SWTEST

PROBE TODAY, FOR TOMORROW

2023 CONFERENCE

Pyramid Probe: RF Calibration and Probe Aging Considerations in HVM High Speed IO Devices

Walter Contrata, Ph.D.

MARVELL™

Daniel Bock, Ph.D.

FormFactor™

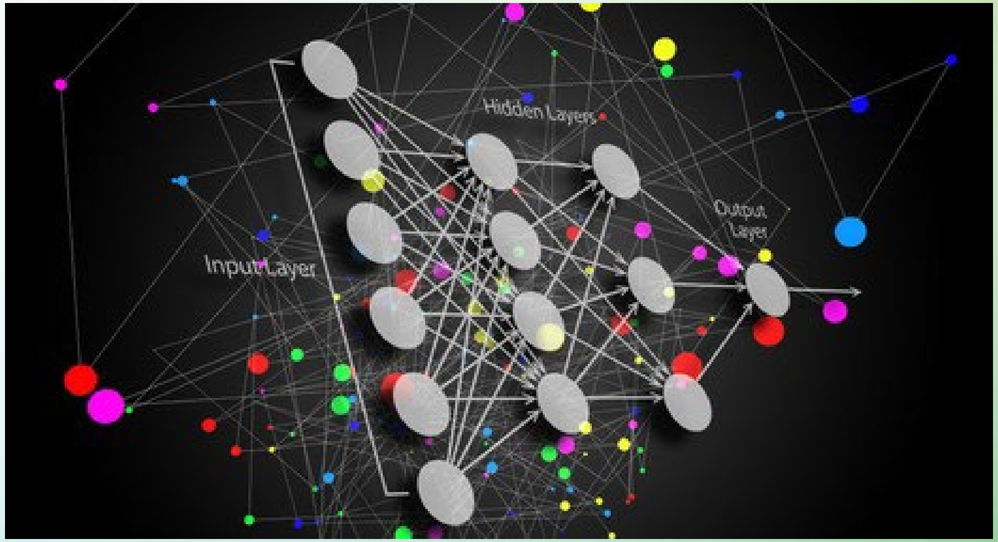
June 5 - 7, 2023

Overview

- Market Drivers
- Test Setup
- Comparison of Cal Methods
- DUT measurements
- Conclusion

Market Drivers

- **The main drivers that are starting to emerge for data rates are coming from the growth in AI/NLP**
  - Chat GPT, Bing AI
- **The largest models today have more than a trillion parameters**
  - For understanding, that is roughly the same number of synapses that are in a mouse
- **In order for these complex models to operate, the data transfer speeds need to increase at the same rate as the models are increasing in size**



What is driving increases in Data Rates?

ChatGPT fuels digital infrastructure boom

Jenny Wiggins

Infrastructure reporter

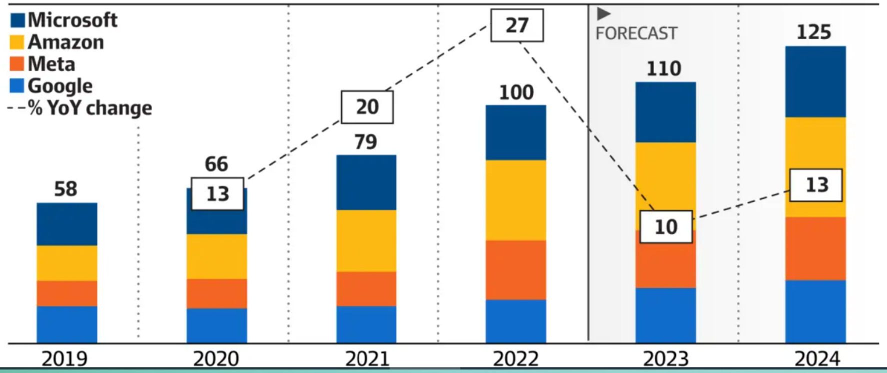
Updated Mar 7, 2023 – 3.48pm,
first published at 3.14pm

Save Share

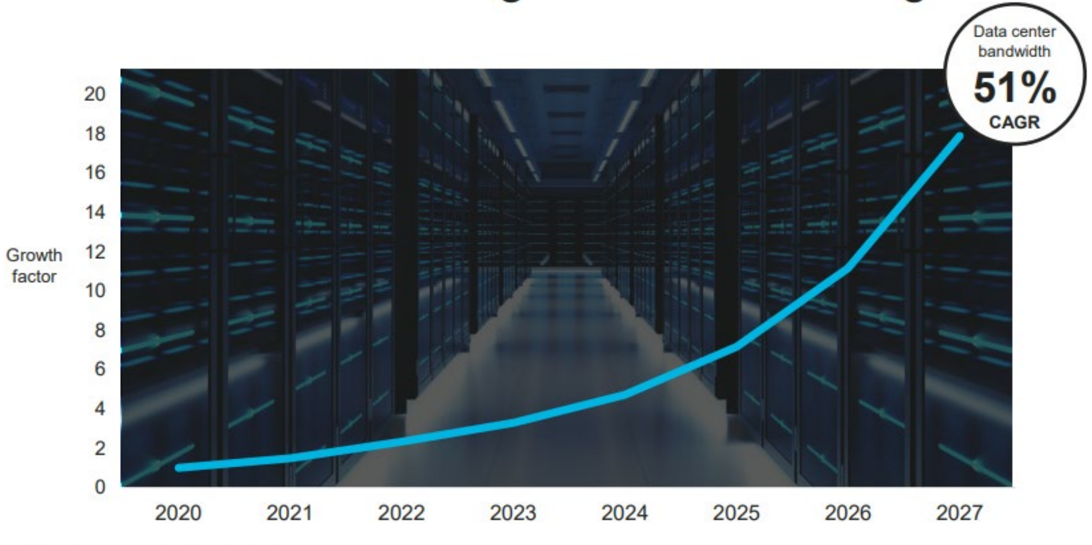
Artificial intelligence is fuelling a boom in data centres and fibre optic networks, says the chief investment officer of infrastructure specialist HRL Morrison & Co, which is positioning itself to take advantage of billions of dollars of spending on new technology such as ChatGPT.

The lifeblood of artificial intelligence is data, and companies that use it need to get data, shift it around, store it and compute it, said William Smales, who helps manage some $27 billion of infrastructure for New Zealand-founded investment group Morrison & Co.

Hyperscale data centre capital spending ($USb) SOURCE: MORGAN STANLEY



Data center bandwidth growth accelerating

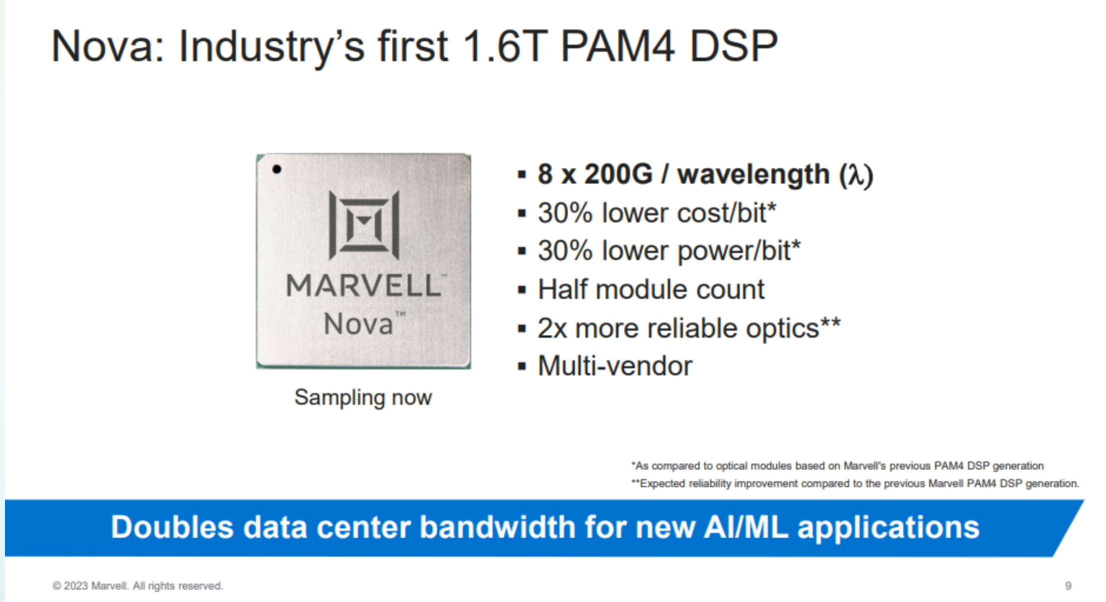


Source: Marvell estimates based on industry analyst forecasts

- REF: https://www.afr.com/companies/infrastructure/chat-gpt-fuels-digital-infrastructure-boom-20230307-p5cpzh

FiberOptic Data Networks

- Marvell's module partners demonstrated 1.6T PAM DSP in pluggable transceivers at OFC2023
- 200 Gbps per channel line-side receiver with companion Marvell 112-Gbaud TIAs, providing best-in-class linearity and low noise



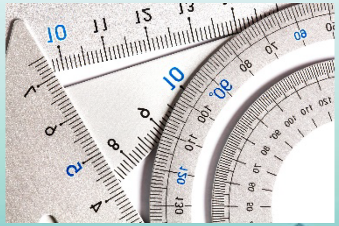
Wafer Test – Why full Speed?

- There is the option to do low speed test at 56 Gbaud BW
  - These have performance margin and could even be ‘guaranteed by design’
- However, speeds are pushing to 112 Gbaud to support Marvell’s NOVA DSP system
  - The performance margin is substantially reduced
  - The packages are getting more and more expensive, with multiple chips in a single package and rework is difficult to impossible
- **These need to be Known Good Die (KGD) because of the high cost for throwing away a full module**

How to Extend RF Measurement Accuracy

- **In order to ensure wafer test is accurate, RF characterization is done to calibrate out the probe card, but periodic calibration slows down the test time**
- **In order to extend calibration lifetime to maximize test cell up time, several questions need to be addressed:**
  - How does the wear of the probe tip (aging) affect measurement accuracy over the lifetime of the probe card?

  - What are the best designs for RF Accuracy in the probe card and the Calibration Substrate to mitigate probe tip aging effects?



What Will We Test?

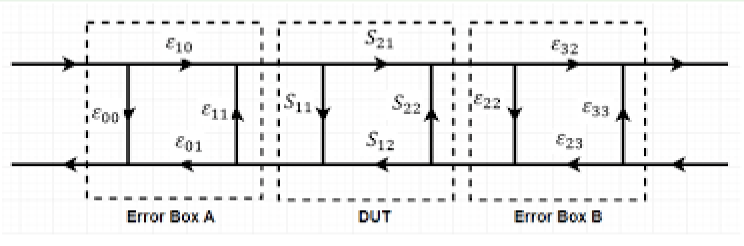
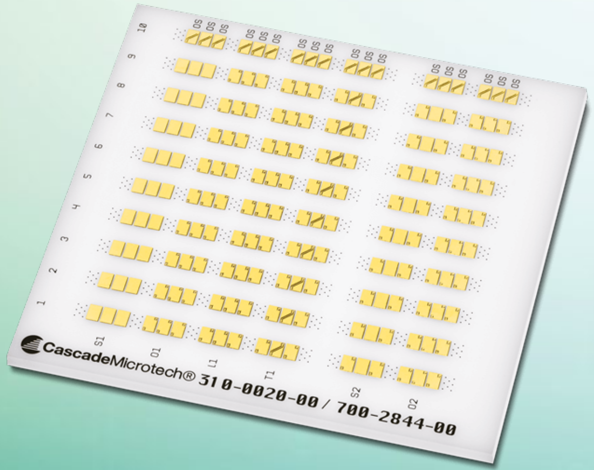


Figure 1 - Network with Error Boxes

Different RF Calibration Algorithms

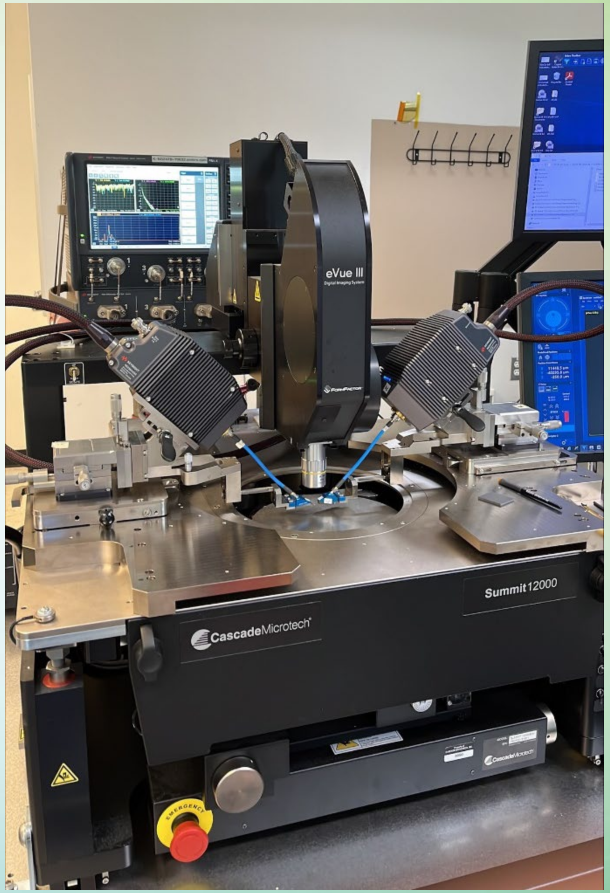


Different ISS Layouts

Probe Head:
Different Transmission Lines

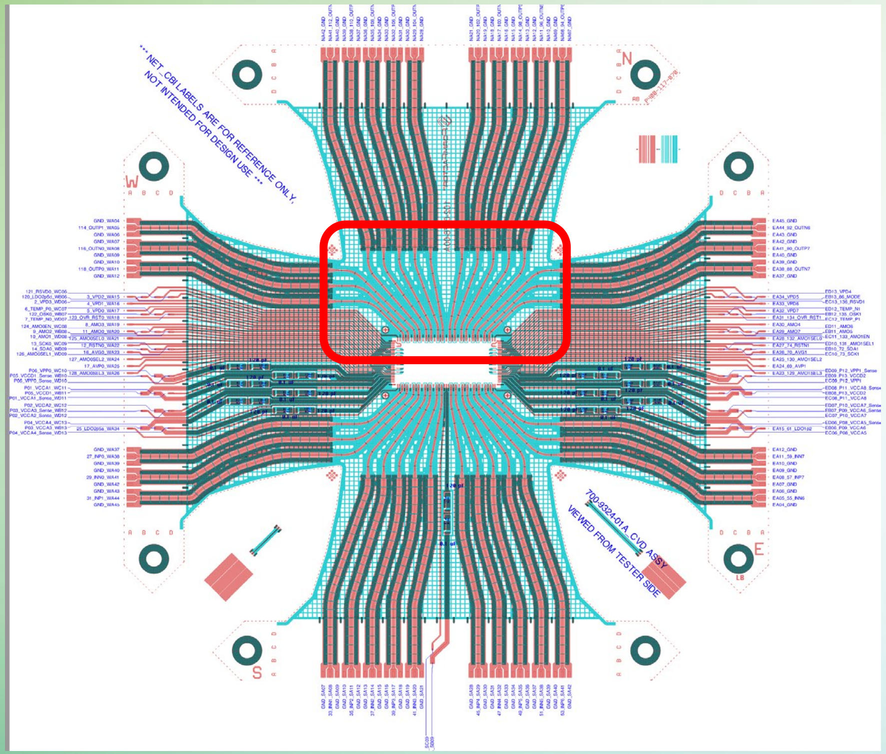
Equipment

- **FormFactor Summit 12000 Semi-Auto Probe Station**
- **Keysight PNA-X**
  - 4-port up to 120 GHz
  - Used 67 GHz eCal module
- **ISS**
  - Standard and Sparse
- **Pyramid Probe**
  - 4 different transmission lines
    - CPW – design 1
    - Inverted microstrip – design 2
    - Microstrip – design 3
    - Mixed Transmission Line– design 4



FFI Summit 12000 with eVue

Pyramid Probe Layouts

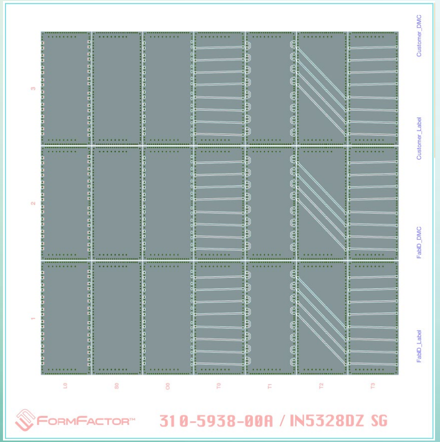


The only difference between the cores is the transmission line near the DUT

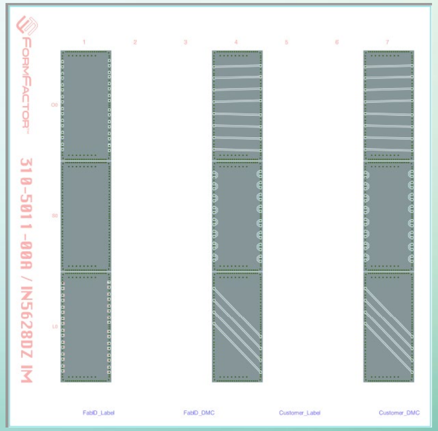
Core #	Transmission Line Type	Isolation Level
Core 1	CPW	Lowest Isolation
Core 2	Inverted Microstrip	High isolation between lines and DUT
Core 3	Microstrip	High isolation between lines
Core 4	Mixed Transmission Line	Highest isolation between lines

ISS Layout

- **There were two different versions of the ISS that were manufactured to investigate ISS design for the best RF calibration performance:**
  - A standard layout to maximize the number of cal sites
  - A sparse layout to maximize isolation of each cal site



Standard ISS



Sparse ISS

Method to 'age' the Probe Head

- **Lapping pad**
  - We used a lapping pad to quickly wear the tips of a Pyramid Probe
    - Instead of take multiple days to wear off 10 um of tip height, we could remove about 10 um in 45-60 min
  - Probe Tip Heights:
    - We performance RF measurements at no wear, and then at two different wear levels, 12 um and 22 um total wear

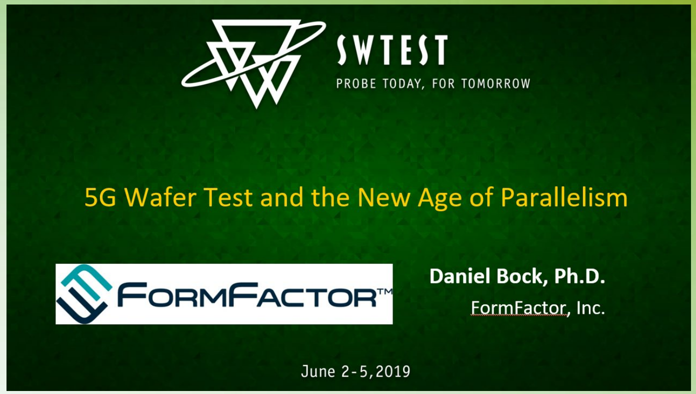
Test	Height
No Wear	~48 um tall
Wear 1	~36 um tall
Wear 2	~ 26 um tall

SOLT vs SOL

- **Building off of 2019, we are continuing to compare RF Cal Methods**
- **We compared two different Calibration methods:**
  - SOL: short, open, load
  - SOLT: short, open, load, thru
- **When we looked at the overall performance, we looked at:**
  - Short, Open, Load, and Thru post calibration and evaluated the Standard Deviation of each

- **We evaluated the performance of the probe head with two different calibration methods**
  1. Using no wear data to generate the calibration files for all measurements
  2. Used the RF data after the probe head was worn (ie, recalibrated)

NOTE: we only used the standard ISS for these tests

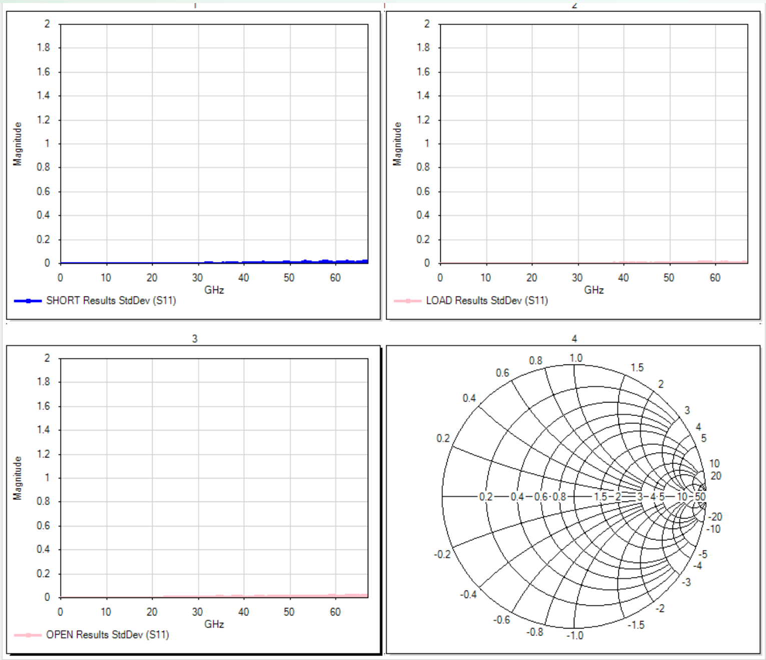


2019 SWTEST: Compared Different Cal Methods previously

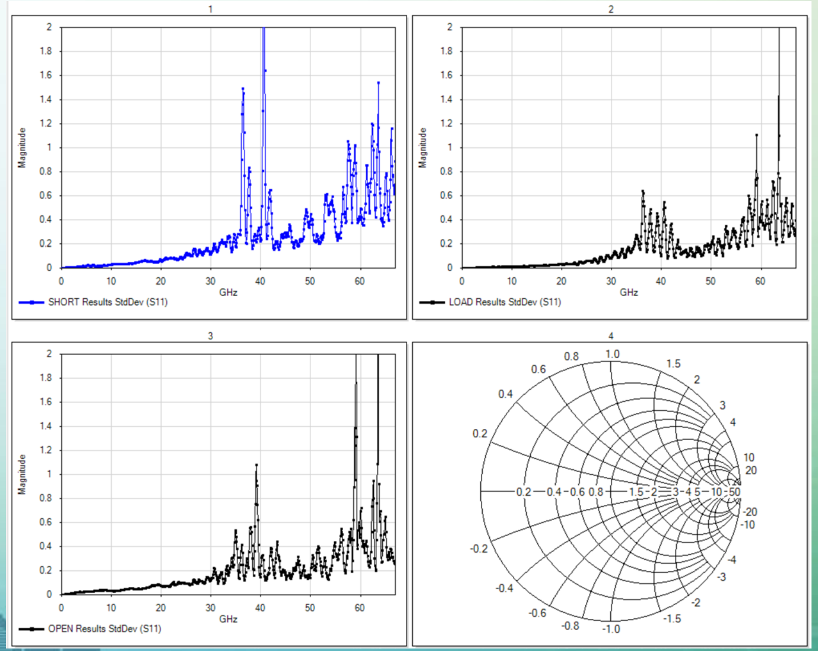
SOL

- **We then combined all of the data across the different cores, and then pulled out the STD Dev of each measured standard at each frequency**
  - We saw a dramatic difference between the situation when you recalibrated after wear to using the no wear calibration data

w/ Recalibration



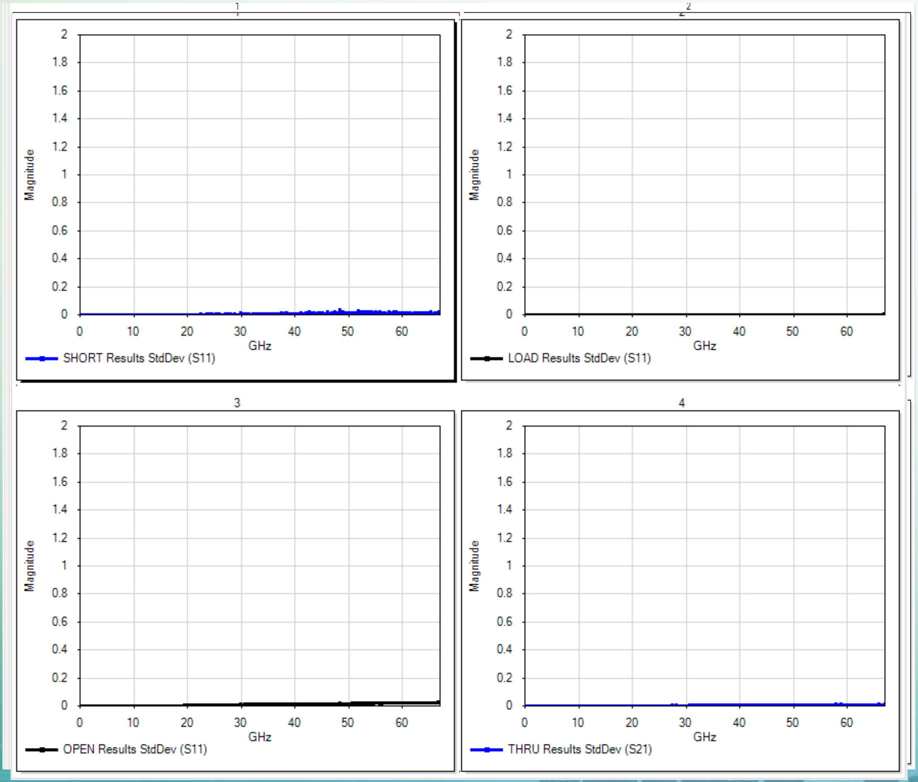
w/o Recalibration



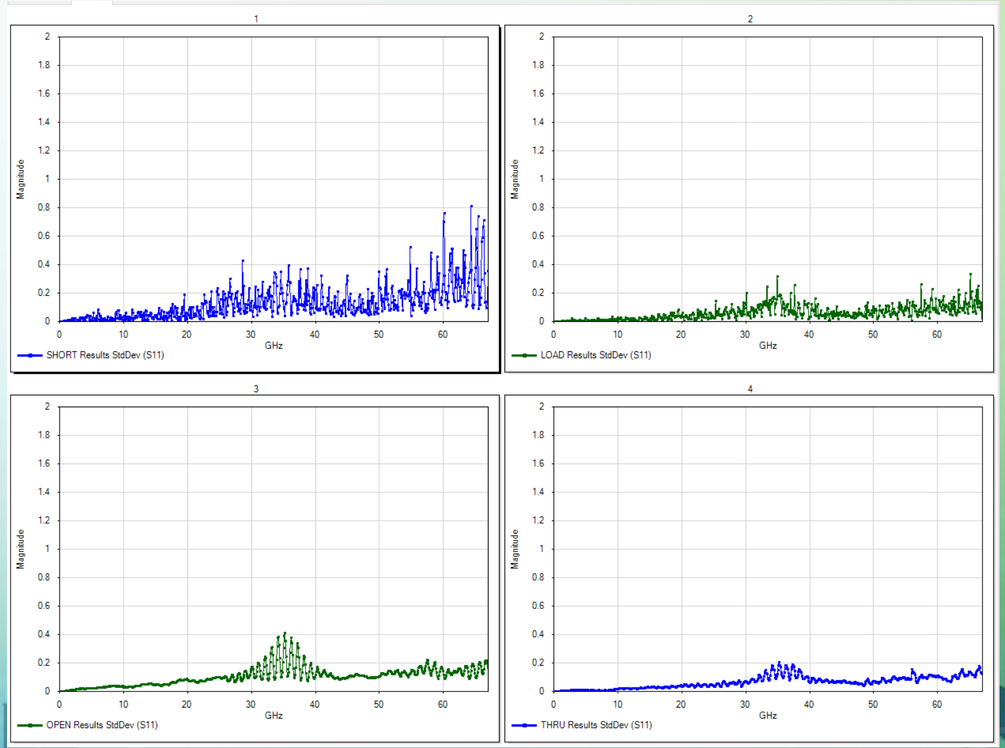
SOLT

- **We then looked at the STD Dev vs frequency for each design**
  - We saw a similar effect as we did for SOL
    - Using no wear calibration data has more variation above 20 GHz

w/ Recalibration



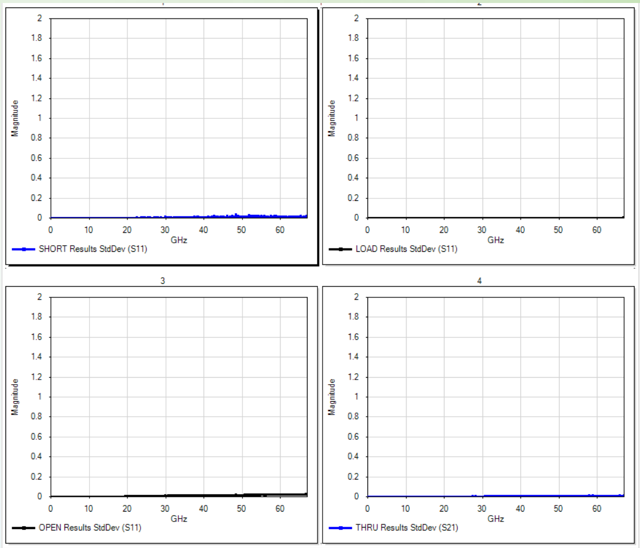
w/o Recalibration

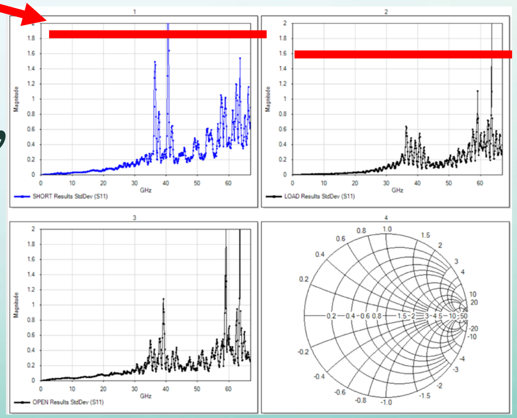


SOL vs SOLT Comparison

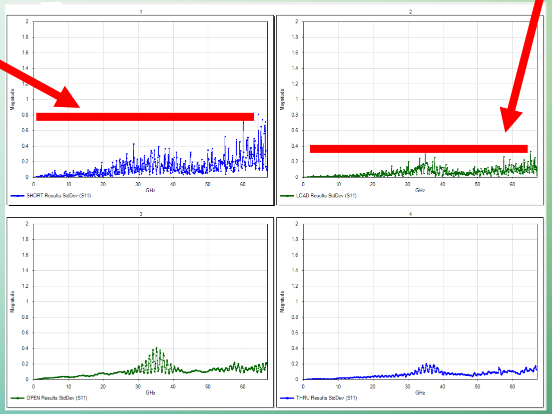
- **Comparing SOL and SOLT, we can say two things:**
  1. Recalibrating periodically has similar, low level variation

  2. Using no wear calibration data, SOL has more variation than SOLT variation, especially above 20 GHz





SOL no Wear Calibration



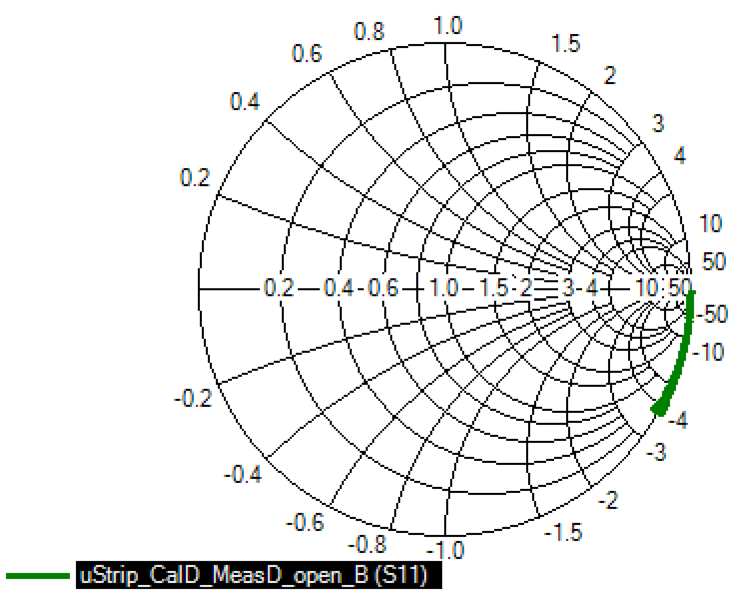
SOLT no Wear Calibration

How to ensure HVM Accuracy?

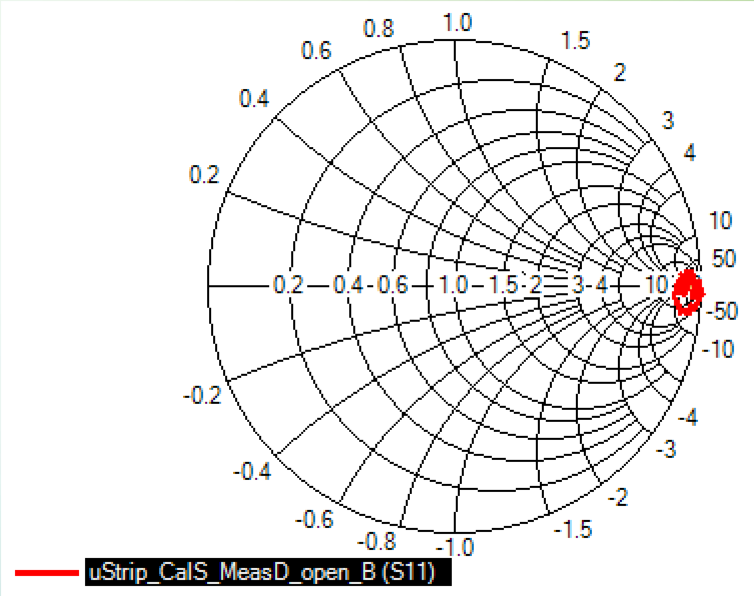
- **Check Cal**
  - Remeasure Cal Std's
  - Expect ideal response

- **Response on right non-ideal**
  - Is the Cal OK?
  - What causes this?

Remeasure open standard



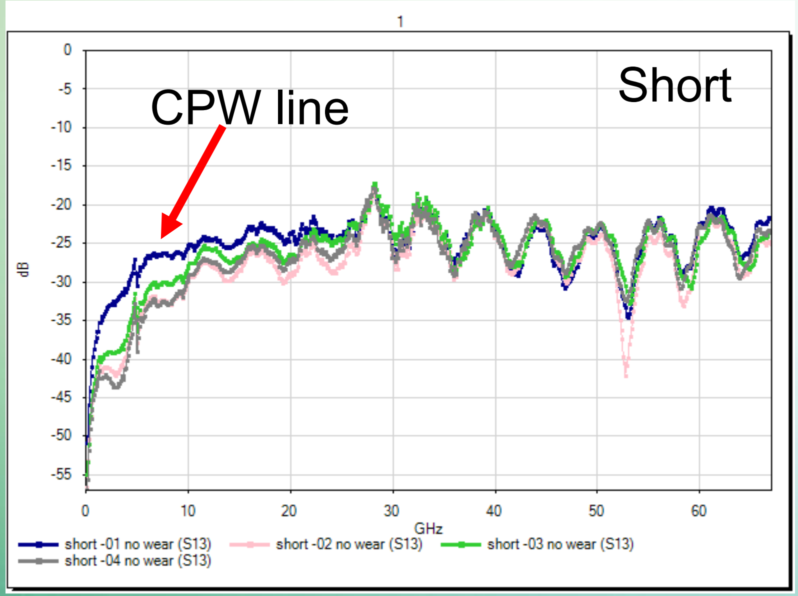
Yes!

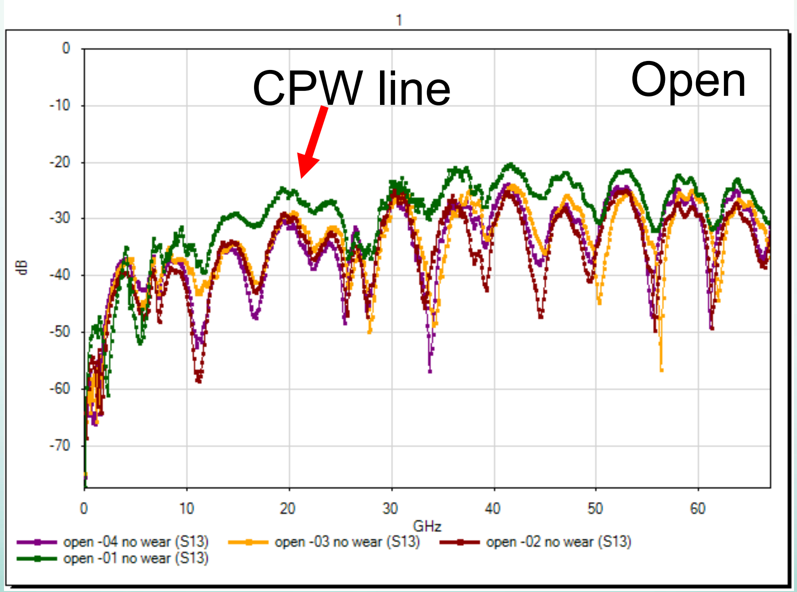


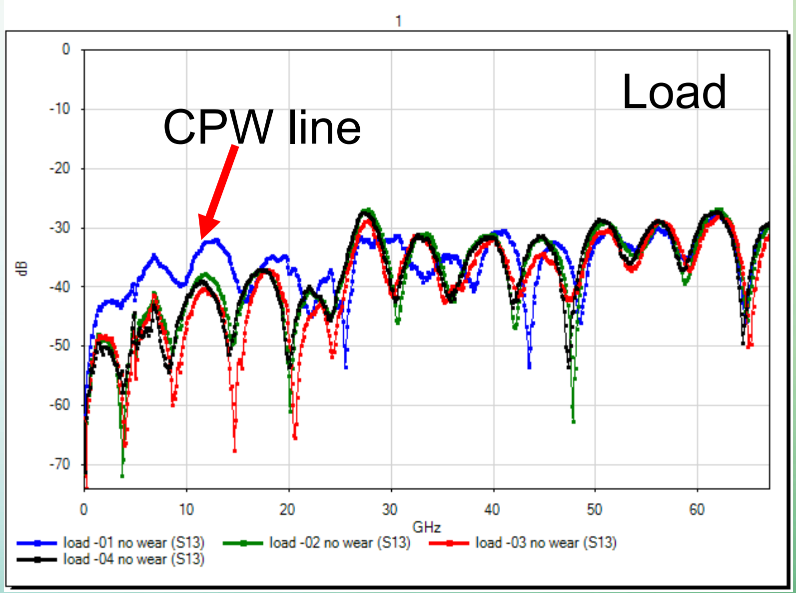
Not sure...

Could Cross Cause Non-ideal Response?

- Cross-talk too low to explain non-ideal response
- CPW probe head has highest cross-talk

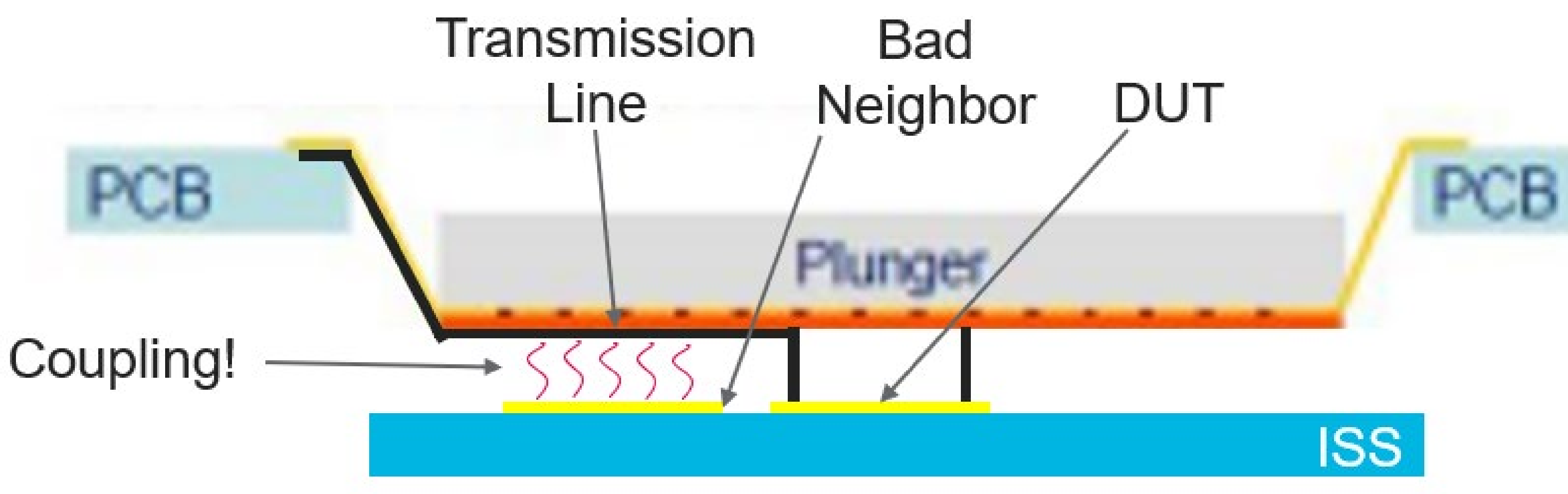






Could “Neighbor Effect” Cause Non-ideal Response?

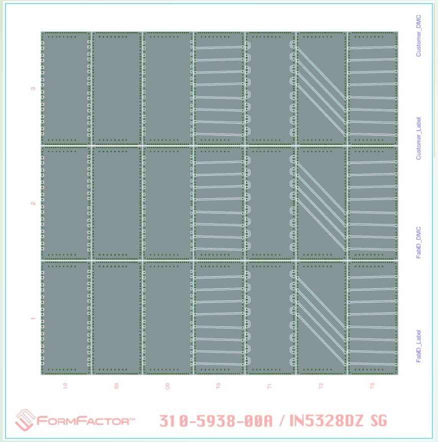
- During calibration, signals pass over standards neighboring standard under test.
- Coupling to neighbor could affect calibration



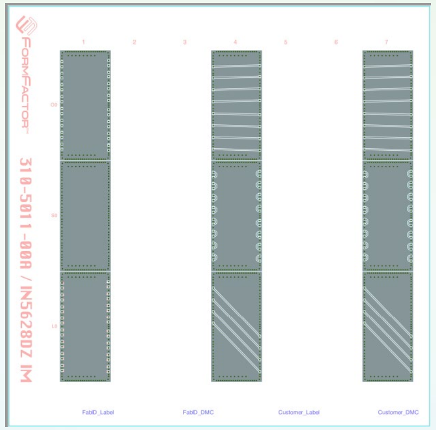
Neighbor Effect Countermeasures

- **Replace Standard ISS with Sparse ISS**

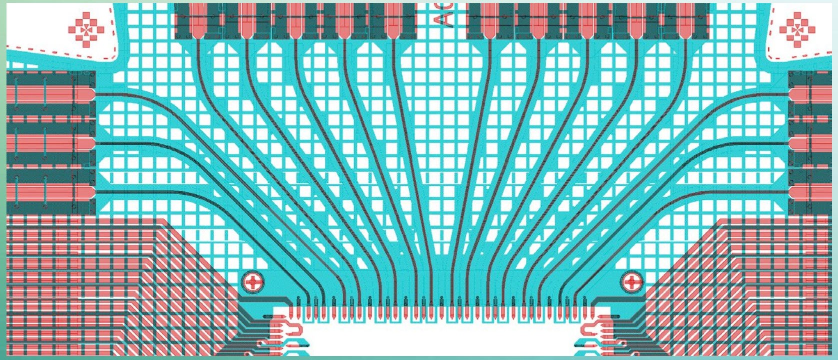
Standard ISS

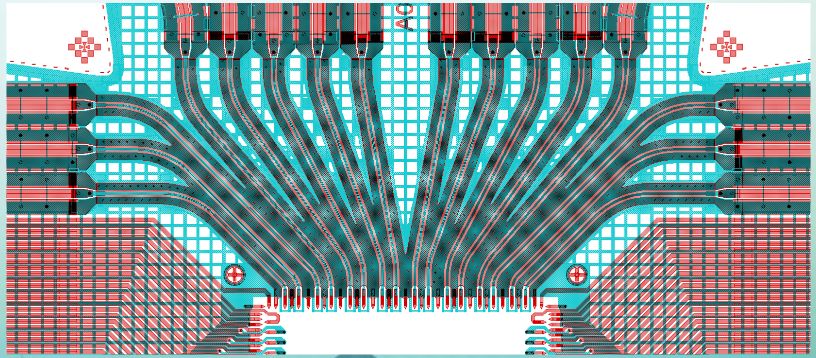


Sparse ISS



- **Replace Standard Microstrip (signal facing wafer) with Inverted Microstrip**

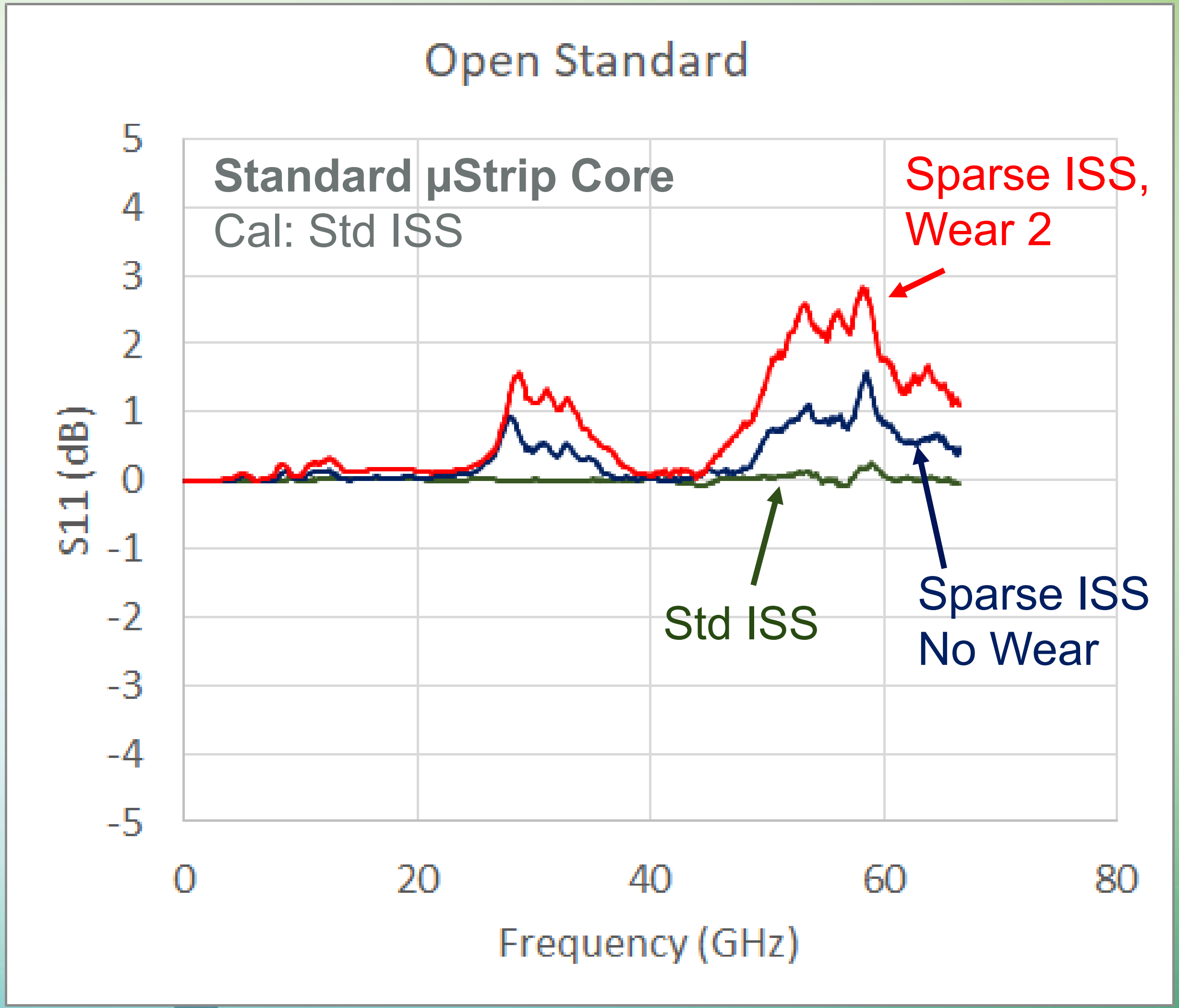




We evaluated these countermeasures...

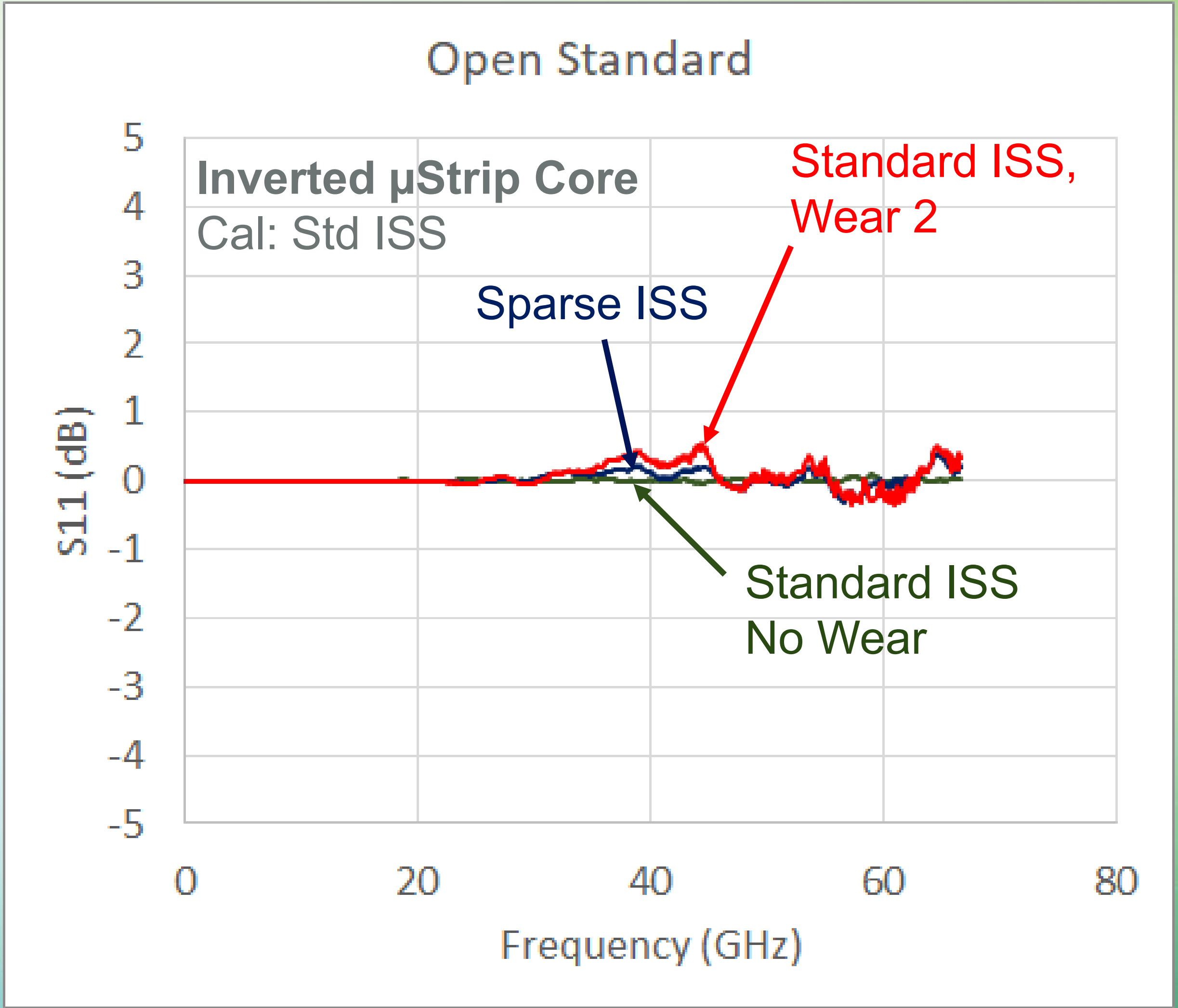
Measured Neighbor Effect– Standard Microstrip

- **Cal on Std ISS (SOLR)**
  - Remeasure Std ISS →Near ideal response
  - Measure Sparse ISS →Not ideal!
- **Standards identical; response differs →Std ISS Neighbors affected Cal**
- **After aging, effect is larger (µStrip closer to ISS)**



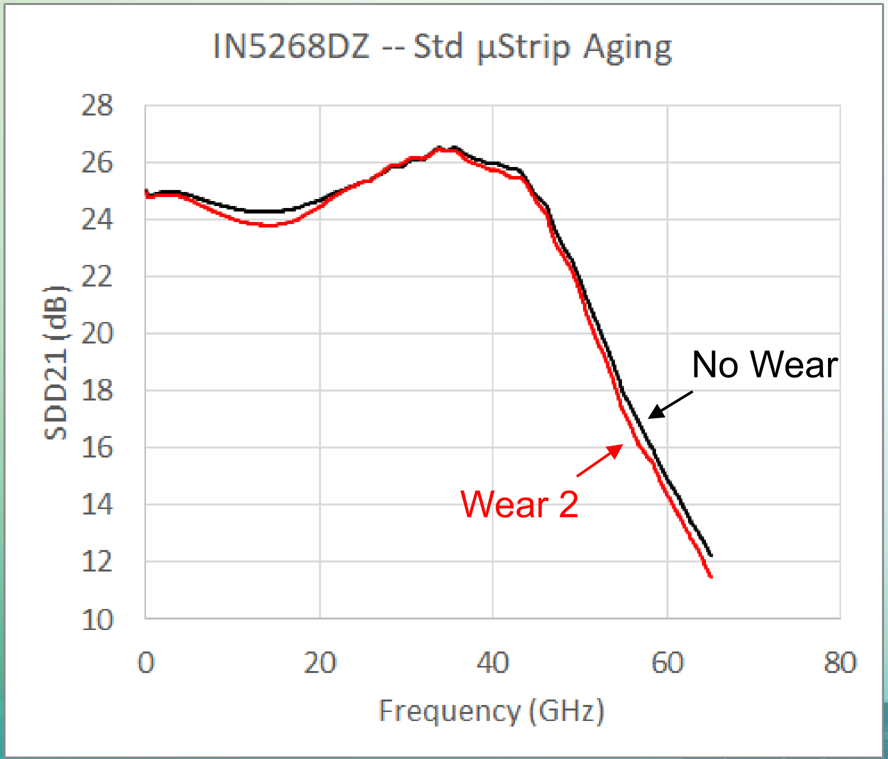
Inverted µStrip Reduces Neighbor Effect

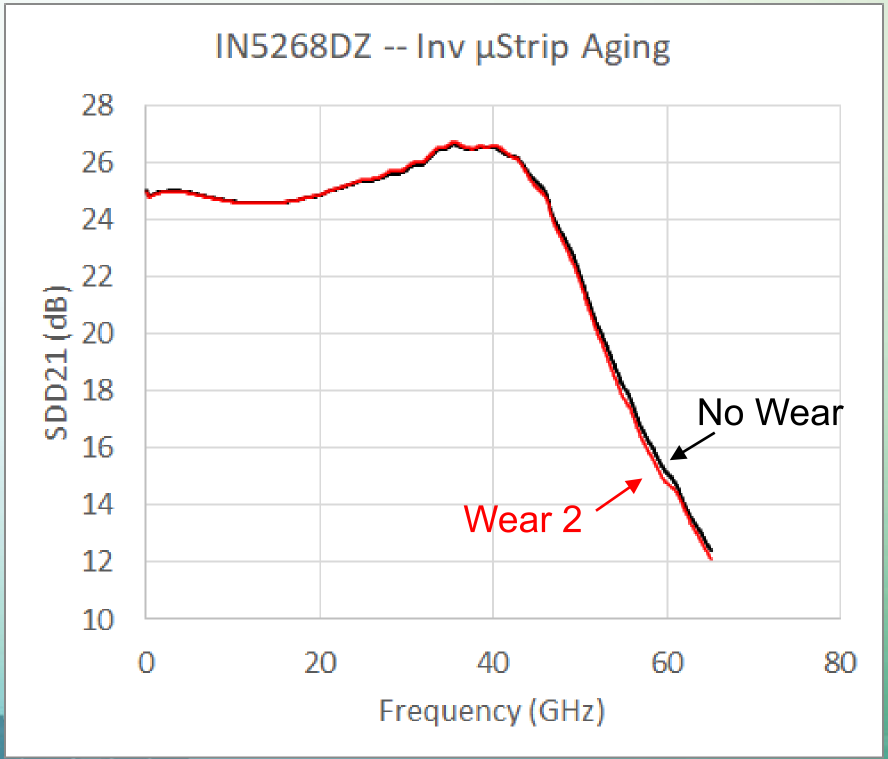
- **Same Methods as for the standard microstrip**
  - Measure Std & Sparse ISS
- **Inverted µStrip shows less neighbor effect (GND under signal trace)**
- **Inverted µStrip insensitive to aging.**



Inverted vs. Standard µStrip in Amplifier Test

- 50 GHz Mach-Zehnder Driver
- Std µStrip: Small change (~0.5 dB) after aging.
- Inv µStrip: Virtually no change after aging.





Conclusion

- **IN order to extend your RF Calibration and maintain the best accuracy:**
  - SOLT less sensitive to probe aging than SOL
    - SOLT could remain valid over probe lifetime (especially at speeds < 20 GHz)
    - SOL calibration or SOL based de-embed file more likely to require re-calibration (depending on required accuracy)
  - CrossTalk: CPW > µStrip ≈ inverted µStrip
    ≈ alternating µStrip
  - Minimize the Neighbor effect
    - exists and increases with probe age, but the effect is small
    - can be reduced by inverted µStrip / sparse ISS

Questions