

Keysight Technologies

Correlation between TDR oscilloscope and VNA generated time domain waveform

Application Note

Time domain analysis (TDA) is a common method for evaluating transmission lines and has been performed using a time domain reflectometer (TDR) oscilloscope. Meanwhile vector network analyzer (VNA) based TDR measurements are gaining attention as an alternative method for time domain analysis. The E5071C option TDR provides a one-box solution for VNA based TDR measurements and offers unique features that are not available in traditional TDR oscilloscopes. The purpose of this application note is to validate the use of the E5071C option TDR by comparing data measured using the E5071C and a Keysight Technologies, Inc. 86100C TDR oscilloscope.

TDR oscilloscope and VNA Basics

TDR oscilloscopes have historically been used for time domain analysis. They launch a fast edge into the device under test (DUT) and directly sample the voltage to reconstruct a waveform in time domain. Though methodology of this echo technique is straightforward, measurement accuracy is low.

VNAs are commonly used for network characterization. They launch sinusoid and measure vector ratios of incident and reflected voltage. The frequency of the sinusoid is swept to provide the response of DUTs as functions of frequency. Since VNAs have wider dynamic range compared to TDR oscilloscopes, more accurate measurements can be made. In VNA based TDR measurements, the measured frequency response is converted into a time response by computing inverse fast

Measurement Data and Comparison

We compared the empirical data of TDR/TDT measurements and eye diagrams extracted from the E5071C and the 86100C.

A. TDR and TDT measurement

An on-board differential trace measurement was made on each instrument using the same DUT as shown in Figure 1. Prior to performing measurements, full 4-port calibration was performed on the E5071C and TDR/TDT calibration was performed on the 86100C. The measurement data from the two instruments is shown in Figure 2. TDR and TDT waveforms are displayed in terms of impedance and voltage, respectively. In this comparison, waveforms acquired by the 86100C are averaged 16 times to stabilize the measured values. The results show that the two methods are highly comparable. For example, the magnitude difference in the TDR waveform is within 0.4 ohm in the range of 0.7 to 1.0 nsec, and the difference in the TDT waveform is within 3 mV in the range of 2.0 to 3.0 nsec.

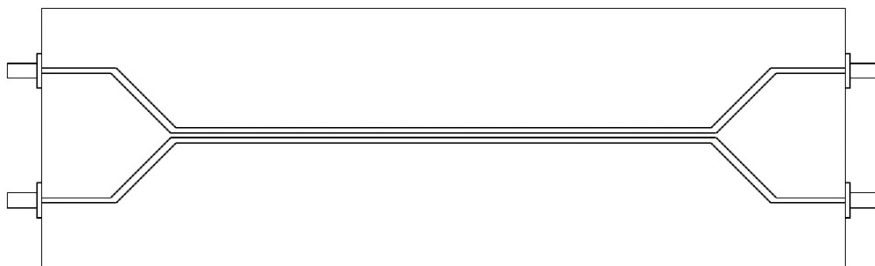


Figure 1. Measured DUT

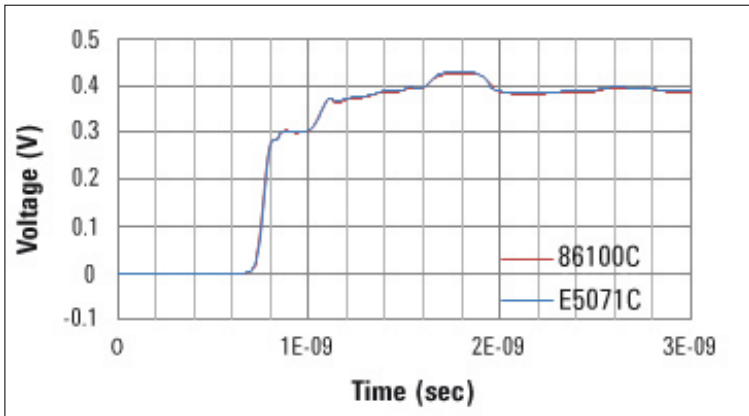
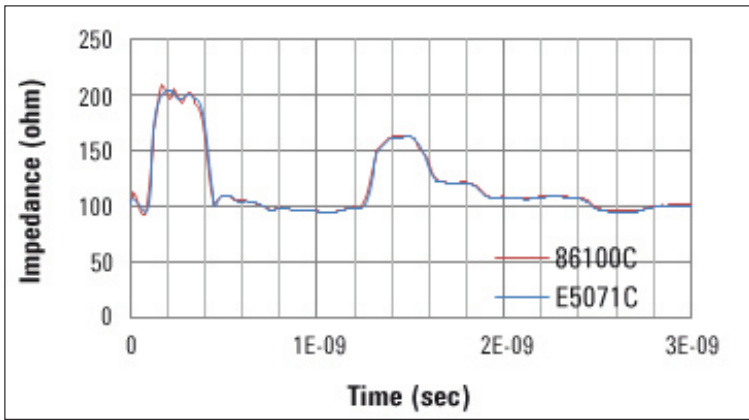


Figure 2. TDR waveforms (top) and TDT waveforms (bottom) acquired by 86100C and E5071C¹

1. In order to eliminate the timing offset due to the difference in calibration method, TDR and TDT waveforms of the E5071C are shifted by +20 psec and -70 psec, respectively.

B. Eye diagram

The Keysight N4903B, a standard bit error rate tester, was used with the 86100C to draw an eye diagram. Meanwhile the E5071C option TDR drew a simulated eye diagram based on an internally generated bit pattern. Cables of equal length were used on both measurement systems and insertion loss of the cables was not compensated for¹. Figure 3 shows eye diagrams drawn by 86100C and E5071C option TDR. They remarkably resemble each other in shape.

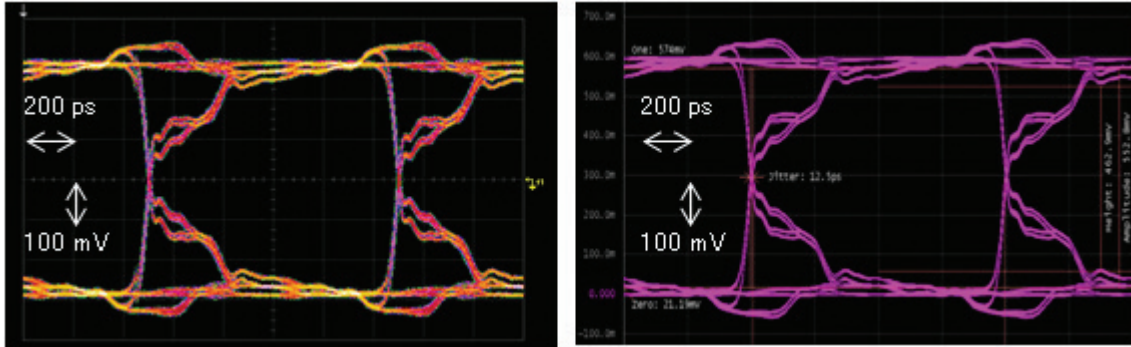


Figure 3. Eye diagram extracted from 86100C (left) and E5071C (right)

Summary

In this technical note, we introduced time domain analysis using E5071C option TDR and compared the results with those of a standard 86100C TDR oscilloscope. The TDR/TDT waveform and eye diagram extracted from each instrument are highly comparable. It ensures the reliability of E5071C option TDR in time domain

Appendix: Test Procedure

Equipment

- Keysight E5071C-4K5 vector network analyzer with TDR option
- Keysight 86100C DCA-J wideband oscilloscope mainframe
 - Left Module: 54754A differential and single-ended TDR/TDT module
 - Right Module: 86112A dual channel electrical module
- Keysight N4903B J-BERT bit error rate tester

1. There is no method to compensate the cable loss on the N4903B.

E5071C option TDR

A. TDR/TDT measurement

1. Connect 3.5 mm SMA cables to all test ports.
2. Open **Setup** menu and click **Default Setup** button.
3. Set the measurement condition using the **Setup Wizard**.
 - Open **Setup** menu and click **Setup Wizard** button.
 - Overview: Check **Use ECal** module check box.
 - **Step 1/5:** Select Differential DUT 2-Port button.
 - **Step 2/5:** Connect ECal module to the cables and click Calibrate button.
 - **Step 3/5:** Skip this step since a fixture is not used.
 - **Step 4/5:** Connect a DUT and click Measure button.
 - **Step 5/5:** Set Rise Time to “35 ps”¹ and select “10-90%” from the drop-down list for Definition.
4. Click **Trace** and select “3” to activate Trace3.
5. Open **TDR/TDT** menu and select “Volt” from the drop-down list for Format. Trace1 shows TDR measurement in terms of impedance and Trace3 shows TDT measurement in terms of voltage.

B. Simulated Eye Diagram

1. Set the measurement condition using the Setup Wizard.
 - Open **Setup** menu and click **Setup Wizard** button.
 - Overview: Uncheck **Use ECal** module check box.
 - **Step 1/4:** Select Differential DUT 2-Port button.
 - **Step 2/4:** Disconnect the DUT and click Deskew button.
 - **Step 3/4:** Connect the DUT and click Measure button.
 - **Step 4/4:** Set Rise Time to “22 ps” and select “10-90%” from the drop-down list for Definition.
2. Click **Trace** and select “5” to activate Trace5.
3. Open **Eye/Mask** menu and set Bit Pattern settings.
Type = PRBS Length (bits) = 2⁷-1
Amplitude = 200 mV Data Rate = 1 Gb/s
4. Click **Draw Eye**.

1. For a more rigorous comparison, step rise should be adjusted based on observed value. Refer to “Step Rise Adjustment” in appendix.

86100C and N4903B

A. TDR/TDT measurement

86100C

1. Press [**Default Setup**] hardkey on the front panel.
2. Calibrate the modules [1] [2].
 - Open **Calibrate** menu and click **All Calibrate** to open the All Calibration dialog box.
 - Perform calibration on both left and right modules with **Module Calibration wizard**.
3. Enter TDR/TDT mode by pressing [**TDR/TDT mode**] hardkey.
4. Set measurement condition.
 - Click **TDR Setup** button under Setup tab on the toolbar to open **TDR/TDT Setup** dialog box.
 - Set **Stimulus Mode** to “Differential” and click the tab which indicates 2-Port Balanced.
 - Perform Deskew on both modules [2].
 - Perform TDR/TDT calibration with the wizard [2].
 - Set **Effective Rise Time** to “35 ps”.
 - Check “Diff TDR” and “Diff TDT” checkbox on **Measurement Results** panel.
 - Close **TDR/TDT Setup** dialog box.
5. Change the unit of measure of TDR waveform
 - Click the button for vertical scale of Channel 1.
 - Click **Advanced** button and set Unit to “Ohm”.

B. Eye diagram

1. Input the trigger clock from the N4903B to the 86100C.
2. Connect DTAT OUT and OUT on N4903B's front panel to Channel 3 and 4 on 86100C, respectively.

N4903B

3. Press [Preset] hardkey on the front panel.
4. Click Select Pattern button under Select tab to open Select Pattern dialog box
 - Select “ 2^n-1 PRBS” and set Pattern Size to “ 2^7-1 ”.
5. Click Bit Rate Setup button under PG Setup tab
6. Enter “1 GHz” on Values and Units text box.

86100C

7. Calibrate the modules in the same way as TDR/TDT measurement.
8. Press [Source] button on the front panel to set the trigger source to “Front Panel”.
9. Open Setup menu and click Trigger to open Trigger dialog box.
 - Set the Trigger Bandwidth to Standard (DC -3.2 GHz).
10. Open Measure menu and click Math... to open Math dialog box.
 - Set Operators to “Subtract” and select “Channel 3” and “Channel 4” for source 1 and 2, respectively.
 - Check Function 1 Display On.
11. Press [Auto Scale] hardkey on the front panel.

Step Rise Adjustment

Step rise should be adjusted on the TDT waveform.

E5071C option TDR

1. Click Trace and select "5" to activate Trace5.
2. Click Marker Search and Rise Time (10-90%) in series, then measured value appears on the upper-left corner of the screen.

86100C

1. Open Measure menu and click TDR/TDT and Risetime in series.
2. Set Source to Response 3 and click OK, then measured results appear on the lower side of the screen.

Fine tune the rise time so that observed values would be equivalent on both instruments.

Reference

1. Keysight 86100C Infiniium DCA-J Wide-Bandwidth Oscilloscope Quick Start Guide. Literature number 86100-90102.
2. Keysight 86100A/B/C Infiniium DCA Online Help.

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