Siglent 2.5G/5G/10G Ethernet Compliance Testing Solution

SOLUTIONS

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1 Overview

With the deep integration of digital economy and age of intelligence, 10 Gigabit Ethernet (2.5G/5G/10GBASE-T) has become the core communication technology in data center, intelligent automobile, industrial automation and other fields because of its high bandwidth, low latency and strong compatibility. However, with the iterative upgrade of IEEE 802.3 and other standards, equipment manufacturers are faced with multiple test challenges such as physical layer signal integrity, protocol compliance and multi-scenario compatibility. As the world's leading provider of electronic test and measurement solutions, SIGLENT, relying on its profound technical accumulation in the field of high-speed signal testing, has released a 10Gigabit Ethernet (2.5G/5G/10GBASE-T) compliance test solution, which provides the technical support for the industry from standard interpretation, test tools to automation processes, and helps customers accelerate product development and market access.

2 Basic knowledge

2.1 Technical definition and innovation breakthrough

10 Gigabit Ethernet (2.5G/5G/10GBASE-T) is a high-speed wired communication technology based on IEEE 802.3 standard, which realizes high-speed (2.5G/5G/10G) transmission through twisted pair:

2.5Gbase-T: 4 twisted pairs, 625Mbps each, with a total speed of 2.5Gbps, supporting Cat5e/Cat6 cables.

5Gbase-T: 4 twisted pairs, 1.25Gbps each, with a total speed of 5Gbps, compatible with Cat6 cables.

10Gbase-T: 4 twisted pairs, 2.5Gbps each, with a total speed of 10Gbps, requiring Cat6a/Cat7 cables.

Its core technology architecture embodies the double breakthrough of high-frequency signal processing and protocol compatibility:

Physical layer: Using PAM4 technology (four-level pulse amplitude-modulated),2 bits of data is transmitted in each symbol period, which improves the information carrying capacity of a single symbol and significantly reduces the transmission loss of high-frequency signals. For example, 10GBASE-T achieves a transmission distance of 100 meters on Cat6a cable through PAM4 technology, while traditional NRZ modulation requires a higher baud rate, which leads to increased signal attenuation; Supports 64B/66B coding (coding efficiency is 97%), improves the precision of signal clock recovery, and combines dynamic equalization technology (DFE/FFE) to compensate the high-frequency attenuation of Cat6a/Cat7 cable.

Data link layer: Using RS-FEC forward error correction technology, 16 bytes of cyclic redundant check are added to every 255 bytes of data, which greatly reduces the bit error ratio and compensates the signal-to-noise ratio loss in high-frequency signal transmission; Consistent with the frame structure of traditional Ethernet and be compatible with existing network devices.

Protocol layer: supports IEEE 802.3bz(2.5G/5GBASE-T) and 802.3by(10GBASE-T) standards, and realizes functions such as auto-negotiation and clock recovery.

2.2 Typical application

With the popularization of 5G, AI, cloud computing, edge computing and other technologies, the data traffic is increasing exponentially. As a key technology to support high-speed data transmission, 10 Gigabit Ethernet is deeply infiltrating into emerging scenarios from traditional neighborhoods: in data center interconnection, 10GBASE-T replaces the traditional optical fiber scheme for intra-rack server cluster interconnection, reducing wiring costs, and supporting iSCSI/NVMe over Fabrics protocol to achieve high-performance storage access; In the field of intelligent automobile electronics, it meets the real-time requirements of the automatic driving domain controller for transmitting laser radar and camera data, and the vehicle network architecture is built through 10GBASE-T1 to ensure the low-delay communication between the regional controller and the central computing platform. In the scene of industrial automation, 10 Gigabit Ethernet supports OPC UA over TSN protocol to realize cooperative control of robots, and at the same time, it connects industrial sensors and edge computing nodes to help build 10 Gigabit industrial Internet.

3 Solution

3.1 Test Items

2.5/5/10GBase-T Ethernet compliance test is used to verify whether the DUT meets the electrical characteristics of PMA specified in IEEE802.3 standards. It is very common and meaningful to carry out Ethernet compliance testing during the development of Ethernet devices, which ensures the interoperability between devices.

2.5GBASE-T Test Items	5GBASE-T Test Items	10GBASE-T Test Items
Maximum Output Drop	Maximum Output Drop	Maximum Output Drop
Maximum Output Drop Positive	Maximum Output Drop Positive	Maximum Output Drop Positive
Maximum Output Drop Negative	Maximum Output Drop Negative	Maximum Output Drop Negative
Transmitter Timing Jitter-Master	Transmitter Timing Jitter-Master	Transmitter Timing Jitter-Master
Transmit Clock Frequency	Transmit Clock Frequency	Transmit Clock Frequency
Transmitter Linearity	Transmitter Linearity	Transmitter Linearity
Tone 1	Tone 1	Tone 1
Tone 2	Tone 2	Tone 2
Tone 3	Tone 3	Tone 3
Tone 4	Tone 4	Tone 4
Tone 5	Tone 5	Tone 5
Transmitter Nonlinear Distortion	Power Tests	Power Tests
Tone 1	Power spectrum density	Power spectrum density
Tone 2	Power level	Power level
Tone 3	MDI return loss	MDI return loss

Tone 4 Tone 5 Power Tests Power spectrum density Power level MDI return loss Transmitter Timing Jitter-Slave	Transmitter Timing Jitter-Slave	Transmitter Timing Jitter-Slave

3.2 Reference Standard

The 2.5/5/10GBase-T Ethernet electrical compliance test scheme launched by SIGLENT follows the standards of <IEEE802.3-2018, Subclause 55、Subclause 126>. The following table details the standards referenced by each test item.

For more information about IEEE802.3 standards, please refer to the website: www.ieee802.org

Reference Standard	Test Mode	Test Item	Test Description
IEEE802.3-2018, Subclause 126.5.3.1	Test mode 6	Maximum Output Droop	2.5GBASE-T, Maximum Output Droop
IEEE802.3-2018, Subclause 126.5.3.3	Test mode 2	Transmitter Timing Jitter-Master	2.5GBASE-T, Transmitter Timing Jitter-Master
IEEE802.3-2018, Subclause 126.5.3.5	Test mode 2	Transmitter Clock Frequency	2.5GBASE-T, Transmitter Clock Frequency
IEEE802.3-2018, Subclause 126.5.3.2	Test mode 4	Transmitter Linearity	2.5GBASE-T, Transmitter Linearity
IEEE802.3-2018, Subclause 126.5.3.2	Test mode 4	Transmitter Nonlinear Distortion	2.5GBASE-T, Transmitter Nonlinear Distortion
IEEE802.3-2018, Subclause 126.5.3.4	Test mode 5	PSD(Power Spectral Density)、Power Level	2.5GBASE-T, PSD(Power Spectral Density)、Power Level
IEEE802.3-2018, Subclause 126.8.2.2	Test mode 5	MDI Return Loss	2.5GBASE-T, MDI Return Loss
IEEE802.3-2018, Subclause 126.5.3.3	Test mode 1 Test mode 3	Transmitter Timing Jitter-Slave	2.5GBASE-T, Transmitter Timing Jitter-Slave
IEEE802.3-2018, Subclause 126.5.3.1	Test mode 6	Maximum Output Droop	5GBASE-T, Maximum Output Droop
IEEE802.3-2018, Subclause 126.5.3.3	Test mode 2	Transmitter Timing Jitter-Master	5GBASE-T, Transmitter Timing Jitter-Master
IEEE802.3-2018, Subclause 126.5.3.5	Test mode 2	Transmitter Clock Frequency	5GBASE-T, Transmitter Clock Frequency
IEEE802.3-2018, Subclause 126.5.3.2	Test mode 4	Transmitter Linearity	5GBASE-T, Transmitter Linearity

IEEE802.3-2018, Subclause 126.5.3.4	Test mode 5	PSD(Power Spectral Density)、Power Level	5GBASE-T, PSD(Power Spectral Density)、Power Level
IEEE802.3-2018, Subclause 126.8.2.2	Test mode 5	MDI Return Loss	5GBASE-T, MDI Return Loss
IEEE802.3-2018, Subclause 126.5.3.3	Test mode 1 Test mode 3	Transmitter Timing Jitter-Slave	5GBASE-T, Transmitter Timing Jitter-Slave
IEEE802.3-2018, Subclause 55.5.3.1	Test mode 6	Maximum Output Droop	10GBASE-T, Maximum Output Droop
IEEE802.3-2018, Subclause 55.5.3.3	Test mode 2	Transmitter Timing Jitter-Master	10GBASE-T, Transmitter Timing Jitter-Master
IEEE802.3-2018, Subclause 55.5.3.5	Test mode 2	Transmitter Clock Frequency	10GBASE-T, Transmitter Clock Frequency
IEEE802.3-2018, Subclause 55.5.3.2	Test mode 4	Transmitter Linearity	10GBASE-T, Transmitter Linearity
IEEE802.3-2018, Subclause 55.5.3.4	Test mode 5	PSD(Power Spectral Density)、Power Level	10GBASE-T, PSD(Power Spectral Density)、Power Level
IEEE802.3-2018, Subclause 55.8.2.1	Test mode 5	MDI Return Loss	10GBASE-T, MDI Return Loss
IEEE802.3-2018, Subclause 55.5.3.3	Test mode 1 Test mode 3	Transmitter Timing Jitter-Slave	10GBASE-T, Transmitter Timing Jitter-Slave

3.3 Test Equipment

Equipment and software requirements	Quantity	Note
High performance oscilloscope SDS7000A	1	Bandwidth ≥ 4 GHz;
2.5/5/10G Ethernet Compliance Analysis Software	1	Activate the 2.5/5/10GBASE-T Ethernet Compliance Analysis Software (Option :SDS7000A-CT-2.5/5/10GBASE-T);
Test Fixture	1	FX _ ETHS: 2.5/5/10Gbase-T Ethernet Compliance Test Fixture, which provides test points after the device under test (DUT) enters the test state;
Active differential probe or SMA cable (SMA-BNC, SMA-N adapter)	several	Active differential probe (such as SAP2500D or SAP5000D): SAP2500D has a bandwidth of 2.5GHz, which is suitable for 2.5G/5GBASE-T, and SAP5000D has a bandwidth of 5GHz, which is suitable for 10GBASE-T, and is used for detecting signals; SMA cable: Connect oscilloscope, spectrum analyzer and other equipment and test fixture for detecting signals.

Spectrum analyzer	1	Used for testing power spectral density, power level, transmitter linearity and transmitter nonlinear distortion;
Vector network analyzer	1	Used for MDI return loss test.
USB cable	2	It is used to connect the USB Host interface of oscilloscope with the USB Device interface of network analyzer and spectrum analyzer, so as to realize the control of oscilloscope on network analyzer and spectrum analyzer and obtain test data.
Arbitrary waveform generator	1	Dual-channel arbitrary waveform generator, the output sine wave frequency should be more than 35MHz, which is used for transmitter nonlinear distortion of 2.5GBASE-T.
Balun	1	When the spectrum analyzer is selected for testing, it is used to test the transmitter linearity, power spectral density and power level. When vector network analyzer is selected for testing, it is used for MDI return loss test.
Power divider	2	Used for transmitter nonlinear distortion test of 2.5GBase-T.

3.4 Test Challenge

3.4.1 Test fixture

The compliance test of 2.5/5/10G Ethernet is inseparable from the test fixture, which is the core link to ensure the signal integrity of the physical layer, and its design and application directly affect the accuracy and compliance of the test results:

2.5/5/10G Ethernet employs PAM4 technology, achieving a signal rate of up to 10Gbps, which imposes stringent requirements on the bandwidth and loss control of the test fixture. Impedance discontinuities in the fixture (such as at connectors or cable junction) can cause signal reflections, leading to excessive return loss. The IEEE 802.3 standard stipulates that the return loss for 10GBASE-T should be better than -15dB at 100MHz. Additionally, 10G Ethernet transmits data in parallel through four pairs of twisted-pair cables, so the fixture needs to ensure the isolation between channels.

The FX-MGETH test fixture of SIGLENT has demonstrated excellent performance in signal integrity guarantee, standard compliance test, environmental adaptability and other aspects by accurately grasping the test difficulties of 2.5/5/10G Ethernet and applying innovative technology. It adopts the modular design concept, including four areas, each of which has different functions and is clearly described on the board. Users can replace the corresponding modules according to different test items.

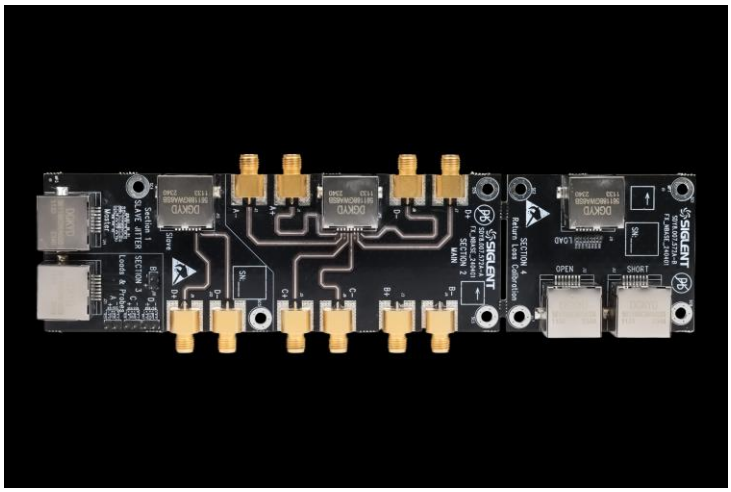


Figure 3-1 FX-MGETH test fixture

3.4.2 Analysis software

The compliance test of 2.5/5/10G Ethernet involves complex standards such as IEEE 802.3, and includes dozens of test items. Because each test item needs to establish a correct connection mode among the test fixture, the tested object and the oscilloscope, only relying on human brain memory, not only the efficiency is reduced, but also the accuracy is not guaranteed, and the compliance test software can solve this problem well. SIGLENT Ethernet compliance analysis software is a solution based on IEEE802.3-2018 specification. The analysis software can flexibly configure test items and control the oscilloscope to automatically complete the test. It shows the connection mode among the fixture, oscilloscope and the tested object in the test process of each measurement item in the form of graphical operation guidance, so that users can correctly set the test environment without memorizing, which can obviously reduce the test time and the probability of measurement errors. The ultimate goal of compliance testing is to obtain certification reports that meet industry standards. The traditional manual sorting of reports is not only time-consuming but also prone to errors. SIGLENT SDS7000A-CT-2.5/5/10GBASE-T compliance testing option has an automatic report generation system built in, and the test report records the whole measurement results, including screenshots of test values and test waveforms, which greatly improves the test efficiency and reduces manual operation errors.

Figure 3-2 SDS7000A-CT-2.5/5/10GBASE-T Ethernet Compliance Analysis Software

SIGLENT 2.5/5/10GBASE-T compliance analysis software has effectively overcome the software problems in compliance testing of 2.5/5/10G Ethernet with its powerful automation function, accurate standard interpretation ability, efficient data processing technology and flexible scene adaptability.

3.4.3 Test environment

In the compliance test of 2.5/5/10G Ethernet, the connection complexity of the test environment and the collaborative requirements of multiple devices constitute the core challenge. Different test items have significant differences in equipment configuration, connection mode and signal processing requirements. Facing these challenges, SIGLENT has provided a comprehensive test environment solution with profound technical accumulation and industry insight.

According to different test items and their different configurations, the test environment can be divided into five situations: oscilloscope test, spectrum analyzer test, vector network analyzer test, transmitter nonlinear distortion test and transmitter timing jitter-slave test. The test items of the three rates are similar, and the following introduction does not distinguish.

(1) Test environment using oscilloscope: maximum output drop, transmitter timing jitter-master, transmit clock frequency, transmitter linearity (tested with oscilloscope), power spectral density (tested with oscilloscope) and power level (tested with oscilloscope). The test environment is the same, and the test fixture is used in area ② or ③. The DUT needs to output the waveform of the test mode corresponding to the corresponding test item. FX-MGETH test fixture supports the use of active differential probes or SMA cables to detect signals.

The connection mode using active differential probe is shown in Figure 3-3:

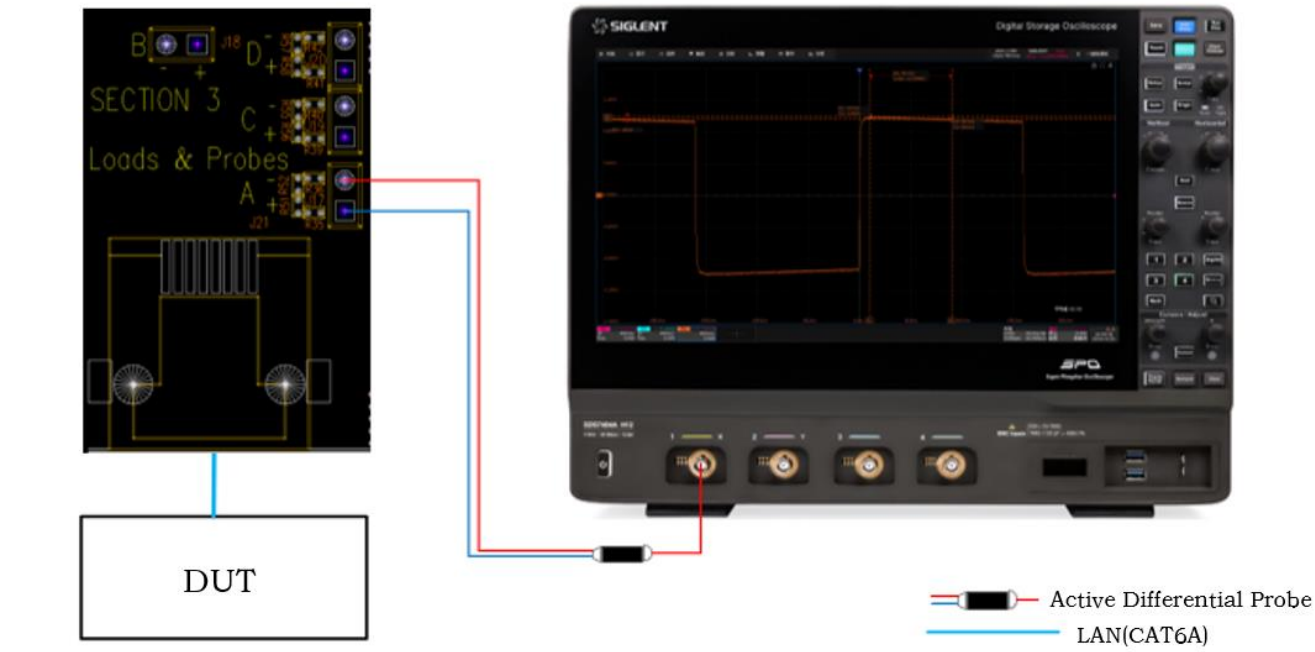


Figure 3-3 Connection Mode of Active Differential Probe

The connection mode using SMA cable is shown in Figure 3-4:

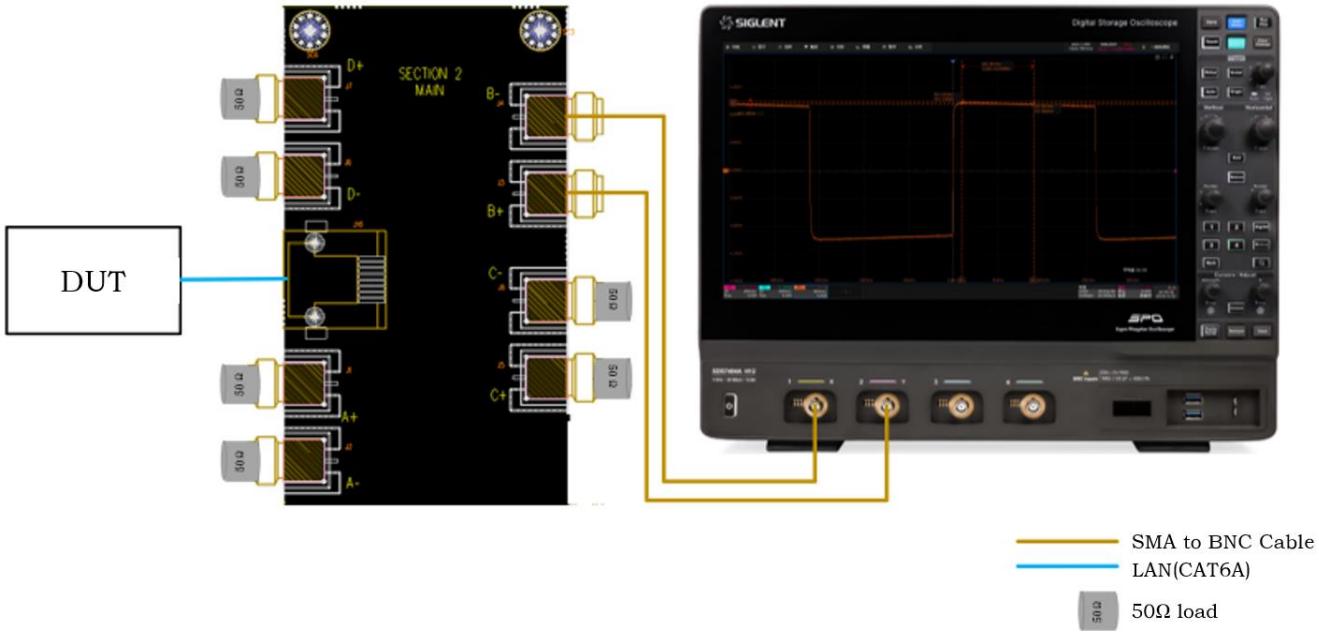


Figure 3-4 Connection Mode of SMA Cable

(2) Test environment using spectrum analyzer: transmitter linearity, transmitter nonlinear distortion, power spectral density and power level. When choosing to use spectrum analyzer for testing, the test environment is the same, and the test fixture area ② and Balun are used. The DUT needs to output the waveform of the test mode corresponding to the corresponding test item. The connection mode is shown in Figure 3-5:

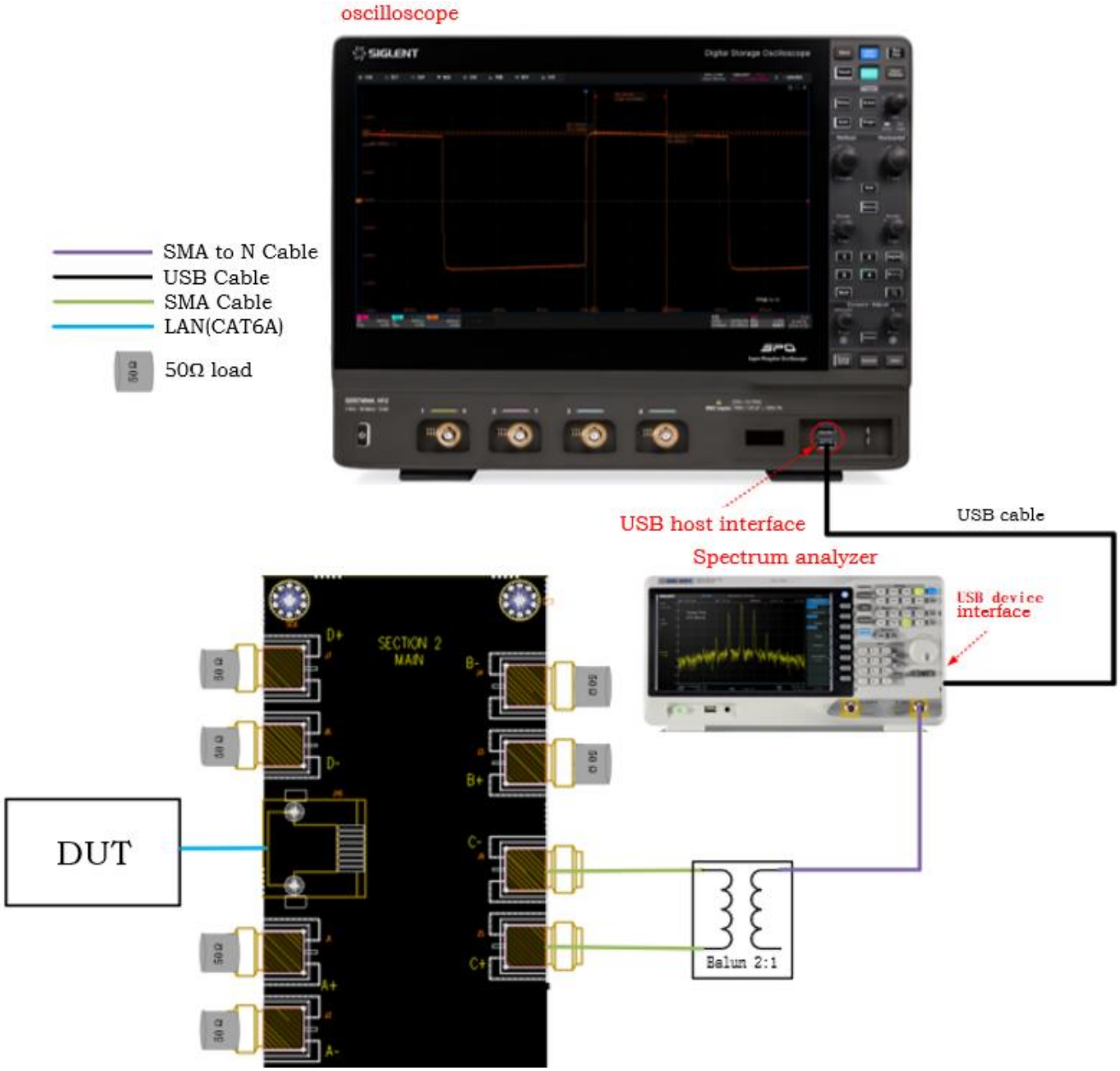


Figure 3-5 Connection Mode Using Spectrum Analyzer

(3) Test environment using vector network analyzer: When testing MDI return loss, vector network analyzer, test fixture area ② and calibration parts are needed. The DUT needs to output the waveform of the test mode corresponding to the corresponding test item. The vector network analyzer needs to be calibrated before MDI return loss test. The connection mode of calibration and test is as follows:

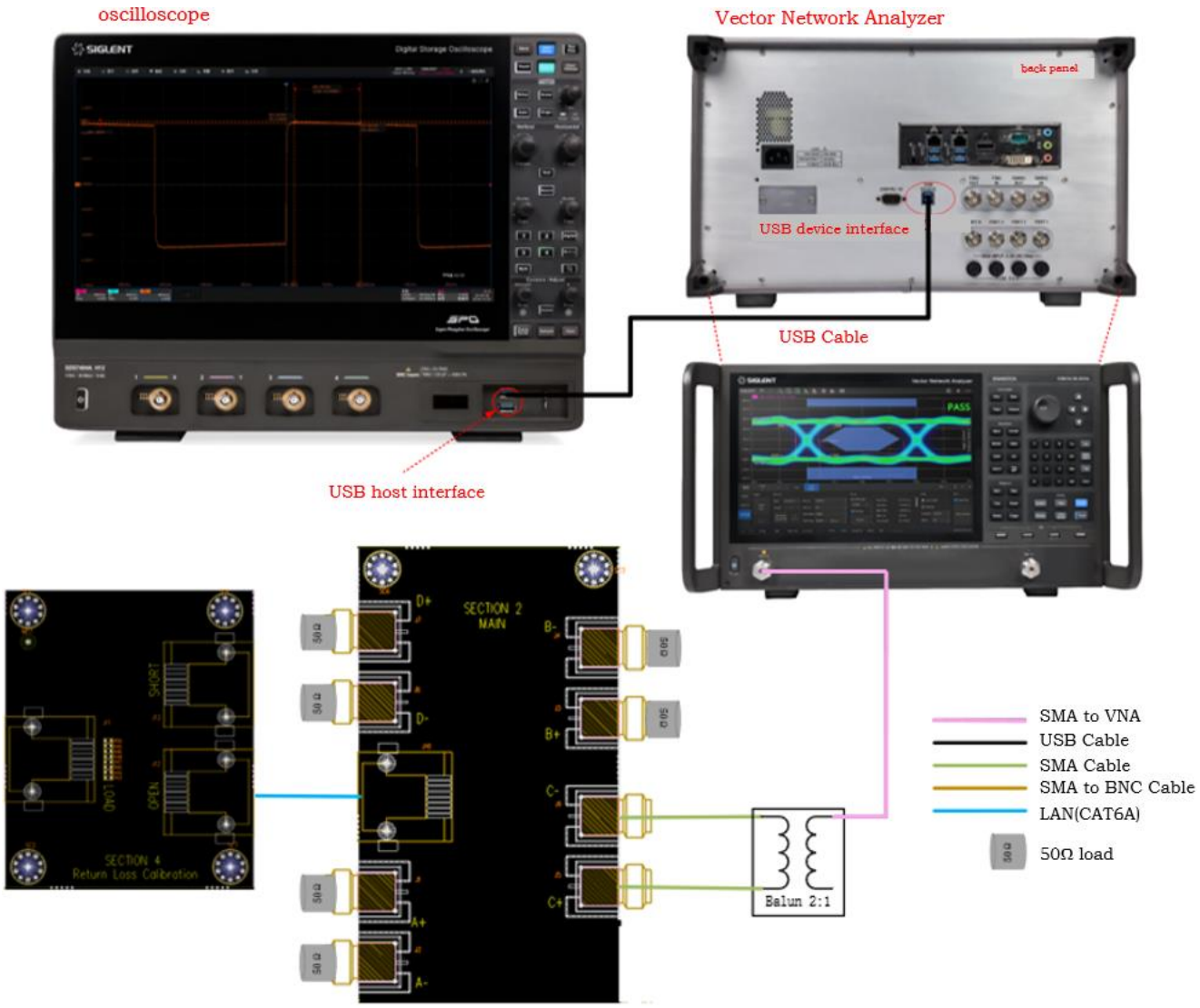


Figure 3-6 MDI Return Loss Calibration Connection Mode

The connection mode of the test is shown in Figure 3-7:

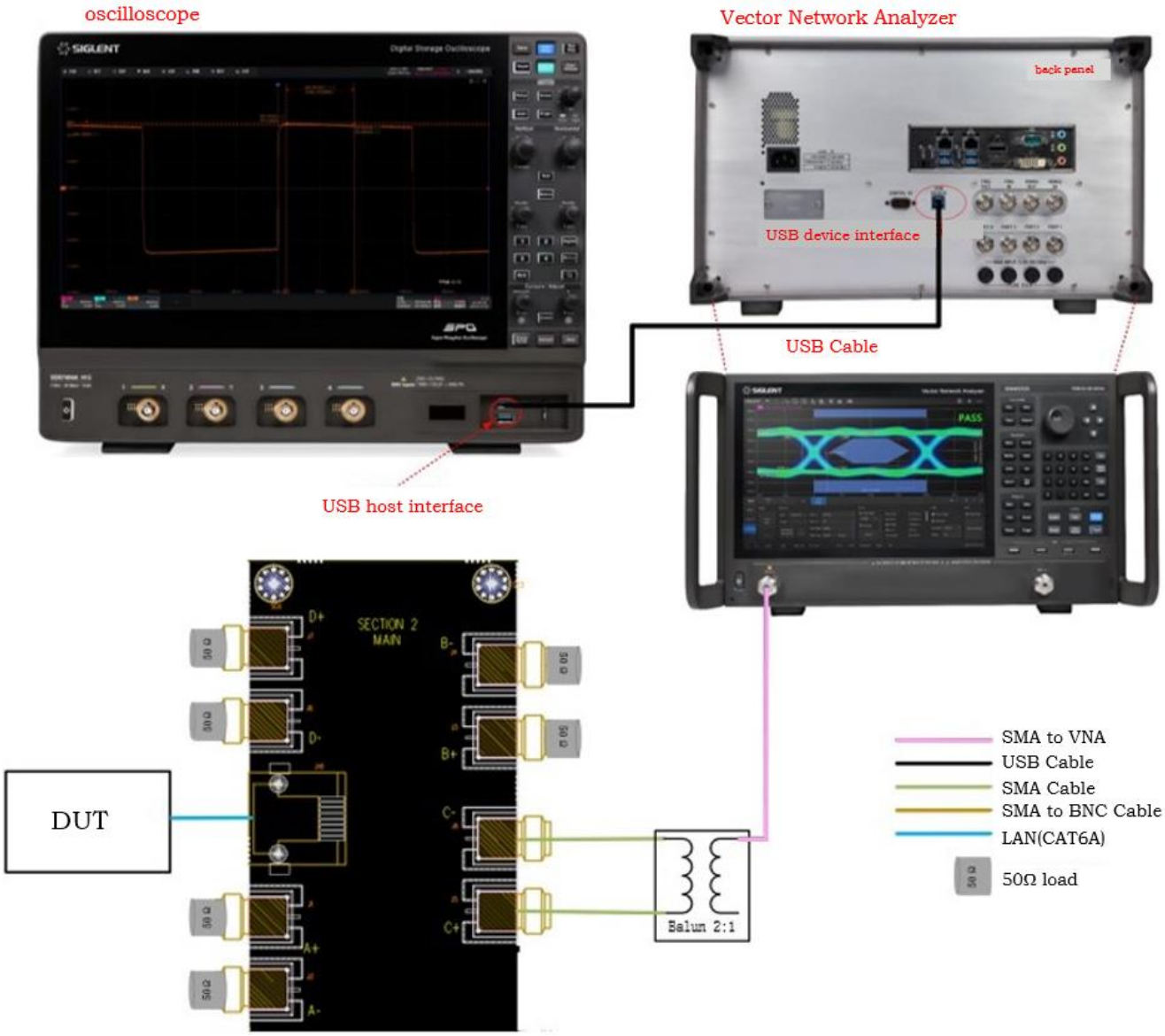


Figure 3-7 Connection Mode of MDI Return Loss Test

(4) Testing environment for transmitter nonlinear distortion: Only 2.5GBASE-T needs to test transmitter nonlinear distortion. When testing the transmitter nonlinear distortion, you need to choose to use an oscilloscope or a spectrum analyzer, but you must need to use arbitrary waveform generator、power divider, and the area ② of the test fixture. The DUT needs to output the waveform of the test mode corresponding to the corresponding test item. The connection method for testing with oscilloscope is as follows:

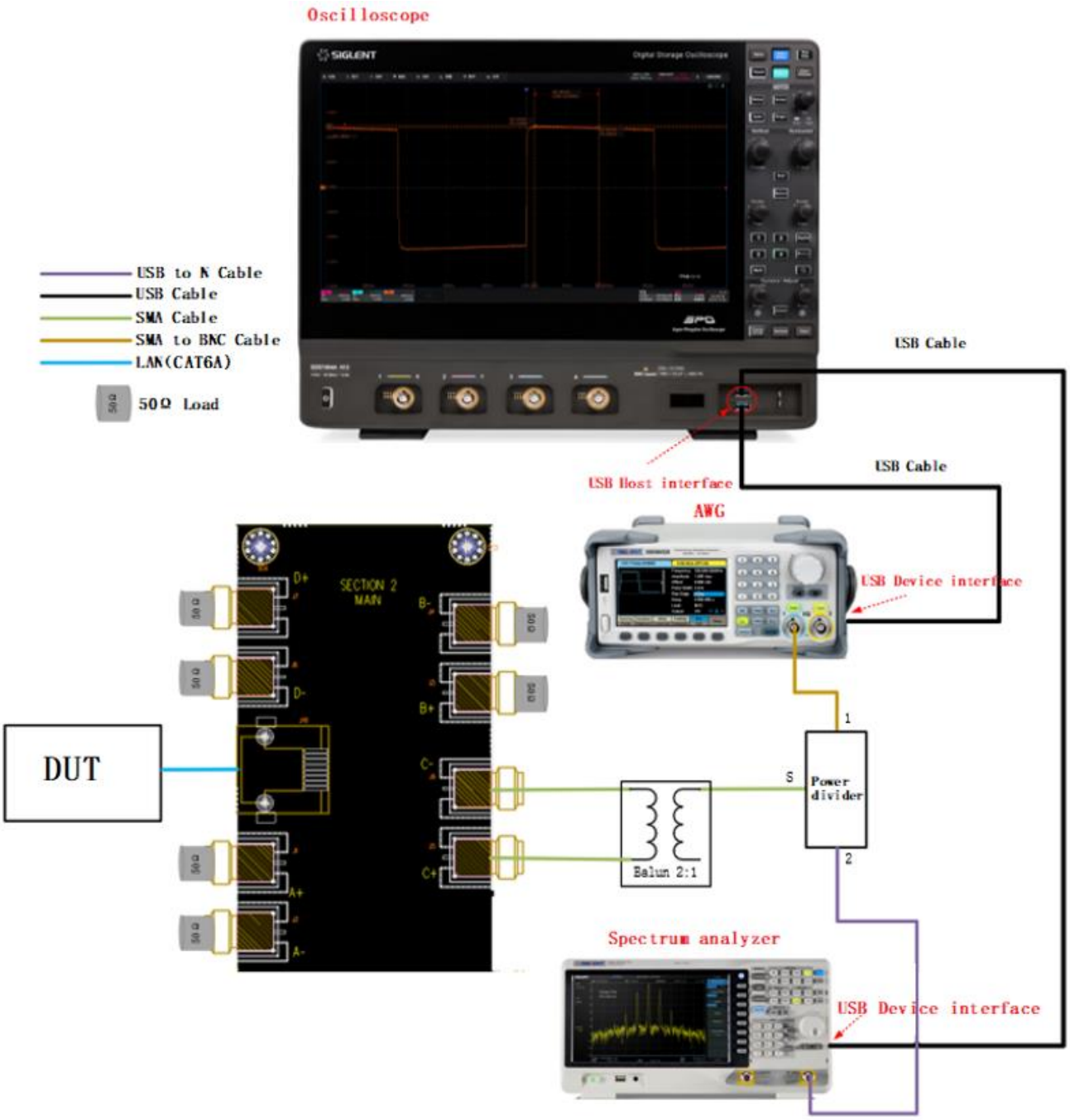


Figure 3-8 Nonlinear Distortion Test with Oscilloscope

The connection mode of spectrum analyzer is shown in Figure 3-9:

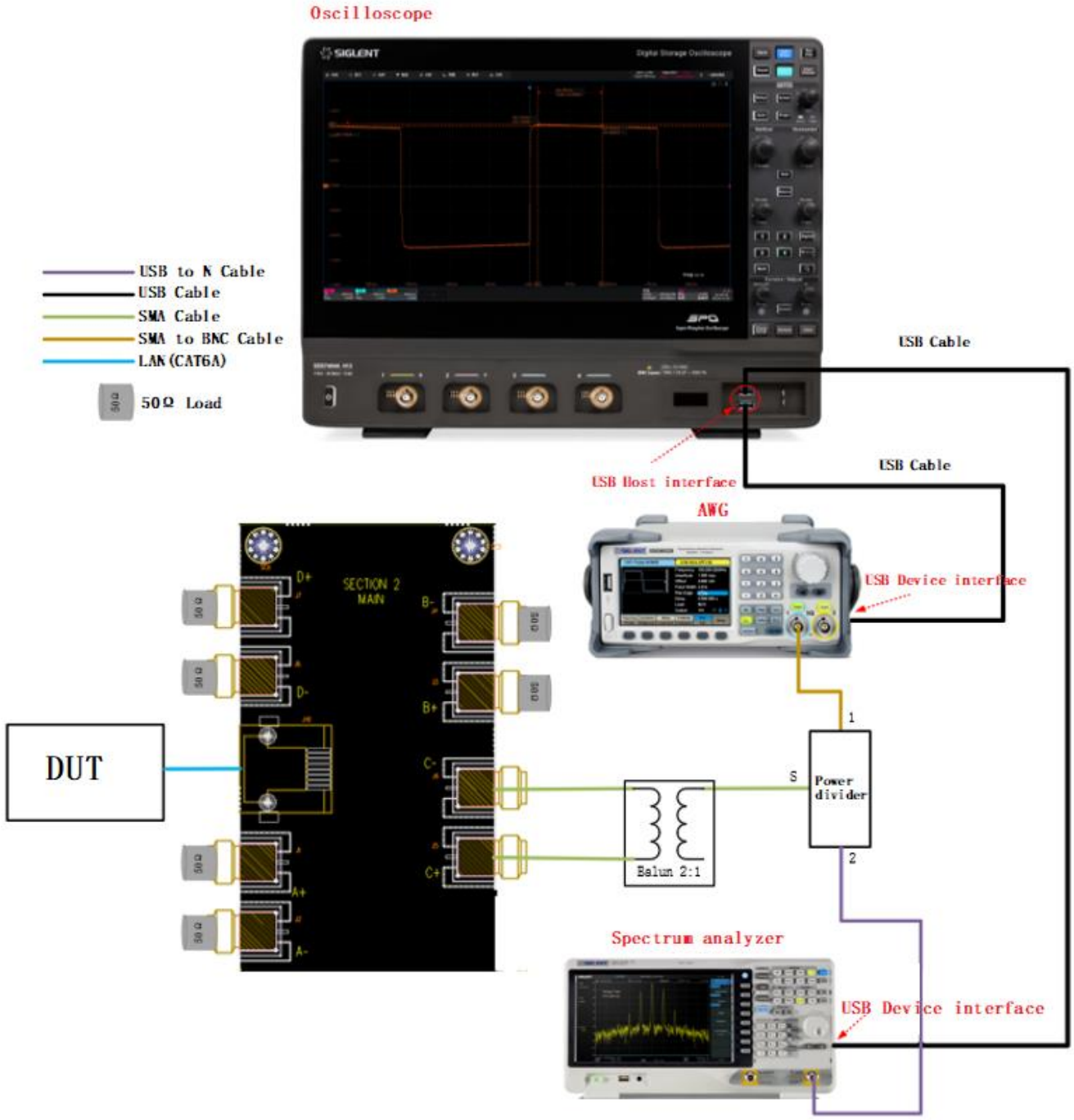


Figure 3-9 Nonlinear Distortion Test Using Spectrum Analyzer

(5) Test environment for transmitter timing jitter-slave mode: only needs to test PairD, use the area ① of the test fixture, two pieces of equipment are needed, one as a DUT, which is configured in test mode 3 (slave PHY) and the other as a Linkpartner, which is configured in test mode 1 (master PHY). The connections are as follows:

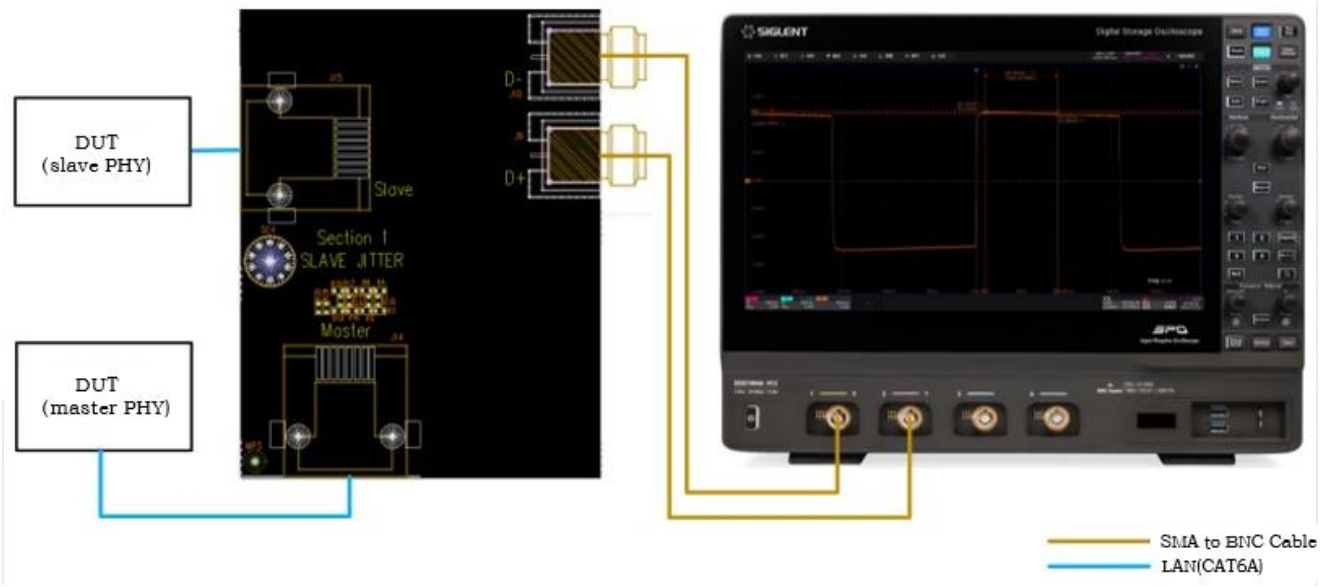


Figure 3-10 Connection mode of Transmitter timing jitter-slave

3.5 Test Steps

Click Test Config to open a specific test window, as shown in Figure 3-11. According to the test process, it is divided into six steps: Setup, Test Select, configure, connect, Run Test and Result.

3.5.1 Setup

- Provides three functions of configuration: Recall, Last and Save.
- There are three options to provide rate selection: 2.5GBase-T, 5GBase-T and 10Gbase-T.

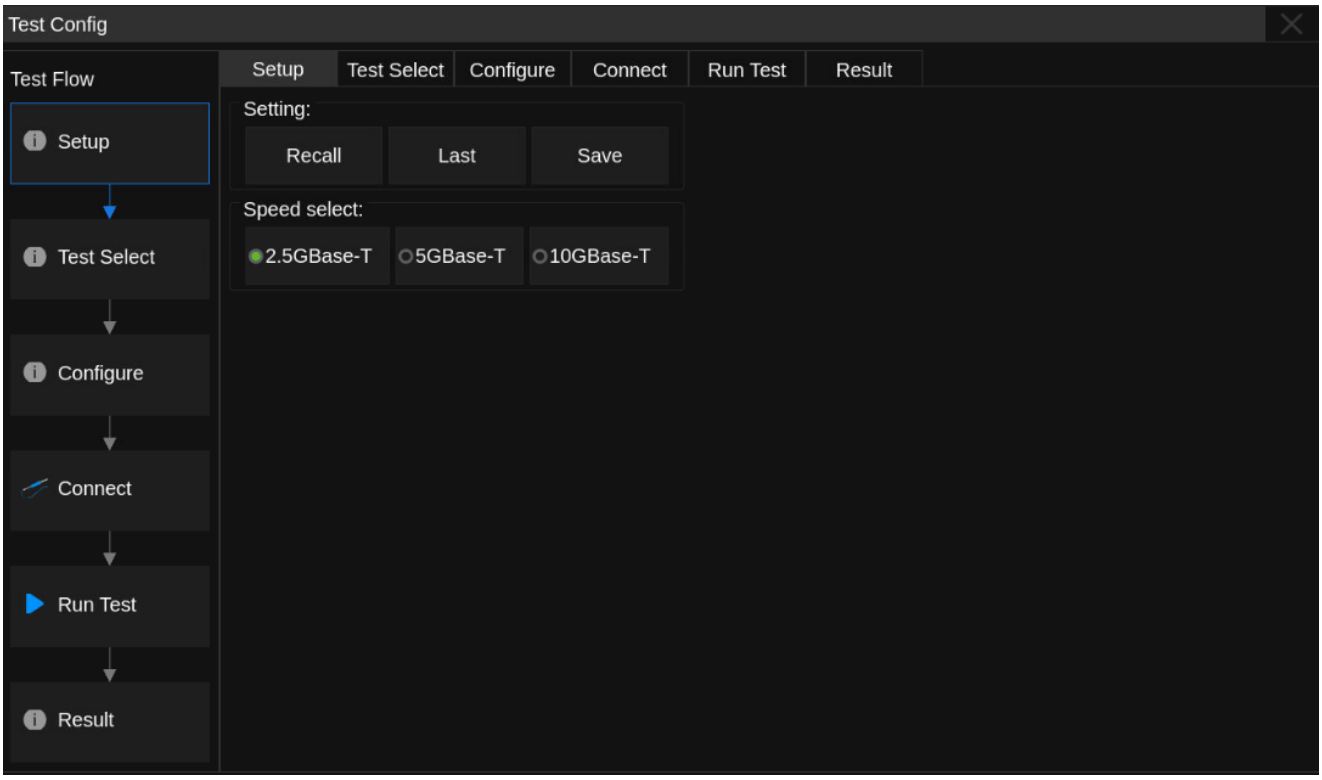


Figure 3-11 Window of Setup

3.5.2 Test Select

Select the items to be tested in this column.

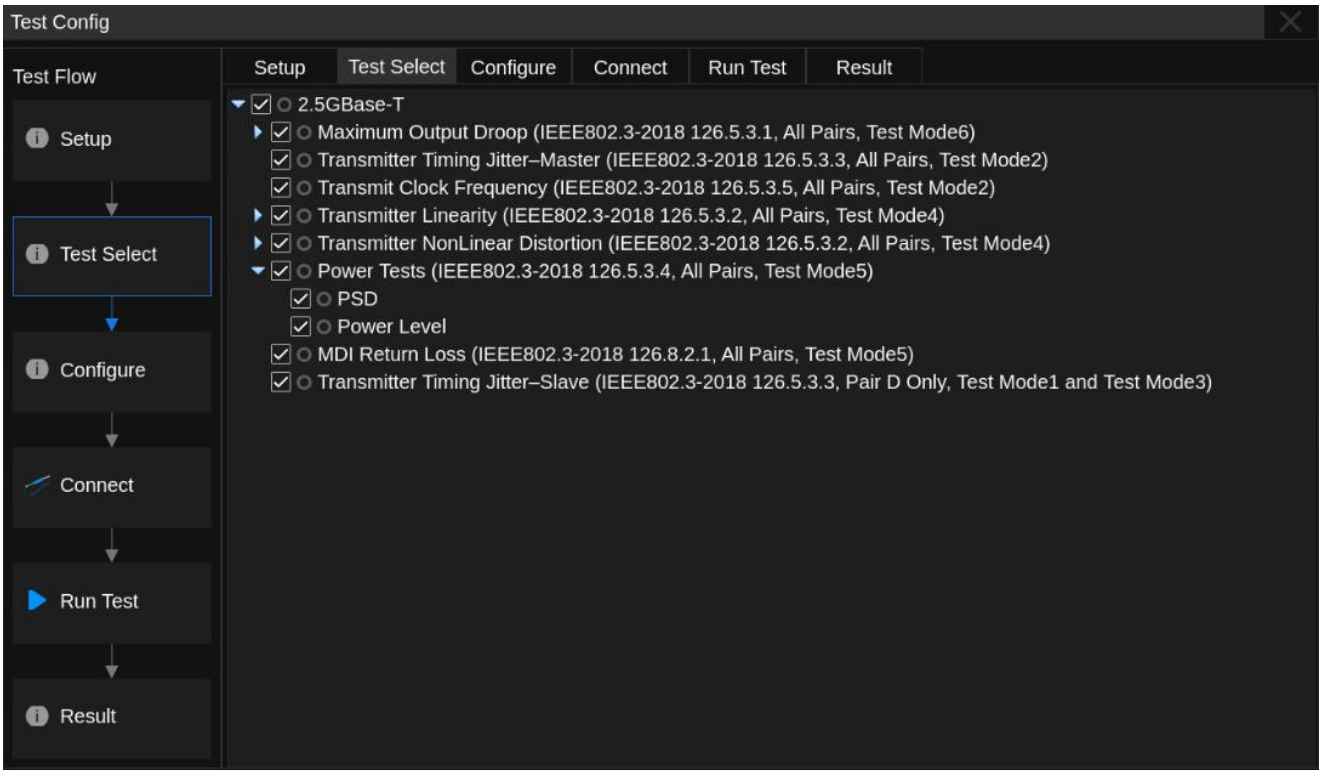


Figure 3-12 Window of Test Select

3.5.3 Configure

The previously selected test items will be highlighted in this section. By clicking on them, you can configure the corresponding test parameters, such as setting the source for oscilloscope measurement, the type of probe, and the signal pairs to be tested.

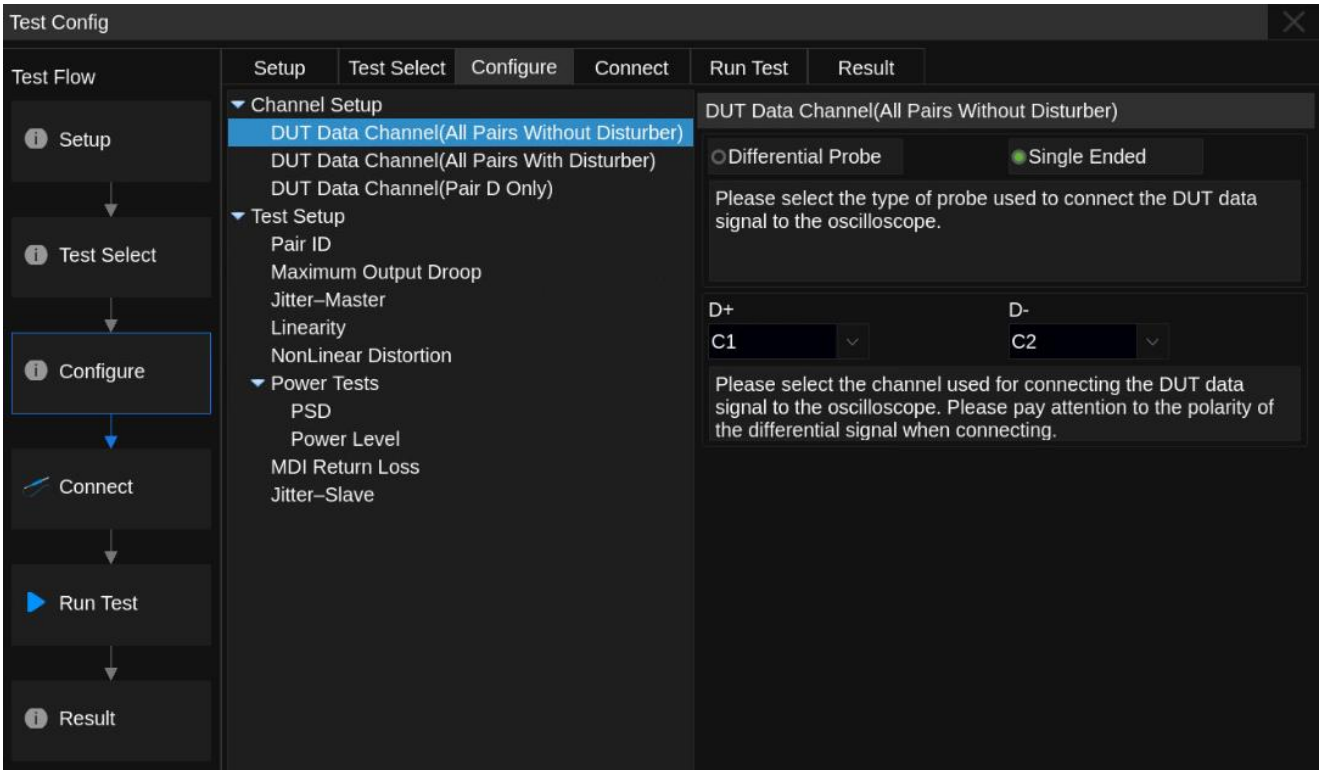


Figure 3-13 Window of Configure

3.5.4 Connect

This column shows the test connecting diagram and test steps. If multiple test items are selected at one time, only the information of the first item to be tested will be displayed. The connecting diagrams of other test items, if the connecting diagram is different, there will be a separate page pop-up prompt after the previous test item.

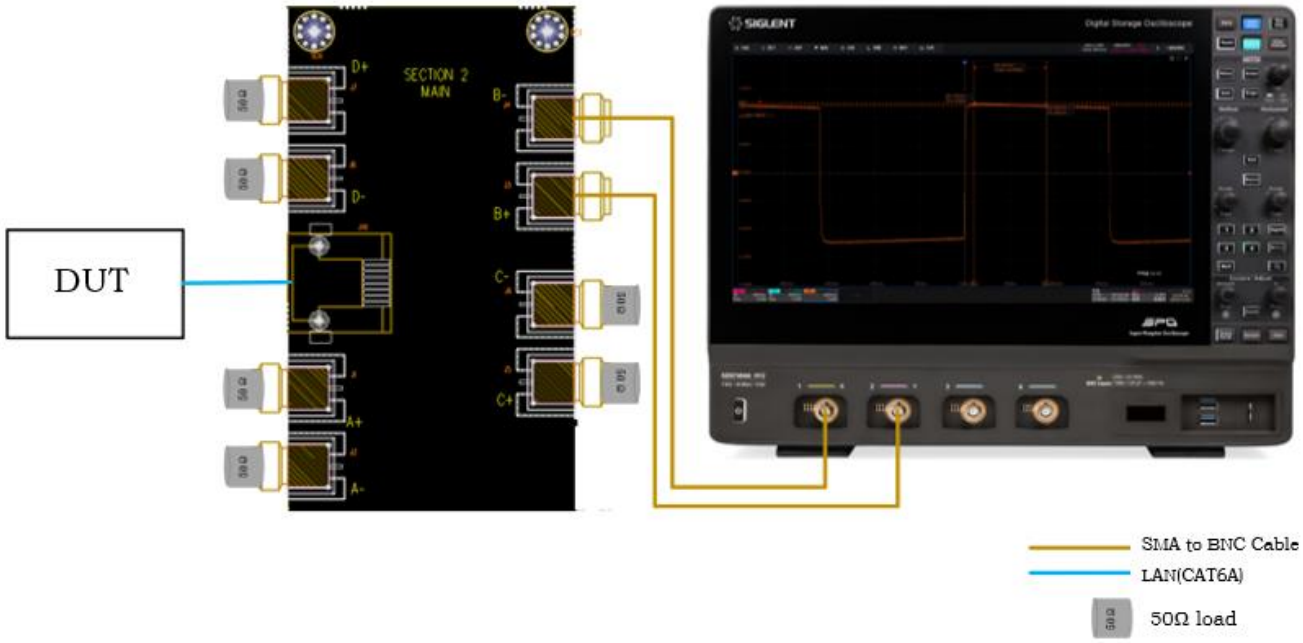


Figure 3-14 Connection diagram displayed in the window of connect

3.5.5 Run Test

- When the test fails, two options, Continue and Stop, are supported.
- Click Run Test in the lower right corner, and check the accuracy of the connection in the pop-up window to start this round of test.
- In the next test process, just follow the pop-up prompts to complete the test, and the test results will pop up after all the test items are completed.
- If multiple test items are selected in a round of testing, a pop-up window will appear to prompt the connection method for the next item when proceeding to it. After completing the connection, simply click the "Run Test" button in the pop-up window to continue with the testing.

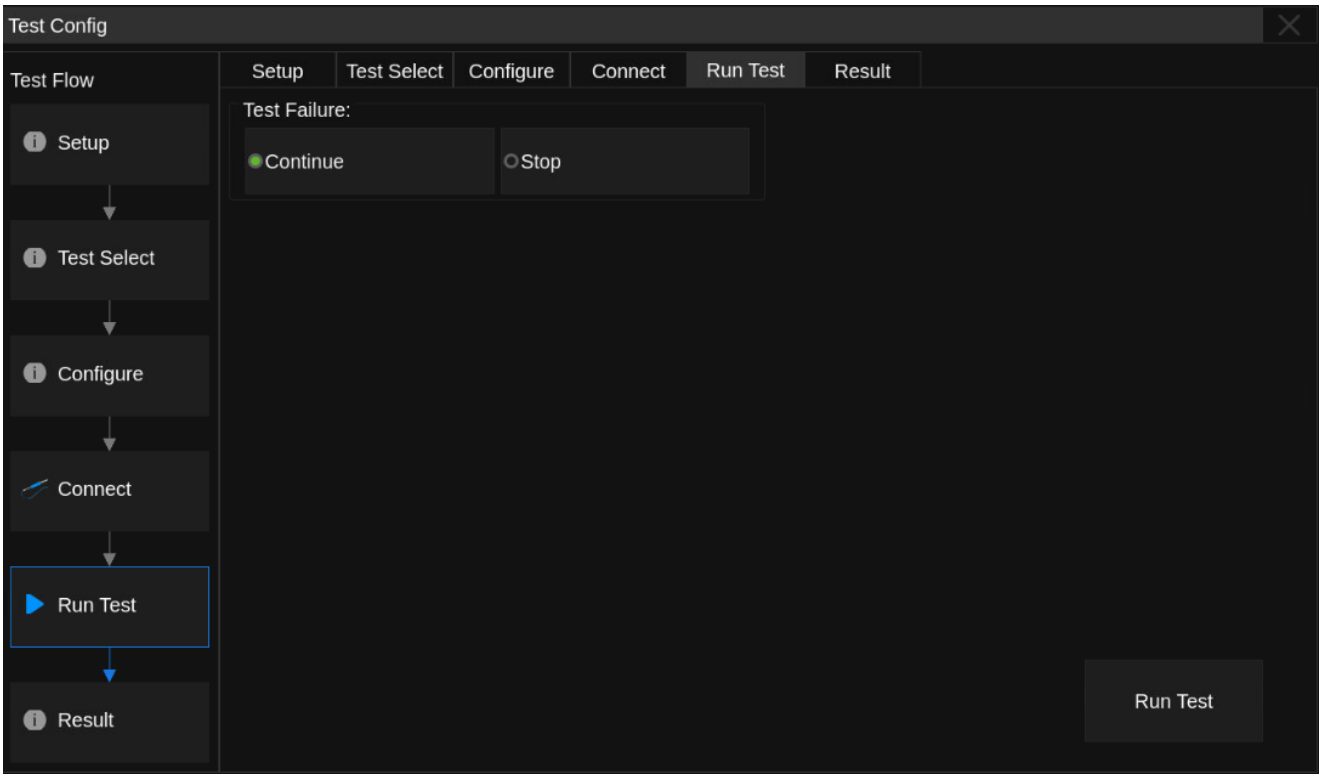


Figure 3-15 window of Run Test

3.6 Test Result

Click "Result" to view the corresponding test results.

The upper part of the test result window is the test items, which provide the test results of each item and the threshold value reference required by the authority. The lower part is the corresponding detail diagram. Click on the item of interest in the upper part, and the corresponding details will be displayed in the lower part. Click on the picture to view the details of the test waveform.

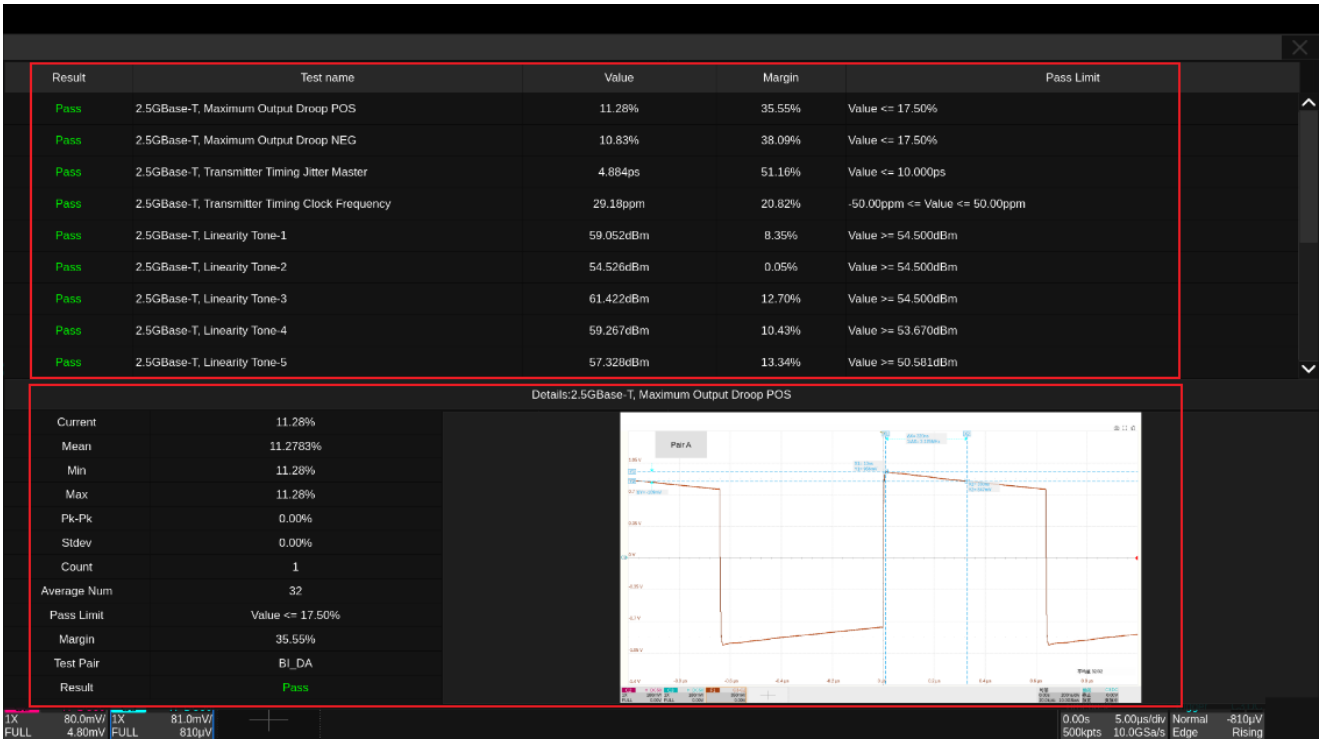


Figure 3-16 Test Results List

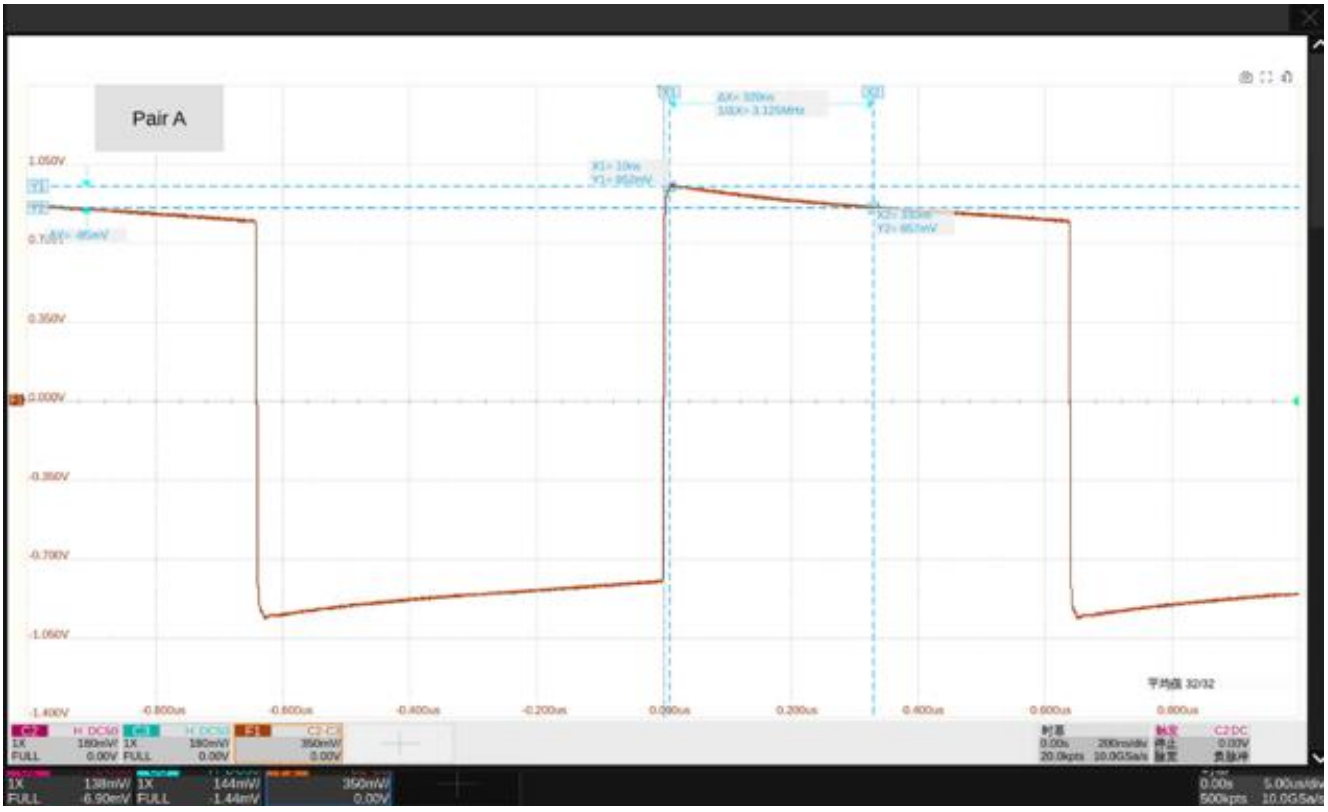


Figure 3-17 Waveform Details

3.7 Test Report

Click "Report Setting", fill in the relevant test information and select the report type; Preview Report

allows you to see the effect of the generated report in advance; Select the saved path in "File Manager" and click "Save" to save the test results.

Note: When saving in HTML format, a folder and an HTML file will be generated. If you need to copy the results, you need to copy them both and keep them in the same path.

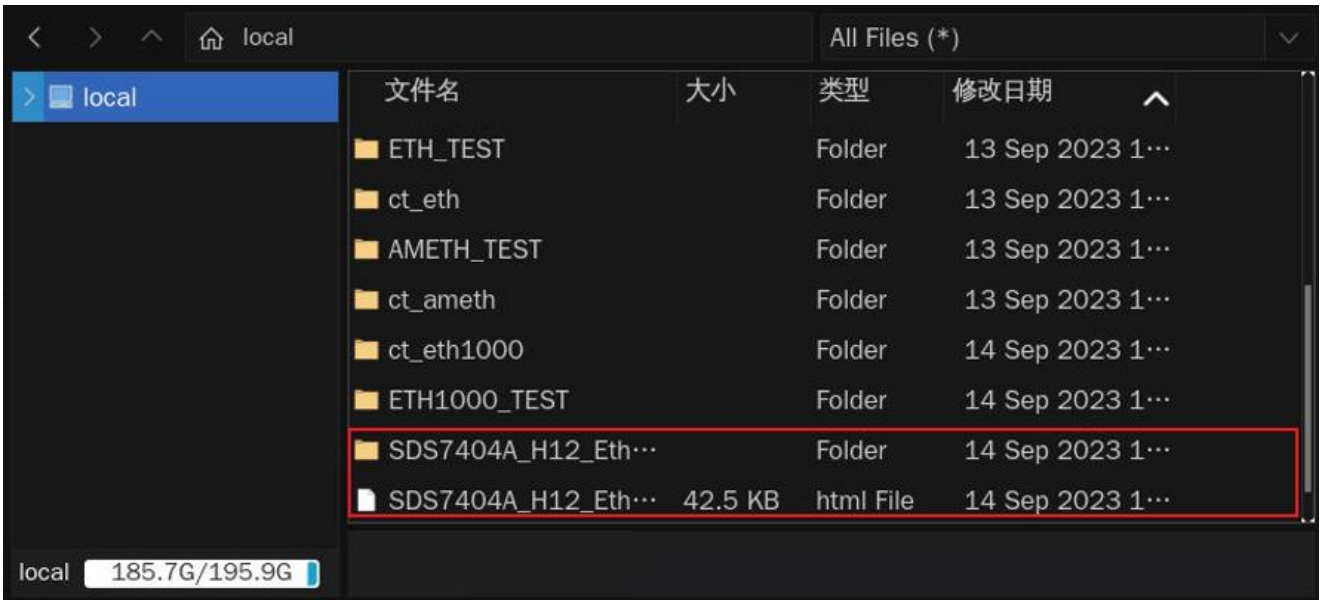
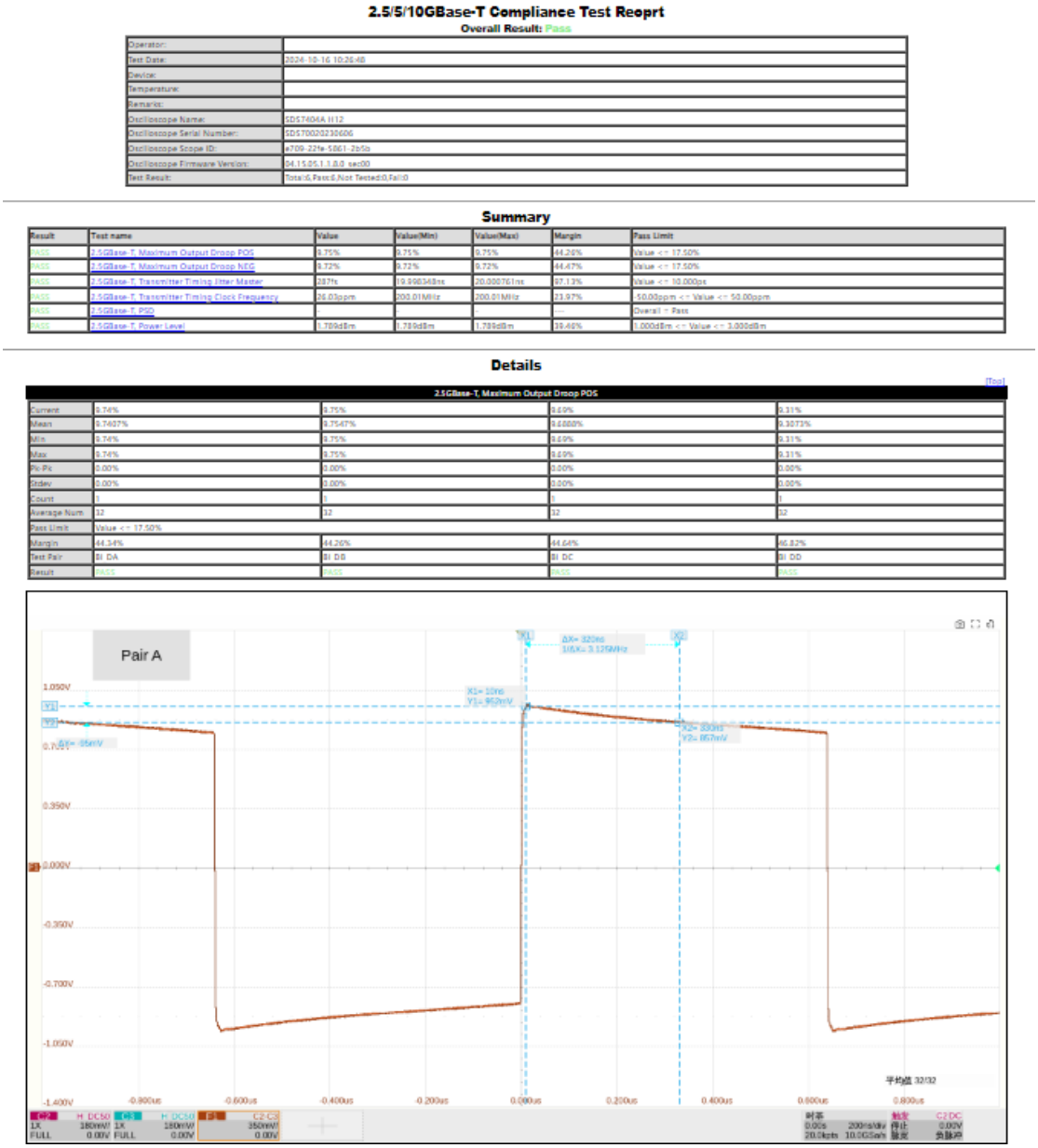


Figure 3-18 Report Generation Settings

The test report includes a summary table of all test results, with hyperlinks to the details page, which includes a screenshot of related tests.



2.5/5/10GBase-T Compliance Test Reoprt

Overall Result: Pass

Operator:	
Test Date:	2024-10-16 10:26:48
Device:	
Temperature:	
Remarks:	
Oscilloscope Name:	SDS7404A H12
Oscilloscope Serial Number:	SDS7002023006
Oscilloscope Scope ID:	a709-22fa-5861-2b5b
Oscilloscope Firmware Version:	04.15.05.1.3.0.0 sec00
Test Result:	Total:6,Pass:6,Not Tested:0,Fail:0

Summary

Result	Test name	Value	Value(Min)	Value(Max)	Margin	Pass Limit
PASS	2.5GBase-T, Maximum Output Droop POS	8.75%	8.75%	8.75%	44.26%	Value <= 17.50%
PASS	2.5GBase-T, Maximum Output Droop NEG	8.72%	8.72%	8.72%	44.47%	Value <= 17.50%
PASS	2.5GBase-T, Transmitter Timing Jitter Master	287fs	19.890368ns	20.000761ns	97.13%	Value <= 10.000ns
PASS	2.5GBase-T, Transmitter Timing Clock Frequency	26.03ppm	200.01MHz	200.01MHz	23.97%	-50.00ppm <= Value <= 50.00ppm
PASS	2.5GBase-T, PSD					Overall = Pass
PASS	2.5GBase-T, Power Level	-1.789dBm	-1.789dBm	-1.789dBm	39.46%	1.000dBm <= Value <= 3.000dBm

Details

2.5GBase-T, Maximum Output Droop POS				
Current	8.74%	8.75%	8.69%	0.31%
Mean	8.7407%	8.7547%	8.6880%	0.3073%
Min	8.74%	8.75%	8.69%	0.31%
Max	8.74%	8.75%	8.69%	0.31%
Pk-Pk	0.00%	0.00%	0.00%	0.00%
Stdev	0.00%	0.00%	0.00%	0.00%
Count	1	1	1	1
Average Num	32	32	32	32
Pass Limit	Value <= 17.50%			
Margin	44.34%	44.26%	44.64%	46.82%
Test Pair	SI DA	SI DB	SI DC	SI DD
Result	PASS	PASS	PASS	PASS

Figure 3-19 Test Report

4 summary

As the core link of product development and mass production, 2.5G/5G/10GBASE-T Ethernet compliance testing undertakes the key mission of ensuring equipment compatibility and reliability in data center, intelligent automobile, industrial automation and other fields. Facing the challenges of multi-device collaboration, high-frequency signal processing and complex protocol verification, SIGLENT 2.5G/5G/10GBASE-T Ethernet compliance test solution reconstructs the efficiency and accuracy of the test process through three core capabilities: standardization, automation and intelligence.

About SIGLENT

SIGLENT is an international high-tech company, concentrating on R&D, sales, production and services of electronic test & measurement instruments.

SIGLENT first began developing digital oscilloscopes independently in 2002. After more than a decade of continuous development, SIGLENT has extended its product line to include digital oscilloscopes, isolated handheld oscilloscopes, function/arbitrary waveform generators, RF/MW signal generators, spectrum analyzers, vector network analyzers, digital multimeters, DC power supplies, electronic loads and other general purpose test instrumentation. Since its first oscilloscope was launched in 2005, SIGLENT has become the fastest growing manufacturer of digital oscilloscopes. We firmly believe that today SIGLENT is the best value in electronic test & measurement.

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