Advances in VNA-based Signal Integrity Tools and Techniques

Greg Bonaguide
National AE – Components
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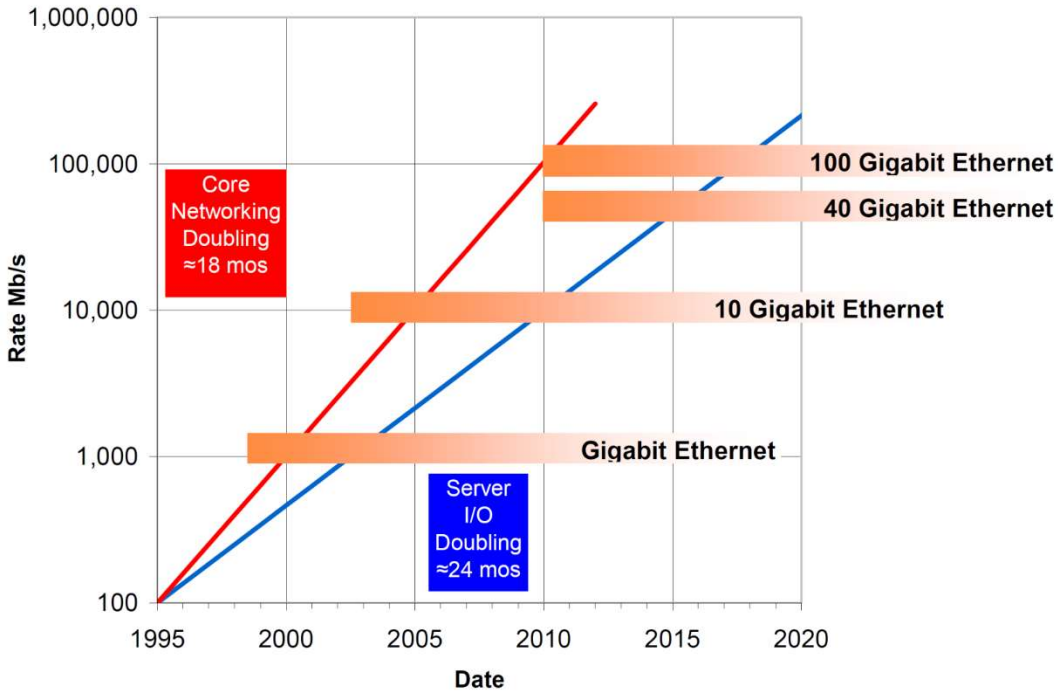
ROHDE&SCHWARZ

Outline

- Technology Driver: Data Rates
- Improving measurement technology for SI applications
  - De-embedding methods
  - De-embedding tools

Data Rate Trajectory

- LTE success driving wired communicating networks
- Amount of data generated has exploded
- Core network capacity doubles every 18 months
- Server I/O doubles every 24 months
- 100 GE is currently deployed



Double Data Rate with PAM4

PAM4 example

- 4 discrete levels (symbols)
- 2 bits per symbol

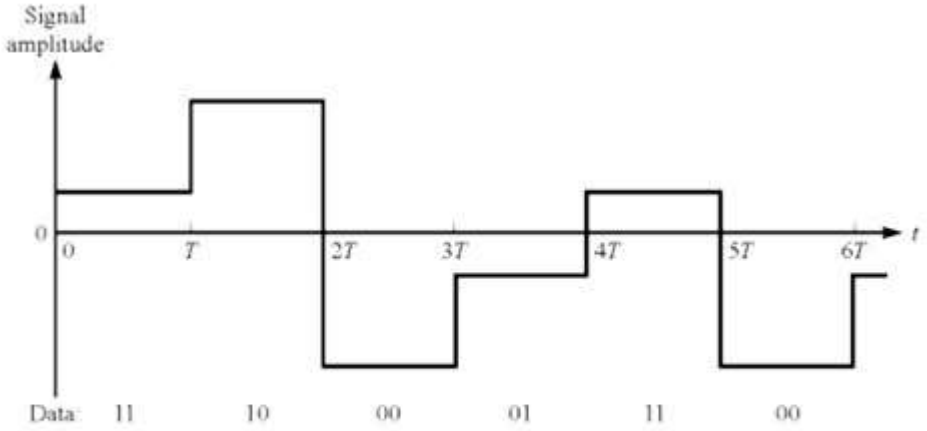
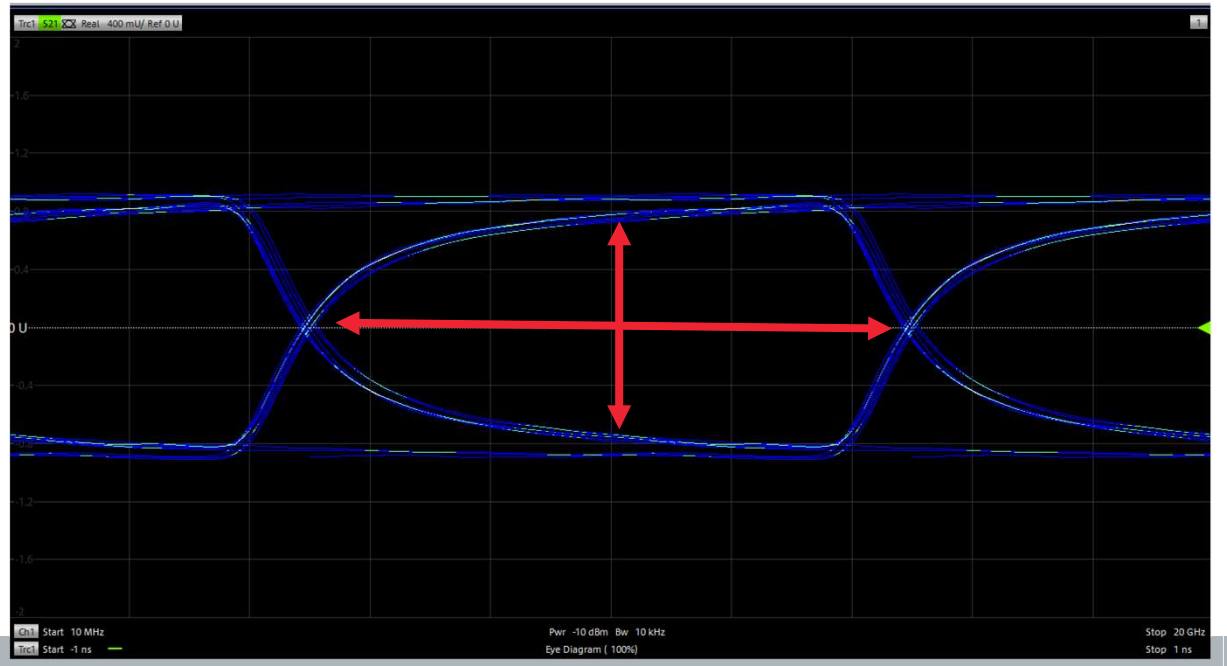


Fig.1 A PAM-4 signal in time domain, T= symbol period.

What is an Eye Diagram?

- Overlay of a bit sequence of a digital signal
- Look at 21-bit sequence ”010101101001110010111”

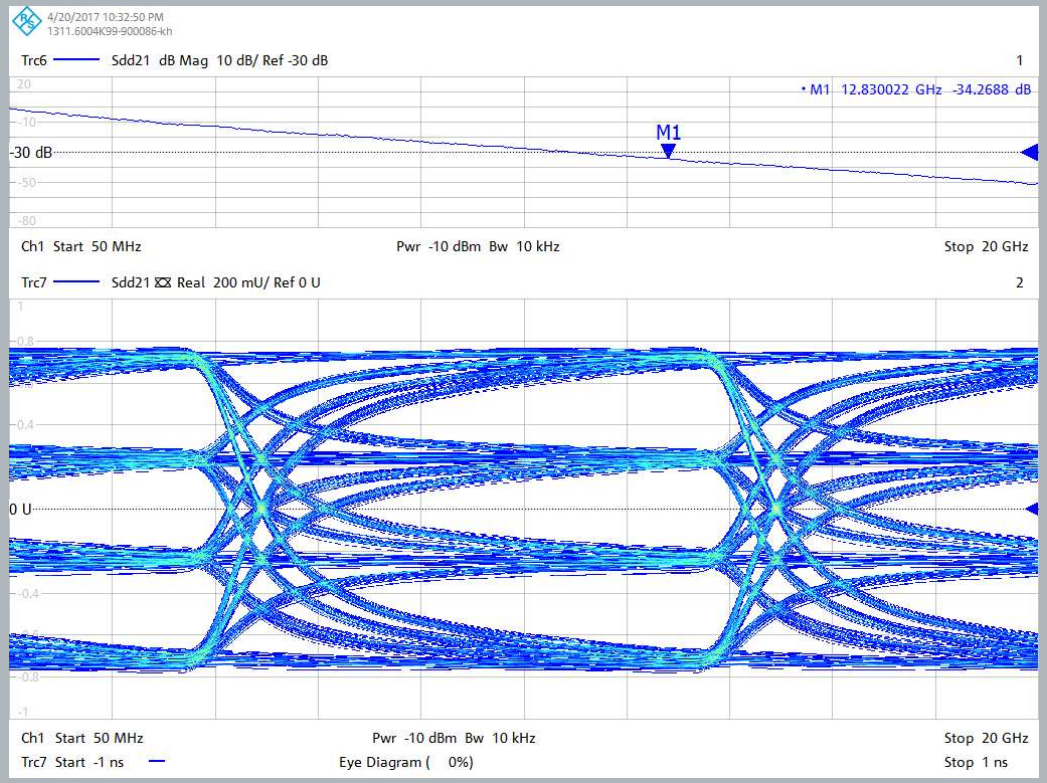
Bit 1
Bit 2
Bit 3
Bit 4
Bit 7
Bit 21



Eye Height

Eye Width

PAM4 Measurement



Comparison of PAM4 vs. NRZ

- Advantages:
  - Requires ½ bandwidth of NRZ
- Challenges:
  - 1/3 eye height of NRZ
  - ½ to 1/3 eye width of NRZ
  - Eye levels are asymmetric
  - More sensitive to ISI than NRZ
  - More sensitive to reflection than NRZ
  - More sensitive to crosstalk than NRZ
  - Much more sensitive to intra-pair skew than NRZ
  - More sensitive to nonlinearities than NRZ

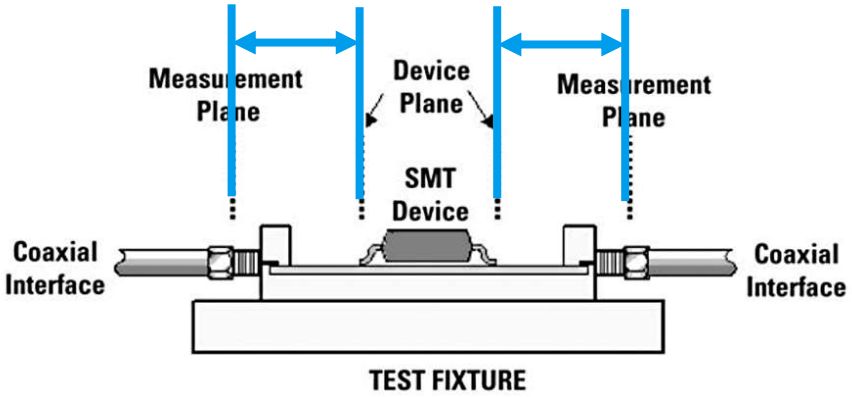
Accurate Channel characterization in crucial for PAM4 signaling

Improving measurement technology for SI applications

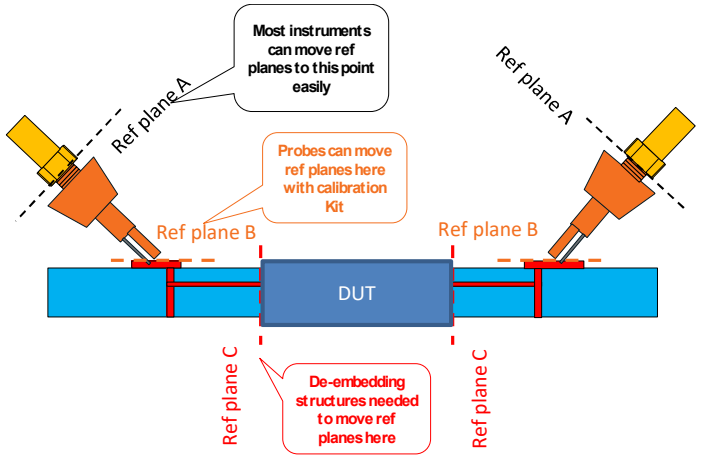
- SI Measurement Objective is similar to ANY VNA Measurement Objective:
  - Measure ONLY the DUT
    - Remove reflections
    - Remove extraneous loss
    - Remove extraneous phase shift/rotations
  - Focus on Ease of Use…

Problem Description: Device Performance

How do you measure this?



- Is the left side = right side?
  - Different length
  - Skew (glass weave skew)?
  - Manufacturing tolerances?
- Is the material the same over the whole PCB
  - Glass/fiber weave effect



Concept of test coupon

- Add test coupon to characterize trace
  - Either on the same board
  - External board but same material
  - External board and different material
- Typical calibration standards
  - TRL calibration standards
  - 2x through
  - 1x through
  - Other reference traces
- Advanced de-embedding methods
  - Can handle coupon with (slightly) different material

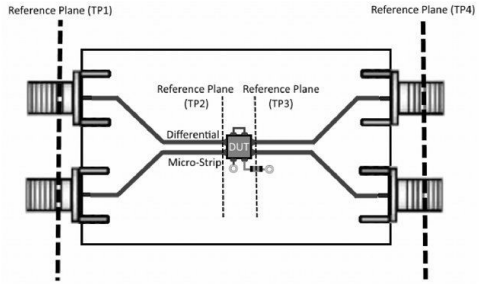
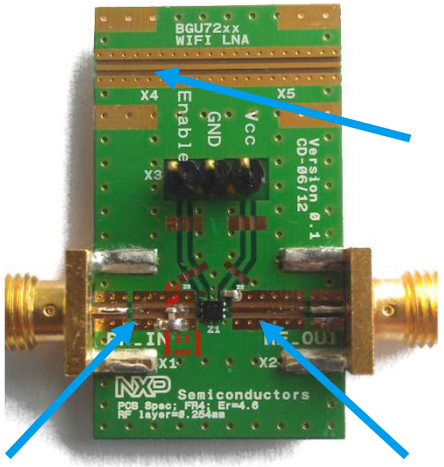


Figure GG-GG — Coaxial connectors on a PCB with differential micro-strip traces to a DUT



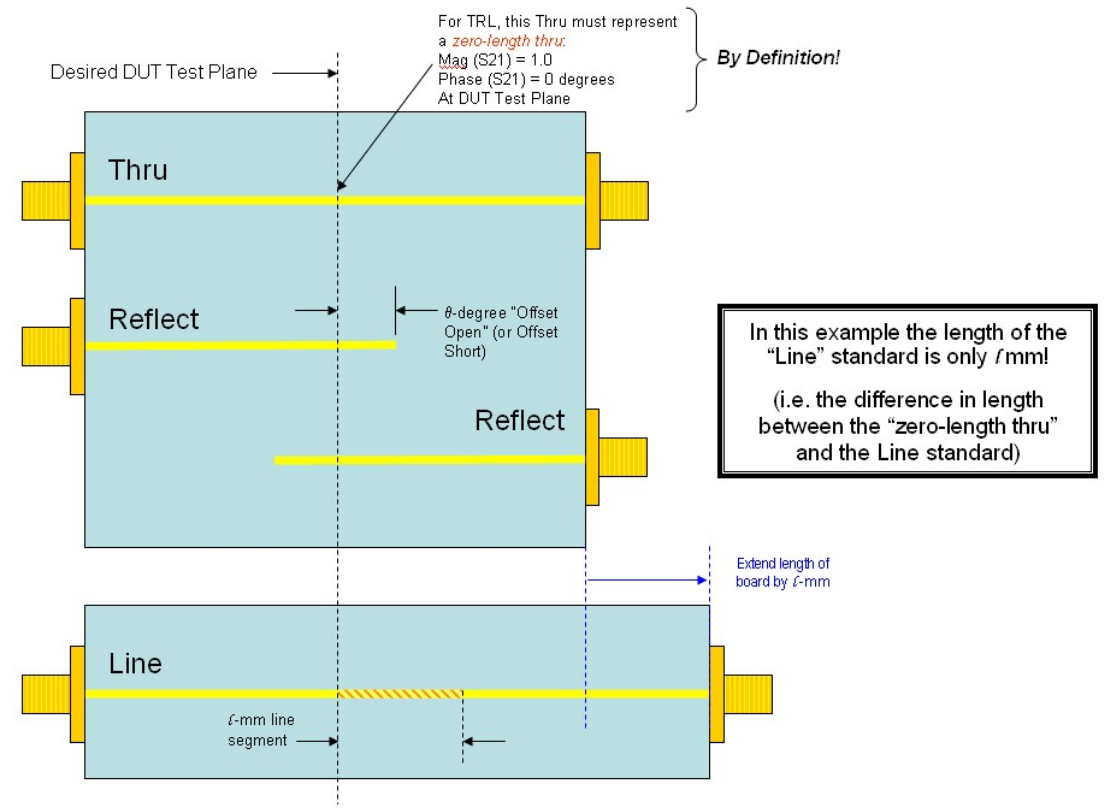
2x through

Fixture left

Fixture right

Classic approach

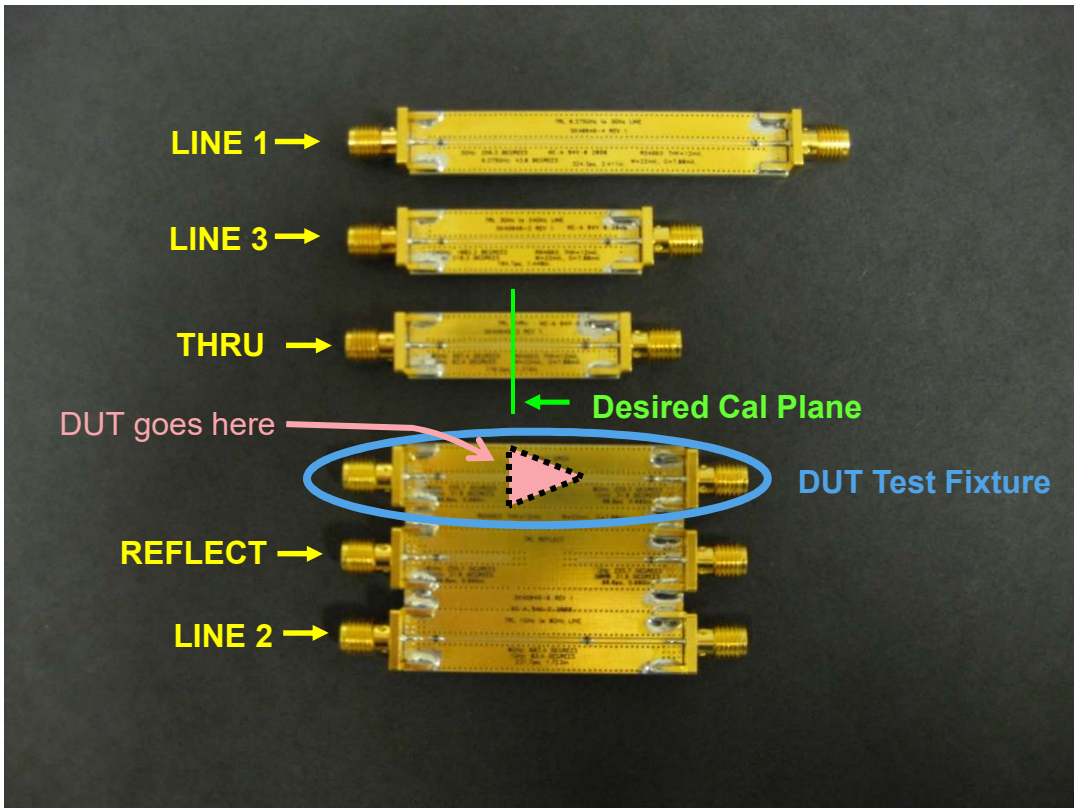
- TRL Calibration
  - Requires:
    - Reflect standard
    - Zero-length through standard
    - Line Standard:
      - 20 degrees at lowest freq
      - 160 degrees at highest freq



TRL Standards for Custom Kit (Three Line standards cover 375 MHz to 24 GHz)

TRL Challenges

- Multiple lines required to cover higher frequencies
- Still requires Match standard for lower frequencies
- Cal Plane established in center of THRU standard



CEI56, VSR, MR, LR

Very Short Reach
- 10 cm
- Chip-to-Chip
- One Connector

Medium Reach
- 50 cm
- Chip-to-Chip
- One Connector

Long Reach
- Chip-to-Chip
- Two Connector

Figure 16-15. CEI-56G-VSR-PAM4 Channel Reference Model

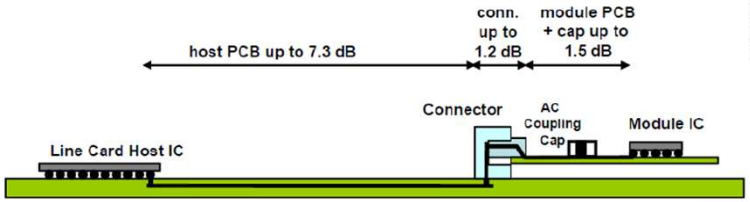
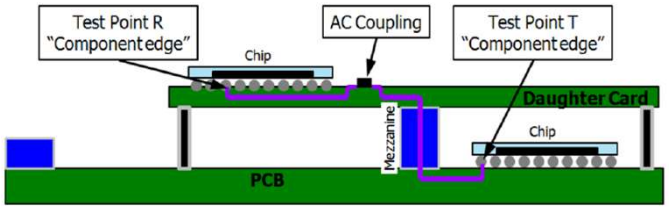
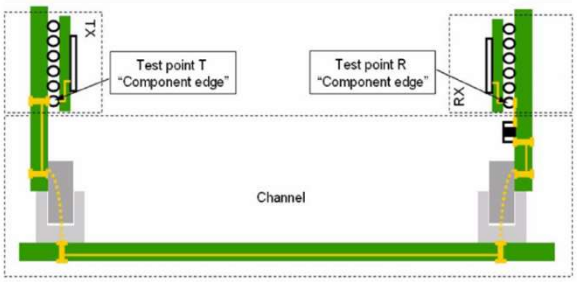


Figure 17-1.CEI-56G-MR Reference Model

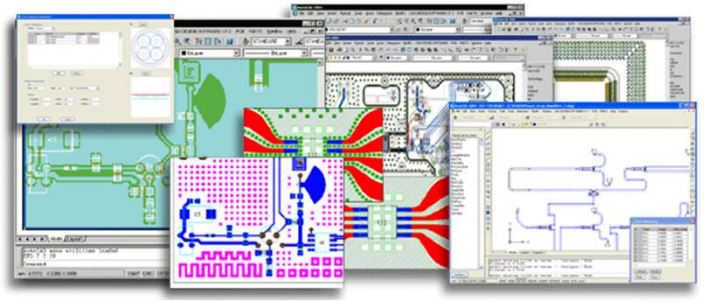




Common Features:
- Equalization
  - CTLE/FFE/DFE
- Error correction
  - FEC

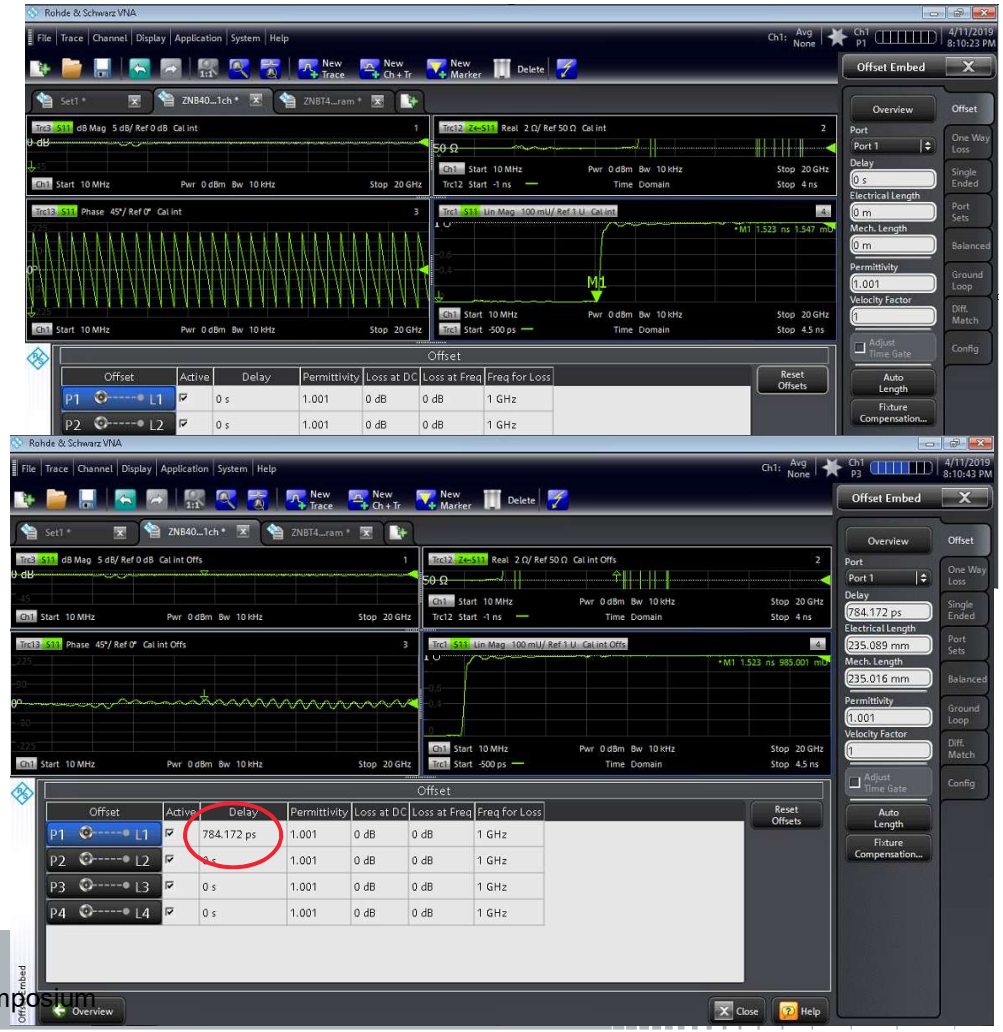
Alternative (simpler) solutions

- Use Offset De-embed
- One Way Loss/Auto Length/Loss
- Use S-parameters from board simulation
- Use advanced fixture de-embedding techniques



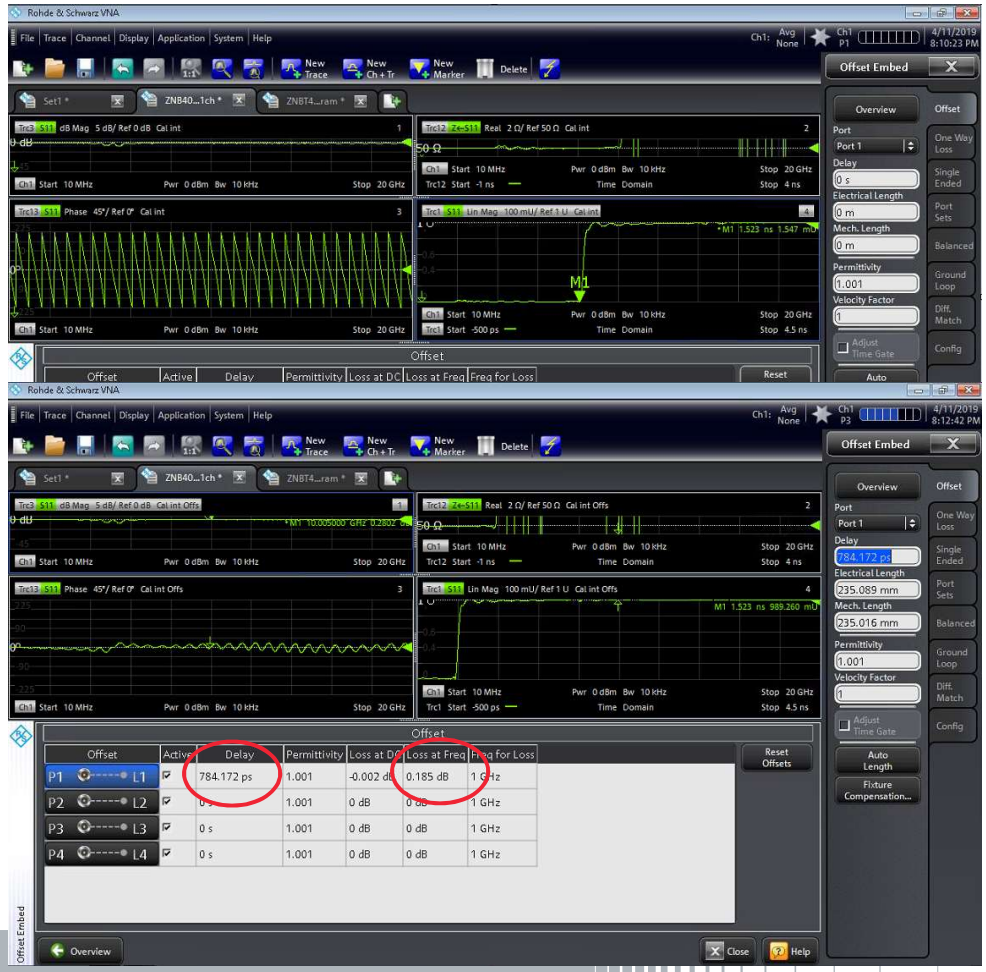
Alternative approaches

- Auto Length
  - Advantages:
    - Simple (requires only an OPEN)
    - Remove reflections
    - Remove extraneous loss
    - Remove extraneous phase shift/rotations
  - Disadvantages:
    - Assumes line (to be removed) is Zo



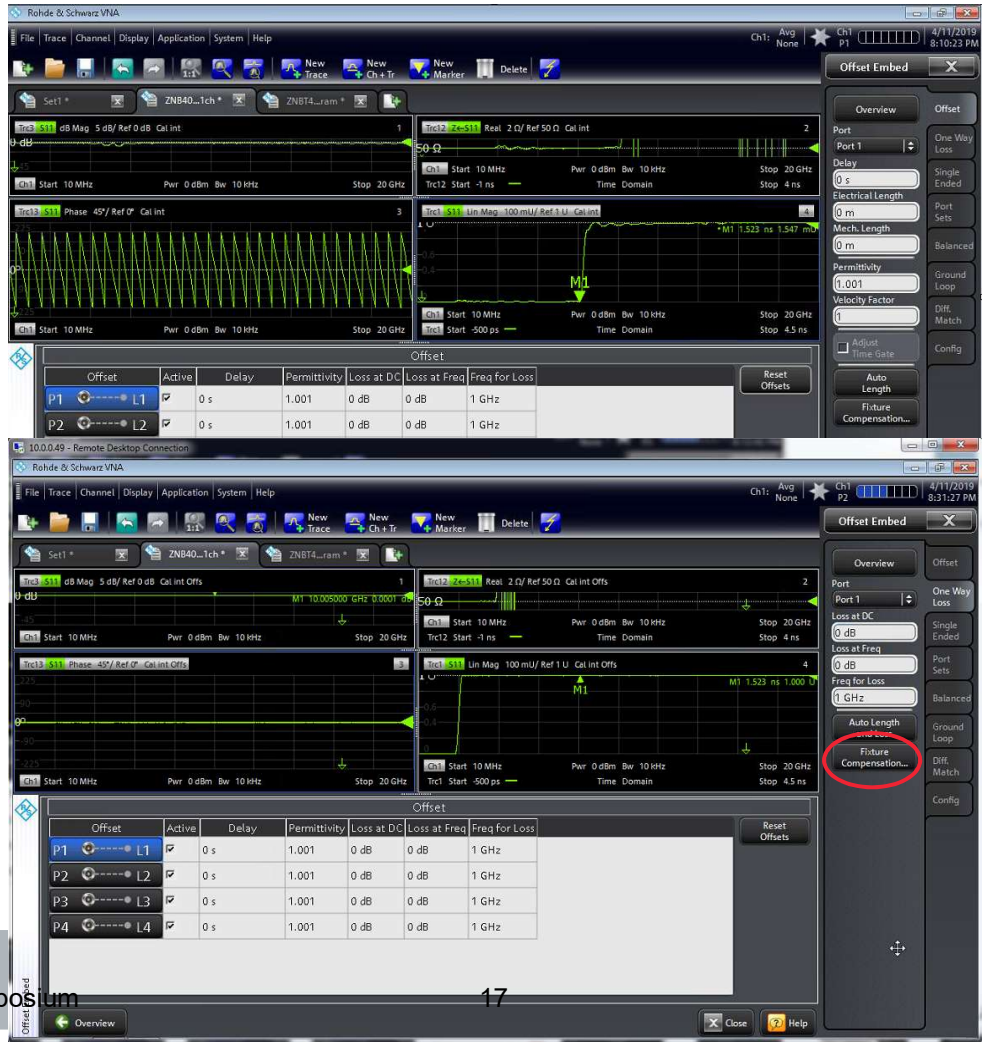
Alternative approaches

- Auto Length & Loss
  - Advantages:
    - Simple (requires only an OPEN)
    - Remove reflections
    - Remove extraneous loss
    - Remove extraneous phase shift/rotations
  - Disadvantages:
    - Assumes line (to be removed) is Zo



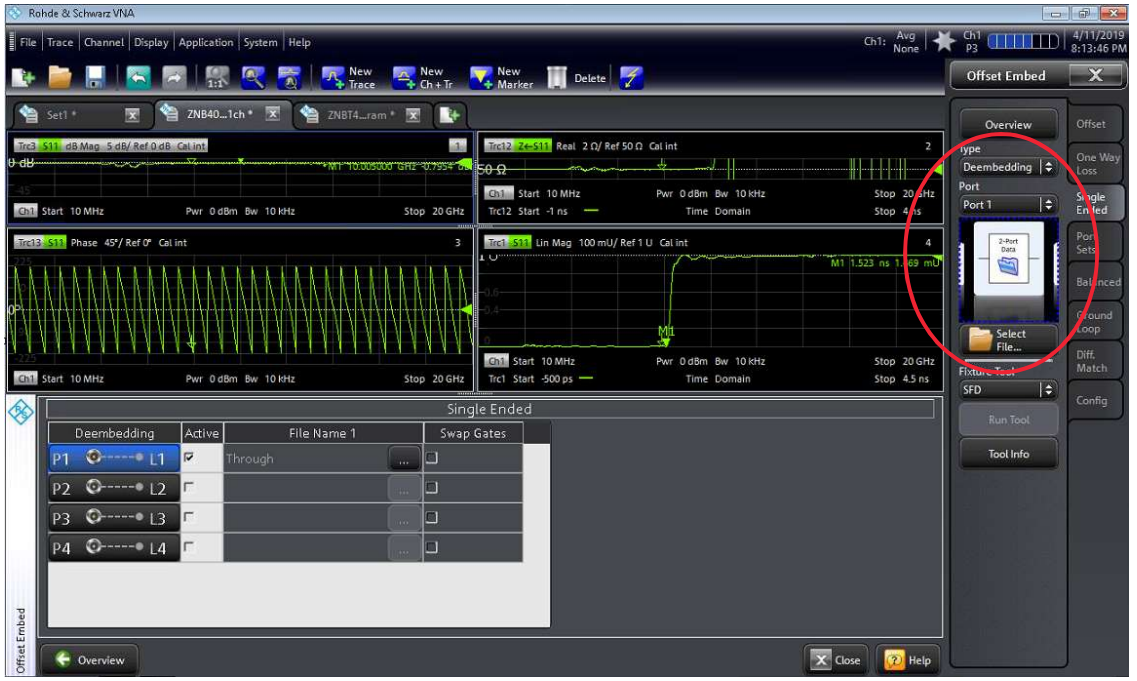
Alternative approaches

- Fixture Compensation
  - Advantages:
    - Simple (requires only an OPEN)
    - Remove reflections
    - Remove extraneous loss
    - Remove extraneous phase shift/rotations
  - Disadvantages:
    - Assumes line (to be removed) is Zo
    - Can provide “overly optimistic” results

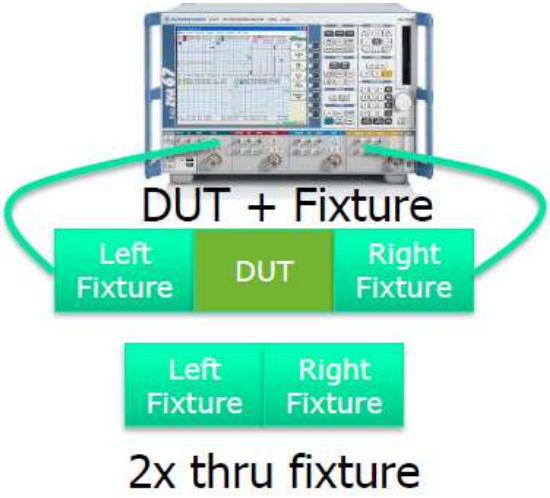


Alternative approaches

- Fixture De-Embedding
  - Advantages:
    - Remove reflections
    - Remove extraneous loss
    - Remove extraneous phase shift/rotations
  - Disadvantages:
    - Requires 2-port s-parameters
      - (measured or modelled)

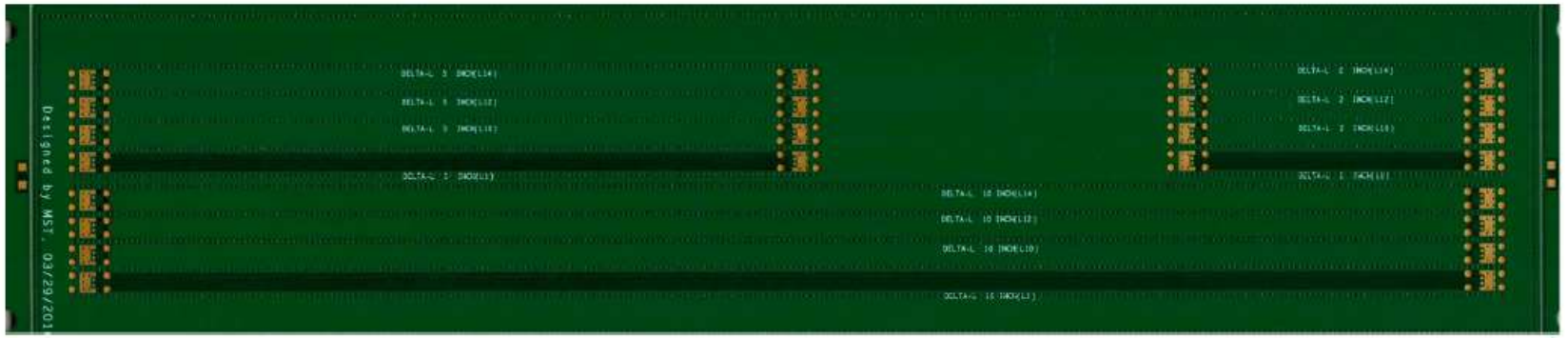


Advanced Fixture De-embedding Techniques



2-X Thru Tools:

- Keysight: AFR (Automatic Fixture Removal)
- Packet Micro: SFD (Smart Fixture De-Embedding)
- Ataitec: ISD (In-Situ De-embedding)
  - Disadvantages:
    - May produce non-casual response



What is causality?

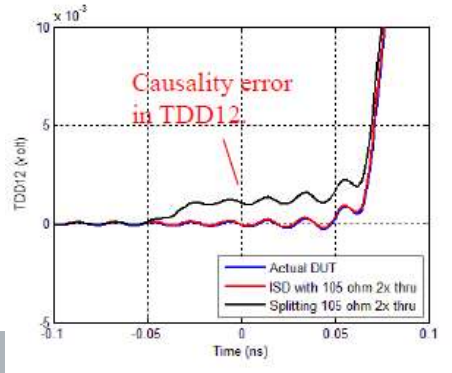
cau·sal·i·ty

noun

1. the relationship between cause and effect.
2. the principle that everything has a cause.

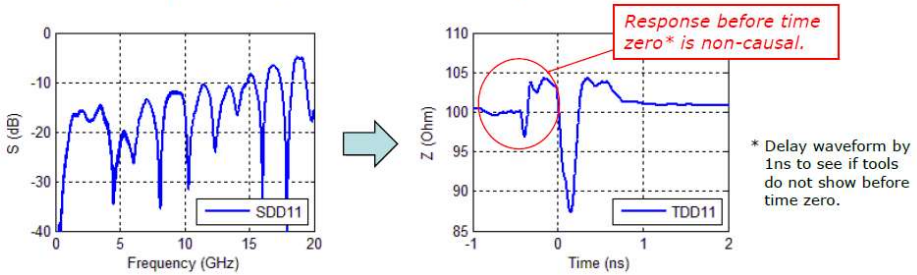
In other words:

Can not get something from nothing.

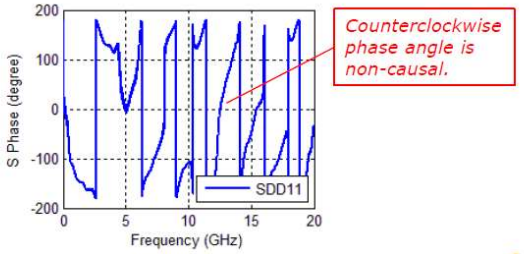


How to identify non-causal S parameter

- Convert S parameter into TDR/TDT.

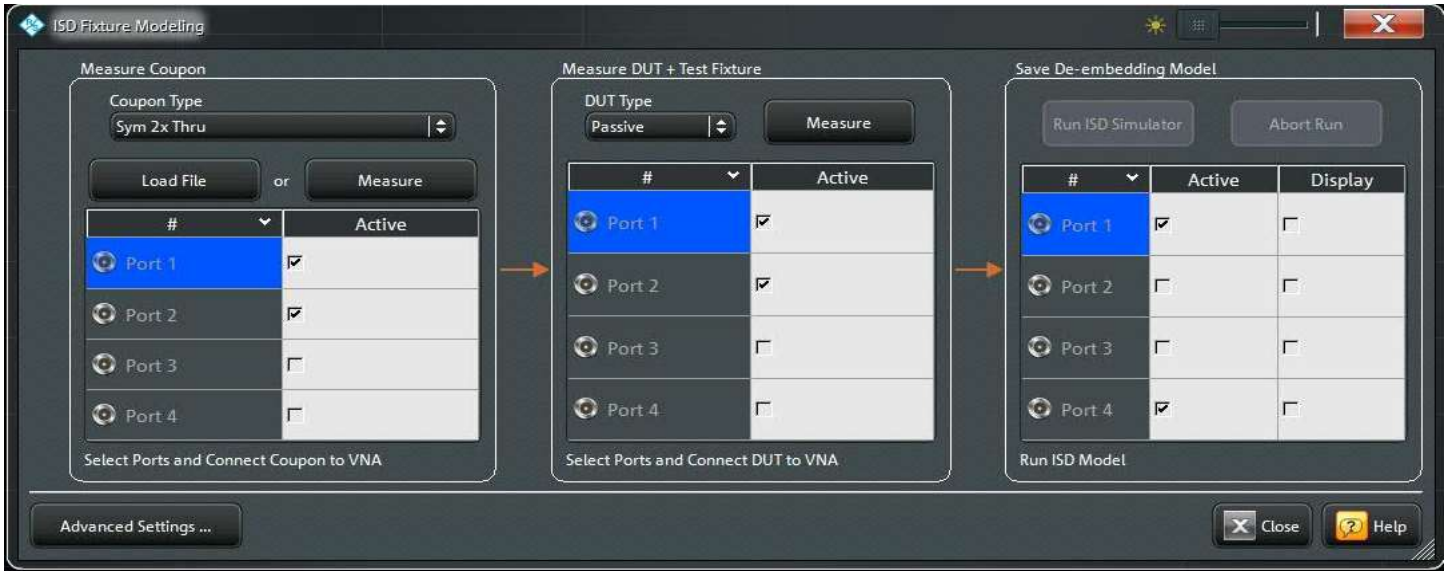


- Check phase angle.



ISD and SFD Dialog in ZNB, ZNBT Vector Network Analyzers

3 steps: 1) Measure Coupon 2) Measure DUT 3) Run De-embedding



ISD provided by Ataitec, SFD provided by PacketMicro