Agilent Technologies


Test Solution Overview Using the Agilent E5071C ENA Option TDR
• This slide will show how to make measurements of 10GBASE-KR/40GBASE-KR4 Backplane Ethernet Interconnect & Transmitter/Receiver (Tx/Rx) Tests by using the Agilent E5071C ENA Option TDR.
<table>
<thead>
<tr>
<th>Standard</th>
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<tbody>
<tr>
<td>USB-Hi-Speed</td>
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<tr>
<td>PCI-Express</td>
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<tr>
<td>Serial ATA</td>
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<tr>
<td>Ethernet</td>
<td>N/A</td>
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</table>

No logo certification program is available for Ethernet.

- PHY tests performed in accordance to test procedure issued by University of New Hampshire InterOperability Laboratory (UNH-IOL).
- Self-compliance.
IEEE Std 802.3™-2012

IEEE Standard for Ethernet

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

IEEE Std 802.3™-2012
Version 12
IEEE Std 802.3-2008

Test Suite for Ethernet
University of New Hampshire
InterOperability Laboratory (UNH-IOL)
10GBASE-KR/40GBASE-KR4 backplane Ethernet is primarily intended to operate over differential, controlled impedance traces up to 1 m including two connectors, on printed circuit boards residing in a backplane environment.

- The backplane interconnect is defined between TP1 and TP4.
- It supports an effective data rate of 10 Gbps in each direction simultaneously (full-duplex operation using a single-lane 10 Gbps PHY).
**IEEE Std 802.3™-2012 72.8 Interconnect characteristics**

Informative interconnect characteristics for 10GBASE-KR/40GBASE-KR4 are provided in Annex 69B.

<table>
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<td>[Annex 69B.4.3]</td>
<td>Insertion loss</td>
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<td>[Annex 69B.4.5]</td>
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<td>[Annex 69B.4.6.1]</td>
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<td>Power sum differential crosstalk (PSXT)</td>
</tr>
<tr>
<td>[Annex 69B.4.6.4]</td>
<td>Insertion loss to crosstalk ratio (ICR)</td>
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</tbody>
</table>

Solution Overview

• 10GBASE-KR/40GBASE-KR4 backplane Ethernet interconnect testing requires parametric measurements in both time and frequency domains.

Time Domain
• Characteristic impedance
• Differential skew

Frequency Domain
• Fitted attenuation
• Insertion loss
• Insertion loss deviation
• Return loss
• Power sum differential near-end crosstalk (PSNEXT)
• Power sum differential far-end crosstalk (PSFEXT)
• Power sum differential crosstalk (PSXT)
• Insertion loss to crosstalk ratio (ICR)

Traditional Solution

New Solution

• ALL parameters can be measured with ENA Option TDR

One-box Solution !!

Configuration

• ENA Mainframe (*1)
  • E5071C-4K5: 4-port, 300 kHz to 20 GHz
• Enhanced Time Domain Analysis Option (E5071C-TDR)
• ECal Module (N4433A)

*1: 10GBASE-KR/40GBASE-KR4 interconnect tests require frequency up to 15 GHz.
*2: The list above includes the major equipment required. Please contact our sales representative for configuration details.

• Method of Implementation (MOI) document, state file (4K5), and VBA project file available for download on Agilent.com

www.agilent.com/find/ena-tdr_compliance
www.agilent.com/find/ena-tdr_ethernet-cabcon

Measurement Parameters

**ENA Option TDR** Compliance Testing Solution is one-box solution which provides complete characterization of interconnects (time domain, frequency domain)

![Diagram showing measurement parameters](image)

- **Ch 1 Freq Domain:** Linear Freq Sweep
- **Ch 2 Freq Domain:** Log Freq Sweep
Multiple reflections from impedance mismatches cause noise at the receiver. Therefore, the impedance profile provides an indication of multiple reflection induced noise.

Impedance is the most used parameter, but is an indirect measure of the signal arriving at the receiver.

The recommended differential characteristic impedance of circuit board trace pairs is $100 \, \Omega \pm 10 \%$. 
IEEE Std 802.3-2012
Annex 69B.3 Differential Skew

The total differential skew from TP1 to TP4 is recommended to be less than the minimum transition time for port type of interest.

Skew = Delay(1) - Delay(2)
IEEE Std 802.3-2012
Annex 69B.4.2 Fitted Attenuation

• The fitted attenuation is defined to be the least mean squares line fit to the insertion loss computed over the frequency range 1 GHz to 6 GHz.
• The maximum fitted attenuation due to trace skin effect and dielectric properties is defined.

It is recommended that the fitted attenuation of the channel be less than or equal to $A_{\text{max}}$ as defined by the equation below, where $f$ is expressed in Hz and coefficient $b_1$ through $b_4$ are given in table.

$$A(f) \leq A_{\text{max}}(f) = 20 \log_{10}(e) \times (b_1f + b_2f^2 + b_3f^3 + b_4f^4)$$

<table>
<thead>
<tr>
<th>Coefficient $b_i$</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b_1$</td>
<td>$2.00 \times 10^{-5}$</td>
</tr>
<tr>
<td>$b_2$</td>
<td>$1.10 \times 10^{-10}$</td>
</tr>
<tr>
<td>$b_3$</td>
<td>$3.20 \times 10^{-20}$</td>
</tr>
<tr>
<td>$b_4$</td>
<td>$-1.20 \times 10^{-30}$</td>
</tr>
</tbody>
</table>
Insertion loss is defined as the magnitude of the differential response measured from TP1 to TP4. It has important consequences for the rise time degradation and the maximum supportable bandwidth.

It is recommended that the insertion loss magnitude be within the high confidence region defined by equations. The values of $f_{\text{min}}$, $f_2$, and $f_{\text{max}}$ are given in tables.

\[
IL(f) \leq IL_{\text{max}}(f) = A_{\text{max}}(f) + 0.8 + 2.0 \times 10^{-10} f
\]

for $f_{\text{min}} \leq f \leq f_2$

\[
IL(f) \leq IL_{\text{max}}(f) = A_{\text{max}}(f) + 0.8 + 2.0 \times 10^{-10} f_2 + 1 \times 10^{-8} (f-f_2)
\]

for $f_2 < f \leq f_{\text{max}}$

<table>
<thead>
<tr>
<th>$f_{\text{min}}$</th>
<th>0.05 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_{\text{max}}$</td>
<td>15.00 GHz</td>
</tr>
<tr>
<td>$f_2$</td>
<td>1.250 GHz</td>
</tr>
</tbody>
</table>
• Insertion loss deviation is the difference between the insertion loss and the fitted attenuation.

It is recommended that insertion loss deviation be within the high confidence region defined by equations.

\[
ILD(f) \geq ILD_{min}(f) = -1.0 - 0.5 \times 10^{-9} f
\]
\[
ILD(f) \leq ILD_{max}(f) = 1.0 + 0.5 \times 10^{-9} f
\]

for \( f_1 \leq f \leq f_2 \).

<table>
<thead>
<tr>
<th>( f_1 )</th>
<th>( f_2 )</th>
<th>GHz</th>
<th>GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.125</td>
<td>1.250</td>
<td>0.312</td>
<td>3.125</td>
</tr>
</tbody>
</table>
IEEE Std 802.3-2012
Annex 69B.4.5 Return loss

- Ratio of reflected voltage to incident voltage. Key parameter when evaluating impedance mismatch.
- When impedance match is poor, transmission signal quality is degraded due to multiple-reflection effects, leading to increase in bit error rate.

It is recommended that the channel loss at TP1 and TP4 be greater than or equal to $RL_{\text{min}}$ as defined by equations. The recommendation applied from 50 MHz.

$$RL(f) \geq RL_{\text{min}}(f) = 12$$
for $50 \text{ MHz} \leq f < 275 \text{ MHz}$ and

$$RL(f) \geq RL_{\text{min}}(f) = 12 - 6.75\log_{10}\left(\frac{f}{275 \text{ MHz}}\right)$$
for $275 \text{ MHz} \leq f < 3000 \text{ MHz}$ and

$$RL(f) \geq RL_{\text{min}}(f) = 5$$
for $3000 \text{ MHz} \leq f \leq 10312.5 \text{ MHz}$. 
IEEE Std 802.3-2012
Annex 69B.4.6.1 Power Sum Differential Near-end Crosstalk (PSNEXT)

• Measure of the coupling between the differential pairs.
• The differential near-end crosstalk at TP4 is calculated as the power sum of the individual NEXT aggressors (PSNEXT).

PSNEXT is computed as equation, where \( \text{NEXT}_n \) is the crosstalk loss (dB) of aggressor n. For the case of a single aggressor, PSNEXT will be the crosstalk loss for that single aggressor.

\[
PSNEXT(f) = -10 \log \left( \sum \frac{1}{10^{\text{NEXT}_n \cdot 10}} \right)
\]
Far-end crosstalk (FEXT) is crosstalk that appears at the far end of a duplex channel, which is coupled from another duplex channel. The differential far-end crosstalk at TP4 is calculated as the power sum of the individual FEXT aggressors (PSFEXT).

\[ PSFEXT(f) = -10 \log \left( \sum_{n} 10^{-FEXT_n(f)/10} \right) \]

PSFEXT is computed as equation, where FEXT\(_n\) is the crosstalk loss (dB) of aggressor n. For the case of a single aggressor, PSFEXT will be the crosstalk loss for that single aggressor.
IEEE Std 802.3-2012
Annex 69B.4.6.3 Power Sum Differential Crosstalk (PSXT)

The differential crosstalk at TP4 is calculated as the power sum of the individual NEXT and FEXT aggressors (PSXT).

\[
PSXT(f) = -10 \log(10^{-PSNEXT(f)/10} + 10^{-PSFEXT(f)/10})
\]

PSXT may be computed as equation.
• Insertion loss to crosstalk ratio (ICR) is the ratio of the insertion loss, measured from TP1 to TP4, to the total crosstalk measured at TP4.

• $ICR_{\text{fit}}$ is defined to be the least mean squares line fit to the ICR computed over the frequency range 100 MHz to 5.15625 GHz.

It is recommended that $ICR_{\text{fit}}$ be greater than or equal to $ICR_{\text{min}}$ as defined by equation.

$$ICR_{\text{fit}}(f) \geq ICR_{\text{min}}(f) = 23.3 - 18.7\log_{10}\left(\frac{f}{5 \text{ GHz}}\right)$$
10GBASE-KR/40GBASE-KR4 Tx/Rx Test Solution

Test Setup

- 10GBASE-KR/40GBASE-KR4 transmitter and receiver are characterized at TP1 and TP4 respectively.
- For the return-loss measurements using VNA, the test fixture is not required for measuring the transmitter specifications.
- Configure the DUT so that it is sourcing normal IDLE signaling then measure the reflection coefficient at the DUT (Hot Return Loss measurement).
### 10GBASE-KR/40GBASE-KR4 Tx Characteristics

#### Electrical Test Item List (Normative)

IEEE Std 802.3™-2012 72.7.1 Transmitter characteristics
UNH-IOL Clause 72 10GBASE-KR PMD Test Suite Version 1.1 Group 2 Impedance Requirements

<table>
<thead>
<tr>
<th>Specification (IEEE Std 802.3™-2012)</th>
<th>Test Procedure (UNH-IOL Clause 72)</th>
<th>Test Items</th>
</tr>
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<tbody>
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<td>[72.7.1.3]</td>
<td>[72.1.1]</td>
<td>Signaling speed</td>
</tr>
<tr>
<td>[72.7.1.4]</td>
<td>[72.1.3]</td>
<td>Differential peak-to-peak output voltage (max.)</td>
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<tr>
<td>[72.6.5]</td>
<td>[72.1.3]</td>
<td>Differential peak-to-peak output voltage (max.) with Tx disabled</td>
</tr>
<tr>
<td>[72.7.1.4]</td>
<td>[72.1.2]</td>
<td>Common-mode voltage limits &amp; deviation (max.) during LPI</td>
</tr>
<tr>
<td>[72.7.1.5]</td>
<td>[72.2.1]</td>
<td>Differential output return loss (min.)</td>
</tr>
<tr>
<td>[72.7.1.6]</td>
<td>[72.2.2]</td>
<td>Common-mode output return loss (min.)</td>
</tr>
<tr>
<td>[72.7.1.7]</td>
<td>[72.1.4]</td>
<td>Transition time (20% - 80%)</td>
</tr>
<tr>
<td>[72.7.1.9]</td>
<td>[72.1.5]</td>
<td>Max output jitter (peak-to-peak) (random jitter, deterministic jitter, duty cycle distortion, total jitter)</td>
</tr>
<tr>
<td>[72.7.1.11]</td>
<td>[72.1.6] [72.1.7]</td>
<td>Transmitter output waveform requirements</td>
</tr>
</tbody>
</table>

Test items measured by VNA
## 10GBASE-KR/40GBASE-KR4 Rx Characteristics

### Electrical Test Item List (Normative)

IEEE Std 802.3™-2012  72.7.2 Receiver characteristics
UNH-IOL Clause 72 10GBASE-KR PMD Test Suite Version 1.1 Group 2 Impedance Requirements

<table>
<thead>
<tr>
<th>Specification (IEEE Std 802.3™-2012)</th>
<th>Test Procedure (UNH-IOL Clause 72)</th>
<th>Test Items</th>
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<td></td>
<td>Bit error ratio</td>
</tr>
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<td>[72.7.2.2]</td>
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<td>Signaling speed</td>
</tr>
<tr>
<td>[72.7.2.3]</td>
<td></td>
<td>Receiver coupling</td>
</tr>
<tr>
<td>[72.7.2.4]</td>
<td></td>
<td>Differential input peak-to-peak amplitude (max.)</td>
</tr>
<tr>
<td>[72.7.2.5]</td>
<td>[72.2.3]</td>
<td>Differential input return loss (min.)</td>
</tr>
</tbody>
</table>

Test items measured by VNA
10GBASE-KR/40GBASE-KR4 Tx/Rx Test Solution

Configuration

• ENA Mainframe (*1)
  • E5071C-280/480: 2/4-port, 9 kHz to 8.5 GHz
  • E5071C-285/485: 2/4-port, 100 kHz to 8.5 GHz
  • E5071C-2D5/4D5: 2/4-port, 300 kHz to 14 GHz
  • E5071C-2K5/4K5: 2/4-port, 300 kHz to 20 GHz

• Enhanced Time Domain Analysis Option (E5071C-TDR) (*2)

• ECAL Module
  • N4431B for E5071C-280/285/480/485
  • N4433A for E5071C-2D5/4D5/2K5/4K5

*1: Select one of frequency options. 10GBASE-KR/40GBASE-KR4 Tx/Rx tests (return loss) require frequency up to 7.5 GHz.
*2: E5071C-TDR is required to use Avoid Spurious function for Hot Return Loss measurement.
*3: The list above includes the major equipment required. Please contact our sales representative for configuration details.

• Method of Implementation (MOI) document and state file (280, 285, 480, 485, 2D5, 4D5, 2K5, 4K5) available for download on Agilent.com

www.agilent.com/find/ena-tdr_compliance
www.agilent.com/find/ena-tdr_ethernet-txrx
**10GBASE-KR/40GBASE-KR4 Tx/Rx Test Solution**

**Measurement Parameters**

**ENA Option TDR** Compliance Testing Solution is one-box solution which provides return-loss characterization of Tx/Rx (frequency domain)

**Frequency Domain (Ch 1)**

- Differential Output Return Loss (Tx) (Sdd11)
- Differential Input Return Loss (Rx) (Sdd11)
- Common-mode Output Return Loss (Tx) (Scc11)
• Ratio of reflected voltage to incident voltage. Key parameter when evaluating impedance mismatch.
• When impedance match is poor, transmission signal quality is degraded due to multiple-reflection effects, leading to increase in bit error rate.

From 50 MHz to 7500 MHz, the differential return loss of the transmitter shall meet the equations. This output impedance requirement applies to all valid output levels. The reference impedance for differential return loss measurement shall be 100 Ω.

\[
\text{ReturnLoss}(f) \geq 9 \\
\text{for } 50 \text{ MHz} \leq f < 2500 \text{ MHz} \\
\text{ReturnLoss}(f) \geq 9 - 12 \log_{10}\left(\frac{f}{2500 \text{ MHz}}\right) \\
\text{for } 2500 \text{ MHz} \leq f \leq 7500 \text{ MHz}
\]
72.7.1.6 / 72.2.2 Common-mode Output Return Loss (Tx)

- Ratio of reflected voltage to incident voltage. Key parameter when evaluating impedance mismatch.
- When impedance match is poor, transmission signal quality is degraded due to multiple-reflection effects, leading to increase in bit error rate.

The transmitter common-mode return loss shall meet the equations. The reference impedance for common-mode return loss measurement is 25 Ω.

\[
ReturnLoss(f) \geq 6 \\
\text{for } 50 \text{ MHz} \leq f < 2500 \text{ MHz} \\
ReturnLoss(f) \geq 6 - 12\log_{10}\left(\frac{f}{2500 \text{ MHz}}\right) \\
\text{for } 2500 \text{ MHz} \leq f \leq 7500 \text{ MHz}
\]
72.7.2.5 / 72.2.3 Differential Input Return Loss (Rx)

- Ratio of reflected voltage to incident voltage. Key parameter when evaluating impedance mismatch.
- When impedance match is poor, transmission signal quality is degraded due to multiple-reflection effects, leading to increase in bit error rate.

From 100 MHz to 7500 MHz, the differential return loss of the receiver shall be greater than or equal to equations. This return loss requirement applies at all valid input levels. The reference impedance for differential return loss measurement is 100 Ω.

\[
\text{Return Loss}(f) \geq 9 \\
\text{for } 50 \text{ MHz} \leq f < 2500 \text{ MHz} \\
\text{Return Loss}(f) \geq 9 - 12\log_{10}\left(\frac{f}{2500 \text{ MHz}}\right) \\
\text{for } 2500 \text{ MHz} \leq f \leq 7500 \text{ MHz}
\]
What is ENA Option TDR?

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

**3 Breakthroughs**

for Signal Integrity Design and Verification

- Simple and Intuitive Operation
- Fast and Accurate Measurements
- ESD Robustness
Advantage of ENA Option TDR for Hot TDR
Fast and Accurate Measurements

**TDR Scopes**

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

  Extensive averaging is necessary to obtain a stable waveform.

**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.
Hot TDR Measurements
Avoiding Errors from the Transmitter Signal

Time Domain
Fluctuations due to Tx signal

Frequency Domain
Spurs due to Tx signal
Hot TDR Measurements
Avoiding Errors from the Transmitter Signal

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

1-click Operation
Advantages of ENA Option TDR for Hot TDR
Simple and Intuitive Operation

The **TDR repetition rate** setting is utilized to avoid the effects 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 during the sweep.

1. Enter data rate
2. Click **[Avoid Spurious]**
ENA Option TDR Compliance Test Solution
Certified MOIs available at [www.agilent.com/find/ena-tdr_compliance](http://www.agilent.com/find/ena-tdr_compliance)

**Cable/Connector/Interconnect**
- USB
  - Time & Frequency
- HDMI®
  - Time & Frequency
- Serial ATA
  - Time & Frequency
- DisplayPort
  - Time & Frequency
- 100BASE-TX
  - Time & Frequency
- 10GBASE-T
  - Time & Frequency
- 10GBASE-KR/40GBASE-KR4
  - Time & Frequency
- BroadR-Reach
  - Time & Frequency

**Transmitter/Receiver (Hot TDR/Hot Return Loss)**
- 10GBASE-KR/40GBASE-KR4
  - Frequency

* For more detail about Thunderbolt and BroadR-Reach compliance test solution using the ENA Option TDR, contact Agilent sales representative.

**More Standards Currently Under Investigation**

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*Anticipate __Accelerate __Achieve*
ENA Option TDR Compliance Test Solution
Certified Test Centers using ENA Option TDR

Test Centers Support ENA Option TDR

ENA Option TDR is used world wide by certified test centers of USB, HDMI, DisplayPort, MHL, Thunderbolt and SATA.
Ethernet Cable Compliance Test Solution

Summary

ENA Option TDR Compliance Testing Solution is ....

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

• Similar look-and-feel to traditional TDR scopes, providing *simple and intuitive operation* even for users unfamiliar to VNAs and S-parameters

• **Fast and Accurate** output/input impedance measurements of transmitter/receiver under operating condition (**Hot TDR / Hot Return Loss**)

• Adopted by test labs worldwide
Questions?
Agilent VNA Solutions

**PNA-X, NVNA**
Industry-leading performance
10 M to 13.5/26.5/43.5/50/67 GHz
Banded mm-wave to 2 THz

**PNA**
Performance VNA
10 M to 20, 40, 50, 67, 110 GHz
Banded mm-wave to 2 THz

**PNA-L**
World’s most capable value VNA
300 kHz to 6, 13.5, 20 GHz
10 MHz to 40, 50 GHz

**PNA-X receiver**
8530A replacement

**Mm-wave solutions**
Up to 2 THz

**ENAs Series**

**E5072A**
Best performance ENA
30 kHz to 4.5, 8.5 GHz

**E5071C**
World’s most popular economy VNA
9 kHz to 4.5, 8.5 GHz
300 kHz to 20.0 GHz

**E5061B**
NA + ZA in one-box
5 Hz to 3 GHz
Low cost RF VNA
100 k to 1.5/3.0 GHz

**FieldFox**
Handheld RF Analyzer
5 Hz to 4/6 GHz
What is ENA Option TDR?

[Video]
Agilent ENA Option TDR
Changing the world of Time Domain Reflectometry (TDR) Measurements

• www.youtube.com/watch?v=hwQNlyyJ5hl&list=UUAJAjd97CfnCehC4jZAfKxQ&index=20&feature=plcp
• www.agilent.com/find/ena-tdr
Additional Resources

• ENA Option TDR Reference Material
  www.agilent.com/find/ena-tdr

• Technical Overview (5990-5237EN)

• Application Notes
  • Correlation between TDR oscilloscope and VNA generated time domain waveform (5990-5238EN)
  • Comparison of Measurement Performance between Vector Network Analyzer and TDR Oscilloscope (5990-5446EN)
  • Effective Hot TDR Measurements of Active Devices Using ENA Option TDR (5990-9676EN)
  • Measurement Uncertainty of VNA Based TDR/TDT Measurement (5990-8406EN)
  • Accuracy Verification of Agilent’s ENA Option TDR Time Domain Measurement using a NIST Traceable Standard (5990-5728EN)

• Method of Implementation (MOI) for High Speed Digital Standards
  www.agilent.com/find/ena-tdr_compliance