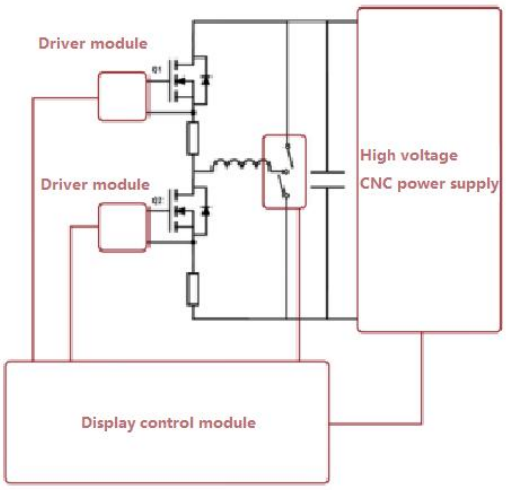
Dynamic Switching & Reverse Recovery

Code	Test Condition
CAB006M12GM3	ID=200A VDD=600V VGE=-4/+15V

	T_{don}	T_R	T_{DOFF}	T_F	E_{ON}	E_{OFF}	E_{RR}	Remark
R_G = 1.5Ω	50	25	80	35	4.7	1.7	0.13	Datesheet
R_G = 1.5Ω	60.4	23.2	97.2	34.4	3.6	1.71	0.18	PowerSemiLab
R_G = 5.0Ω					9.2	2.8		Datesheet
R_G = 5.0Ω					9.3	2.74		PowerSemiLab

4. Introduction of TF1000D

The internal functional modules of the **TF1000D** double pulse test DEMO fixture include: a 1000V high-voltage power supply, a double pulse generator, a high-speed isolated drive module, high and low side SiC MOSFET devices for forming a half bridge topology, air core inductors, broadband coaxial shunt, and all functional circuits and components required for dual pulse testing. Users can set and execute all control functions through the external 3.5-inch smart touch screen. According to the diagram below, we can control the internal relay through software to switch between different connection positions of the air core inductor, in order to configure two different modes of driving the upper tube or driving the lowe rmosfet in the double pulse test.

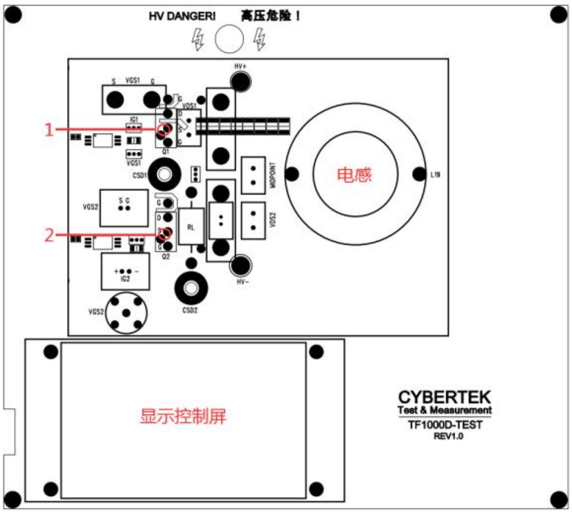


Hardware name	Parameter	Note
Air core inductor	L=0.1mH	
High voltage DC power supply	50V-700V	50V step (this device is limited to 700V)
Initial value of dual pulse time	5us/2us/2us	
Dual pulse total conduction time range	2-10uS	1uS step
Dual pulse cut-off time range	1-10uS	1uS step
I_D Typical current value	Id=U*T/L=35A	L=0.1mH U=500V 5us/2us/2us

Driver module	Driver IC	ACPL-W346
	Drive resistor	5R
	Driving voltage	15V/-2V
SiC half bridge	C3M0075120K SiC MOSFET (TO-247-4L package) * Two pieces	32A/1200V
V_{DS} Rise time	500V/15ns	
V_{DS} Fall time	500V/15ns	

5. Probe testing access point of TF1000D

The circuit board of this equipment integrates the connection terminals (sockets) for all probes required for double pulse testing, which can also be used by engineers to verify the performance of current and voltage probes. We can provide collected waveforms such as V_{GS} and I_G waveforms on the input side, V_{DS} and I_D waveforms on the output side of MOSFETs.



Note:
1. When using the TO-247-3L package, be sure to short-circuit the two points inside the red circle, otherwise the MOSFET is easy to damage;
2. When using the TO-247-3L package, be sure to short-circuit the two points inside the red circle, otherwise the MOSFET is easy to damage;

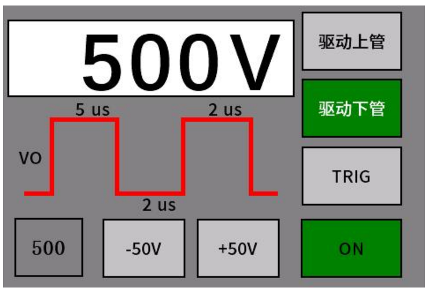
Area for testing	**Project**	**Project definition**	**Form of testing point**	**Probe type**	**Available probe model**
Upper tube of the half bridge	$V_{GS}1$	Upper MOSFE driving voltage	4mm banana socket	High voltage differential probe	DPX6150B
			MMCX	Optical isolated voltage probe	OPL6050
	I_G1	Upper MOSFET driving current	MMCX	Optical isolated voltage probe	OPL6050
	I_D1	Upper MOSFET DS current	BNC	Coaxial current shunt + optical isolated voltage probe	CSD01M20+OPL6050
	$V_{DS}1$	Upper MOSFET DS voltage	4mm banana socket	High voltage differential probe	DPX6150B
			5.08 socket	Optical isolated voltage probe	OPL6050
Middle	V_{SW}mid	Test the CMRR	MMCX	Optical isolated	OPL6050

point of the half bridge	point of the half bridge	effect of high-voltage differential probes or optically isolated voltage probes		voltage probe	
			4mm banana socket	High voltage differential probe	DPX6150B
			5.08 socket	Optical isolated voltage probe	OPL6050
Lower tube of the half bridge	$V_{GS}2$	Lower MOSFET driving voltage	MMCX	Optical isolated voltage probe	OPL6050
			BNC	Passive probe	P6251
			2.54 socket	Low voltage differential probe	DP6020B
	I_G2	Lower MOSFET driving current	2.54 socket	Low voltage differential probe	DP6020B
	I_D2	Lower MOSFET DS current	BNC	Coaxial current shunt	CSD01M20
	$V_{DS}2$	Lower MOSFET DS voltage	4mm banana socket	High voltage differential probe	DPX6150B
			5.08 socket	Optical isolated voltage probe	OPL6050

6. Double pulse test for driving tube mode

The S of the low-side MOSFET lof the half bridge topology is connected to the same ground as the oscilloscope, so there is no requirement for floating ground and CMRR for the measuring probe of the equipment to be tested. Usually, single-end passive probes and low-voltage differential probes can be used to measure the drain -source voltage V_{DS} and gate- source voltage V_{GS} . In addition, if high bandwidth current measurement is required, the CYBERTEK CSD series high-speed coaxial current shunt can be used to achieve it. When using a coaxial current shunt, it can be directly connected to the oscilloscope (50 ohm impedance)input without isolation. It can be seen that when using the mode of driving the lower tube, the requirements and cost of peripheral probes are lower.

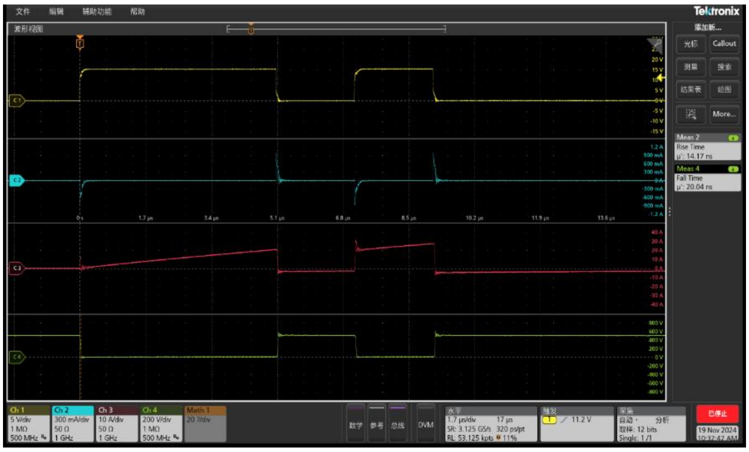
Setup of TF1000D is shown below:



1. Measure the four main waveforms of the lower mosfet: driving waveform VGS2, driving current IG2, drain current ID2, and drain source voltage VDS2. The ultra bandwidth coaxial current shunt produced by our company is used to measure the drain current ID2. The displayed waveform is ideally pure, which is very beneficial for accurate calculation of Eon and Eoff .

The driving current IG2 is achieved by measuring the voltage across a 5-ohm driving resistor using a low-voltage differential probe produced by our company.

Oscilloscope Channel	**CH1**	**CH2**	**CH3**	**CH4**
Test project	$V_{GS}2$	$I_{G}2$	$I_{D}2$	$V_{DS}2$
Probe type	10：1 passive probe	Low voltage differential probe	Coaxial current shunt	High voltage differential probe
Probe model	P6501	DP6020B	CSD01M20	DP6150

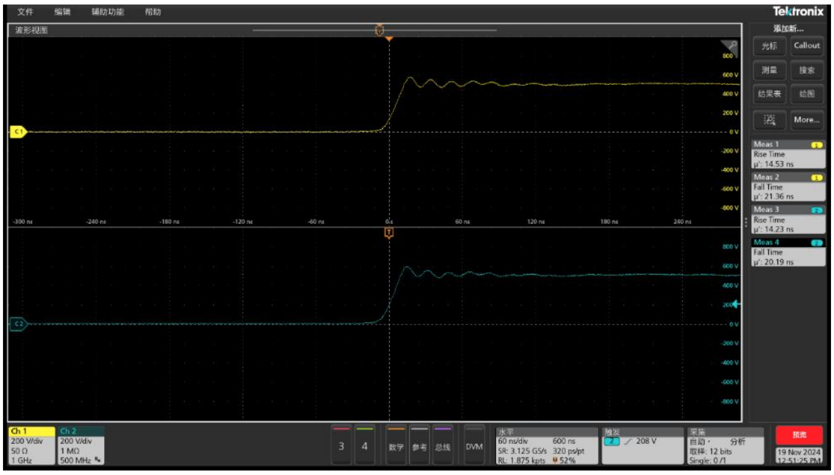


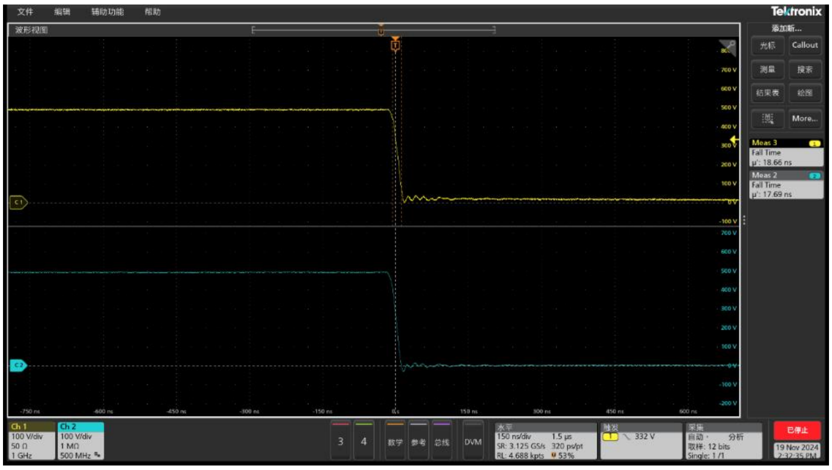
2. The three probe tests showed consistent VGS driving waveforms, which mutually confirmed the accuracy of the measurement results.

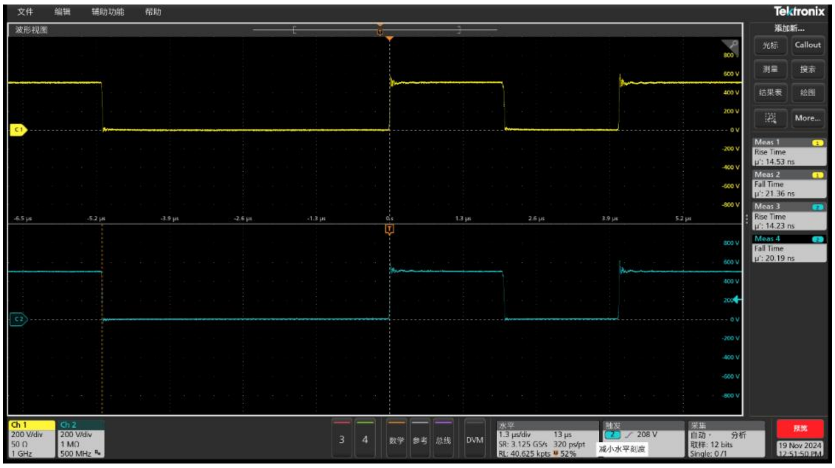
Oscilloscope Channel	**CH1**	**CH2**	**CH3**
Test project	$V_{GS}2$	$V_{GS}2$	$V_{GS}2$
Probe type	10：1 passive single end probe	Low voltage differential probe	Optical isolated voltage probe
Probe model	P6501	DP6020B	OPL6050

3. The VDS waveform tested by the high-voltage differential probe and the optical isolated voltage probe is consistent, which mutually confirms the accuracy of the measurement results.

Oscilloscope channel	**CH1**	**CH2**
Test project	V_{DS}	V_{DS}
Probe type	Optical isolated voltage probe	High voltage differential probe
Probe model	OPL6050	DP6150
Rise time	14.5ns	14.3ns
Fall time	21.4ns	20.2ns



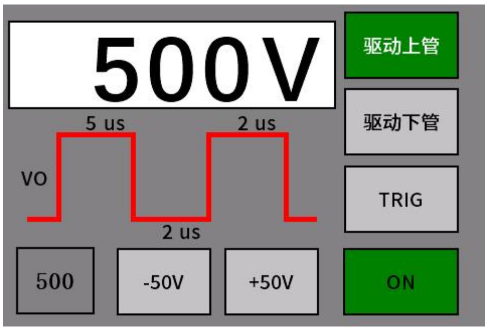




7. Driving upper tube double pulse test

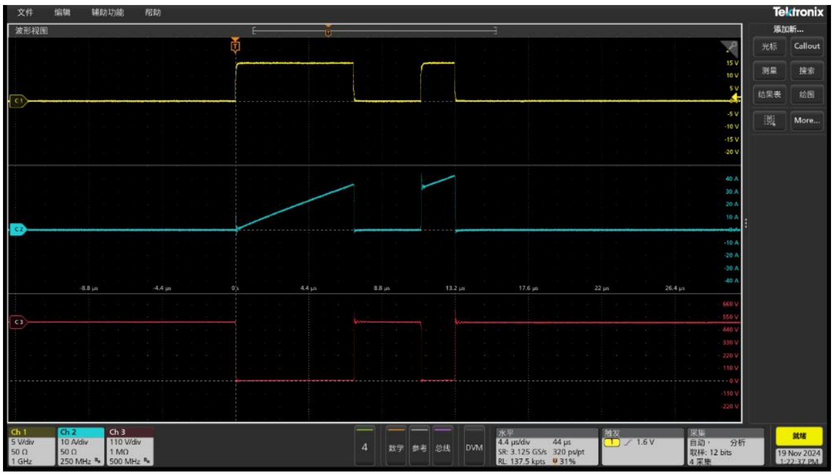
The high side switching MOSFET located in the half bridge topology are in a high voltage floating ground state, so the probe must be able to withstand a certain common mode high voltage and achieve a high common mode rejection ratio. The CYBERTEK OPL and OPB series optical isolated voltage probes can withstand a common mode voltage of 60kV and have a very high CMRR, making them very suitable for measuring the V_{GS} and I_G waveforms on the gate input side, as well as the V_{DS} and I_D waveforms on the output side (with a coaxial current shunt) of the upper tube device. The high and low side devices both use SiC MOSFET and corresponding high-speed gate driver ICs, so the voltage rise/fall swing time at the midpoint (AC) is extremely short, reaching 500V/15ns and 33kV/us respectively. This testing environment poses a challenge to the common mode rejection performance of the probes.

The setup of TF1000D is shown below:



1. This demonstrates the measured waveforms of the V_{GS} voltage of the upper-side MOSFET tested using one optical isolated voltage probe and the I_D current tested using another optical isolated voltage probe and coaxial shunt under common mode interference conditions with fast rise/fall times (500V/15ns). From the waveform, it can be seen that the two waveforms are not affected by high-frequency common mode interference and are completely consistent with the V_{GS} and I_D waveforms of the tube tested earlier. This result confirms that the optical isolated voltage probe used by CYBERTEK has excellent CMRR.

Oscilloscope channel	**CH1**	**CH2**	**CH3**
Test project	$V_{GS}1$	I_D1	$V_{DS}1$
Probe type	Optical isolated voltage probe	Coaxial current shunt + optical isolated voltage probe	High voltage differential probe
Probe model	OPL6050	CSD01M20+OPL6050	DP6150



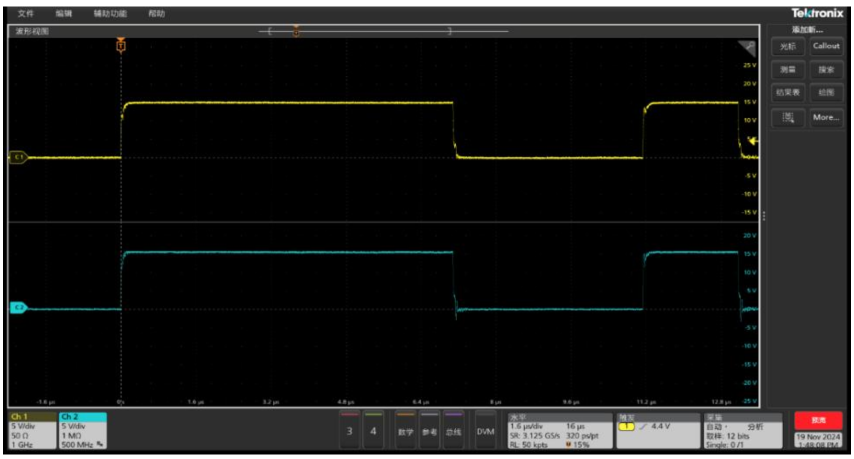
2. This demonstrates the measurement waveforms of V_{GS} voltage of the upper-side MOSFET using one optical isolated voltage probe and I_G current (voltage across the output resistance Ron-5 Ω of the driving core) using

another optical isolated voltage probe under common mode interference conditions with fast rise/fall times (500V/15ns). Through actual testing, it can be seen that the two waveforms are not affected by high-frequency common mode interference, and are completely consistent with the V_{GS} and I_G waveforms of the tube tested before. This result confirms that the optical isolated voltage probe used by CYBERTEK has excellent common mode rejection ratio.

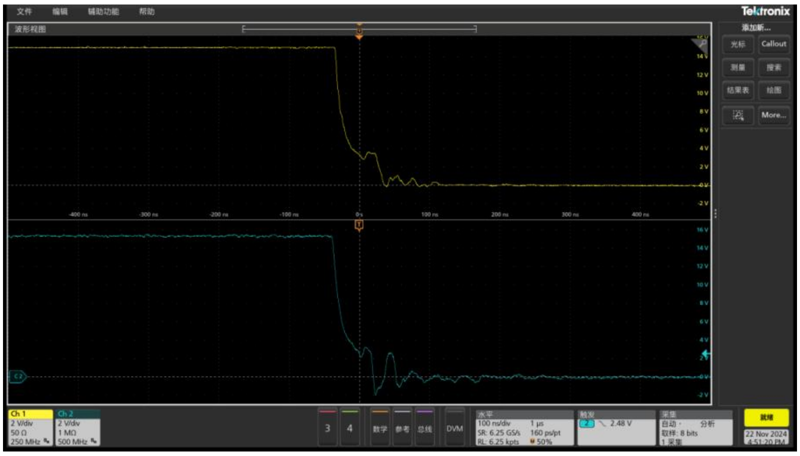
Oscilloscope channel	**CH1**	**CH2**	**CH3**
Test project	$V_{GS}1$	I_G1	$V_{DS}1$
Probe type	Optical isolated voltage probe	Optical isolated voltage probe	High voltage differential probe
Probe model	OPL6050	OPL6050	DP6150

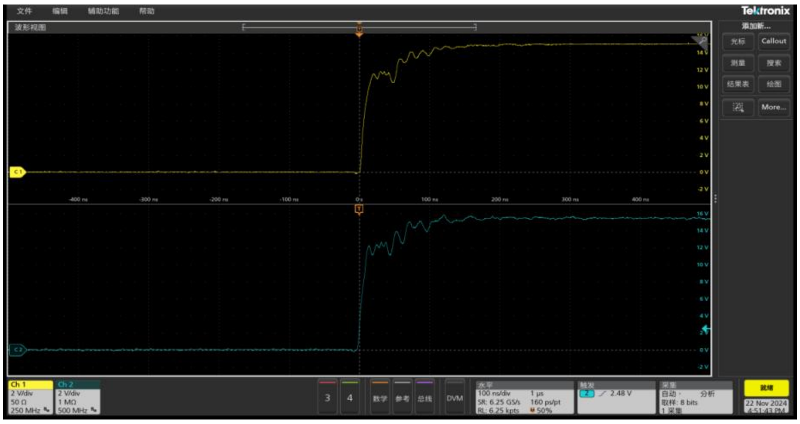
3. This demonstrates the waveform of the V_{GS} voltage on the test tube under common mode interference conditions with fast rise/fall time (500V/15ns). Although the waveform measured by the high voltage differential probe used was slightly inferior to that of the optical isolated voltage probe (as indicated by the red circle), it was far superior to similar competing probes on the market. This result confirms that the common mode suppression of the differential probe is superior, making it a low-cost floating V_{GS} measurement solution.

Oscilloscope channel	**CH1**	**CH2**
Test project	$V_{GS}1$	$V_{GS}1$
Probe type	Optical isolated voltage probe	High voltage differential probe
Probe model	OPL6050	DP6150



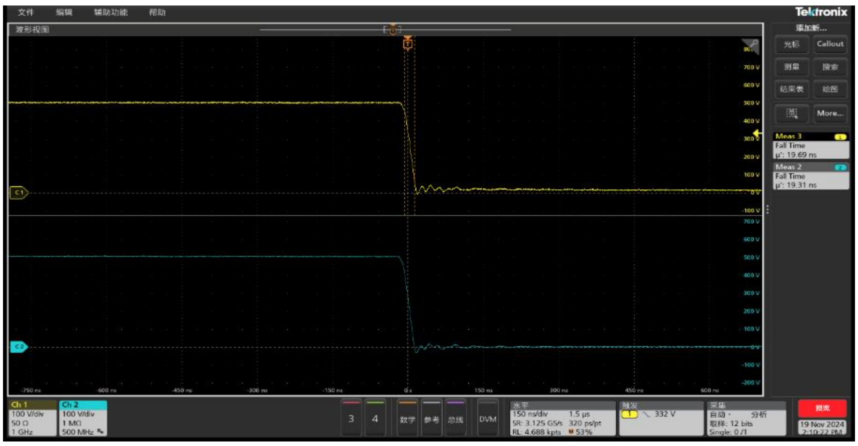
The following is the zoomed image of the rising and falling edges of the driving waveform of the upper -side MOSFET. It can be observed that the rising edge waveform is almost identical, while the falling edge waveform differential probe exhibits some oscillation.

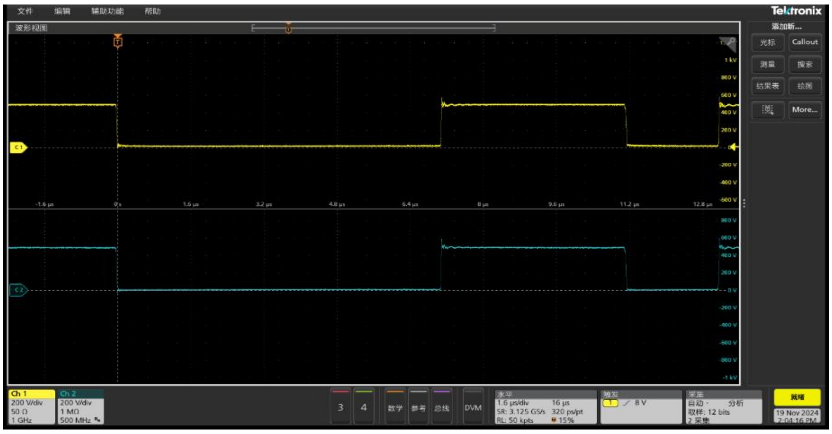


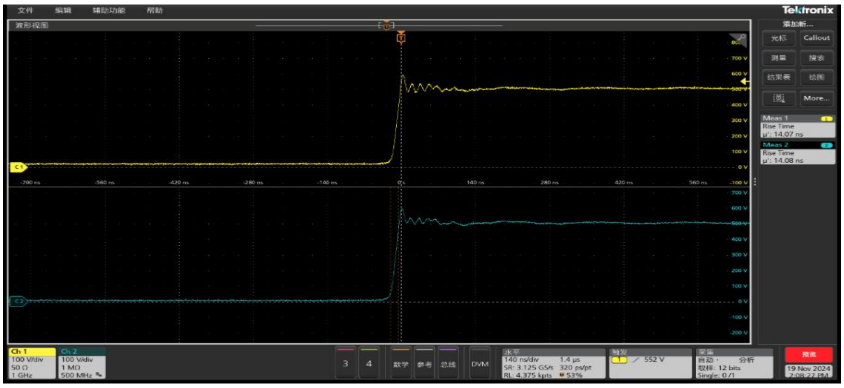


4. The upper-side MOSEFT was tested using a known optical isolated voltage probe and a high-voltage differential probe. Under common mode interference conditions with a fast rise/fall time (500V/15ns), the waveforms of the two probes were completely consistent. This once again confirms that the common mode rejection of the differential probe used by CYBERTEK is relatively excellent, and it is also a low-cost measurement solution for floating ground V_{DS} voltage.

Oscilloscope channel	**CH1**	**CH2**
Test project	Vds1	Vds1
Probe type	Optical isolated voltage probe	High voltage differential probe
Probe model	OPL6050	DP6150



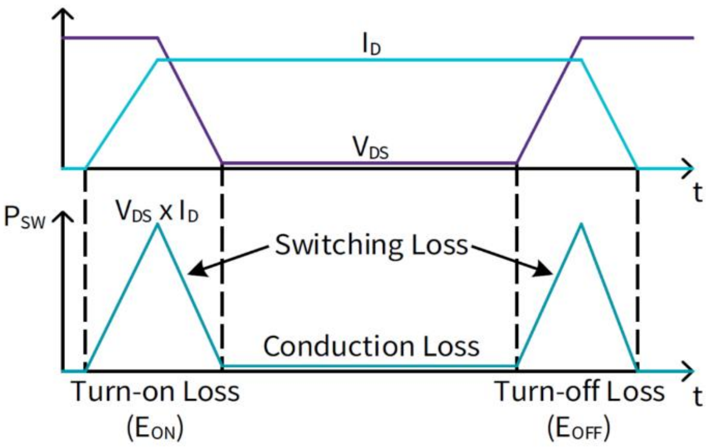




8. Measurement of turn-on loss (EON) and turn-off loss (EOFF) of the lower side-MOSFET

Measuring and calculating the turn-on loss (E_{ON}) and turn off loss (E_{OFF}) of MOSFETs is an important project in double pulse testing. The calculation method is to multiply the waveforms of voltage and current to obtain a loss power curve. Integrating the power during the turn-on or turn-off period yields E_{ON}/E_{OFF}. Integrating the power during the conduction period of MOSFET yields the conduction loss.

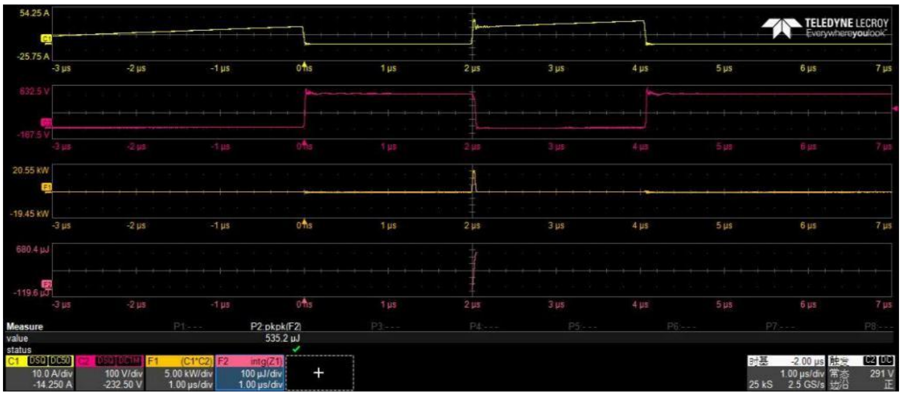
It is particularly important to note that the relative delay parameters of the voltage probe and current probe must be accurately measured and then input into the oscilloscope. If the relative delay parameters of the voltage probe and current probe are inaccurate or cause significant deviations in the calculation of the turn-on loss EON and turn-off loss EOFF.



The following tests the E_{ON}/E_{OFF} of MOSFETs on this equipment

Test conditions: V=500V, R_G=5R, I_D=25A, V_{GS}=0/15V, L=100uH, room temperature

Oscilloscope Channel	CH1	CH2
Test project	I_D	$V_{DS}2$
Probe type	Coaxial current shunt	High voltage differential probe
Probe model	CSD01M20	DP6150
1-meter coaxial cable delay	5.2ns	5.2ns
Delay of coaxial current shunt (length 30mm)	0.1ns	
High-voltage differential probe		7.1ns
Delay difference displayed on oscilloscope	0	+7ns

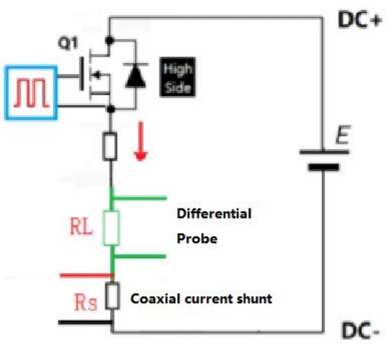


Test result: turn-on loss E_{ON}=535 uJ. Due to the relatively small turn off loss $E_{OFF}$of this SiC MOSET component, this experiment will not be analyzed.

9. Perform calibration measurement of voltage and current probe delay on this device

The key to deskew calibration of voltage probes and coaxial current probe is to generate a fully synchronized rising edge signal of voltage and current. This can apply a fast rising pulse voltage on a non- inductive high-power resistor. This device is capable of generating a pulse voltage of 500V with a fast rise time, and is fully capable of performing this job.

As shown in the figure below, when Q1 is conducting, the voltage across the non inductive power resistor RL and the rising edge of the current flowing through the same non inductive coaxial current shunt Rs are completely synchronized. The delay difference between the two waveforms on the oscilloscope is the actual delay difference of the voltage and current probe.

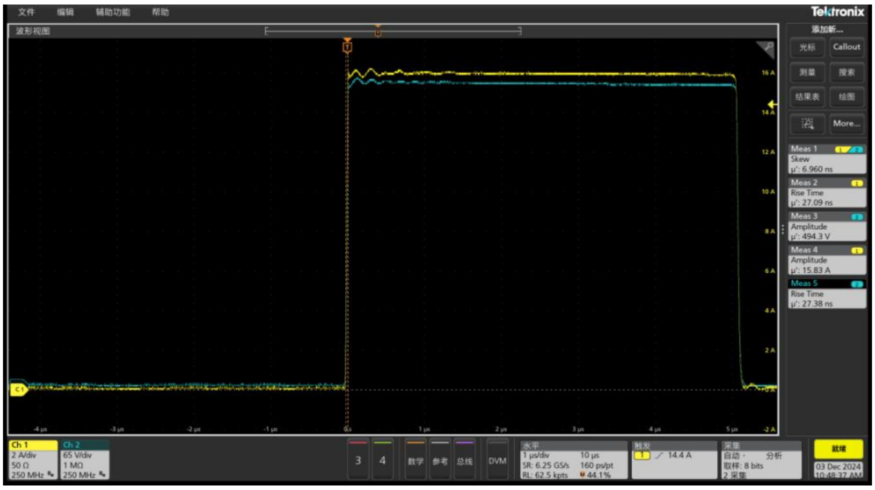


How to operate:

- When this equipment is just turned on, the touch buttons for driving the upper mosfet mode and driving the lower mosfet mode are both displayed in gray on the touch screen, which means they are invalid. At this point, both relays inside the equipment are all disconnected, which means that the inductor and power circuit used for the internal double pulse test are disconnected. This allows the low-side MOSEFT to be replaced with a non inductive resistor. After the double pulse test, the touch buttons for driving the upper MOSFET mode or driving the low-side MOSEFT mode may not display gray. Please press the touch button to turn it gray and cancel its function.
- Remove the half bridge low-side MOSFET from the socket and replace it with a 33 ohm non inductive resistor.
- Trigger a double pulse test of 500V.
- Oscilloscope collects the I_d current waveform and V_{ds} voltage waveform of the low-side .

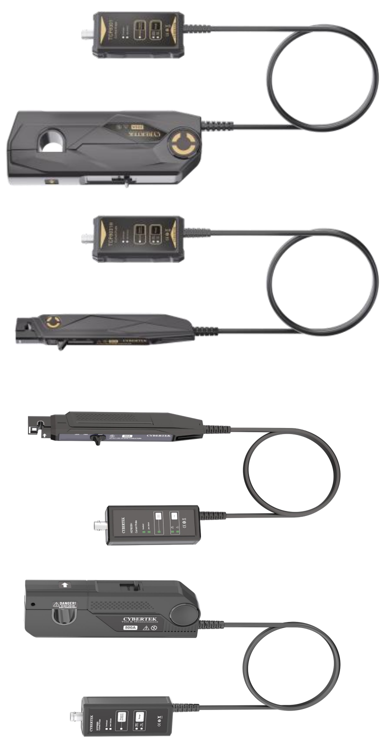
The following figure shows the current waveform displayed on the actual test oscilloscope ahead of the voltage waveform by 7ns. The voltage probe lag calculated based on the parameters of the probe and coaxial cable earlier is also 7ns.

The test result of these two methods are completely the same.



This equipment can also measure the delay parameters of the CP9000 series Rogowski coil current probe and the HCP8000 series high-frequency AC/DC current probe. Just clip the current probe onto the non inductive resistor mentioned above.

Appendix: The current and voltage probes of our company that can be verified by this equipment

Voltage probe	Optical isolated voltage probe	OPB6000 Series OPL6000 Series OPLX60000 Series	
	Passive voltage probe	P6251/P6501	
	High voltage differential probe	HVP6000（E/F/G/H）Series DP6000（A/B/D) Series DPX6000（A/B/D) Series P1300	
	Low voltage differential probe	DP60*0B Series	
Current probe	High frequency AC/DC current probe	TCP8000 Series HCP8000(HCPX8000/HCP8000C) Series	

	Rogowski coil current probe	CP9000 Series CPX9000 Series CPHX9000 Series	 
	Coaxial current shunt	CSD*M Series	 

10. Packing List

Packing list	
TF1000D	1
BNC cable (CK-310)	1
AC power supply cable (CK-318)	1
Instruction manual	1
Warranty card	1

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Published in China, Oct. 1, 2025