Advanced Product Design & Test for High-Speed Digital Devices

Presenters

Part 1 - 30 min.
Hidekazu Manabe
Application Marketing Engineer
Agilent Technologies

Part 2 - 20 min.
Mike Engbretson
Chief Technology Engineer
Granite River Labs
Webcast Agenda

Advanced Product Design & Test for High-Speed Digital Devices

Part 1

• Trends in High Speed Digital Test
• Stressed Eye Diagram Analysis of Interconnects
• Hot TDR Measurements
• Information and Resources
• Summary

Part 2

• 5 Reasons We like the Agilent ENA presented by Granite River Lab
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Trends in High Speed Digital Compliance Test
Evolution of ENA Option TDR

With the increase in bit rates, standards continue to evolve and new measurements are often the result. There is a growing need in the industry for more thorough evaluation of components, as well as evaluation under actual operating conditions.

<table>
<thead>
<tr>
<th>High-speed serial standards</th>
<th>Compliance Test Parameters</th>
<th>Agilent ENA Option TDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990s</td>
<td>• time domain (impedance, delay, skew, …)</td>
<td>ENA Option TDR Rev. A.01.50 Released in September, 2011 “One-box Solution with Three Breakthroughs”</td>
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<tr>
<td>Gen 1 (~100s Mbps)</td>
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<tr>
<td>2000~</td>
<td>• time domain (impedance, delay, skew, eye diagram) • frequency domain (insertion loss, return loss, …)</td>
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<tr>
<td>Gen 2 (<del>1</del>3 Gbps)</td>
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<td>• time domain (impedance, delay, skew) • frequency domain (insertion loss, return loss, crosstalk, mode conversion, …)</td>
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<td>Gen 3 (~3 Gbps)</td>
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<td>2010~</td>
<td>• time domain (impedance, impedance in active state, delay, skew, stressed eye diagram) • frequency domain (insertion loss, return loss, return loss in active state, crosstalk, mode conversion, …)</td>
<td>New features</td>
</tr>
<tr>
<td>Next Gen (~6 Gbps)</td>
<td></td>
<td>1) Advanced Waveform Analysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2) Avoid Spurious</td>
</tr>
</tbody>
</table>

New features

1) Advanced Waveform Analysis
2) Avoid Spurious
Trends in High Speed Digital Compliance Test

For More Information

Webcast: “Breakthrough in High Speed Interconnect Analysis and Compliance Testing”

Delivered Date: April 27, 2011

URL: http://agilent.techonline.com/s/agilent_apr2711
Trends in High Speed Digital Compliance Test
New Features Overview ~ Advanced Waveform Analysis ~

Determine optimal emphasis and equalization settings for your link
Emphasis and equalization are commonly used signal conditioning techniques when transmitting signals at gigabit data rates. The term emphasis is used to describe signal conditioning on the transmitter, while the term equalization is used on the receiver side.

Simulate real-world signals through jitter insertion
Stressed Eye Diagram Analysis of Interconnects can be realized with jitter insertion. Impairments such as random and periodic (sinusoidal) jitter can be configured.
Impedance analysis of active devices under actual operating conditions

For Hot TDR measurements of transmitters, the data signal from the transmitter causes measurement error. The **Avoid Spurious** feature determines the spurious frequencies from the data rate (user input) and sets the optimum frequency sweep to minimize measurement error.
Webcast Agenda

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Stressed Eye Diagram Analysis of Interconnects

Why Measure?

Interconnects can be characterized by measuring parametric characteristics such as insertion loss and impedance.

One challenge with such characterization is how to translate the measurements into what the eye diagram will look like at the end of a link....
Another approach is to measure the interconnect driven by the expected worst case performance of the transmitter. This has the advantage of allowing direct measurement of eye characteristics at the end of the link. This process is called "stressed" eye testing.

If the interconnect can correctly transmit a stressed signal with eye characteristics equal to or better than what is specified at the receiver, then it should operate with the signal of any compliant transmitter. To this end, the stressed signal is composed of the worst-case compliant signal generated by the transmitter.
Stressed Eye Diagram Analysis of Interconnects
HDMI 1.4b

Option of testing either:
A) Parametric parameters
B) Stressed eye diagram

+HDMI Specification Version 1.4b (October 11, 2011) 4.2.6
+HDMI Compliance Test Specification Version 1.4b (October 11, 2010), pp 44-59.
Stressed Eye Diagram Analysis of Interconnects

Measurement Challenges

Many instruments…

⚠️ How to setup for proper measurements?

⚠️ Total solution cost?

Only eye diagram measurements available…

⚠️ How to troubleshoot and isolate root cause upon device failure?
The **ENA Option TDR** is application software embedded on the ENA, which provides a **one-box solution** for high speed serial interconnect analysis.

**One-box solution**

for Stressed Eye Diagram Analysis of Interconnects

- Complete Characterization
- Simple Setup and Operation
- Affordable Solution

**Comprehensive Signal Integrity Measurement Solution for Next Generation High Speed Digital Standards**
Stressed Eye Diagram Analysis of Interconnects
Advantages of ENA Option TDR ~Complete Characterization~

Traditional Solution

- Stressed Eye Diagram Analysis (TDR, Scop and VNA)
- Impedance
- Delay, Skew
- Return Loss
- Insertion Loss

Both stressed eye diagram and parametric analysis available in one-box.

- ENA Option TDR

Stressed eye diagram tells pass/fail at a glance while parametric parameters provide insight into root cause of device failure.

Difficult to translate measurements into stressed eye diagram which is the end of a link upon device failure just by looking at eye diagram.

- Mismatch?
- Crosstalk?
- Skew?
- Loss?
Consists of many instruments and setup and operation is complicated.

Traditional Solution

One-box solution providing simple setup and operation.

ENA Option TDR

Stressed Eye Diagram and Parametric Analysis
Stressed Eye Diagram Analysis of Interconnects
Advantages of ENA Option TDR ~Affordable Solution~

Traditional Solution (Real-time Scope + SG + TDR Scope + VNA)

Solution too expensive for majority of cable MFRs !!

ENA Option TDR

- 8.5GHz, 4P 64K
- 14GHz, 4P $69K
- 20GHz, 4P 76K
Stressed Eye Diagram Analysis of Interconnects

Demo ~HDMI Cable~

HDMI Stressed Eye Test with jitter insertion

HDMI Stressed Eye Test with equalization
Webcast Agenda

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Hot TDR Measurements

Video

Open Your Eye with ENA Option TDR

www.agilent.com/find/ena-tdr
Hot TDR Measurements

Serial ATA

7.4.13 Return Loss and Impedance Balance

**Transmitters (Tx):**
- When measuring output impedance of transmitters the operating condition shall be during transmission of **MFTP**. This is to assure the measurement is performed during a mode of operation that represents normal operation.
- The amplitude of external excitation applied shall not exceed -**13.2 dBm** 50 Ohms (139 mVpp) single ended on each differential port of the transmitter.

**Receiver s (Rx):**
- When measuring input impedance of receivers the operating condition shall be during a PHYRDY Interface Power State (see section 8.1).
- The amplitude of external excitation applied shall not exceed -**6.48 dBm** 50 Ohms (300 mVpp) on each differential port of the receiver.

Definitions:
**MFTP** (mid frequency test pattern)
This pattern provides a middle frequency which is allowed within the Serial ATA encoding rules.
Pattern: 1100110011001100b = encoded D24.3. The pattern is repetitive.

---

Figure 154 – Return Loss Test
Hot TDR Measurements

Measurement Challenges

How to avoid effects of Tx excitation on measurement?

MFTP from Tx

How to decrease amplitude to a level compliant with requirements?

External excitation < -13.2 dBm (Tx) 
< -6.48 dBm (Rx)
Hot TDR Measurements
Advantages of ENA Option TDR ~Overview~

The **ENA Option TDR** is application software embedded on the ENA, which provides a **one-box solution** for high speed serial interconnect analysis.

### 3 Breakthroughs for Hot TDR Measurements

- **Fast and Accurate Measurements**
- **Simple and Intuitive Operation**
- **ESD Robustness (Typ. 3,000V)**

**Comprehensive Signal Integrity Measurement Solution for Next Generation High Speed Digital Standards**
Hot TDR Measurements
Advantages of ENA Option TDR ~Fast and Accurate Measurements~

**TDR Scopes**

- **Wideband Receiver** captures all of the signal energy from the transmitter.

To obtain a stable waveform, **extensive averaging** is necessary.

**ENA Option TDR**

- **Narrowband Receiver** minimizes the effects of the data signal from the transmitter.

In many cases, **averaging is not necessary** to obtain a stable waveform.

**Narrowband Receiver**
Sweeps across desired frequency range. From the data rate (user input), spurious frequencies can be determined and avoided during the sweep.
Hot TDR Measurements
Advantages of ENA Option TDR ~Simple and Intuitive Setup~

The TDR repetition rate setting is utilized to avoid the effects of the Tx signal.

Non-optimal settings typically result in an excessive amount of noise and/or ripple on the measured impedance profile, and/or spikes in the frequency domain response.

The measurement can typically be improved by changing the TDR repetition rate setting to a value that results in better removal of the Tx signal.

The ideal TDR repetition rate setting is unique to each DUT (as the ideal setting is related to the harmonic relationship of the rep rate and the Tx signaling rate).

The process for finding the ideal setting is usually best determined by trial and error.

From the data rate (user input), spurious frequencies are determined and automatically avoided.

1. Enter data rate
2. Click [Avoid Spurious]
Hot TDR Measurements

Advantages of ENA Option TDR ~Simple and Intuitive Setup~

TDR Scopes

ENA Option TDR

ENA Option TDR has internal variable attenuators to allow for flexibility in setting the stimulus level to comply with requirements.

- Option 23x/24x/26x/28x/43x/44x/46x/48x

<table>
<thead>
<tr>
<th>Range</th>
<th>Attenuation Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 kHz to 5 GHz</td>
<td>-55 to 10 dBm</td>
</tr>
<tr>
<td>5 GHz to 6 GHz</td>
<td>-55 to 9 dBm</td>
</tr>
<tr>
<td>6 GHz to 7 GHz</td>
<td>-55 to 8 dBm</td>
</tr>
<tr>
<td>7 GHz to 8.5 GHz</td>
<td>-55 to 7 dBm</td>
</tr>
</tbody>
</table>

- Option 2D5/2K5/4D5/4K5

<table>
<thead>
<tr>
<th>Range</th>
<th>Attenuation Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 kHz to 1 MHz</td>
<td>-85 to 8 dBm</td>
</tr>
<tr>
<td>1 MHz to 6 GHz</td>
<td>-85 to 10 dBm</td>
</tr>
<tr>
<td>6 GHz to 8 GHz</td>
<td>-85 to 9 dBm</td>
</tr>
<tr>
<td>8 GHz to 10.5 GHz</td>
<td>-85 to 7 dBm</td>
</tr>
<tr>
<td>10.5 GHz to 15 GHz</td>
<td>-85 to 3 dBm</td>
</tr>
<tr>
<td>15 GHz to 20 GHz</td>
<td>-85 to 0 dBm</td>
</tr>
</tbody>
</table>

TDR scopes normally has a fixed TDR step voltage.

Attenuators are connected to the instrument to decrease amplitude to a level compliant with requirements.
Hot TDR Measurements
Advantages of ENA Option TDR ~ESD Robustness~

TDR Scopes

TDR scopes are sensitive to ESD.

Implementing a protection circuit is difficult, because it will slow down the rise time of the step stimulus.

ENA Option TDR has higher robustness against ESD, because protection circuits can be implemented more easily.

ENA Option TDR measures the vector ratios of the transmitted and received signals. Therefore, the effects of the protection circuit will be canceled out.

Proprietary ESD protection chip significantly increase ESD robustness, while at the same time maintaining excellent RF performance (22ps rise time for 20GHz models).
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• 5 Reasons We Like the Agilent ENA presented by Granite River Lab
Information and Resources

Campaign Information

“Save 50% on an Enhanced Time Domain Option With the Purchase of an E5071C ENA Series Network Analyzer”

• **End Date:** June 30, 2012
• **URL:** [www.agilent.com/find/promotions](http://www.agilent.com/find/promotions)

Resources

ENA Option TDR Reference Material

• Visit [www.agilent.com/find/ena-tdr](http://www.agilent.com/find/ena-tdr)

Method of Implementation (MOI) for High Speed Digital Standards

• Available at [www.agilent.com/find/ena-tdr_compliance](http://www.agilent.com/find/ena-tdr_compliance)

Hot TDR Measurements

Webcast Agenda

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• 5 Reasons We Like the Agilent ENA presented by Granite River Lab
ENA Option TDR provides …. 

• *One-box solution* for *complete characterization* of high speed digital interconnects (time domain, frequency domain, eye diagram)

• Capability for stressed eye diagram analysis at *affordable* price with *simple setup and operation*.

• More flexibility to Hot TDR measurements with *fast and accurate measurements, simple and intuitive operation*, and *ESD robustness*. 
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Q and A Session

What questions do you have?
High Speed Digital Standards
ENA Option TDR Compliance Updates

One-box Solution

S Parameters

- Cable & Connector
- Intra-Pair Skew
- Far End Noise
- Return Loss
- Insertion Loss
- Near End Noise
- Inter-pair Skew

Simulated Eye Diagram

MOIs

- Cable/Connector
  - USB
  - DisplayPort
  - PCIe
  - MHL
  - HDMI

- Transmitter/Receiver
  - D-PHY
  - M-PHY

For more detail about compliance test solution by the ENA Option TDR, visit www.agilent.com/find/ena-tdr_compliance
High Speed Digital Standards
ENA Option TDR Compliance Updates

E5071C ENA is used worldwide by certified test centers of USB, HDMI, DisplayPort, SATA, and PCIe

For more detail about compliance test solution by the ENA Option TDR, visit www.agilent.com/find/ena-tdr_compliance
High Speed Digital Standards
ENA Option TDR Compliance Updates

Available for download on Agilent.com… www.agilent.com/find/ena-tdr_compliance

MOI (Method of Implementation)
Step-by-step procedure on how to measure the specified parameters in the specification document using ENA Option TDR.

State Files (48x, 4D5, 4K5) and cali kit definition file for official cal fixtures.
Stressed Eye Diagram Analysis of Interconnects

Correlation

E4887A & 90K Scope

TP1

3.4 Gbps

TP2

3.4 Gbps with 2.25GHz EQ

ENA Option TDR

TP1

3.4 Gbps

TP2

3.4 Gbps with 2.25GHz EQ

5m HDMI cable

DUT

Agilent Technologies
TDR/TDT Correlation

- DUT: USB3.0 Cable
- 50 ps rise time (20-80%)
SATA Gen 2 Differential Mode Return Loss
Correlation

TX-03 Differential Mode Return Loss

RX-03 Differential Mode Return Loss
Gen 1 Pair Differential Impedance

Correlation

TX-01 Pair Differential Impedance

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<tr>
<th>Time (sec)</th>
<th>Impedance (Z)</th>
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<tbody>
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<td>0</td>
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<tr>
<td>2E-09</td>
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<tr>
<td>4E-09</td>
<td>90</td>
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<tr>
<td>6E-09</td>
<td>85</td>
</tr>
<tr>
<td>8E-09</td>
<td>80</td>
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</table>

RX-01 Pair Differential Impedance

<table>
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<th>Time (sec)</th>
<th>Impedance (Z)</th>
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<tr>
<td>0</td>
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<td>6E-09</td>
<td>85</td>
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<tr>
<td>8E-09</td>
<td>80</td>
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</tbody>
</table>

Legend:
- E5071C
- 86100C

Agilent Technologies
## High Speed Digital Standards

### ENA Option TDR Compliance Updates

<table>
<thead>
<tr>
<th>Measurement Equipment</th>
<th>Measurement Parameter</th>
<th>USB</th>
<th>SATA</th>
<th>HDMI</th>
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<td><strong>Time Domain</strong></td>
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<td>TDR Oscilloscope</td>
<td>Differential Impedance</td>
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<td>Option TDR</td>
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<td>Propagation Delay</td>
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<td>Near End Cross Talk (NEXT)</td>
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<td>X</td>
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<td></td>
<td>Far End Cross Talk (FEXT)</td>
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<td>X</td>
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<td>Near End Cross Talk (NEXT)</td>
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<td>X</td>
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<td>Far End Cross Talk (FEXT)</td>
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<td><strong>Eye Diagram</strong></td>
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<td>Inter-Symbol Interference (ISI)</td>
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<td>Pattern Generator</td>
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</table>

### TDR Oscilloscope

### Option TDR

### Pattern Generator

### E5071C ENA

### Agilent Technologies
Stressed Eye Diagram Analysis of Interconnects
Agilent Solution for Stressed Eye Diagram Analysis

E4887A & 90K Scope (Certified Solution)

- TMDS Signal Generator (E4887A)
  - E4887A-007 (620 Mb/s to 7 Gb/s) $328K
  - E4887A-037 (up to 3.4 Gb/s) $219K
  - E4887A-003 (economic; up to 3.4 Gb/s) $161K
- SG (E4438C-506/UNJ: 6GHz) 2/ea $35K * 2/ea
- Oscilloscope (DSO90804A) $89K

Certified Solution but too expensive and complicated for most cable manufacturers.

$320K-487K

New ENA Option TDR

- E5071C with ENA Option TDR
  - Test Set Option 480/485 $63K
  - Test Set Option 4K5 $75K
- Electronic Calibration Module
  - N4431B $13K
  - N4433A $19K

The same test can be done with lower price and simpler configuration!

$76K-94K

Agilent Technologies
Stressed Eye Diagram Analysis of Interconnects

Test Setup

Eye Diagram Test (Test ID 5-3)

Adjust the jitter amplitude to create the input worst case eye diagram.

Measure the output eye diagram with the specified equalizer.
**Cable/Connector Compliance Test Configuration**

**ENA Option TDR Typical Solution Configuration**

- **ENA Mainframe**
  - E5071C-480: 4-port, 9kHz to 8.5GHz
  - E5071C-485: 4-port, 100kHz to 8.5GHz
  - E5071C-4D5: 4-port, 300kHz to 14GHz
  - E5071C-4K5: 4-port, 300kHz 20GHz

- **Enhanced Time Domain Analysis Option (Option TDR)**

- **Calibration Standard (One or Two of below)**
  - ECal Module
    - N4431B for E5071C-480/485
    - N4433A for E5071C-4D5/4K5
  - **Mechanical Calibration Kit**
    - 85033E-100 for E5071C-480/485
    - 85052D for E5071C-4D5/4K5
  - **Certified Fixture Standards**

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**Cable Test Fixtures**

Official Fixtures for testing cable assemblies and connectors

Below is an example set of fixtures for USB 3.0 cable assemblies and connectors

Available for purchase through Allion and BitifEye.
http://www.usb.org/developers/ssusb/ssusbtools/
Fast & Accurate Measurement for Efficient Debug and Troubleshooting
Wide Dynamic Range

ENA Option TDR

<table>
<thead>
<tr>
<th>Frequency [GHz]</th>
<th>Dynamic Range [dB]</th>
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<tr>
<td>0</td>
<td>ENA (SPD)</td>
</tr>
<tr>
<td>10</td>
<td>120</td>
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<tr>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>30</td>
<td>80</td>
</tr>
<tr>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>60</td>
<td>20</td>
</tr>
</tbody>
</table>

>100 dB DR across wide frequency range

Traditional TDR

<table>
<thead>
<tr>
<th>Frequency [GHz]</th>
<th>Dynamic Range [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10 avg</td>
</tr>
<tr>
<td></td>
<td>50 avg</td>
</tr>
<tr>
<td></td>
<td>250 avg</td>
</tr>
</tbody>
</table>

DR is inversely proportional to frequency
<50 dB @20 GHz (10avg)

ENA Option TDR has…
• wider dynamic range (50-60 dB wider than traditional TDR)
• sufficient margin for latest compliance tests
  ex. crosstalk and common mode noise below 30 dB
Fast & Accurate Measurement for Efficient Debug and Troubleshooting
Low Noise in Time Domain

DUT: 50 Ohm pattern

ENA Option TDR  
TDR Oscilloscope

VNA Based TDR measurements = Low Noise
Fast & Accurate Measurement for Efficient Debug and Troubleshooting
No Averaging Requirement

DUT: 50 Ohm pattern

ENA Option TDR

TDR Oscilloscope

Averaging... can lower noise

BUT...
Fast & Accurate Measurement for Efficient Debug and Troubleshooting

Real-Time Analysis

DUT: 50 Ohm pattern

ENA Option TDR

TDR Oscilloscopes

Real-Time Analysis

Find Real-Time analysis comparison video at www.agilent.com/find/ena-tdr
Robustness for Lower Cost of Ownership

Internal Bias-tee

• Internal Bias-Tees
Some devices need DC bias to be activated for Hot TDR measurements
ENA has internal bias-tees on each test port, and DC bias can easily be applied to the device

Bias Input Ports (+/- 35VDC)
VNA based TDR Theory

In VNA based time domain analysis, a frequency response is converted into a time response by inverse Fourier transform.
Why VNA has Wider Dynamic Range

Assumptions to simplify the discussion

- Two instruments have the same cutoff frequency ($f_c$).
- The noise is uniform up to cutoff frequency, which is white noise.
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The magnitude of stimulus and noise remain unchanged.

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The VNA demonstrates a better SN ratio by the factor of \(fc/IFBW\).