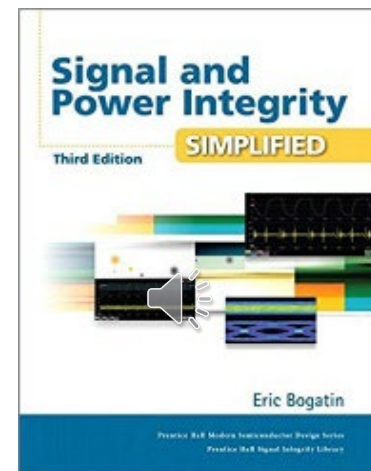
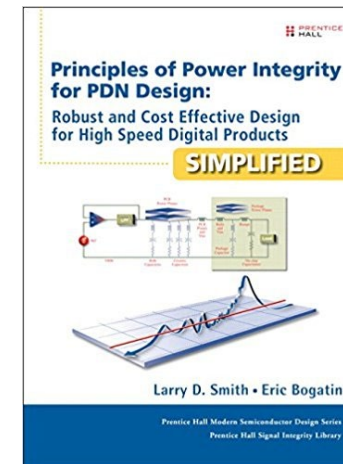
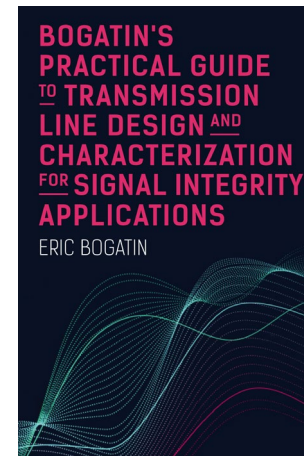


Characterizing a MEMS switch for High-speed SerDes Interfaces

Prof Eric Bogatin,
University of Colorado, Boulder,
Fellow, Teledyne LeCroy



TELEDYNE LECROY
Everywhereyoulook™



About Teledyne LeCroy



Extensive range of tools for electrical, physical, logical and protocol layer testing

Protocol Analyzers and Test Appliances

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Electronic Test Equipment

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Device and Systems Testing

About the Presenter



Eric Bogatin
Prof, University of Colorado, Boulder
Fellow: Teledyne LeCroy
Technical Editor, Signal Integrity Journal
Dean, Teledyne LeCroy Signal Integrity Academy

- Physics: BS MIT '76 and PhD U of A Tucson, '80
- Senior management and engineering positions at Bell Labs, Raychem, Sun Micro, Ansys, Interconnect Devices Inc
- Started Bogatin Enterprises in 1992, created the Signal Integrity Academy, acquired by LeCroy in 2011. Teledyne LeCroy Fellow
- Full time Prof, ECEE dept University of Colorado, Boulder, since 2021, teaching signal integrity, PCB design, Capstone Senior Design Lab
- Author: 15 books, including popular textbooks and science fiction novels, monthly columns



Characterizing a MEMS switch for High-speed SerDes Interfaces

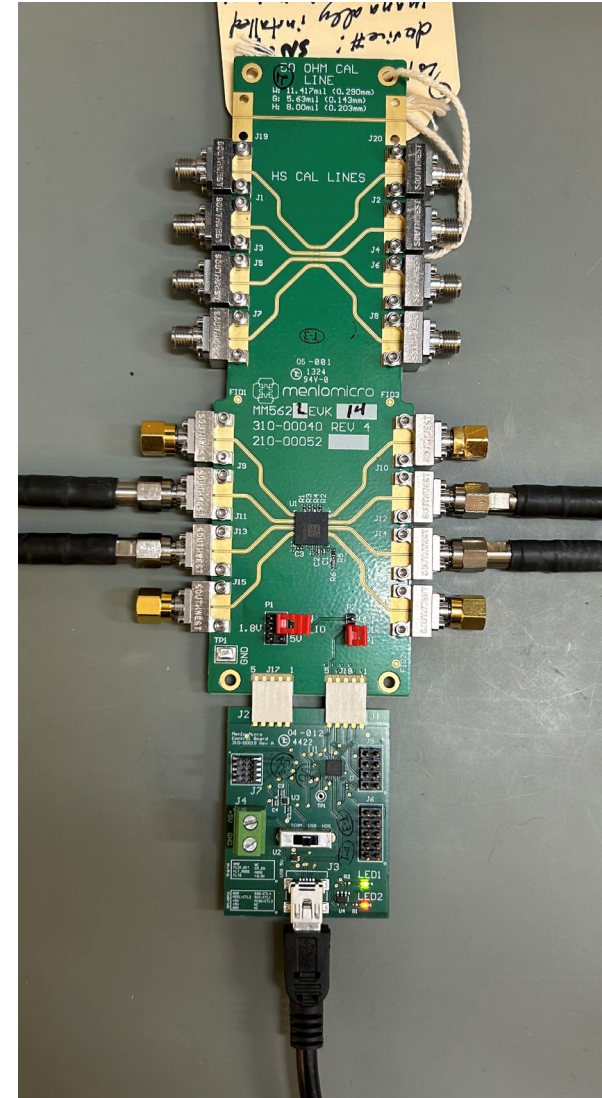
Prof Eric Bogatin (eric.bogatin@colorado.edu)

University of Colorado, Boulder

<https://www.colorado.edu/faculty/bogatin/>

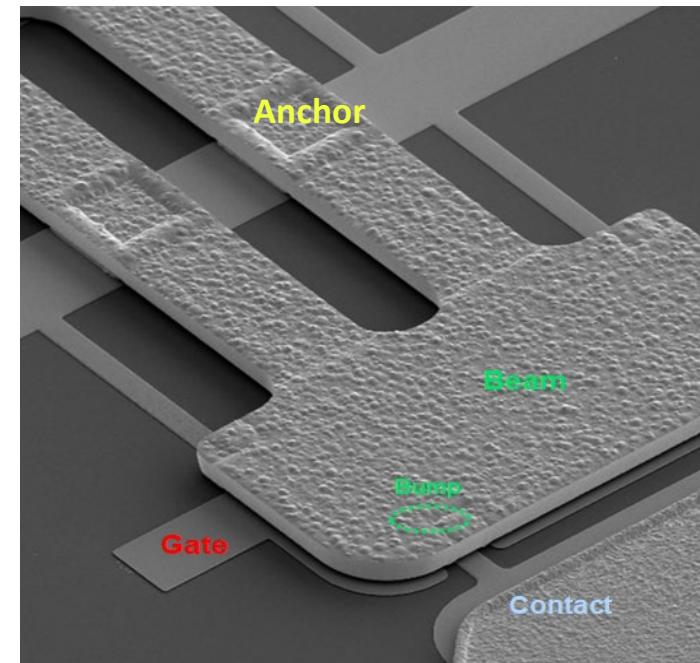
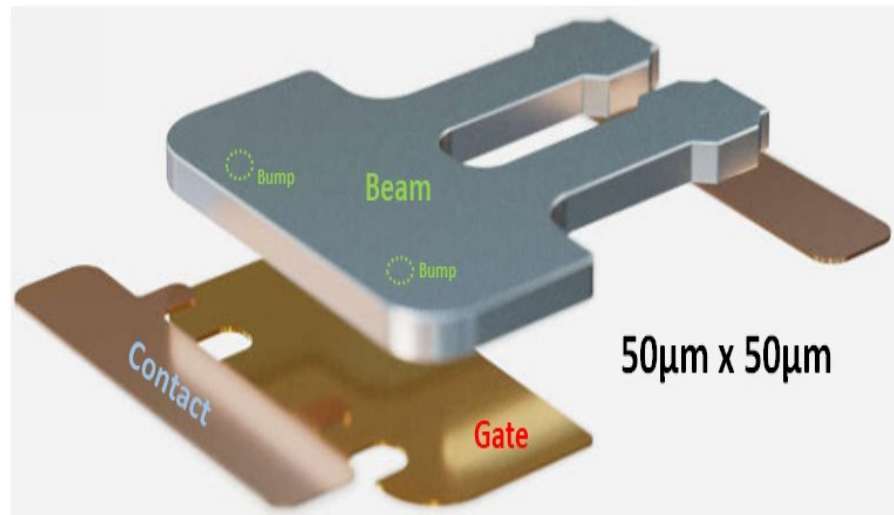
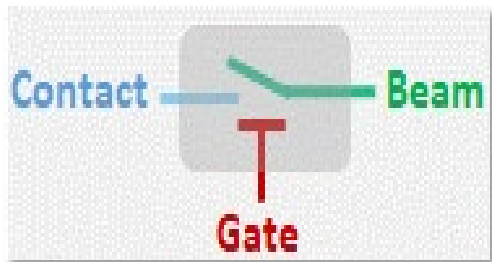
Agenda

- Changing out the cables in the Wave Pulser
- Reference Thru,
 - ✓ w, wo terminated adjacent traces
 - ✓ SE response and XTK
 - ✓ Diff Response, time and freq, mode conversion
 - ✓ Self De-embedding the Thru ref
- Measuring the switch
 - ✓ SE response
 - ✓ de-embedding
 - ✓ Differential response
 - ✓ After de-embedding
- Open performance of the switch
- Using the switch S-parameters to emulate a channel
- Explore application space using behavioral model and system simulator
 - ✓ 10 Gbps NRZ
 - ✓ 28 Gbps NRZ
 - ✓ 32 Gbps NRZ
 - ✓ 64 Gbps PAM4



What is Menlo's Ohmic MEMS Switch?

- MEMS stands for **M**icro-**E**lectro**M**echanical **S**ystem
- Miniaturized mechanical structure - metal to metal contact
- Air gap between beam and contact is switched by electrostatic actuation
- Range of frequencies from DC to 70+ GHz
- Power handling capability from milliwatts to kilowatts



Implemented in Small Footprint Packages

Unit Cell
50µm x 50µm



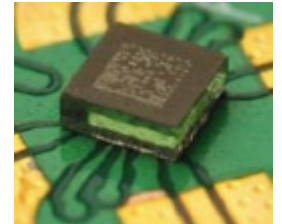
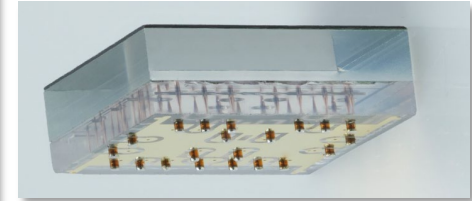
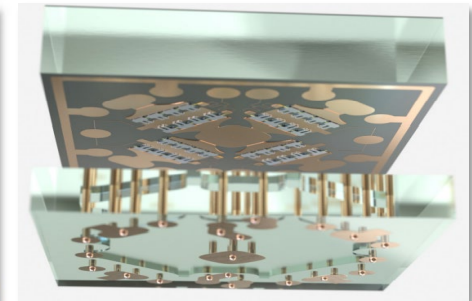
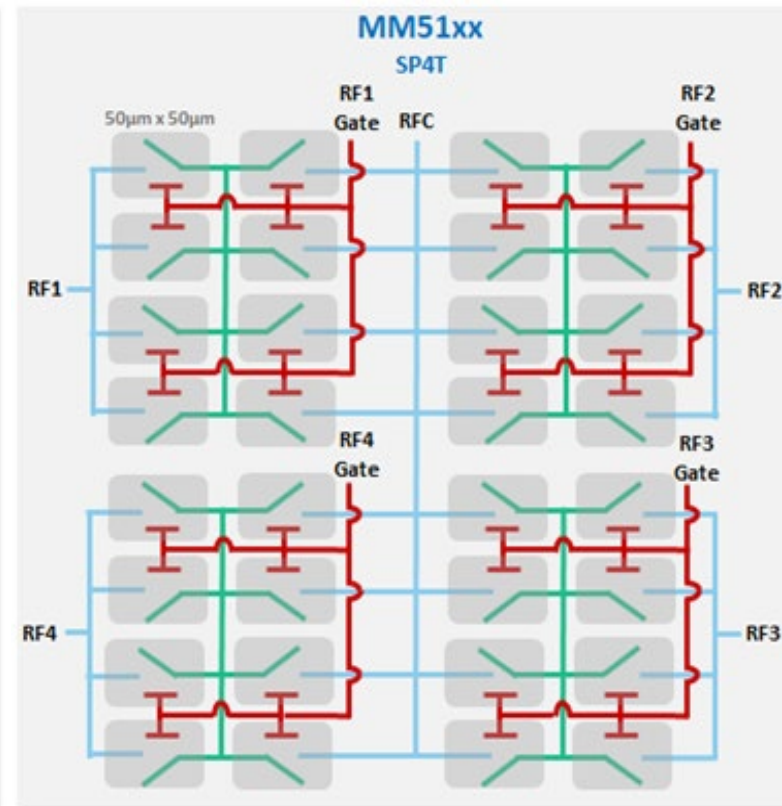
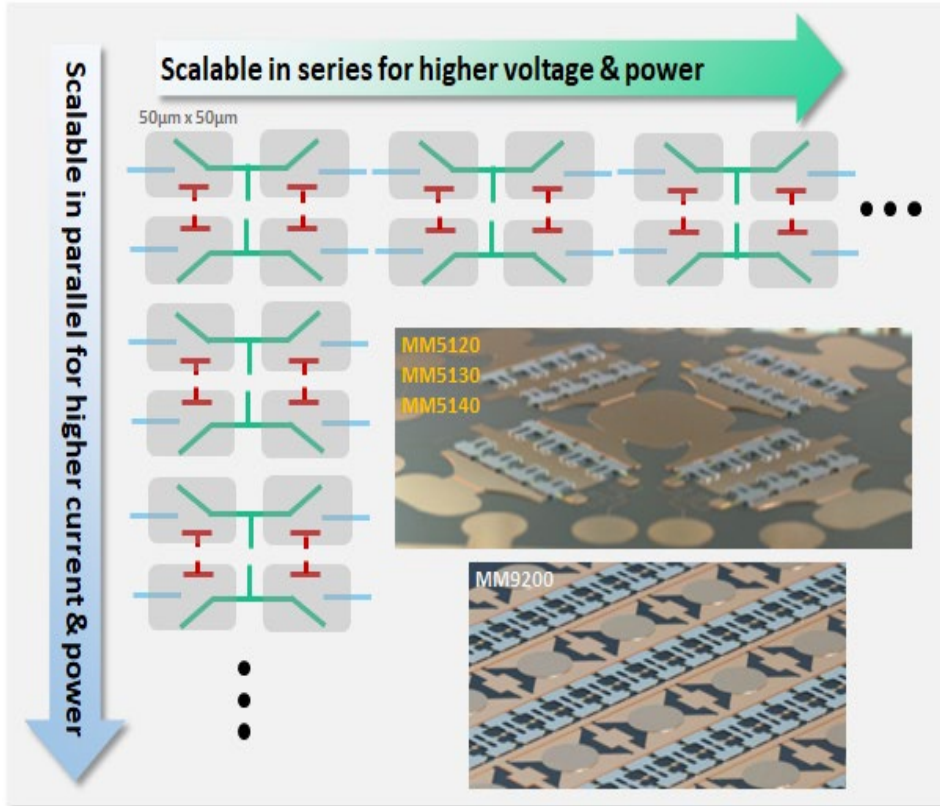
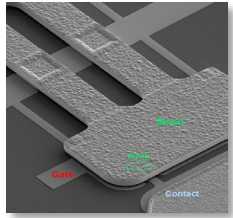
2D
Scalability



Switch
Portfolio



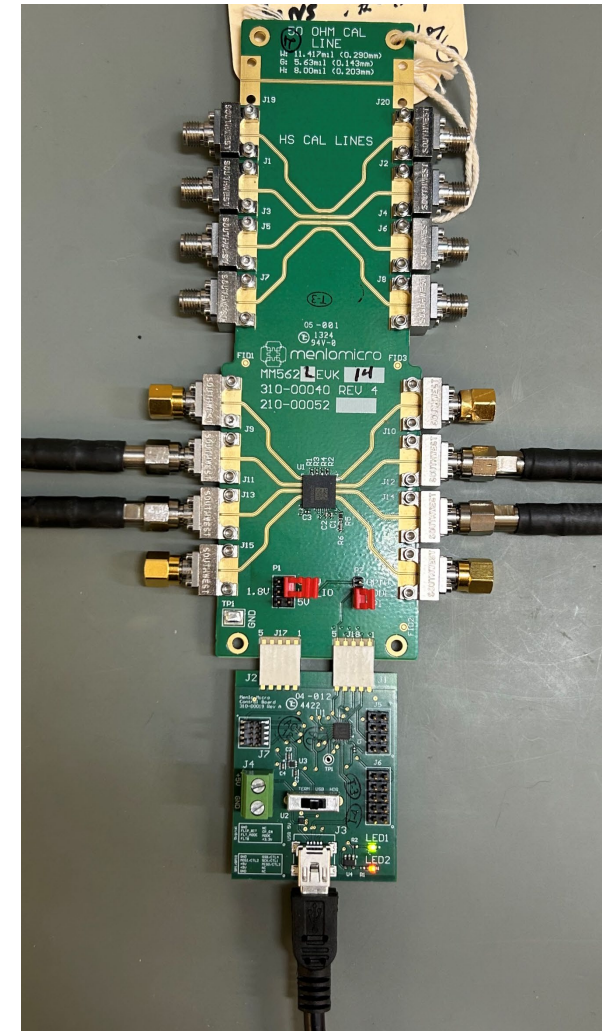
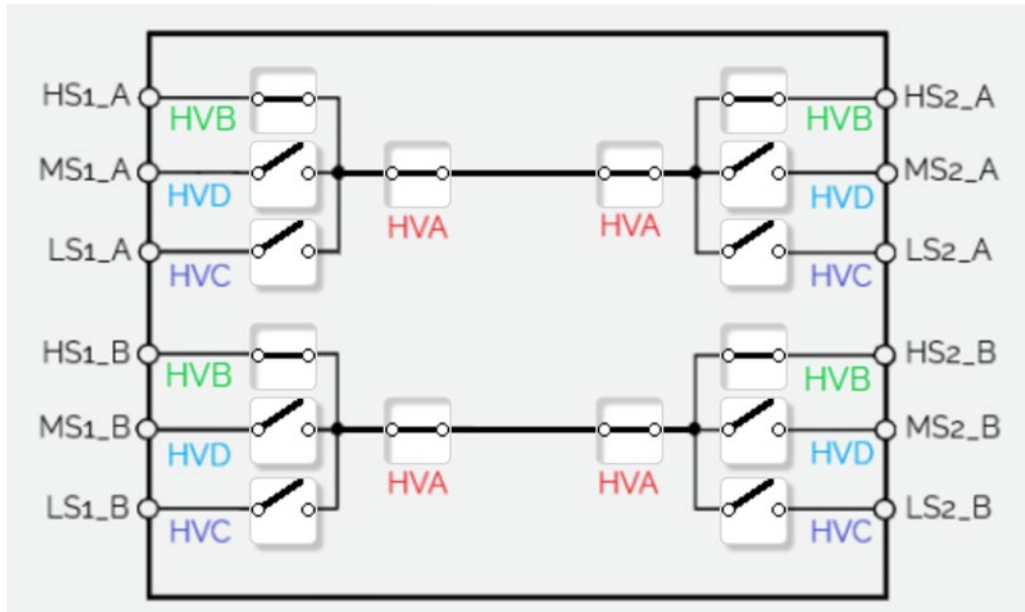
System In Glass
SiG



Package Size:
2.5 x 2.5 x 0.9 mm³

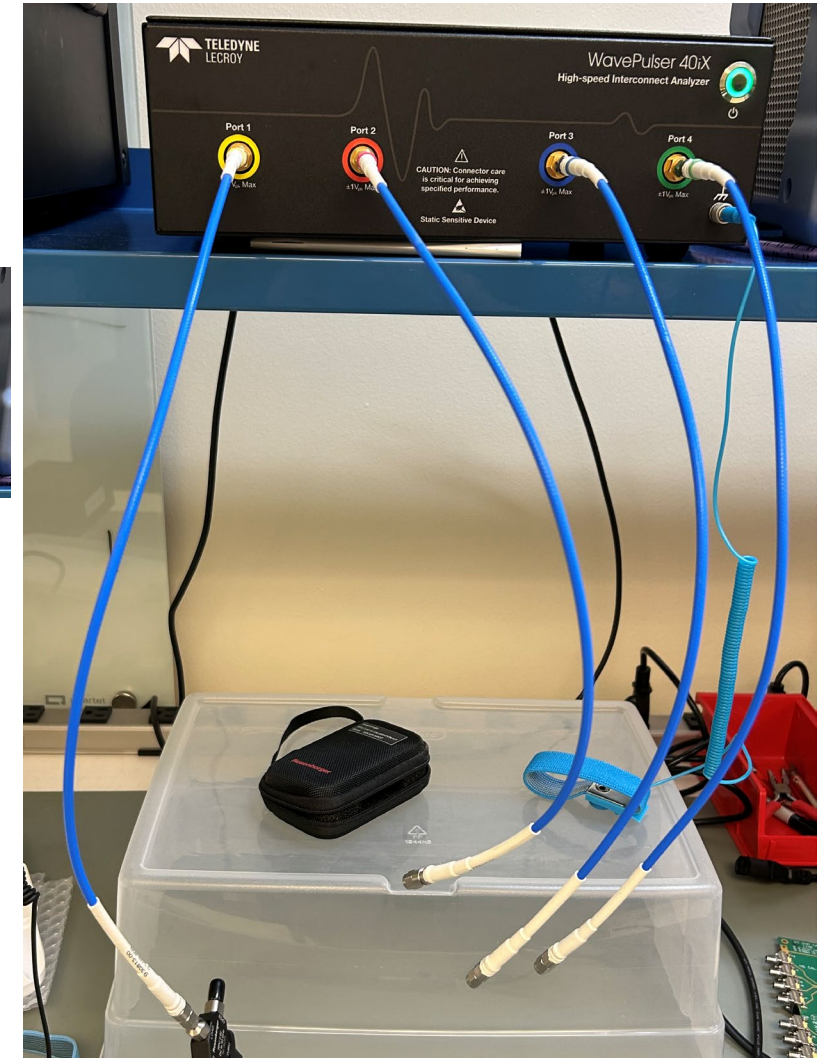
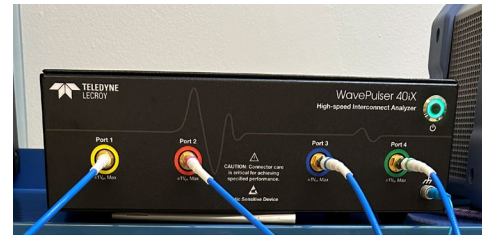
A Simple, General-Purpose Eval Board

- Electronics board has USB interface to control the switches



WavePulser Uses a Simple Calibration Process

- No user calibration is required
- WavePulser turns on calibrated
 - ✓ Built in ecal establishes the reference plane to the front connectors of the WavePulser
 - ✓ Each cable has been measured with a WavePulser
 - ✓ S-parameter file of each cable is de-embedded from all measurements



Wanted to Change out the Cables

- Shipped cables are short and rigid
- Want to use new cables that are long and flexible
 - ✓ Graciously donated by Junkosha USA and Packet Micro
 - ✓ Junkosha Cables MWX161

Junkosha Microwave/mmWave Coaxial Cable Assembly

1 Series Cable Assemblies with Wide Temperature Range & High Durability for Measuring Instruments

161

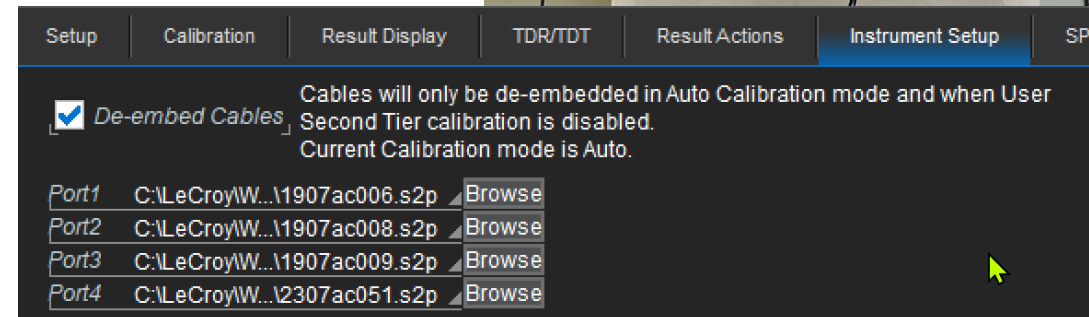
Features

- Phase Stability: Static Bending
- Phase Stability: Temperature Change
- Slim and Durable
- Maximum Operating Frequency: 67.0 GHz
- Temperature Range: -65 to 125°C
- Days to Ship: 11 Business Days
- RoHS Compliant

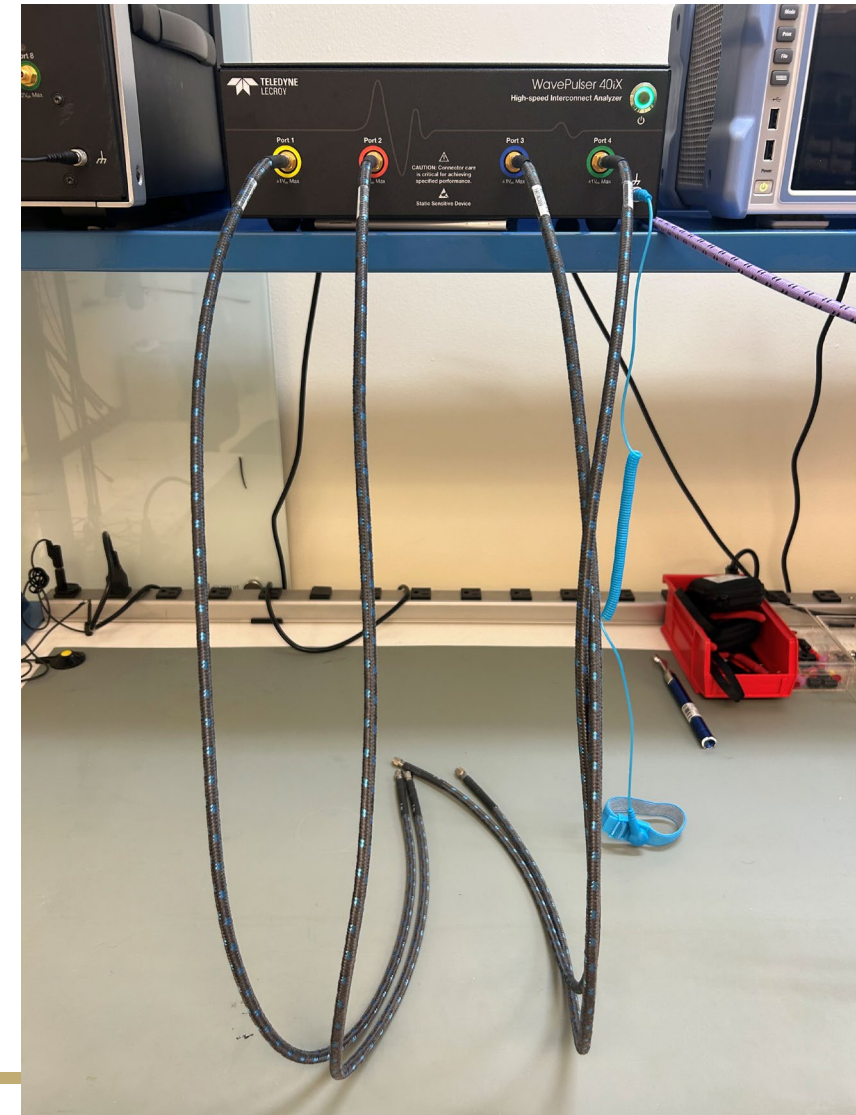


Simple process:

- Measure each cable
- Use these S-parameter files in the instrument set up



Old and New Cables

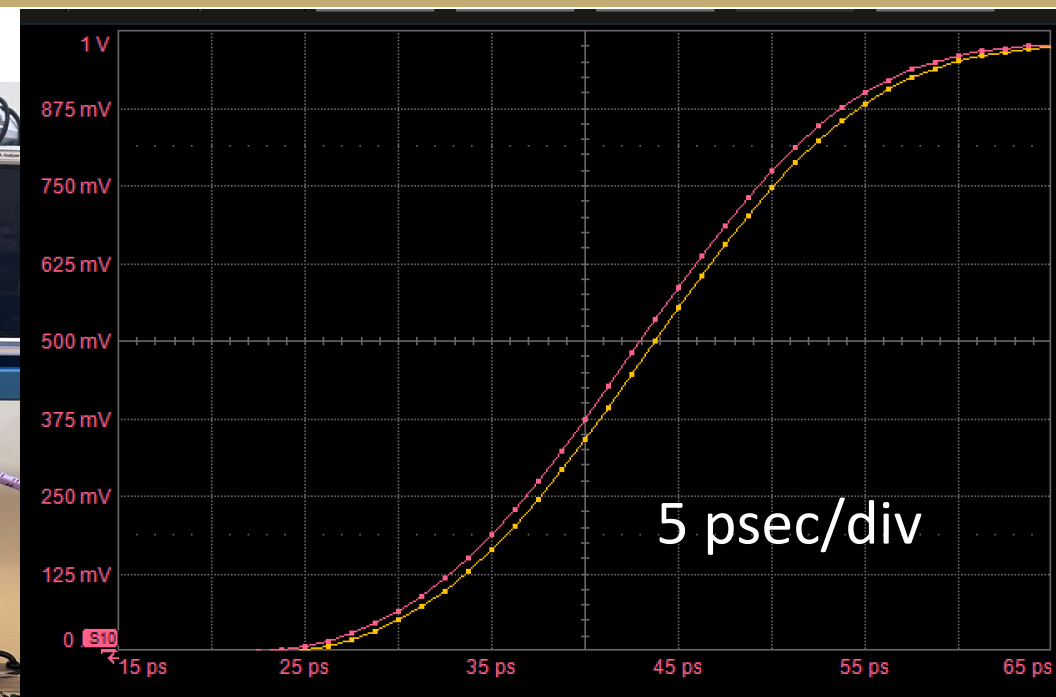
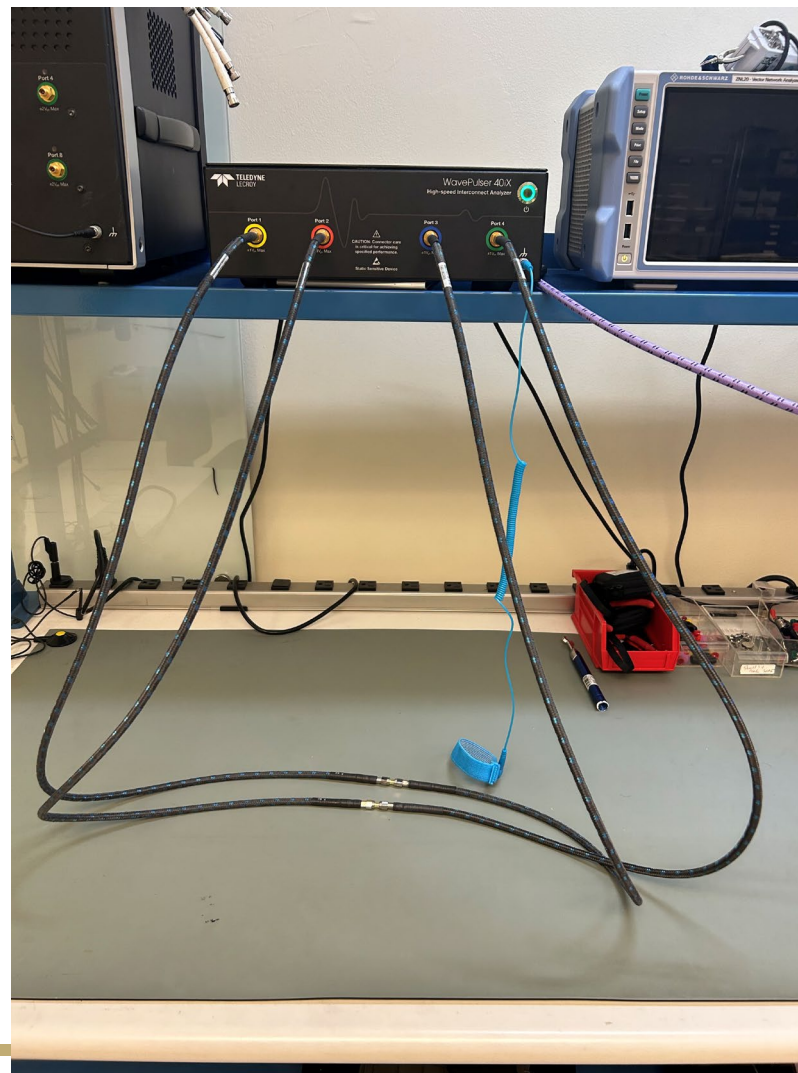
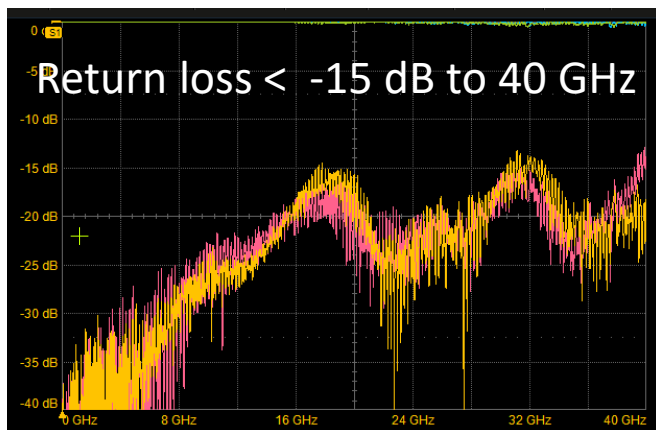


Thru Connection Delays

Using low cost, \$1 SMA barrels

Port 1 → 3

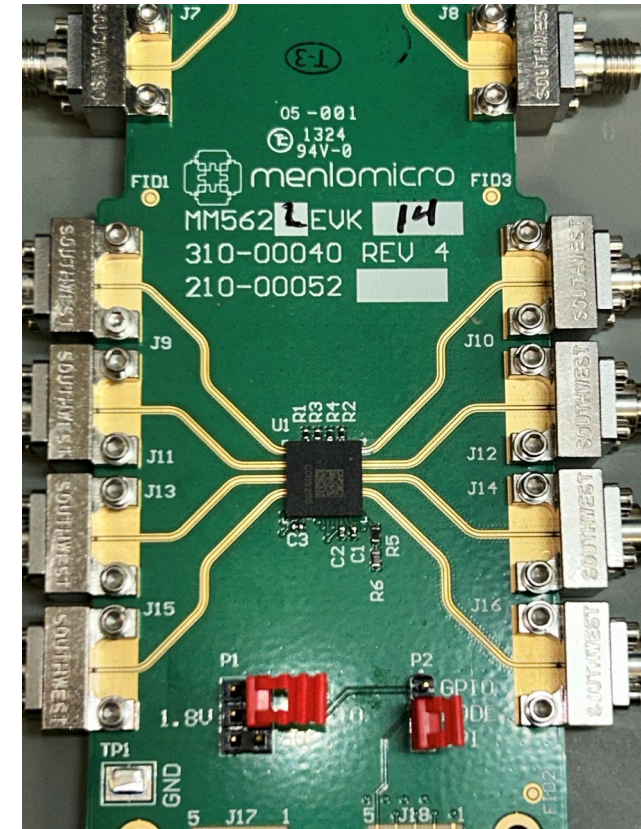
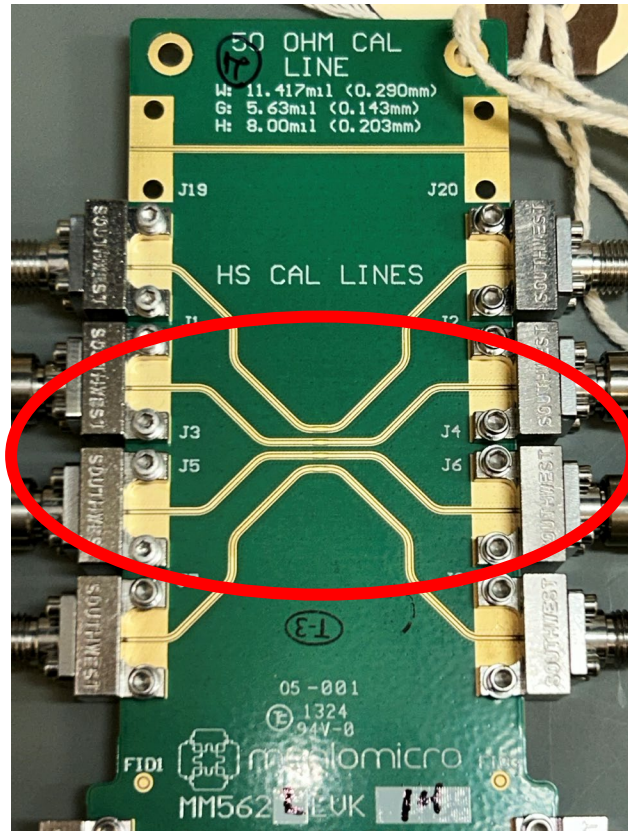
Port 2 → 4



- Residual skew in delay of the thru cables is < 1 psec
- Important metric in p, n skew in differential measurements

The Menlo Micro MEMS Switch Fixture Board

Fixture reference board

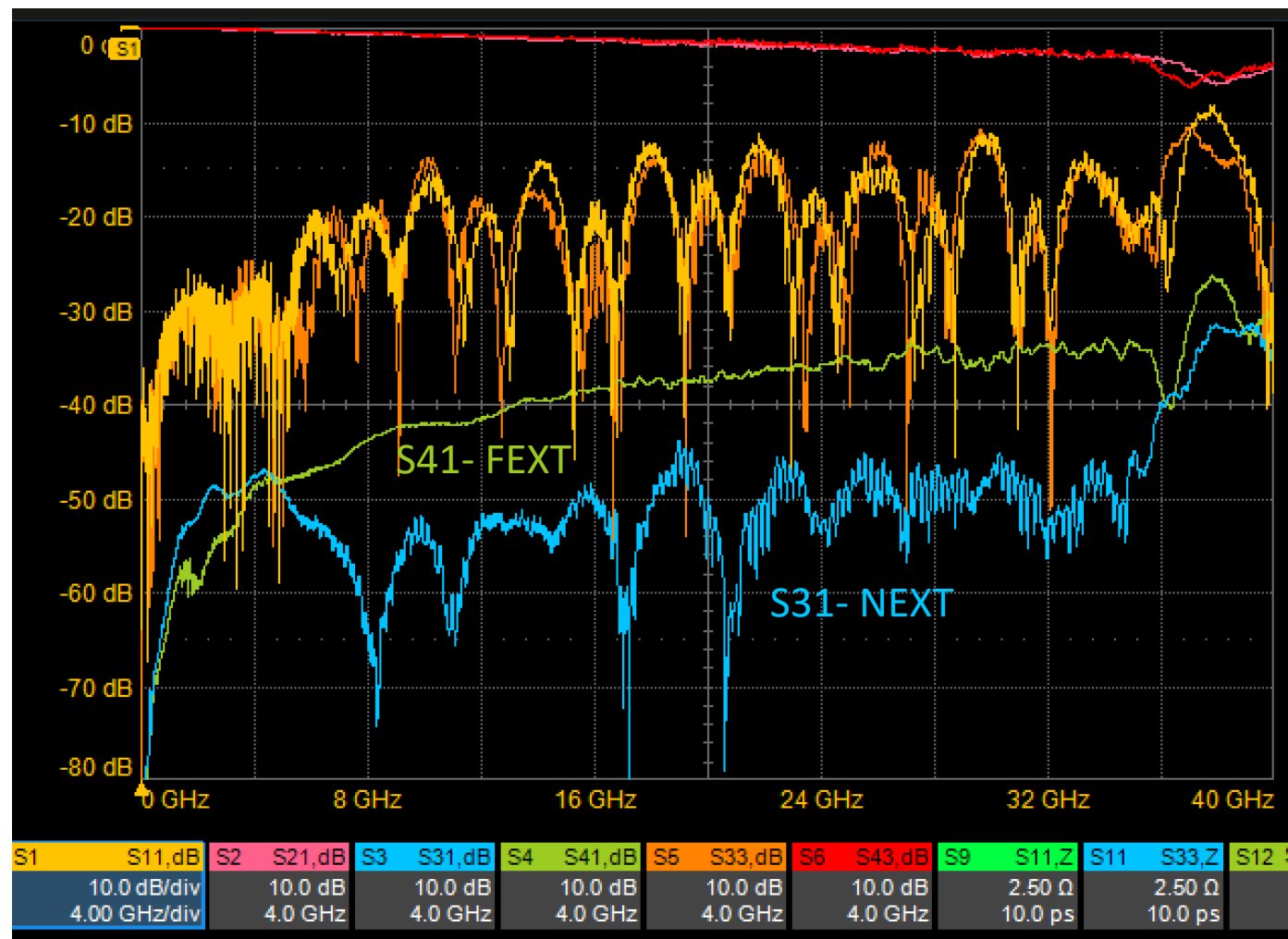
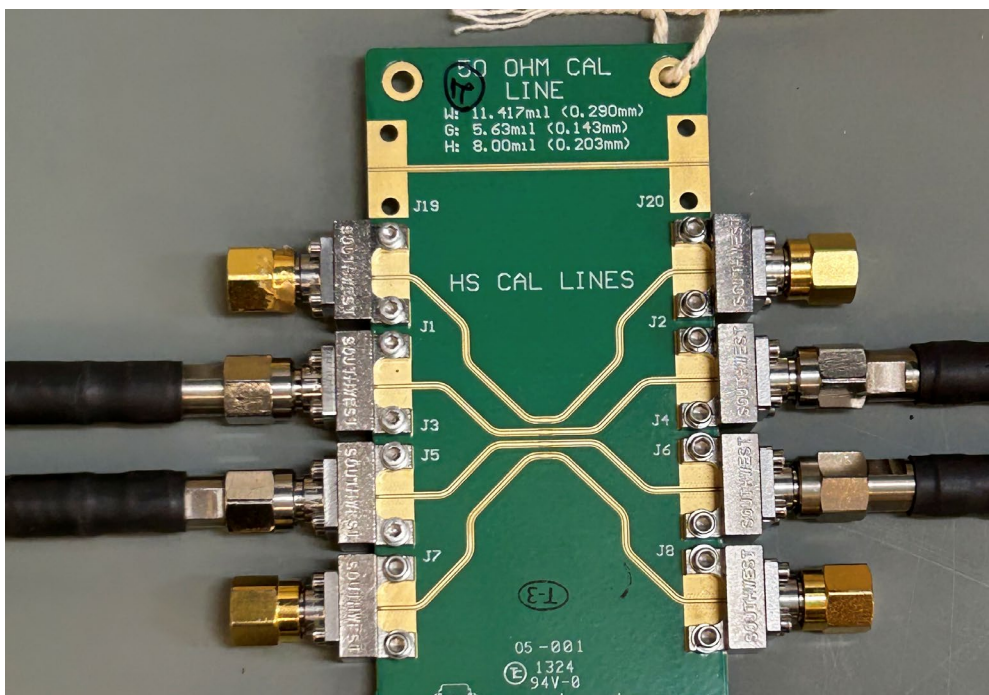


Process

- Measure and evaluate 4-port S-parameters of Fixture board
 - ✓ SE, impedance, losses, cross talk, p, n delay
 - ✓ Diff: impedance, losses, mode conversion
- Measure and evaluate the fixture with MEMS switch
 - ✓ SE, impedance, losses, cross talk, p, n delay
 - ✓ Diff: impedance, losses, mode conversion
 - ✓ De-embed using IEEE S-370 method: impedance corrected 2x Thru
 - ✓ Correct for the losses
- Use the SE .s4p S-parameters as a behavioral model to simulate any system performance

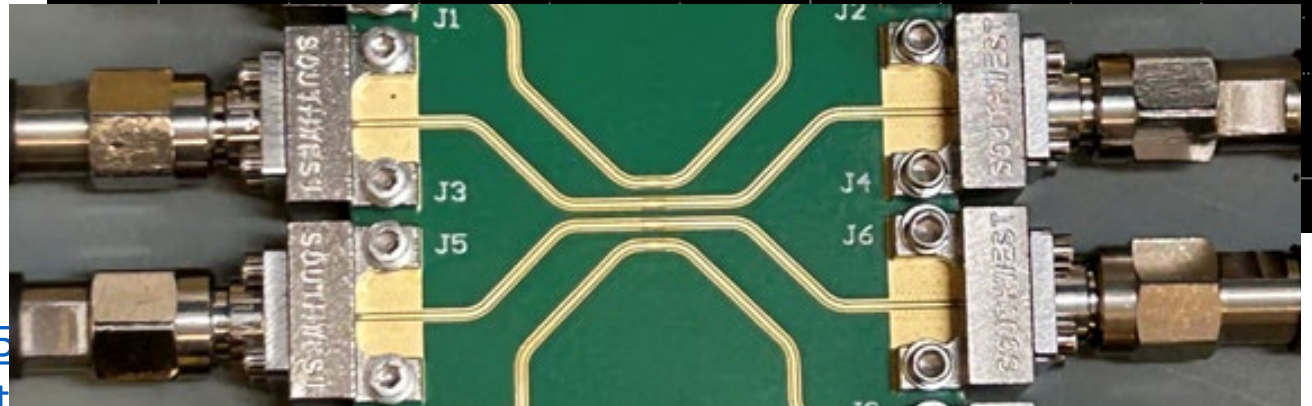
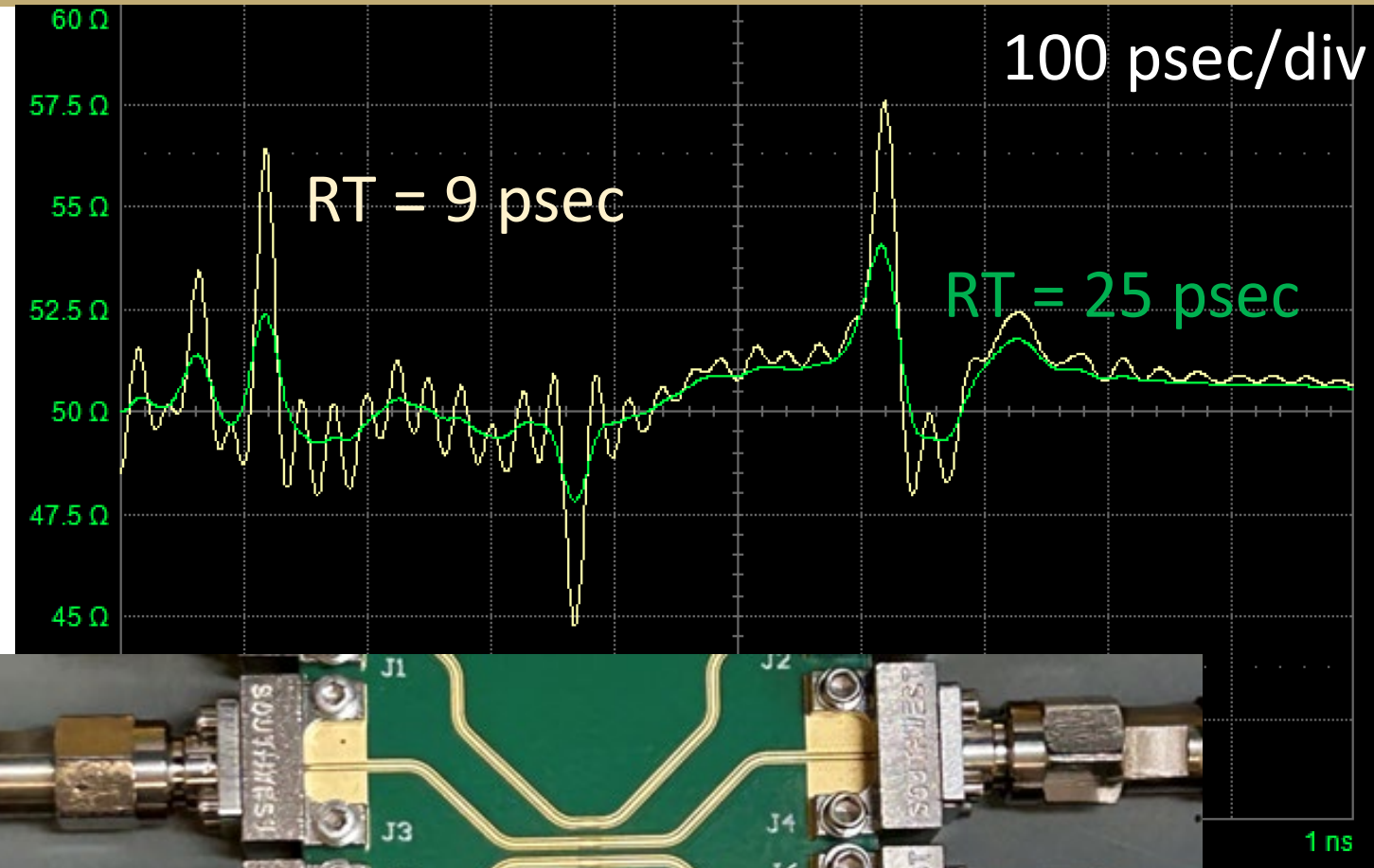
SE Response of the Fixture

- Virtually no cross talk- SE and diff response, of fixture will be the same



SE TDR Response

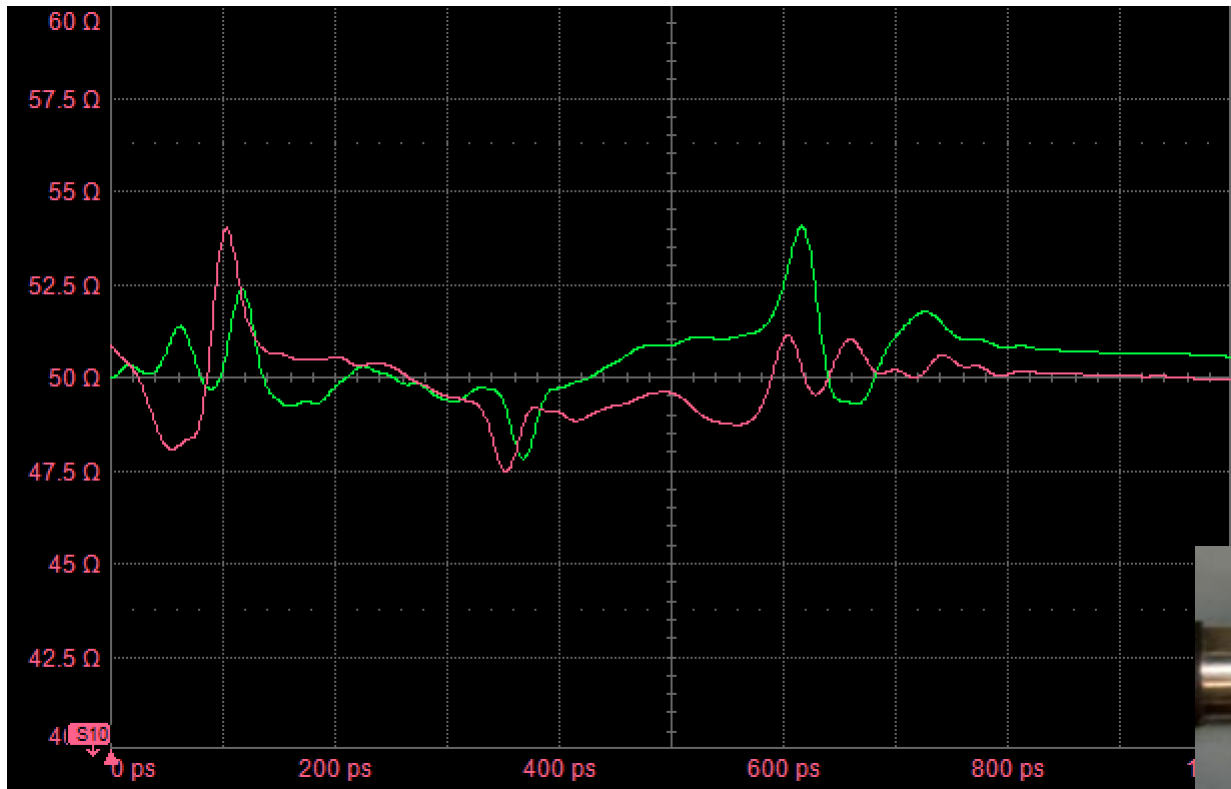
- What rise time to use?
- Default is $0.35/BW = 0.35/40G = 9 \text{ psec}$
 - ✓ Results in Gibbs ringing artifact
- Better rule of thumb is $RT = 1/BW = 1/40 \text{ GHz} = 25 \text{ psec}$



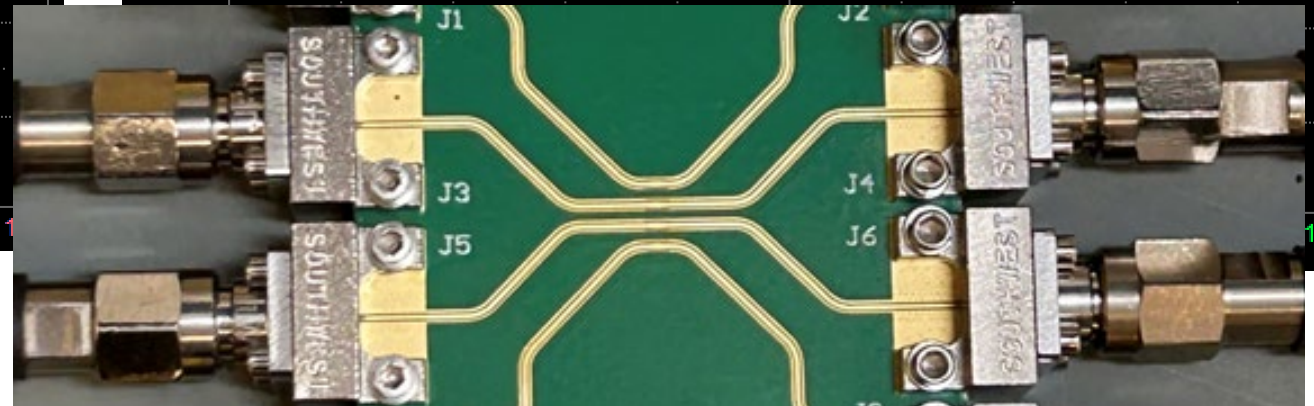
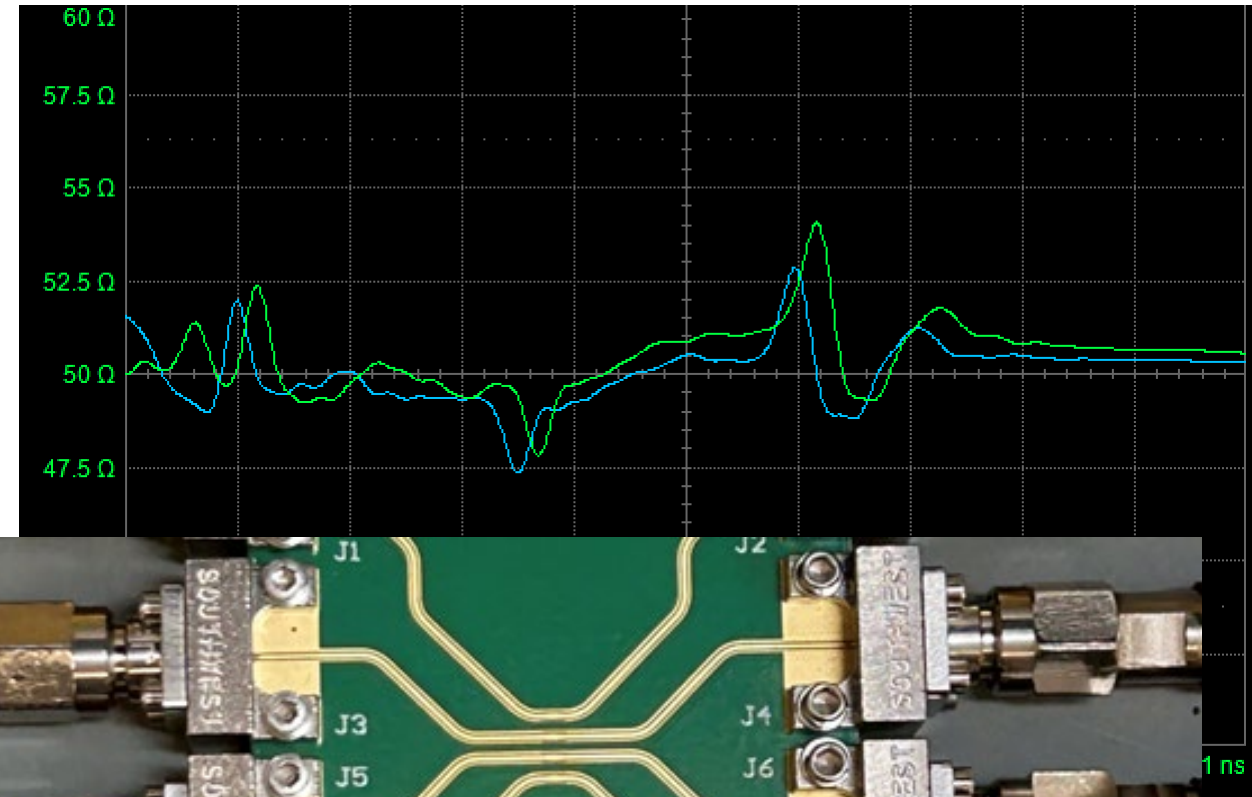
<https://www.signalintegrityjournal.com/articles/2175-how-to-avoid-gibbs-ringing-artifacts-in-measurements>

Small Complication with the 2x Fixture: Asymmetry

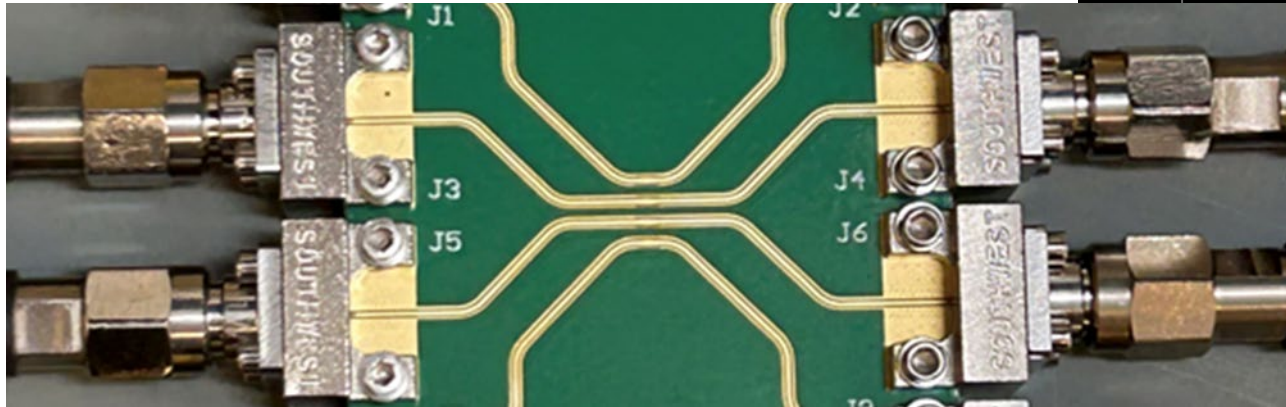
Left-right asymmetry



p, n asymmetry

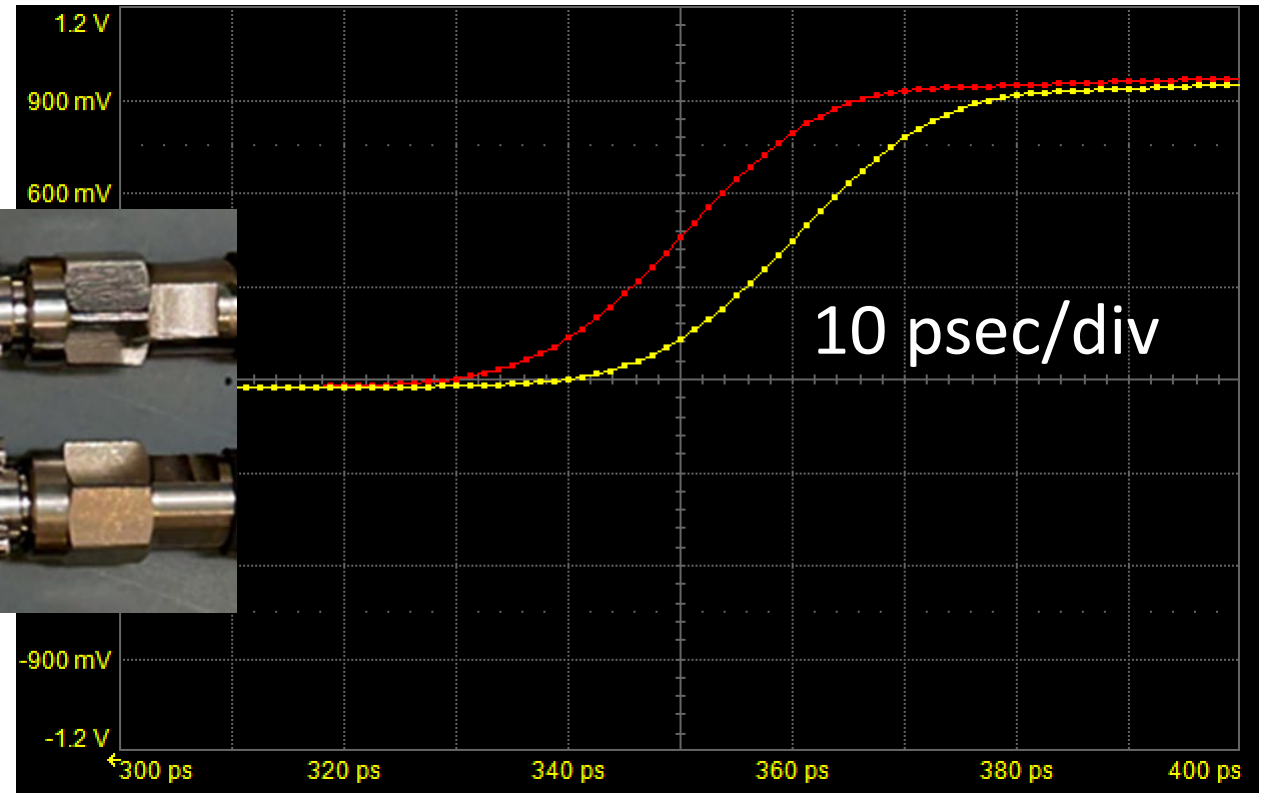


Time Delay Difference in p, n channels

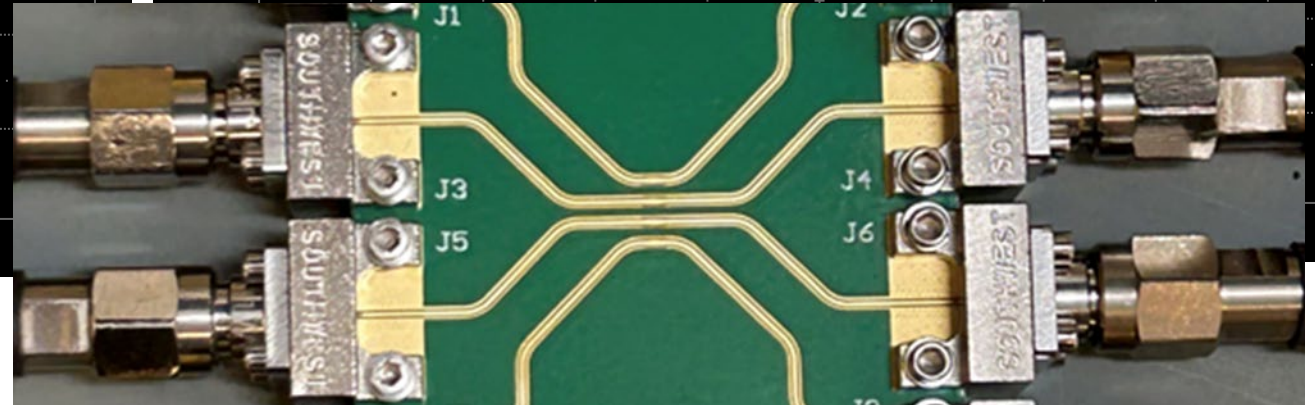
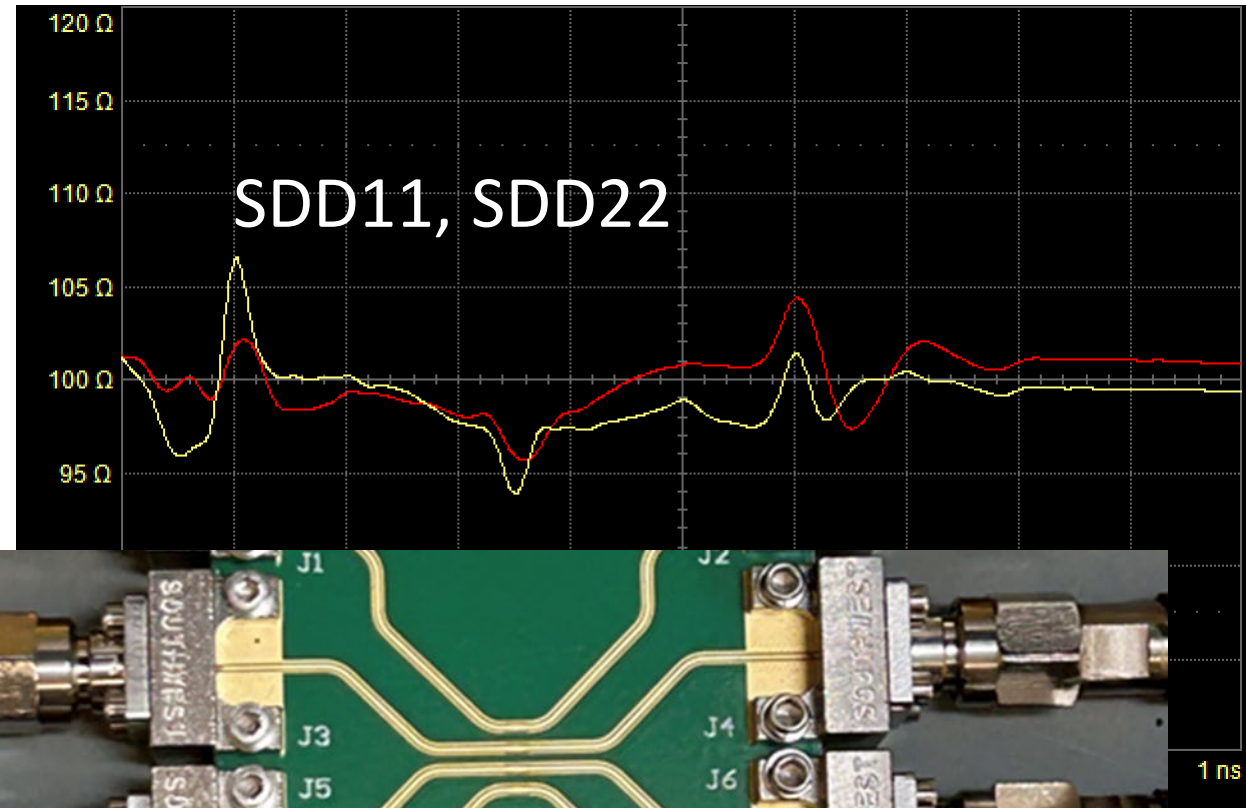
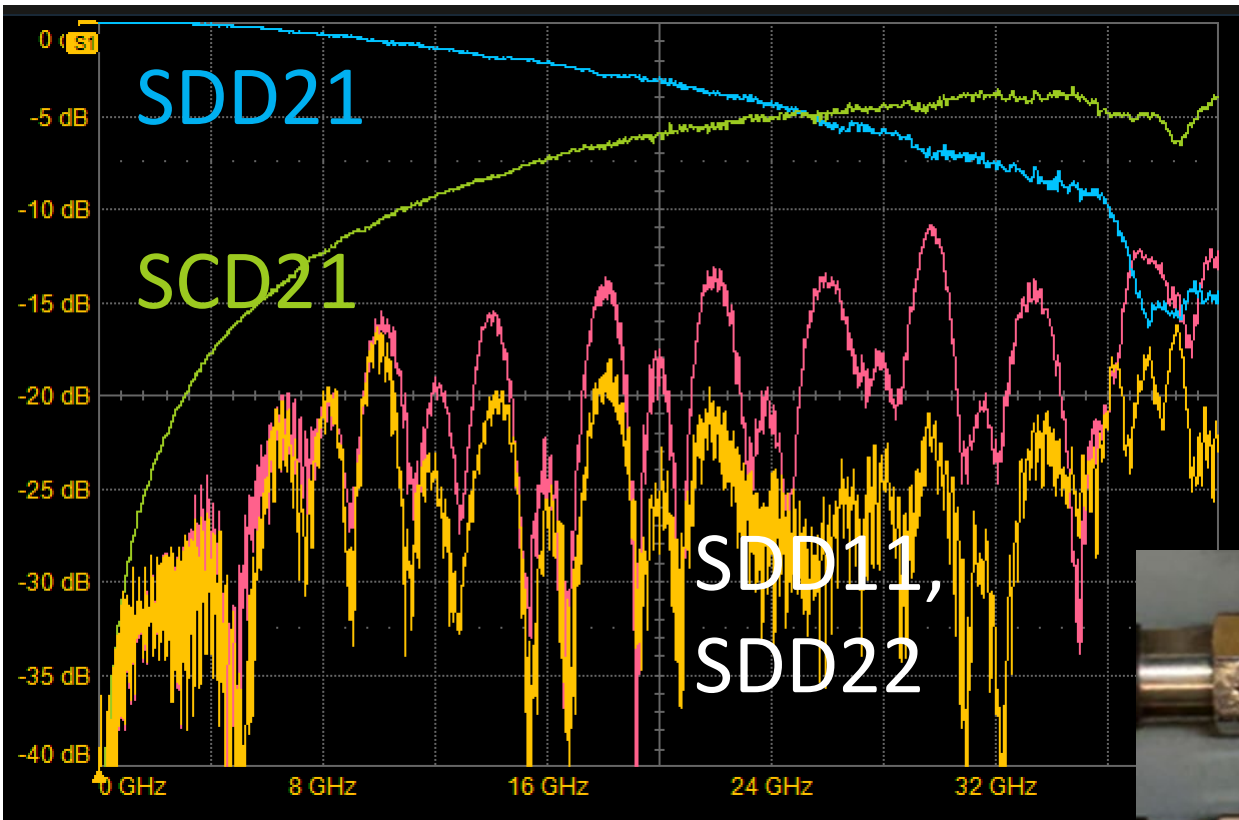


10 psec difference is ~ 70 mils path length difference
Probably related to the connector launch

@ 40 GHz, period is 25 psec, 10 psec is significant.



Differential Response

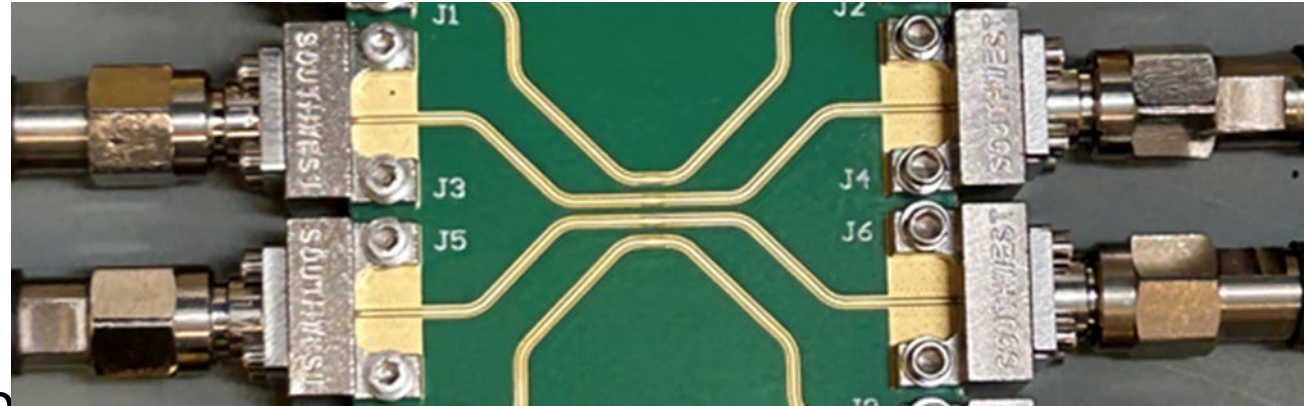


Drop in SDD21 from attenuation and from mode conversion
@ 40 GHz, period = 25 psec, skew is 10 psec

Some end to end asymmetry, but not a problem

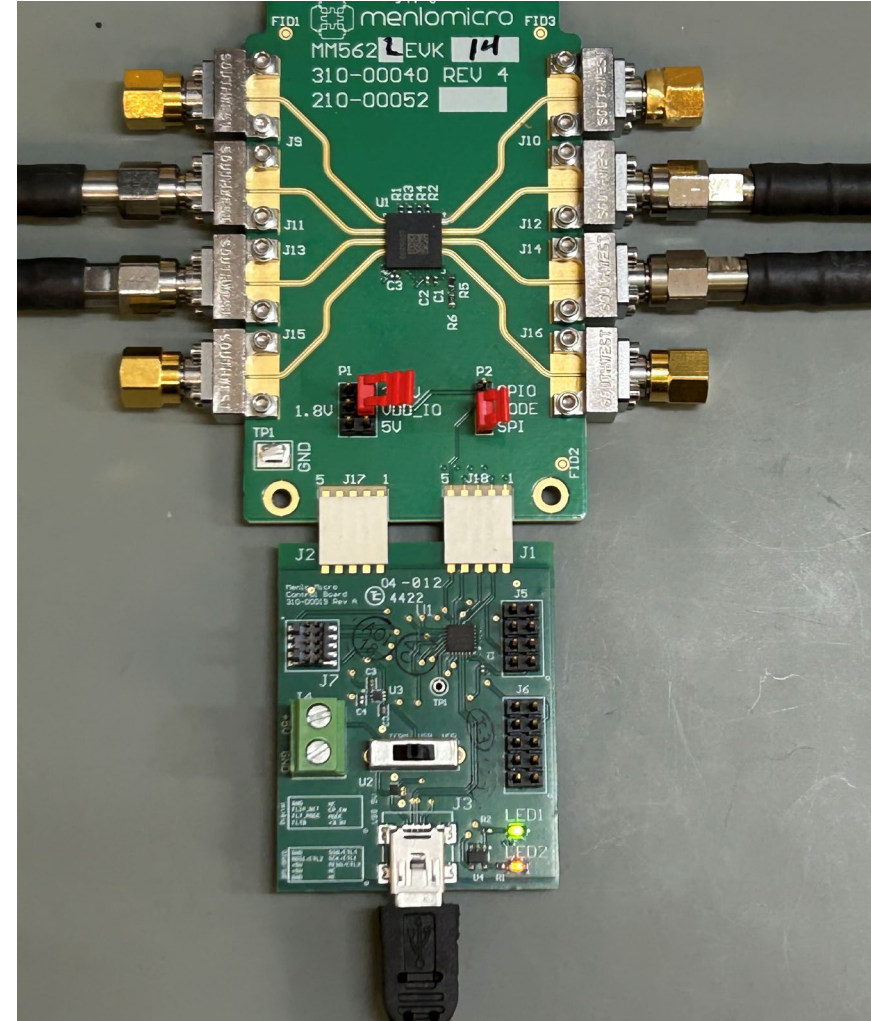
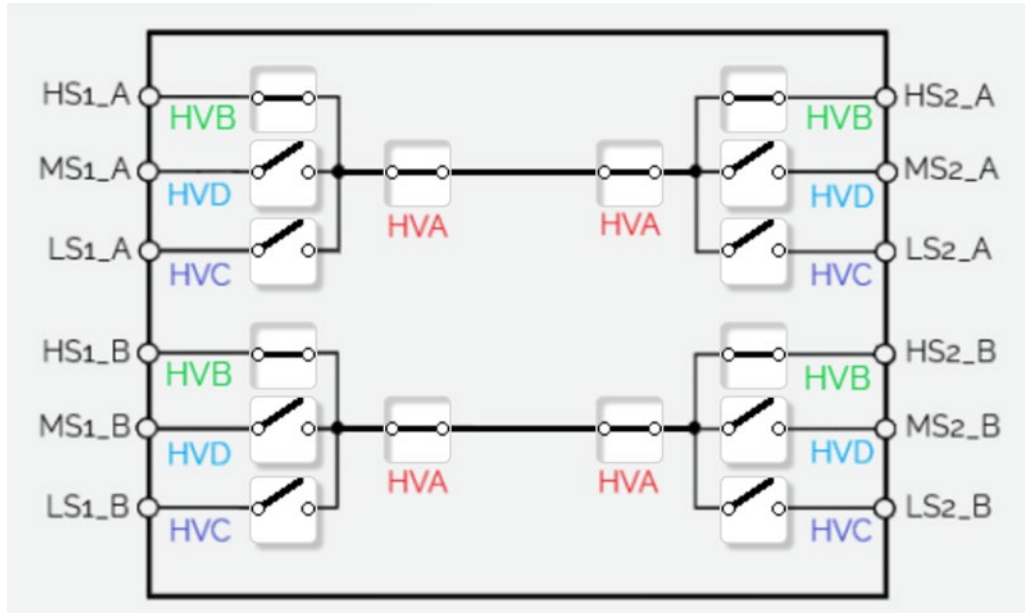
Observations

- In the fixture board:
 - ✓ Some line-to-line asymmetry
 - ✓ Some discontinuities from the connectors
 - ✓ Some interconnect attenuation
 - ✓ Some p, n line length contributing to mode conversion
- In the switch:
 - ✓ Pay attention to the mode conversion
 - ✓ Pay attention to connector asymmetry
 - ✓ Pay attention to the fixture attenuation

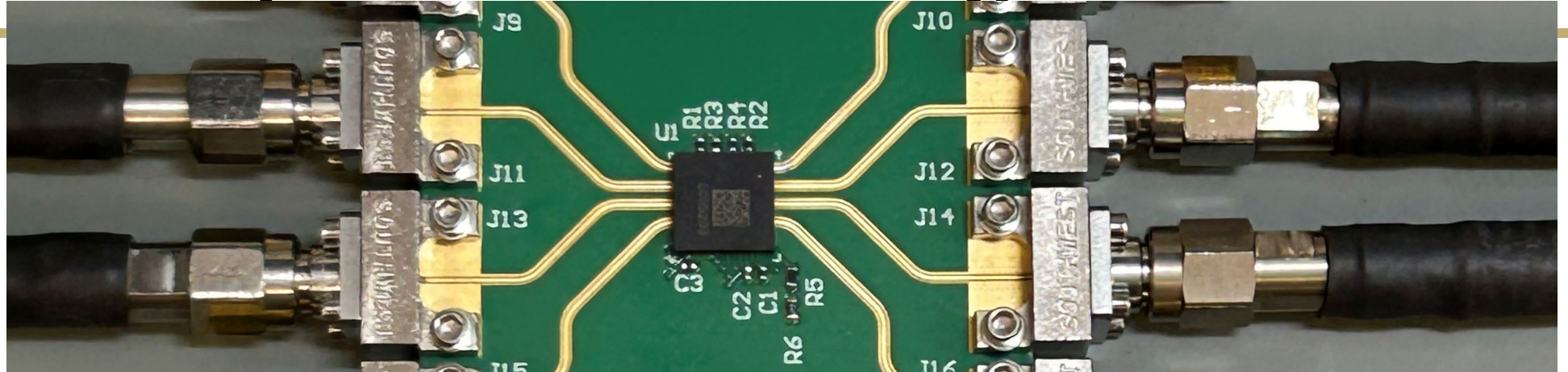


Controlling the Switch with the USB Interface

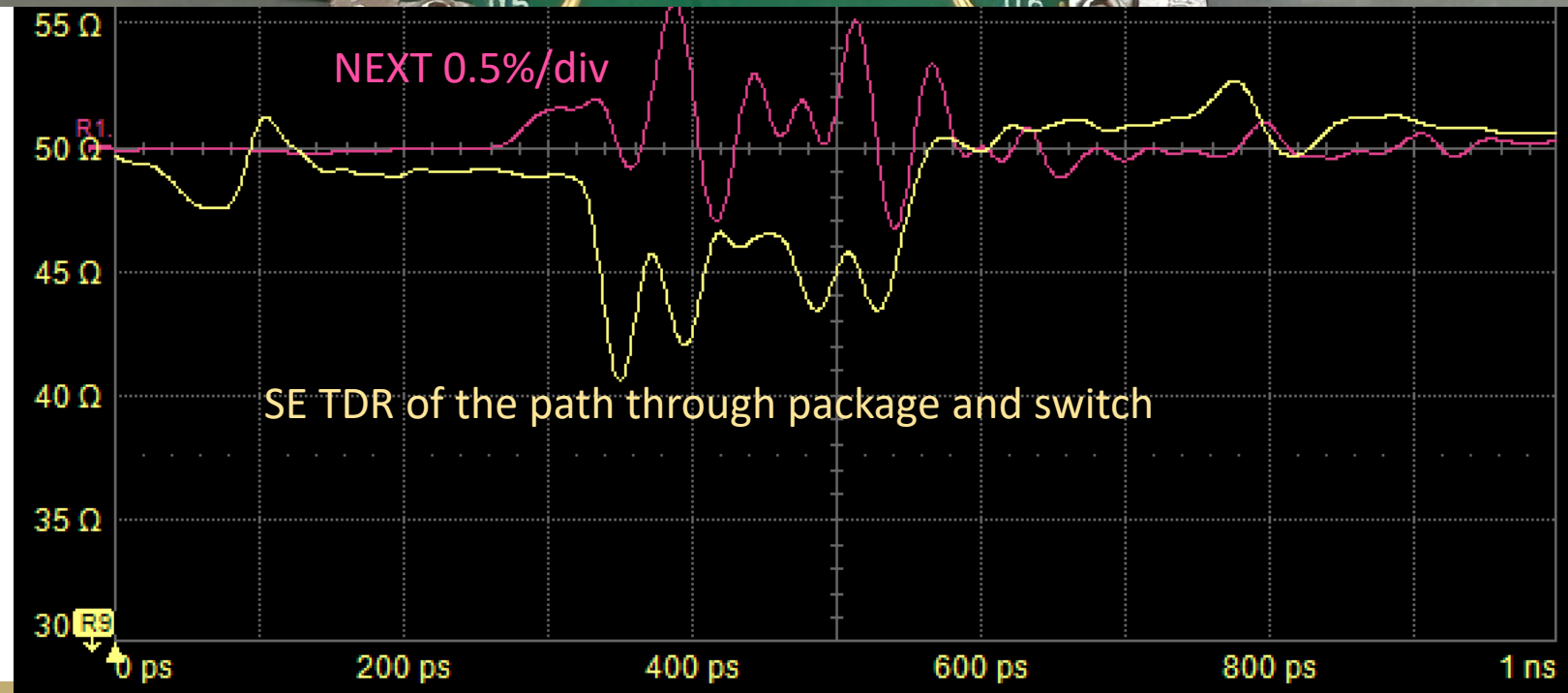
- Electronics board has USB interface to control the switches



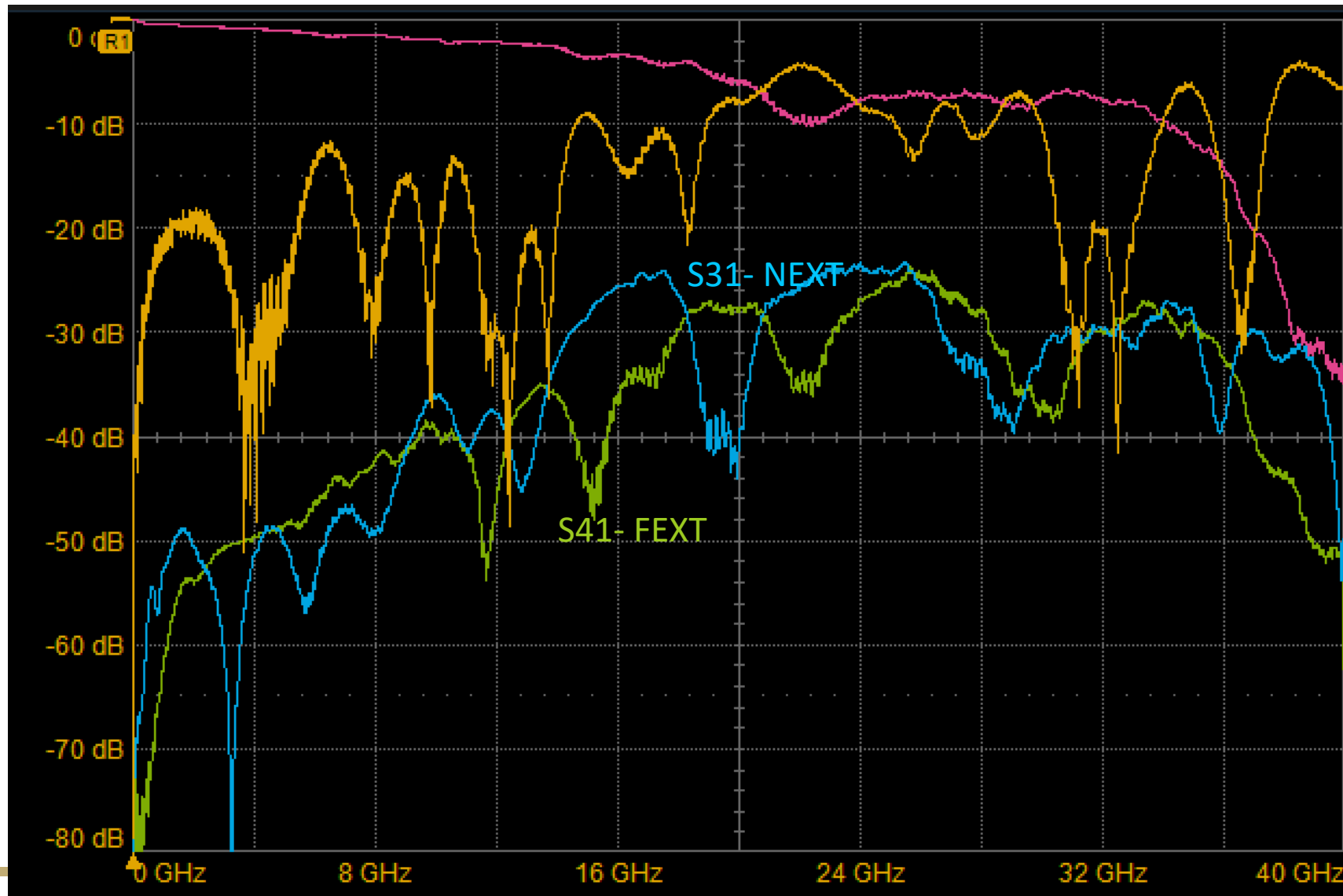
Impact of the Package



Virtually uncoupled structure, SE and diff response will be the same



SE S-Parameter Response

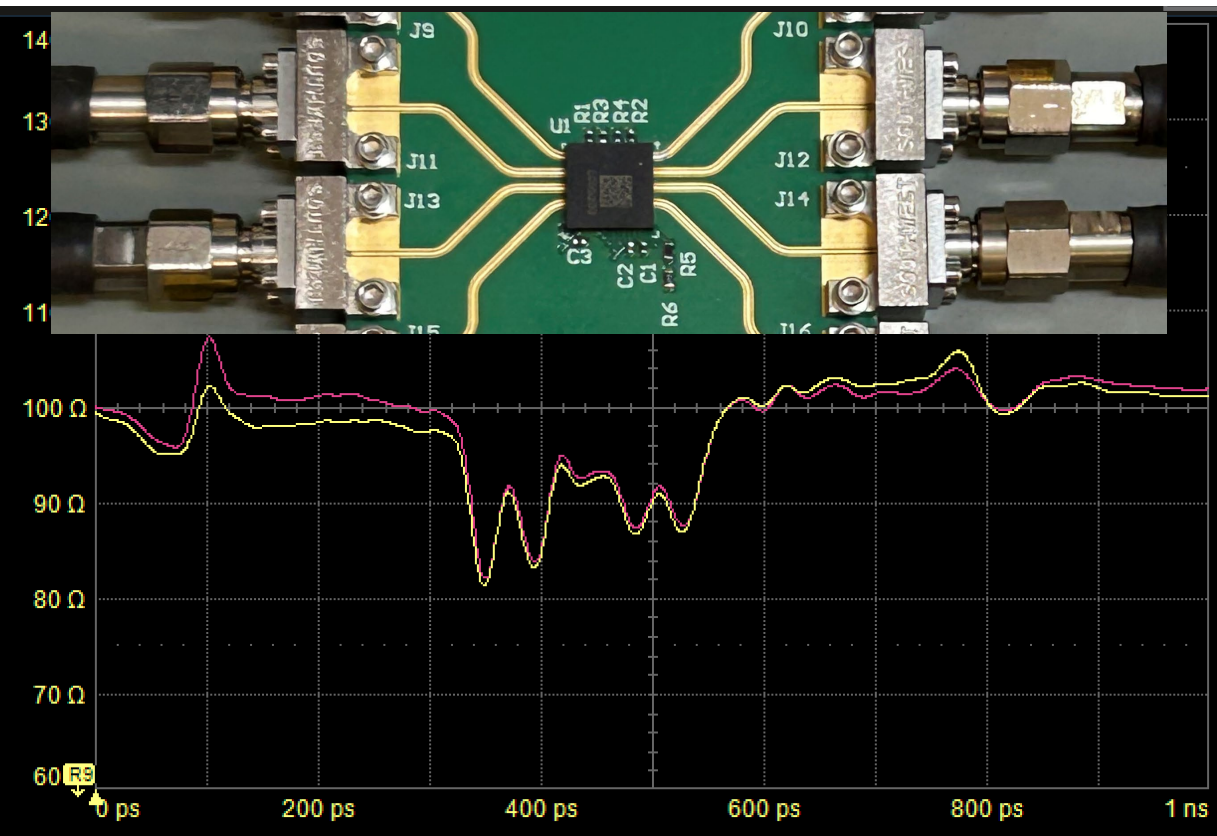
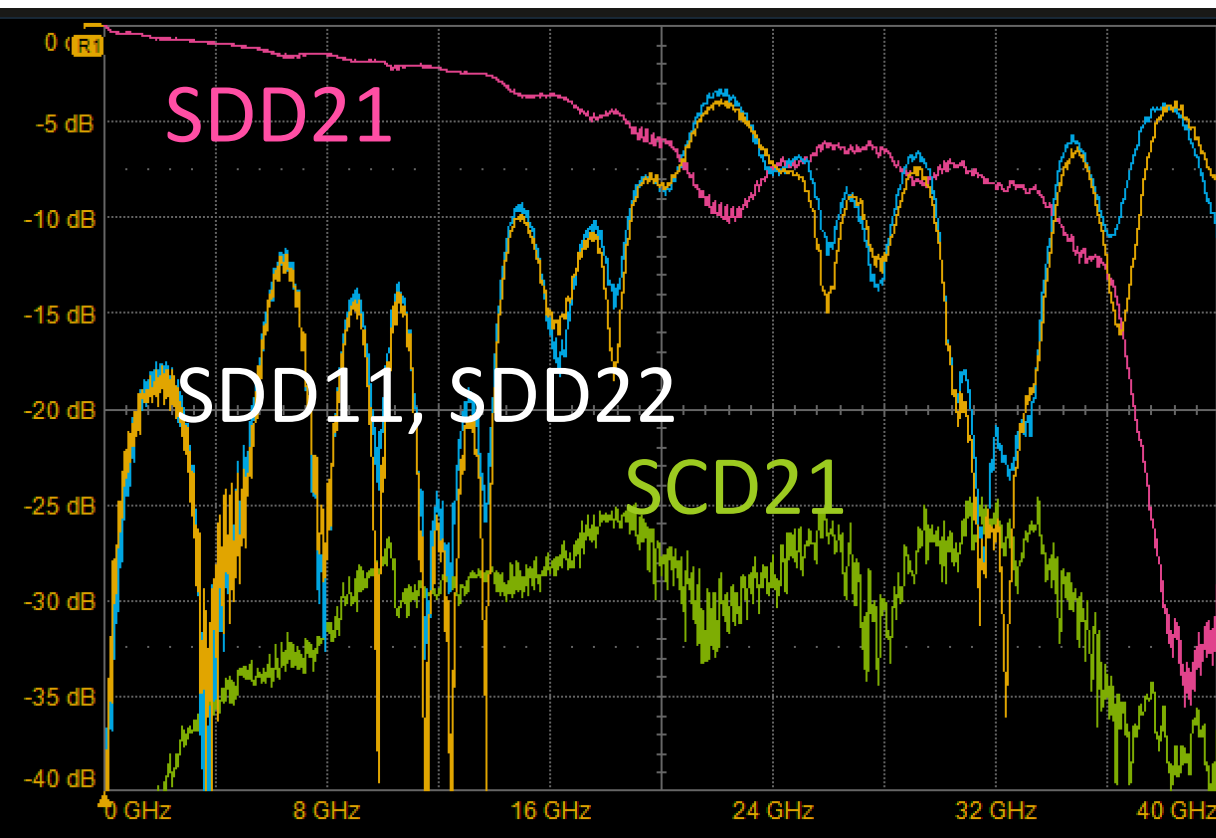


Impact on S21 from fixture losses

When $S_{11} > -10$ dB, expect some impact on S21

Discontinuities in package at 22 GHz causes drop insertion loss to -10 dB

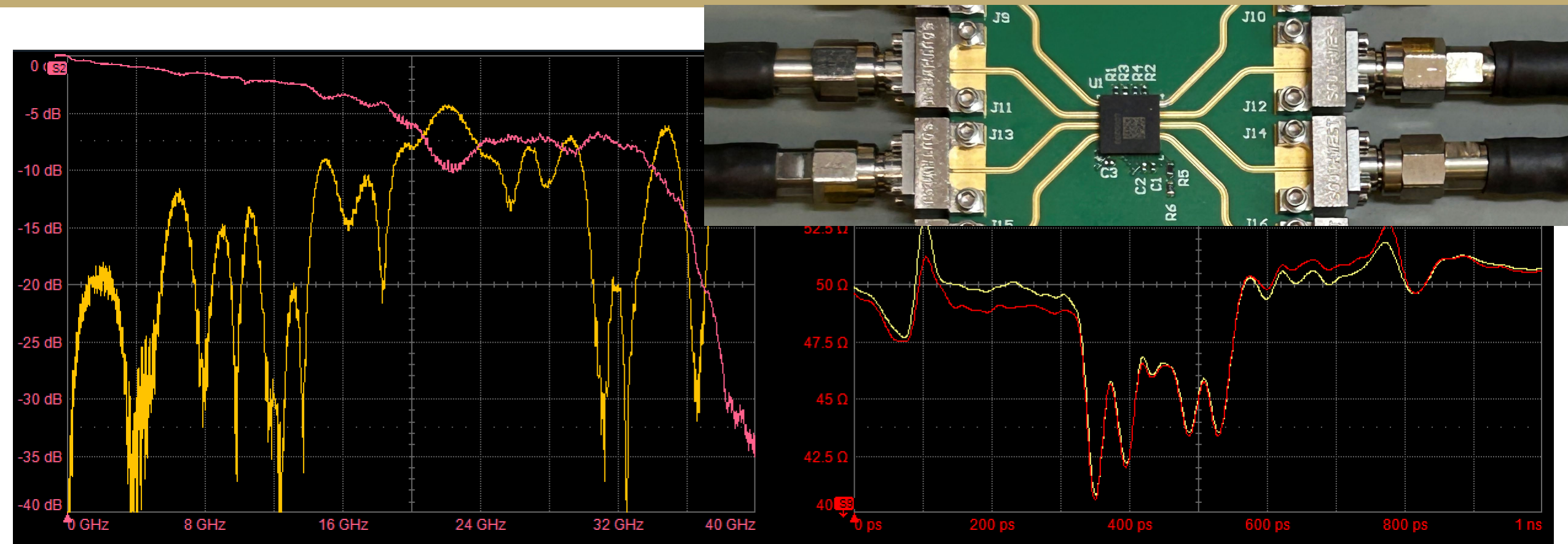
Differential Response



Mode conversion not significant in this board

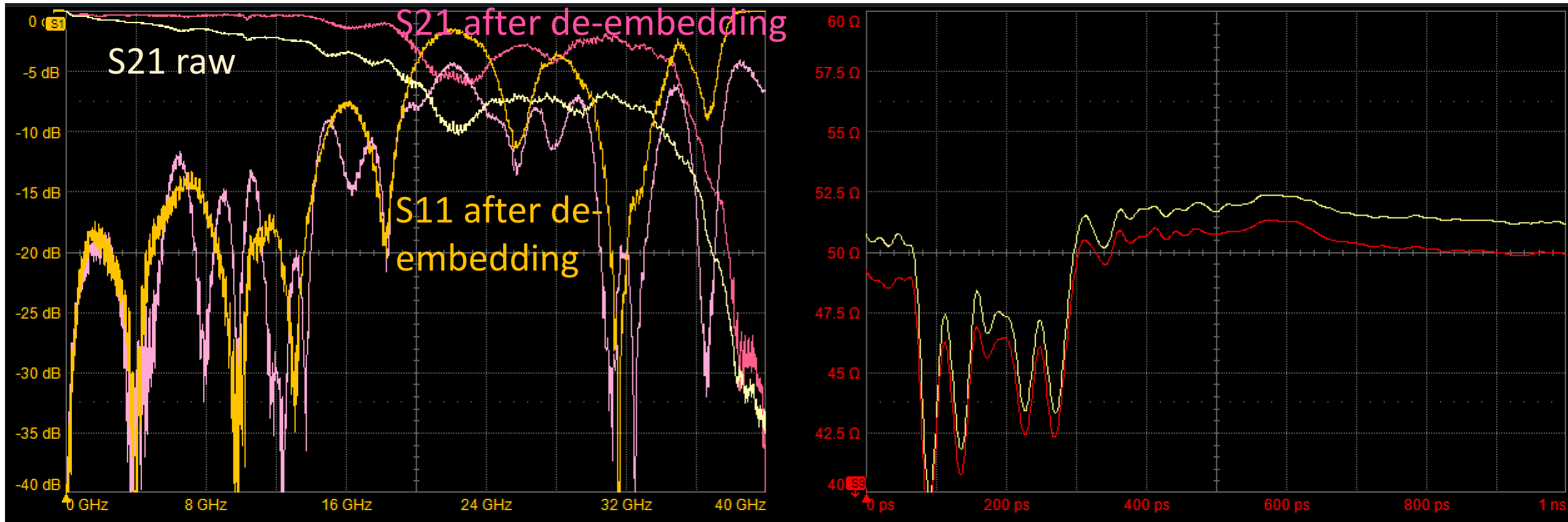
Losses from the fixture board contribute to the insertion loss, in addition to package discontinuities

ONLY Export SE Behavioral Model to Use in System Simulation



Need to de-embed the connector launches and the losses in the board traces

SE With De-embedding to Remove the Losses



At 16 MHz, S21 goes from -3.5 dB to -1.5 dB

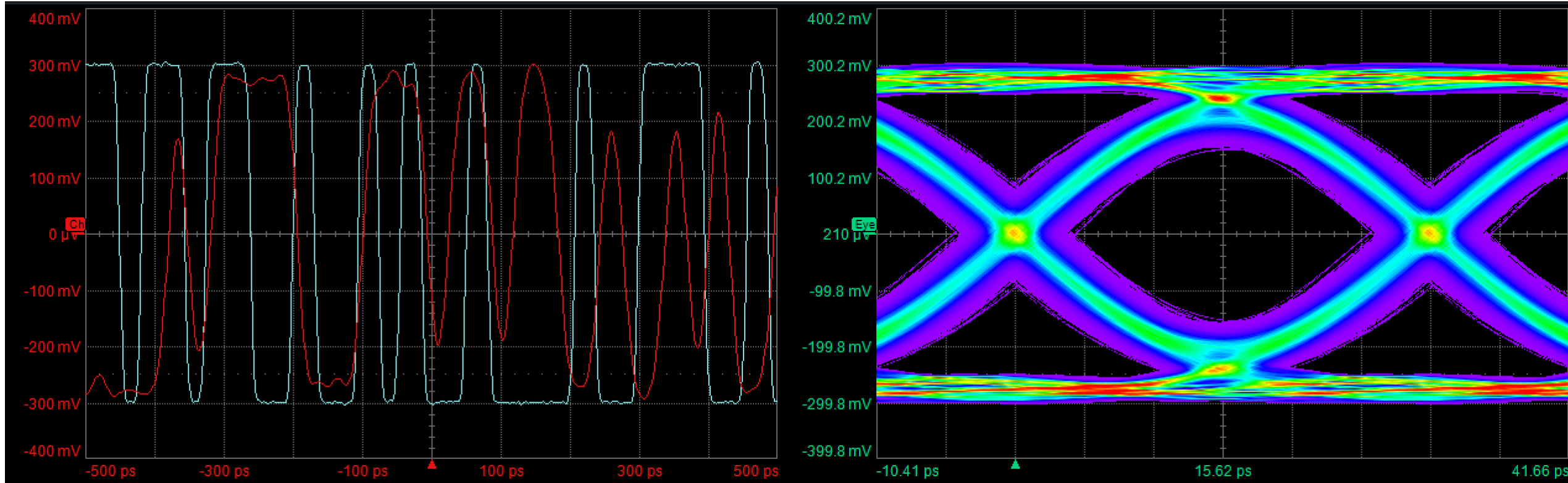
BW of the switch? As limited by the package: -5 dB BW is 20 GHz, -6 dB BW is 35 GHz

Expect ok performance at ~ 40 Gbps NRZ, maybe 80 Gbps PAM4

26

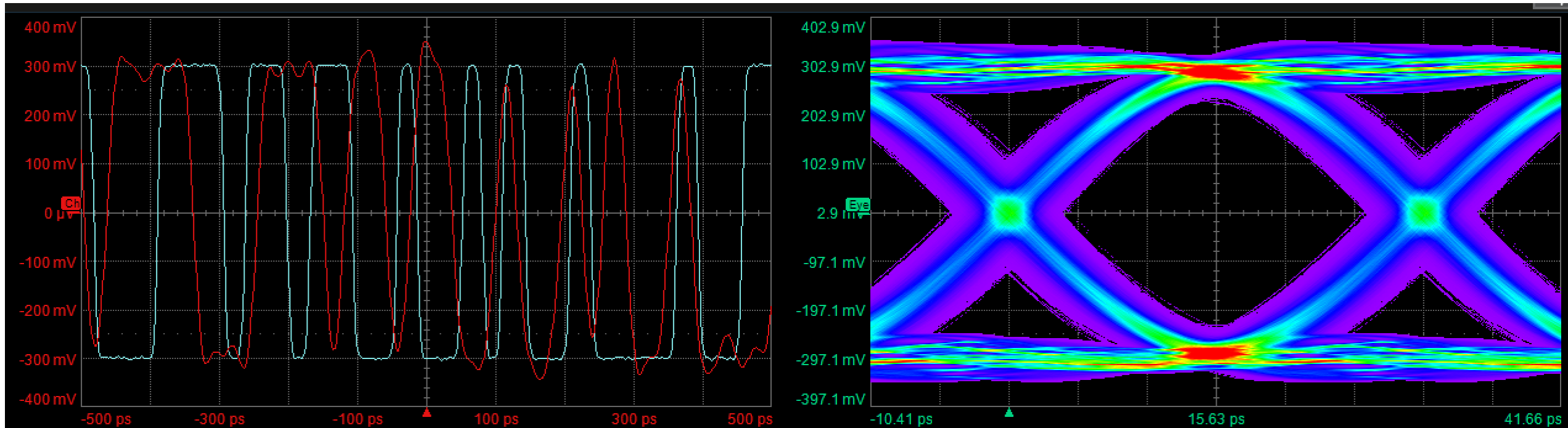
Application space: 32 Gbps NRZ PCIe gen 5

Using raw measurements



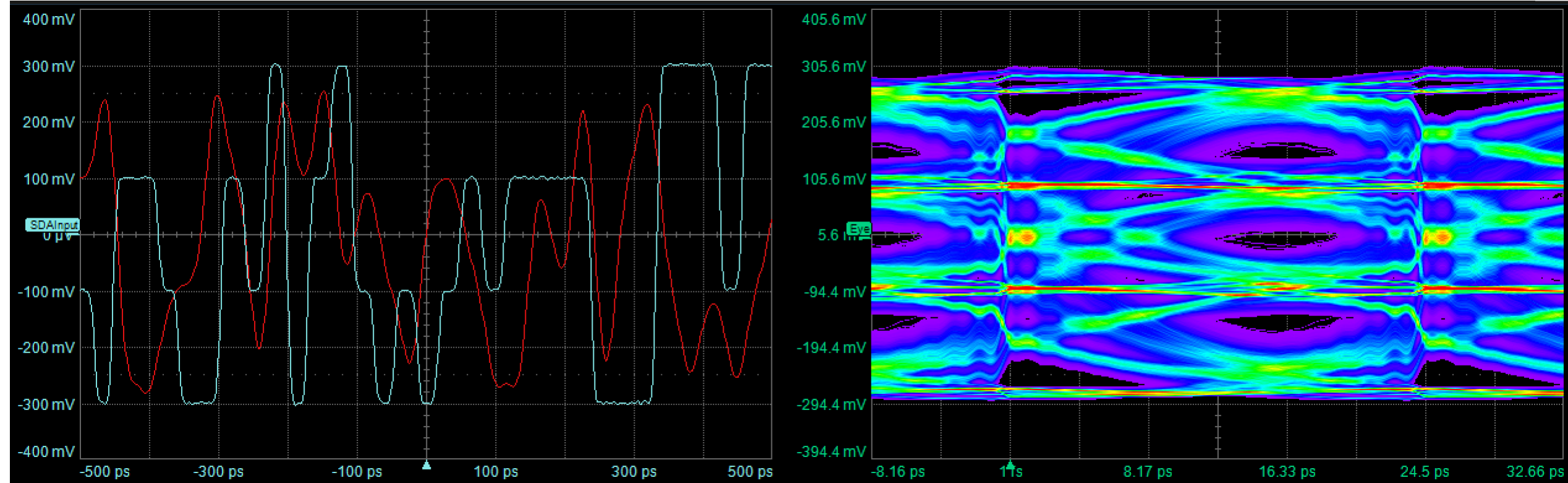
Application space: 32 Gbps NRZ (PCIe gen 5)

Using DUT with fixture board losses de-embedded



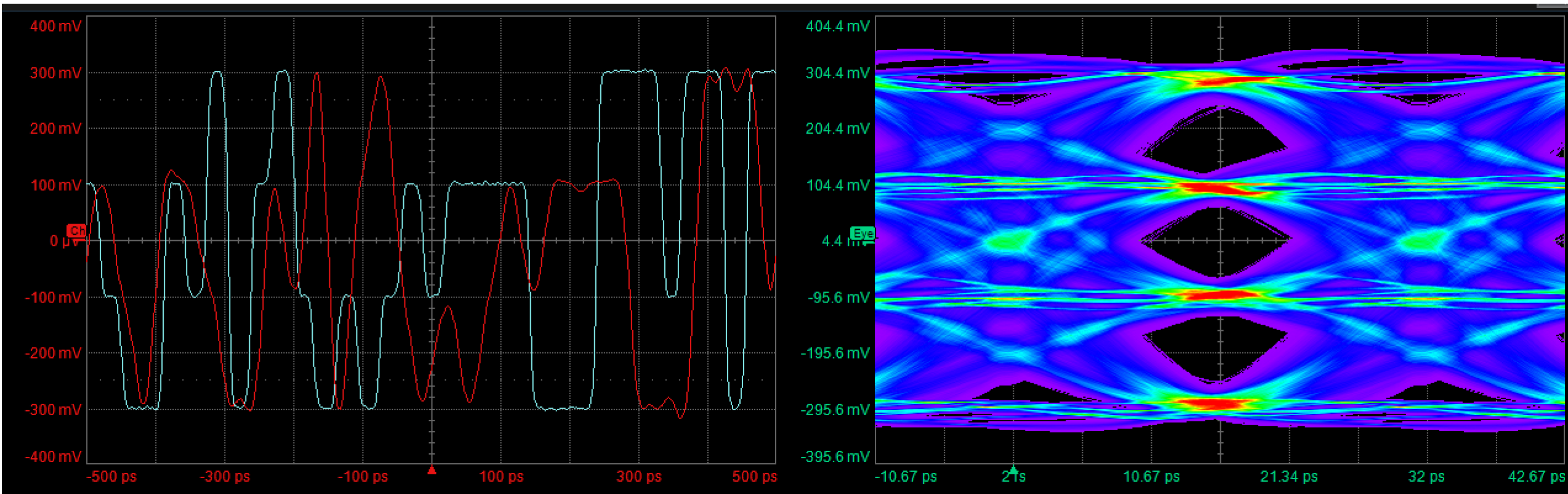
64 Gbps PAM4 (PCIe gen 6)

Using raw measurements



64 Gbps PAM4 (PCIe gen 6)

Using DUT with fixture board losses de-embedded



Summary

- After-market upgrading WavePulser cables is very easy
- Understanding your fixture is very important
- Look at all the S-parameters available
- Take advantage of some of the special de-embedding features in the WavePulser software to optimize your DUT performance
- Extract single-ended S-parameters as the behavioral model for system simulation
- At 32 Gbps and above, everything matters. Like losses from traces in the fixture
 - ✓ Can make the difference between margin and pretty good



Thank you!