Tale of a Differential Pair Measurement

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SPEAKER

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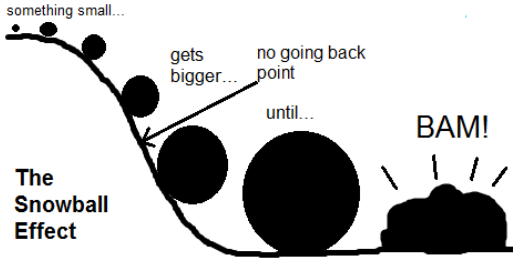
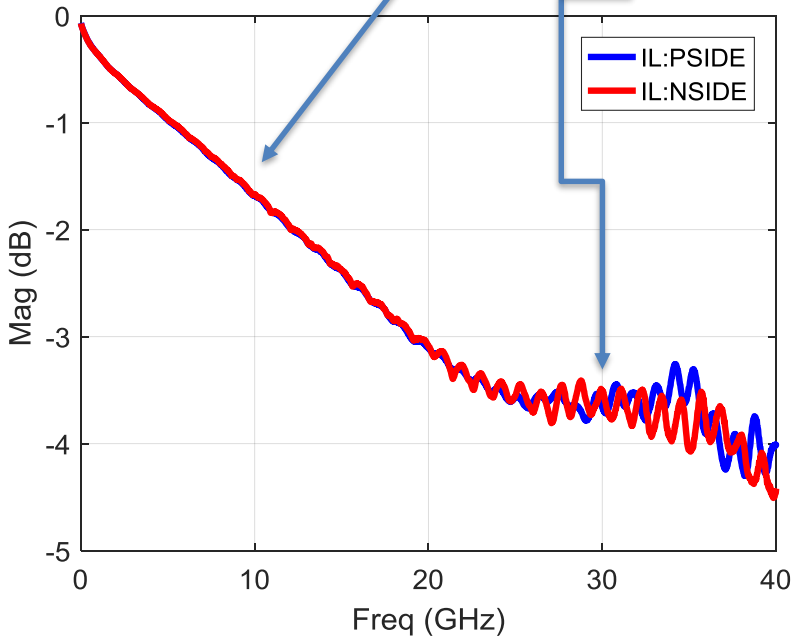
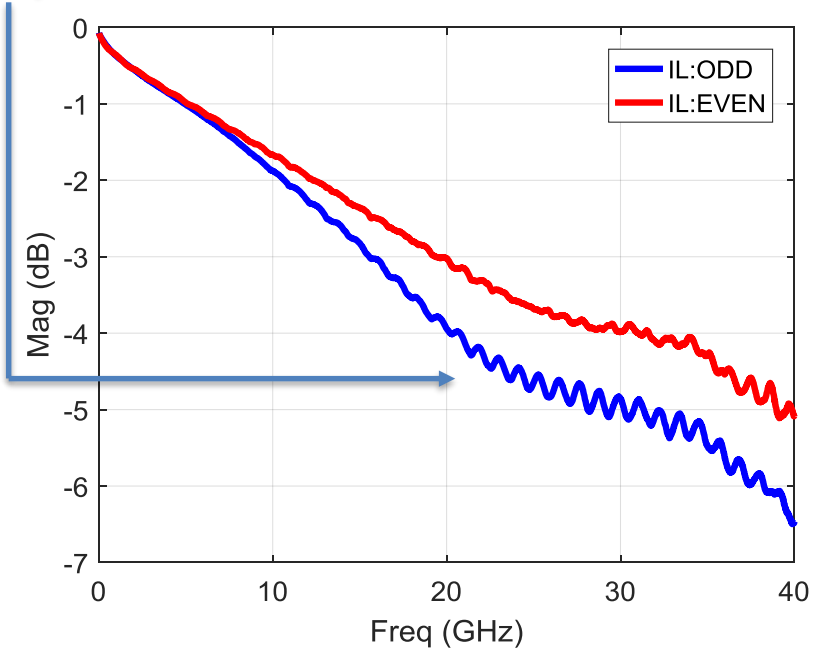
Senior Principal Engineer leading the SI/PI team at Oracle Corporation. In addition to his leadership roles, he's charged with the development of new SI/PI methodologies, high speed characterization, tools and modeling in general. Gustavo has twenty plus years of experience in Signal Integrity and high speed circuits.

Motivation

- Just wanted to do a simple material characterization
- I'll try to show you THE GOOD, THE BAD and THE UGLY!!

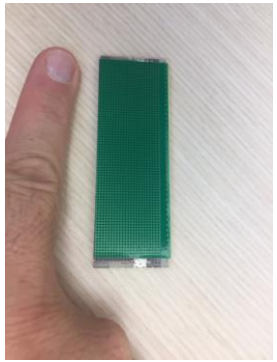




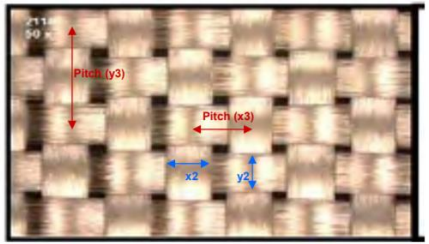


DUT

PLANE	1/2 oz of HVLP	
PREG	4.0mils (2)1035 65%	
SIG	1/2 oz of HVLP	
CORE	3.9mils (2)1035 - 65%	
PLANE	1/2 oz of HVLP	
5.55mils	6.45mils	5.55mils
Target Impedance: 85 Ohms		



Dimensions as defined in stack-up



	Measurements Results (mils)					
Glass Fabric	X1	X2	X3	Y1	Y2	Y3
1035	1.12	10.20	16.10	0.53	10.90	15.50
106	1.00	4.80	18.50	0.60	10.20	20.60
1067	0.82	8.85	14.30	0.78	12.40	13.70
1080	1.60	8.20	17.00	1.10	12.10	22.40
1086	1.44	10.80	16.60	1.00	14.70	17.10
2113 / 2313	2.40	10.50	17.00	1.00	15.30	18.20
3313	1.90	13.10	16.20	1.50	11.00	16.30
3070	1.70	12.70	14.80	1.70	12.60	14.20
2116	2.20	14.10	17.20	2.00	14.50	17.30
1652	2.40	15.30	17.50	2.90	15.90	18.80

Weave of Flat Glass, (1035 used, first on the list above)

http://www.isola-group.com/wp-content/uploads/Understanding-Glass-Fabric.pdf

Two similar lines on the same board were measured:

SHORTER = 2.718” (on layer SIG-3)

LONGER = 3.2” (on layer SIG-6)

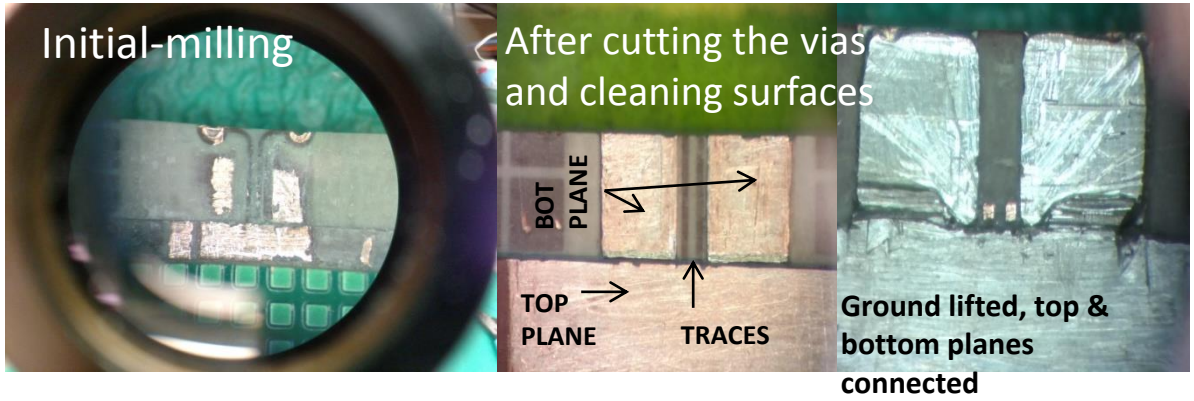
Measurement Technique

HOW?

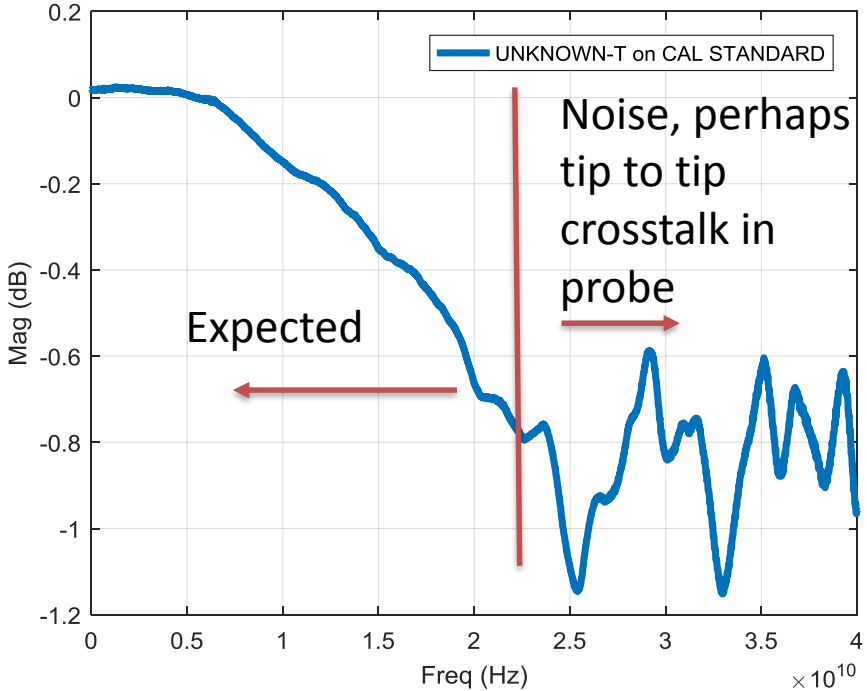
- Mill the board to get direct access to the differential trace
- Use a G-S-S-G wafer probe (WP)

WHY?

- Allows most direct measurement of the trace without assumptions (de-embedding), considered better for glass reinforced materials
- G-S-S-G probe have same pattern as a differential trace, so the probe can be landed without DUT modification



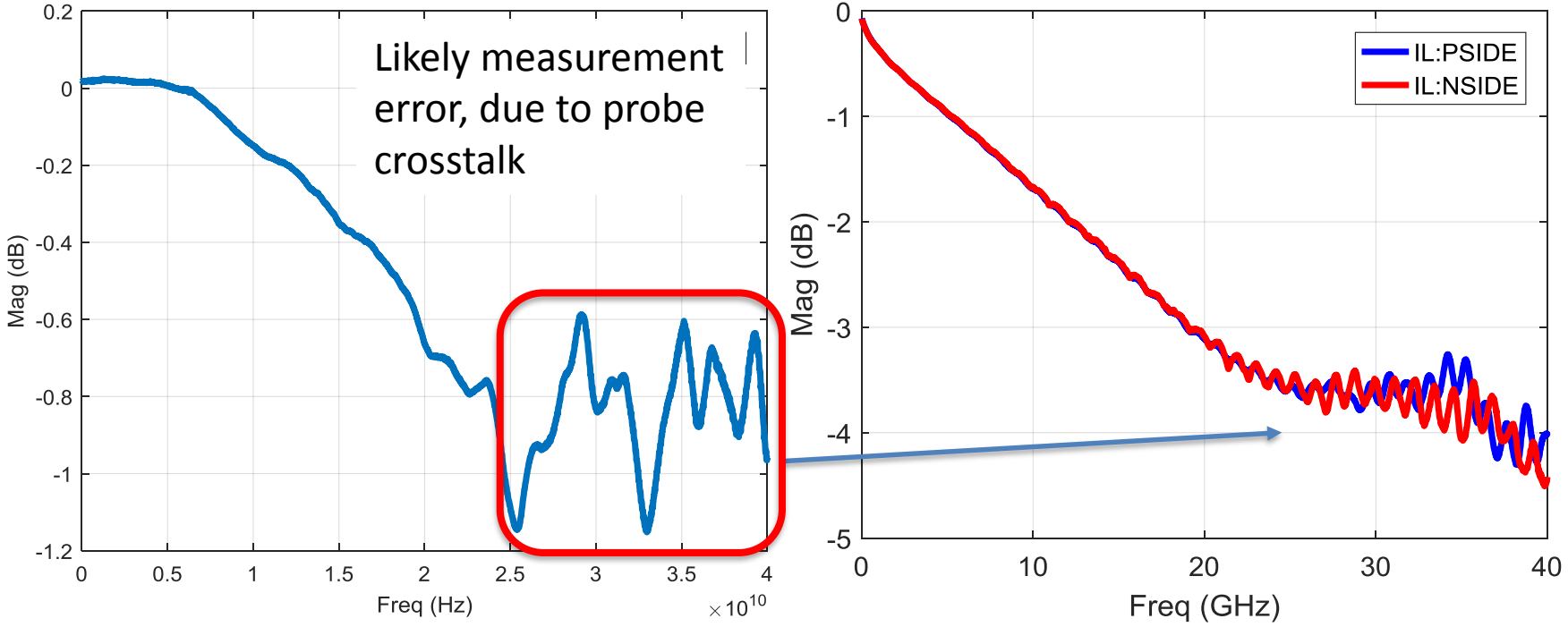
SOLT Calibration (500um G-S-S-G probe)



Substrate Through measurement after calibration

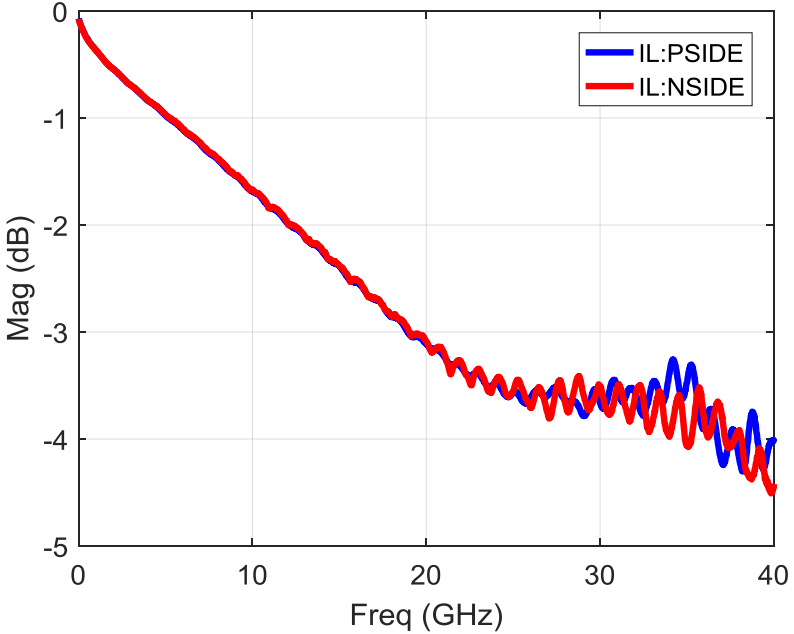
- Measurement right after calibration, without moving the probe after the last Through calibration step.
- Expect uniform decay due to losses.
- Up to 25GHz looks decent
- Ringing observed above 25GHz likely related to tip to tip crosstalk in probe

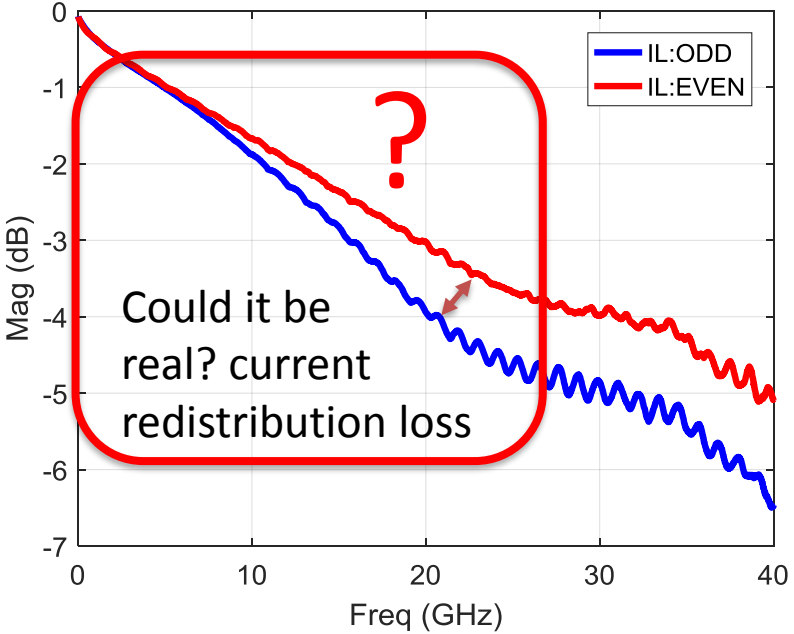
The Bad!! (after 25GHz)



The Ugly???

Let's do more post-processing to identify the issue

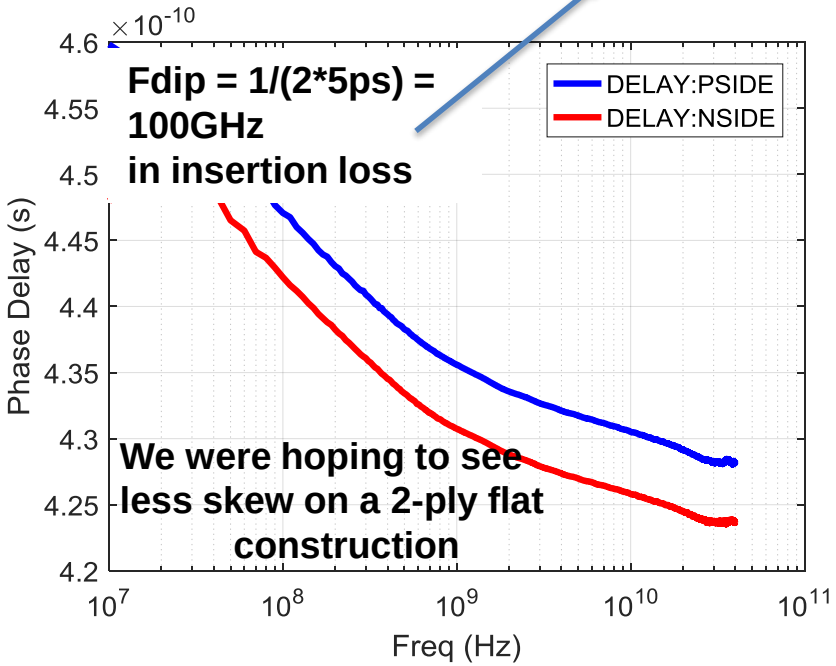


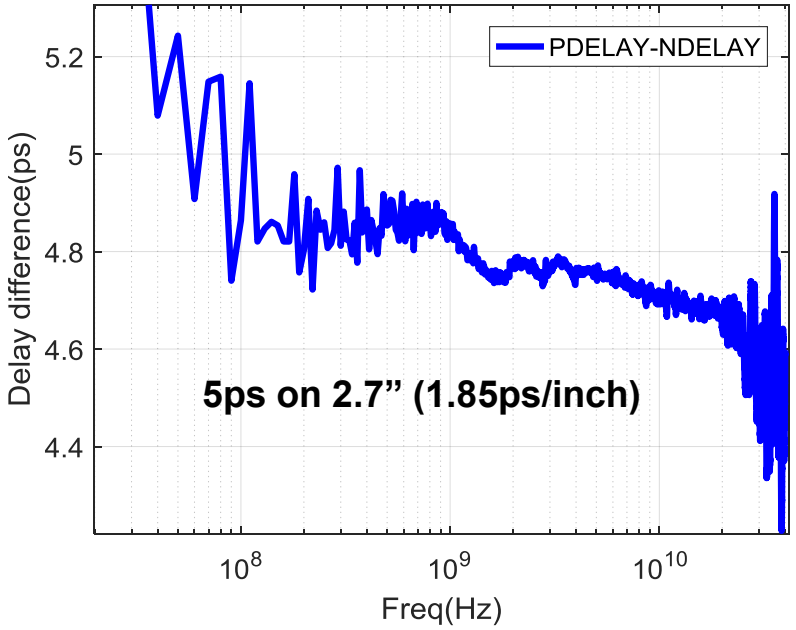


Is it real, or some kind of measurement error that it's ONLY seen in the Mixed Mode S-parameters?

Phase Delay

http://www.electrical-integrity.com/Paper_download_files/DC07_SUN_difflosses_v14.pdf





More likely to find high delta delay [ps/inch] values on shorter traces. On longer traces the normal meandering of the weave tends to statistically equalize the delay, although can't be guaranteed in the worst case

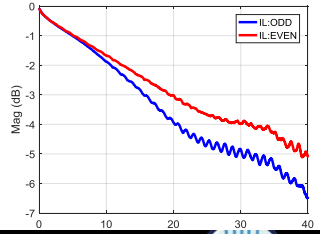
Time Domain

Everything checks out fine!!!!

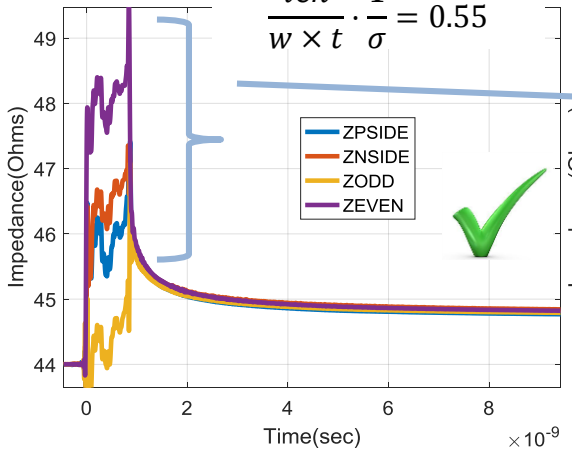
Observation:

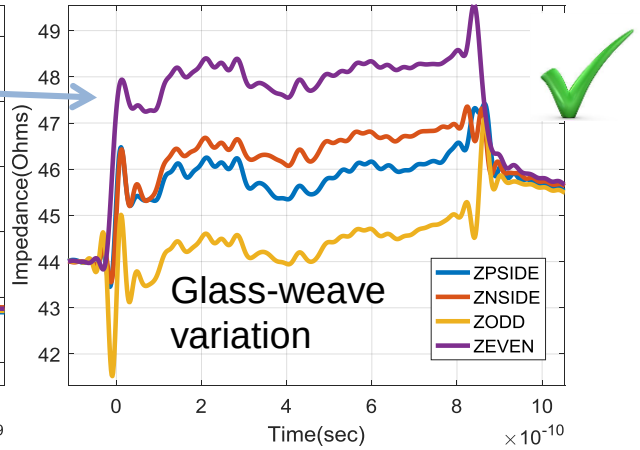
- **Positive far end Crosstalk (more on this later)**

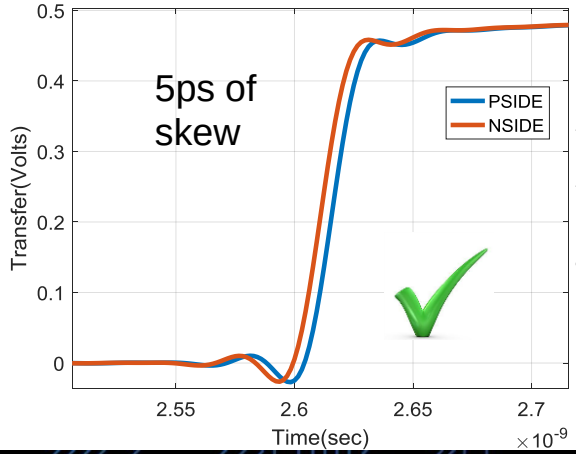
Maybe the difference in Insertion loss between ODD and EVEN is real???

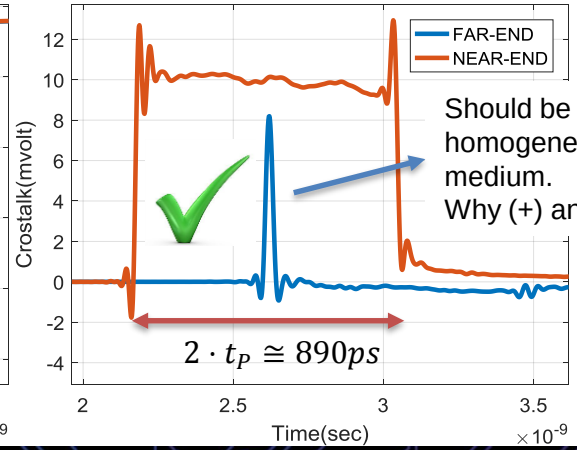


$$\frac{len}{w \times t} \cdot \frac{1}{\sigma} = 0.55$$







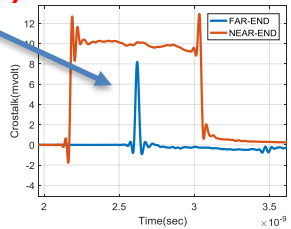


Should be zero in homogeneous medium.
Why (+) and not (-)

Simulations (what is going on?)

If we assume most field goes through resin for crosstalk in between conductors, since resin-dk < glass-dk we should see:

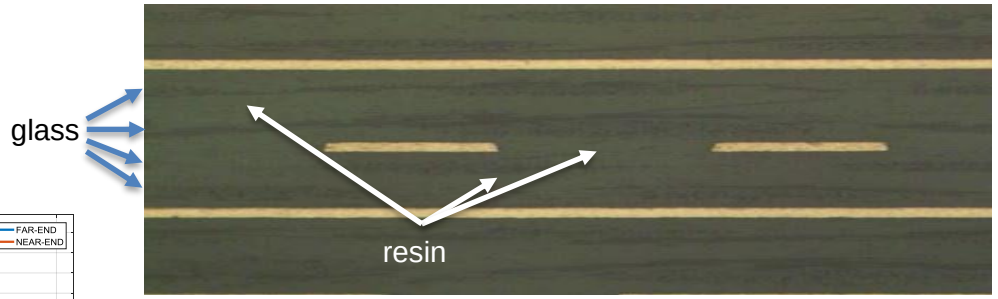
- Capacitive coupling < Inductive coupling
- Should result on negative far-end crosstalk
- **(WRONG-ASSUMPTION IN THIS CASE)**
- If we model the glass weave as layers, we can tune the far end crosstalk sign, just by moving up and down the glass with respect to the trace

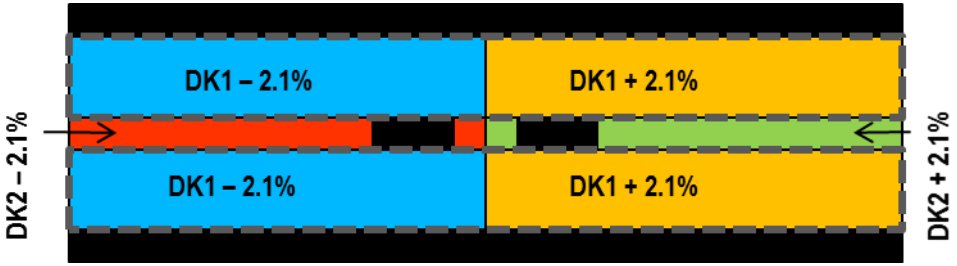


For simulation purposes I'll take a simplified black-box approach:

- Same dielectric on Pre-preg and Core
- Variation on DK left to right, to model the skew observed in measurements
- Increased DK between conductors to capture the (+ sign) of the far-end crosstalk

Resin-Dk < Glass-Dk



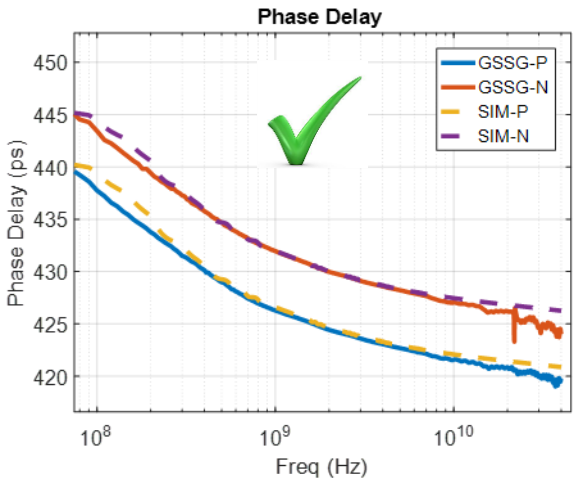


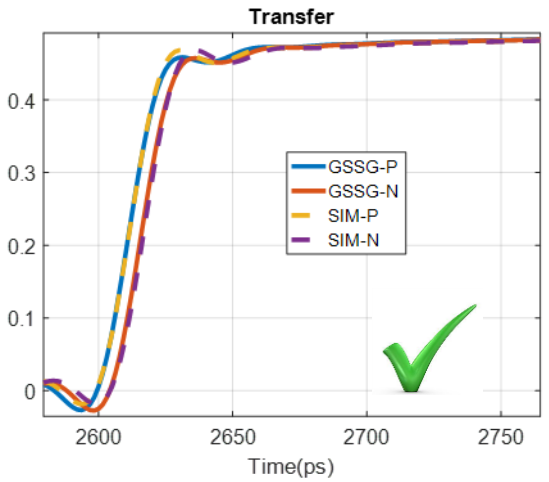
DK2 > DK1

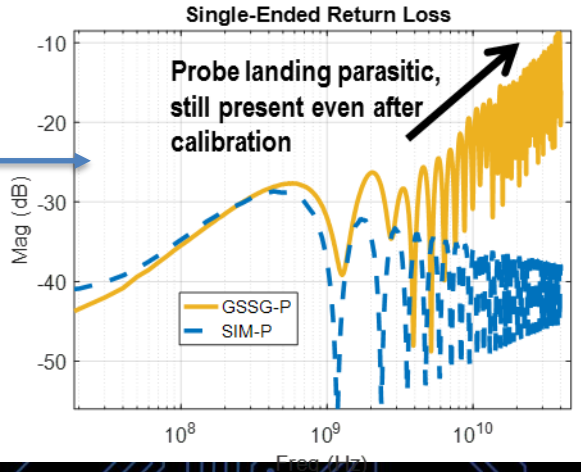
Correlation/Fitting

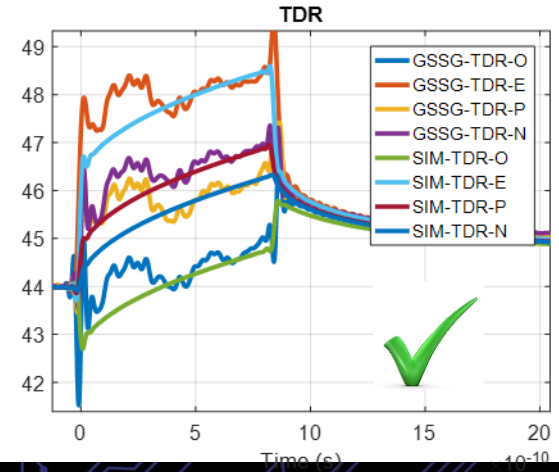
Excellent fitting:

- Phase delay and transfer on top of each other
- TDR is capturing very well the deltas between mixed-mode and single ended behavior
- In the return loss we see something known, which is the small un-calibrated portion of the measurements when the probe is landing on the real DUT (as opposed to the SOLT substrate)



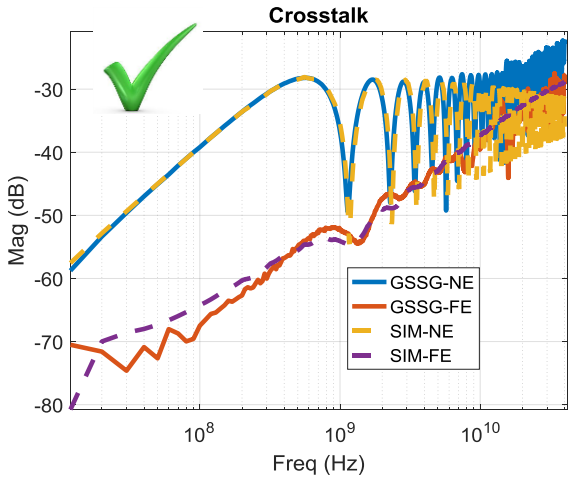


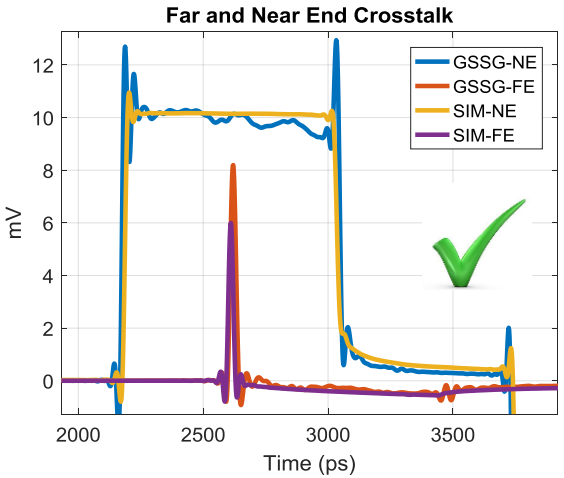




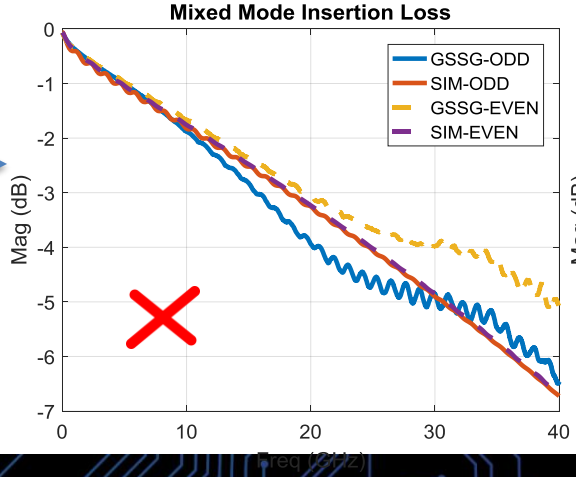
Correlation/Fitting

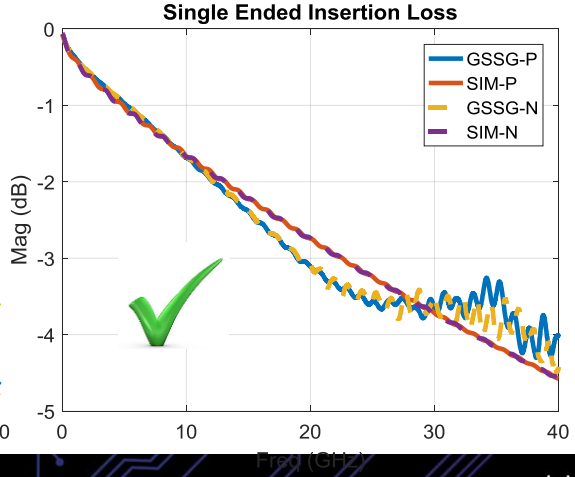
- Crosstalk is looking very good (both near and far end)





- **OOPSSS**: NO separation between modes (odd/even) in simulation……..

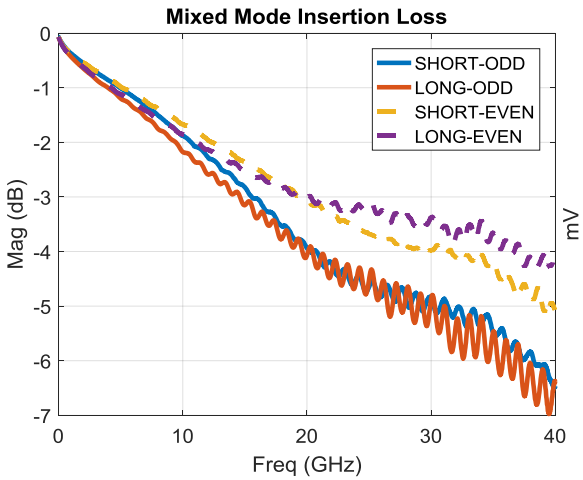


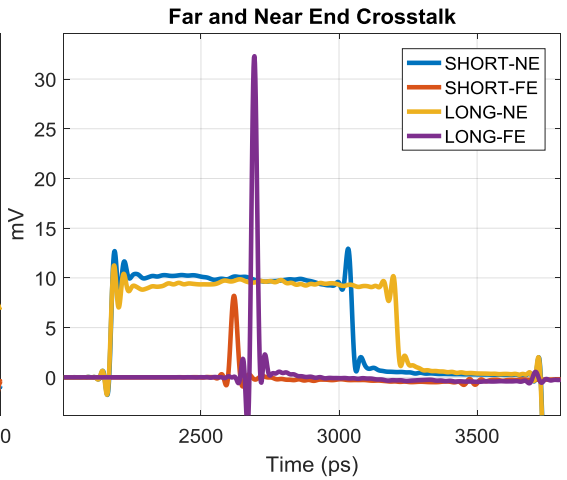


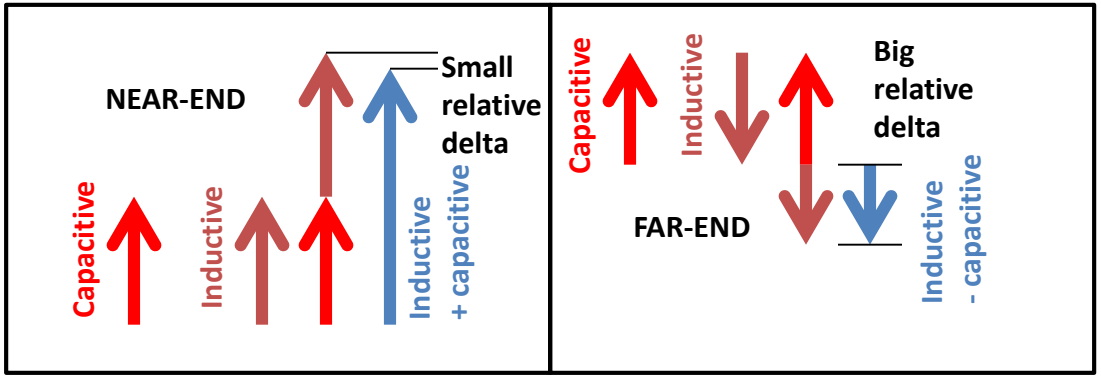
Maybe this was a FLUKE measurement (let's try another one)

Longer Trace Measurement

- Measure a 500mil longer trace on a different layer same board:
  - Short trace = 2.7in (original)
  - Long trace = 3.2in (new meas)
- We see the SAME, deviation between modes
- We also see an unreasonable delta on far-end crosstalk
- Conclude that FEXT is very sensitive and dangerous (on glass reinforce materials) to use for fitting



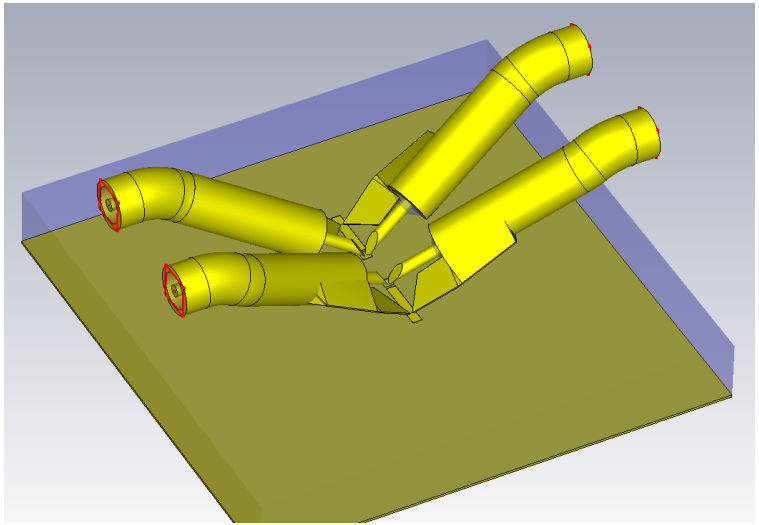


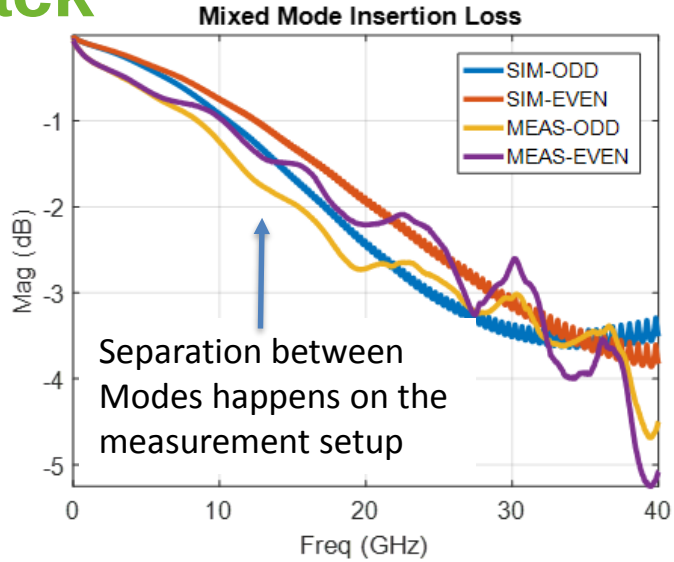


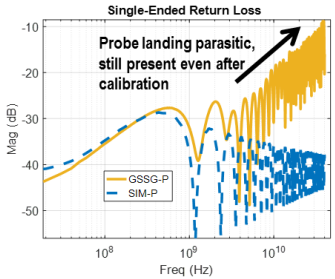
CONCLUDE: THERE SOMETHING SUBTLE ON THE MEASUREMENT, EFFECT IS NOT REAL !!!!!

Probe Measurement Back to Back

- Let's remove the trace out of the equation
- Do a Calibration to the end of the cables
- Measure the probes back-to-back (no trace)

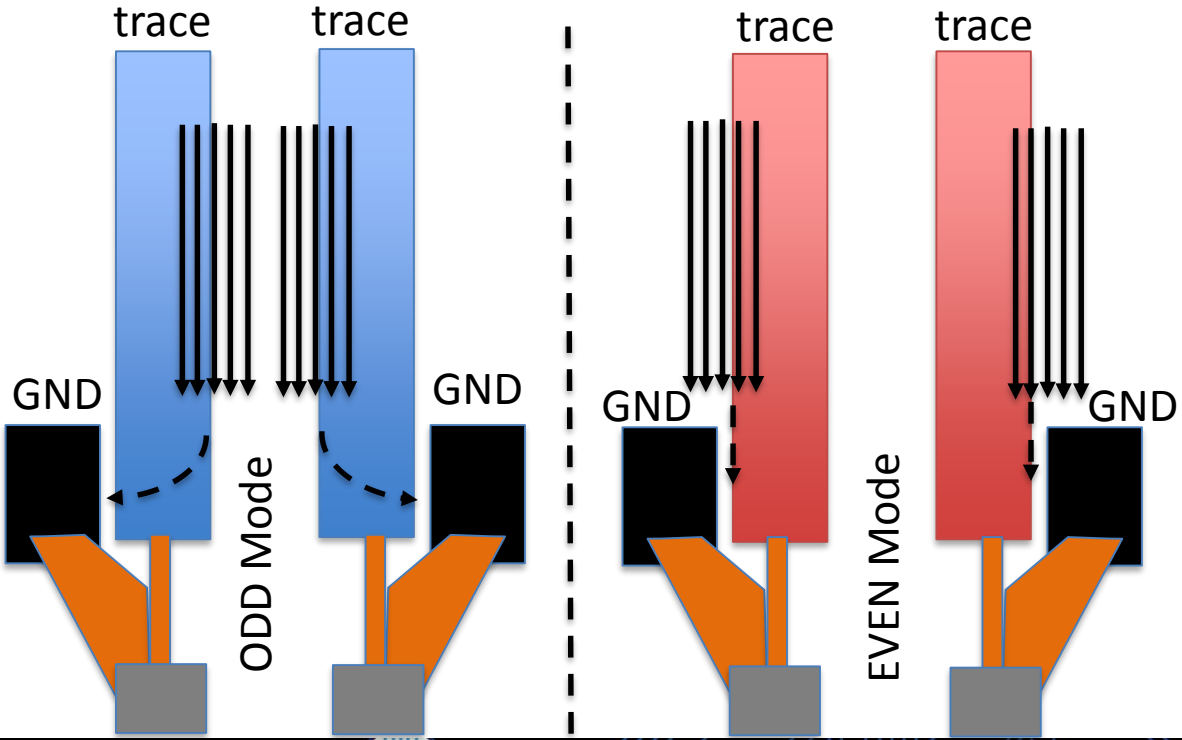




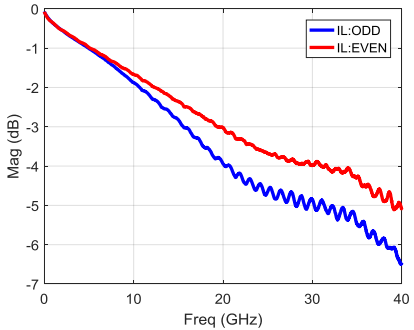


Hypothesis

Source of the issue???

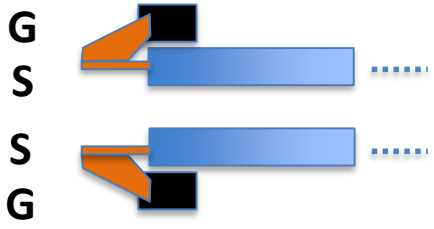


Probe's GND blades slightly favoring EVEN mode return current path
(less loss)

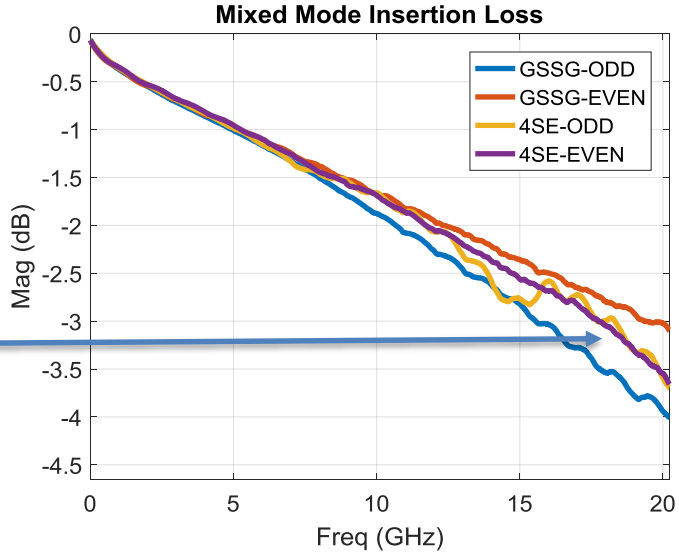


Back Ground Blade Position

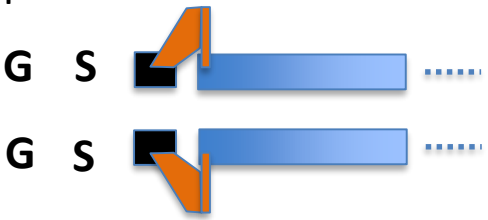
Standard G-S-S-G differential probes



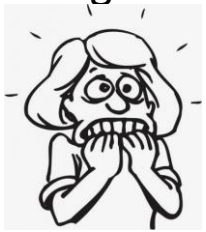
When the GND blade is "approximately" on the back, the ODD and EVEN mode Insertion loss are the same.

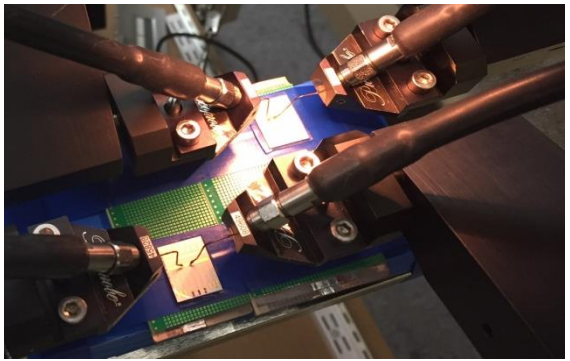


Using 2 Single Ended probes per side



Picture of the cumbersome calibration of four Single Ended probes simultaneously

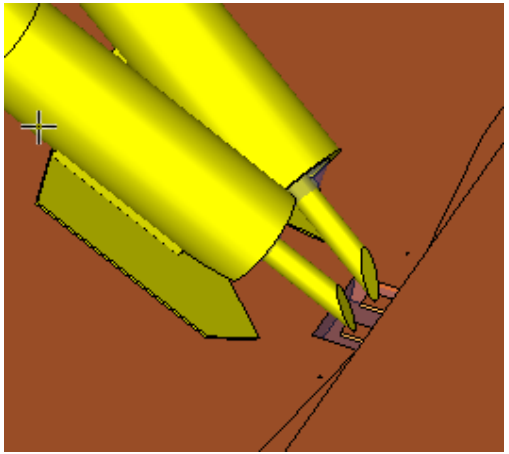


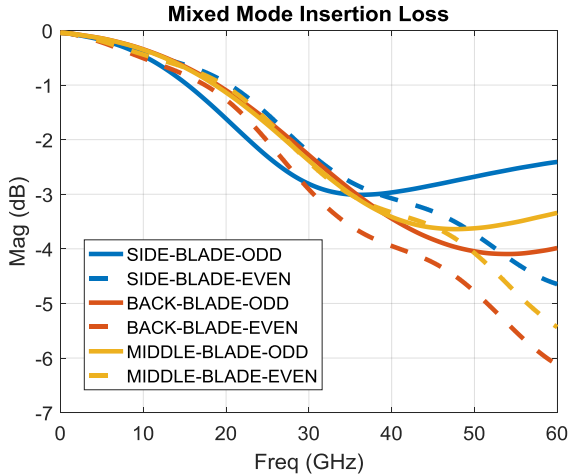


Probe Simulations (different GND blade locations)

- Rotating the probe from the back through the middle to the side
- We can clearly see how the delta between the modes is affected as we rotate the GND blades of the probes with respect to the traces
- Side Blades (0°) : IL-ODD > IL-EVEN
- Middle Blades (45°): IL-ODD = IL-EVEN
- Back Blades (90°): IL-ODD < IL-EVEN

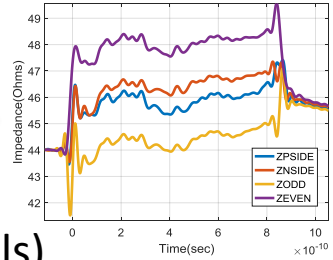
- Other probe configurations will allow better current redistribution and less crosstalk simultaneously

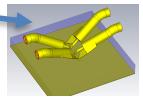


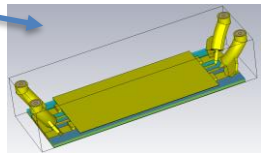


Other Calibration Methods

- Various calibration methods available, but other than SOLT and any of its variants, the two most prevalent seems to be:
  - TRL (Through-Reflect-Line)
  - Probe de-embedding (AFR/In situ de-embedding)
- TRL: Very accurate mathematically, but requires:
  - Known impedance (difficult to guarantee on glass-reinforced materials)
  - A DUT board (not available to us for this test)
- De-embedding: A two tier calibration (SOLT calibration to the end of the cables)
  - Tier-1: Through measurements of the probes back to back (or to OPEN/SHORT) to extract probe model
  - Tier-2: DUT measurements including probes.
  - De-embed the probes from measurements, keeping only desired DUT
  - **Good chance to capture current re-distribution at the probe tips!!!!!!**

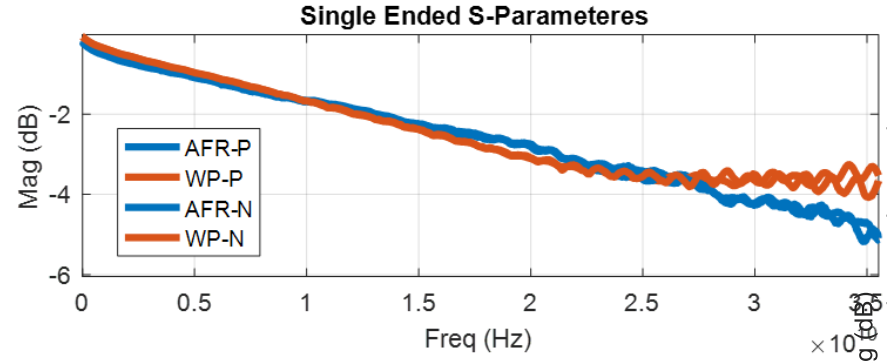


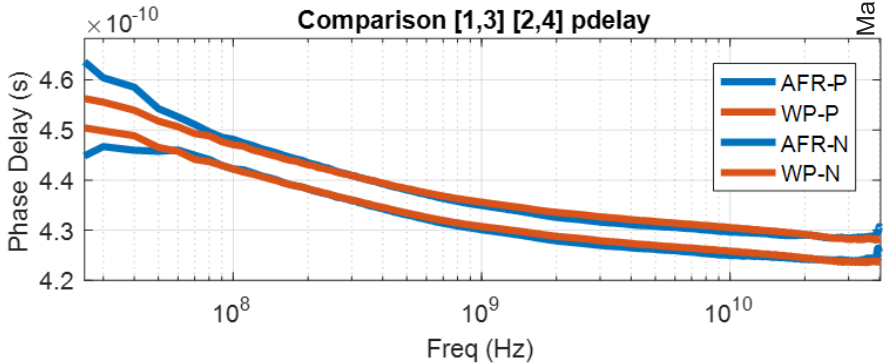


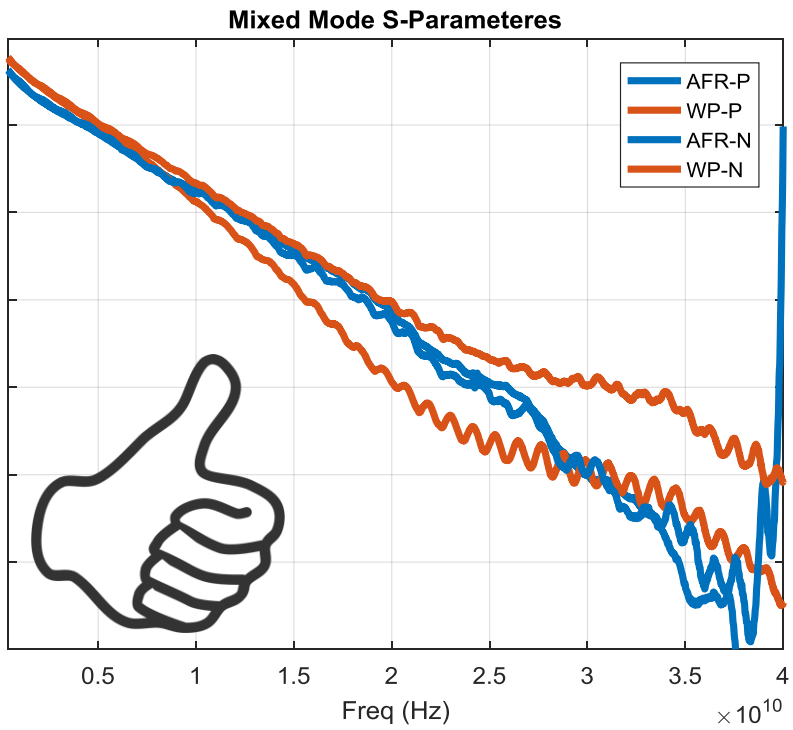


De-embedding Results (frequency domain)

!!!!Yeah!!!!!!

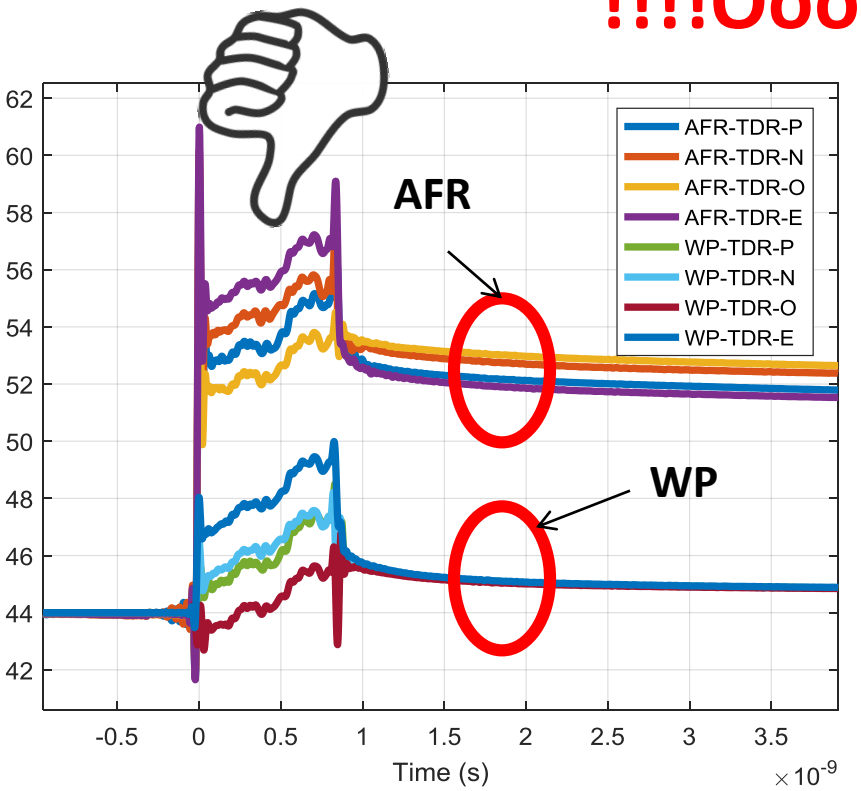


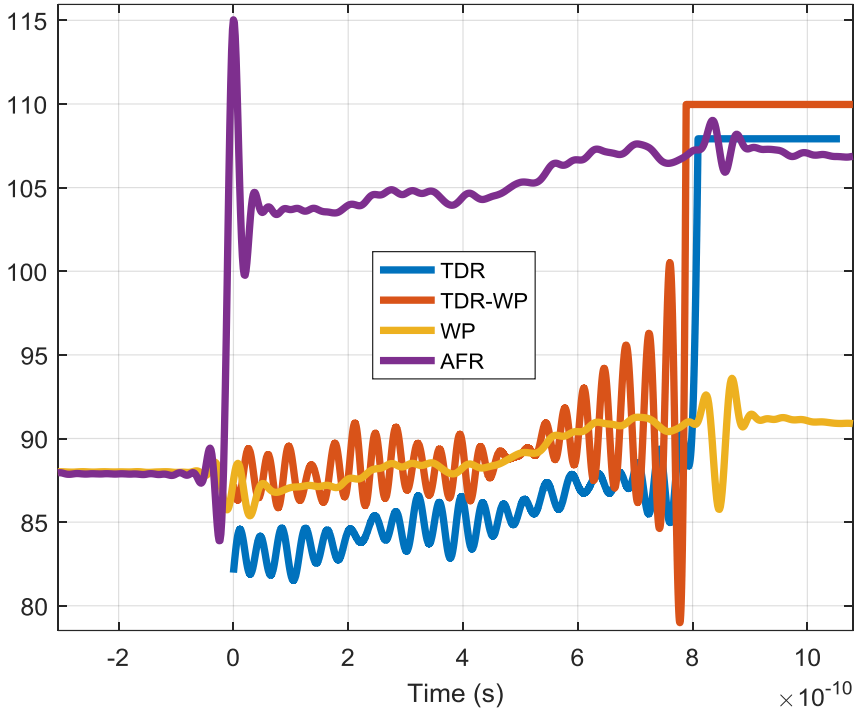




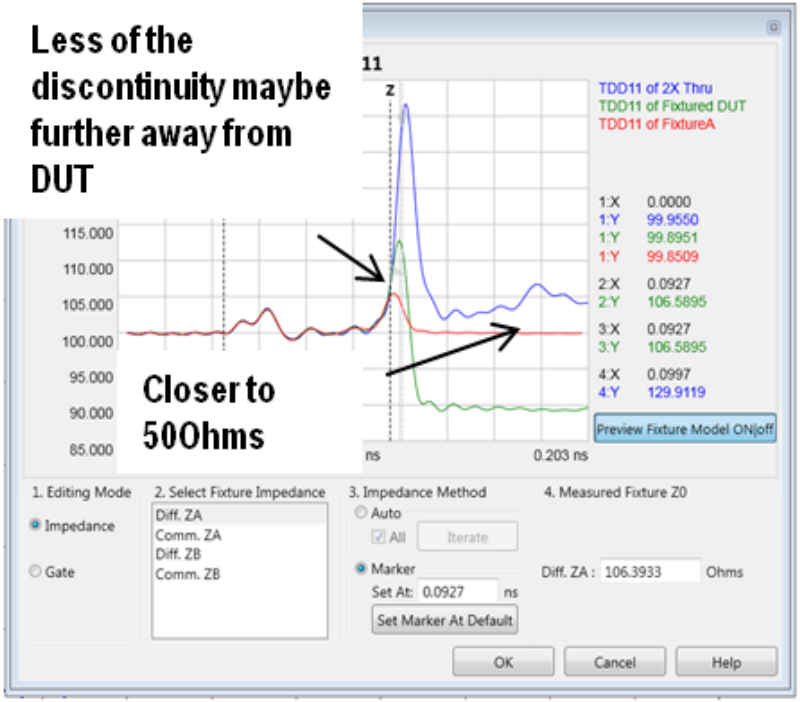
De-embedding Results (time domain)

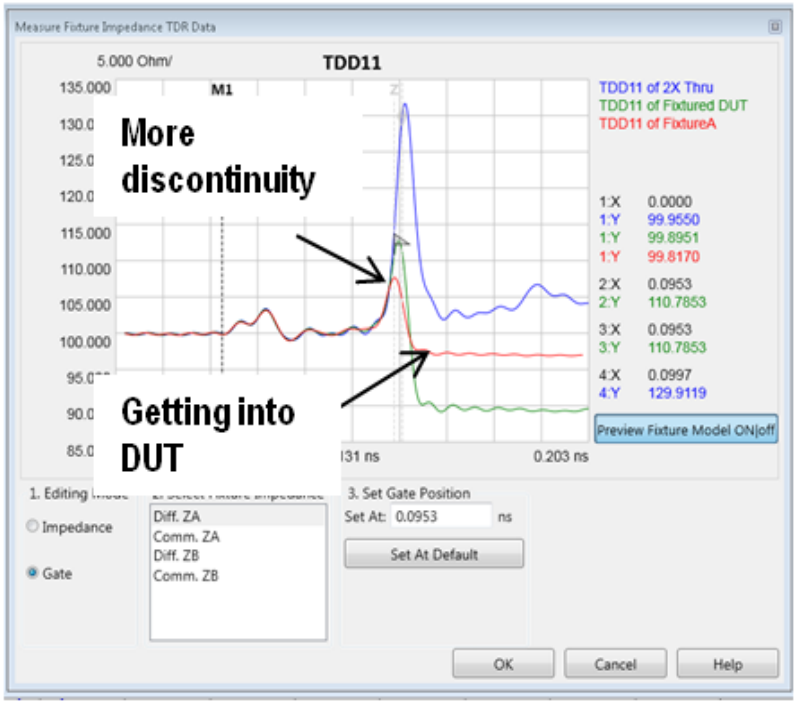
!!!!Ooops!!!!!!





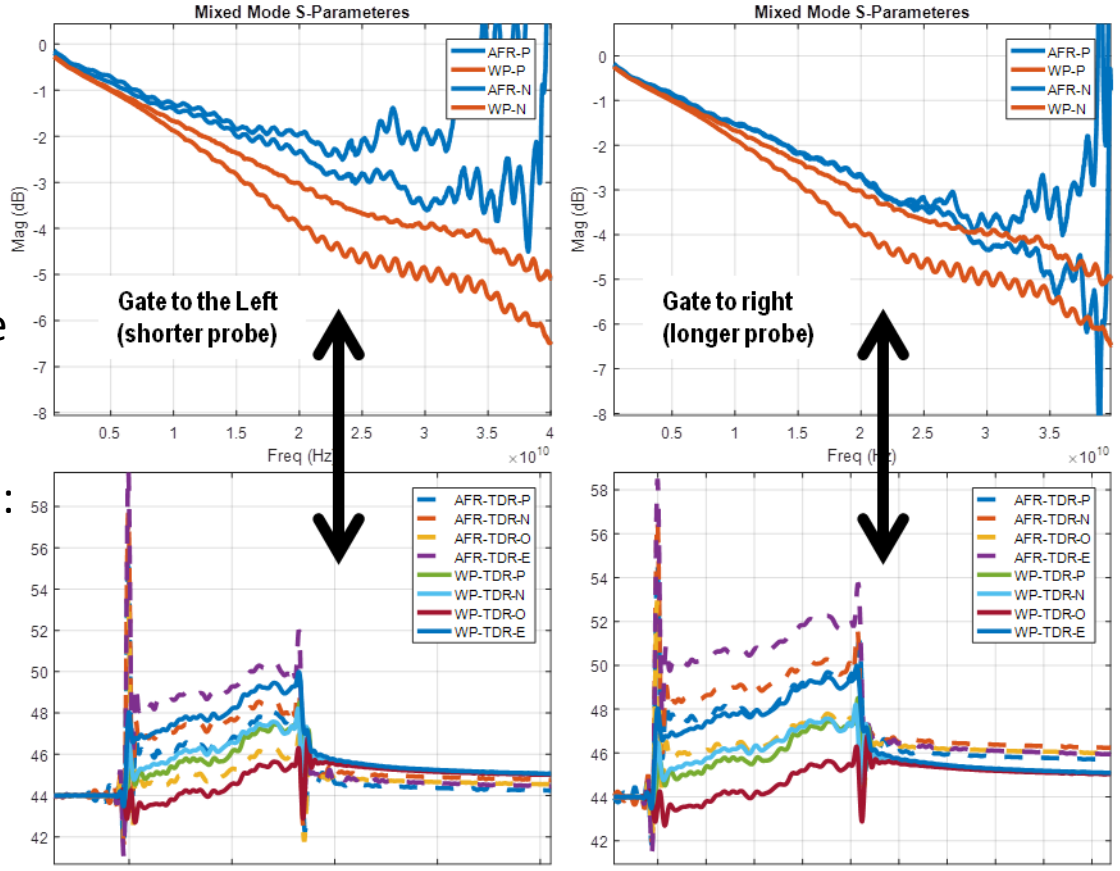
De-embedding (technique to get the probes)





De-embedding, Moving the Gate

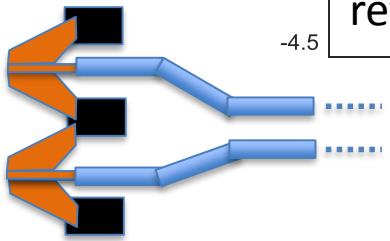
- When moving the gate we are literally changing the extracted probe model
- Many more cases have been done with simulation models to try the algorithm
- The issues found on this structure:
  - Very short structure, virtually lossless
  - Manual intervention to get a result (how do you know what is right?)

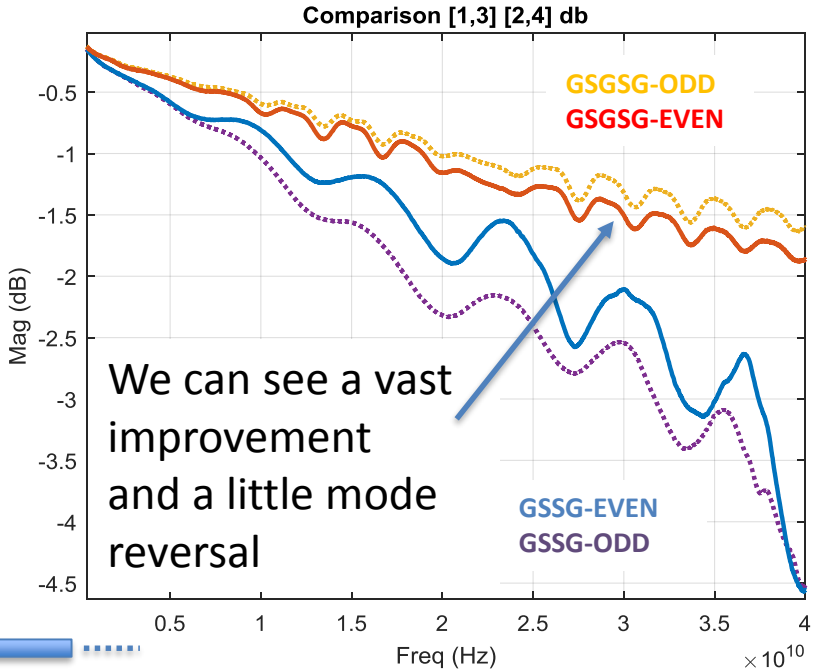


Probe with Middle Ground (G-S-G-S-G)

- By adding the GND in between two things are happening:
  1. Better isolation (lower crosstalk) between probe tips
  2. Improving current redistribution and reducing IL loss difference between modes
- The drawback on PCB application is that we need to create a special DUT.
- We need to add small bends

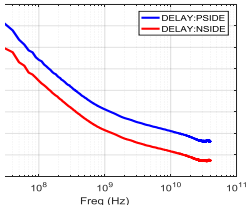
- Since we did not have an special DUT, we measured the probes back-to-back on the calibration substrate



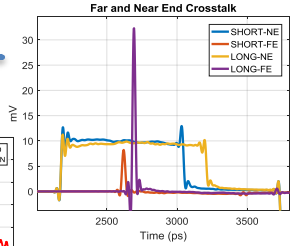


Summary (lessons learned)

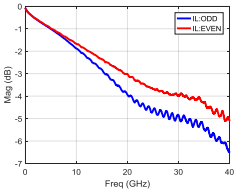
- Not much of a surprise, but we see how even a 2-ply flat glass weave can experience substantial skew, easily seen on short lines



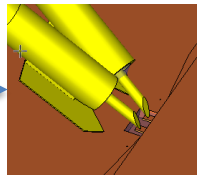
- Far-end crosstalk is very sensitive, not recommended for correlations, sign is (+), not (-) as originally expected by us.



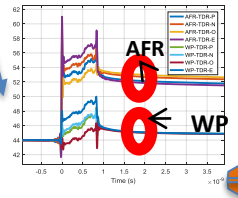
- SOLT calibration with G-S-S-G probe has a current redistribution error at the probe tips mostly seen on mixed mode



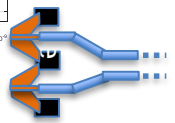
- Simple probe modification can be implemented to improve error



- De-embedding shows promise. For short structure probe extraction does not seem reliable yet requiring a lot of manual intervention (almost fitting)



- G-S-G-S-G seems to provide the best solution, both in IL and crosstalk (at the expense of tweaking the DUT to fit the extra GND blade)



Thank you!

QUESTIONS?