Keysight Solutions for EMI Measurements in the Automotive Lab

Updated February 6, 2018
Keysight & Partners to Offer a Broad Range of Compliance Test Solutions

Keysight Solution Partners + Keysight

... a winning combination!

Chambers

Compliance Software

Integrated Systems

Keysight Solutions for EMI Measurements
Agenda

– EMC Basics and Standards

– EMC Precompliance vs Compliance Measurement Solutions

– Impact of Mismatch and the Importance of Network Analyzers (Ford R115)

– Modern Signal Integrity Solutions
Agenda

– EMC Basics and Standards

– EMC Precompliance vs Compliance Measurement Solutions

– Impact of Mismatch and the Importance of Network Analyzers (Ford RI115)

– Modern TDR Solutions for Signal Integrity
Getting started – Basic terms
EMI, EMS, EMC

Today, We focus here!
What is EMI?

Electromagnetic Interference

- EMI is disturbance that affects an electrical circuit due to either electromagnetic conduction or electromagnetic radiation emitted from an external source.

- EMI emissions can be well captured by a spectrum analyzer.

- A spectrum analyzer tells you the frequency, power, and other important properties of an EMI emission.
Sources of EMI (1/3)

Natural Sources (also called radio-frequency interference or RFI)

- Natural sources below 10MHz are dominated by atmospheric noise generated by electrical storms.  
  - Lighting

- Above 10 MHz natural sources consist primarily of cosmic noise and solar radiation.
Sources of EMI (2/3)

Intentional Man Made Sources

- 2-way radio communication
- Cellular Phones
- Radio and TV broadcasters
- Internet Of Things (IoT)
- Oscillators

Caused by:

- Transmitted signal
  - Intended transmission of a frequency
  - Sometimes called ‘On carrier’ or ‘Carrier frequency’
  - A Continuous Wave (CW) signal
    - Control Signal
    - Beacon
  - Modulated Signal
    - Analog Voice or Data
    - Digital Voice or Data
Sources of EMI (3/3)

Un-Intentional Man Made Sources

- Toaster ovens
- Bug zappers
- Hair dryers
- Electric Motors
- Etc.

Caused by:

- Leakage
  - RF frequency leaking out of an enclosure

- Harmonics
  - Multiples of a frequency

- Spurs
  - Addition and subtraction of frequencies can generate spurs
3 elements in EMC

Interference source

Radiated

Propagation path

Conducted

Victim

AC power network
The impact of an EMI failure during the product development cycle

Many manufacturers use (EMI) measurement systems to perform conducted and radiated EMI emissions evaluation prior to sending their product to a test facility for full compliance testing.

The cost of an EMI failure increases as the product development cycle moves on!
Important!
EMC evaluation is along with your product NPI cycle

Product Development Cycle Including EMC Testing

- Investigation: Viable
- Breadboard: Pass
- Proto: Pass
- Pilot run: Pass
- Compliance testing: Pass

Redesign: No

EMC Education ↔ EMC diagnostic evaluation ↔ Pre-Compliance testing ↔ Compliance testing

Increasing flexibility to solve EMI problems
Increased cost to solve EMI problems
EMC standards
From international to commercial

Categories:
- International
  - IEC
  - CISPR
- Commercial
  - FCC
  - ETS/EN
  - GB

CISPR standard Structure:

Basic Standards
- Provide general and fundamental rules
- Serve as a reference but not applicable to specific products

Generic Standards
- Provide essential test requirements and procedure in a specific environment
- Also provide limits

Product Standards
- Apply to specific products or families of products
- Provides test procedures and limits for these products
CISPR Recommends Commercial Limits, Measuring Equipment and Methodologies

- **CISPR** (Comité International Spécial des Perturbations Radioélectriques)
  English: (Special International Committee on Radio Interference)

  - A sub committee of the IEC (International Electrotechnical Commission)
  - Determines and recommends required emissions and immunity:
    - **limits** for products sold in the worldwide commercial market
    - **test equipment requirements**
    - **test procedures/methodologies**
CISPR Product Groups

- **CISPR 11** - Industrial, Scientific, and Medical (ISM) Radio-Frequency Equipment
- **CISPR 12** - Vehicles, Motorboats, and Spark-Ignited Engine-Driven Devices
- **CISPR 13** - Sound and Television Broadcast Receivers and Associated Equipment
- **CISPR 14** - Household Appliances, Electric Tools, and Similar Apparatus
- **CISPR 15** - Electrical Lighting and Similar Equipment
- **CISPR 17** - Suppression Characteristics of Passive Radio Interference Filters and Suppression Components.
- **CISPR 18** - Overhead Power Lines and High-Voltage Equipment
- **CISPR 20** - Sound and Television Broadcast Receivers and Associated Equipment
- **CISPR 21** - Interference to Mobile Radio communications
- **CISPR 22** - Information Technology Equipment—Radio Disturbance Characteristics
- **CISPR 24** - Information Technology Equipment—Immunity Characteristics
- **CISPR 25** - Receivers Used on Board Vehicles, Boats, and on
- **CISPR 32** – Multimedia devices emission testing (under development)
- **CISPR 35** – Multimedia devices immunity testing (under development)
Example of Products subject to CISPR 11 Testing

T&M instruments follows CISPR 11

Keysight Solutions for EMI Measurements

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Which Standards to test against?

Depends on your product plan

Three preliminary questions to answer when developing a product:

1. Where will the product be sold (for example, Europe, United States, Japan)?

2. What is the classification of the product?
   a) Information technology equipment (ITE)
   b) Industrial, scientific or medical equipment (ISM)
   c) Automotive or communication
   d) Generic (equipment not found in other standards)

3. Where will the product be used (for example home, commercial, light industry or heavy industry)?
Agenda

– EMC Basics and Standards

– EMC Precompliance vs Compliance Measurement Solutions

– Impact of Mismatch and the Importance of Network Analyzers (Ford RI115)

– Modern TDR Solutions for Signal Integrity
Pre-compliance vs. Full Compliance Solutions

Pre-compliance Measurement Solutions:
Evaluate the conducted and radiated emissions of a device using correct detectors and bandwidths before going to a test house for compliance testing. Gives an approximation of the EMI performance of the EUT.

Full Compliance Measurement Solutions:
Full compliance testing requires an EMI receiver that is tested to meet all CISPR 16-1-1 requirements.
## Compliance vs. Precompliance

<table>
<thead>
<tr>
<th></th>
<th>Compliance Test</th>
<th>Precompliance scanning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Purpose</strong></td>
<td>To achieve certificates (e.g. C-tick, CE, UL, KC, CCC, FCC)</td>
<td>To increase the confidence level at final compliance test</td>
</tr>
<tr>
<td><strong>Overall</strong></td>
<td>Must follow the standard procedure</td>
<td>Not identical to, but can simulate the standard procedure as much as possible</td>
</tr>
<tr>
<td><strong>Physical setup requirements</strong></td>
<td>Must be done in test house (for certification)</td>
<td>Can be done in house, throughout the design process</td>
</tr>
<tr>
<td></td>
<td>Must be in an anechoic chamber</td>
<td>Can be done in a shielded room, or an open area</td>
</tr>
<tr>
<td></td>
<td>Must use an EMI receiver</td>
<td>EMI receiver or spectrum analyzer</td>
</tr>
<tr>
<td></td>
<td>Must use standard test setup</td>
<td>Simplified test setup</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Expensive and time consuming</td>
<td>Much less expensive, and quick turn-around</td>
</tr>
<tr>
<td><strong>Result</strong></td>
<td>Will report an EMI failure</td>
<td>Will report an EMI risk</td>
</tr>
<tr>
<td></td>
<td>Cannot tell where the failure comes from</td>
<td>Able to track to the interference source with diagnostic tools</td>
</tr>
</tbody>
</table>
Example Radiated Emission Testing Environments

Definitions:

Anechoic Chamber → Room with no echoes; absorbers on all 6 sides
Semi-anechoic → Ground plane; reflection like OATS; correlation to OATS
OATS → Open Area Test Site
CISPR 16-1-1 Compliant Receiver

A CISPR 16-1-1 receiver must have the following functionality in the range 9 kHz - 18 GHz:

- A normal +/- 2 dB absolute accuracy
- CISPR-specified resolution bandwidths (-6 dB)
- Peak, quasi-peak, EMI average, and RMS average detectors
- Specified input impedance with a nominal value of 50 ohms; deviations specified as VSWR
- Be able to pass product immunity in a 3 V/m field
- Be able to pass the CISPR pulse test (implies pre-selector below 1 GHz)
- Other specific harmonic and intermodulation requirements
About quasi-peak detection

- There are three commonly used detection modes for making EMI measurements, including peak, average, and quasi-peak detection.

- Why use Quasi-peak detection?
  - Used for CISPR based measurements.
  - Weighting signals as a function of repetition rate.
  - Lower repetition rate noise has less “annoyance factor” and thus gets less emphasis
  - CISPR bandwidth: 200 Hz, 9 kHz, and 120kHz bandwidth.
Detection Modes
Peak ≥ Quasi-Peak ≥ Average
# RBW for CISPR & MIL

## Commercial (CISPR)

<table>
<thead>
<tr>
<th>Bands</th>
<th>Frequency range</th>
<th>CISPR RBW</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>9 – 150 kHz</td>
<td>200 Hz</td>
</tr>
<tr>
<td>B</td>
<td>150 kHz – 30 MHz</td>
<td>9 kHz</td>
</tr>
<tr>
<td>C</td>
<td>30 – 300 MHz</td>
<td>120 kHz</td>
</tr>
<tr>
<td>D</td>
<td>300 MHz – 1 GHz</td>
<td>120 kHz</td>
</tr>
<tr>
<td>E</td>
<td>1 – 18 GHz</td>
<td>1 MHz</td>
</tr>
</tbody>
</table>

## Military (MIL-STD-461)

<table>
<thead>
<tr>
<th>Frequency range</th>
<th>RBW</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 Hz – 1 kHz</td>
<td>10 Hz</td>
</tr>
<tr>
<td>1 – 10 kHz</td>
<td>100 Hz</td>
</tr>
<tr>
<td>10 – 150 kHz</td>
<td>1 kHz</td>
</tr>
<tr>
<td>150 kHz – 30 MHz</td>
<td>10 kHz</td>
</tr>
<tr>
<td>30 MHz – 1 GHz</td>
<td>100 kHz</td>
</tr>
<tr>
<td>Above 1 GHz</td>
<td>1 MHz</td>
</tr>
</tbody>
</table>
Some example items used for EMI testing of a EUT

Log Periodic Antenna: High gain antennas

Biconical Antenna: Broadband antennas

Close Field Probe Set: Diagnostics antennas

Tripods: used to raise and lower antennas

LISN: Line Impedance Stabilization Network

Rotating Table: To rotate EUT for testing

EUT: Equipment Under Test, same as Device Under Test (DUT)
Measurement Equipment – Emissions Testing

Radiated Emissions

Conducted Emissions

Keysight Equipment: X-series signal analyzers

LISN - (line impedance stabilization network)
Provides AC power for DUT and captures interference signal for EMI receiver / spectrum analyzer
Measurement Equipment – Immunity Testing

Radiated Immunity

Conducted Immunity

ESD source

Directional coupler

transducer

EUT

EUT

Power Control Feedback

Power Control Feedback

Artificial Mains Network

Keysight Equipment: USB Power Sensors
RF Sources
Oscilloscopes

Keysight Solutions for EMI Measurements
Problem solving and troubleshooting

At this point, after the product is tested and the results are recorded and printed, your product is either ready for full compliance testing and production or it must go back to the bench for further diagnosis and repair.

If the product needs further troubleshooting, the following process is recommended:

• Use the spectrum analyzer with a Close Field Probe to locate the source or sources of the problem frequencies.

• Use a multi-trace spectrum analyzer you can set trace one to peak hold, tune the analyzer to one of the problem frequencies and capture the signal. Save the trace for future recall.

• Make necessary modifications or circuit changes to reduce the emissions.
  • Add or change circuit components
  • Redesign the problem circuit
  • Add shielding as necessary

• Now recall trace one and then make trace two active, you can make live comparisons to trace one, repeat the process as necessary to achieve the level desired.

• Repeat the above steps for all problem frequencies.
Signal Troubleshooting Example
Probing for Radiated Signals

- Placing the display of the analyzer in {Max Hold} mode to collect the strongest emissions
- Scanning the close-field probe along the seam records the worst-case values. This result is then saved.
- Returned to {Clear Write} mode so that the strongest source of emissions can be located.

Keysight N9311X-100
Close Field Probe Set: 30 MHz – 3 GHz

N9311X Probe Introduction Video
1.24 min.
Keysight Offers a Full Range of EMI Solutions

Design Software

Test Equipment

Compliance and Pre-compliance Test Systems (with Solution Partners)
Keysight Simulation/Design Software

ADS

Common Database Integration

ADS Layout Export

EMPro

Momentum Simulator
Method of Moments

FEM Simulator
Finite Element Method

FDTD Simulator
Finite Difference Time Domain
Types of EMI/EMC Problems Solved in EMPro

- EMI - Estimate emission level at specified distance and compare against EMI compliance (Limit)
- Near Field - Hotspot Analysis

- EMC Characterization (Immunity Test) with Plane Wave Excitation
- Coupling Analysis with S-parameter
Does My Chassis Meet EMI Spec?

EMI/EMC

E-field @ 2.235GHz

EMI Calculation: Predict Radiated Emission

E-field @ 5.68GHz

EMC Characterization: Freq dependency on the noise received on power plane

Rack Mount Chassis with 4-layer PCB

Keysight Solutions for EMI Measurements
Does Slot on Ground Plane Radiate?

USB 3.0 EMI Emission

Emission level at 3 meters with Both SS channel enabled
Keysight Signal Analyzers

- Pre-compliance
  - X series Analyzers
    - N9000B CXA
    - N9010B EXA
    - N9020B MXA
    - N9030B PXA
    - N9040B UXA
  - Handheld Analyzers
    - N934xC Handheld Analyzer
    - FieldFox RF Analyzer

- Compliance
  - N9038A MXE
Keysight Software

Option EMC versus N6141C EMI Measurement application

- Keysight Spectrum Analyzers have 2 EMI software applications
  - Option EMC and N6141C
N90x0B option EMC

Provides the essential capabilities on EMI interference analysis

N9000B-EMC option provides:

- CISPR 16-1-1 (2010) fully-compliant detectors
- CISPR band presets to 18 GHz
- Measure at marker with three detectors
- Tune and listen for signal discrimination

Measurement parameters set according to CISPR bands

One-button EMI presets
N90x0B option EMC
Measure at marker with 3 detectors simultaneously

Measure at marker with three detectors:
- Peak
- Quasi-peak
- EMI average
Built-in CISPR and MiL-STD limit line
A list of commercial limits for recalling
N6141C EMI measurement application
Runs inside Signal Analyzer

EMI precompliance test capabilities:
- Built-in CISPR and Mil-STD compliant BW, detectors and band presets
- Automated testing to regulatory limit lines with user-selected margins
- Amplitude corrections for antennas, LISNs, NF probes, etc

Measurement features:
- 3 simultaneous detectors (Peak, Quasi-peak, Average)
- Built-in signal list tracking those non-compliance emissions
- Strip chart for analysis of emissions versus time
- Supports precompliance “Click” measurements
Reference work flow:
Instrument Setup → Scan → Peak search → Measure

1. Setup
   - Frequency range
   - Y axis unit
   - RBW, VBW
   - Edit from PC software for:
     ● Limit file
     ● Amplitude correction file

2. Scan
   - With peak detector
   ● Load limit
   ● Limit test with Pass/Fail indicator

3. Peak search
   - Put markers on those failed points

4. Measure
   - Use Quasi-peak detector

Based on CISPR recommended test flow
N9038A MXE EMI Receiver Blends World-Class EMI Measurement Functionality

- Update three detectors simultaneously
- Amplitude correction
- Regulatory limit lines
- Both Time-Domain and Frequency-Domain scanning
- Automatic testing to limit lines and user-defined margins
- Automated signal list collection
- Automated signal list measurement
……with State of the Art EMI Diagnostic Capability

- Extensive set of built-in diagnostic tools
  - Signal Analysis
  - Monitor Spectrum (IF Scan)
  - Strip Chart
  - Real-Time Spectrum Analysis (RTSA)
  - Global frequency linkage
  - Spectrogram
  - Zone Span

Now with RTSA!

More than an EMI receiver….the MXE includes powerful diagnostic capability!
Agenda

– EMC Basics and Standards

– EMC Precompliance vs Compliance Measurement Solutions

– Impact of Mismatch and the Importance of Network Analyzers (Ford RI115)

– Modern TDR Solutions for Signal Integrity
Why Use S-Parameters?

- Relatively easy to obtain at high frequencies
  - measure voltage traveling waves with a vector network analyzer
  - don't need shorts/opens which can cause active devices to oscillate or self-destruct
- Relate to familiar measurements (gain, loss, reflection coefficient ...)
- Can cascade S-parameters of multiple devices to predict system performance
- Can compute H, Y, or Z parameters from S-parameters if desired
- Can easily import and use S-parameter files in our electronic-simulation tools
Network Analysis Terminology

**Reflection**

\[ \frac{\text{Reflected}}{\text{Incident}} = \frac{A}{R} \]

- **SWR**
- **S-Parameters** \( S_{11}, S_{22} \)
- **Reflection Coefficient** \( \Gamma, \rho \)
- **Return Loss**
- **Impedance, Admittance** \( R+jX, G+jB \)

**Transmission**

\[ \frac{\text{Transmitted}}{\text{Incident}} = \frac{B}{R} \]

- **Gain / Loss**
- **S-Parameters** \( S_{21}, S_{12} \)
- **Transmission Coefficient** \( T, \tau \)
- **Insertion Phase**
- **Group Delay**

Keysight Solutions for EMI Measurements
Measuring S-Parameters

\[ S_{11} = \frac{\text{Reflected}}{\text{Incident}} = \frac{b_1}{a_1} \quad \text{a}_2 = 0 \]
\[ S_{21} = \frac{\text{Transmitted}}{\text{Incident}} = \frac{b_2}{a_1} \quad \text{a}_2 = 0 \]
\[ S_{12} = \frac{\text{Transmitted}}{\text{Incident}} = \frac{b_1}{a_2} \quad \text{a}_1 = 0 \]
\[ S_{22} = \frac{\text{Reflected}}{\text{Incident}} = \frac{b_2}{a_2} \quad \text{a}_1 = 0 \]

**Forward**
- Incident
- Reflected
- Transmitted
- Load

**Reverse**
- Incident
- Reflected
- Transmitted
- Load

S11 = forward reflection coefficient (input match)
S22 = reverse reflection coefficient (output match)
S21 = forward transmission coefficient (gain or loss)
S12 = reverse transmission coefficient (isolation)
Keysight VNA Portfolio
Industry’s Broadest Price/Performance Choices

- Wireless RF components
- Production test
- High-speed digital
- LF-RF components
- CATV / 75-ohm

- Basic S-parameter (wireless components, A/D, etc.)
- High-volume mfg.
- True Multiport Test
- Multi-site Test

FieldFox
Carry precision with you
30 k to 50 GHz

- Installation & Maintenance
- A/D service/maintenance

PXA VNA
Drive down the size of test
300 k to 26.5 GHz

- Broadest range of applications
- Metrology & cal lab
- Complete linear & nonlinear active device characterization

ENA Series
Drive down the cost of test
5 Hz to 20 GHz

E5080A
The next-generation ENA

E5061B, E5063A
High-performance RF NA
NA + ZA in one-box
Low cost RF NA

E5071C, E5072A
High-performance Microwave NA

PNA Family
Reach for unrivaled excellence
300 k to 1.1 THz

PNA-L (N523XB)
Economy Microwave NA

PNA (N522XB)
High-performance Microwave NA

PNA-X (N524XB), NVNA
Most advanced & flexible Microwave NA

PNA-X Receiver
8530A Antenna Replacement

mm-wave Solution
Up to 1.1 THz

Keysight Solutions
for EMI Measurements
RF Immunity: RI 115

Test Setup

RI 115 simulates near-field electromagnetic field exposure from cellular transmitters and covers the frequency range from 360 to 2700 MHz.

Prior to testing, characterization of test setup shall be performed in accordance with the procedures delineated in Annex C. The characterization will determine the forward power required to generate the specified net power.
Annex C (Normative): RI 115 Characterization Procedures

- Facilitates accurate delivery of net power to the transmit antenna.
- Procedure is based on ISO 11451-3, but considers the effects of mismatch losses that if not controlled will impact the accuracy of the net power.

**ISSUE:**
The equations for forward/reflected power neglect the effect of mismatch losses which can impact the net power if not controlled. To assure accurate delivery of the net power to the transmit antenna, all transmission and mismatch losses must be managed or accounted for.
Annex C (Normative): RI 115 Characterization Procedures

**Note:**
Differences between EMC-CS-2009.1 (FEB10) and FMC1278 (JUL15): New Characterization procedure presented in Annex C. Requires use of vector or scalar network analyzer.

### Test Parameters

<table>
<thead>
<tr>
<th>Test Parameters</th>
<th>Limits @ RI 115 Frequencies (360 MHz to 2700 MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.1 Directional Coupler Parameter Verification</td>
<td></td>
</tr>
</tbody>
</table>
| C.1.1 VSWR and Transmission Loss Measurement | • VSWR < 1.3  
• Insertion Loss (DC) < 0.5 dB |
| C.1.2 VSWR and Forward Coupling Factor Measurement | • VSWR < 1.3  
• Forward Coupling Factor (CF_F) > 20 dB |
| C.1.3 VSWR and Reflected Coupling Factor Measurement | • VSWR < 1.3  
• Reverse Coupling Factor (CF_R) > 20 dB |
| C.2 SBA Antenna Reflection Coefficient Measurement | |
| C.3 RF Component VSWR Verification | • VSWR < 1.3 |
| C.4 Characterization of VSWR and Transmission Loss for the Coupler/Antenna Interconnect | • VSWR < 1.3 of respective connections  
• Transmission loss (T1) < 4 dB |
Annex C (Normative): RI 115 Characterization Procedures

C.1 Directional Coupler Parameter Verification

C.1.1 VSWR and Transmission Loss Measurement

Limits:
- VSWR < 1.3
- Insertion Loss (DC) < 0.5 dB

C.1.2 VSWR and Forward Coupling Factor Measurement

Limits:
- VSWR < 1.3
- Forward Coupling Factor ($\text{CF}_F$) > 20 dB

C.1.3 VSWR and Reflected Coupling Factor Measurement

Limits:
- VSWR < 1.3
- Reverse Coupling Factor ($\text{CF}_R$) > 20 dB

Keysight Solutions for EMI Measurements Page 54
C.2 SBA Antenna Reflection Coefficient Measurement

Figure C-7: Measurement of $\rho$ of Transmit Antenna

> 250 mm

> 500 mm

Conducting Surfaces

VNA

Port 1

> 500 mm

> 250 mm

Note: Only Schwarzbeck antenna SBA9113 with elements 420NJ shall be used for this test.

C.3 RF Component VSWR Verification

Each of the components used in the RI 115 test setup (e.g. cables, adapters, coaxial connectors) shall be verified to have a **VSWR of less than 1.3** over the entire RI 115 frequency range.
Annex C (Normative): RI 115 Characterization Procedures

C.4 Characterization of VSWR and Transmission Loss for the Coupler/Antenna Interconnect

Figure C-8: Measurement of $T_1$

Limits:
- VSWR < 1.3 of respective connections
- Transmission loss ($T_1$) < 4 dB

C.4 Characterization of VSWR and Transmission Loss for the Coupler/Power Sensor Interconnect

Figure C-9: Measurement of $T_2$ and $T_3$

Limits:
- VSWR < 1.3 of respective connections
Keysight VNA Portfolio
Industry's Broadest Price/Performance Choices

Meet strict amplitude accuracy requirement

PNA Family
Reach for unrivaled excellence
300 kHz to 1.1 THz

PNA-L (N523XB)
Economy Microwave NA

PNA (N522XB)
High-performance Microwave NA

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High-performance RF NA

E5071C, E5072A
Low cost RF NA

PXI VNA
Drive down the size of test
300 kHz to 26.5 GHz

FieldFox
Carry precision with you
30 kHz to 50 GHz

PNA-X Receiver
8530A Antenna Replacement

mm-wave Solution
Up to 1.1 THz

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- Impact of Mismatch and the Importance of Network Analyzers (Ford RI115)
- Modern TDR Solutions for Signal Integrity
Intro: What is TDR?

Time Domain Reflectometry (TDR)
1. Launch a fast step into the Device Under Test (DUT)
2. See what REFLECTS back from the DUT.

Example measurements:
- Impedance - locate the position and nature of each discontinuity
- Propagation/Time delay
- Excess Reactance (Capacitance or Inductance)

For validation/development look here for insight regarding what in the device is causing reflections
Intro: What is TDT?

**Time Domain Transmission (TDT)**

1. Launch a fast step into the Device Under Test (DUT)
2. See what is transmitted THROUGH the DUT.

For development and validation, look here for loss data to support simulation or for de-embedding.

Example Measurements:
- Step Response
- Propagation/Time delay
- Rise time degradation

**TDT (Step Response)**

**S-parameters (Insertion Loss)**
Time Domain and Frequency Domain Measurements

**NO** difference in information content between the time domain view, or the frequency domain view.

The 2 domains tell the same story, they just emphasize different parts of the story.
Time Domain and Frequency Domain Measurements

Using Fourier Transform techniques, the time domain response can be mathematically transformed into the frequency domain response and back again without changing or losing any information.
Why use a VNA instead of a TDR Scope?

- Measurement domain
  - VNA
  - TDR Scope

- Display domain
  - Frequency Domain
  - Time Domain
Three Key Advantages for Signal Integrity Design and Verification – Best Dynamic Range

EDN (Oct 12, 2006)

No time-domain instrument can surpass the accuracy, sensitivity, noise floor, and autocalibration routines inherent to a network analyzer.
Three Key Advantages
for Signal Integrity Design and Verification – Best Dynamic Range

TDR Scope

[Source]
• Source power rapidly decreases with increase in frequency
  => loss of accuracy for higher frequencies

[Receiver]
• Broadband
  • All noise up to the bandwidth of the system is observed
  => NO noise reduction

ENA Option TDR

[Source]
• Source power leveled and constant across entire frequency range
  => NO loss of accuracy for higher frequencies

[Receiver]
• Narrowband
  • Noise attenuated in stopband of filter
  => Noise reduction

For further details (including mathematical analysis), refer to the White Paper "Comparison of Measurement Performance between Vector Network Analyzer and TDR Oscilloscope" (5990-5446EN).
Three Key Advantages
for Signal Integrity Design and Verification –
Best Dynamic Range

Dynamic Range Comparison
VNA vs TDR Scope

Freq [GHz]

[0, 5, 10, 15, 20]

[0, 20, 40, 60, 80, 100, 120, 140, 160, 180, 200, 220]

E5071C-4K5
86100C-202
(ave=16)
Three Key Advantages for Signal Integrity Design and Verification – Real time Response

- Real time Response
- ENA Option TDR
- TDR Scope

DUT: 50 Ohm pattern

VNA Based TDR measurements = Low Noise
Three Key Advantages
for Signal Integrity Design and Verification – Real time Response

ENA Option TDR

TDR Scope

DUT: 50 Ohm pattern

Averaging…

Averaging
can lower noise

BUT…
Three Key Advantages
for Signal Integrity Design and Verification –
Real time Response

DUT: 50 Ohm pattern

ENA Option TDR

TDR Scopes

Real-Time Analysis
Three Key Advantages for Signal Integrity Design and Verification – ESD Protection

Difficult to implement protection circuits inside the instrument without sacrificing performance.

“In addition, protection diodes cannot be placed in front of the sampling bridge as this would limit the bandwidth. This reduces the safe input voltage for a sampling oscilloscope to about 3 V, as compared to 500 V available on other oscilloscopes.”

Tektronix ApNote “XYZ of Oscilloscopes”, p17 (02/09, 03W-8605-3)

External ESD protection module (80A02) available, but rise time is degraded.

- Single-channel protection and plugs into sampling mainframe
- $4K USD / module
- Reflected rise time when used with 80E04: 28ps -> 37ps
Three Key Advantages for Signal Integrity Design and Verification – ESD Protections

Higher robustness against ESD, because protection circuits are implemented inside the instrument for all ports, while maintaining excellent RF performance.

Proprietary ESD protection chip significantly increase ESD robustness, while at the same time maintaining excellent RF performance (22ps rise time for 20GHz models).

To ensure high robustness against ESD, ENA Option TDR is tested for ESD survival according to IEC801-2 Human Body Model.

<table>
<thead>
<tr>
<th>ESD Survival</th>
<th>IEC 801-2 Human Body Model. (150 pF, 330 Ω) RF Output Center pins tested to 3 kV, 10 cycles</th>
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Three Key Advantages for Signal Integrity Design and Verification – ESD Protection

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

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

The ENA Option TDR is an application software embedded on the E5071C, which provides an **one-box solution** for high speed serial interconnect analysis.

- **Simple and Intuitive Operation**
- **Fast and Accurate Measurements**
- **High ESD Robustness**
One-box Solution for High Speed Serial Interconnect Analysis

Time domain

Frequency domain

Eye diagram

Time Domain

Frequency Domain

Return Loss

Insertion Loss
One-box Solution for High Speed Serial Interconnect Analysis

- Time domain
- Frequency domain
- Eye diagram

- Automatic display allocation for most common measurement parameters depending on selected device topology
- Up to 9 markers
- Zoom
- Rise time
- Dedicated controls for common adjustments
- Flexibility to set measurement parameter for each individual trace
- Set rise time to characterize expected performance at slower edge speeds
- ∆ Time (skew) measurement
One-box Solution
for High Speed Serial Interconnect Analysis

Eye Diagram

Time domain

Frequency domain

Eye diagram

Keysight Solutions for EMI Measurements
Wrap up

EMI basics and EMI measurement tools

– It is important to evaluate your new product’s EMI performance before you go to the test house

– The conducted and radiated emissions can be captured and analysis with a spectrum analyzer and corresponding accessories

– Spectrum analyzers help you on EMI precompliance test, and the EMI diagnostics

  • Understand the compromises/value in the precompliance scanning
    • It cannot duplicate the final compliance test, but it can tell you the EMI trend and the change of trend in your device

– Modern Vector Network Analyzers address component characterization requirements and are also a valuable signal integrity tool