Characterizing a MEMS switch for High-speed SerDes Interfaces

Prof Eric Bogatin,

University of Colorado, Boulder,

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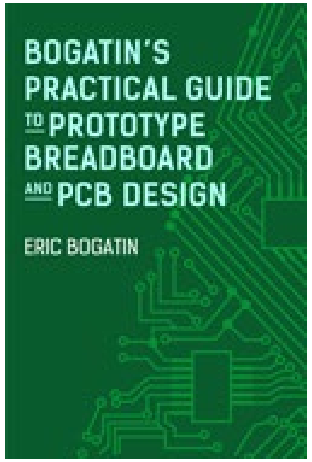
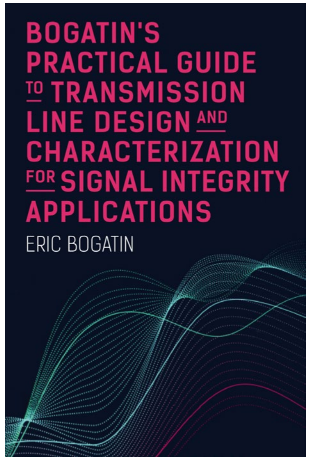
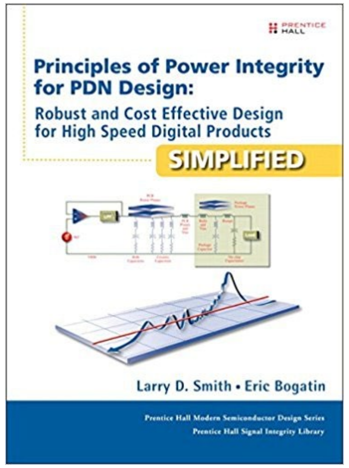
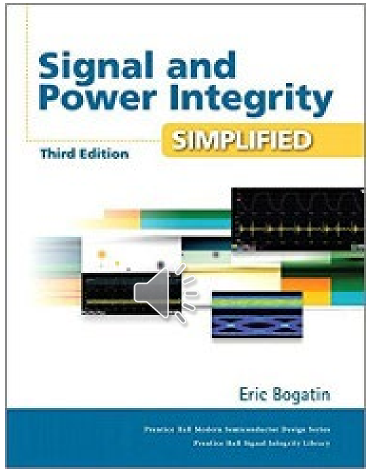






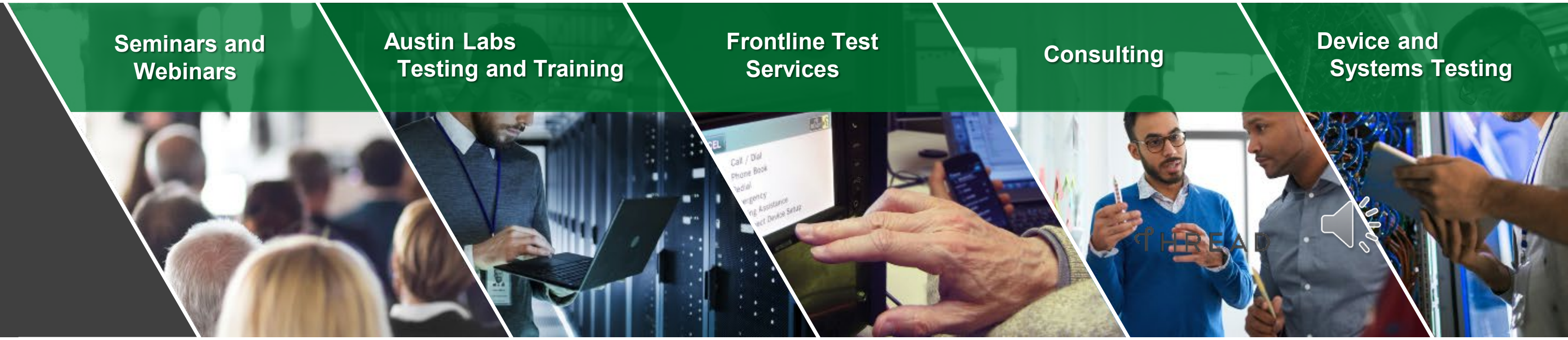


About Teledyne LeCroy

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

Broad array of test solutions for serial data standards and next-gen technologies

Expert-level testing services and world-class training and educational services



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

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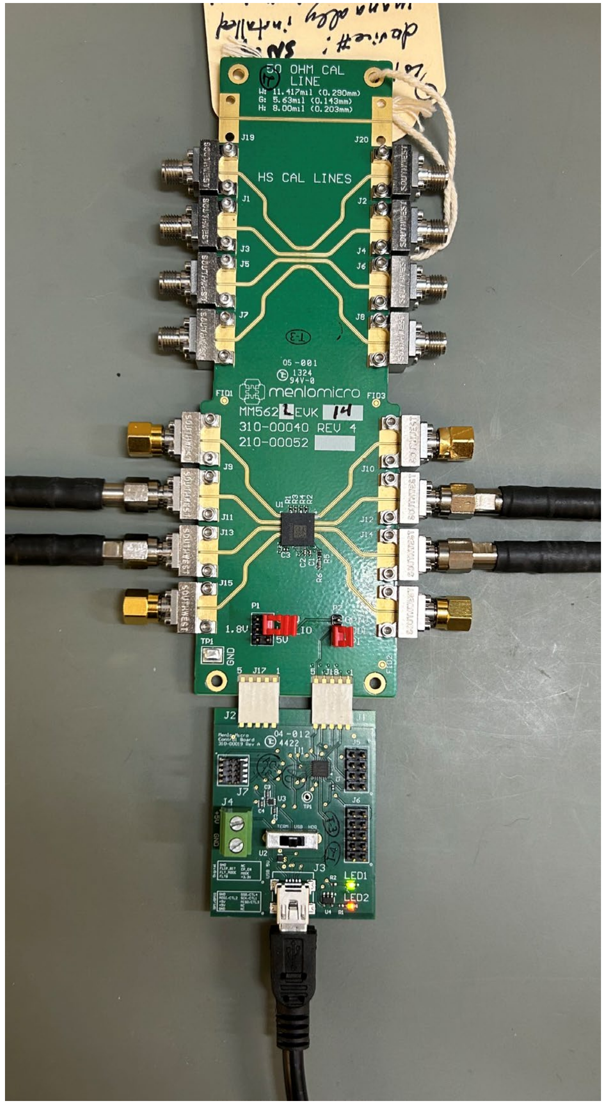
University of Colorado, Boulder
https://www.colorado.edu/faculty/bogatin/

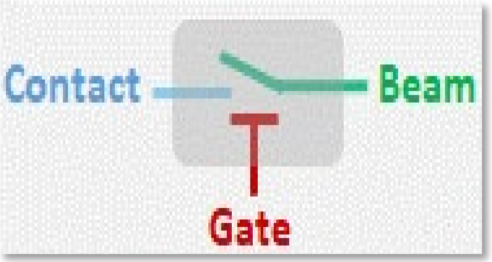
Agenda

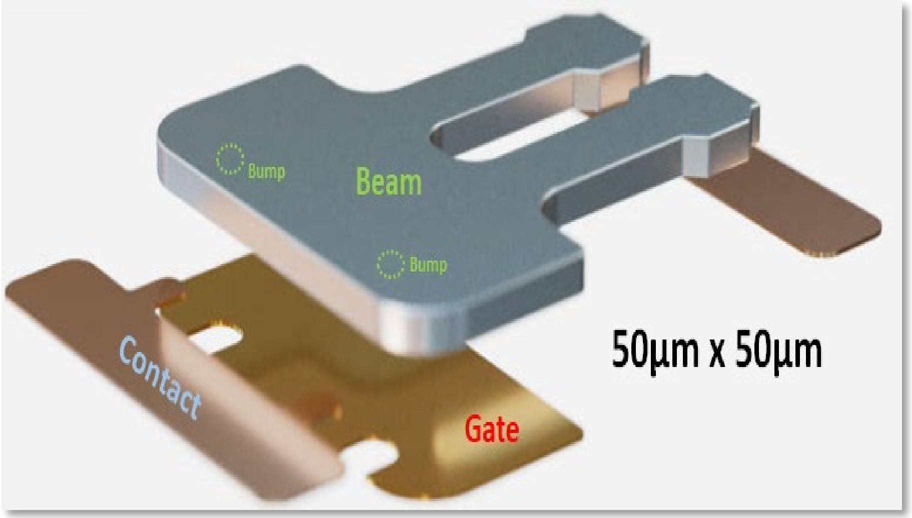
- Changing out the cables in the Wave Pulser
- Reference Thru,
  - ✓ w, wo terminated adjacent traces
  - ✓ SE response and XTK
  - ✓ Diff Response, time and freq, mode conversion
  - ✓ Self De-embedding the Thru ref
- Measuring the switch
  - ✓ SE response
  - ✓ de-embedding
  - ✓ Differential response
  - ✓ 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

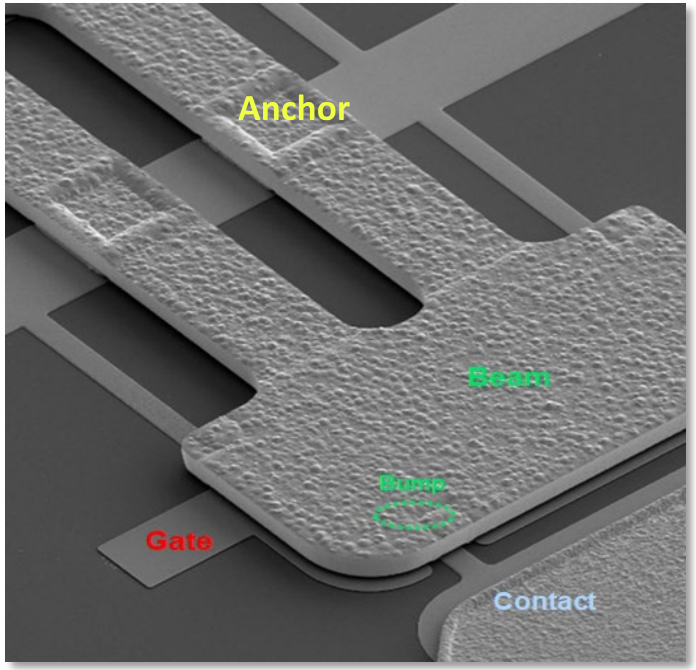


What is Menlo's Ohmic MEMS Switch?

- MEMS stands for Micro-ElectroMechanical System
- 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

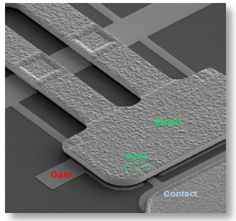


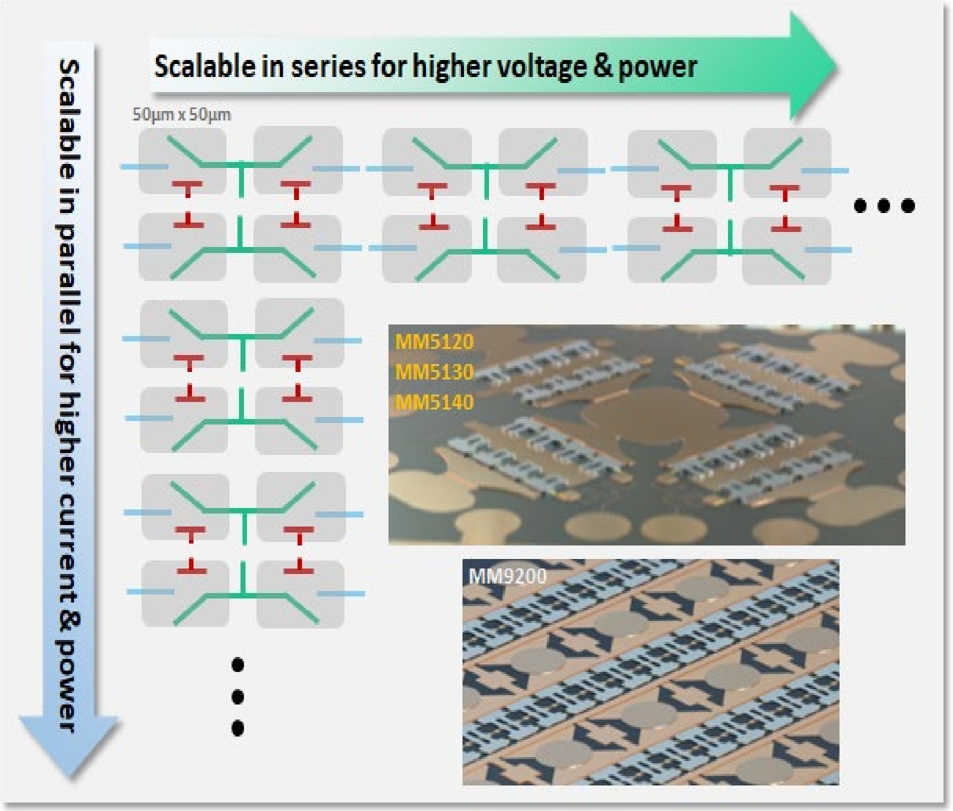


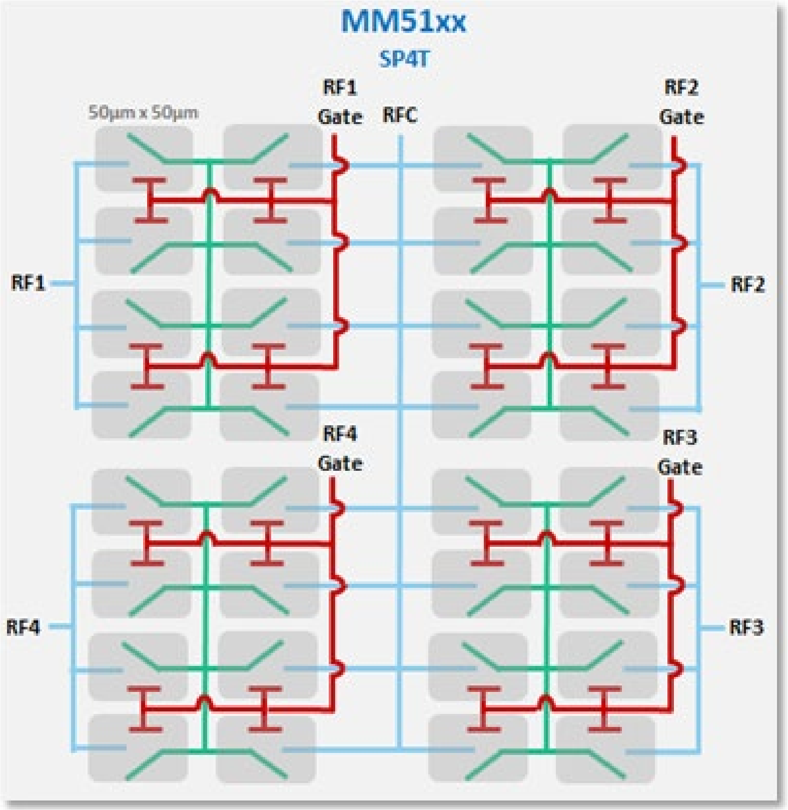


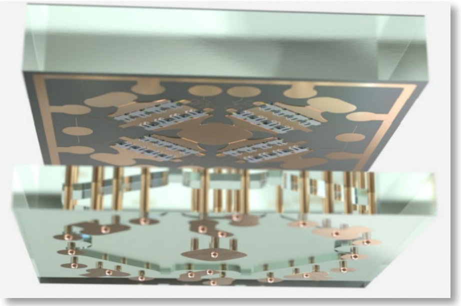
Implemented in Small Footprint Packages

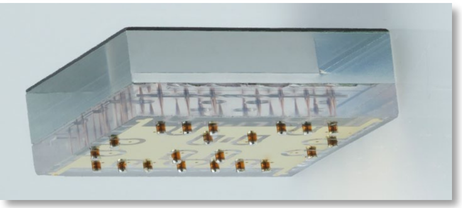
Unit Cell 50µm x 50µm → **2D Scalability** → **Switch Portfolio** → **System In Glass SiG**

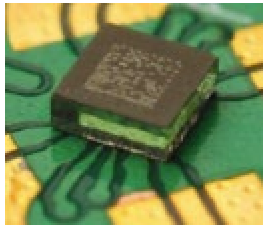








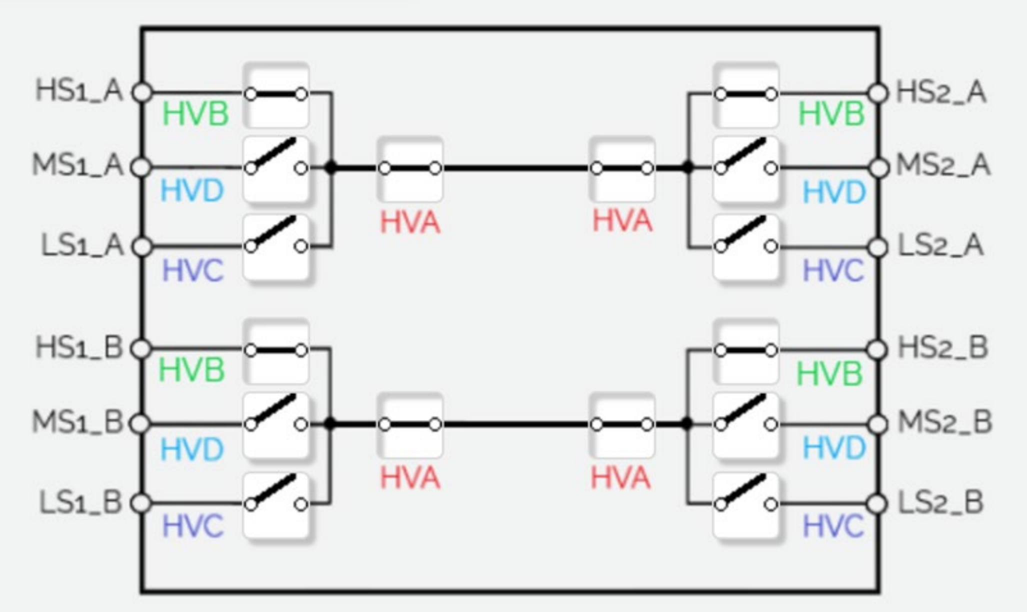


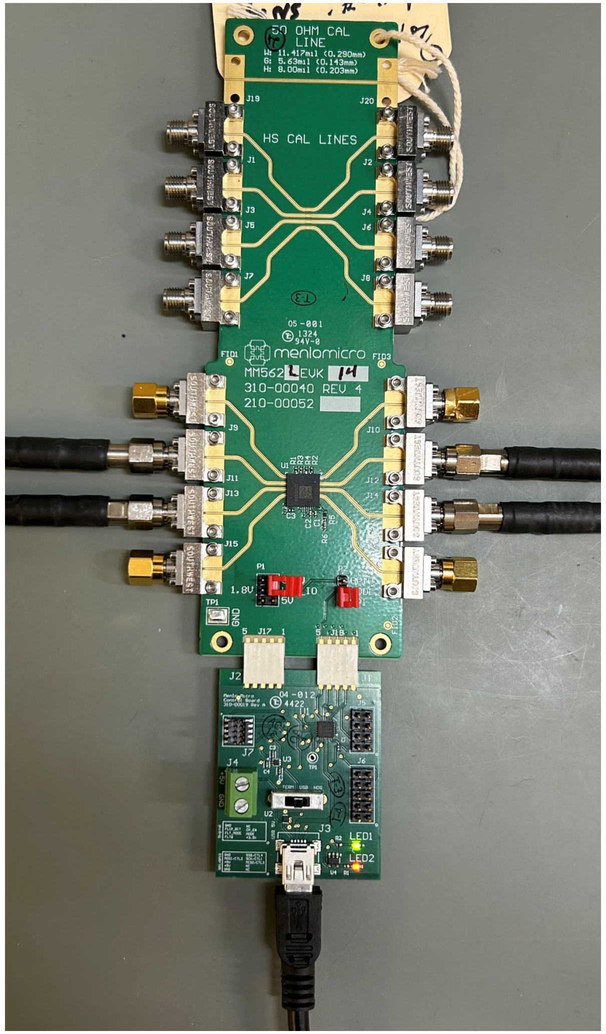


Package Size:
2.5 x 2.5 x 0.9 mm^3

A Simple, General-Purpose Eval Board

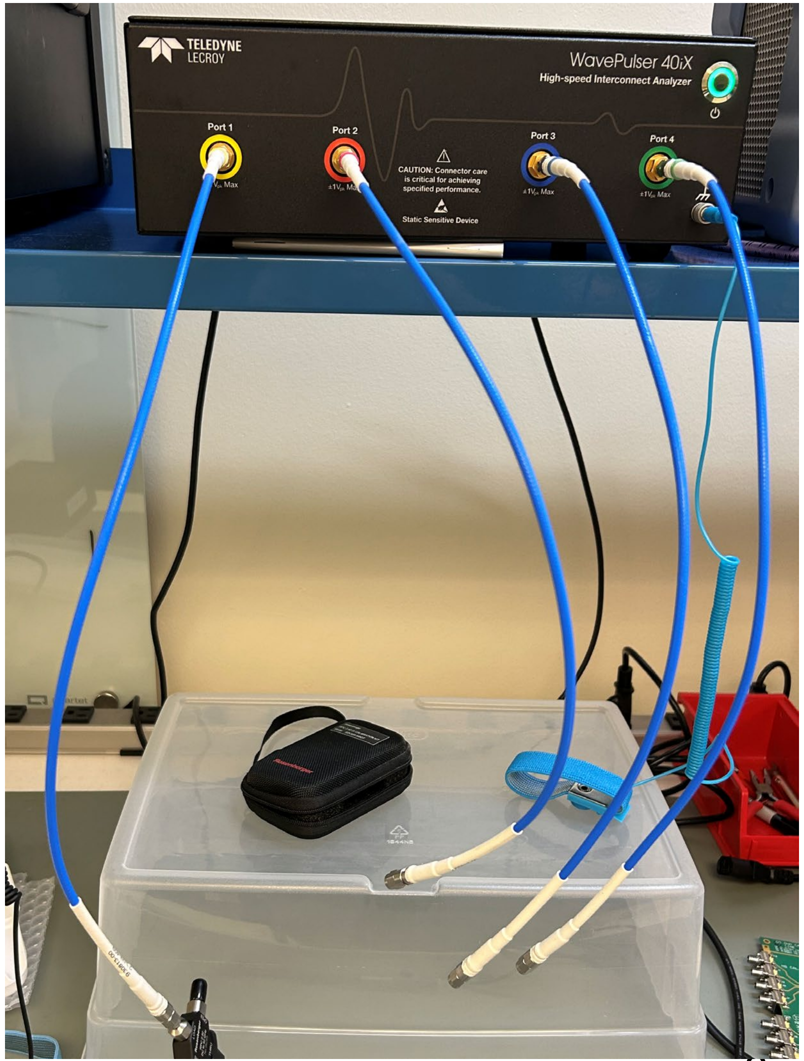
- Electronics board has USB interface to control the switches





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

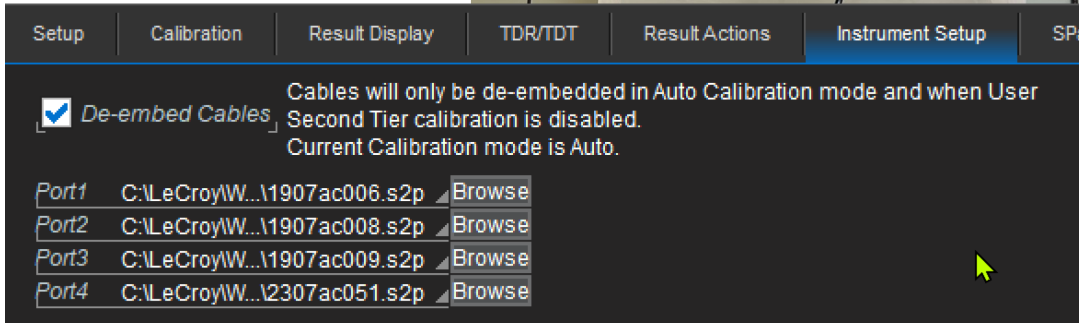


Wanted to Change out the Cables

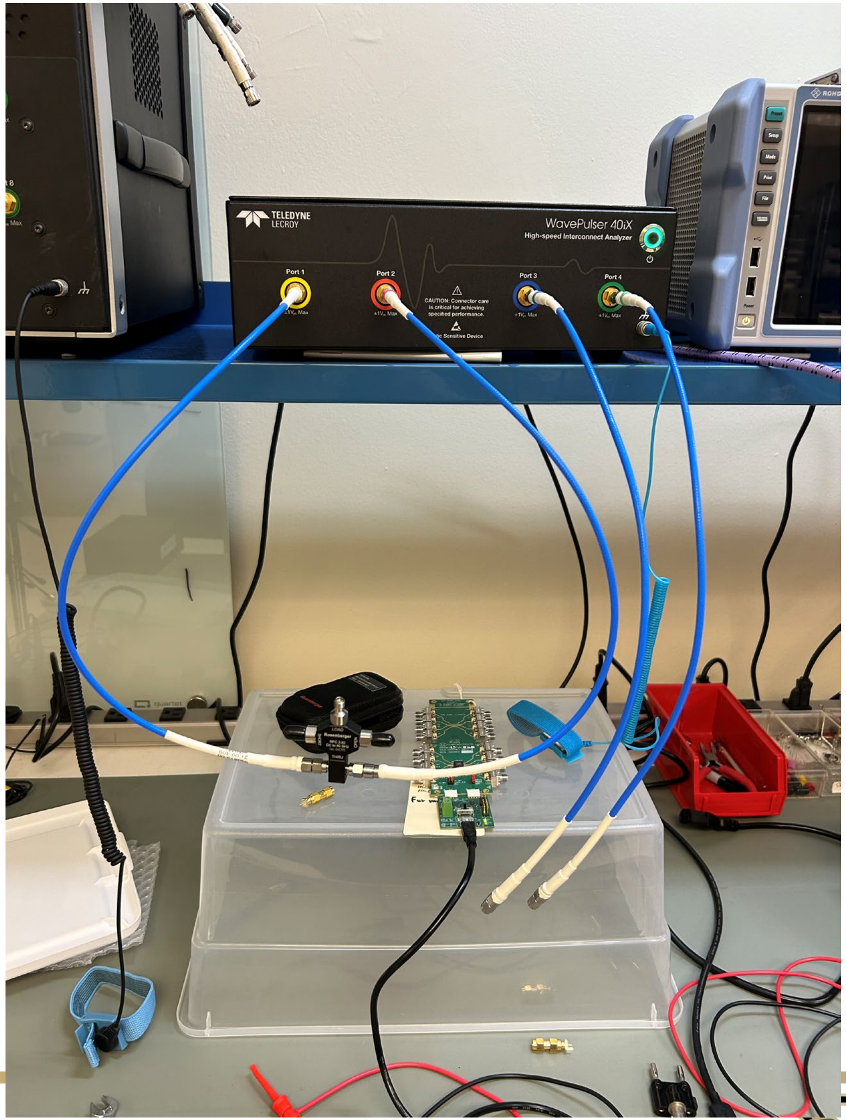
- Shipped cables are short and rigid
- Want to use new cables that are long and flexible
  - ✓Graciously donated by Junkosha USA and Packet Micro
  - ✓Junkosha Cables MWX161

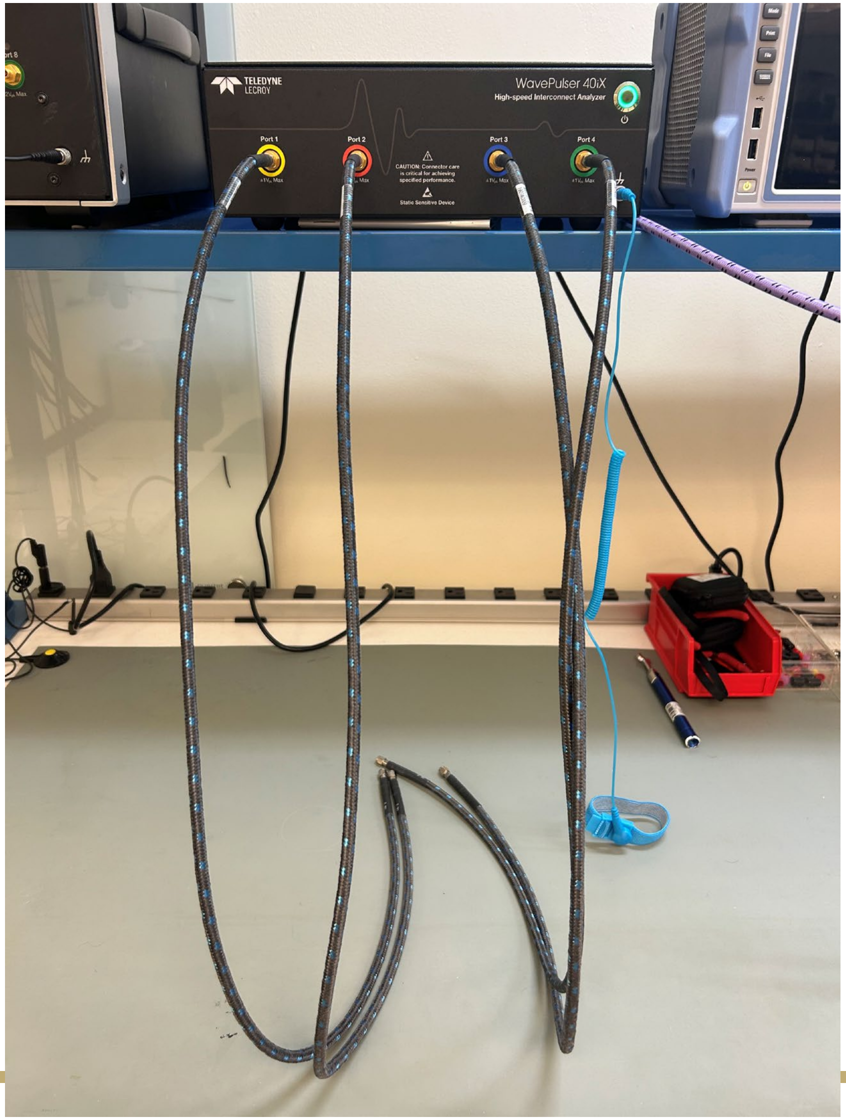
Simple process:

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



Old and New Cables

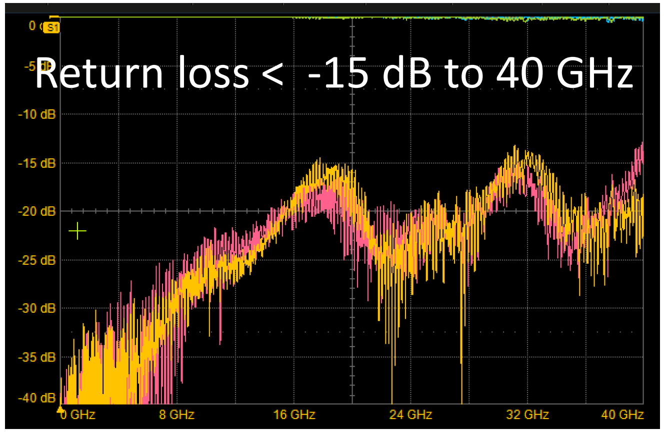


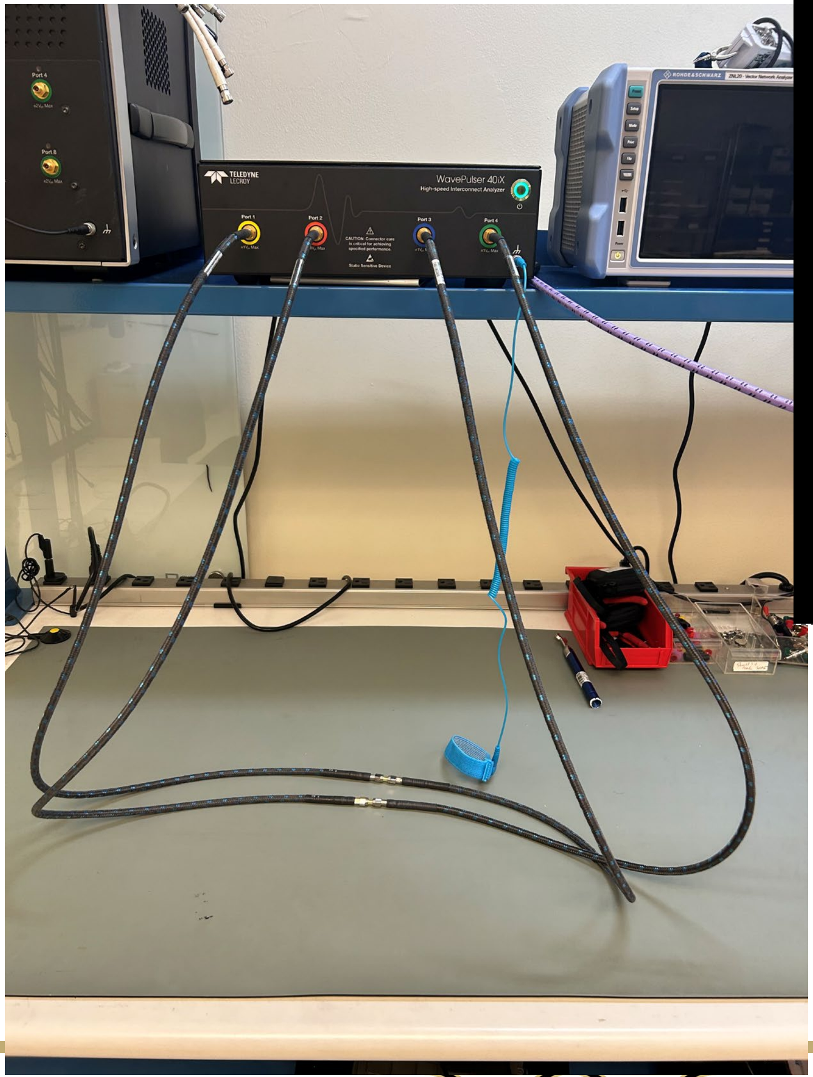


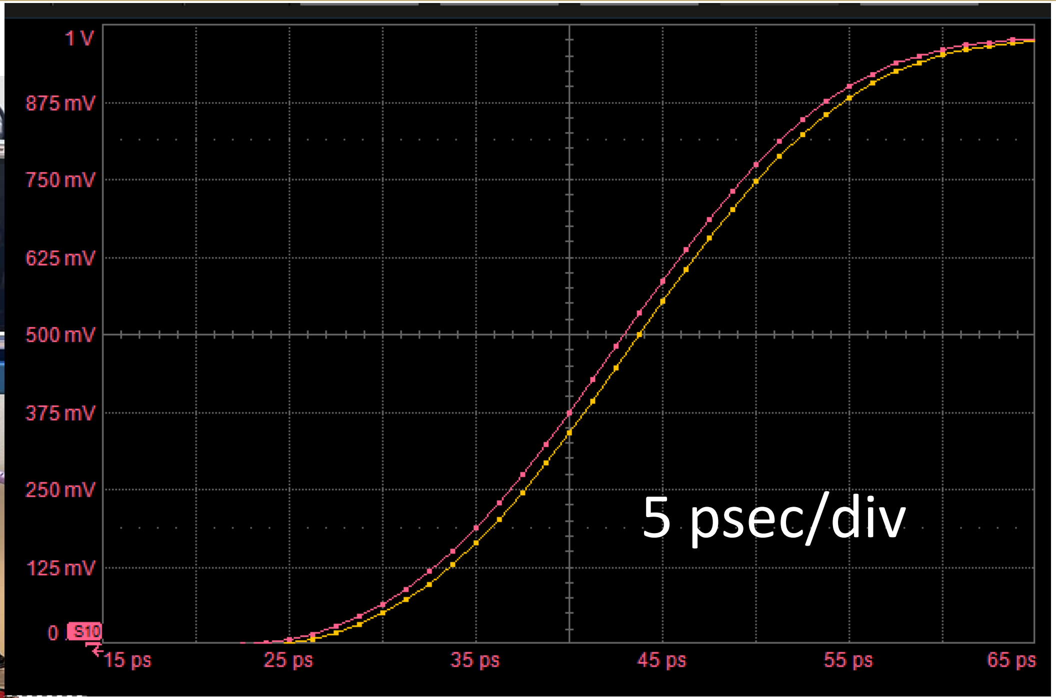
Thru Connection Delays

Using low cost, $1 SMA barrels

Port 1 → 3
Port 2 → 4



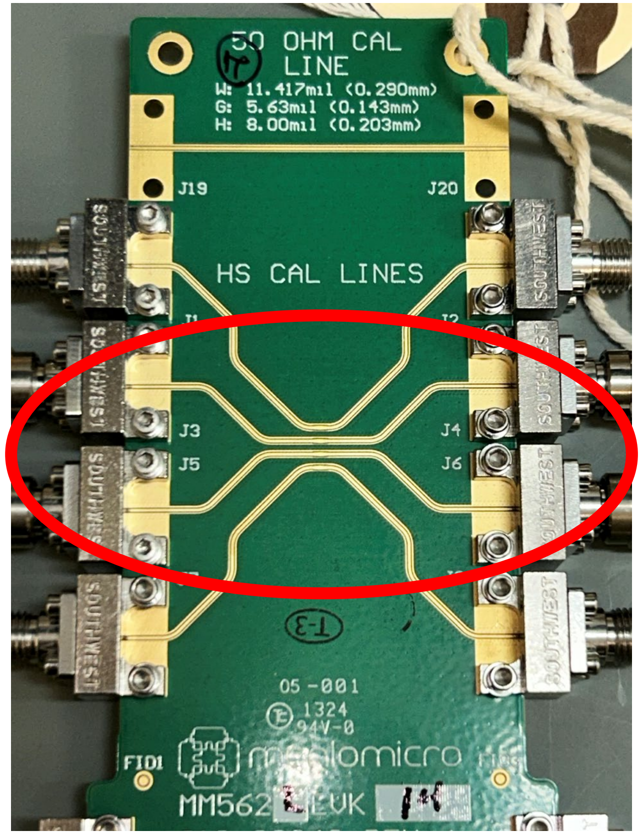


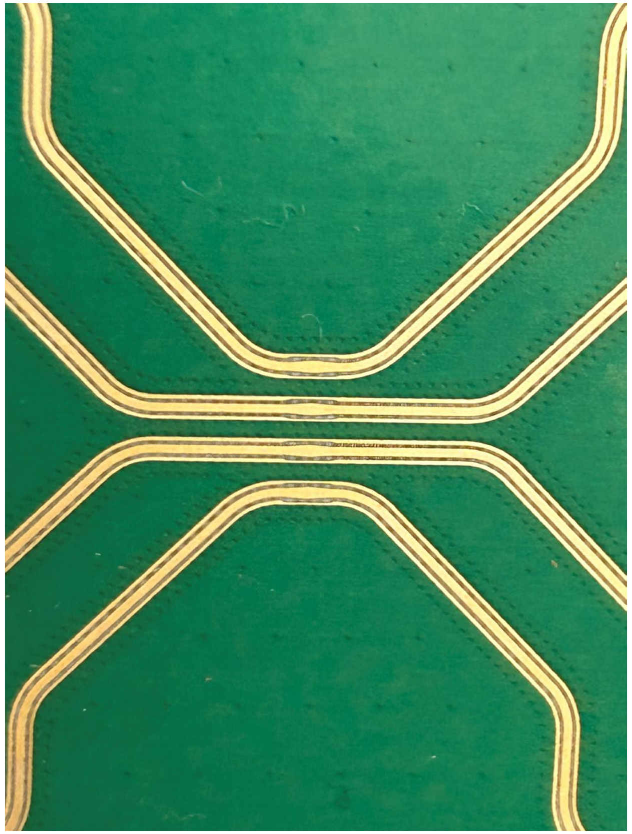


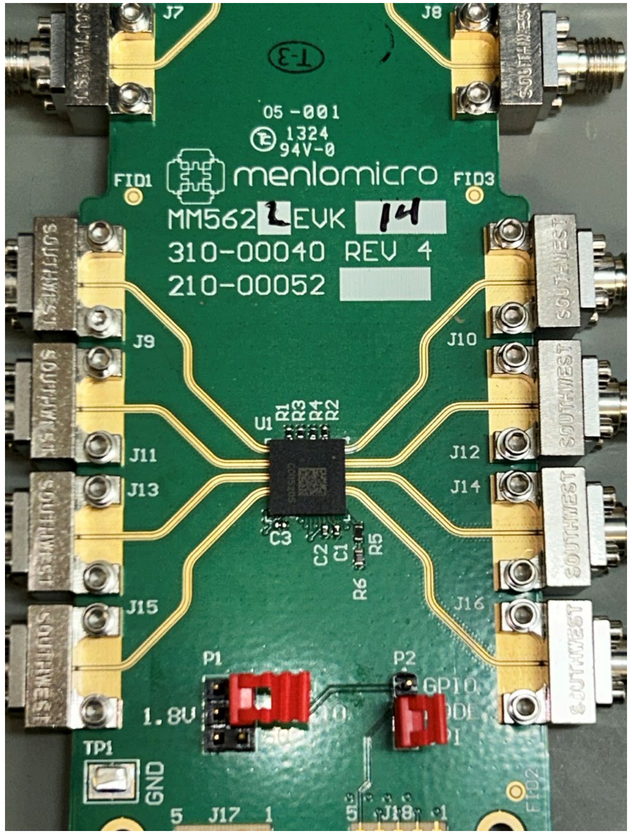
- Residual skew in delay of the thru cables is < 1 psec
- Important metric in p, n skew in differential measurements

The Menlo Micro MEMS Switch Fixture Board

Fixture reference board





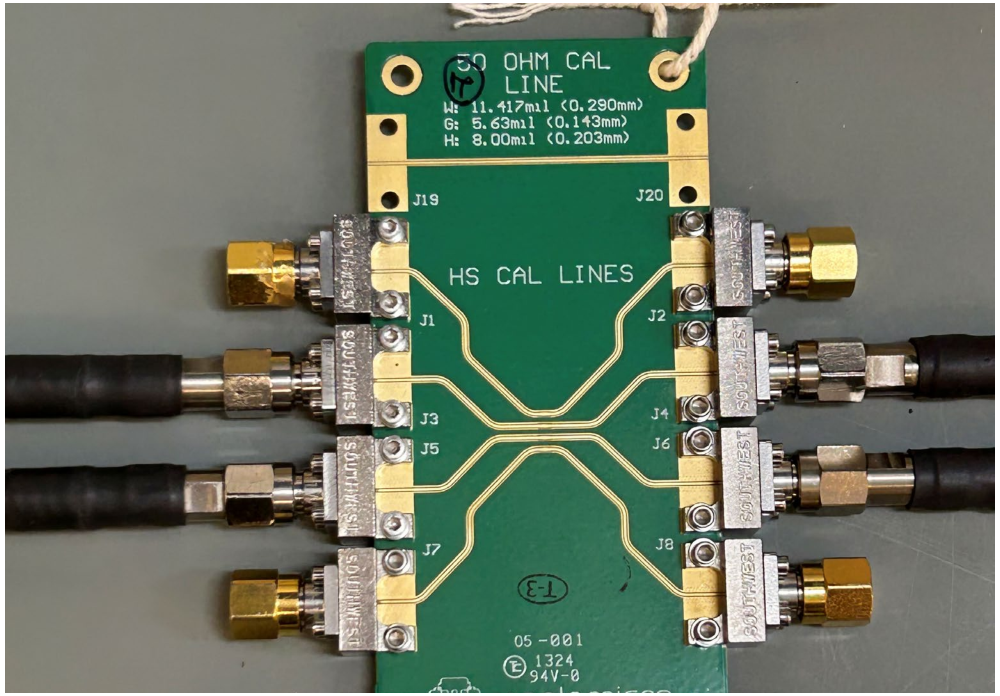


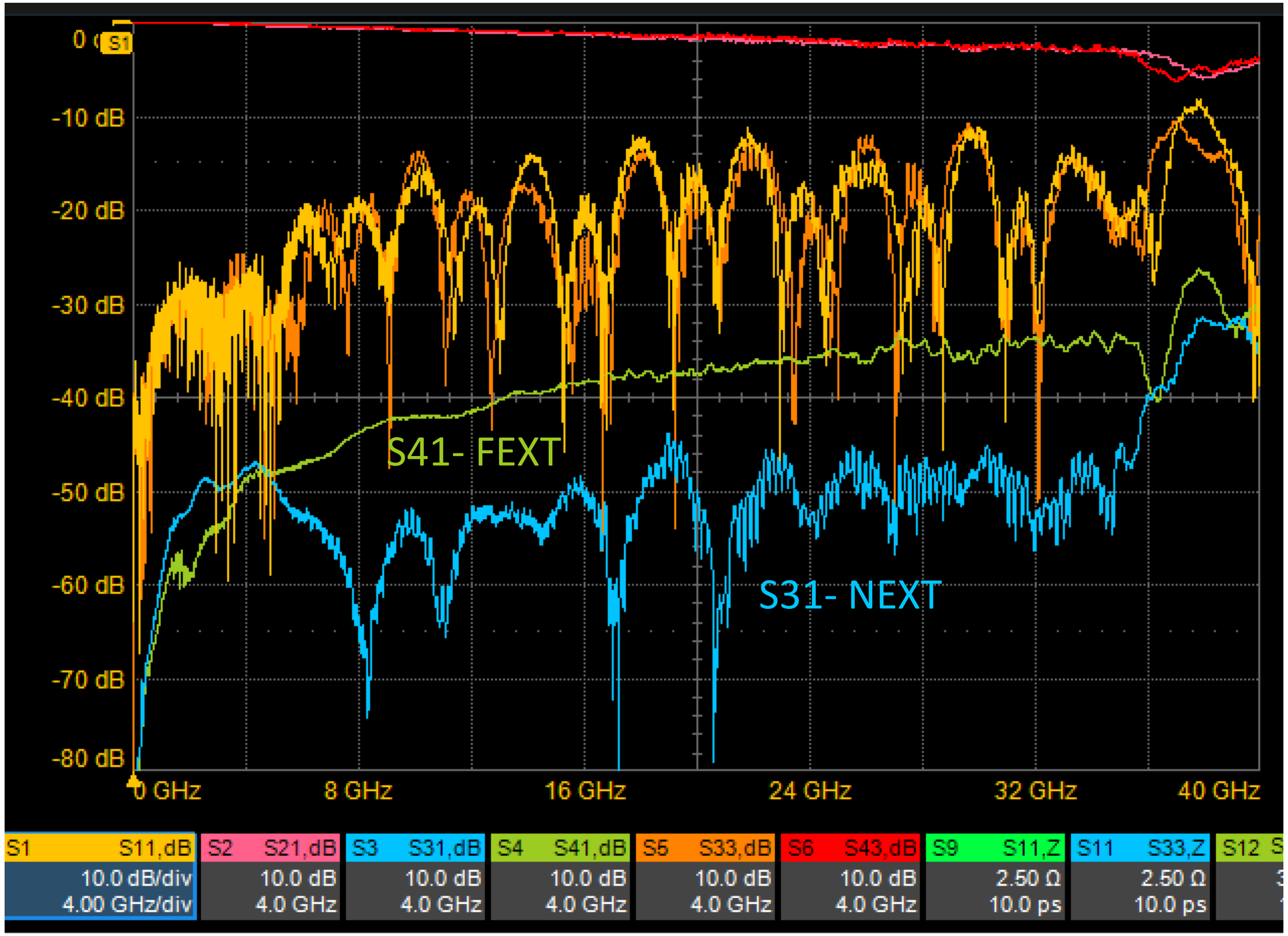
Process

- 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

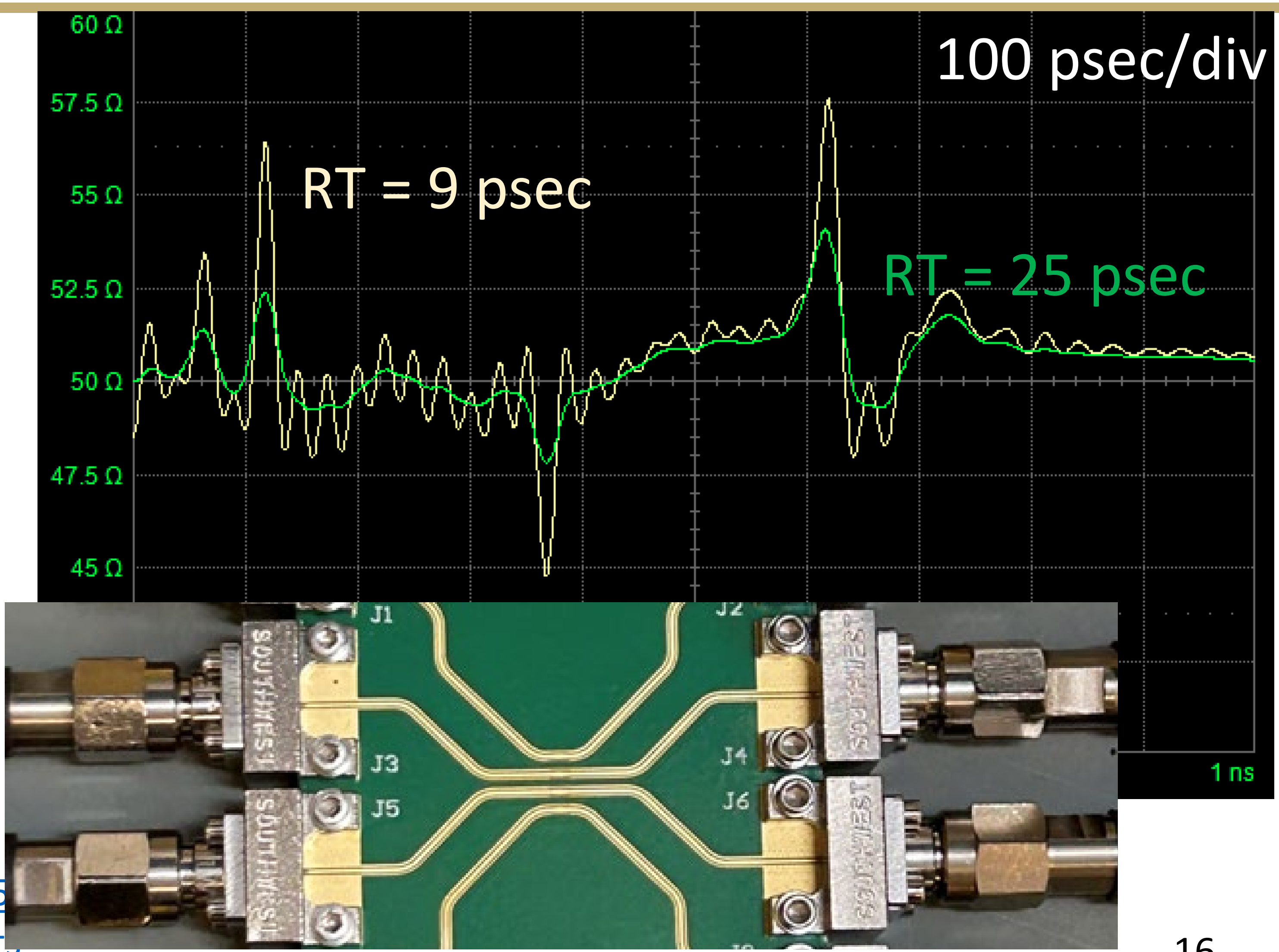
- Virtually no cross talk- SE and diff response, of fixture will be the same





SE TDR Response

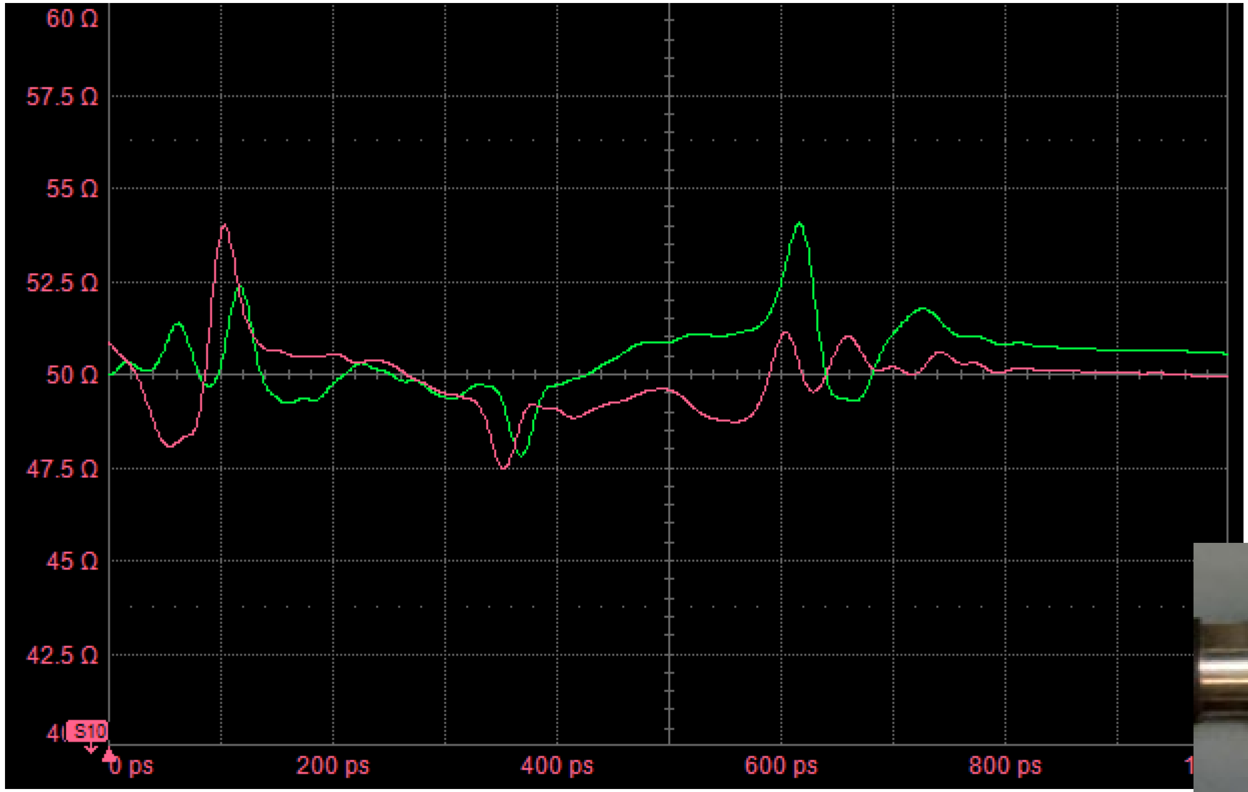
- What rise time to use?
- Default is 0.35/BW = 0.35/40G = 9 psec
  - ✓Results in Gibbs ringing artifact
- Better rule of thumb is RT = 1/BW = 1/40 GHz = 25 psec



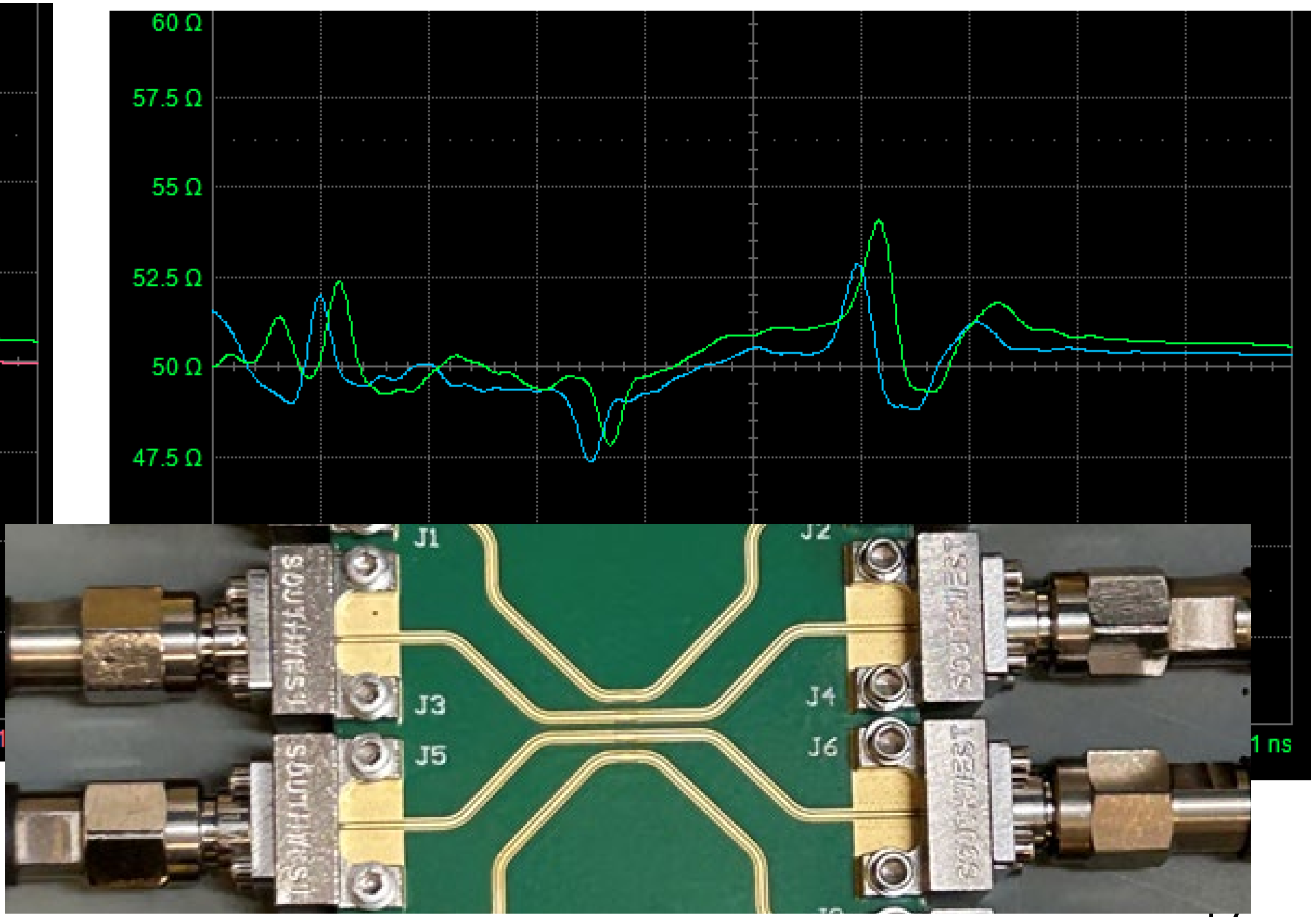
https://www.signalintegrityjournal.com/articles/2175
how-to-avoid-gibbs-ringing-artifacts-in-measurements

Small Complication with the 2x Fixture: Asymmetry

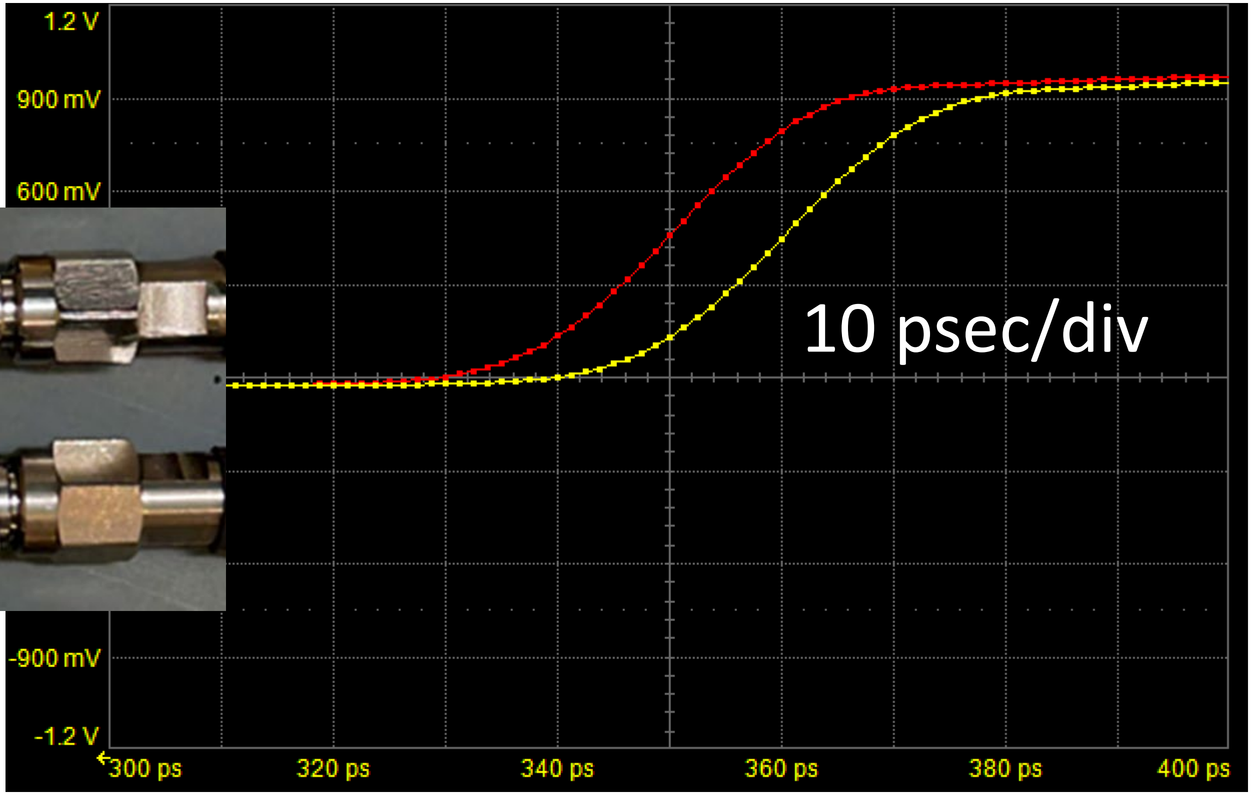
Left-right asymmetry

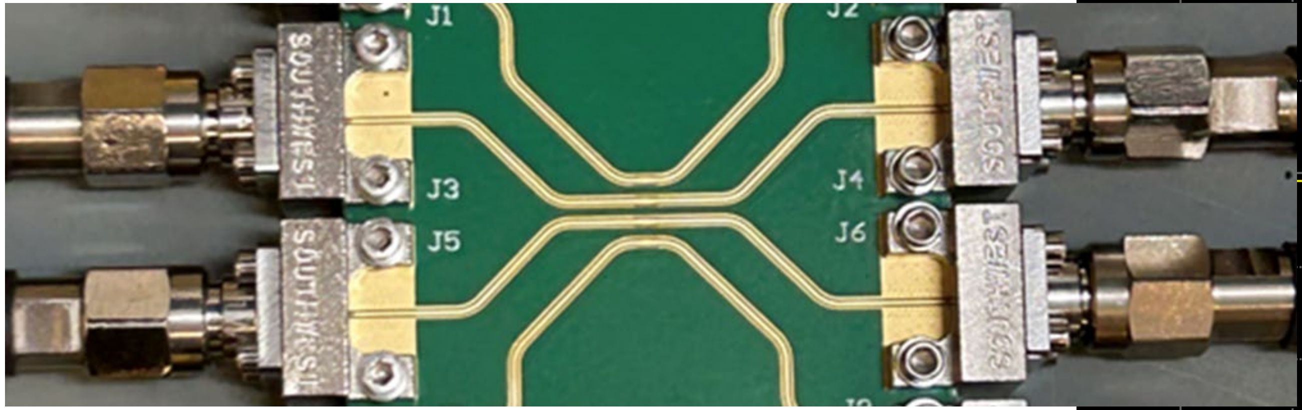


p, n asymmetry



Time Delay Difference in p, n channels

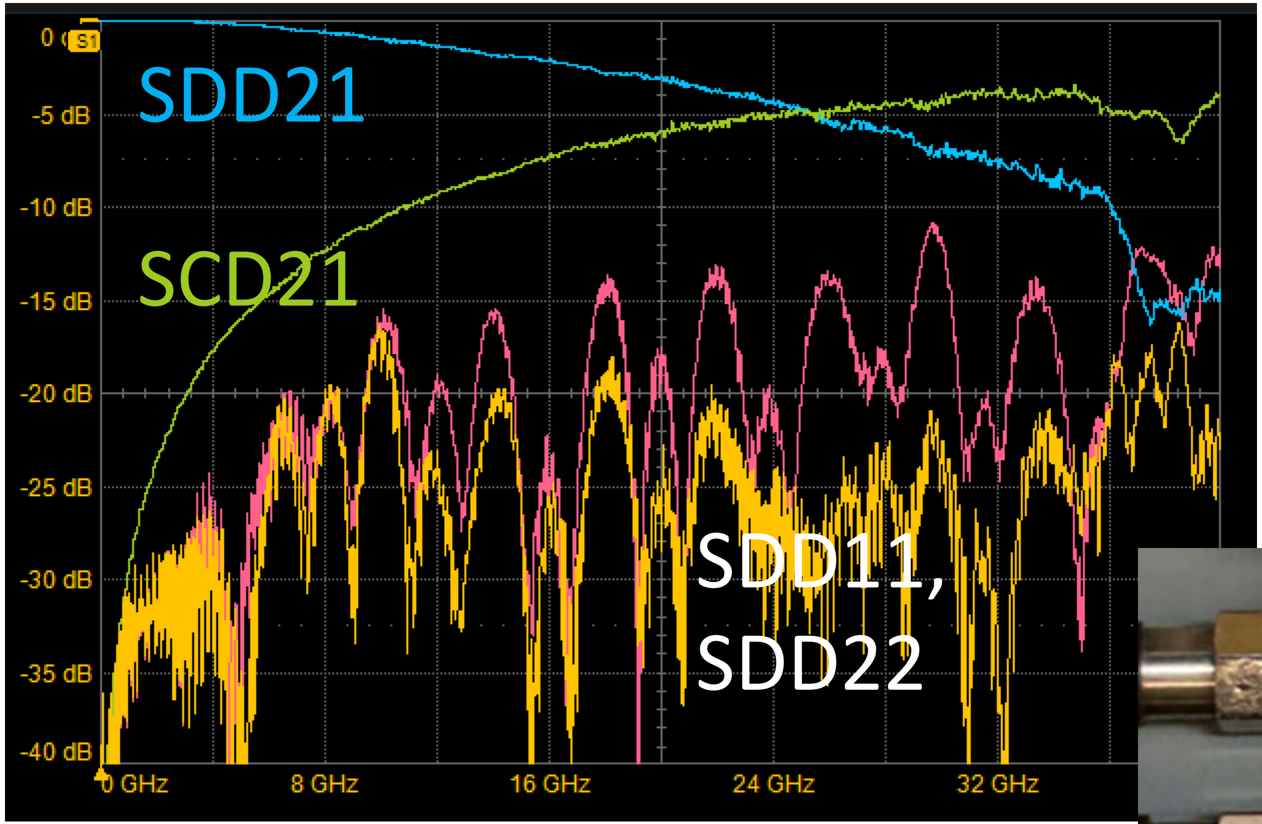


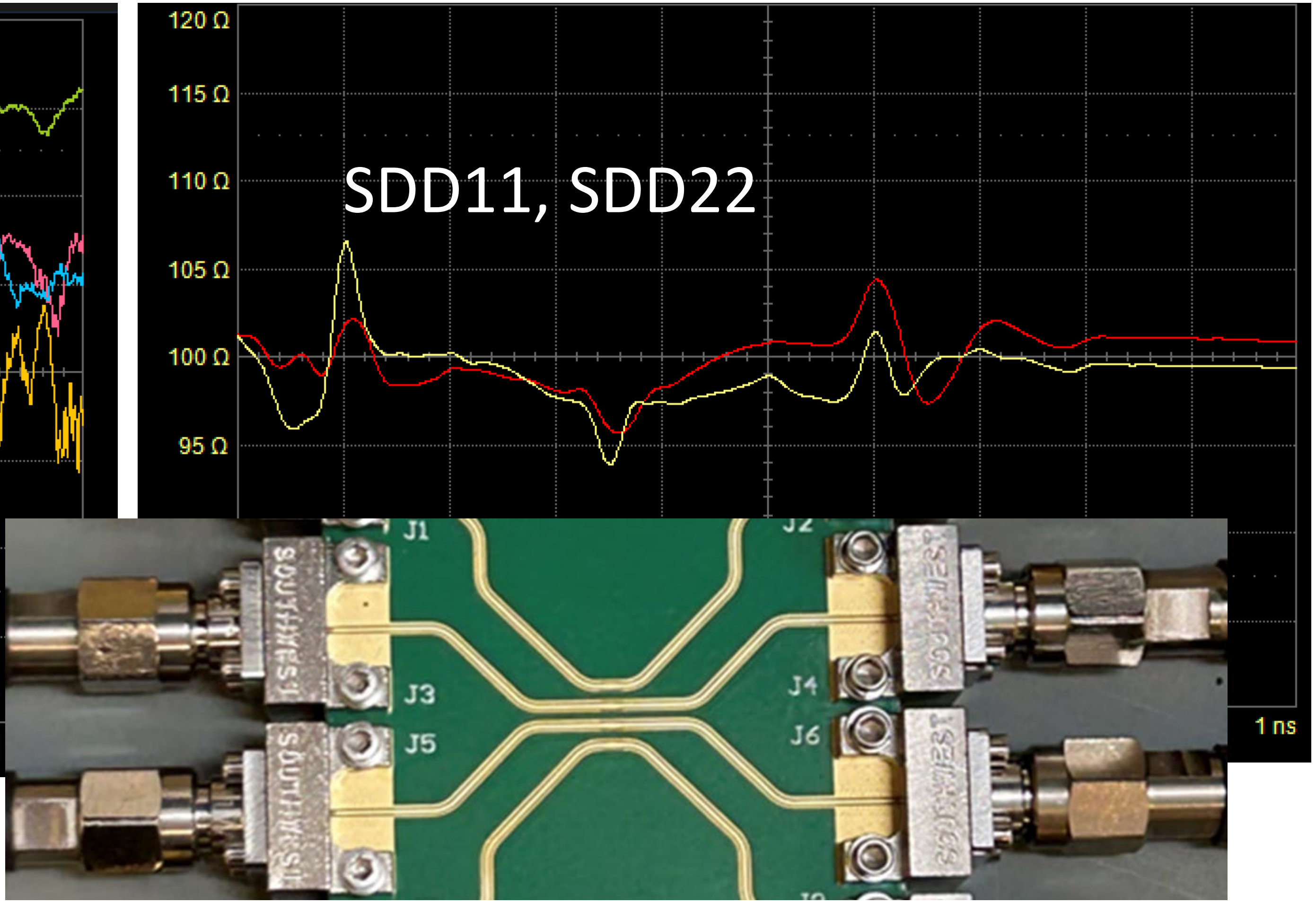


10 psec difference is ~ 70 mils path length difference
Probably related to the connector launch

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

Differential Response

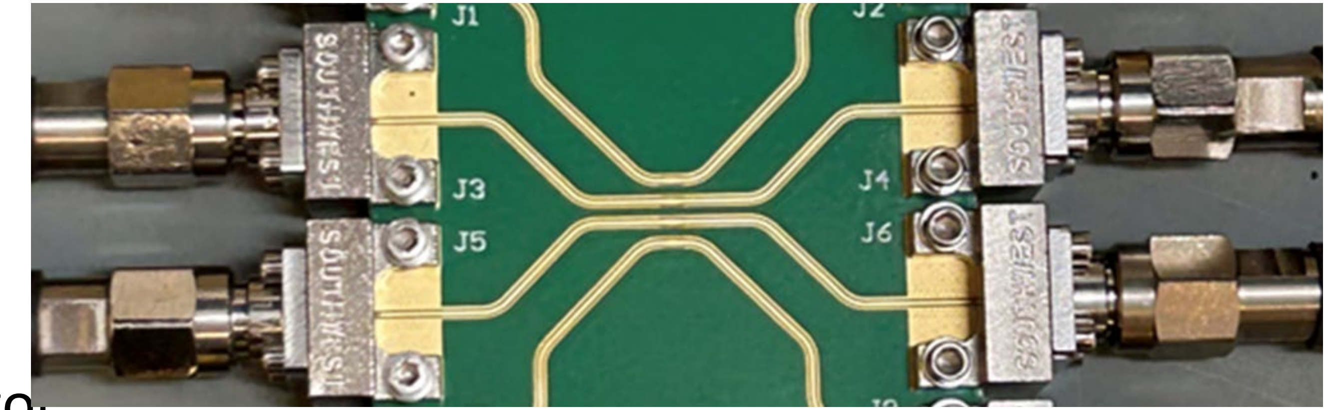




Drop in SDD21 from attenuation and from mode conversion
@ 40 GHz, period = 25 psec, skew is 10 psec

Some end to end asymmetry, but not a problem

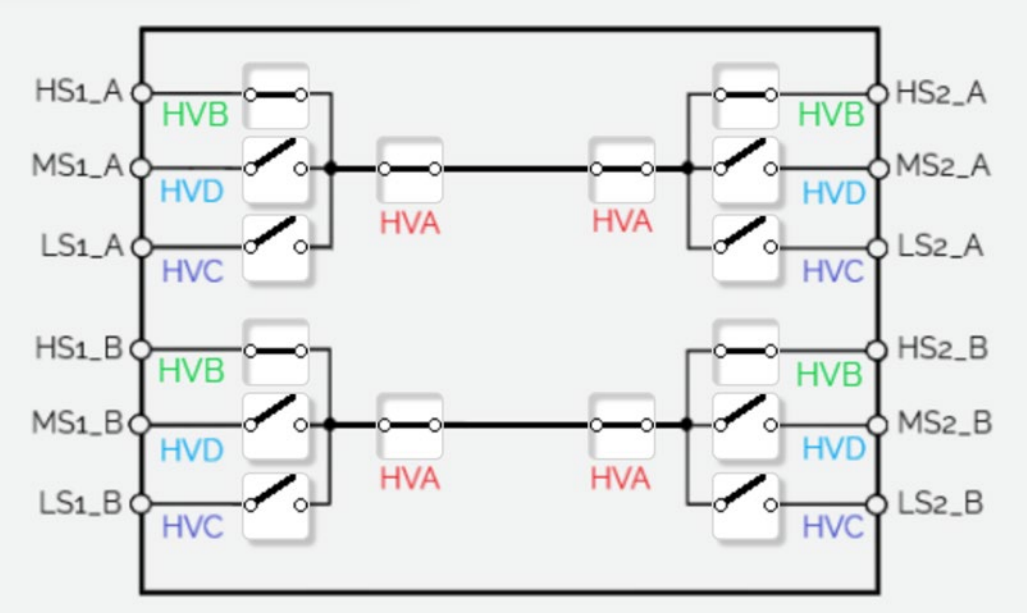
Observations

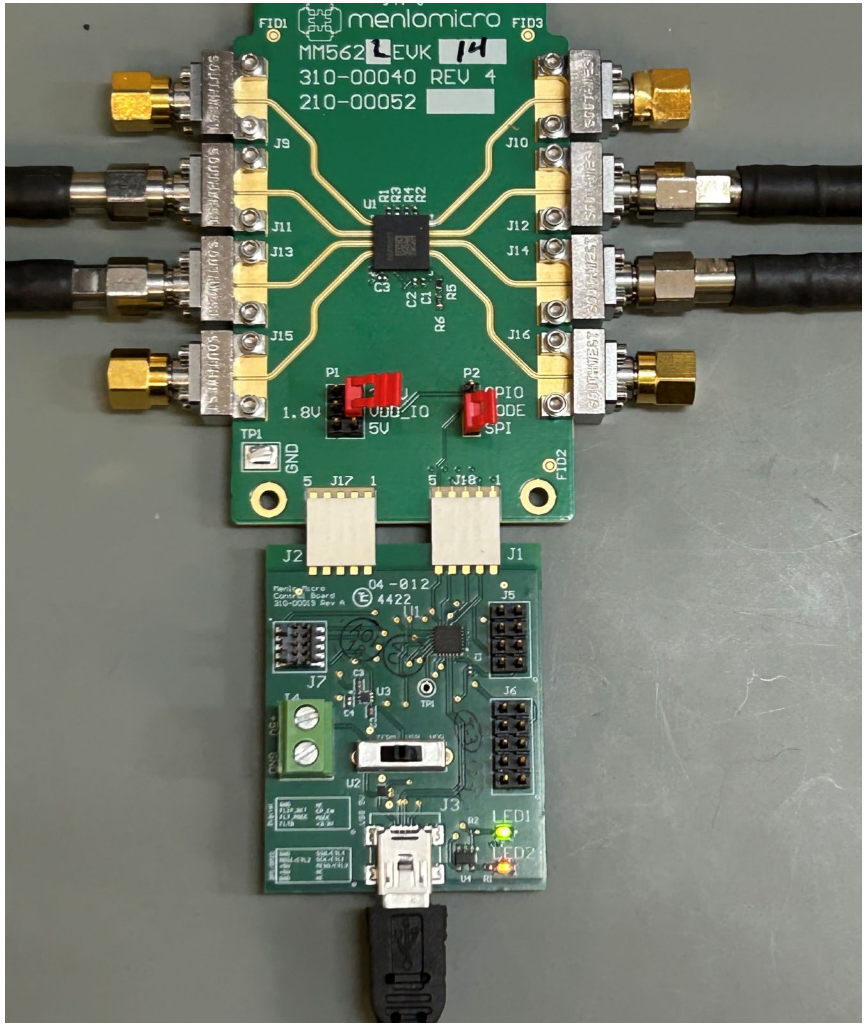


- In the fixture board:
  - ✓Some line-to-line asymmetry
  - ✓Some discontinuities from the connector
  - ✓Some interconnect attenuation
  - ✓Some p, n line length contributing to mode conversion
- In the switch:
  - ✓Pay attention to the mode conversion
  - ✓Pay attention to connector asymmetry
  -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

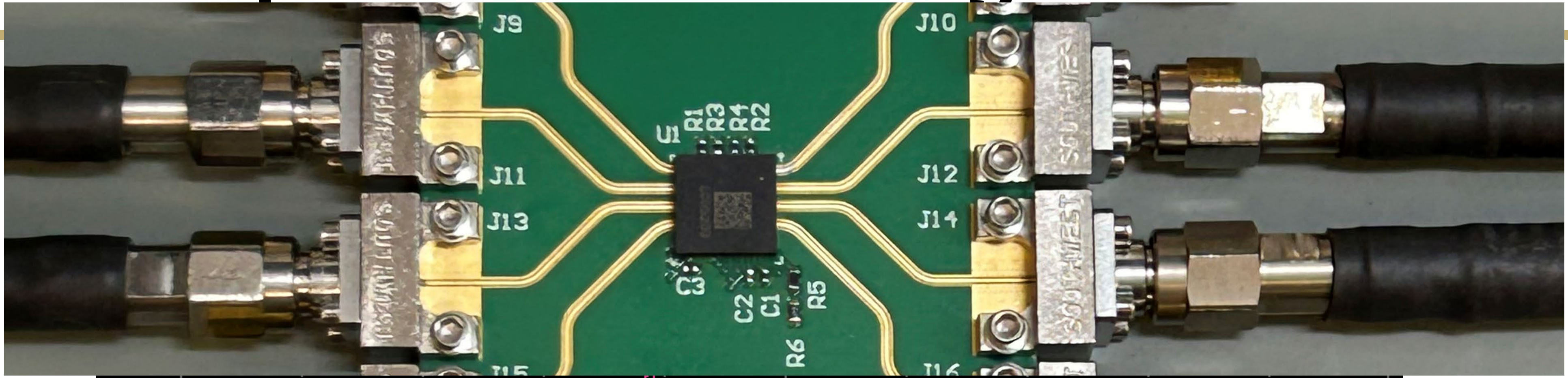
Controlling the Switch with the USB Interface

- Electronics board has USB interface to control the switches

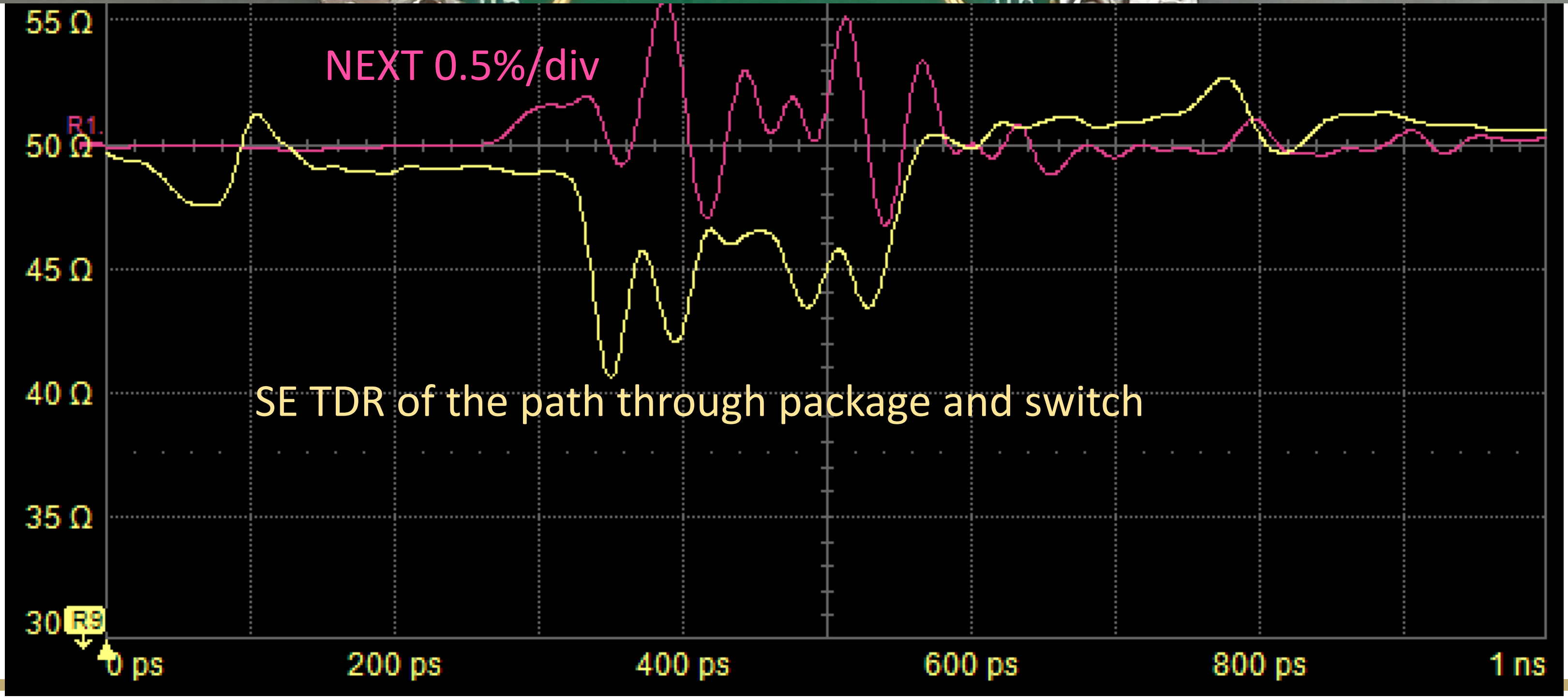




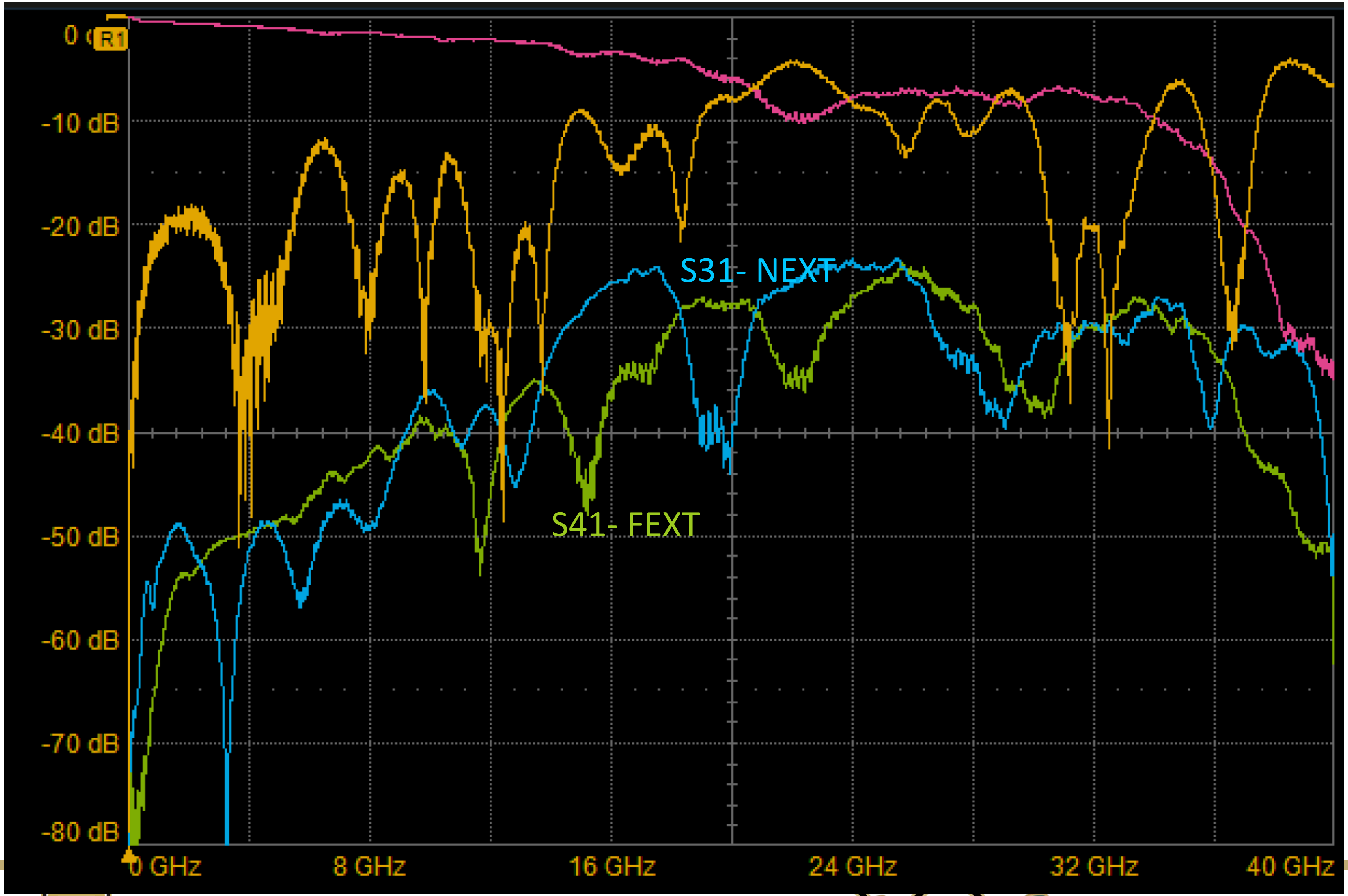
Impact of the Package



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



SE S-Parameter Response

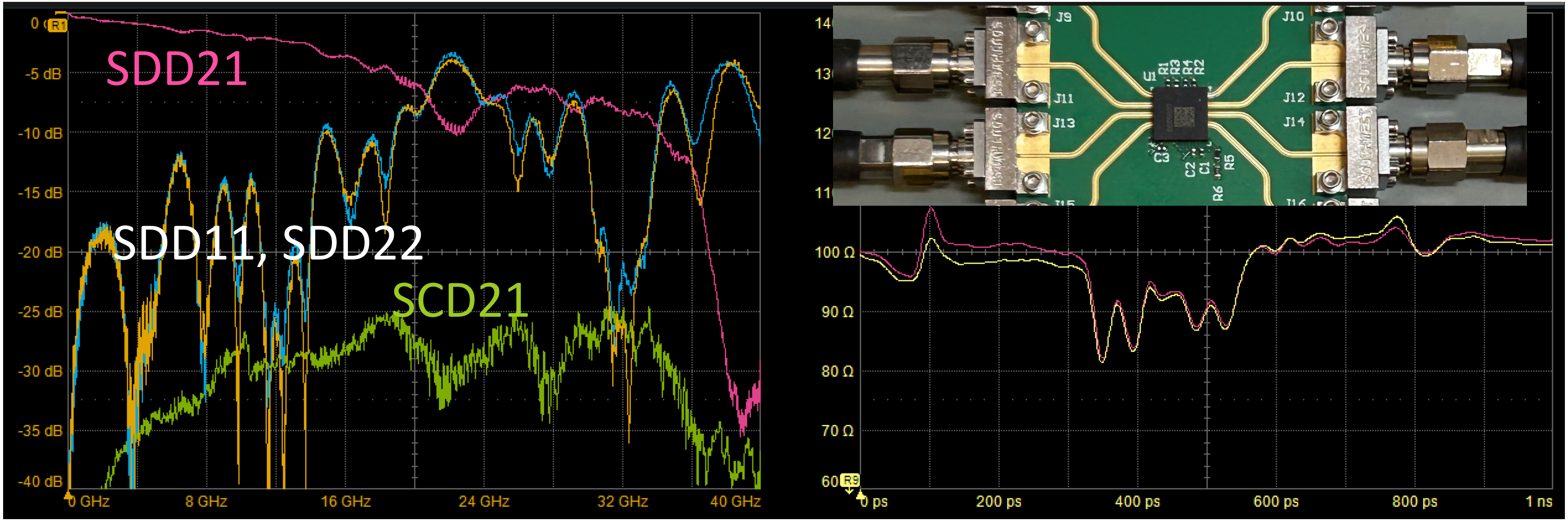


Impact on S21 from fixture losses

When S11 > - 10 dB, expect some impact on S21

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

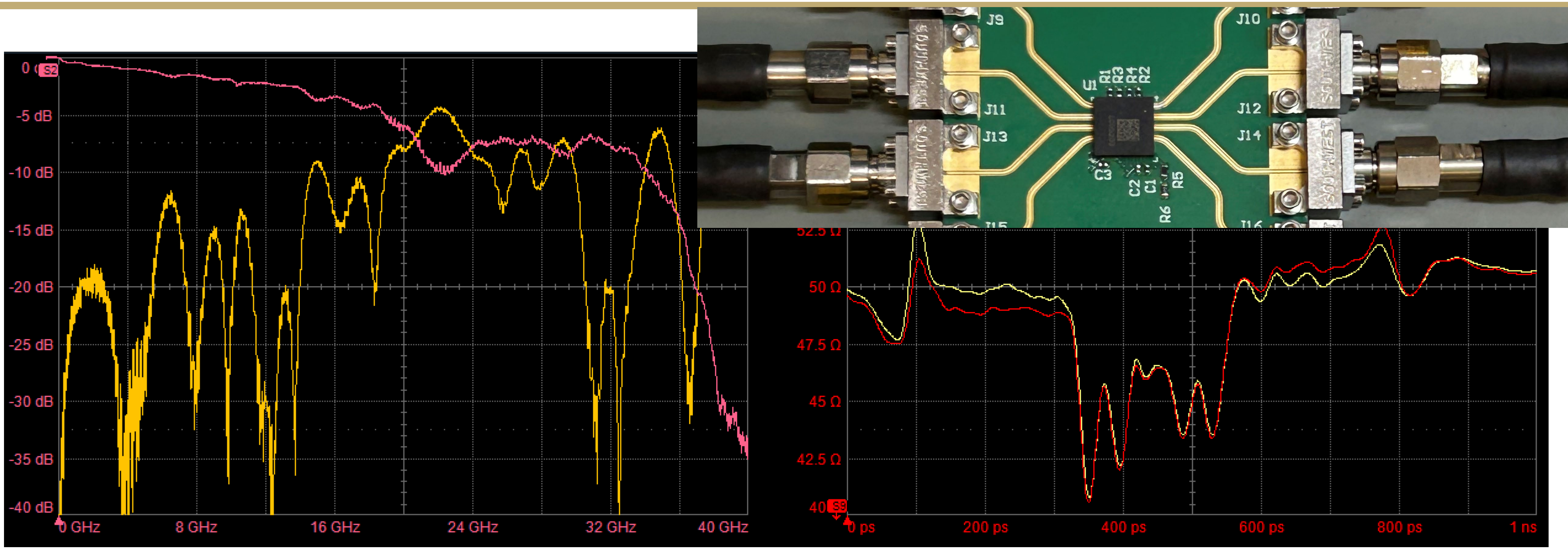
Differential Response



Mode conversion not significant in this board

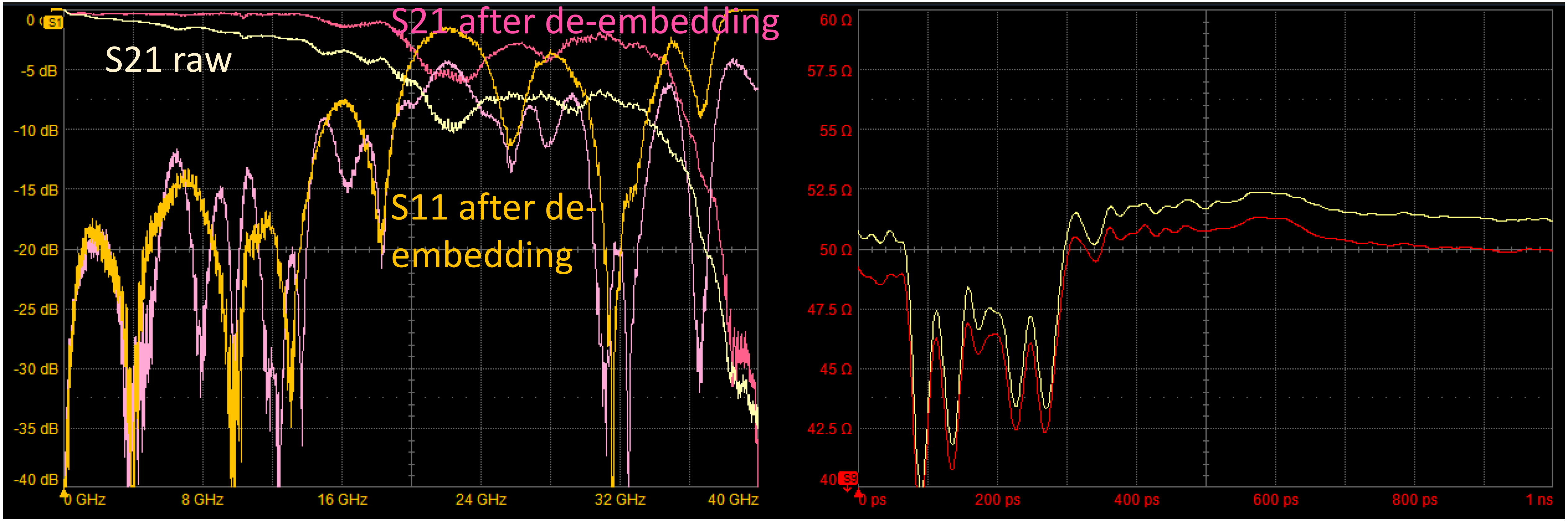
Losses from the fixture board contribute to the insertion loss, in addition to package discontinuities

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

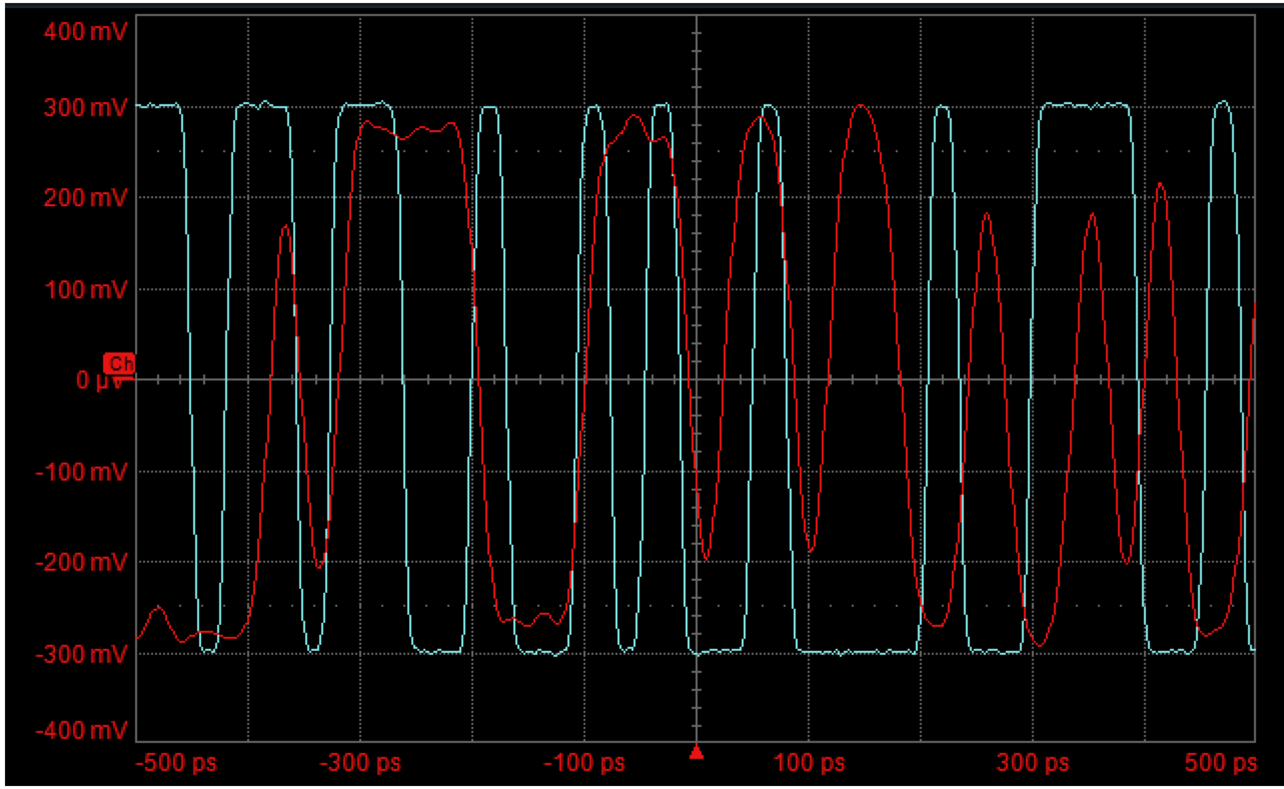


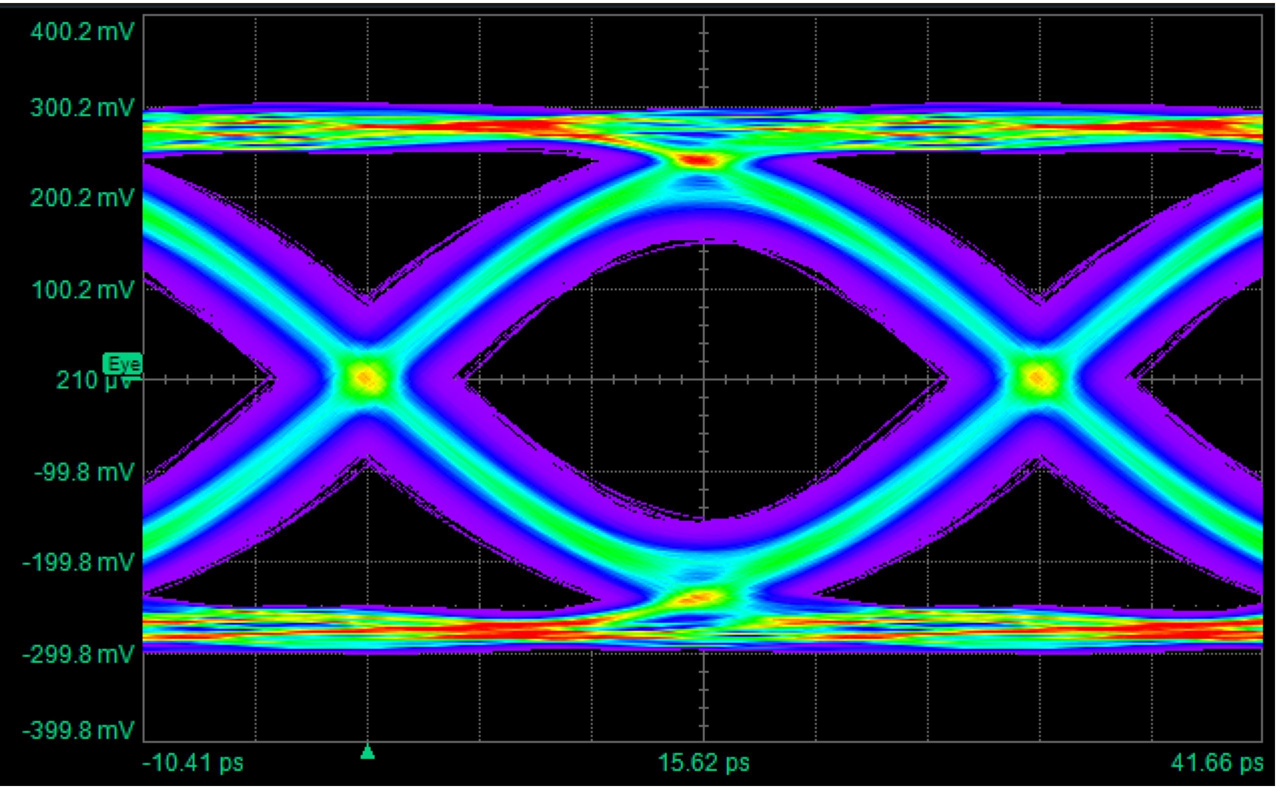
At 16 MHz, S21 goes from -3.5 dB to -1.5 dB
BW of the switch? As limited by the package: -5 dB BW is 20 GHz, -6 dB BW is 35 GHz

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

Application space: 32 Gbps NRZ PCIe gen 5

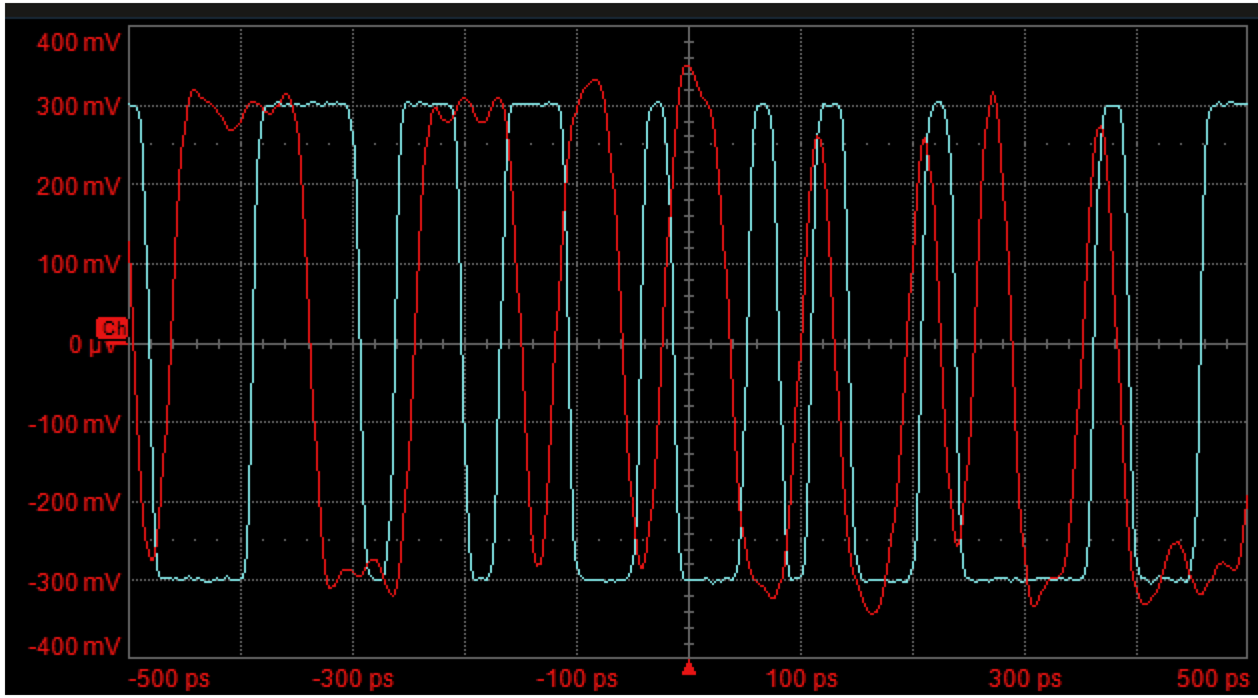
Using raw measurements

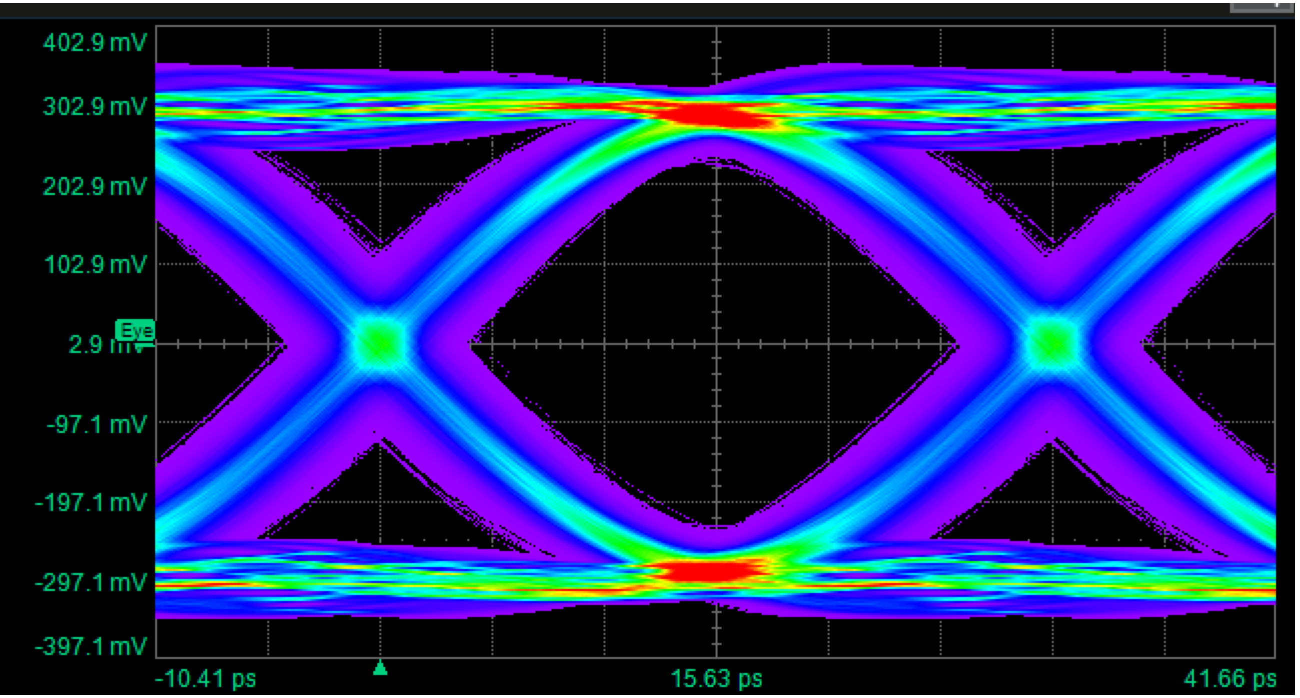




Application space: 32 Gbps NRZ (PCIe gen 5)

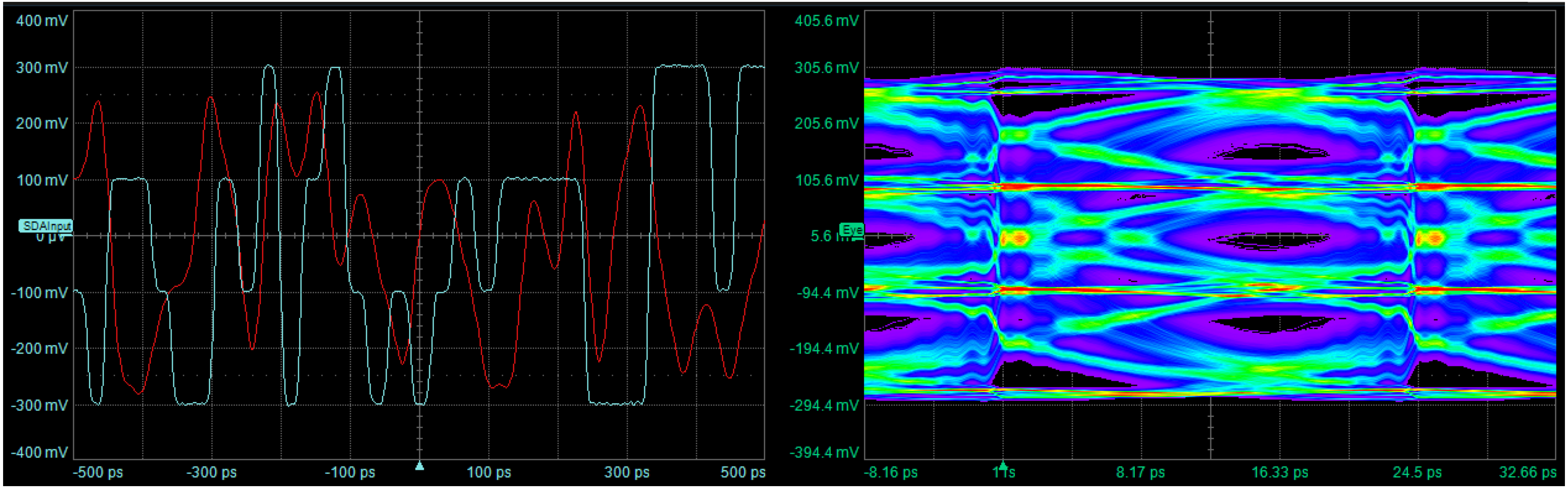
Using DUT with fixture board losses de-embedded





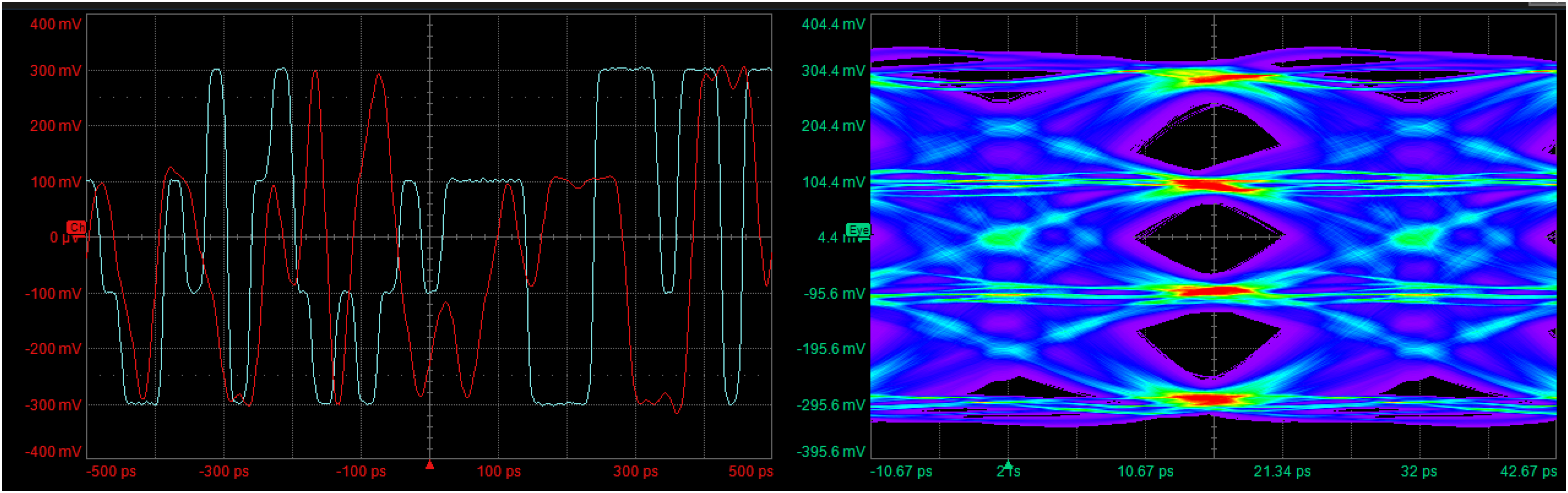
64 Gbps PAM4 (PCIe gen 6)

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!