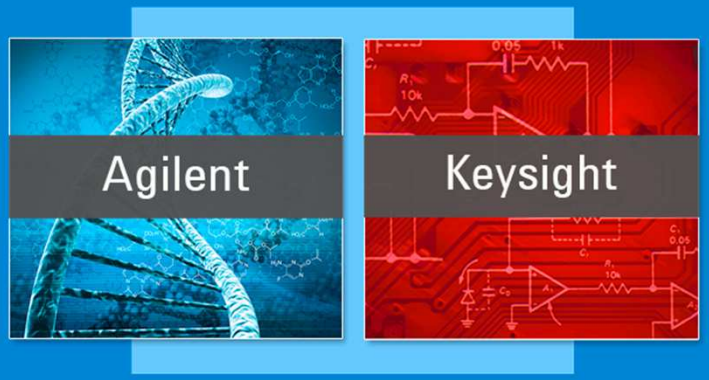
INTEGRIDAD DE SEÑAL

Fundamentos y Metodologías: tiempo y frecuencia



Héctor Carreño
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91 631 3300

AGENDA

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years

- Introduction / Signal Integrity Definition
- Evolution of Test Parameters
- Traditional TDR/TDT instrument
- Vector Network Analyzer Basis
- Single Ended / Differential Topologies
- Physical Layer Test System (PLTS Software)

AGENDA

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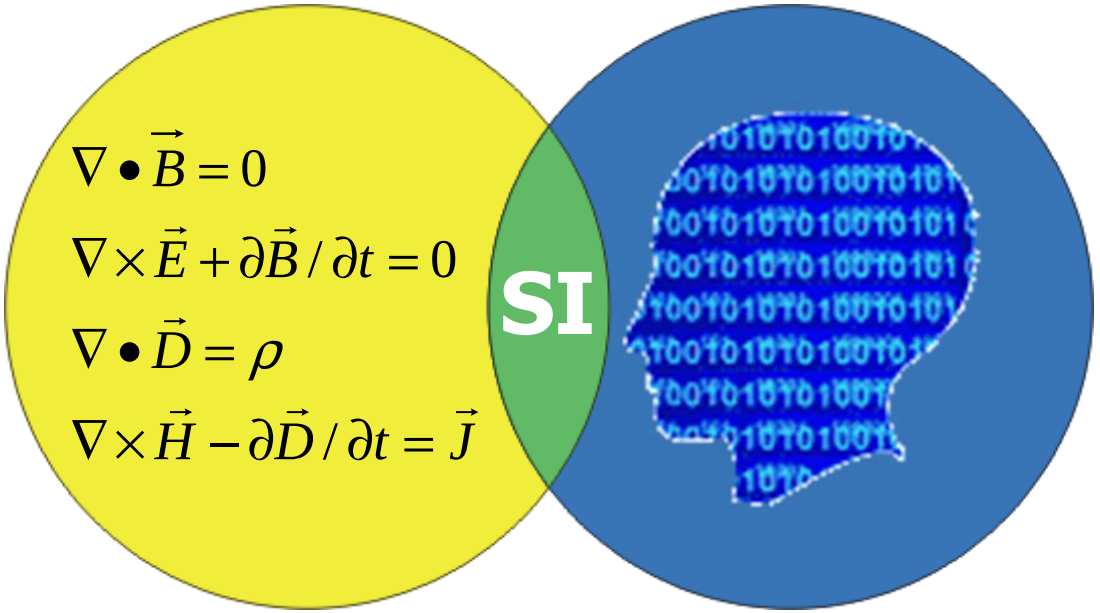
What is Signal Integrity ?

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years

- from Marketing's Viewpoint



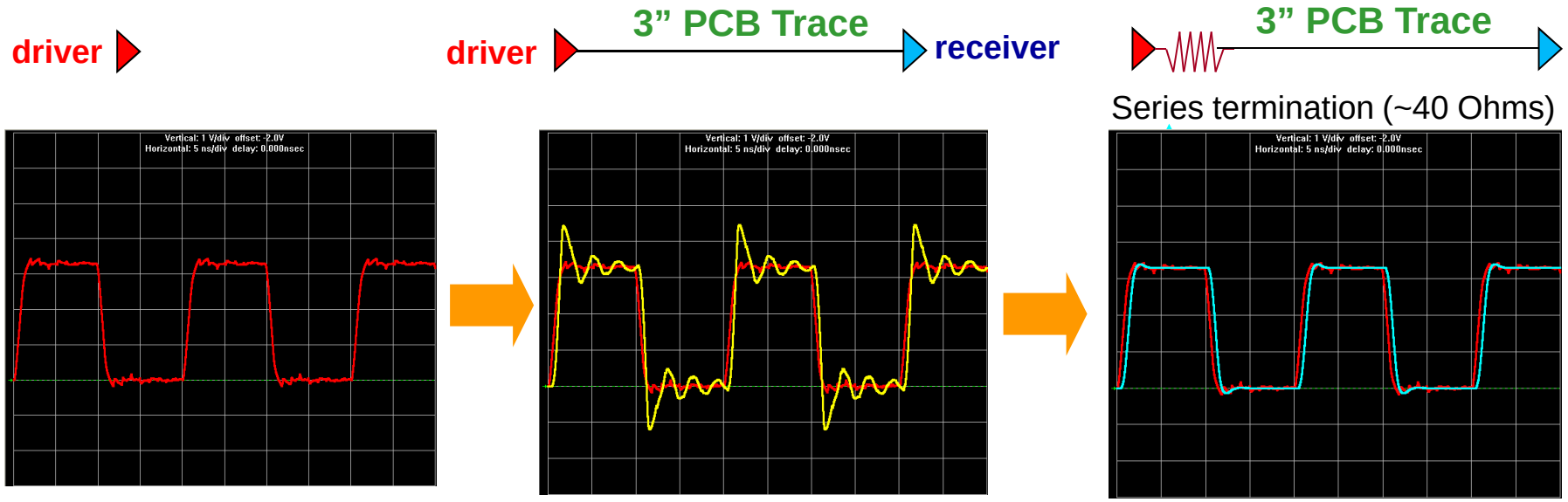
Mr. Maxwell meet Mr. Boole and Mr. Moore !

What is Signal Integrity ?

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years

➢ from Engineer's Viewpoint



Signal Integrity = Where the electrical properties of the interconnects can cause significant distortions in digital signals.

What is Signal Integrity ?

KEYSIGHT TECHNOLOGIES

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- from http://en.wikipedia.org/wiki/Signal_integrity

Signal integrity or **SI** is a measure of the **quality of an electrical signal**. In digital electronics, a stream of binary values is represented by a voltage (or current) waveform.

Over short distances and at low bit rates, a simple conductor can transmit this with sufficient fidelity. However, at **high bit rates** and over **longer distances**, various effects can degrade the electrical signal to the point where errors occur, and the system or device fails.

Signal integrity engineering is the task of analyzing and mitigating these impairments. Signal integrity engineering is at all levels of electronics packaging, from internal connections of an IC through the package, the printed circuit board (PCB), the backplane, and inter-system connections.

Some of the main issues of concern for signal integrity are *ringing, crosstalk, ground bounce, distortion, signal loss, and power supply noise.*

4 SI problems and their cause

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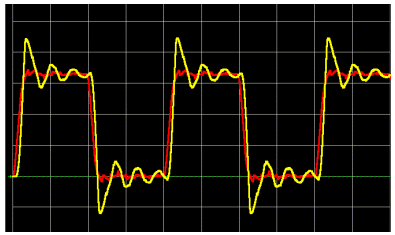
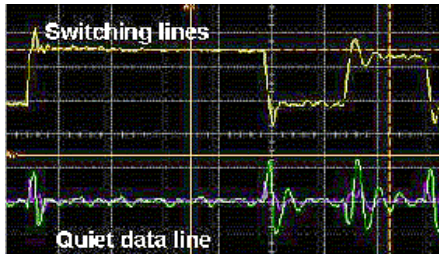
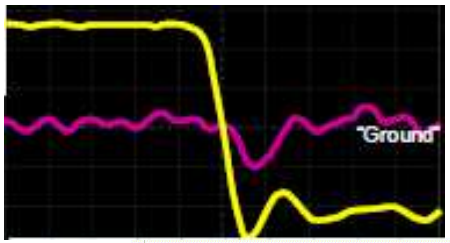
1. **Poor signal quality of one net:** reflections and distortions from impedance discontinuities in the signal or return path. Manufacturing tolerances for PCB and packages. Line width changes, Vias, Serpentines, Connectors, Cables…



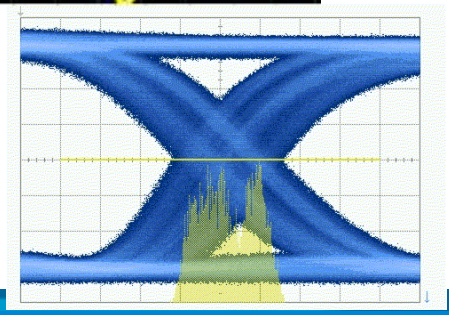
2. **Crosstalk between multiple nets:** electromagnetic coupling between signal lines. Trace-to-trace crosstalk, Via-to-Via coupling, Digital-to-RF coupling.



3. **Power/Ground Noise:** voltage drops across impedance in the power/ground network



4. **Jitter** and **EMI** from causes listed above and variety of other sources



Today High Speed I/O Standards

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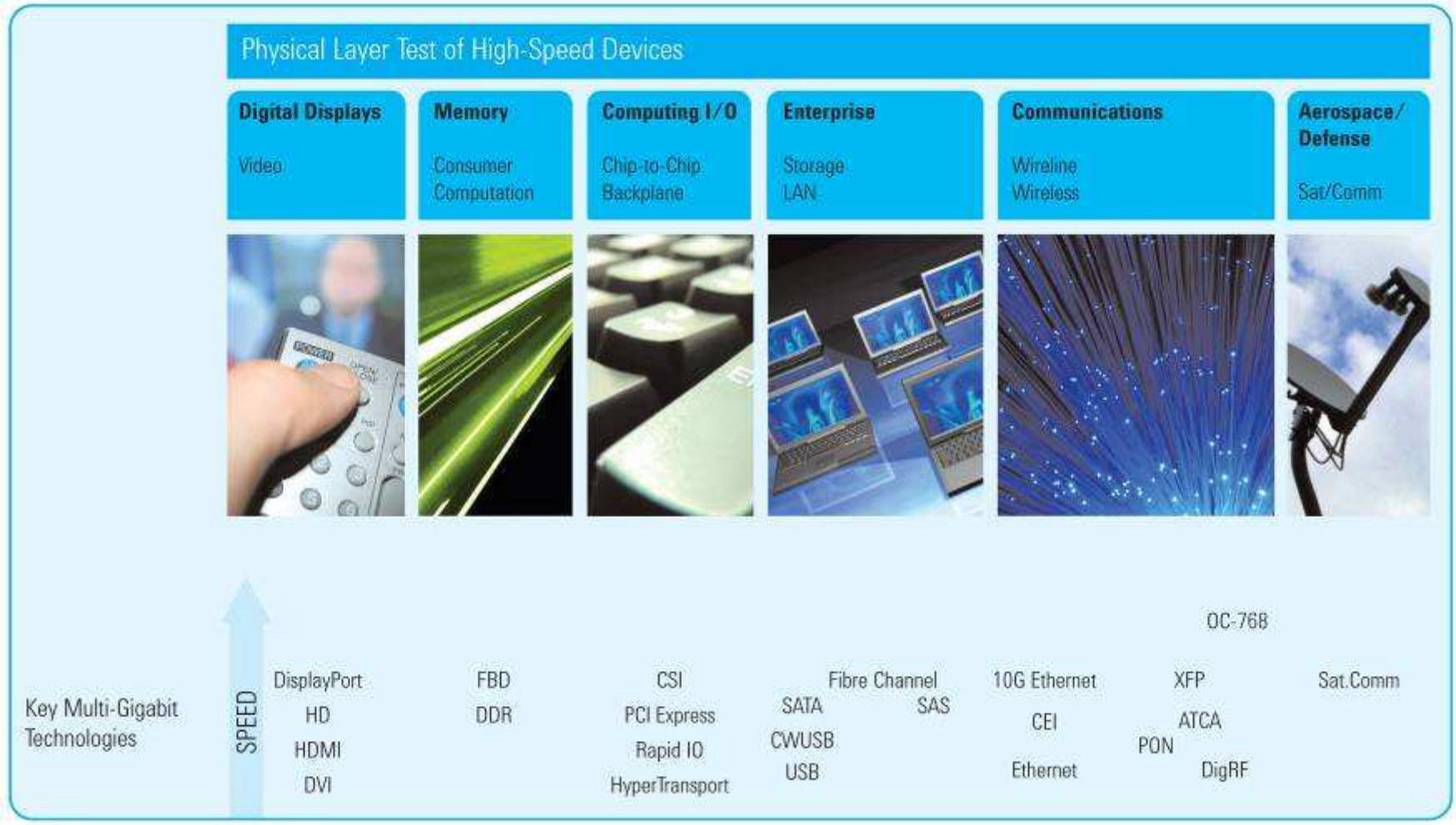

Data Rates continuously increasing

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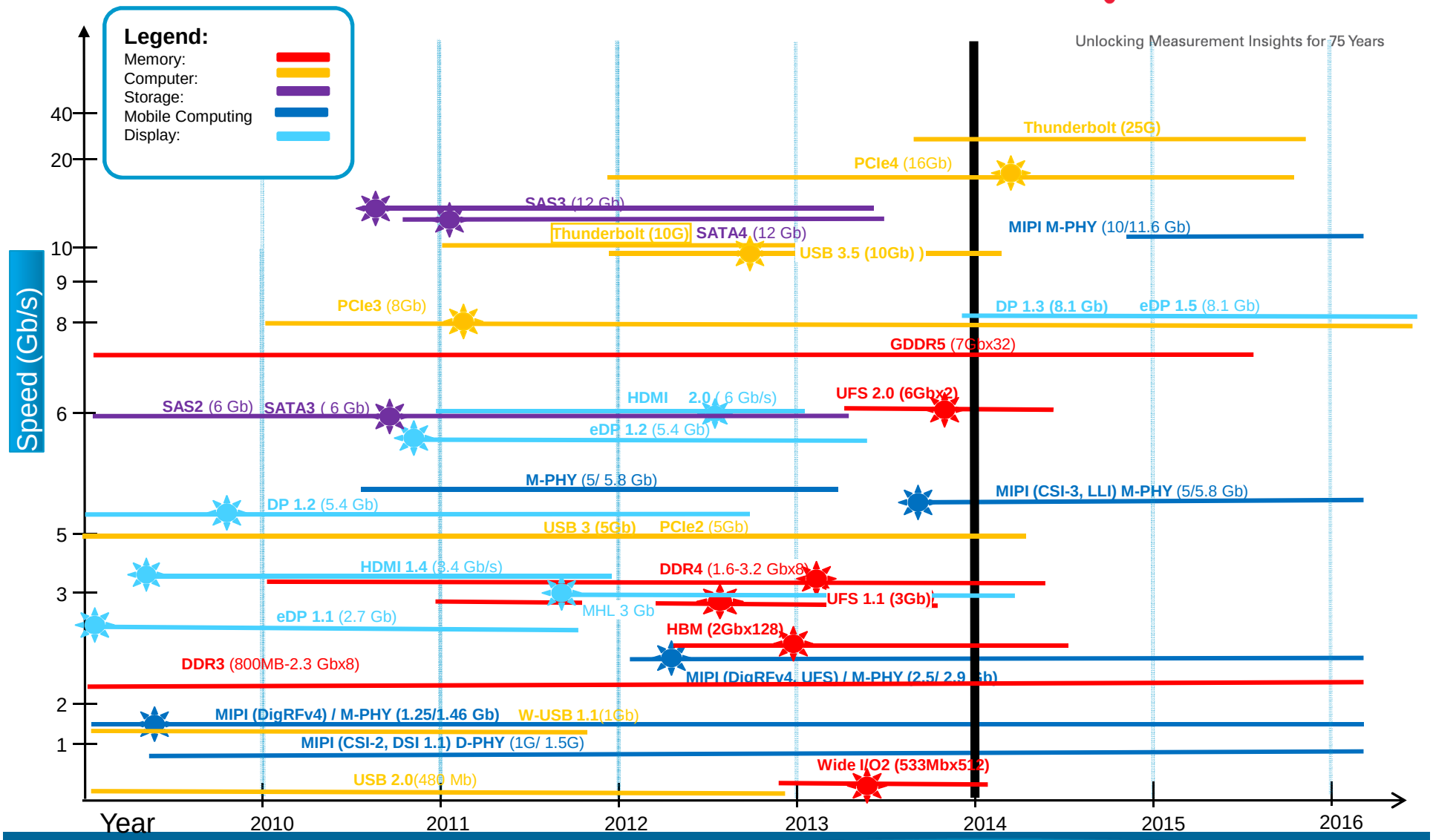

Agilent Technologies

SI is becoming more important

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High Speed Digital Committees

PCI SIG

HDMI

SERIAL ATA

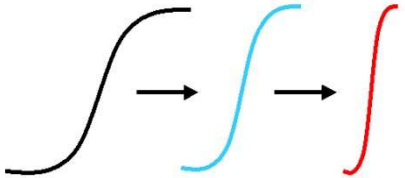
HI-SPEED CERTIFIED USB

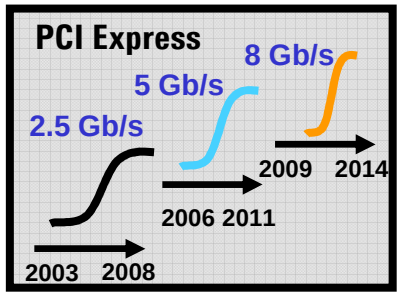
VESA

JEDEC

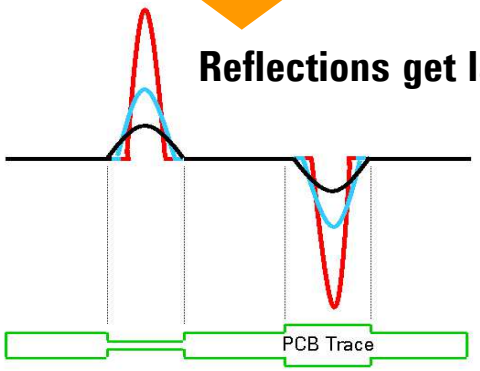
mipi mobile industry processor interface

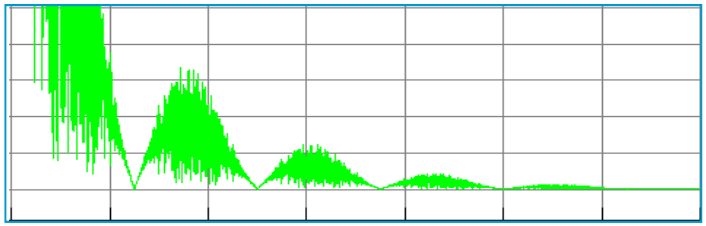
Risetimes become faster





Reflections get larger





Frequency Domain data is ALSO required

What about using existing channels ?

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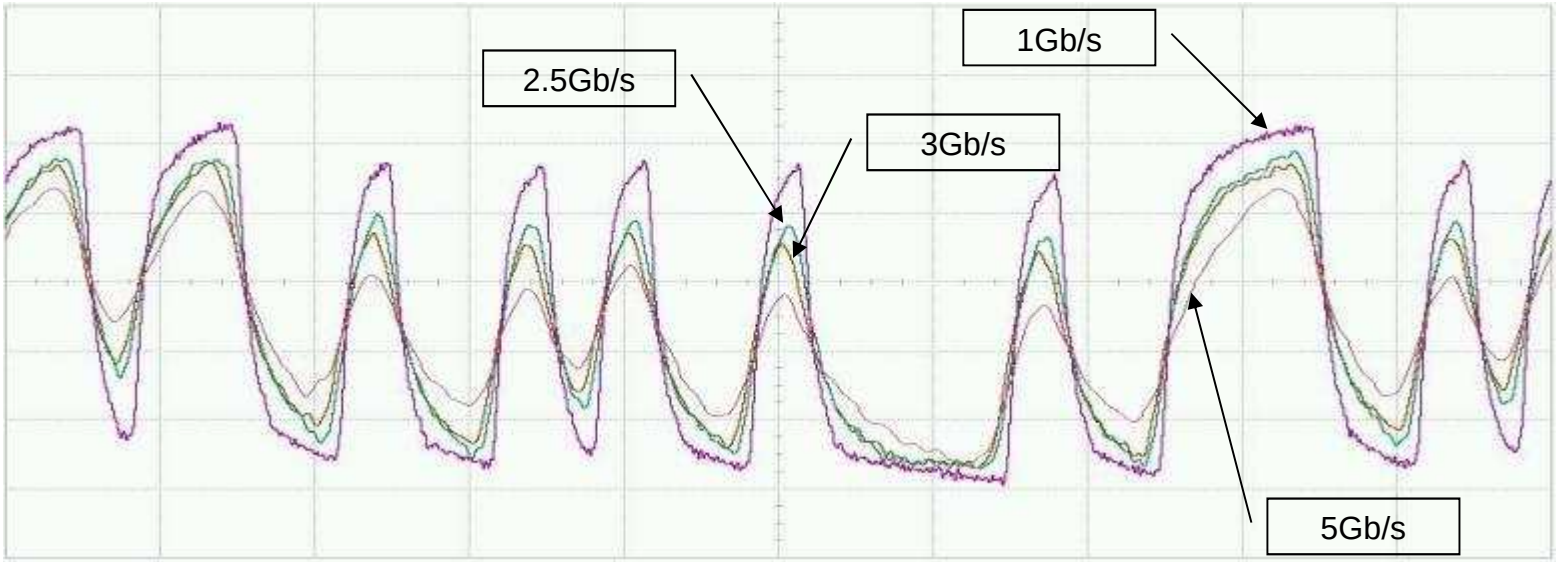

Transmitter → Channel → Receiver

Channel

Backplane, short/long cable, board trace.
Causing Inter-symbol interference (ISI),
loss, reflections, cross-talk.

Example: FR4 is showing its limitations

KEYSIGHT TECHNOLOGIES

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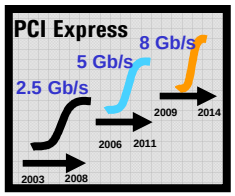
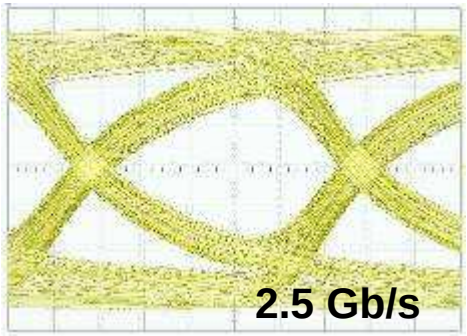
FR4 is common, low cost and easy to manufacture BUT it has problems:

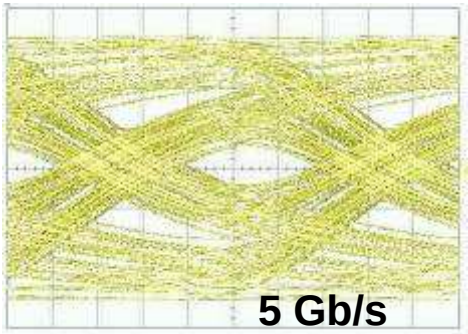
- Reflections at high speeds
- Dispersion varies with frequency
- High Insertion Loss
- ISI induced Jitter
- Effects vary with temperature and humidity



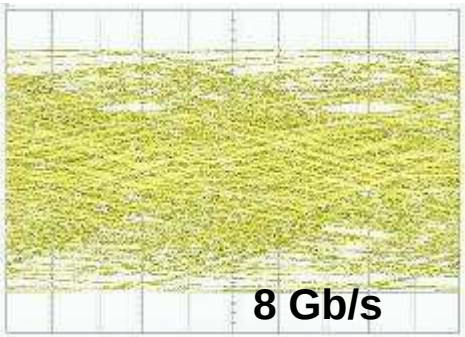
What Works Today



Gets Worse The Next Time



No longer usable



Signal Integrity Challenge

KEYSIGHT TECHNOLOGIES

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USB 3.0	4.8 Gb/s
HDMI	5 Gb/s
DVI	8 Gb/s
DP	8.6 Gb/s
PCIe	5 Gb/s
SATA	3 Gb/s
DDR3	0.8-2.133 Gb/s

Signal Integrity problems everywhere !

KEYSIGHT TECHNOLOGIES

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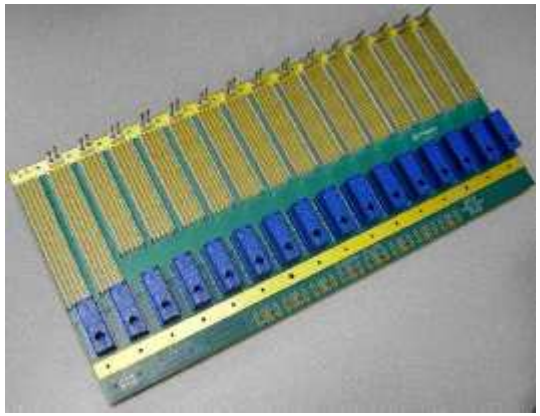
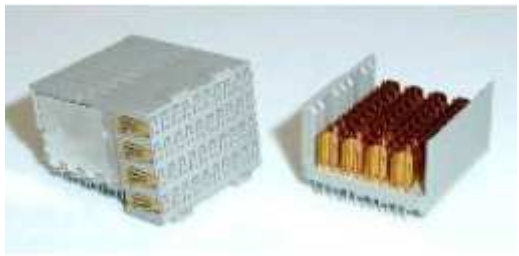
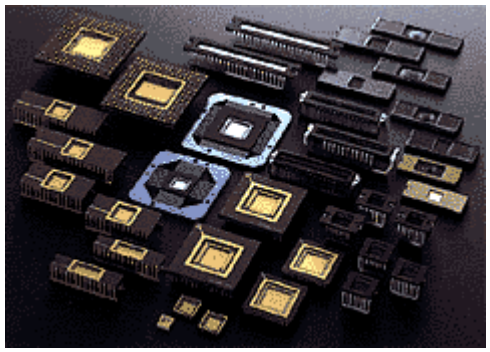
Backplanes



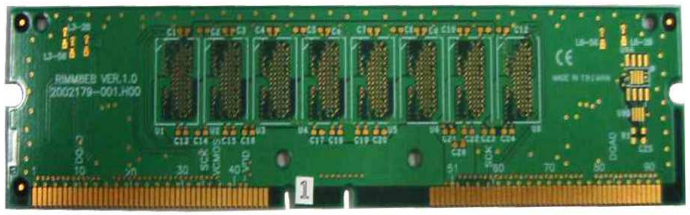


Connectors



IC Packages

PC Boards



Cables

AGENDA

KEYSIGHT TECHNOLOGIES

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Trends in Compliance Test

KEYSIGHT TECHNOLOGIES

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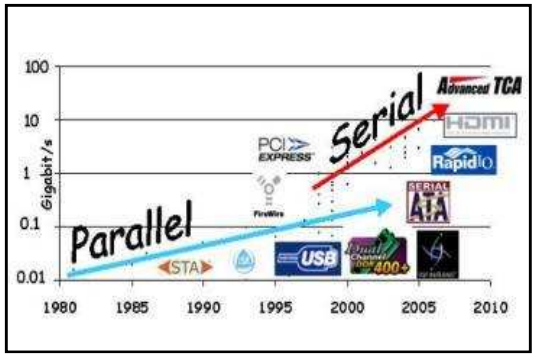
With the increase in bit rates, standards continue to evolve and new measurements are often the result. There is a growing need in the industry for more thorough evaluation of components, as well as evaluation under actual operating conditions



	High-speed serial standards	Compliance Test Parameters
1990s	Gen 1 (~100s Mbps)	•time domain (**impedance, delay, skew**, …)
2000~	Gen 2 (1~3 Gbps)	•time domain (impedance, delay, skew) •frequency domain **(insertion loss, return loss, …)**
2007~	Gen 3 (~3 Gbps)	•time domain (impedance, delay, skew) •frequency domain (insertion loss, return loss, **crosstalk, mode conversion**, …)
2010~	Next Gen (~6 Gbps)	•time domain (impedance, **impedance in active state**, delay, skew, **eye diagram**) •frequency domain (insertion loss, return loss, crosstalk, mode conversion, …)

Traditional Test

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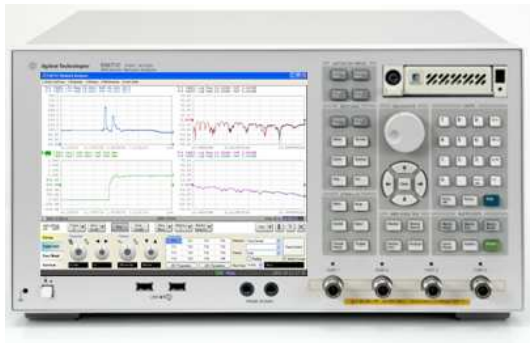
Time Domain
(impedance, delay, skew, eye diagram)

Frequency Domain
(return/insertion losses, xtalk, mode conv.)

Oscilloscopes / TDRs



Vector Network Analyzers

AGENDA

KEYSIGHT TECHNOLOGIES

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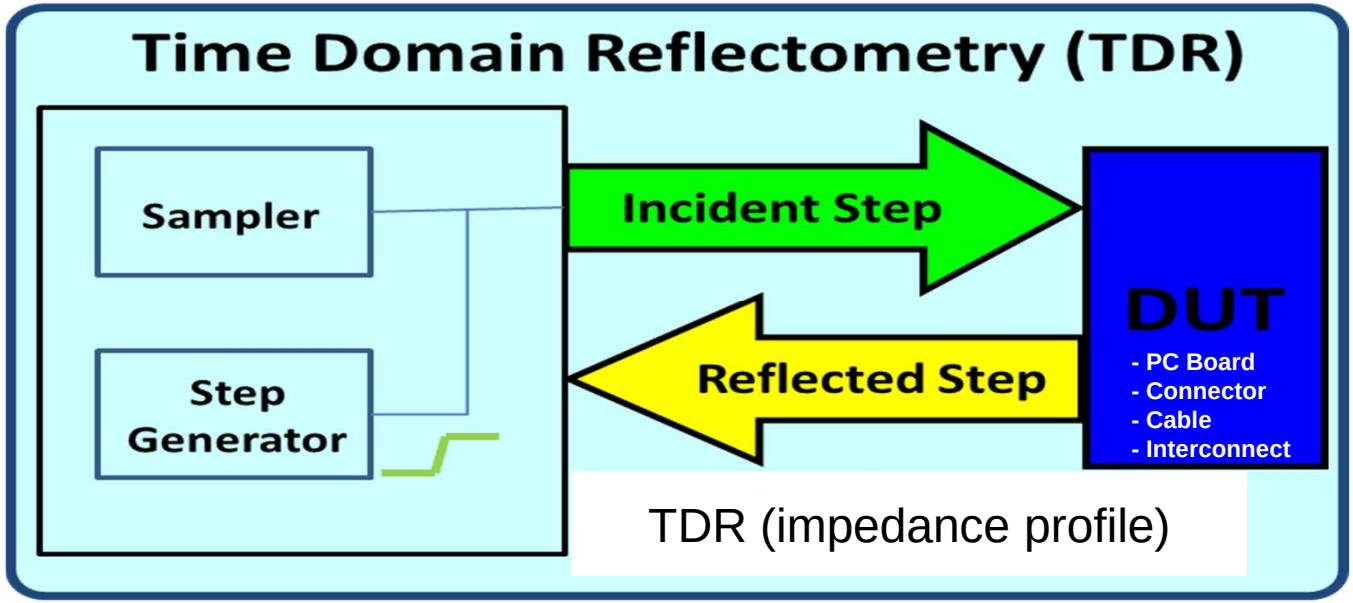
Time Domain Reflectometry (TDR)

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years



Time Domain Reflectometry (TDR)

- Impedance measurements
- Locate the position and nature of each discontinuity
- Propagation/Time delay
- Excess Reactance (Capacitance or Inductance)
- Effective dielectric constant

TDR - Short Termination

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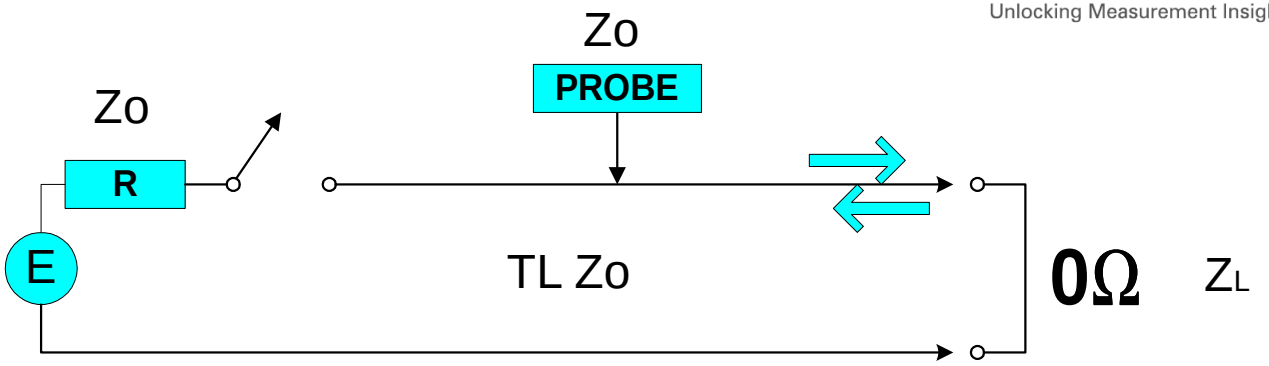
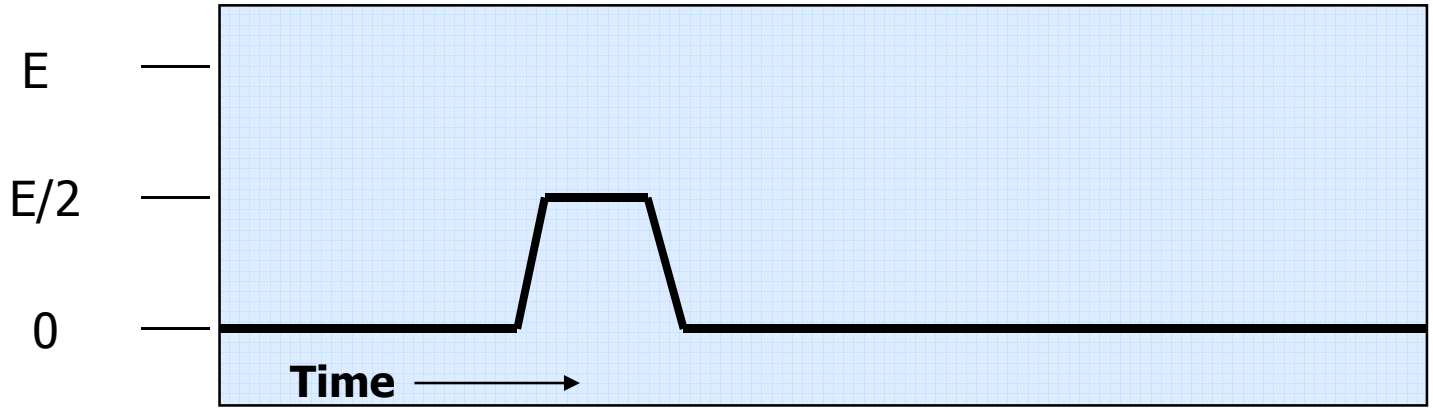


What do you expect to see at the probe before, during, and after you close the switch?



TDR - Open Termination

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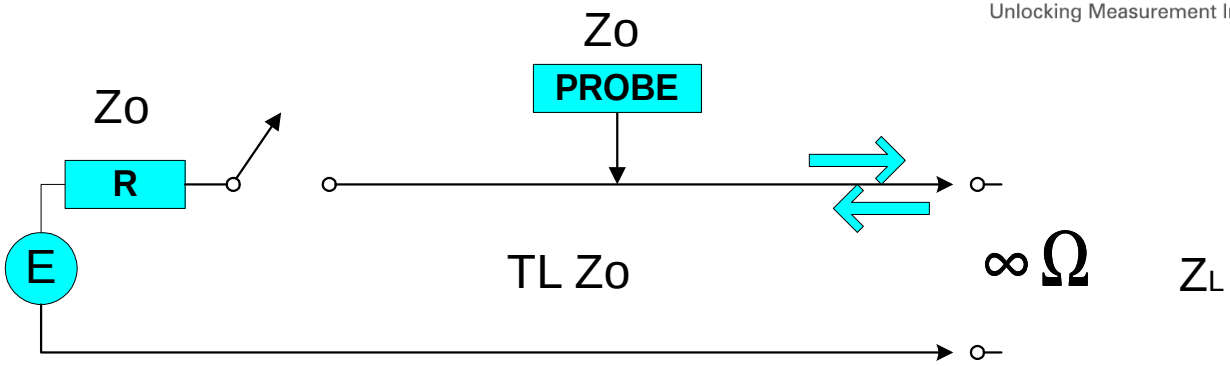

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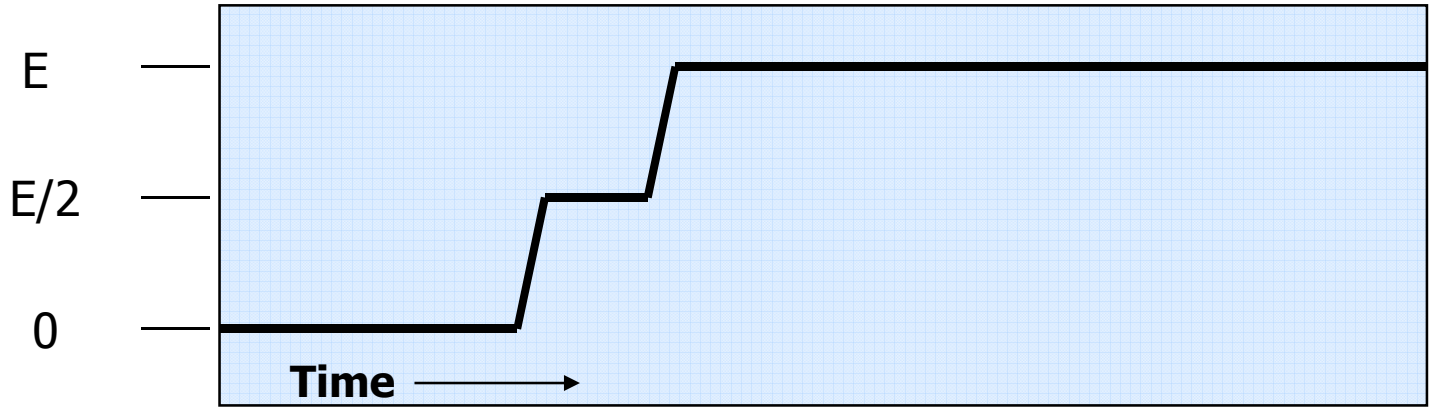

TDR - Perfect Termination

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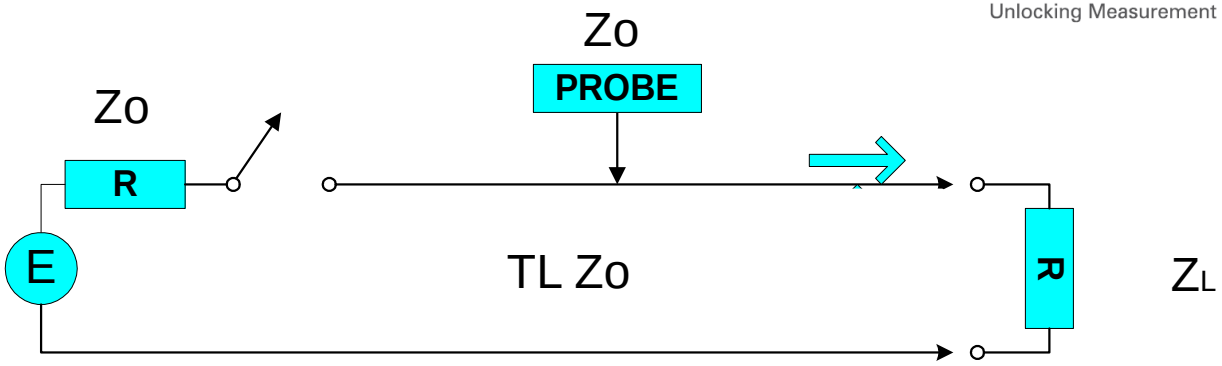
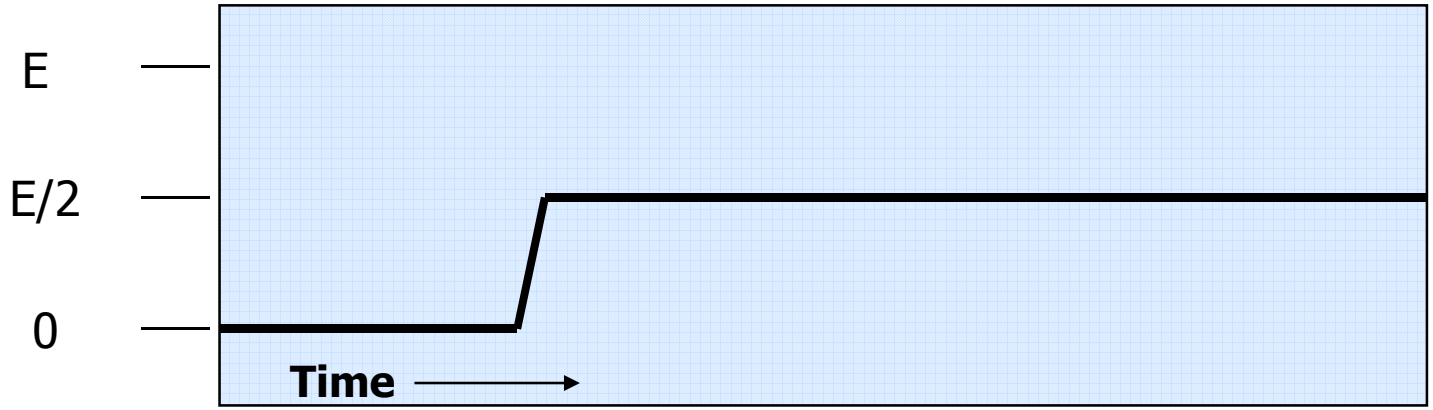


What do you expect to see at the probe before, during, and after you close the switch?



TDR - Unknown Termination

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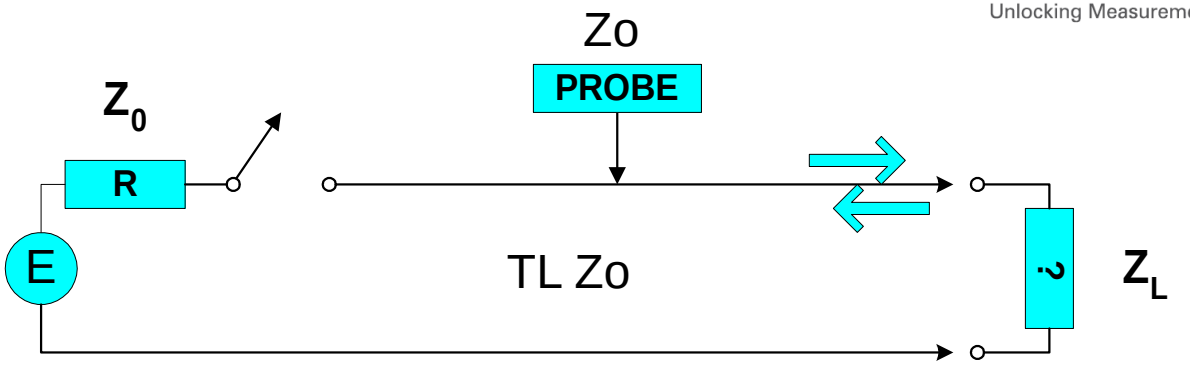
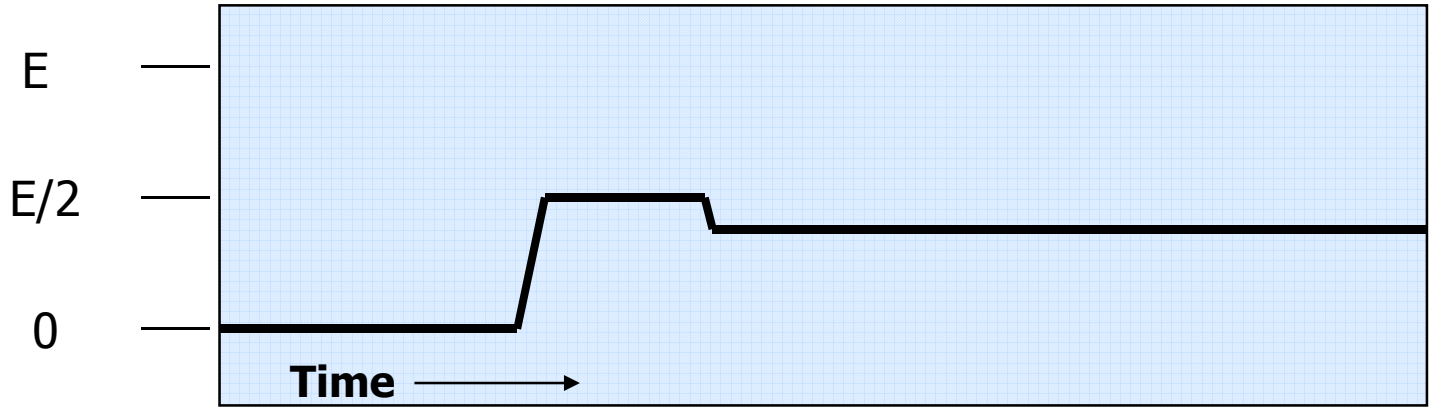


Is the unknown resistor closer to a short (zero Ω) or an open (∞ Ω)?



TDR - Impedance Mismatch Terms

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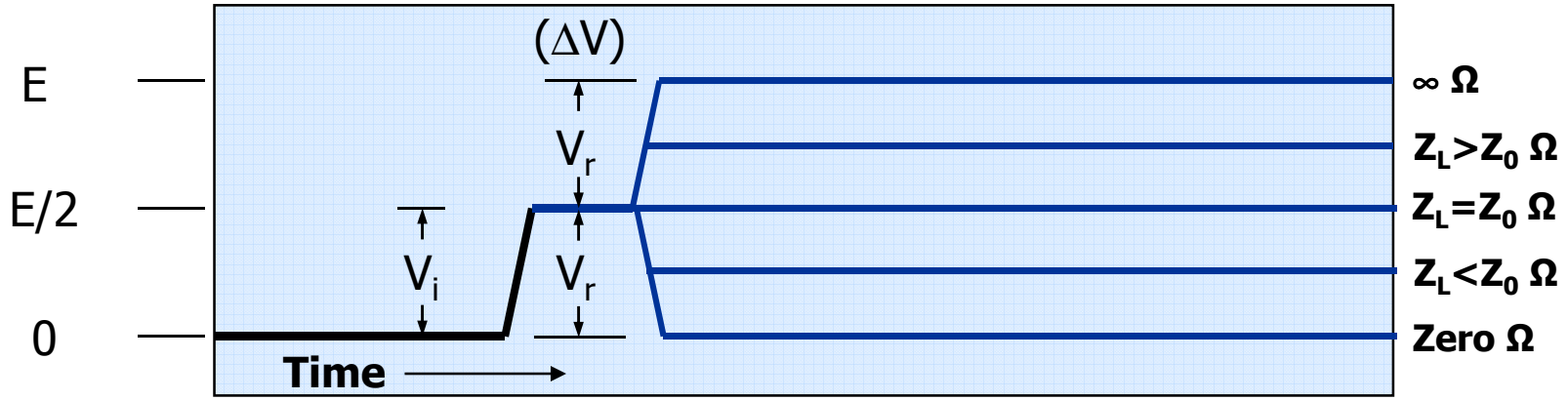
What is the value of Zload?

$$Z_L = Z_0 \frac{1+\rho}{1-\rho}$$

Impedance Calculated from Source Impedance and Reflection Coefficient.

$$\rho = \frac{V_r}{V_i}$$

Reflection Coefficient, rho: How much was reflected?



TDR - Multiple Discontinuities

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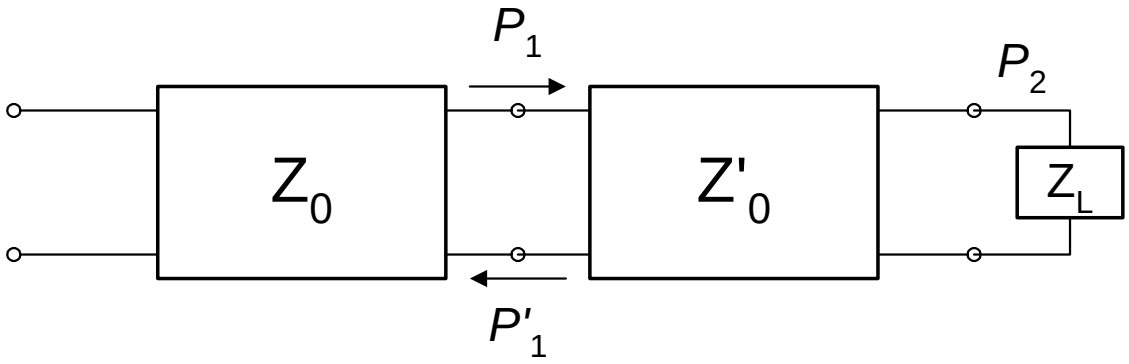
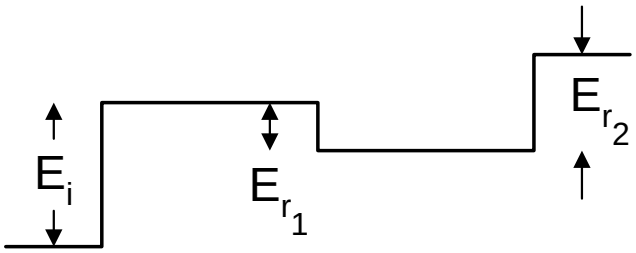


$$P_1 = \frac{Z_0' - Z_0}{Z_0' + Z_0} \qquad P_2 = \frac{Z_L - Z_0'}{Z_L + Z_0'}$$



Accuracy decreases as you look further down a line with multiple discontinuities

TDR in the time domain

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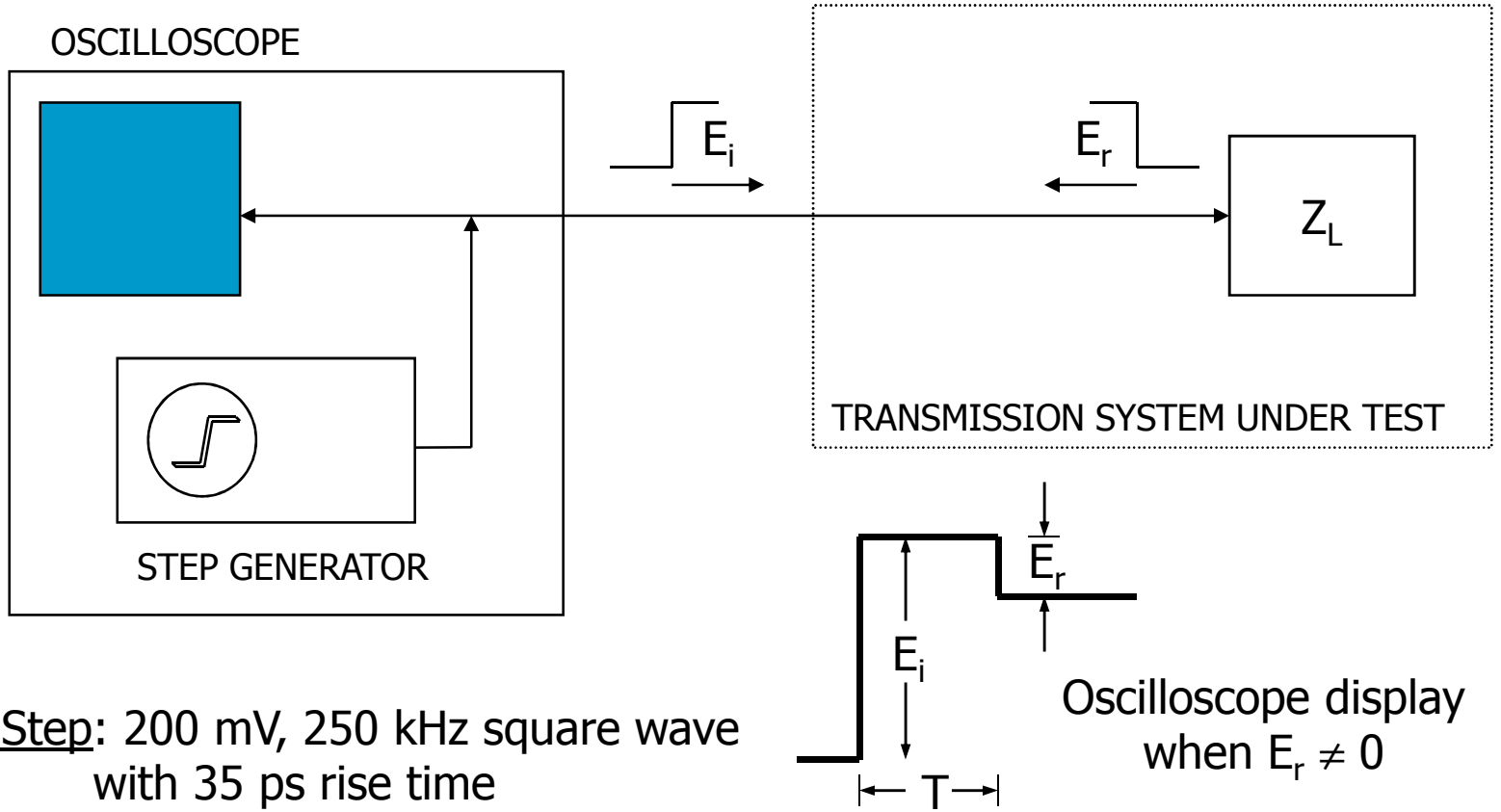

Typical Step: 200 mV, 250 kHz square wave with 35 ps rise time

Oscilloscope display when $E_r \neq 0$

TDR measurement based on Scope

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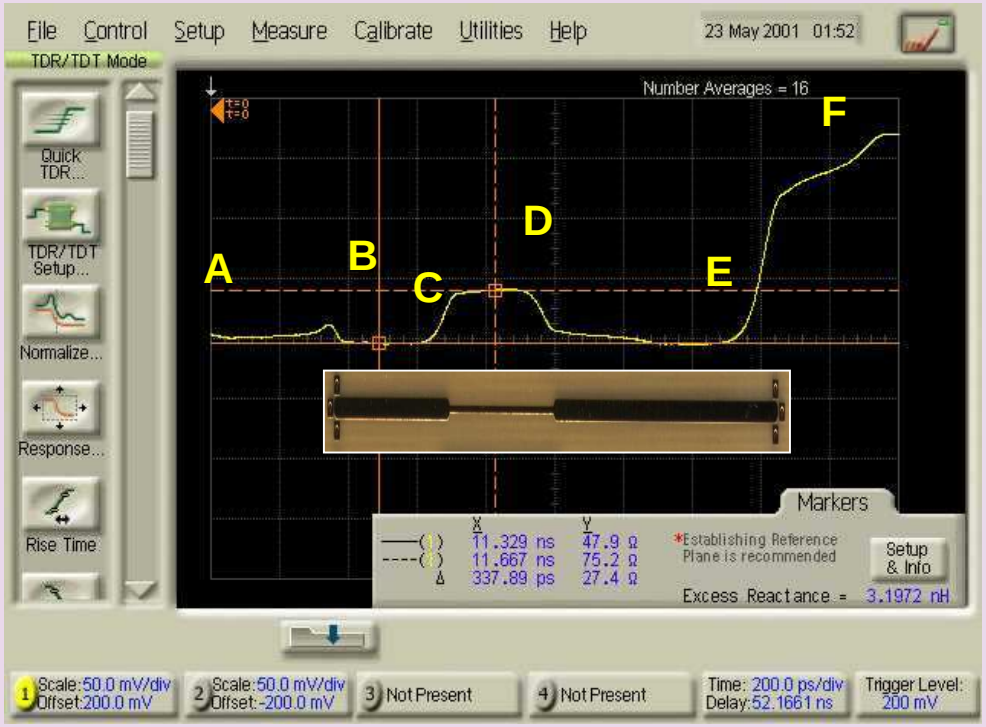
Unlocking Measurement Insights for 75 Years

Typical TDR result

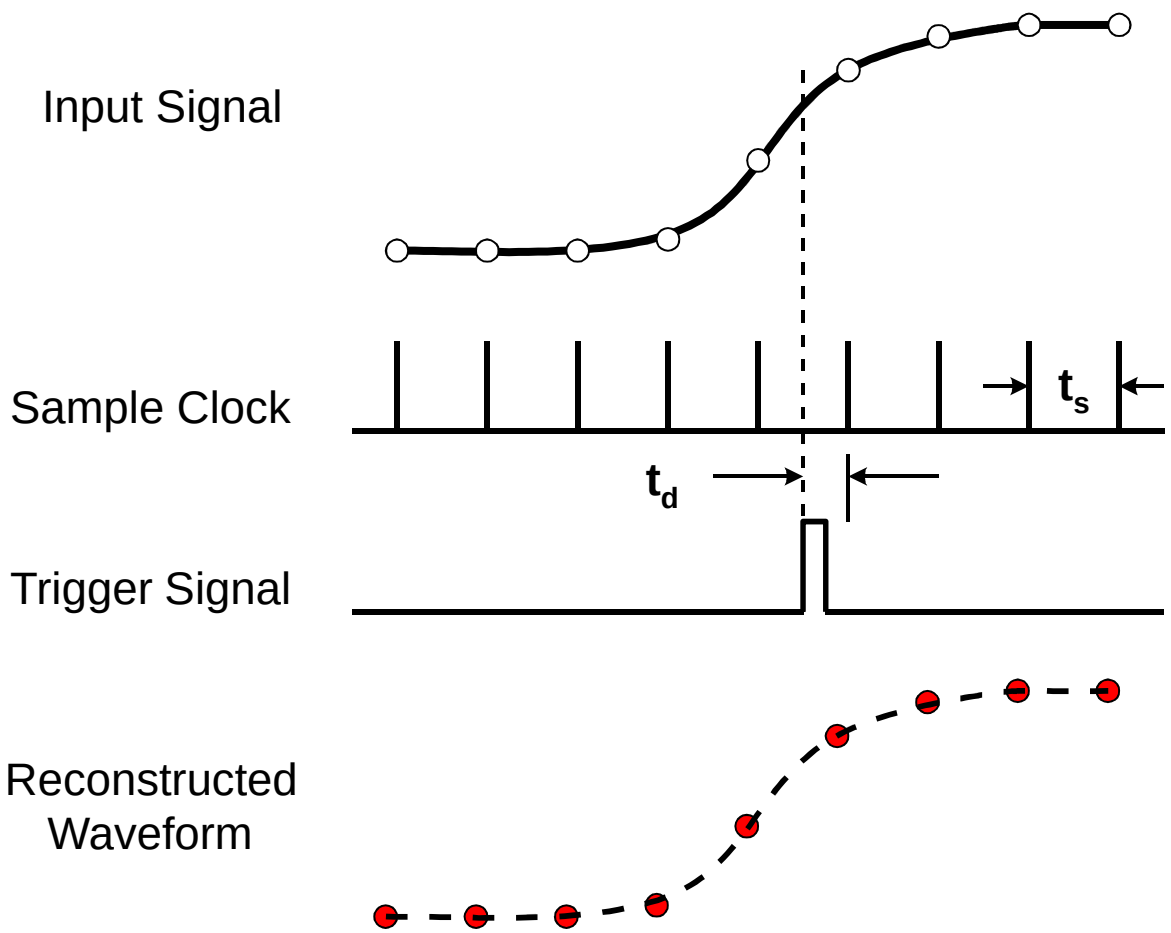
- A: 50 Ohm cable
- B: Launch to microstrip
- C: 50 Ohm microstrip
- D: 75 Ohm microstrip
- E: 50 Ohm microstrip
- F: “open” circuit



Real-Time Oscilloscope

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years



Equivalent Time Oscilloscope

KEYSIGHT TECHNOLOGIES

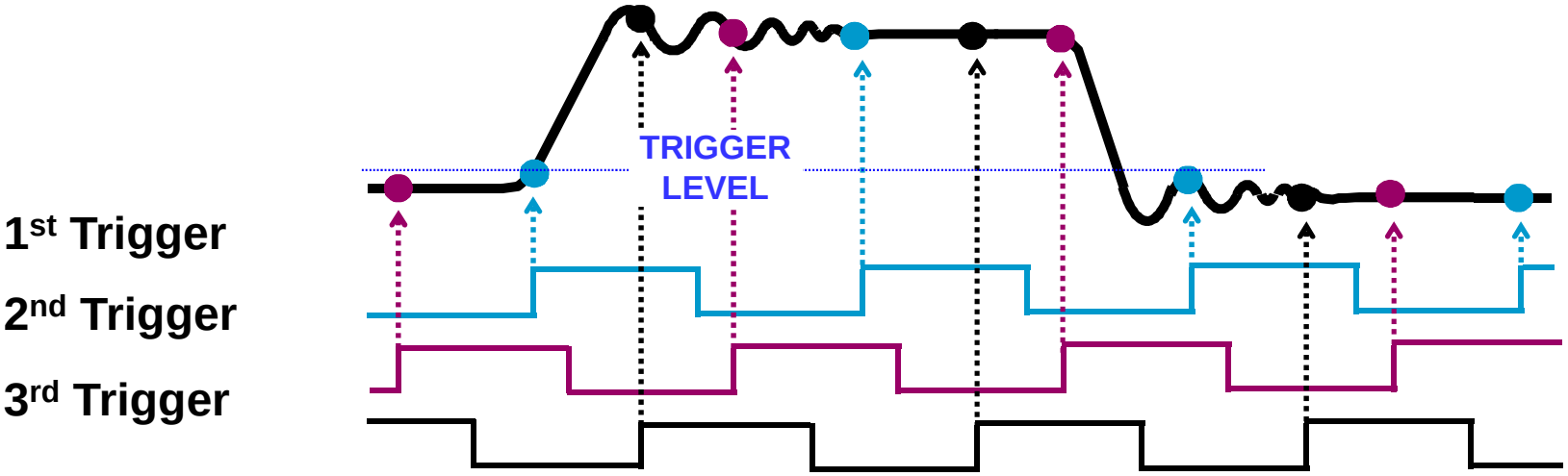
Unlocking Measurement Insights for 75 Years

1) Builds up the waveform over several sweeps

2) samples part of the signal on the first sweep, then another part on the second sweep, and so on….

3) Laces all information together to recreate the waveform

- Useful for high-frequency signals
- Used ONLY with Repetitive Signals! No Glitches will be captured!
- Sample Rate is Not a Major Factor



Equivalent Time (Repetitive) Technique

KEYSIGHT TECHNOLOGIES

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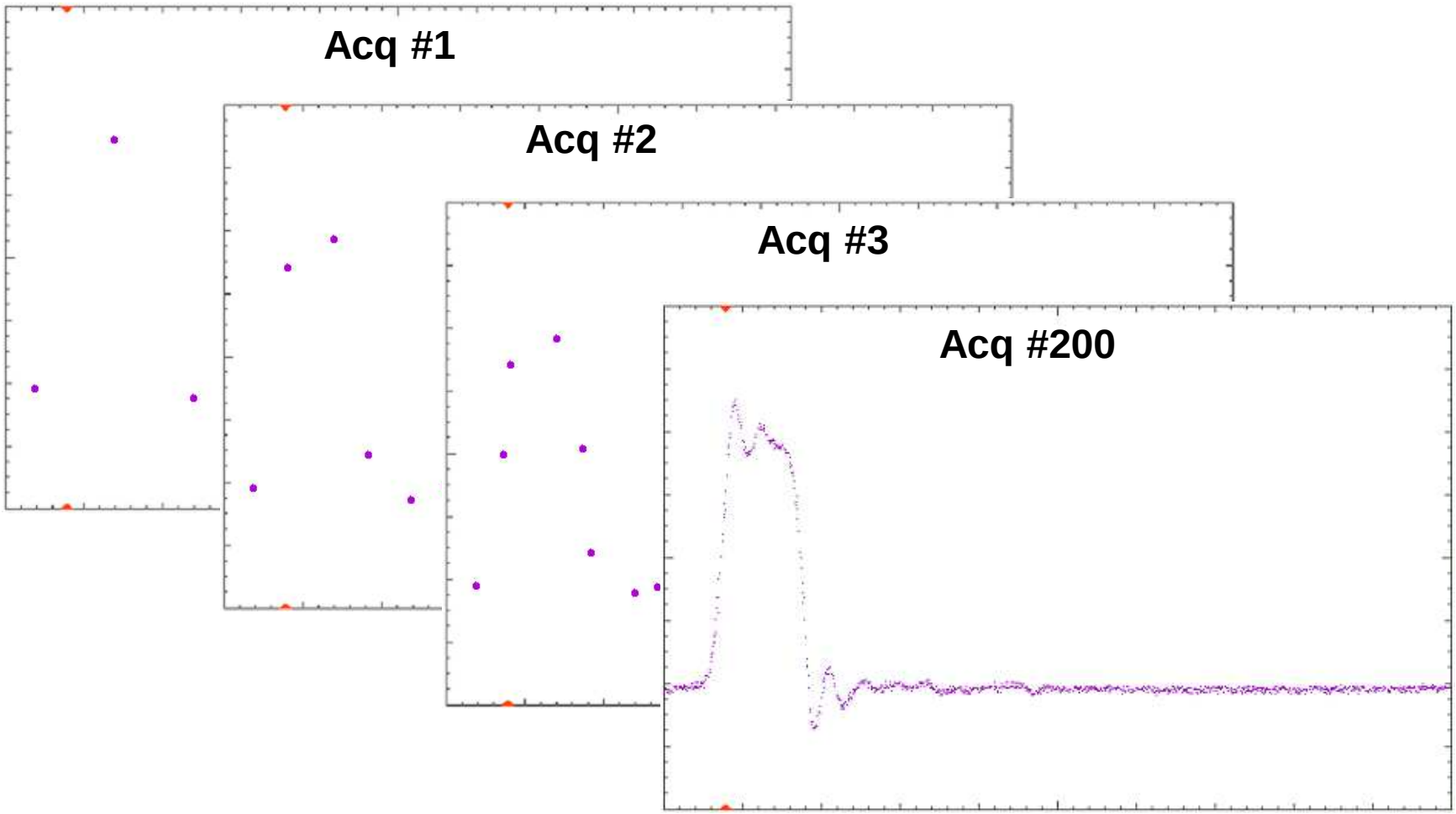
Build Up of Waveform over multiple sample events



TDR – Spatial Resolution

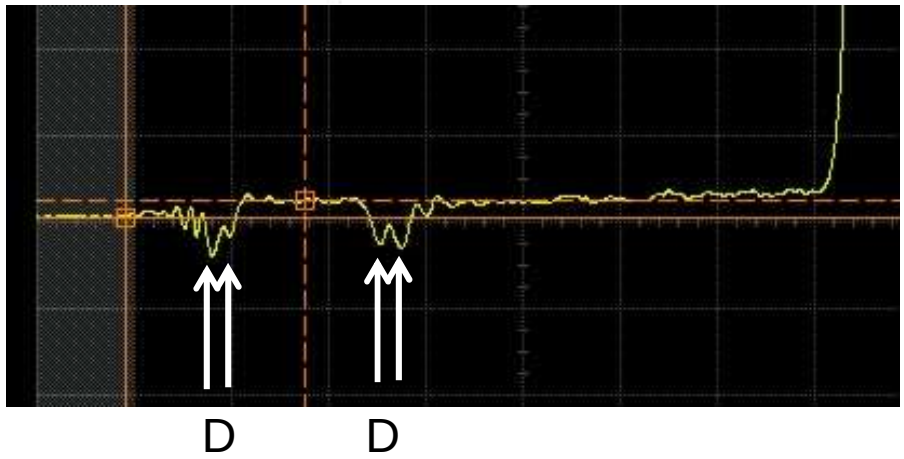
KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years

TDR Resolution

The faster the edge, the closer two impedance discontinuities can be identified as separate events on the TDR trace.

$$D_{min} = \frac{c \bullet t_{rise}}{2\sqrt{\varepsilon}}$$



- $t_{r_{system}} = \sqrt{t^2_{r_{step}} + t^2_{r_{scope}}}$
- Ɛ = dielectric constant of the transmission system
- c = speed of light in a vacuum.

For Ɛ = 4 and system rise time of 8 ps, D_{min} < 1mm.

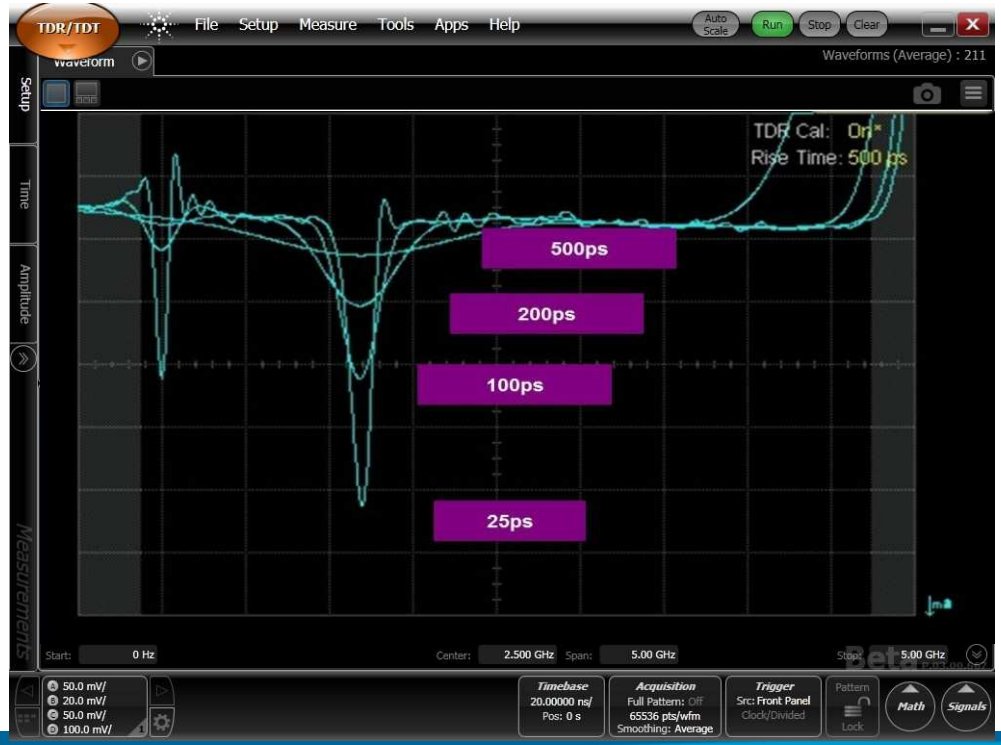
What TDR edge should I use?

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years

Select a solution based on your **application**:

- **Too fast:** you'll see impedance discontinuities that will not affect the real signals in your design (you'll waste time fixing things that do not matter)
- **Too slow:** discontinuities are masked



Time Domain Transmission (TDT)

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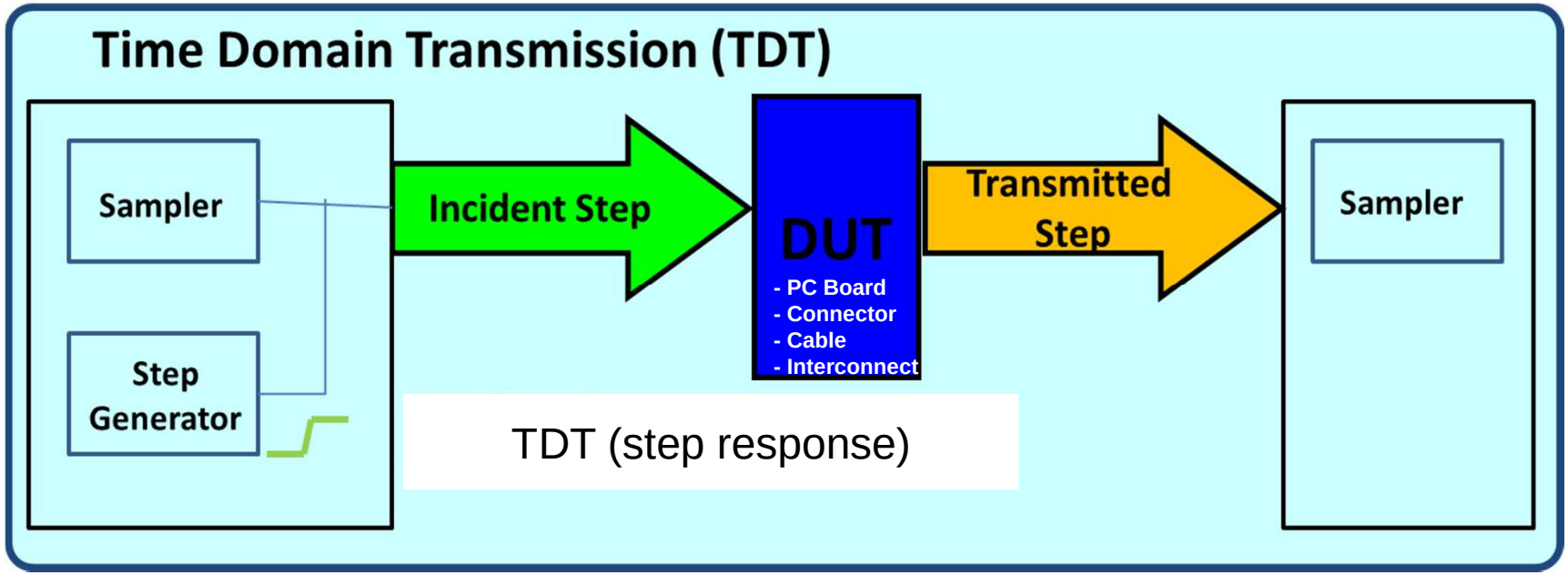


Time Domain Transmission (TDT)

- Step Response
- Propagation/Time delay
- Propagation velocity
- Rise time degradation
- Near-end crosstalk (NEXT)
- Far-end crosstalk (FEXT)
- Skew

AGENDA

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years

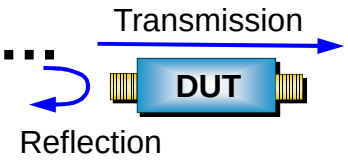
- Introduction / Signal Integrity Definition
- Evolution of Test Parameters
- Traditional TDR/TDT instrument
- **Vector Network Analyzer Basis**
- Single Ended / Differential Topologies
- Physical Layer Test System (PLTS Software)

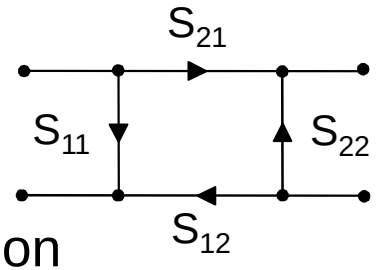
What is Vector Network Analyzer?

KEYSIGHT TECHNOLOGIES

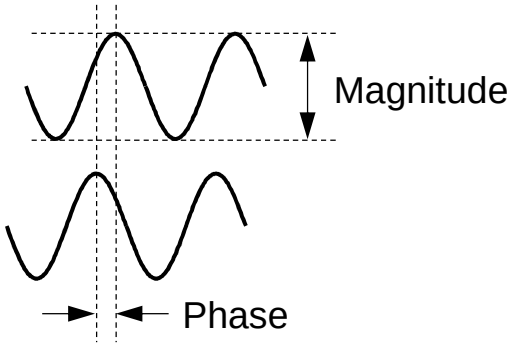
Unlocking Measurement Insights for 75 Years

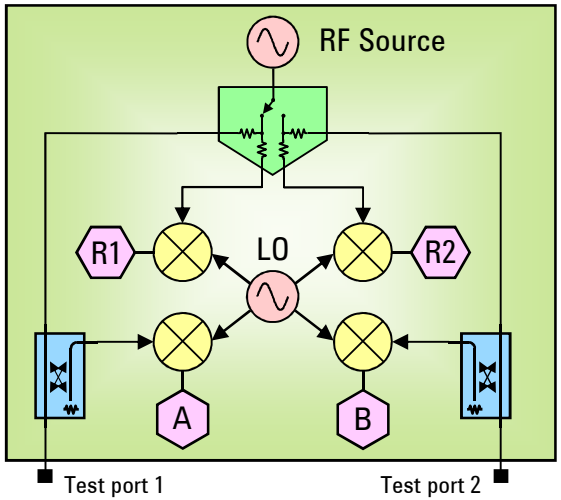
Vector network analyzers (VNAs)…





- Are stimulus-response test systems
- Characterize forward and reverse reflection and transmission responses (S-parameters) of RF and microwave components
- Quantify linear magnitude and phase
- Are very fast for swept measurements
- Provide the highest level of measurement accuracy





Reflection / Transmission Coefficients

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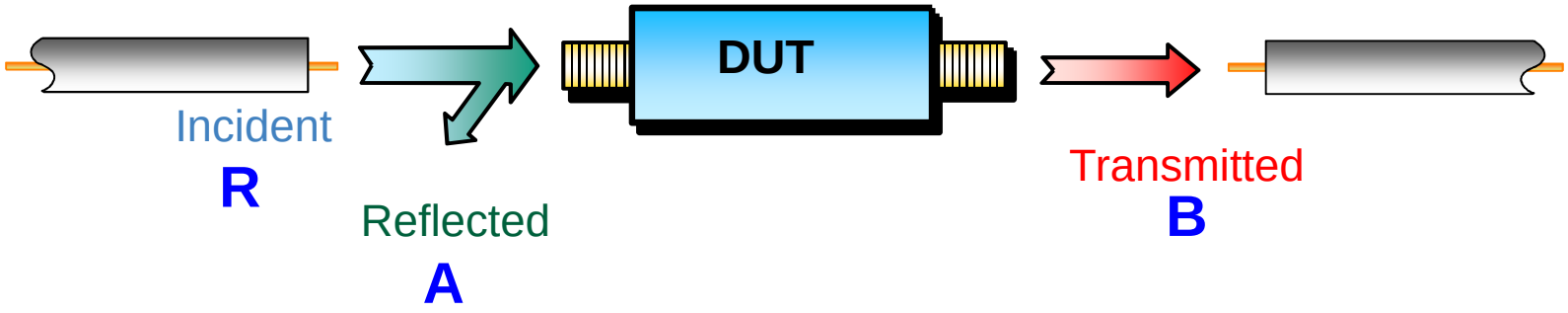
Unlocking Measurement Insights for 75 Years



REFLECTION

$$\frac{\text{Reflected}}{\text{Incident}} = \frac{A}{R}$$

- SWR
- S-Parameters S_{11}, S_{22}
- Reflection Coefficient Γ, ρ
- Impedance, Admittance R+jX, G+jB
- Return Loss

TRANSMISSION

$$\frac{\text{Transmitted}}{\text{Incident}} = \frac{B}{R}$$

- Gain / Loss
- S-Parameters S_{21}, S_{12}
- Transmission Coefficient T, τ
- Insertion Phase
- Group Delay

Signal Integrity vs S-Parameters

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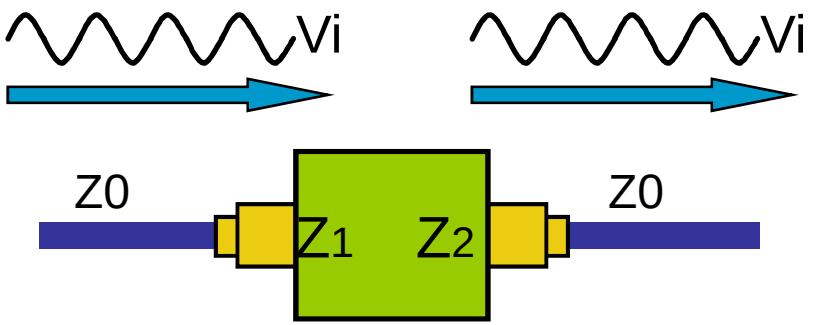
GOOD Signal Integrity



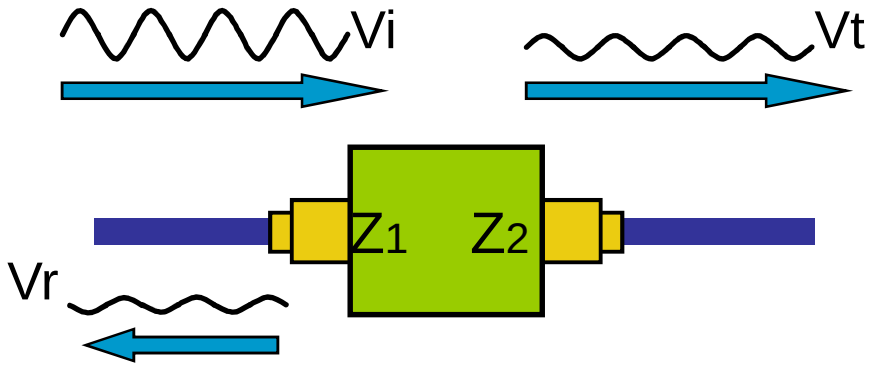
Z1=Z2=Z0

→ Well Controlled Impedance Environment

S11→low reflections

S21→high transmission

POOR Signal Integrity



Z1,Z2≠Z0

→ Impedance Discontinuities Present

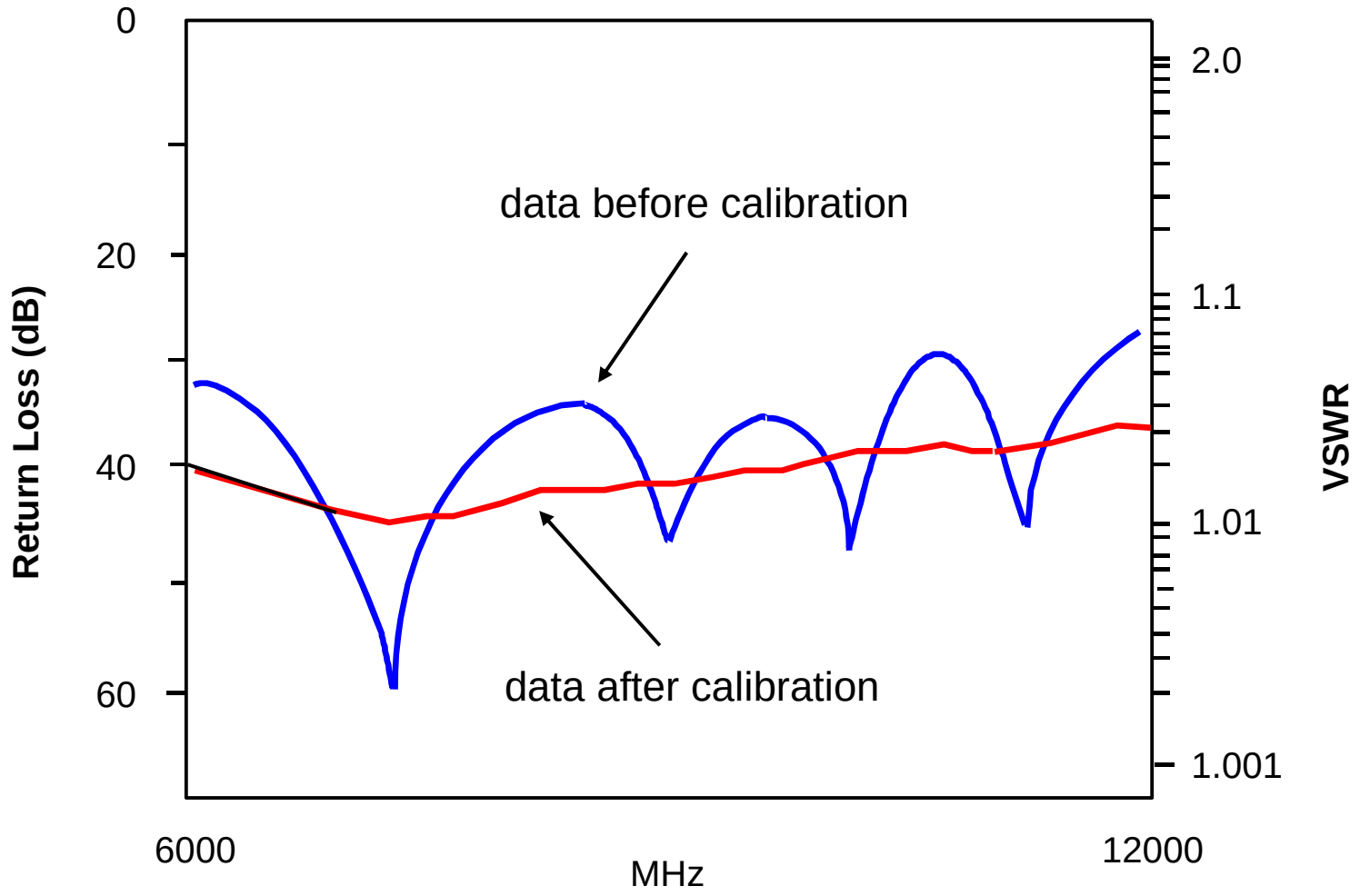
S11→high reflections

S21→low transmission

Importance of Calibration !

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years



AGENDA

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years

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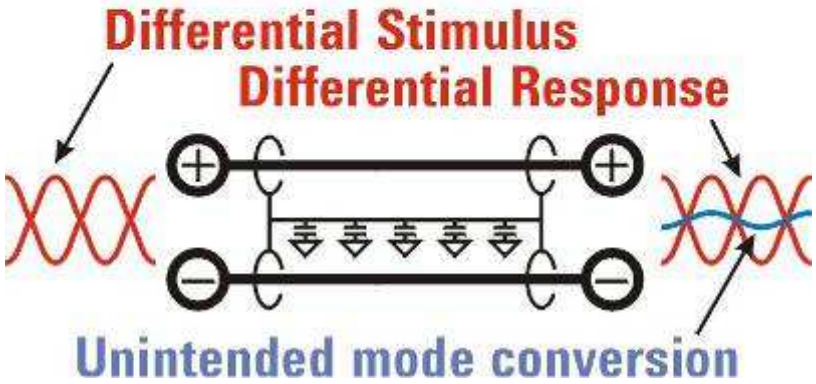
- Physical Layer Test System (PLTS Software)

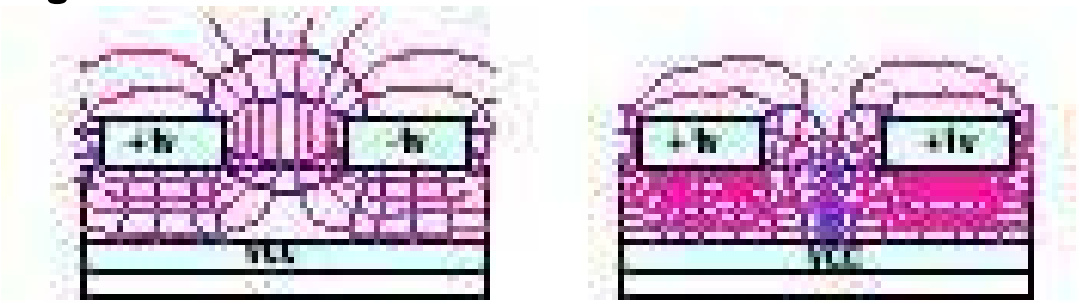
Trend to Differential Topologies

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years

- **Ideal differential devices**
  - Low voltage requirements
  - Noise and EMI immunity
  - Virtual grounding
- **Non-ideal devices are not symmetric**
  - Can be identified by mode-conversions
    - Differential → Common
    - Common → Differential
- **Differential signal integrity design tools are needed**



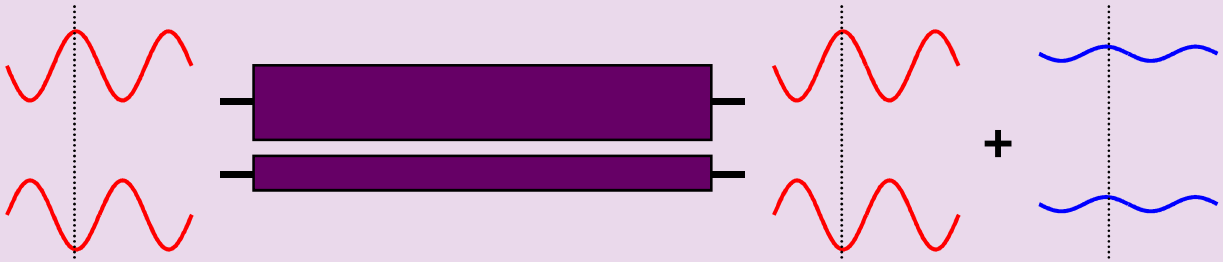


What about non-ideal devices?

KEYSIGHT TECHNOLOGIES

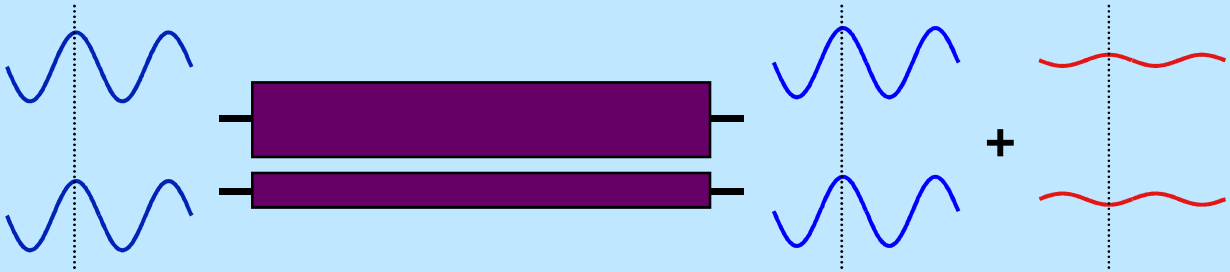
Unlocking Measurement Insights for 75 Years

- **Differential-stimulus to common-response conversion**



Imperfectly matched lines mean the electromagnetic fields of the signals are not as well confined as they should be – giving rise to generation of interference to neighboring circuits.

- **Common-stimulus to differential-response conversion**

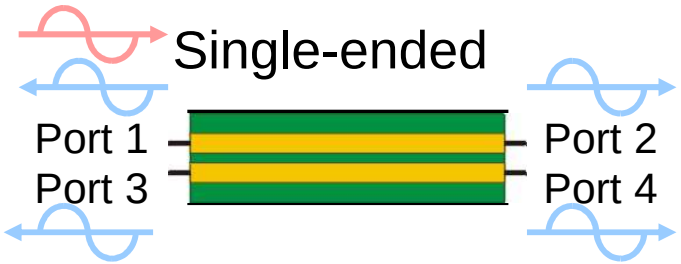


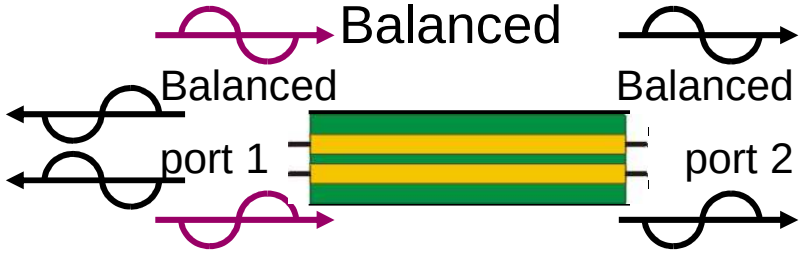
Imperfectly matched lines mean that interfering signals do not cancel out completely when subtraction occurs at the receiver. Measured by stimulating common-mode to simulate interference.

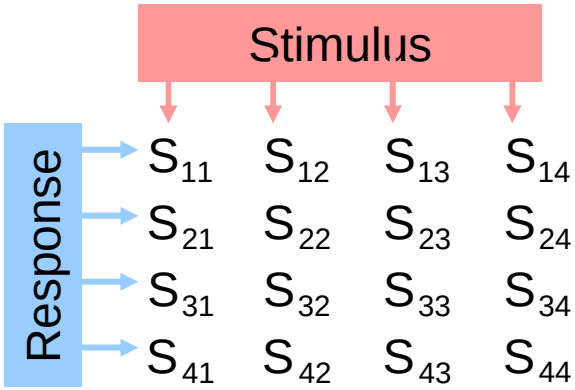
Single-ended to Differential [S]

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years







MATH…

		Differential-Mode Stimulus		Common-Mode Stimulus	
		Port 1	Port 2	Port 1	Port 2
Differential-Mode Response	Port 1	S_{DD11}	S_{DD12}	S_{DC11}	S_{DC12}
	Port 2	S_{DD21}	S_{DD22}	S_{DC21}	S_{DC22}
Common-Mode Response	Port 1	S_{CD11}	S_{CD12}	S_{CC11}	S_{CC12}
	Port 2	S_{CD21}	S_{CD22}	S_{CC21}	S_{CC22}

Naming Convention:

$S_{\text{mode res., mode stim., port res., port stim.}}$

Mixed-Mode S-Parameters

KEYSIGHT TECHNOLOGIES

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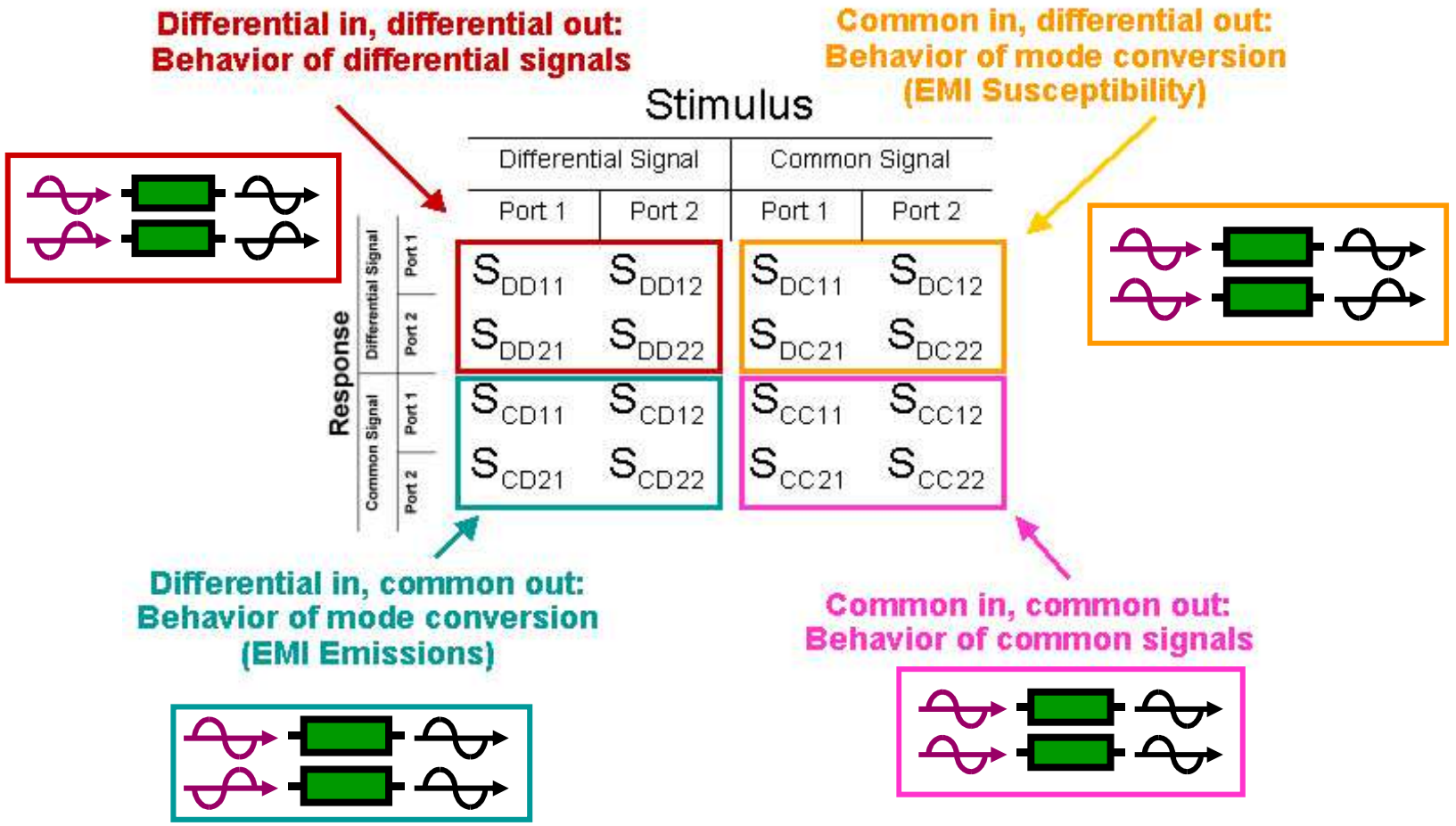

Example S_{CD21}: *Drive port 1 differentially and measure what has been converted to common mode at port 2*

AGENDA

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years

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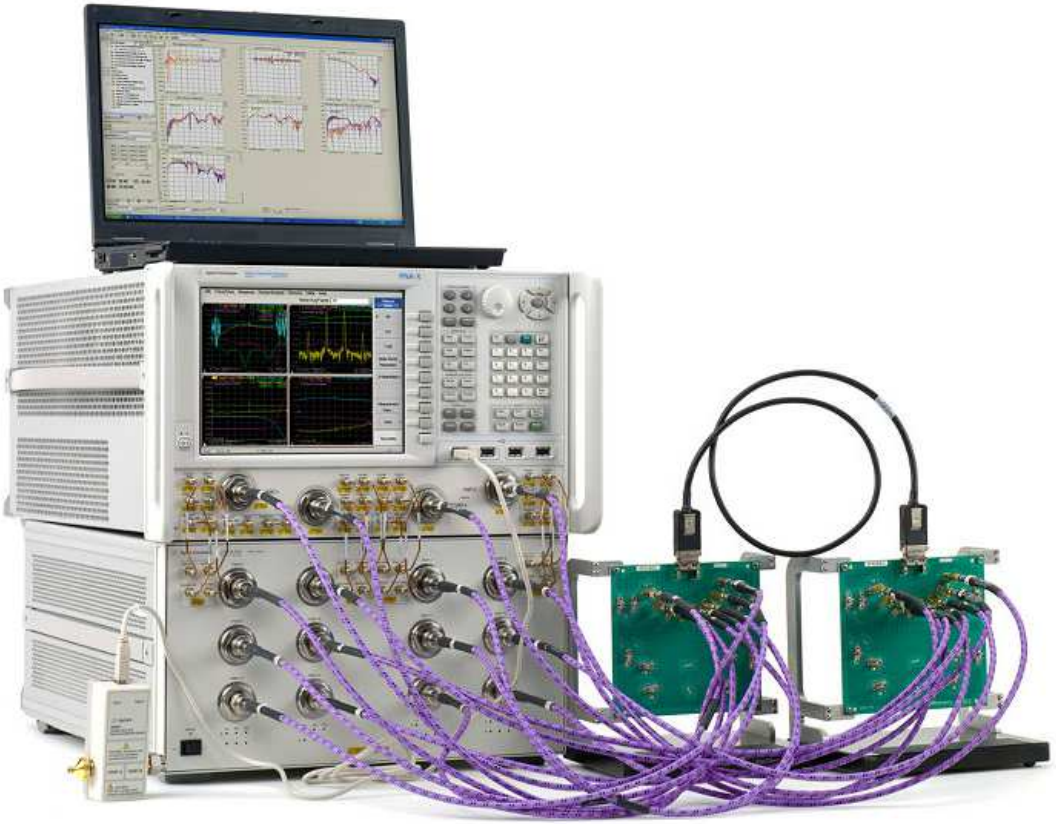
- Single Ended / Differential Topologies
- **Physical Layer Test System (PLTS Software)**

What is PLTS?

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years



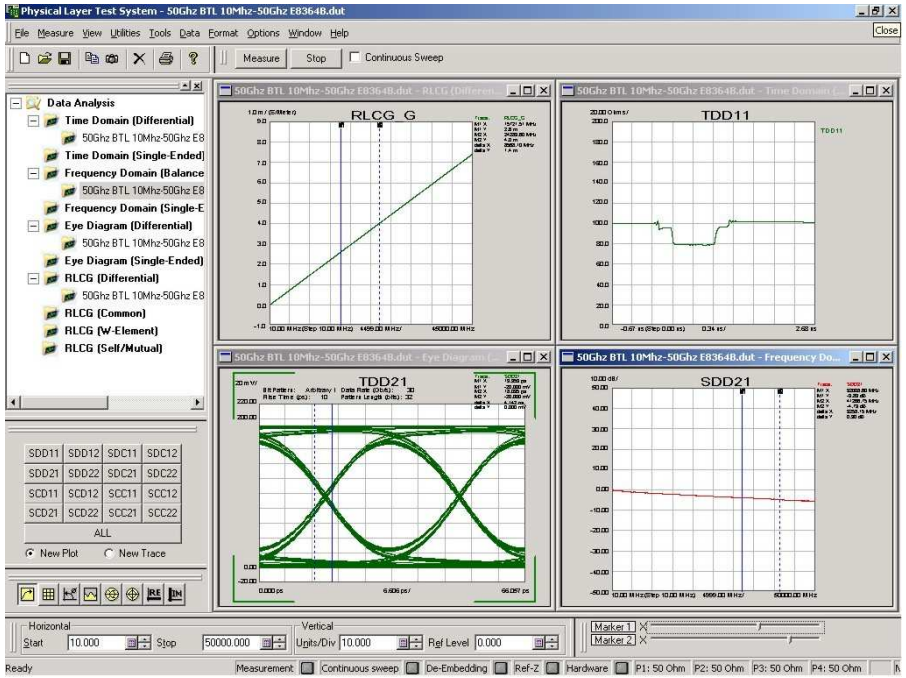
- N1930B - Software Solution
- Industry standard for interconnect analysis
- Calibrate, measure and analyze linear passive devices
- Use either VNA or TDR
- Provides Advanced Calibration Techniques

PLTS: The Ultimate SI Solution

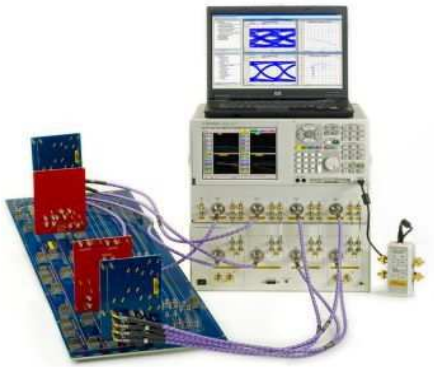
KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years

Agilent Physical Layer Test Systems (PLTS) are the most accurate and comprehensive tools for characterizing high-speed digital interconnects.

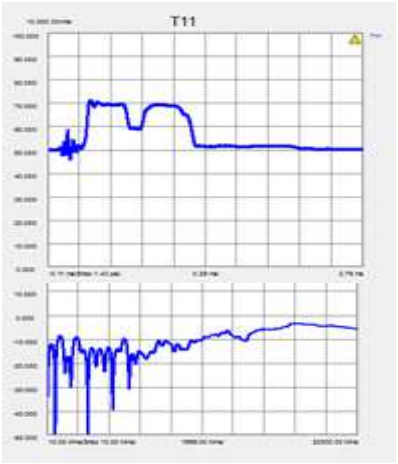


- Reduce development times
- Increase performance margins
- Improve signal quality
- Reduce EMI emissions/susceptibility
- Improve models for simulation
- Develop more competitive products



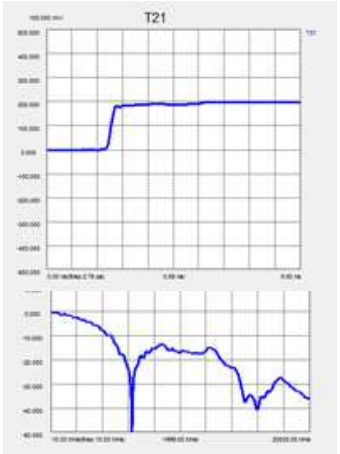
N1930B Physical Layer Test System (PLTS)

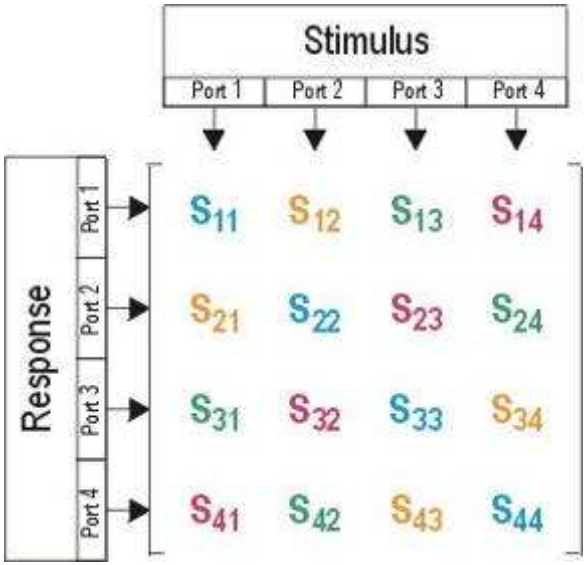
TDR/TDT and S-Parameters



Tremendous insight together.

Four-port single-ended device





Return Loss or TDR

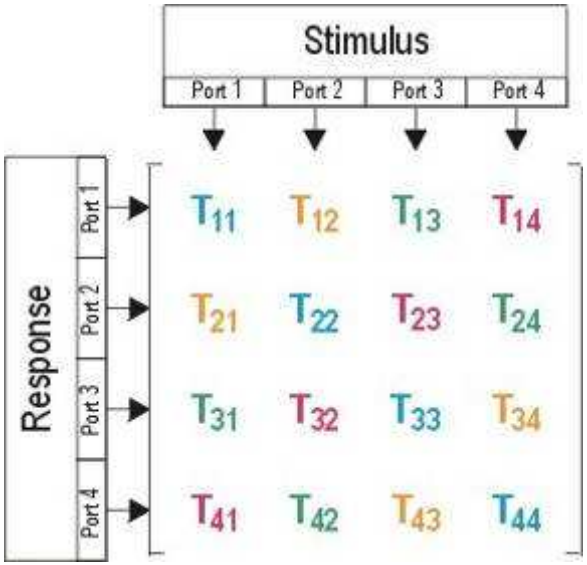
Insertion Loss or TDT

Near End Crosstalk (NEXT)

Far End Crosstalk (FEXT)

← FFT —

— IFFT →



Frequency Domain Parameters

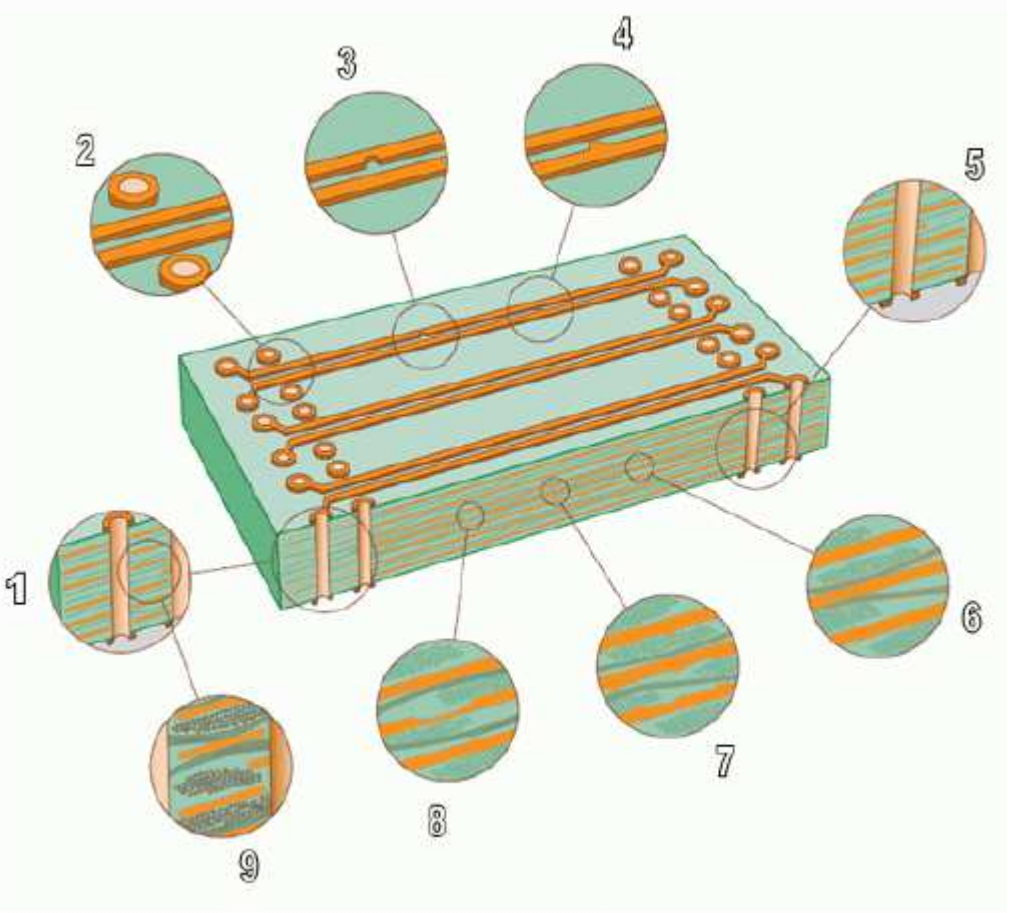
Time Domain Parameters

Find out what's causing impedance discontinuities on your PCB

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years

1. Parasitic capacitance in through hole
2. Localized crosstalk
3. Localized changes in conductor width
4. Localized changes in conductor spacing
5. Reflections due to via stub
6. Non-uniform dielectric
7. Dielectric constant variation
8. Surface treatment thickness non-uniformity
9. Localized changes in foil thickness

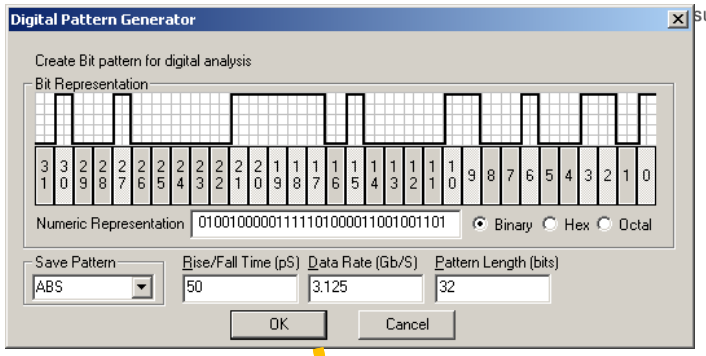


PLTS Eye diagram

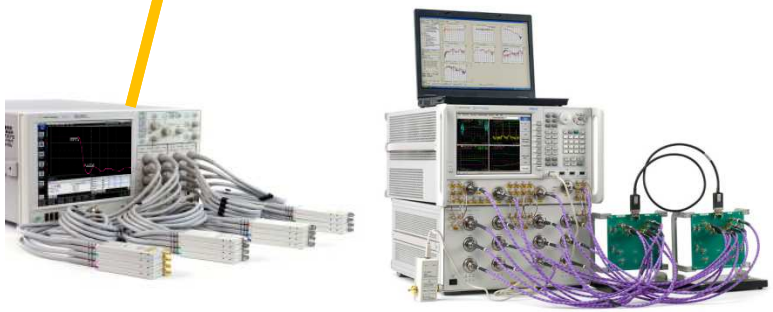
KEYSIGHT TECHNOLOGIES

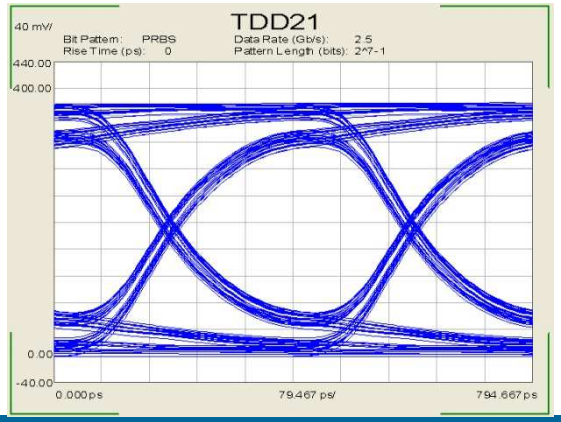
surement Insights for 75 Years

PLTS
Virtual Pattern Generator



Measured Data (TDR or VNA) → Impulse Response → Convolution → Eye Diagram





PLTS RLCG Model Extraction

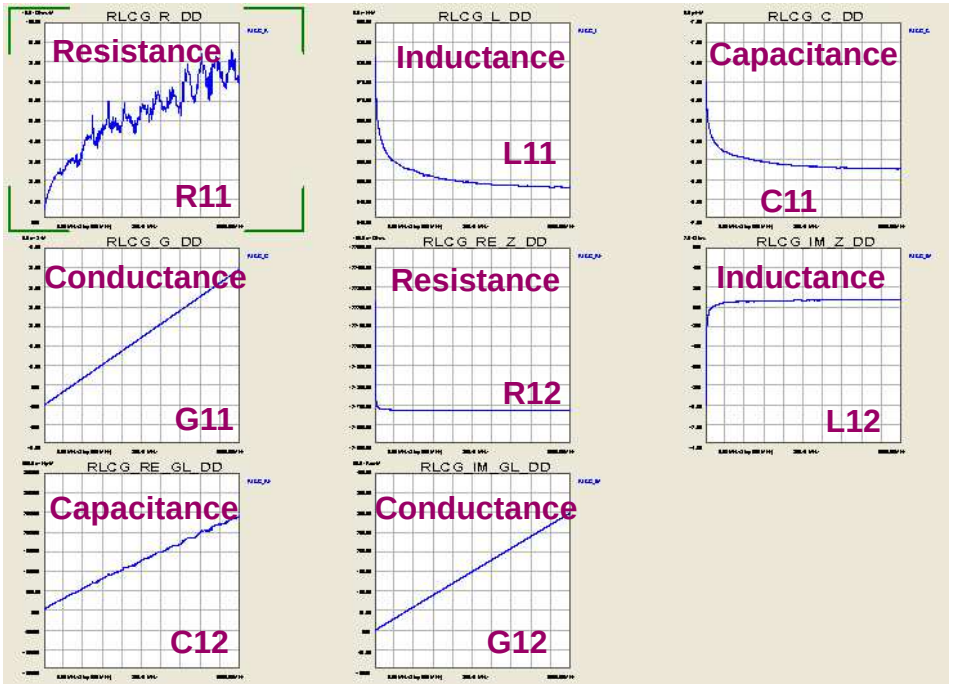
KEYSIGHT TECHNOLOGIES

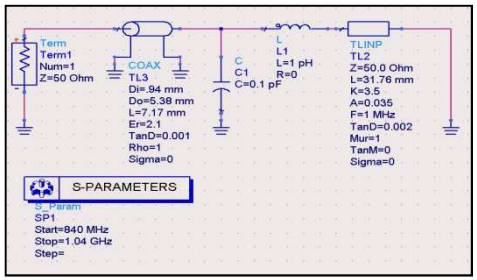
Unlocking Measurement Insights for 75 Years

RLCG models describe electrical behavior of passive transmission lines in an equivalent circuit model

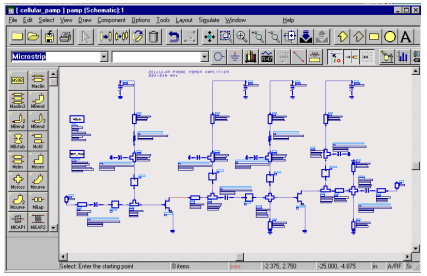
PLTS creates highly accurate, measurement-based coupled transmission line model

PLTS can export into modeling and simulation software such as Agilent ADS, Synopsis HSPICE, and TDA Systems Iconnect





Transmission line RLCG model



ADS schematic

Demo: PLTS

KEYSIGHT TECHNOLOGIES

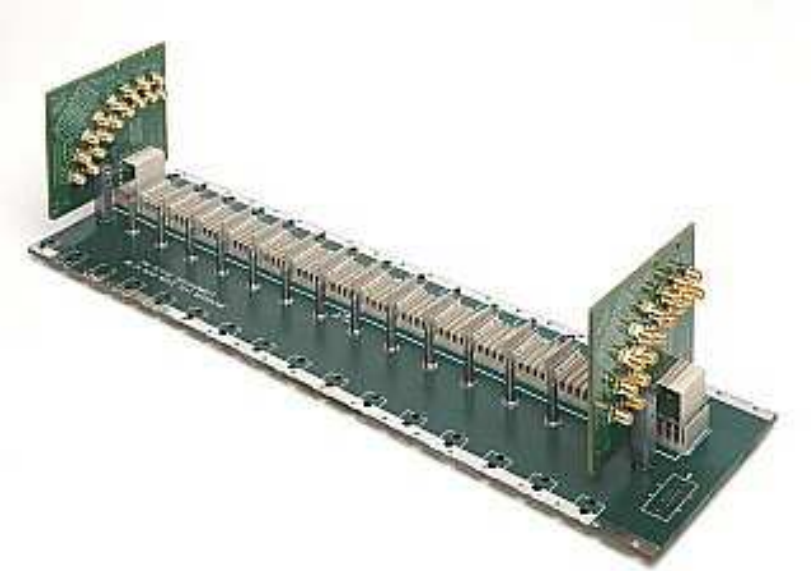
Unlocking Measurement Insights for 75 Years

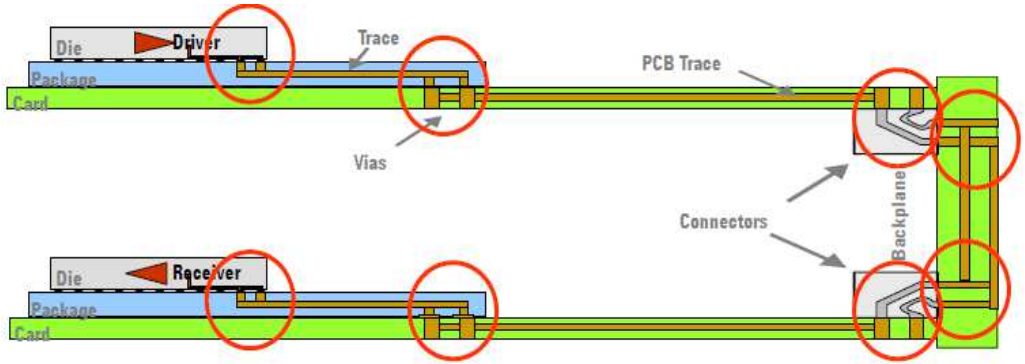
XAUI Backplane Interconnect

The XAUI is designed as an interface extender, and the interface, which it extends, is the XGMII, the 10 Gigabit Media Independent Interface.

Differential Topology, Data Rate = 3.125Gbps , rise time = 60ps

Want to know more about XAUI?... http://cp.literature.agilent.com/litweb/pdf/5988-5509EN.pdf





Non Coaxial Challenge

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years

Signal Integrity devices do not have coax connecters

- Packages, high speed differential connectors, traces, cables, backplanes, etc

Many RF devices are fixtured for measurements

There are two choices (both can give good results):

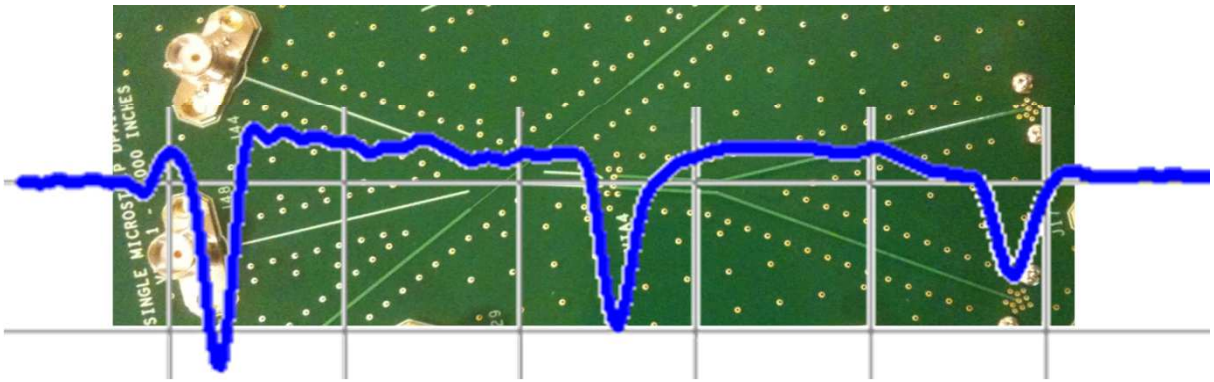
- **Probe your device**
  - Expensive, probing expertise required, can be difficult
- **Build a Fixture for your device to get to coax**
  - How to remove your fixture effects when they can't be ignored?

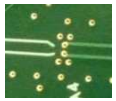
The Problem…

KEYSIGHT TECHNOLOGIES

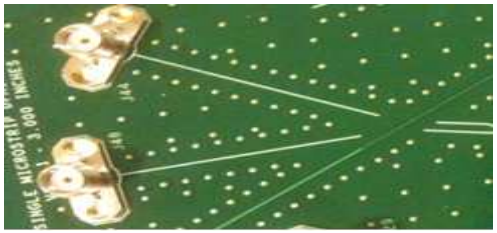
Unlocking Measurement Insights for 75 Years

What I want to measure is embedded in the middle of a bunch of interconnect I don't care about





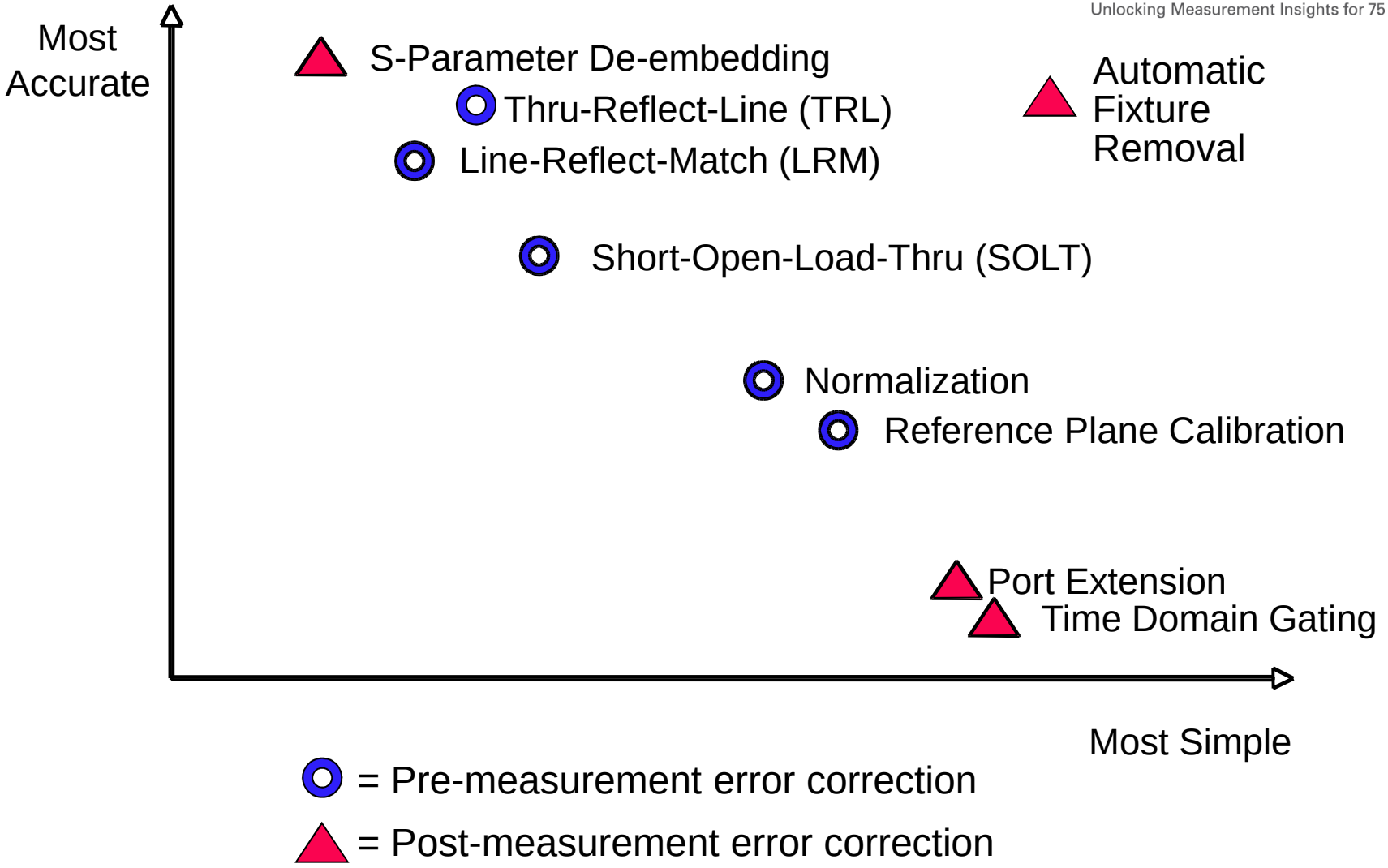
I just want the via structure, or the connector, or the cable, or the interface, or the uniform trace,…



Error Correction Techniques

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years



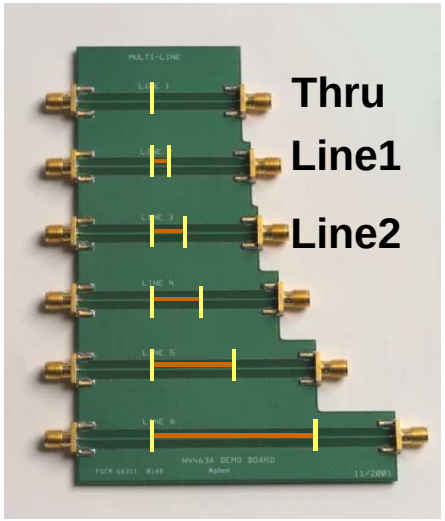
The Solution…

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years

Traditional Calibration

- SOLT
- TRL (thru, reflect, line)
- LRM (line, reflect, match)



De-embedding using

- Measured text fixtures
- Calculated test fixtures by 3D full wave field solver
- Calculated text fixtures by approximation (port extension)

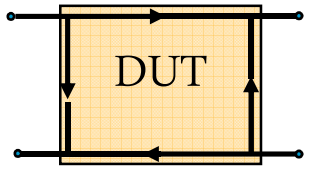
The new way: really simple, **automatic fixture removal (AFR)**

De-Embedding “Automagically”

KEYSIGHT TECHNOLOGIES

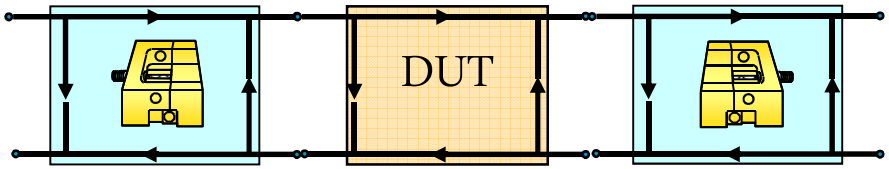
Unlocking Measurement Insights for 75 Years

What we want: DUT performance



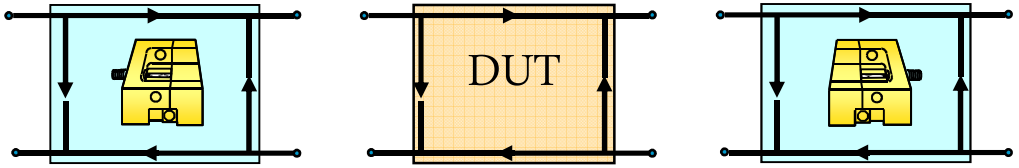
S_D

What we measure: composite measurement of DUT and fixtures



S_A S_D S_B

With the separate fixtures’ S-Parameters, we can de-embed the DUT alone from the composite measurements



S_A S_D S_B

The challenge: *getting the S_A and S_B de-embed files*

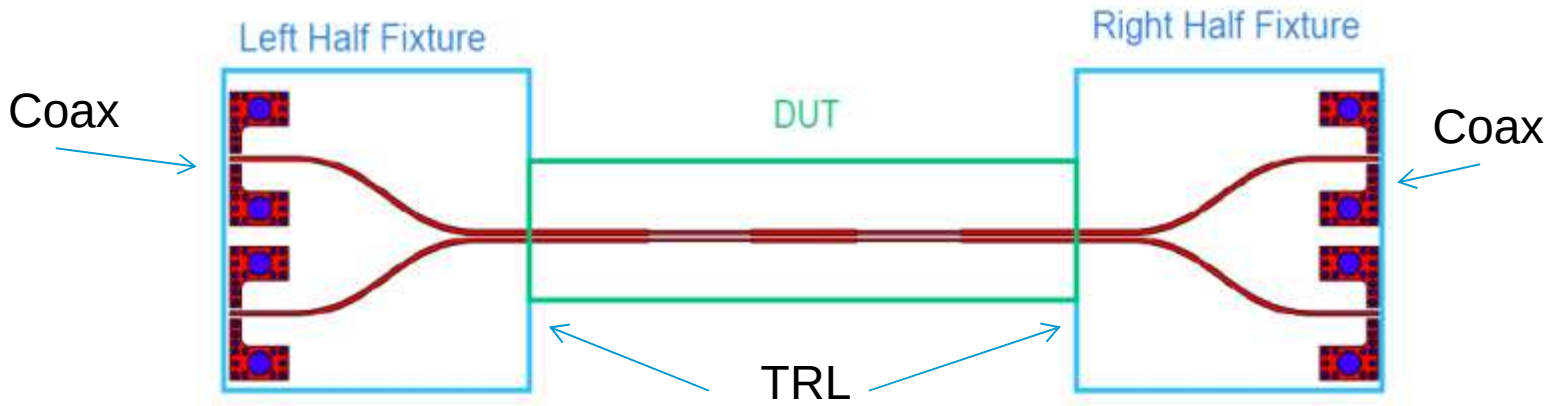
Removing Fixtures

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years

Historically – 2 methods:

- Model fixture using EM Simulation and de-embed the fixtures from the measurement
- Use a TRL calibration technique to move measurement reference planes to the DUT.



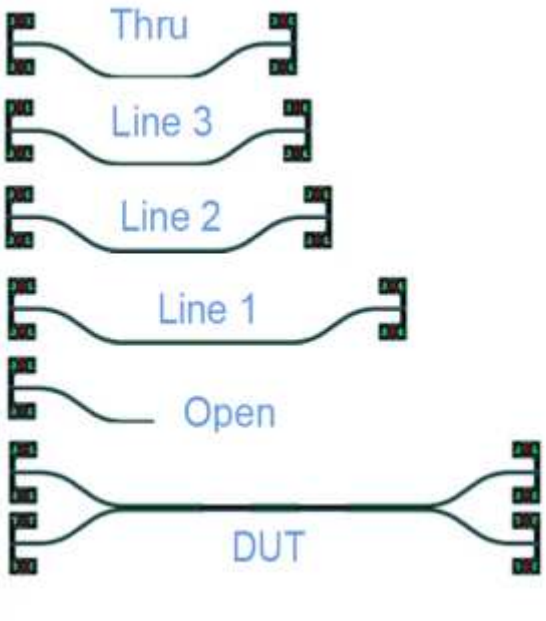
TRL (Single Ended)

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years

Assumptions for single ended TRL

- Connectors and launches are identical
- All lines have same Transmission Line characteristics
  - Impedance, loss, propagation
  - Only differ in length
- Lines are usable 20 to 160 degrees relative to thru
- No coupling in fixture is removed
- Usually 2-4 lines depending on frequency range



Differential Cross Talk Calibration

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years

4-port TRL Calibration Technique

Fixture may be asymmetric

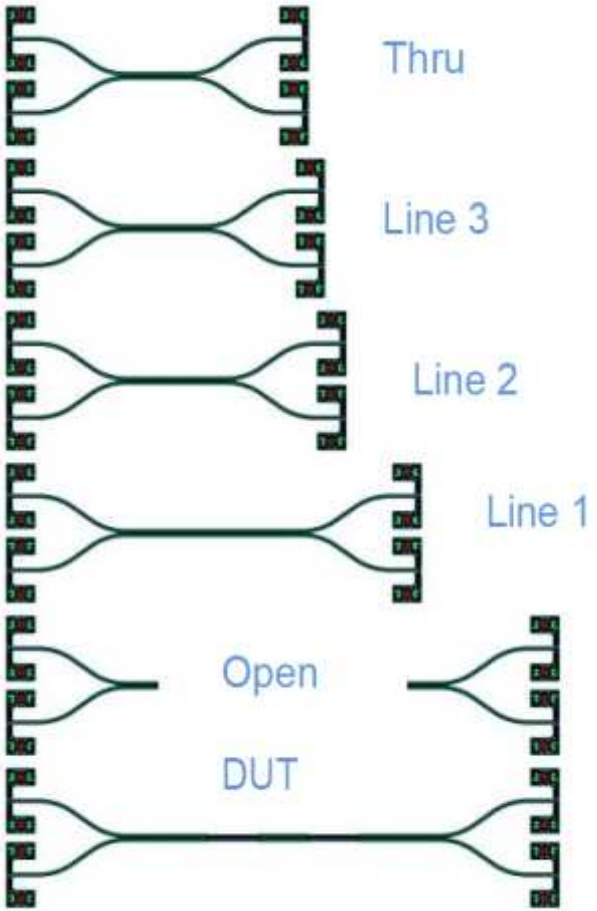
Similar assumptions to single ended TRL

- Repeatability of connector, launch, and line
- lines are usable 20 to 160 degrees relative to thru

Additional differential constraints

- SDCnm and SCDnm < -30 dB
- Skew between lines < 10 degrees

Coupling in fixture is removed



Design/ Verify in PLTS your TRL calkits

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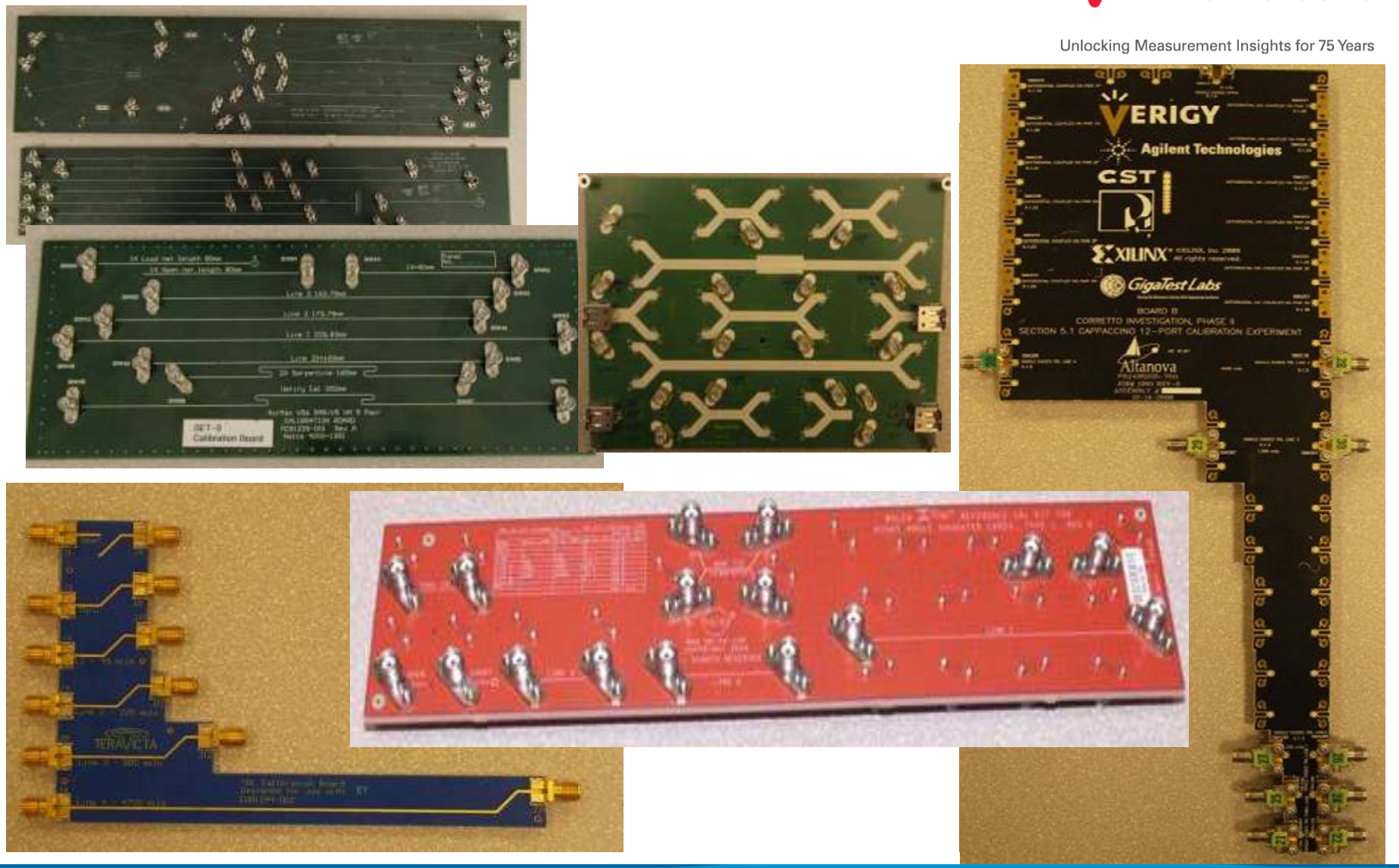

Automatic Fixture Removal !!!

KEYSIGHT TECHNOLOGIES

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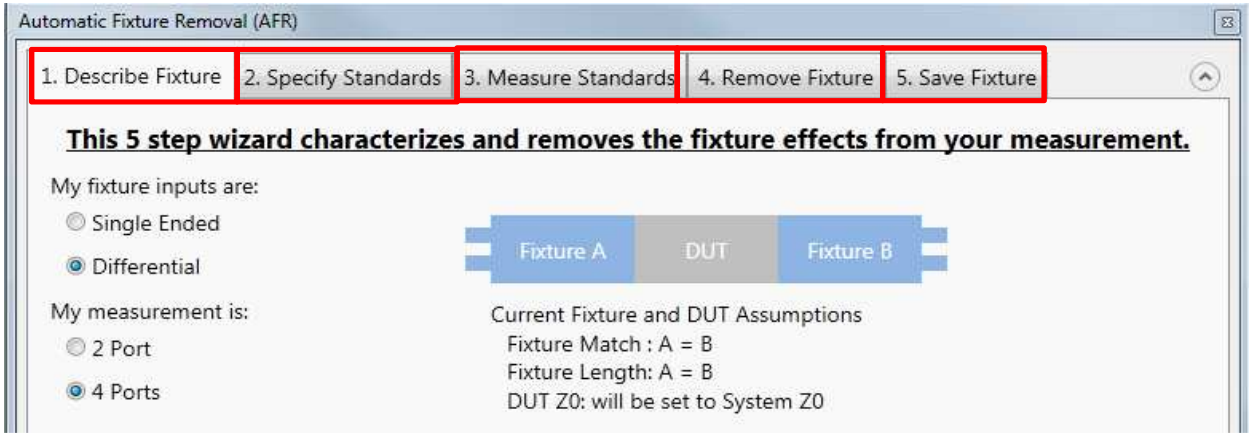
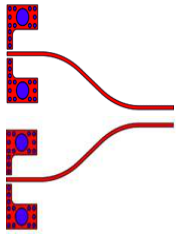
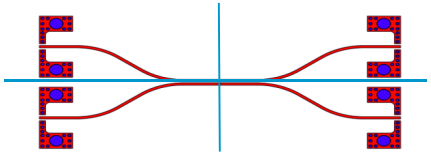
New 5 Step Wizard makes it easy to define your fixture and remove it from your measurement.



Open or Short



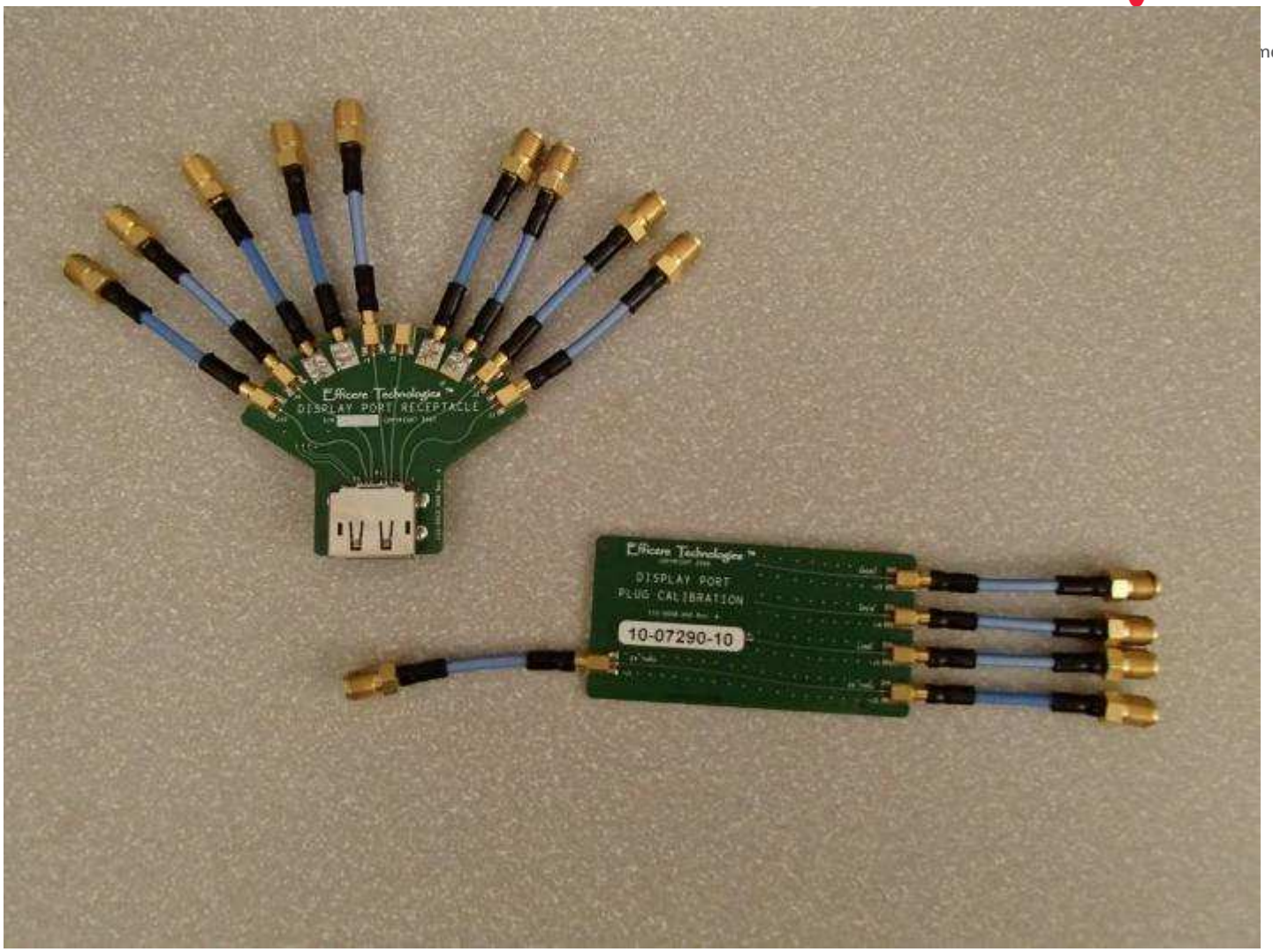
2xTHRU



Cable Fixtures – Display Port

KEYSIGHT TECHNOLOGIES

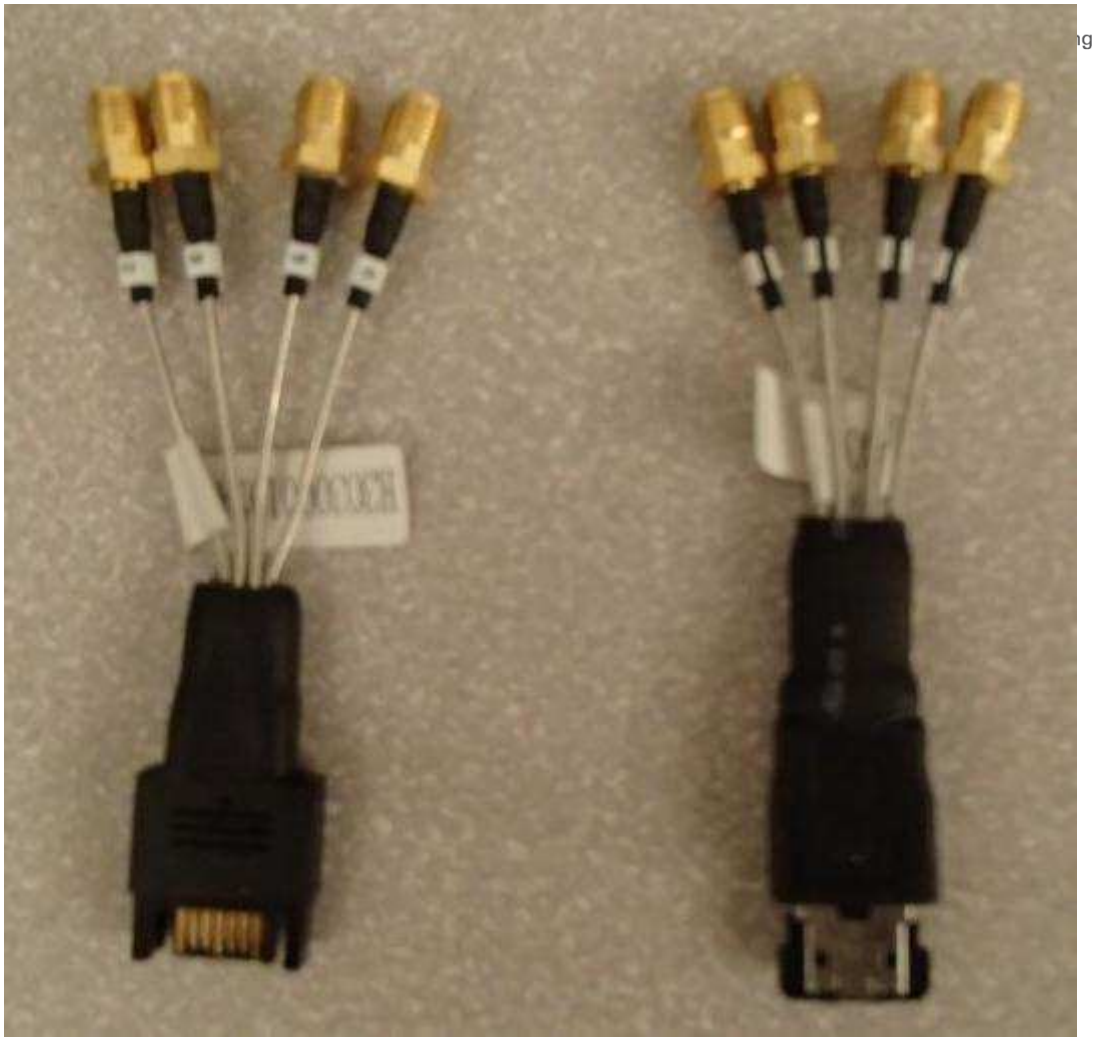
ment Insights for 75 Years



Cable Fixtures – SATA

KEYSIGHT TECHNOLOGIES

ng Measurement Insights for 75 Years



Cable Fixtures – HDMI

KEYSIGHT TECHNOLOGIES

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Cable Fixtures – Bullseye Connector Fixture

KEYSIGHT TECHNOLOGIES

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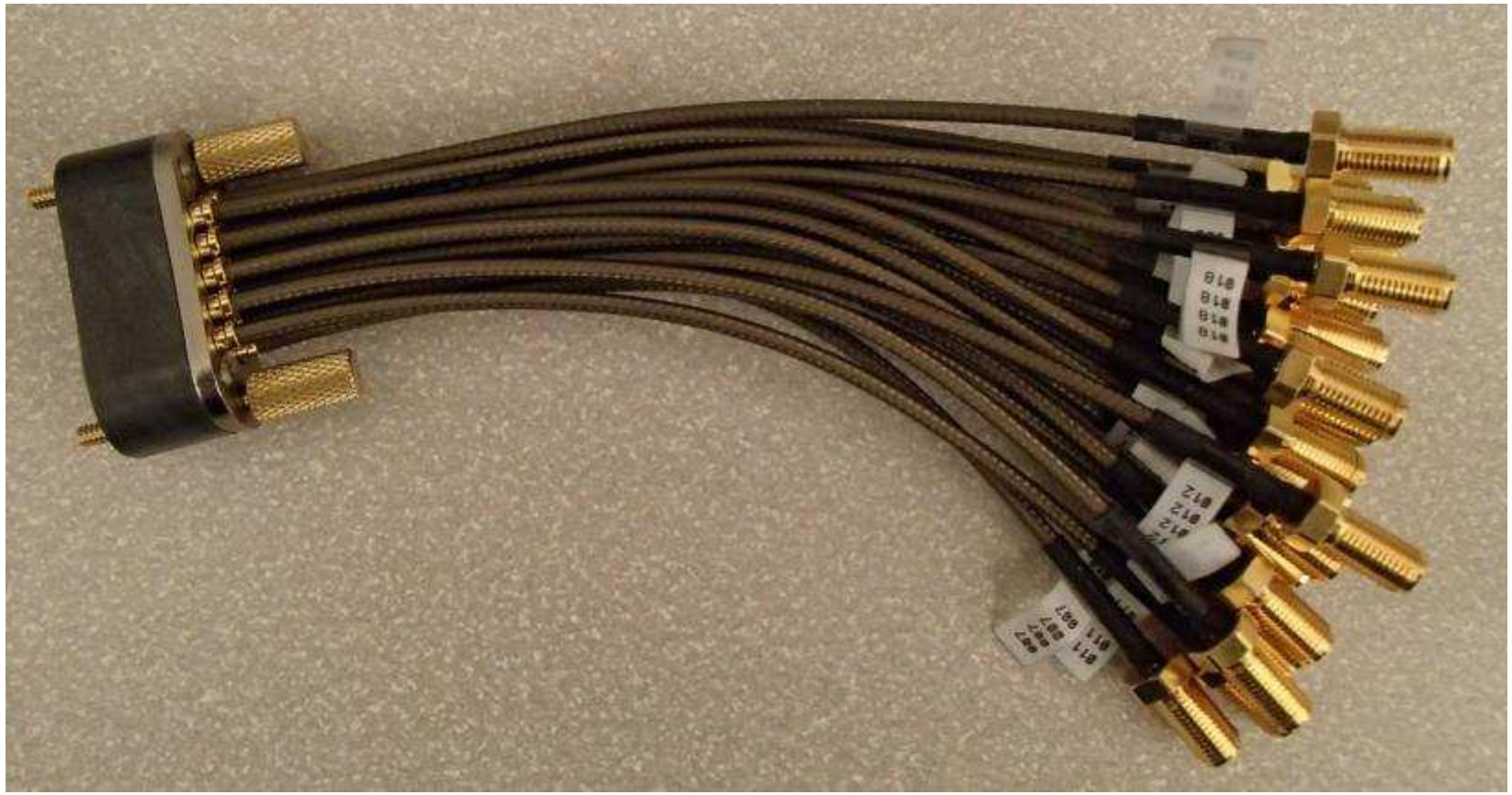

Demo: PLTS-AFR

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years

One-Port Automatic Fixture Removal