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Your Port for EMC+SIPI Compliance

Systematic approach to PCB interconnects analysis to measurement validation

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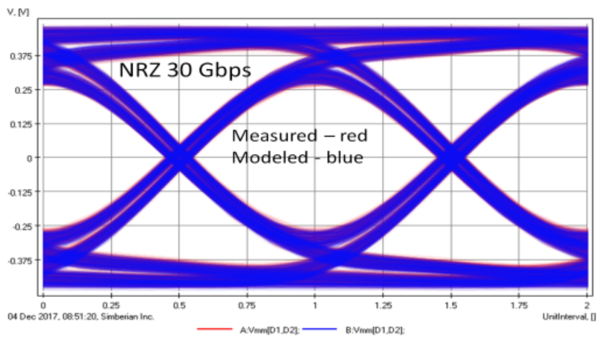
Outline

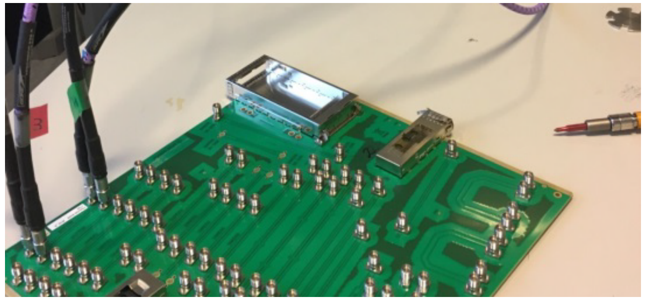
- Introduction
- Systematic “sink or swim” validation process
- EvR-1 test board design
- Measurements and GMS-parameters extraction
- Board cross-sectioning
- Material model identification with GMS-parameters
- Validation: Expectations vs. Reality
- Conclusion
- Reality above 30 GHz

How to make predictable interconnects?

Design success "fire triangle"



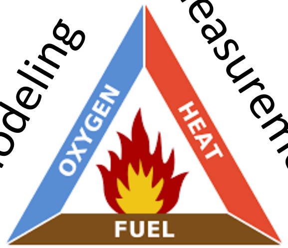
Accuracy of EDA tools must be systematically validated (most are not)



Pristine VNA measurements from 10 MHz to 40-50 GHz are required - difficult

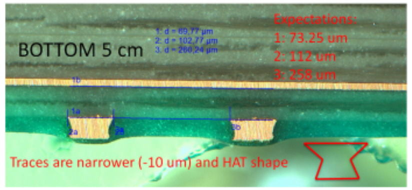
modeling

measurements



manufacturing

Material models and manufacturing adjustments must be identified (PCB are not manufactured as designed)



Predictable – analysis correlate with measurement

Geometry Adjustments +
Material Models +
Validated Software =
Predictable Interconnects

Systematic validation is the KEY to success...

Systematic "sink or swim" validation process

1. Select materials and define PCB stackup with the manufacturer
2. Design test structures with the EM analysis (simple links, launches, vias,…)
3. Manufacture the board, mount connectors (if any)
4. Measure S-parameters and validate quality of the measurements
5. Cross-section the board and identify the manufacturing adjustments (if any)
6. Identify broad-band dielectric and conductor roughness models with GMS-parameters or SPP Light techniques
7. Simulate all structures with the identified or validated material models and confirmed adjustments consistently and compare S-parameters and TDR with the measurements (no further manipulations with the data)

This presentation is a brief report of lessons learned from such validation…

EvR-1 Validation Board

“Trust but Validate”

Stackup design and initial models

1990

Stack up	Description	Base Thickness	Processed Thickness	εr	Impedance ID	Copper Coverage	Comments
	Liquid PhotoImageable Mask			4.00			
TOP	Copper Foil	18.00	35.00		1, 2	60.00	
	Panasonic Meg-6 PrePreg 1035 (75% RC)	74.00	73.25	3.19			Spread glass weave
		18.00	15.00			80.00	
	Panasonic Meg-6 (2*1035)	100.00	100.00	3.37			Core with H-VLP copper
INNER1		18.00	15.00		3, 4	20.00	
	Panasonic Meg-6 PrePreg 1035 (70% RC)	60.00	54.00	3.23			Spread glass weave
	Panasonic Meg-6 PrePreg 1035 (70% RC)	60.00	54.00	3.23			Spread glass weave
		18.00	15.00			80.00	
	Panasonic Meg-6 (2*1035)	100.00	100.00	3.37			Core with H-VLP copper
INNER2		18.00	15.00		5, 6	20.00	
	Panasonic Meg-6 PrePreg 1027 (75% RC)	49.00	43.00	3.19			Spread glass weave
	Panasonic Meg-6 PrePreg 1027 (75% RC)	49.00	43.00	3.19			Spread glass weave
		18.00	15.00			80.00	
	Panasonic Meg-6 (2*1035)	100.00	100.00	3.37			Core with H-VLP copper
INNER3		18.00	15.00		7, 8	20.00	
	Panasonic Meg-6 PrePreg 1027 (75% RC)	49.00	43.00	3.19			Spread glass weave
	Panasonic Meg-6 PrePreg 1027 (75% RC)	49.00	43.00	3.19			Spread glass weave
		18.00	15.00			80.00	
	ShengYi S1000-2 (1*106)	50.00	50.00	3.72			
		18.00	15.00			80.00	
	Panasonic Meg-6 PrePreg 1027 (75% RC)	49.00	48.25	3.19			Spread glass weave
	Panasonic Meg-6 PrePreg 1027 (75% RC)	49.00	48.25	3.19			Spread glass weave
		18.00	15.00			80.00	
	ShengYi S1000-2 (1*106)	50.00	50.00	3.72			
		18.00	15.00			80.00	
	Panasonic Meg-6 PrePreg 1027 (75% RC)	49.00	48.25	3.19			Spread glass weave
	Panasonic Meg-6 PrePreg 1027 (75% RC)	49.00	48.25	3.19			Spread glass weave
		18.00	15.00			80.00	
	ShengYi S1000-2 (1*106)	50.00	50.00	3.72			
		18.00	15.00			80.00	
	Panasonic Meg-6 PrePreg 1027 (75% RC)	49.00	43.00	3.19			Spread glass weave
	Panasonic Meg-6 PrePreg 1027 (75% RC)	49.00	43.00	3.19			Spread glass weave
INNER4		18.00	15.00			20.00	
	Panasonic Meg-6 (2*1035)	100.00	100.00	3.37			Core with H-VLP copper
		18.00	15.00			80.00	
	Panasonic Meg-6 PrePreg 1027 (75% RC)	49.00	43.00	3.19			Spread glass weave
	Panasonic Meg-6 PrePreg 1027 (75% RC)	49.00	43.00	3.19			Spread glass weave
INNER5		18.00	15.00			20.00	
	Panasonic Meg-6 (2*1035)	100.00	100.00	3.37			Core with H-VLP copper
		18.00	15.00			80.00	
	Panasonic Meg-6 PrePreg 1035 (70% RC)	60.00	54.00	3.23			Spread glass weave
	Panasonic Meg-6 PrePreg 1035 (70% RC)	60.00	54.00	3.23			Spread glass weave
INNER6		18.00	15.00			20.00	
	Panasonic Meg-6 (2*1035)	100.00	100.00	3.37			Core with H-VLP copper
		18.00	15.00			80.00	
	Panasonic Meg-6 PrePreg 1035 (75% RC)	74.00	73.25	3.19			Spread glass weave
BOTTOM	Copper Foil	18.00	35.00			60.00	
	Liquid PhotoImageable Mask			4.00			

HVLP copper - nothing for roughness modeling

Materials: T=20[°C],...
- "COPPER", RR=1
- "035.56UM_CU", RR=1
- "017.78UM_CU", RR=1
- "FR-4", Dk=3.72, LT=0.02, PLM=WD, Dk(0)=4.48, Dk(inf)=3.39
- "Air"
- "Solder Mask", Dk=4, LT=0.02, PLM=WD, Dk(0)=4.82, Dk(inf)=3.65
- "Meg-6 TopBot", Dk=3.19, LT=0.002, PLM=WD, Dk(0)=3.26, Dk(inf)=3.16
- "Meg-6 Inner1 (P)", Dk=3.23, LT=0.002, PLM=WD, Dk(0)=3.3, Dk(inf)=3.2
- "Meg-6 2x1035 (C)", Dk=3.37, LT=0.002, PLM=WD, Dk(0)=3.44, Dk(inf)=3.34
- "Meg-6 Inner2 (P)", Dk=3.19, LT=0.002, PLM=WD, Dk(0)=3.26, Dk(inf)=3.16
- "Meg-6 Inner3 (P)", Dk=3.19, LT=0.002, PLM=WD, Dk(0)=3.26, Dk(inf)=3.16
- "Meg-6 Av", Dk=3.19, LT=0.002, PLM=WD, Dk(0)=3.26, Dk(inf)=3.16

No data on resistivity and roughness for conductors

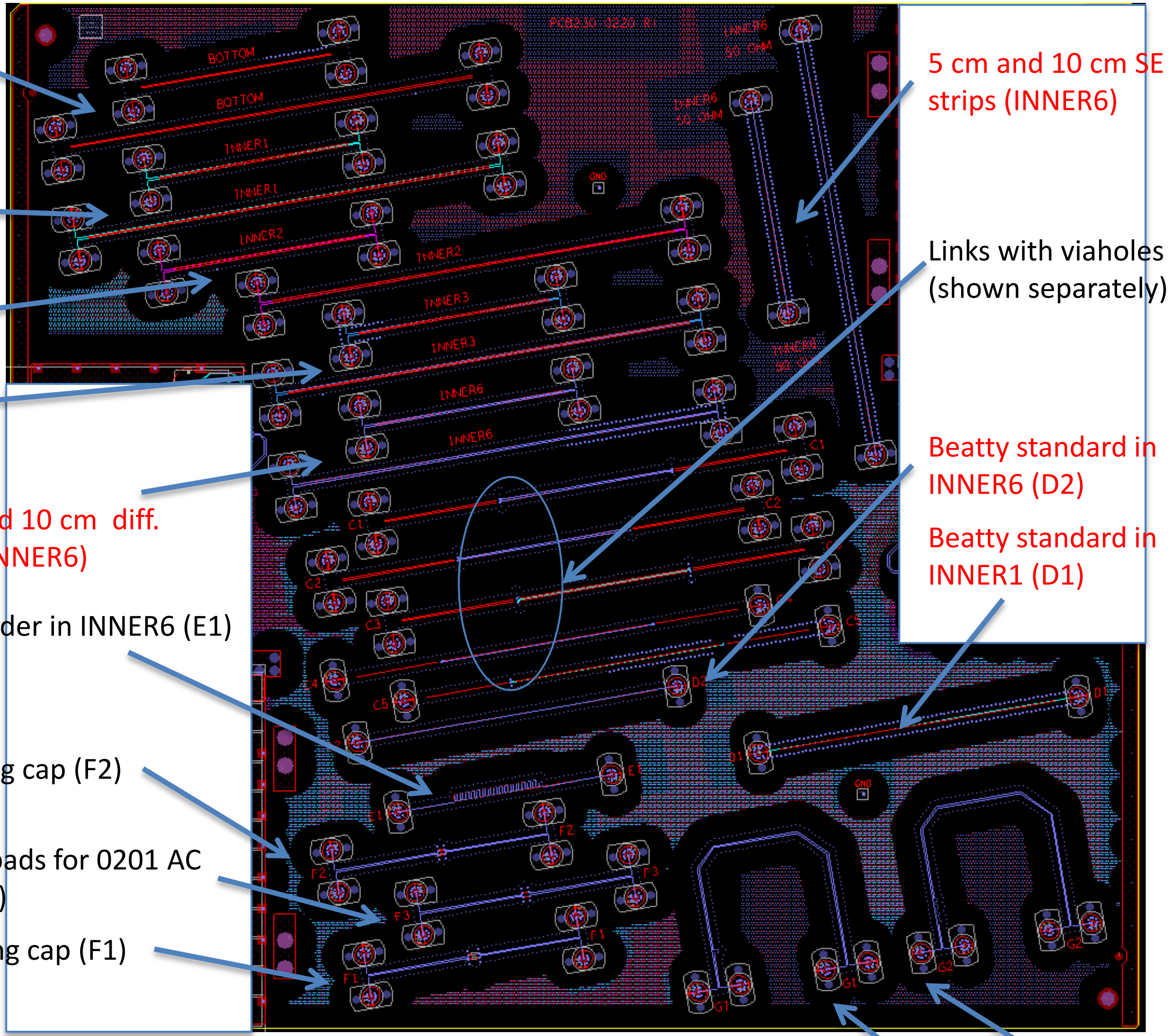
Wideband Debye with Dk and LT @ 1 GHz

StackUp: LU=[um], NL=20, T=2030.12[um], CSM=("Solder Mask", 40[um])
- 1| Signal: "TOP", T=35.56, Ins="Air", Cond="035.56UM_CU"
- 2| Medium: T=73.25, Ins="Meg-6 TopBot", DIE_003
- 3| Plane: "GND1", Cond="017.78UM_CU", T=15, Ins="Meg-6 TopBot"
- 4| Medium: T=100, Ins="Meg-6 2x1035 (C)", DIE_005
- 5| Signal: "INNER1", T=15, Ins="Meg-6 Inner1 (P)", Cond="017.78UM_CU"
- 6| Medium: T=108, Ins="Meg-6 Inner1 (P)", DIE_007
- 7| Plane: "GND2", Cond="017.78UM_CU", T=15, Ins="Meg-6 Av"
- 8| Medium: T=100, Ins="Meg-6 2x1035 (C)", DIE_009
- 9| Signal: "INNER2", T=15, Ins="Meg-6 Inner2 (P)", Cond="017.78UM_CU"
- 10| Medium: T=86, Ins="Meg-6 Inner2 (P)", DIE_011
- 11| Plane: "GND3", Cond="017.78UM_CU", T=15, Ins="Meg-6 Inner2 (P)"
- 12| Medium: T=100, Ins="Meg-6 2x1035 (C)", DIE_013
- 13| Signal: "INNER3", T=15, Ins="Meg-6 Inner3 (P)", Cond="017.78UM_CU"
- 14| Medium: T=86, Ins="Meg-6 Inner3 (P)", DIE_015
- 15| Plane: "GND4", Cond="017.78UM_CU", T=15, Ins="Meg-6 Av"
- 16| Medium: T=50, Ins="FR-4", DIE_017
- 17| Plane: "VCC1", Cond="017.78UM_CU", T=15, Ins="Meg-6 Av"
- 18| Medium: T=96.5, Ins="Meg-6 Av", DIE_019
- 19| Plane: "GND5", Cond="017.78UM_CU", T=15, Ins="Meg-6 Av"
- 20| Medium: T=50, Ins="FR-4", DIE_021

Half

This is the best we can do – we will see how accurate it is…

Validation board design



5 cm and 10 cm diff. microstrips (BOTTOM)

5 cm and 10 cm diff. strips (INNER1)

5 cm and 10 cm diff. strips (INNER2)

5 cm and 10 cm diff. strips (INNER3)

5 cm and 10 cm diff. strips (INNER6)

SE meander in INNER6 (E1)

0201 AC coupling cap (F2)

Short-circuited pads for 0201 AC coupling cap (F3)

0402 AC coupling cap (F1)

5 cm and 10 cm SE strips (INNER6)

Links with viaholes (shown separately)

Beatty standard in INNER6 (D2)

Beatty standard in INNER1 (D1)

Diff. trace length compensation structures (G1 and G2)

Material identification structures - red

Designed trace dimensions:

BOTTOM: 120-250-120 [um]
INNER1/6: 110-250-110 [um]
INNER2/3: 100-250-100 [um]
INNER6 SE: 110 [um]
BEATTY INNER1 and INNER6: 110 um 2.5 cm, 330 um 2.5 cm

Dimensions from manufacturer:

BOTTOM: 112-258-112 [um]
INNER1/6: 107-250-107 [um]
INNER2/3: 99-245-99 [um]
INNER6 SE: 109 [um]
BOTTOM SE: 127 [um]

Post-layout observations

- The PCB is manufactured with the “impedance control” process – all trace width and spacing are adjusted by the PCB manufacturer (must be accounted in the analysis)
- No information on trace shape (etching)
- No reliable information on solder mask shape/parameters
- No information on conductor roughness model
- No information on actual backdrilling
- **All this makes analysis inaccurate and practically useless for the target bandwidth**

Measurements and GMS-parameters extraction

“If measurements do not confirm the model, too bad for the measurements”…

Making pristine measurements from 10 MHz up to 40 GHz is very challenging

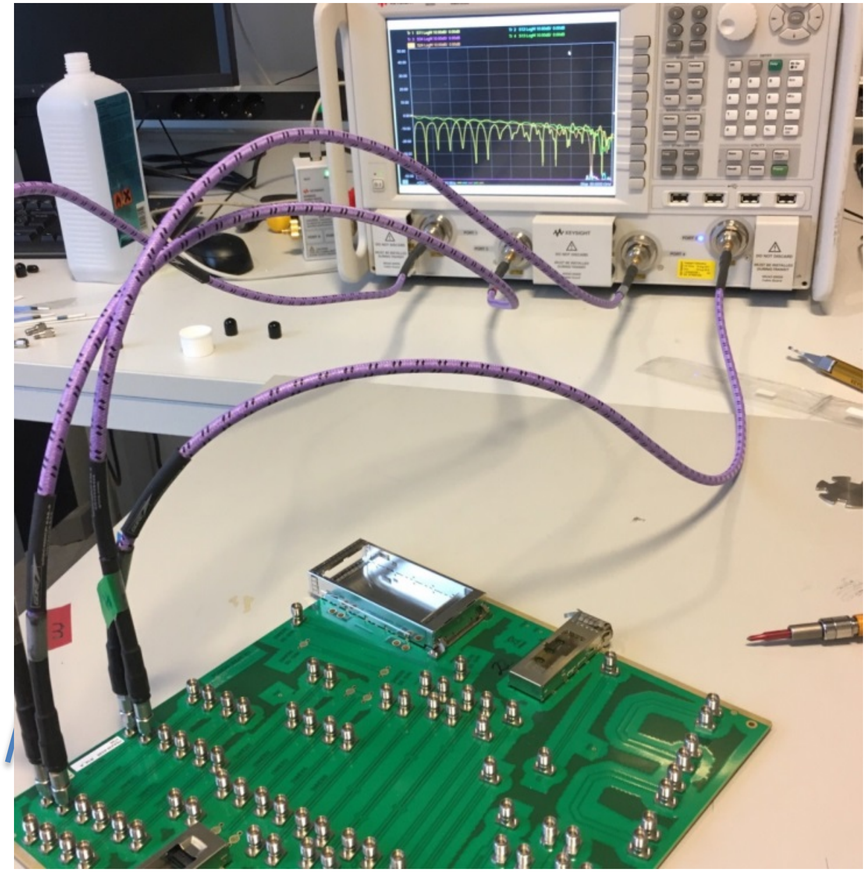
- TDNA, 2.92 mm connectors (not acceptable for material identification)
- 27 GHz VNA, 2.92 mm connectors (failure)
- 40 GHz VNA, 2.92 mm connectors (low frequency problem, acceptable)
- 50 GHz VNA, 2.4 mm connectors (low frequency problem, acceptable)
- A few VNA from different vendors evaluated – may be suitable for a separate report…

Measurements with 50 GHz VNA

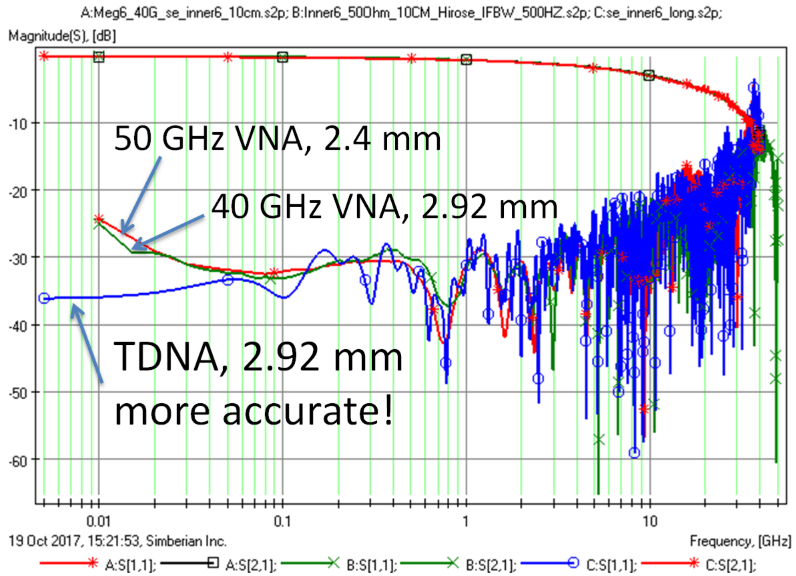
C:\Repository\Simbeor\Support\Infinera\March31_2017_board_and_measurement

File name	Quality	Passivity	Reciprocity	C
BOTTOM_10CM_2_4MM.s4p	99	100	99.6	-
BOTTOM_5CM_2_4MM.s4p	99.1	100	99.5	-
C1_2_4MM.s4p	99.2	100	99.7	-
C2_2_4MM.s4p	99.3	100	99.7	-
C3_2_4MM.s4p	99.2	100	99.6	-
C4_VIA_HIROSE_IFBW_500HZ.s2p	99.7	100	99.9	-
C5_VIA_HIROSE_IFBW_500HZ.s2p	99.7	100	99.8	-
D1_BEATTY_25OHM_INNER1.s2p	99.6	100	99.7	-
D2_BEATTY_25OHM_INNER6.s2p	99.7	100	99.6	-
E1_Meander_10cm_Hirose_con_IFBW_500H...	99	100	99.8	-
F1_2_4MM.s4p	99.3	100	99.6	-
F2_2_4MM.s4p	99.3	100	99.7	-
F3_2_4MM.s4p	99.2	100	99.5	-
G1_2_4MM.s4p	91	100	99.6	-
G2_2_4MM.s4p	97.5	100	99.6	-
INNER1_10CM_2_4MM.s4p	96.6	100	99.8	-
INNER1_5CM_2_4MM.s4p	99.1	100	99.8	-
INNER2_10CM_2_4MM.s4p	93.6	100	99.8	-
INNER2_5CM_2_4MM.s4p	99.2	100	99.8	-
INNER3_10CM_2_4MM.s4p	91.2	100	99.8	-
INNER3_5CM_2_4MM.s4p	99.2	100	99.8	-
INNER6_10CM_2_4MM.s4p	97.7	100	99.8	-
Inner6_10cm_SE_Amp_con_IFBW_500Hz.s2p	99.5	100	99.9	-
Inner6_10cm_SE_Hirose_con_IFBW_1kHz.s2p	99.4	100	97	-
Inner6_50Ohm_10CM_Hirose_IFBW_500HZ.s...	99.6	100	99.7	-
Inner6_50Ohm_5CM_Hirose_IFBW_500HZ.s2p	99.5	100	99.8	-
INNER6_5CM_2_4MM.s4p	98.8	100	99.7	-

GOOD QUALITY, SMALL NOISE, MINOR RECIPROCITY VIOLATIONS

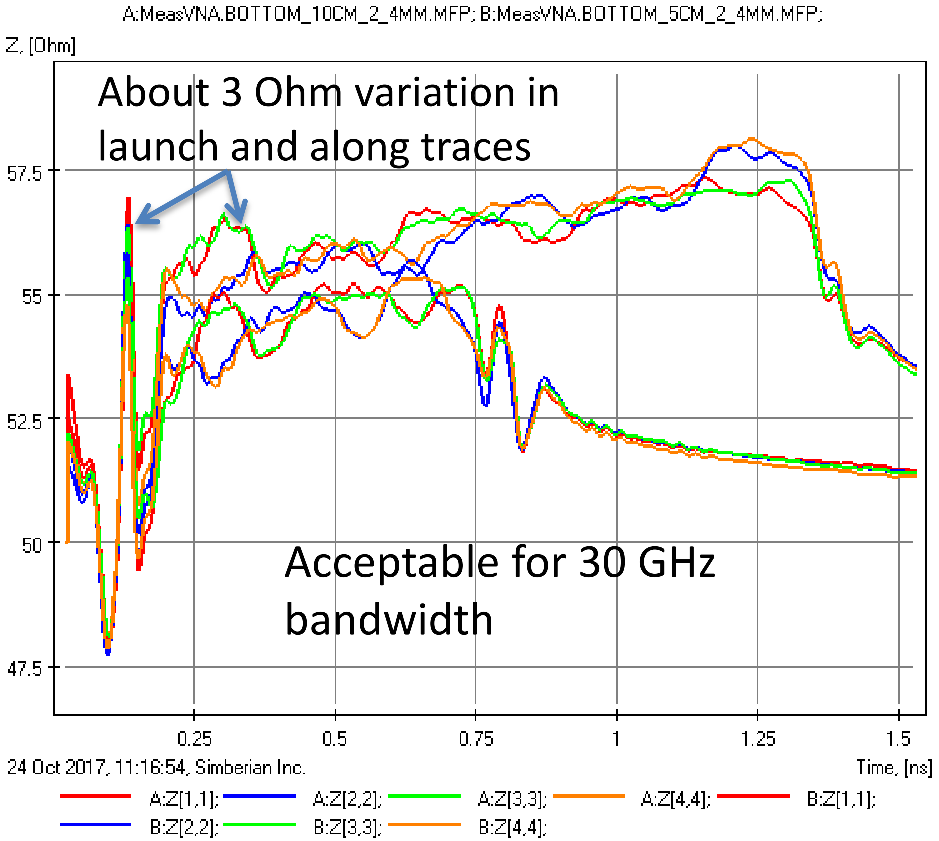


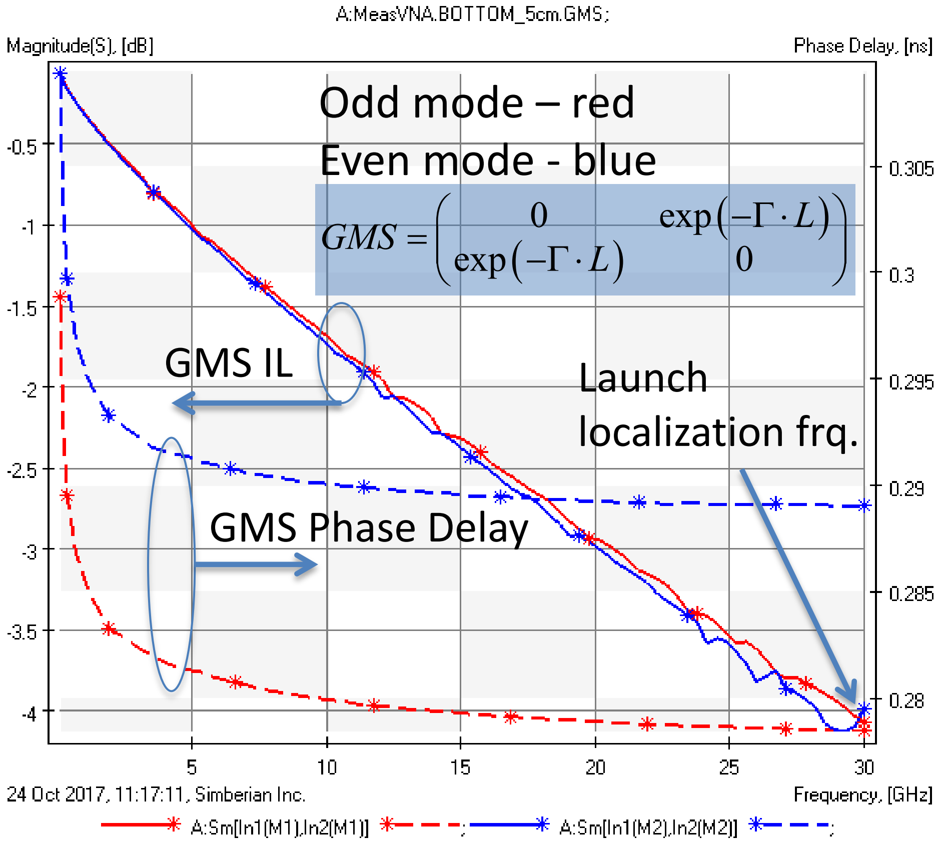
Problems at low frequencies – wrong DC convergence, passivity violation (ECAL kit)



Problem solved with separate measurements with mechanical calibration (for resistivity identification) and cutting S-parameters below 70 MHz and rational fitting

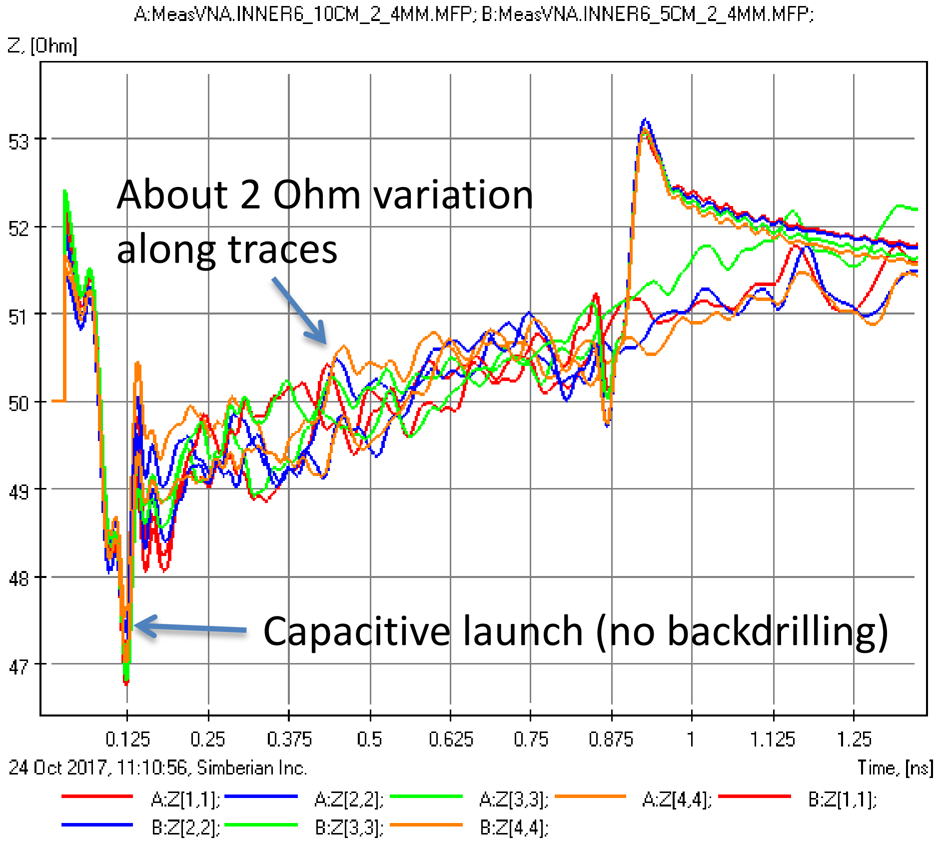
TDR and GMS-parameters: BOTTOM

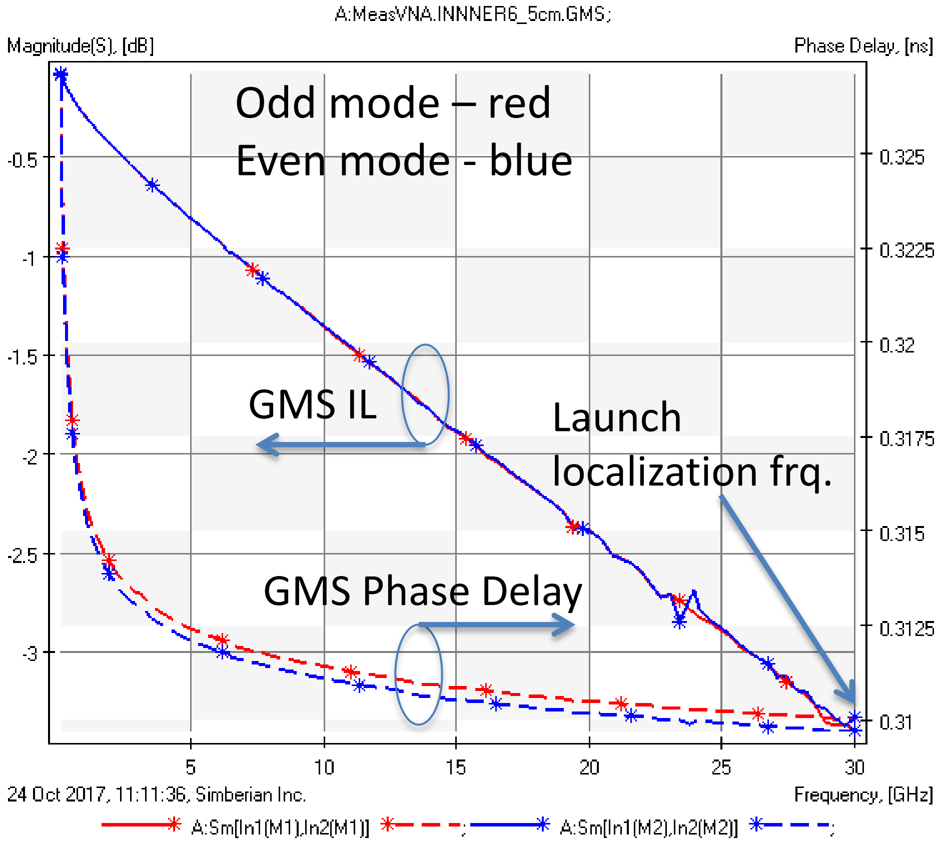




Difference in phase delay (cause FEXT) is expected…

TDR and GMS-parameters: INNER6





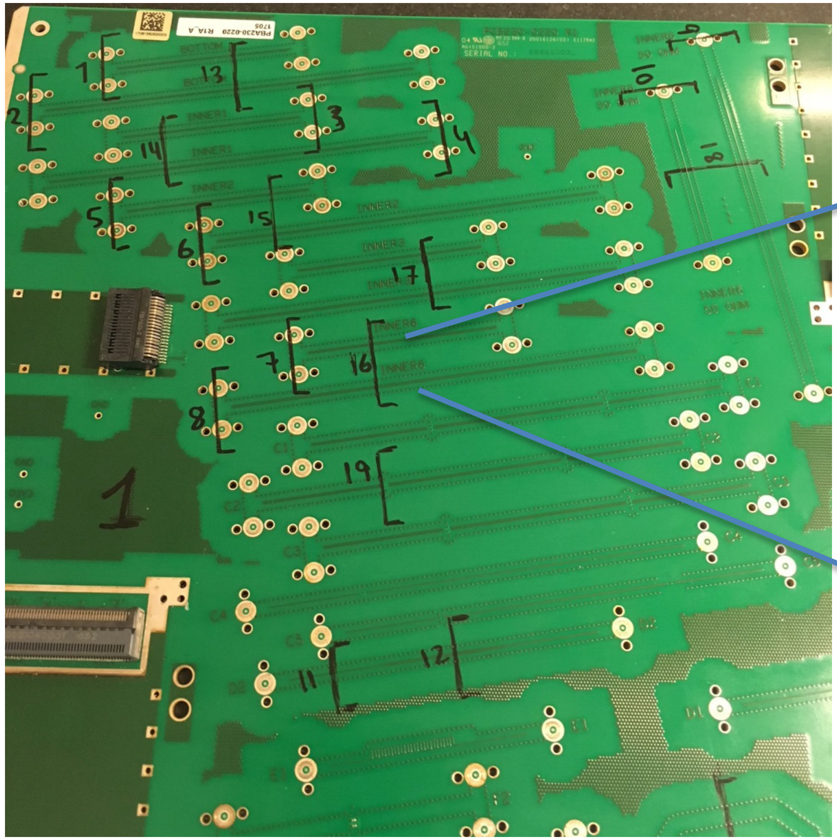
Difference in phase delay (cause FEXT) indicated dielectric inhomogeneity…

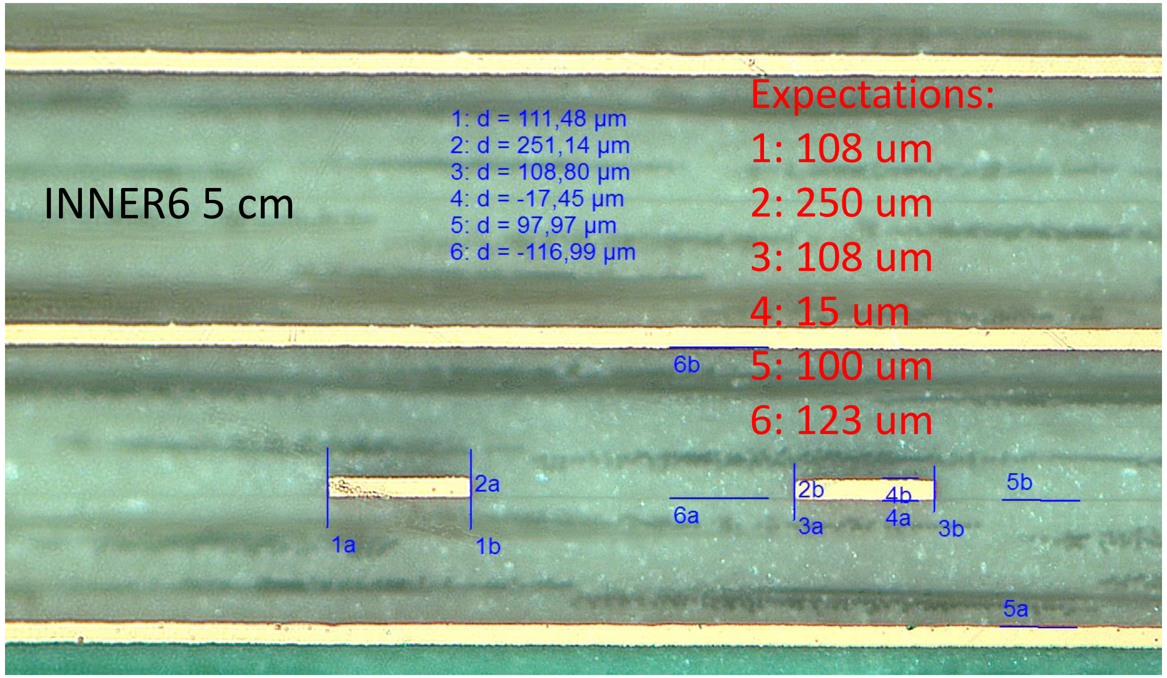
Reality: What is in the board?

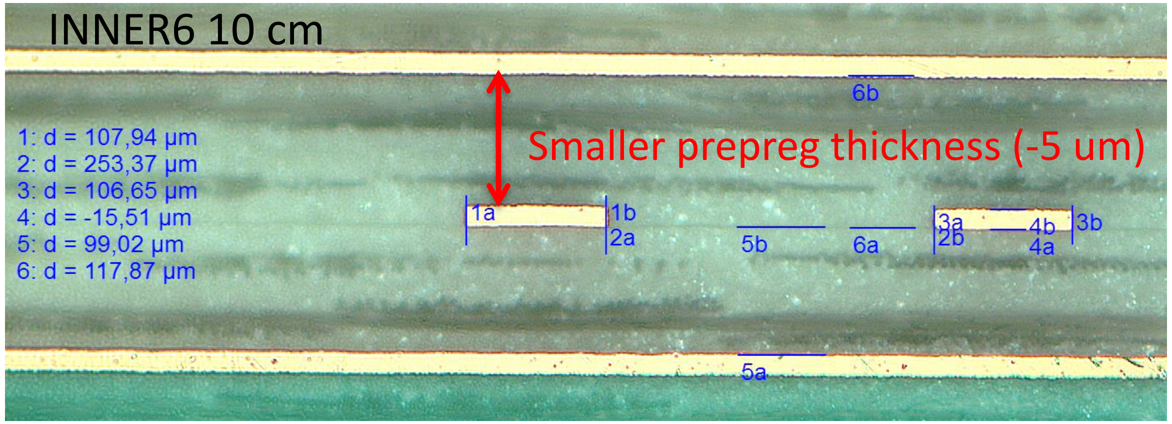
"What is done by night appears by day"…

INNER6

Difference in prepreg thickness
Close shape and geometry



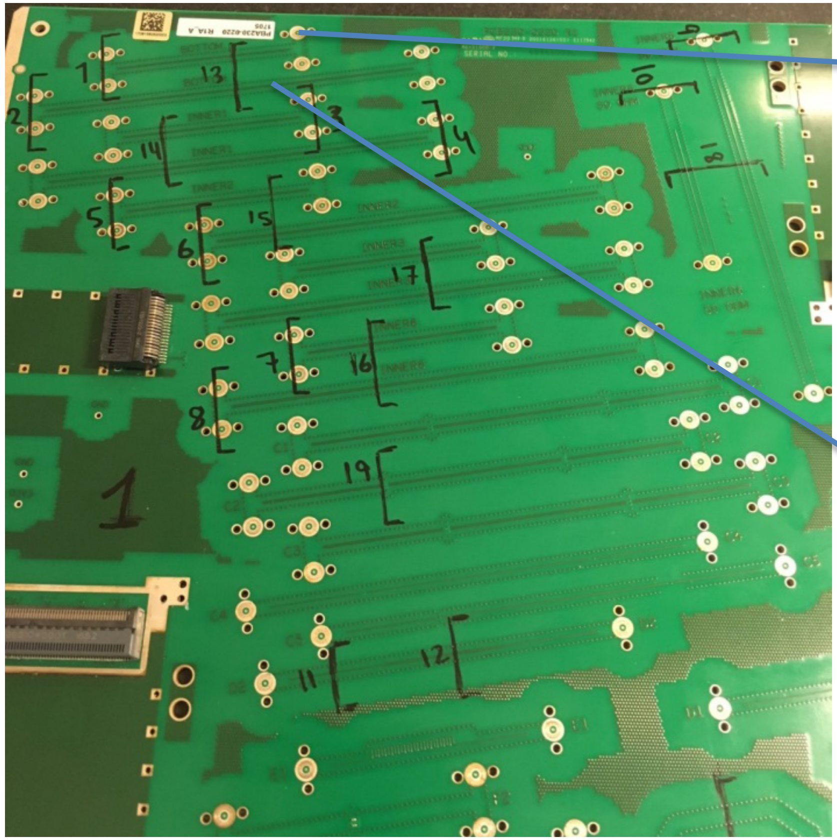


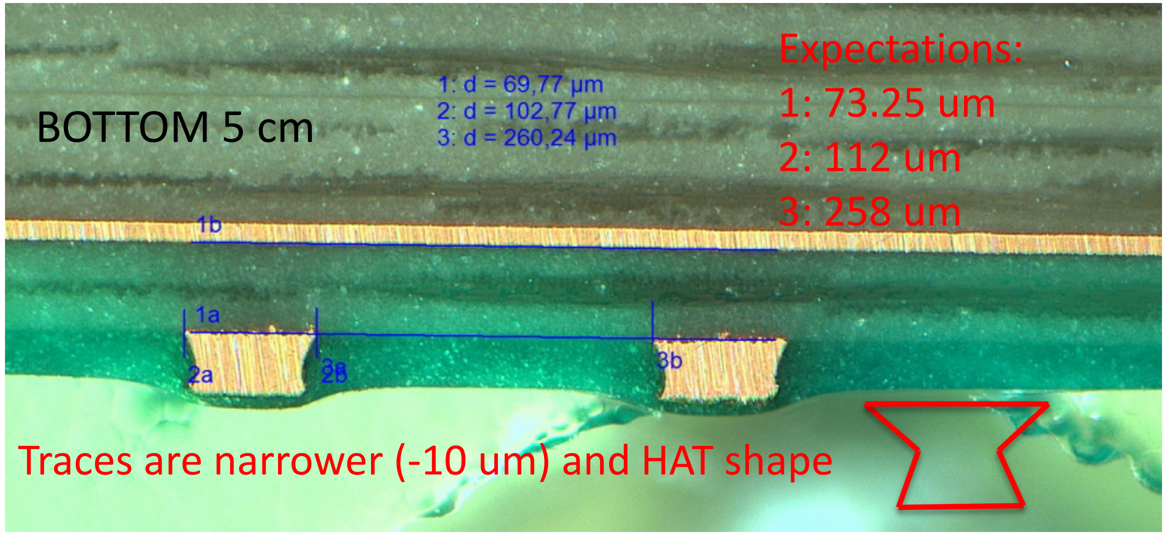


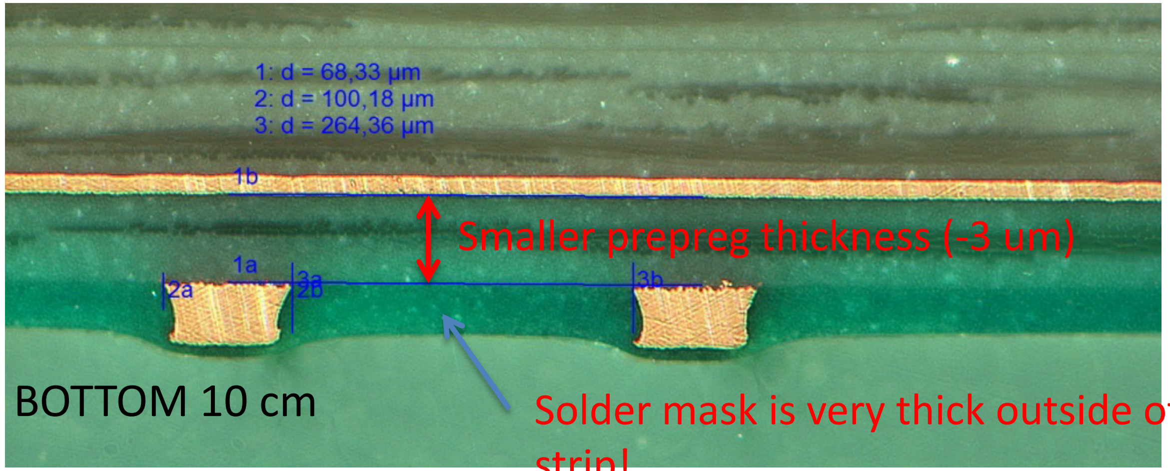
No data from PCB manufacturer to anticipate this

BOTTOM

Difference in prepreg thickness as well as in thace width, shape and solder mask parameters!

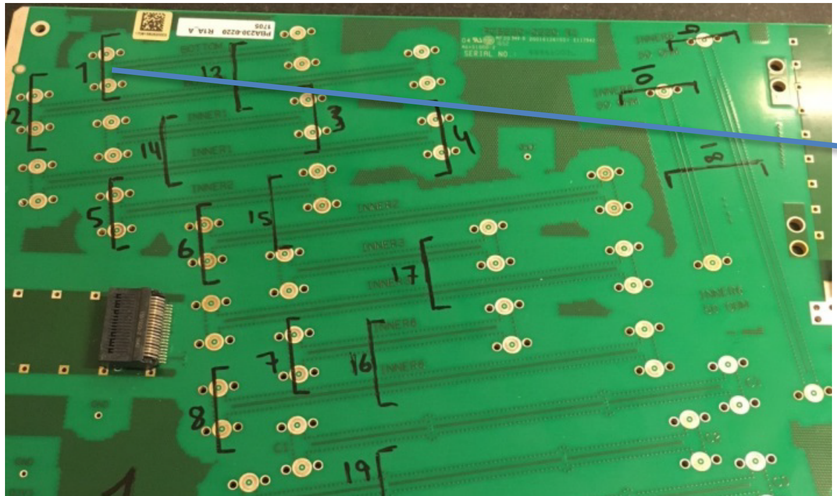


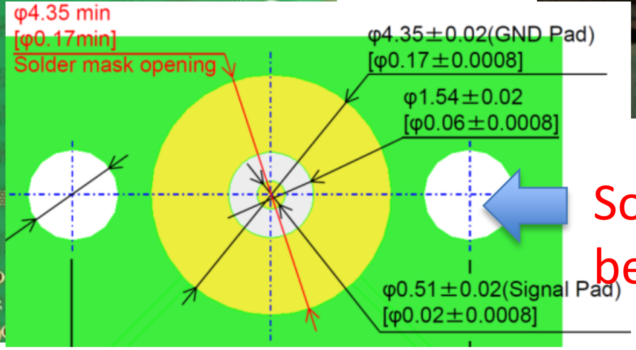


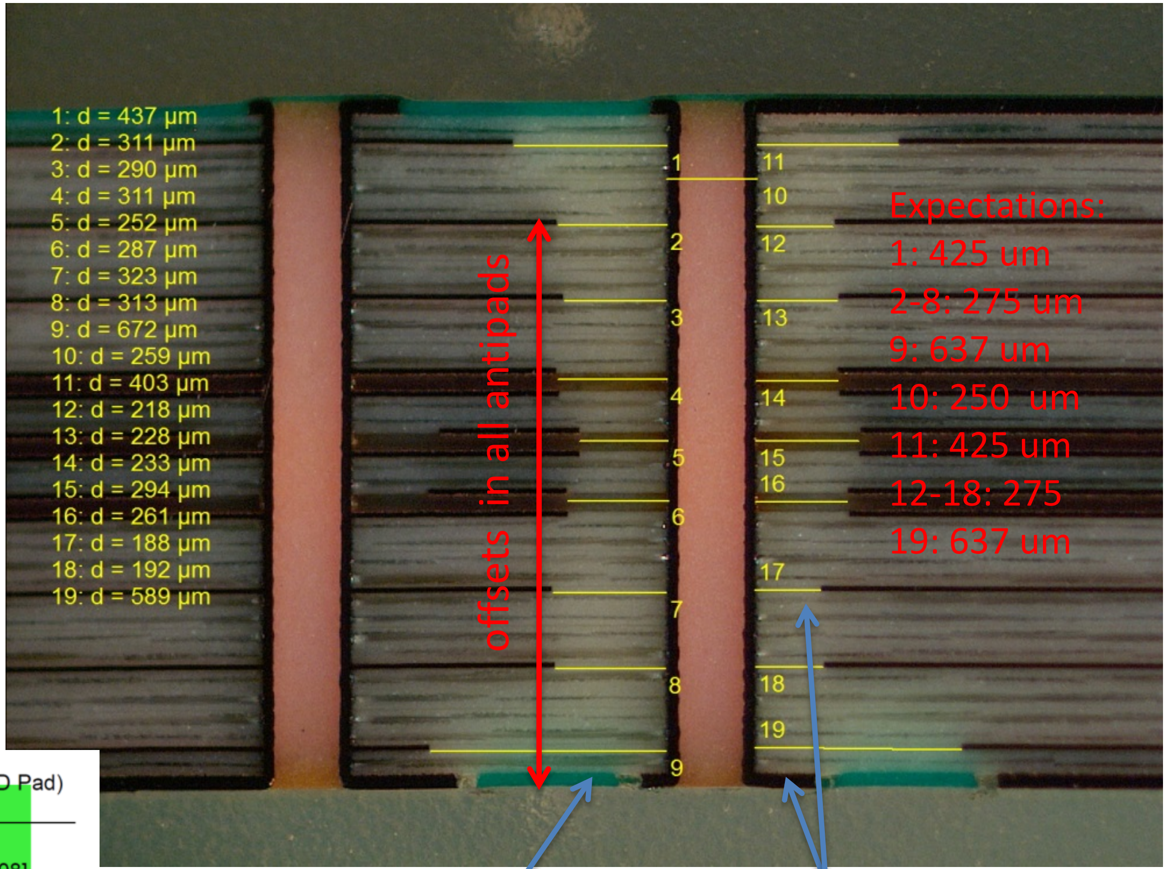


Launch to BOTTOM

Difference in prepreg thickness as well as in thace width, shape and solder mask parameters!







Solder mask (should not be there)!

Offset in pads and antipads (misregistration)

Final trace geometry adjustments

Designed trace dimensions:
BOTTOM: 120-250-120 [um]
INNER1/6: 110-250-110 [um]
INNER2/3: 100-250-100 [um]
INNER6 SE: 110 [um]
BEATTY INNER1 and INNER6:
110 um 2.5 cm, 330 um 2.5 cm

Dimensions from manufacturer:
BOTTOM: 112-258-112 [um]
INNER1/6: 107-250-107 [um]
INNER2/3: 99-245-99 [um]
INNER6 SE: 109 [um]

Dimensions after cross-sectioning:
BOTTOM: HAT(89/97)-260-HAT(89/97) [um]
INNER1/6: 107-255-107 [um]
INNER2/3: 96-254-96 [um]
INNER6 SE: 109 [um]
BEATTY INNER 6:
109 um 2.5 cm + 326 um 2.5 cm

These ones are very critical!
Parameters for strip layers are closer to expectations

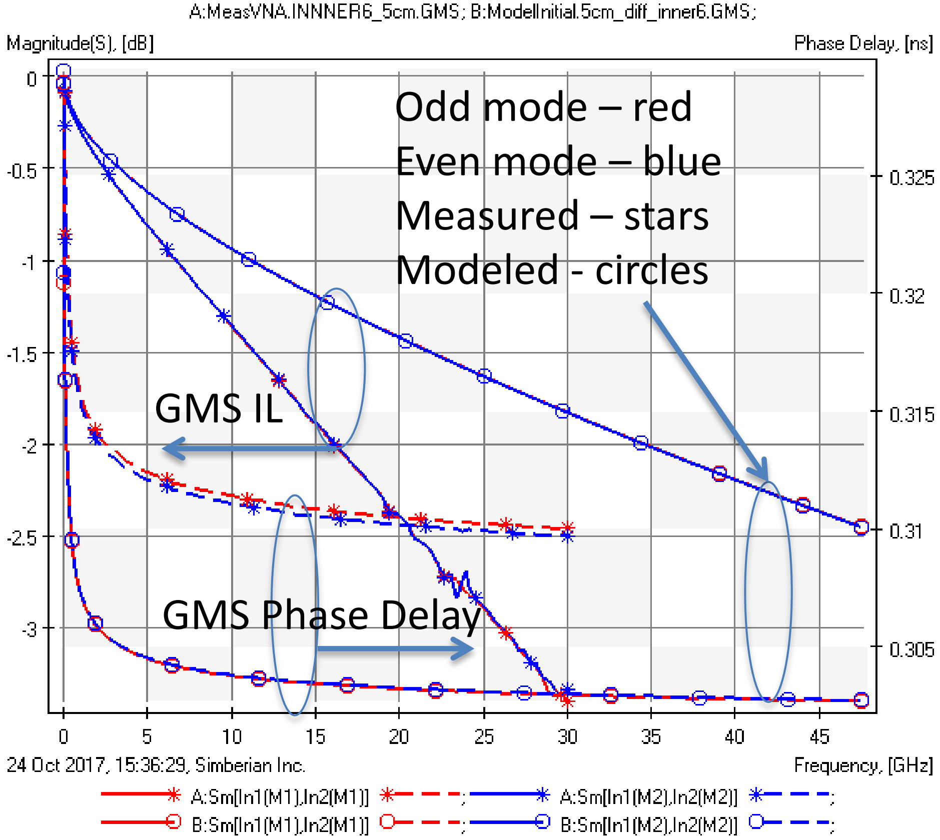
Thickness of prepreg layers is reduced by 3-5 um – it is almost the same thickness as for the core (it should be)
Microstrip layer metal thickness is 48 um instead of 35 um
Solder mask layer – 10 um over strips and 38 um between the strips!

Material Model Identification

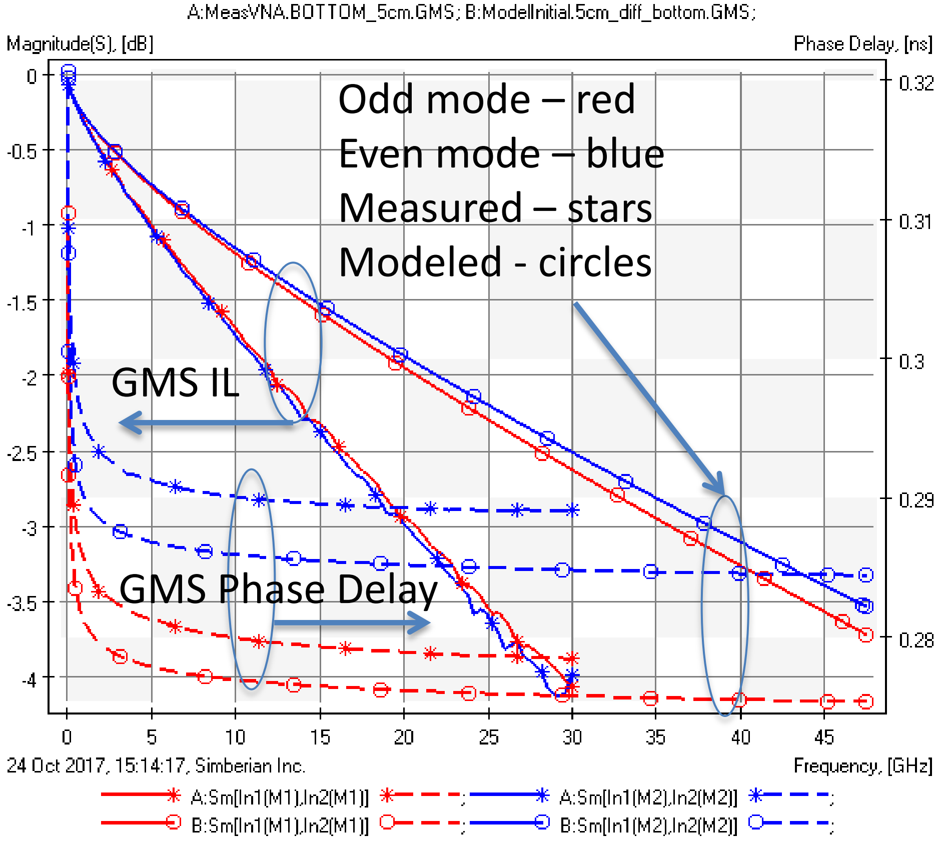
Done with GMS-parameters in Simbeor

Measured GMS vs. model with the spreadsheet data

INNER6



BOTTOM



Model phase delay and loss are much smaller, no visible difference between the strip modes…

Material model identification

Using measured and simulated GMS-parameters:

a) Identify copper resistivity by matching GMS IL at lowest frequencies

b) Identify dielectric Dk by matching GMS phase delay (GMS PD)

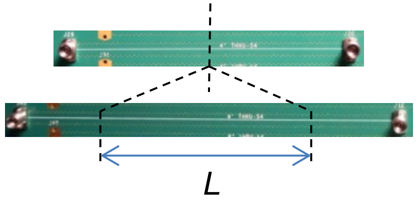
c) Identify LT by matching GMS IL at lower frequencies

   Re-adjust Dk to match GMS PD

d) Identify roughness model parameters by matching GMS IL at high frequencies

   Re-adjust Dk to match GMS PD

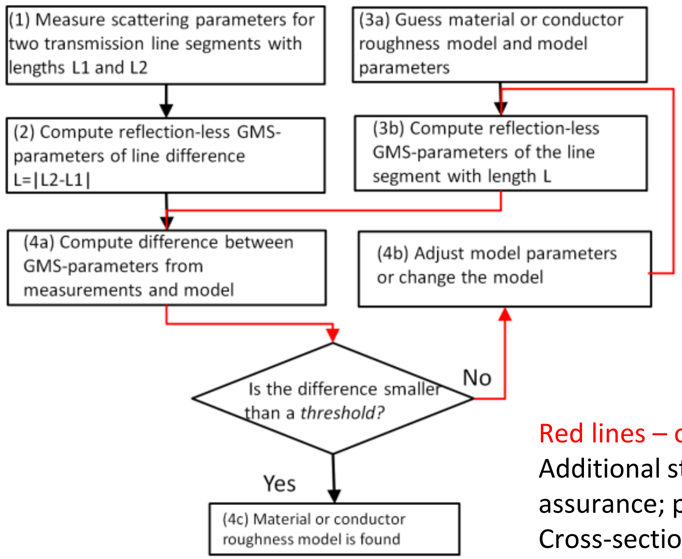
e) Do it for all unique dielectrics



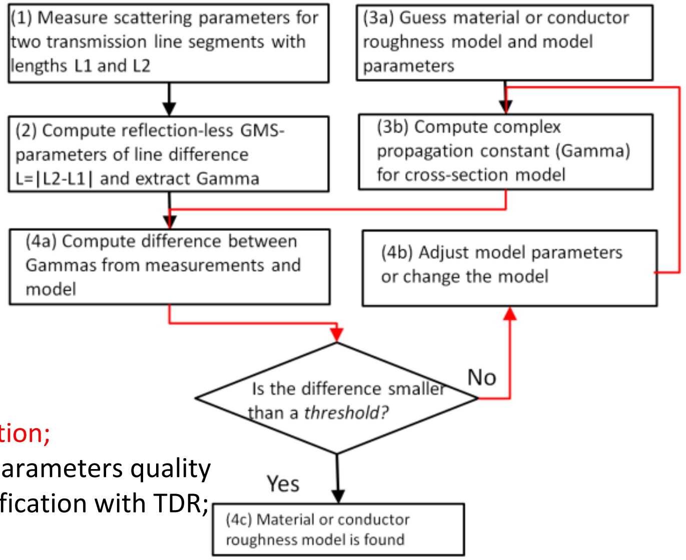
$$GMT = eigenvals\left(T2 \cdot T1^{-1}\right) = \begin{pmatrix} \exp(-\Gamma \cdot L) & 0 \\ 0 & \exp(\Gamma \cdot L) \end{pmatrix}$$

$$GMS = \begin{pmatrix} 0 & \exp(-\Gamma \cdot L) \\ \exp(-\Gamma \cdot L) & 0 \end{pmatrix}$$

Use of raw GMS-parameters



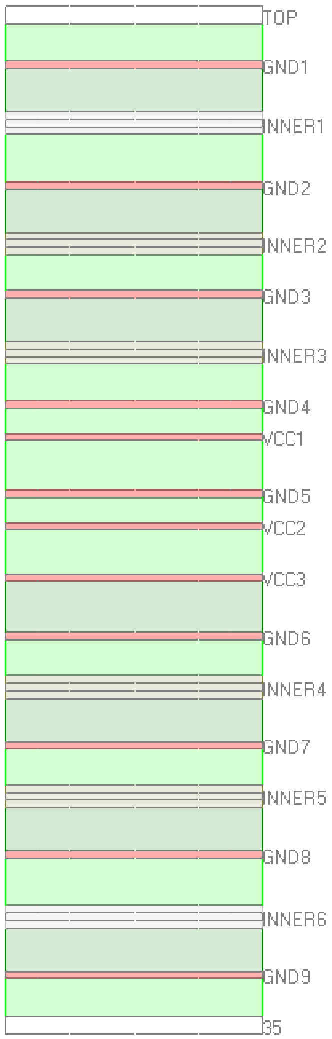
Gamma extraction – "SPP Light"

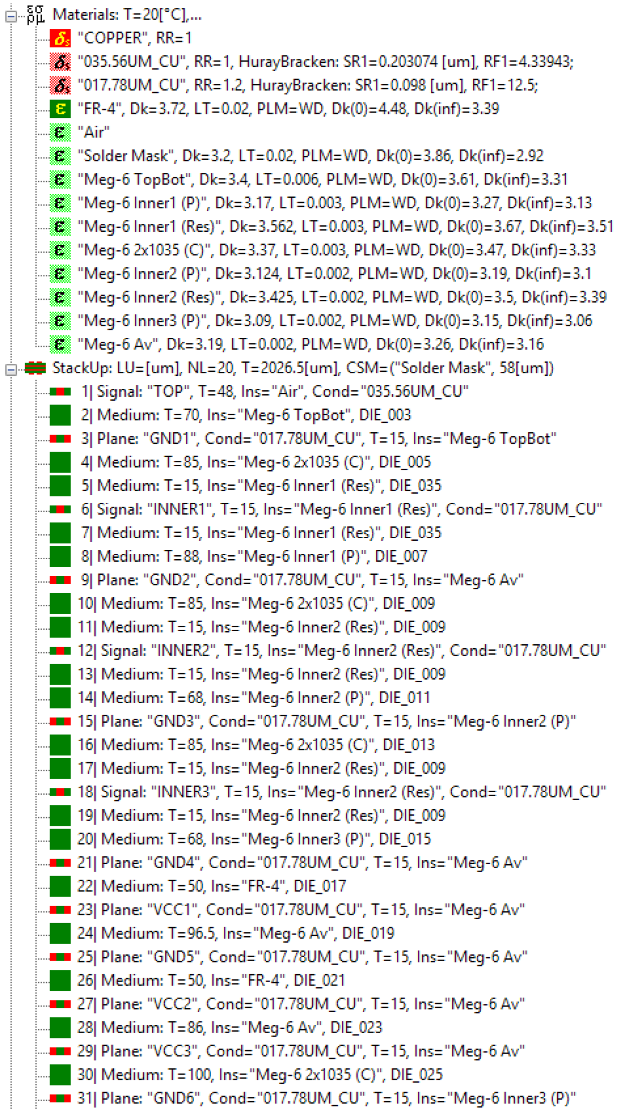


Red lines – optimization;
Additional steps: S-parameters quality assurance; pre-qualification with TDR; Cross-sectioning;

Y. Shlepnev, Broadband material model identification with GMS-parameters, EPEPS 2015.
Y. Shlepnev, Y. Choi, C. Cheng, Y. Damgaci, Drawbacks and Possible Improvements of Short Pulse Propagation Technique, EPEPS 2016.

Identification results (best case)





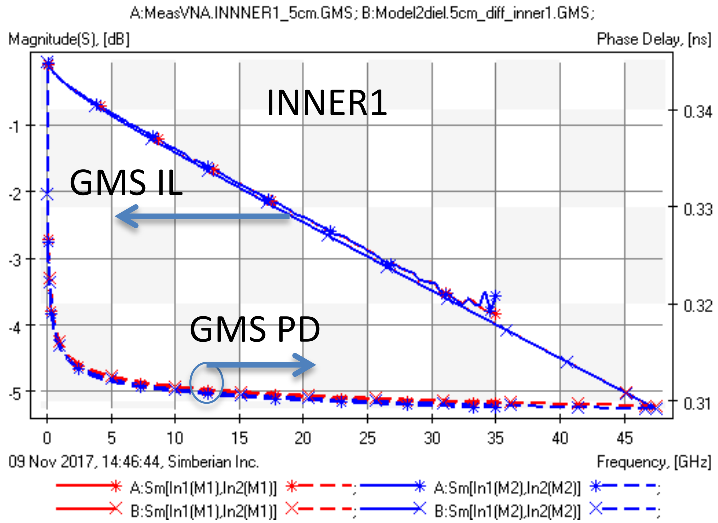
Huray-Bracken Roughness Models (causal):
Strips: SR=0.098 um, RF=12.5
Microstrips: SR=0.229 um, RF=3.77

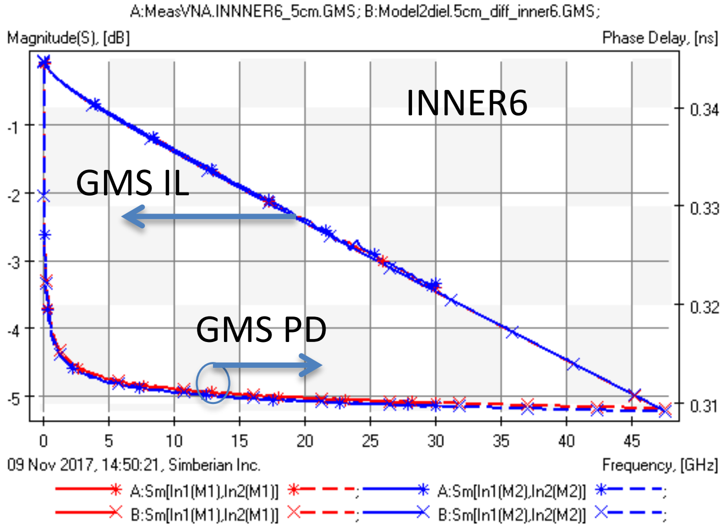
Wideband Debye models with Dk and LT @ 1 GHz (initial in brackets):
CORE (all layers): Dk=3.37 (3.37), LT=0.003 (0.002)
Prep. INNER1/INNER6: Dk=3.17 (3.23), LT=0.003 (0.002)
Resin INNER1/INNER6: Dk=3.562, LT=0.003
Prep. INNER2: Dk=3.124 (3.19), LT=0.002 (0.002)
Prep. INNER3: Dk=3.09 (3.19), LT=0.002 (0.002)
Resin INNER2/INNER3: Dk=3.425, LT=0.002
TOP/BOTTOM: Dk=3.4 (3.19), LT=0.006 (0.002)
Solder Mask: Dk=3.2 (4.0), LT=0.02

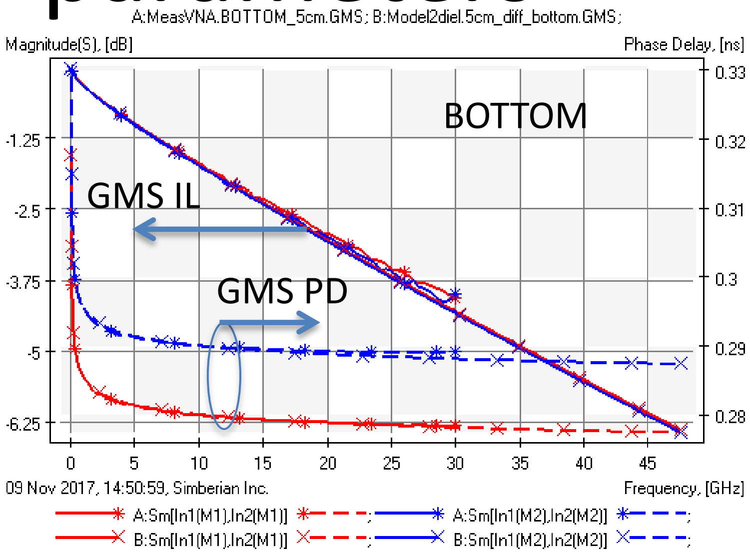
2 roughness models and 8 dielectric models – more difficult to identify, but is necessary for FEXT analysis

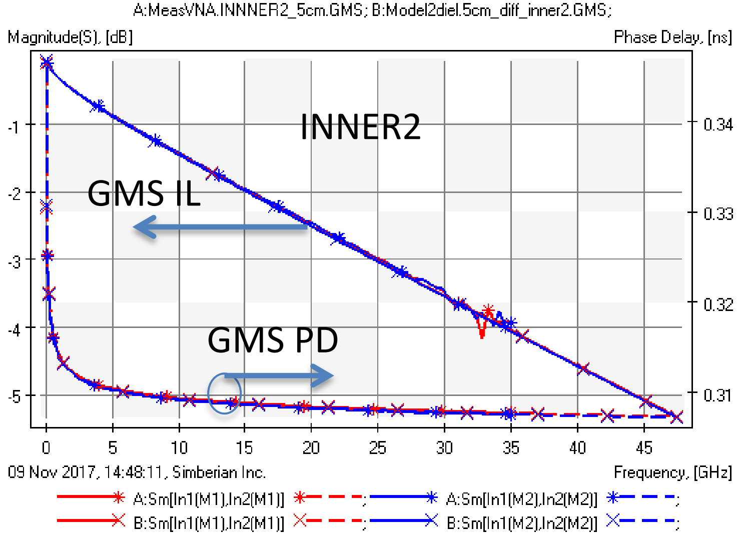
Let's see how close are GMS-parameters…

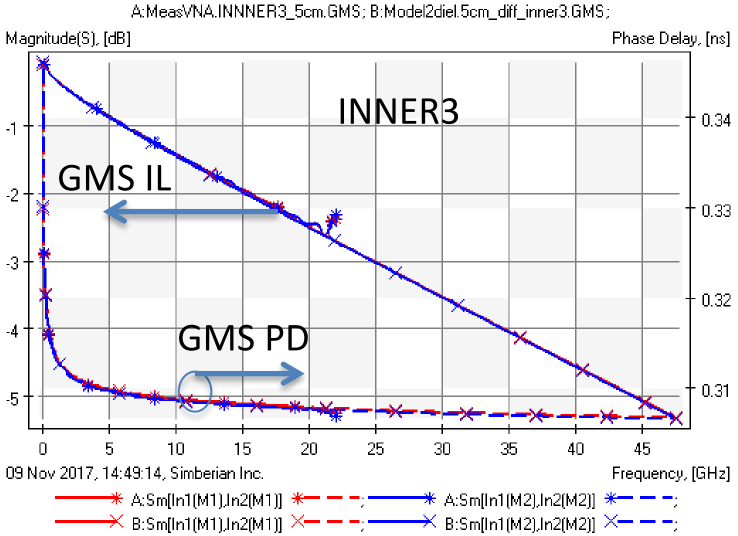
Measured and modeled GMS-parameters







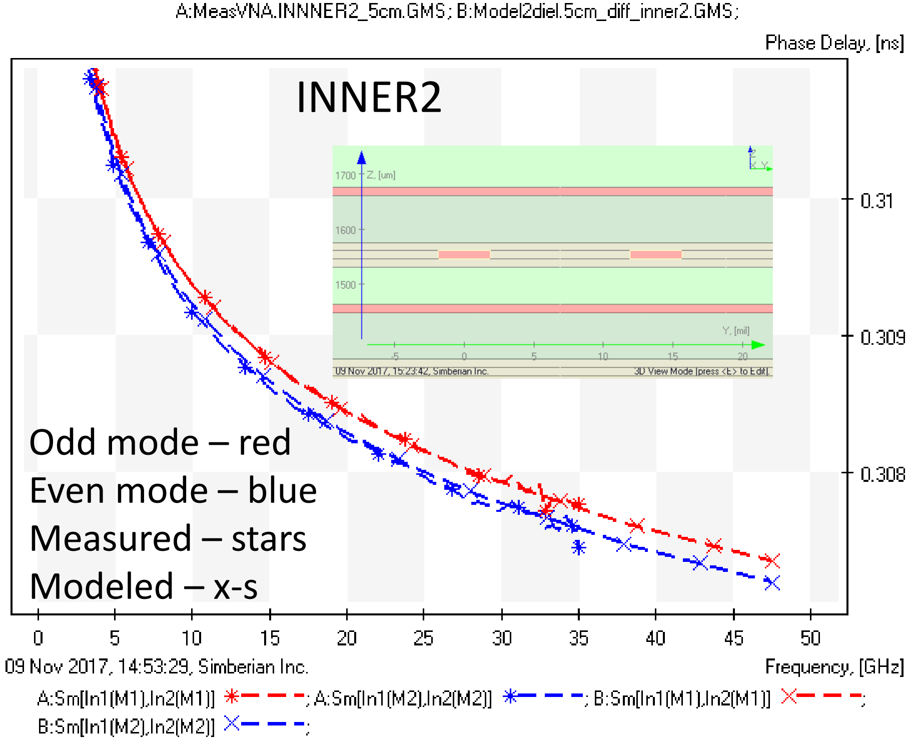


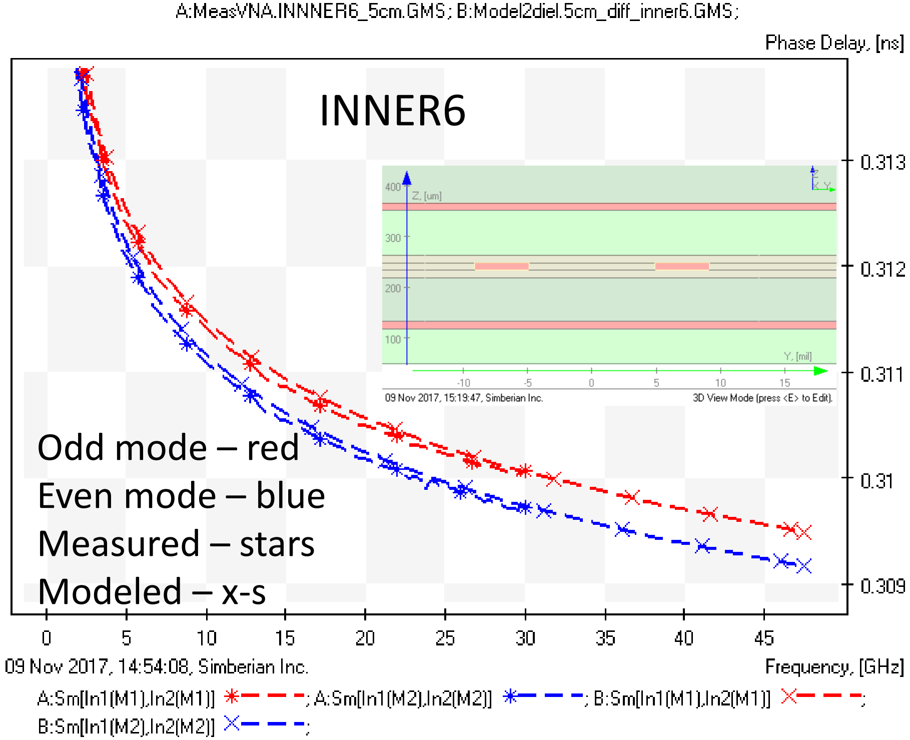


Odd mode – red
Even mode – blue
Measured – stars
Modeled – x-s

Modal phase delay

- Close match for odd and even modes



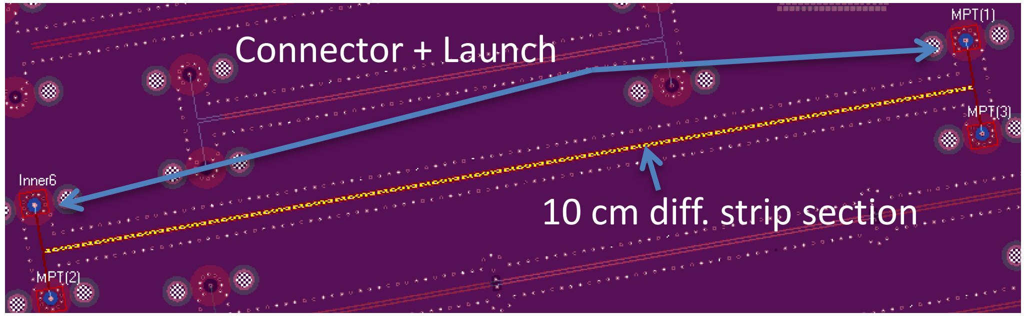


Should give good match in FEXT…

Validation:
Expectations vs. Reality

“The Moment of Truth”…

INNER6: 10 cm diff. strip link

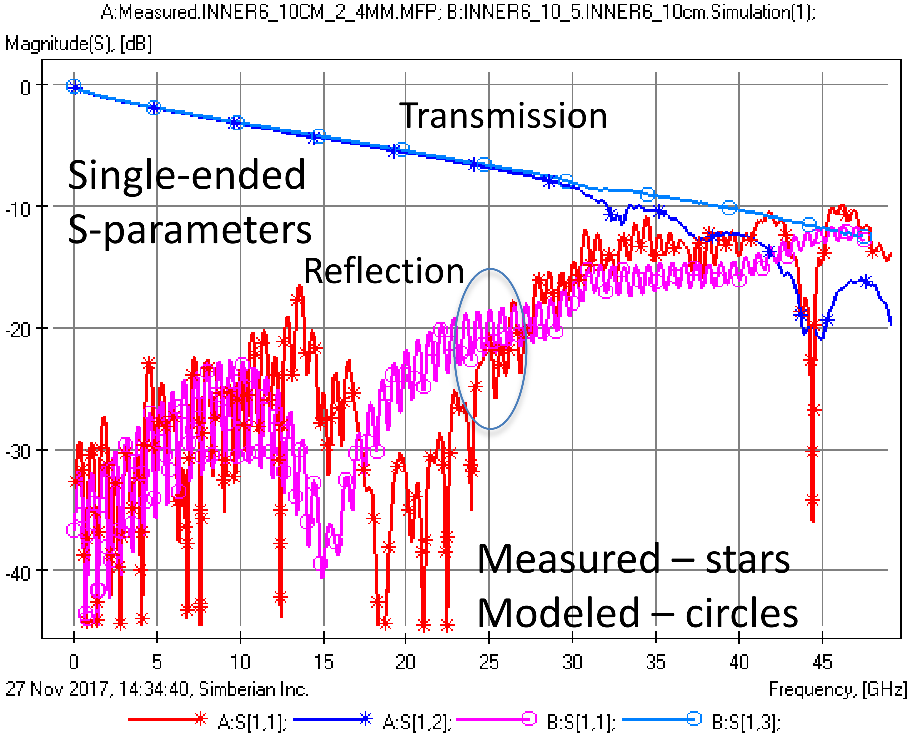


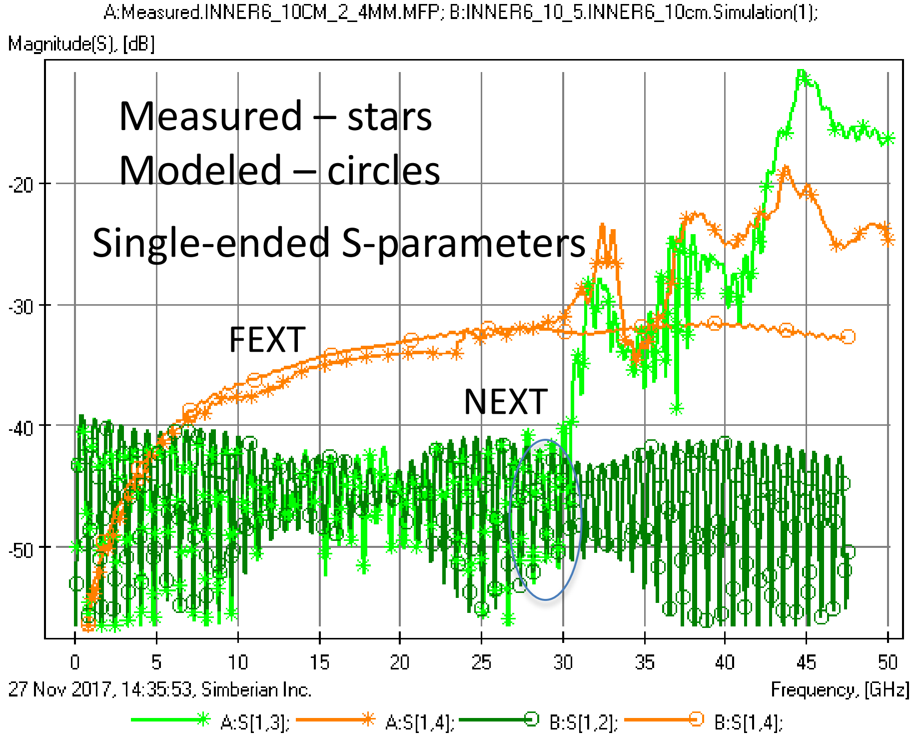
De-compositional EM analysis
All trace widths and shapes are adjusted

Single-ended S-parameters

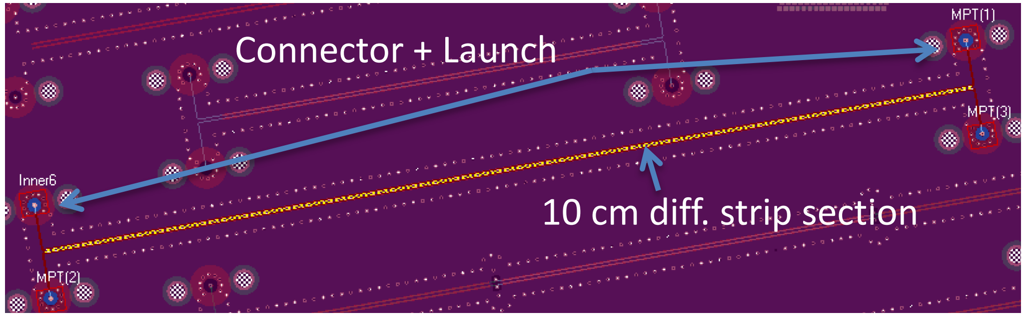
Reality: Large difference above 30 GHz – see reality above 30 GHz…

Acceptable correspondence up to 30 GHz





INNER6: 10 cm diff. strip link

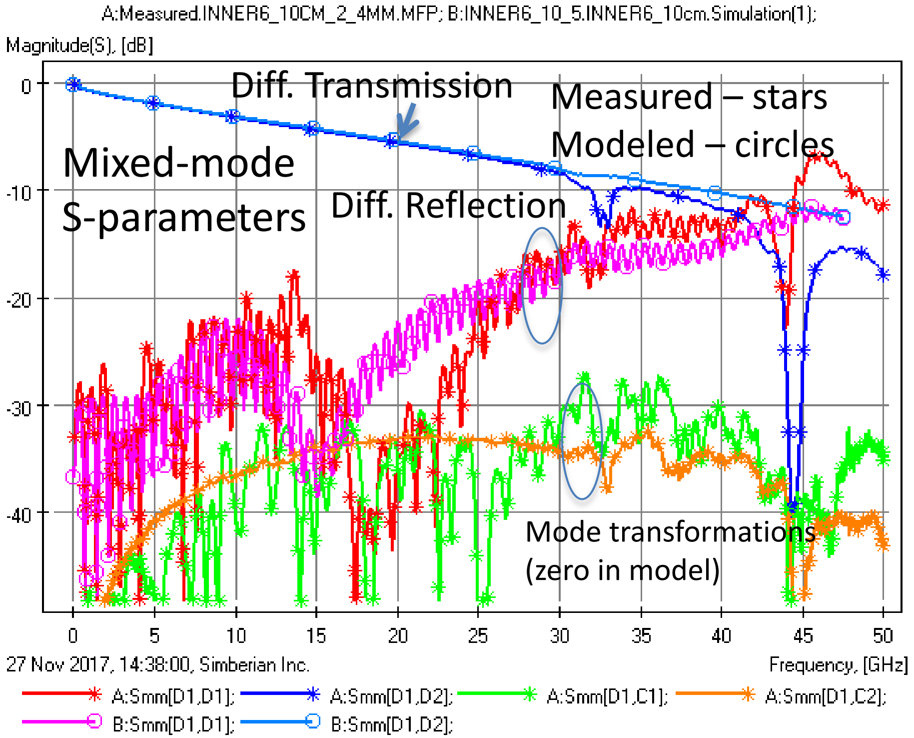


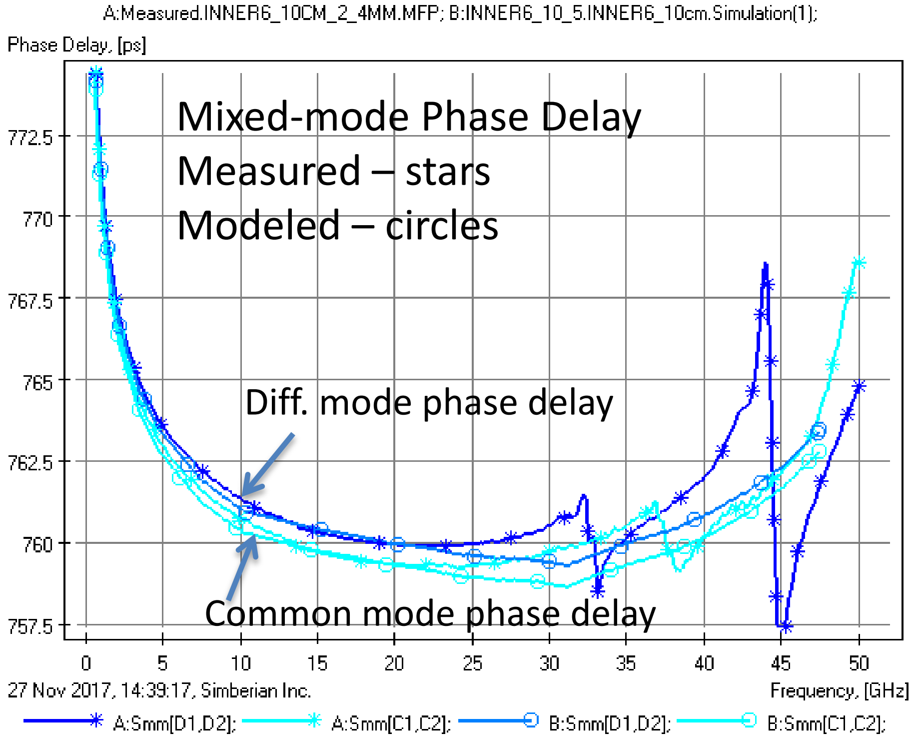
De-compositional EM analysis
All trace widths and shapes are adjusted

Mixed-mode S-parameters

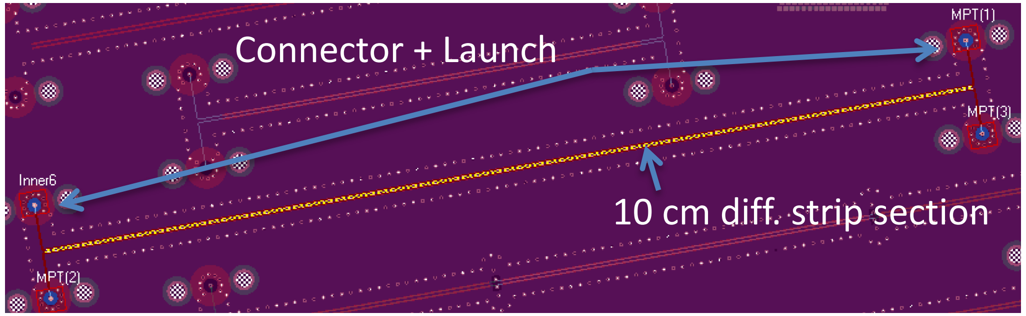
Reality: Difference in reflection between 10 to 30 GHz (now expected due to geometry differences), above 30 GHz – see reality above 30 GHz…

Acceptable correspondence up to 30 GHz





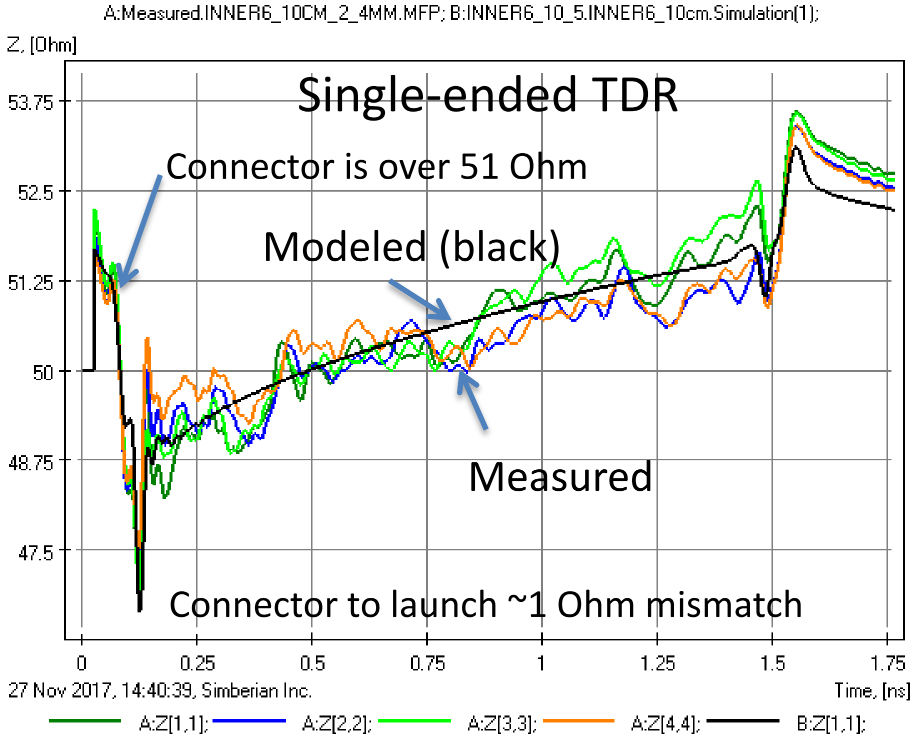
INNER6: 10 cm diff. strip link

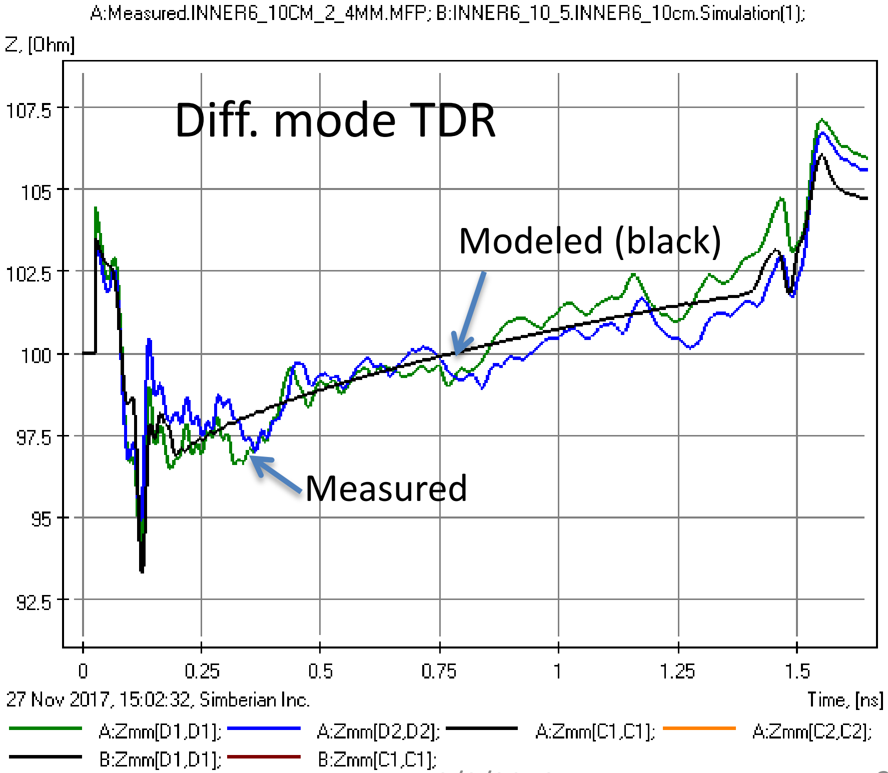


De-compositional EM analysis
All trace widths and shapes are adjusted

Reality: Variation of impedance along the traces (expected)

Acceptable correspondence within 1 Ohm



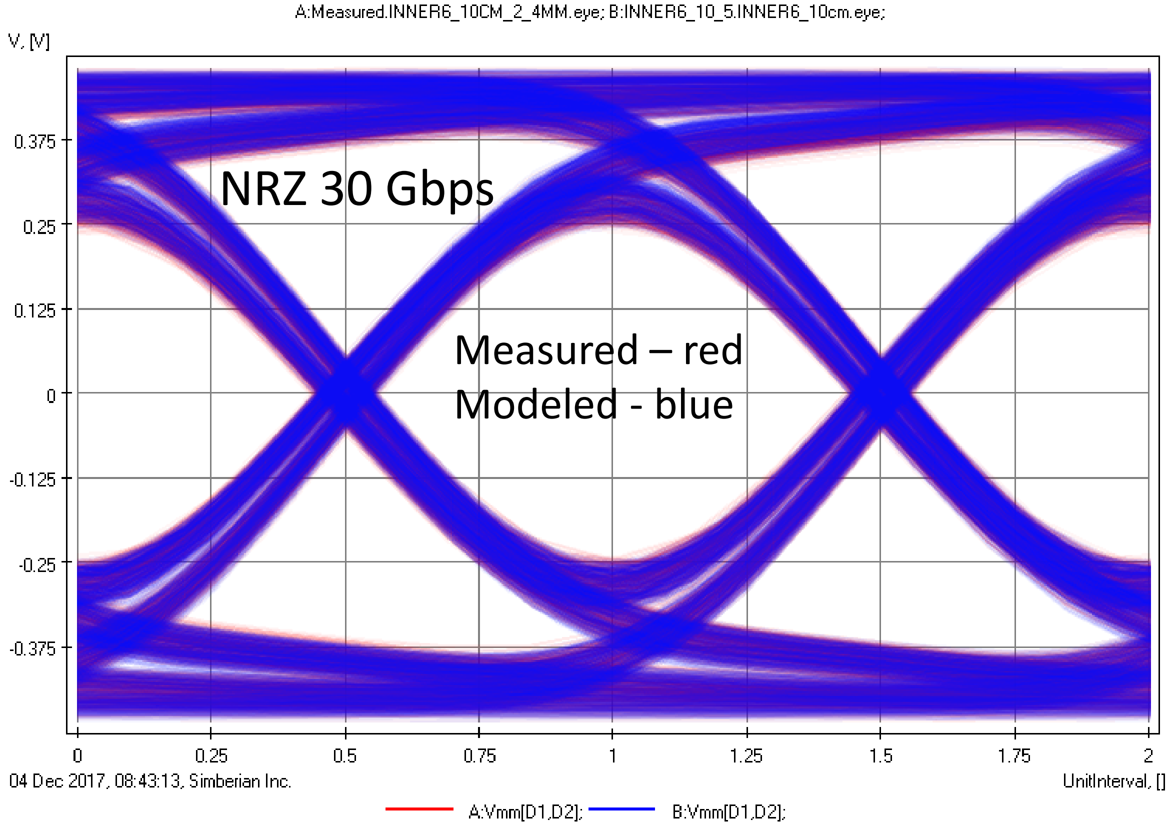


INNER6: 10 cm diff. strip link

Eye Analyzer

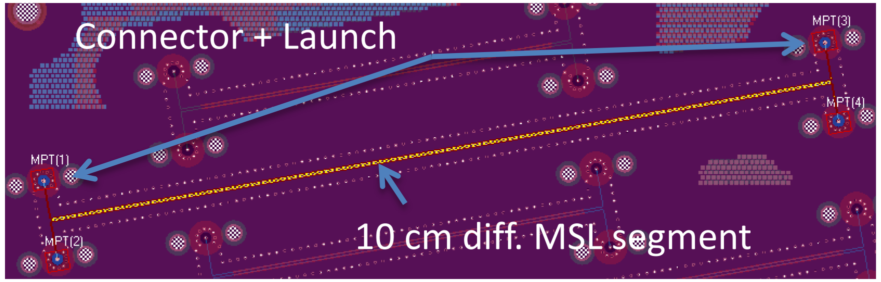
Show Eye Metrics: Selected   Auto-open

Parameter	Measured.INNER6...	INNER6_10_5.IN...
Eye Level Zero (V)	-0.358943	-0.357034
Eye Level One (V)	0.358254	0.36771
Eye Level Mean (V)	-0.00219978	-0.0024401
Eye Amplitude (V)	0.717197	0.724743
Eye Height (V)	0.47057	0.480019
Eye Width (UI)	0.86031	0.869623
Eye Opening Factor	0.656123	0.66233
Eye Signal to Noise	5.51347	5.56869
Eye Rise Time (20-80) (UI)	0.518454	0.518457
Eye Fall Time (80-20) (UI)	0.517761	0.515182
Eye Jitter (PP) (UI)	0.13969	0.130377
Eye Jitter (RMS) (UI)	0.0318694	0.0320182



~2% difference in eye heights, ~1% in widths; Possible reason – impedance variations, launch mismatch and localization loss...

BOTTOM: 10 cm diff. microstrip link

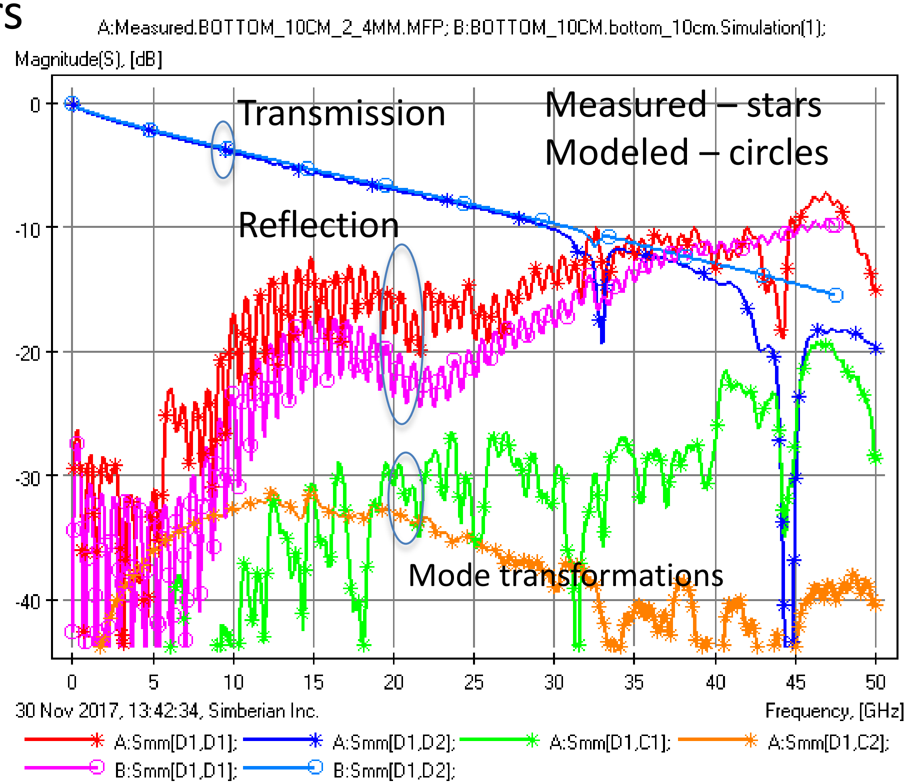


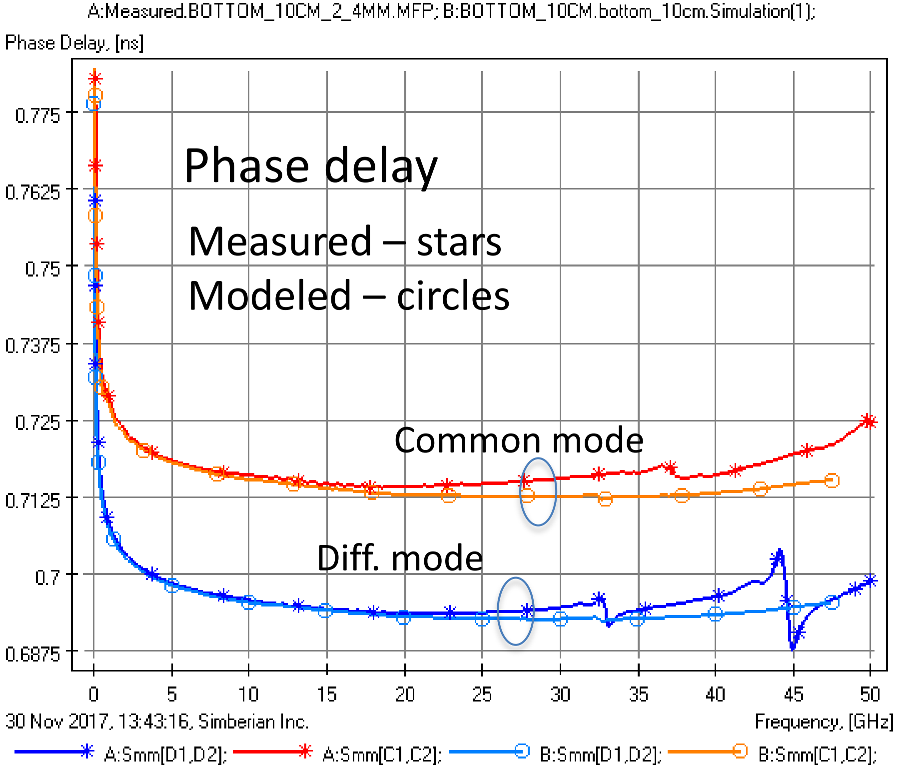
De-compositional EM analysis
Shape and size of all MSL sections are adjusted…

Mixed-mode S-parameters

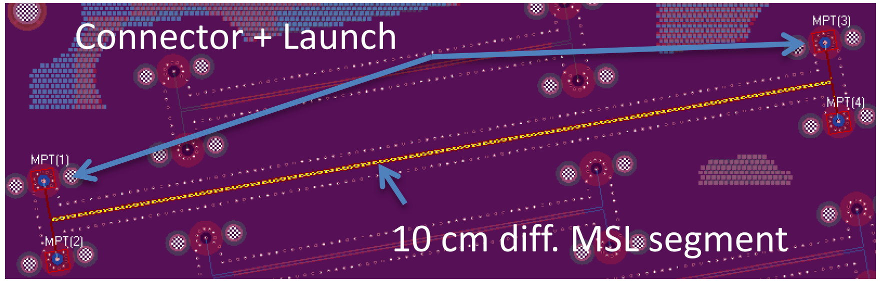
Reality: more reflections from 10 to 30 GHz (investigate)…

Acceptable correspondence up to 30 GHz





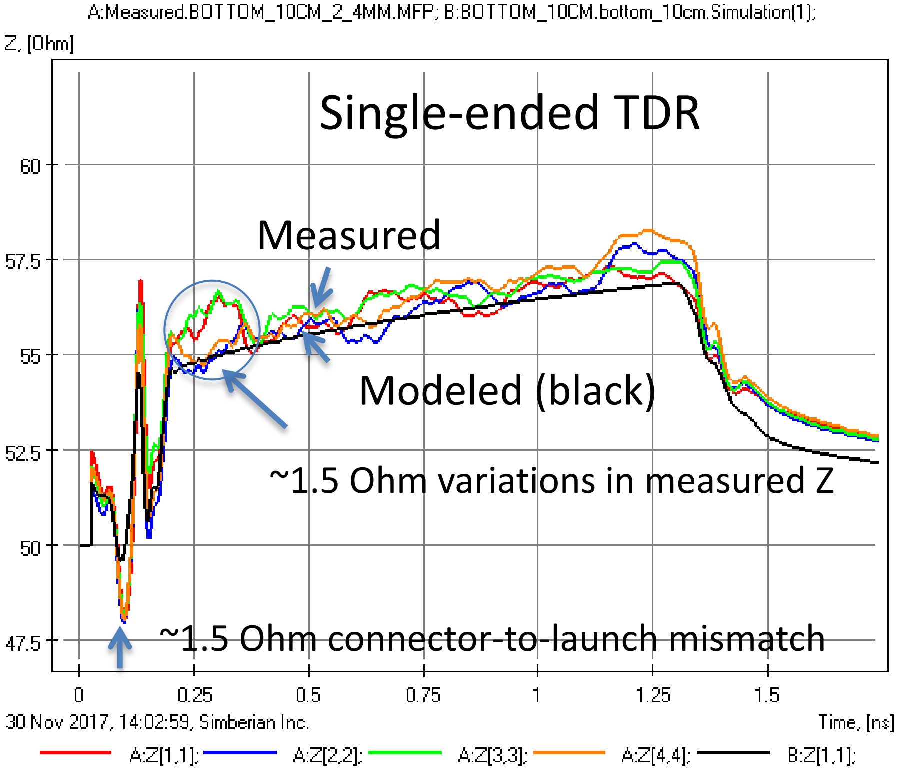
BOTTOM: 10 cm diff. microstrip link

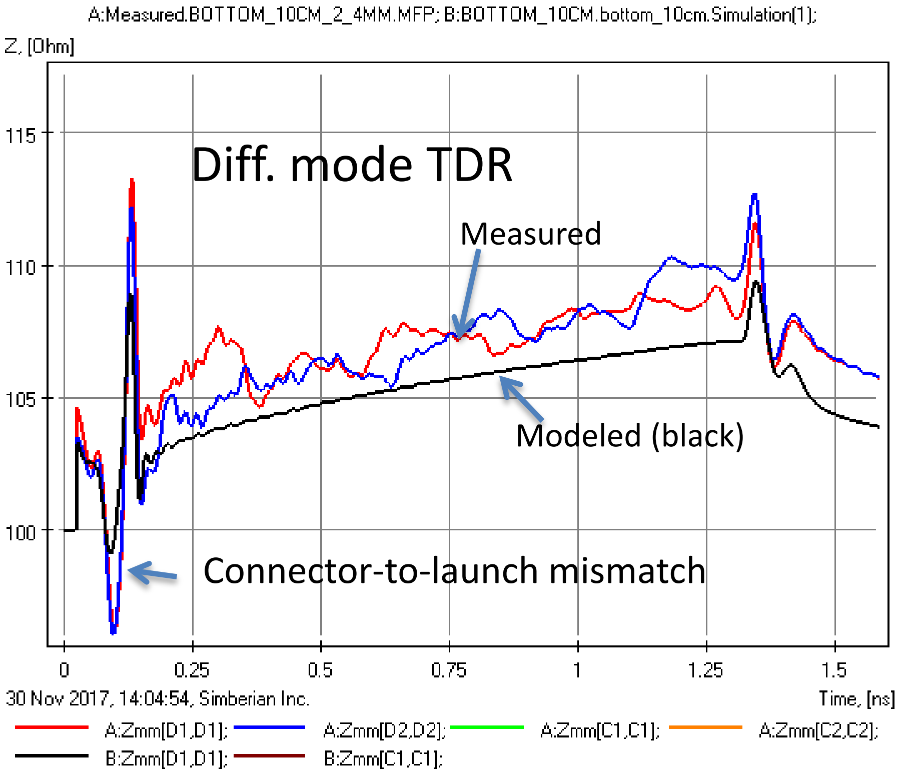


De-compositional EM analysis
Shape and size of all MSL sections are adjusted…

Reality: more reflection at the microstrip launch (investigate)…
Large variations of impedance along the traces (investigate)…

Acceptable correspondence;



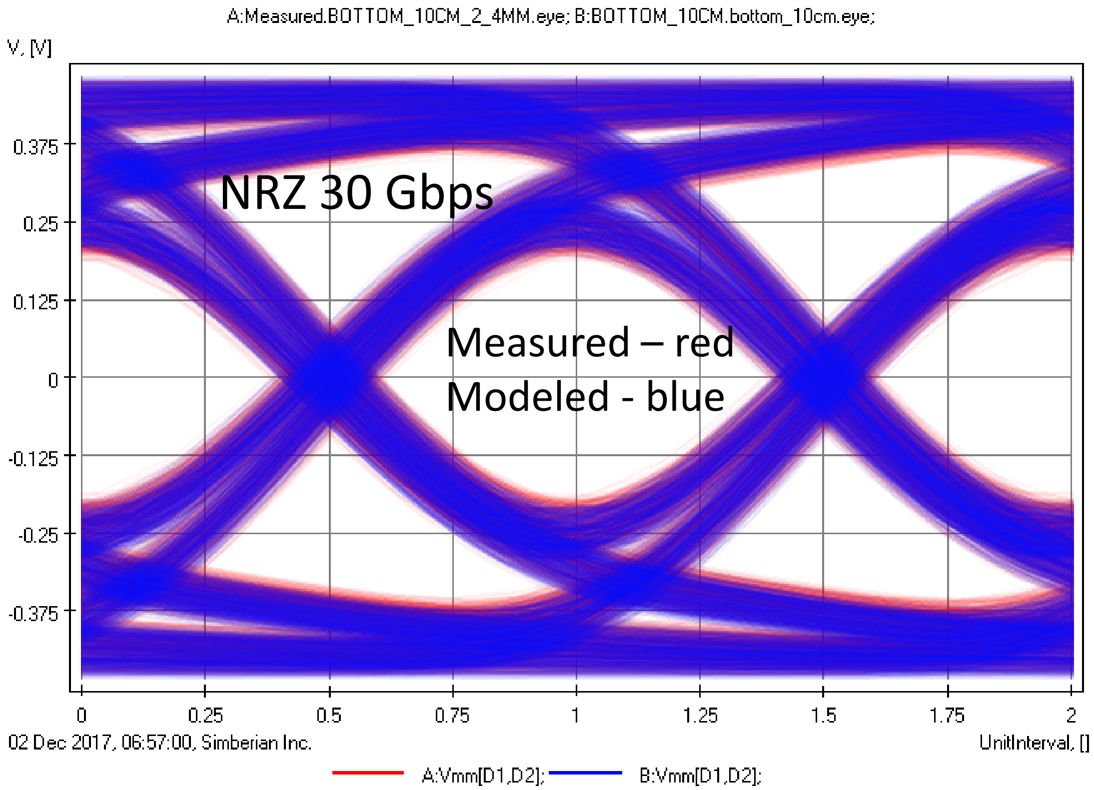


BOTTOM: 10 cm diff. microstrip link

Eye Analyzer

Show Eye Metrics: Selected   Auto-open

Parameter	Measured.BOTTO...	BOTTOM_10CM....
Eye Level Zero (V)	-0.334196	-0.343371
Eye Level One (V)	0.33443	0.339881
Eye Level Mean (V)	-0.000438433	1.49821e-005
Eye Amplitude (V)	0.668627	0.683252
Eye Height (V)	0.368693	0.38681
Eye Width (UI)	0.757871	0.769845
Eye Opening Factor	0.551418	0.56613
Eye Signal to Noise	4.19297	4.34656
Eye Rise Time (20-80) (UI)	0.565492	0.559771
Eye Fall Time (80-20) (UI)	0.565037	0.561818
Eye Jitter (PP) (UI)	0.242129	0.230155
Eye Jitter (RMS) (UI)	0.0494993	0.0478879



~6% difference in eye heights, 1.5% in widths; Possible reason – large impedance variations, launch mismatch and localization loss…

Example of the validation report

Structure	IL [GHz] SE & MM	RL [GHz] SE & MM	FEXT & NEXT [GHz]	TDR (Ω) ~ SE / MM	Eye (30 Gbps, diff.)	Notes
INNER1 5cm 10cm	 25 25	 15 15	 30	 1 / 2 1 / 2	 1% EH & EW	There is uncertainty in the epoxy filling after the backdrilling, the launches is more inductive then predicted. DM/CM phase delay correlate up to 25GHz.
INNER2 5cm 10cm	 30 30	 25 25	 30	 1 / 2 1 / 2	 1% EH & EW	Trace width seems to be 95um instead of 99um. Launch more inductive then predicted, PCB trace width variation. DM/CM phase delay correlate up 30 GHz.
INNER3 5cm 10cm	 30 30	 30 30	 30	 1 / 2 1 / 2	 3.6% EH, 1% EW	Core/prepreg dielectric models – layered anisotropy. Resonance frequency little lower than predicted. Launches have long stubs (not backdrilled).
INNER6 5cm 10cm	 30 30	 10-15 10-15	 30 30	 1 / 3 2 / 4	 2% EH, 1% EW	Differences in RL expected due to geometry differences Mode conversions in measurements up to -30dB DM/CM phase delay correlation ~ 30GHz Impedance variations, launch mismatch, loss of localization.
D2 Beatty INNER6	 30	 30	 N/A	 1 / N/A	 N/A	Loss and dispersion models work for much wider strips! Good correspondence in phase delay and TDR.
BOTTOM 5cm 10cm	 30 30	 10-15 10-15	 30 30	 2 / 4 2.5 / 5	 6% EH, 1.5% EW	more reflections from 10 to 30 GHz (investigate)… Large variations of impedance along the traces (investigate)…
G2 Skew INNER6	 30	 30	 30	 ~3 / 3	 2% EH, 1% EW	Reality: Large difference in mode transformation – investigate what causes it… One trace is 1mm longer then the other in layout.
C1 Diff via INNER6 (with stubs)	15 & 30	15 & 30	15		Large difference in EW and EH	Reality: Differences in reflection and in transmission above 10-15 GHz (loss of localization or geometry?) Large difference in eye width and height Reality: much larger ISI due to differences in stub behavior and launch with small anti-pads (sensitive to manufacturing variations)…
C2 Diff via INNER6 (backdr.)	 30	 15	 25	 1 / 2	 5% EH, 1% EW	Reality: differences in diff. reflection from 10 to 25 GHz and in transmission above 30 GHz. Mode conversions in measurement up to -30dB.

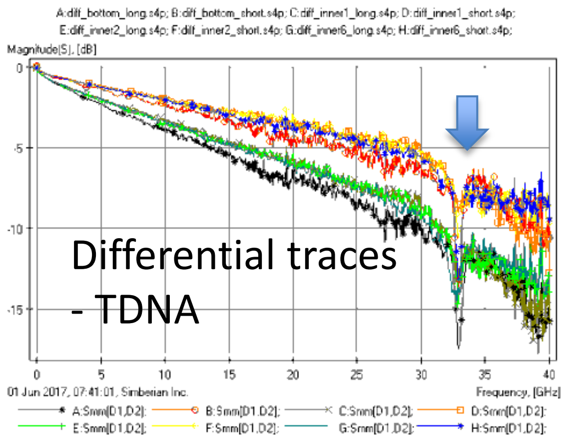
Conclusion: Making predictable interconnects

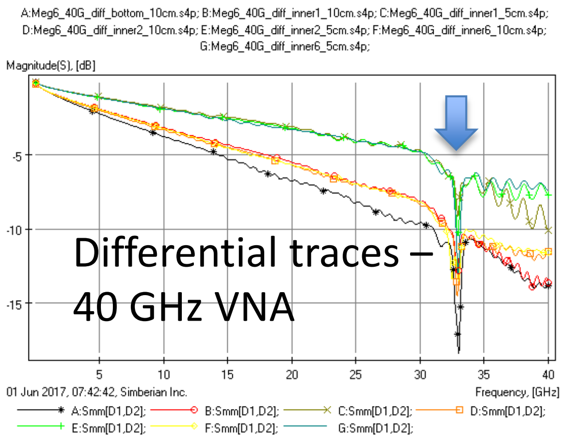
- Systematic approach with two steps:
  1. **Geometry adjustments identification**
  2. **Material model identification (dielectric and conductor roughness)**
- And one condition: **Use of software validated for PCB or packaging interconnects**
- Test boards and “sink or swim” validation process should be used to identify problems
- Accurate prediction of PCB behavior up to 40 GHz with typical trace width and low-cost manufacturing process is very ambitious goal due to the SI problem bandwidth and equal importance of low and high frequencies
  - In this project interconnects were predictable only up to 30 GHz due to launch localization and manufacturing tolerances
  - Try before you invest into any measurement equipment – no matter how reputable is the vendor (applicable to EDA tools)
  - Cross-sectioning revealed that manufacturer adjustments for strip lines are very close, but for microstrips are not acceptable
  - Conductor roughness is the major contributor to the signal degradation - analysis without proper conductor roughness model would be useless, use of causal Huray-Bracken roughness model is critical to have good correlation
  - Identified dielectric parameters are very close to the PCB vendor specs (inhomogeneity matter for FEXT)

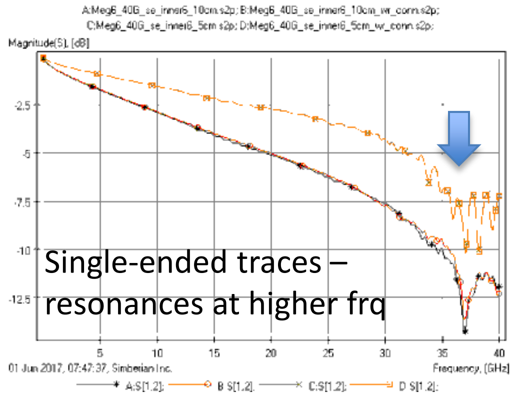
Reality above 30 GHz

"So many blissful revelations
The spirit of enlightment hides!"...

Reality: What caused the resonances?



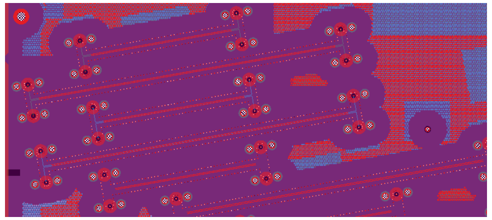


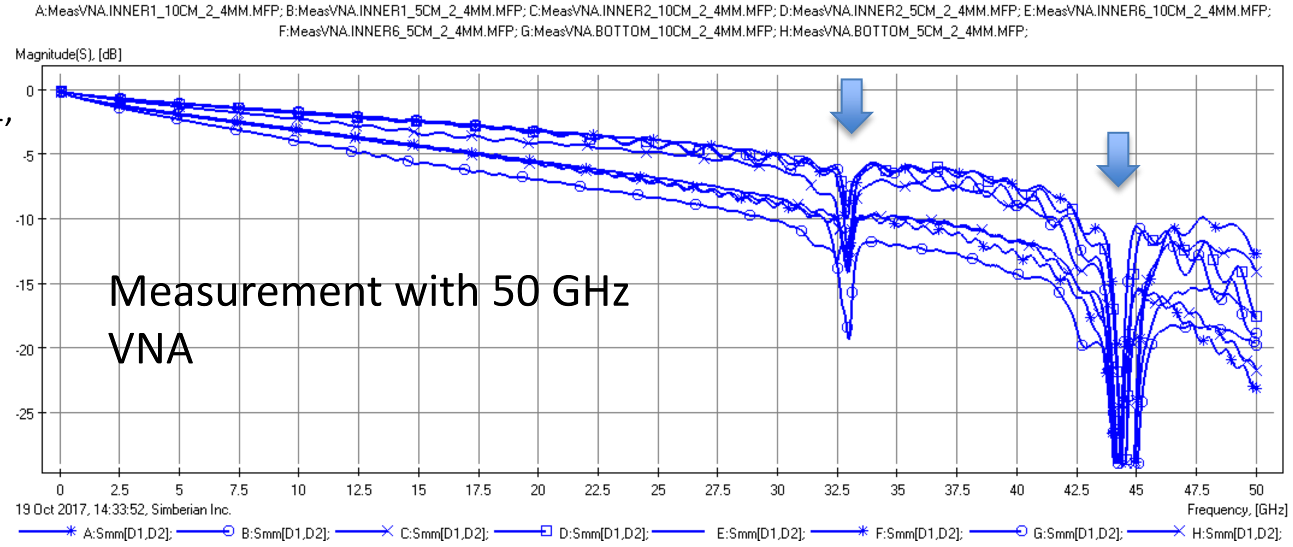


What caused it?

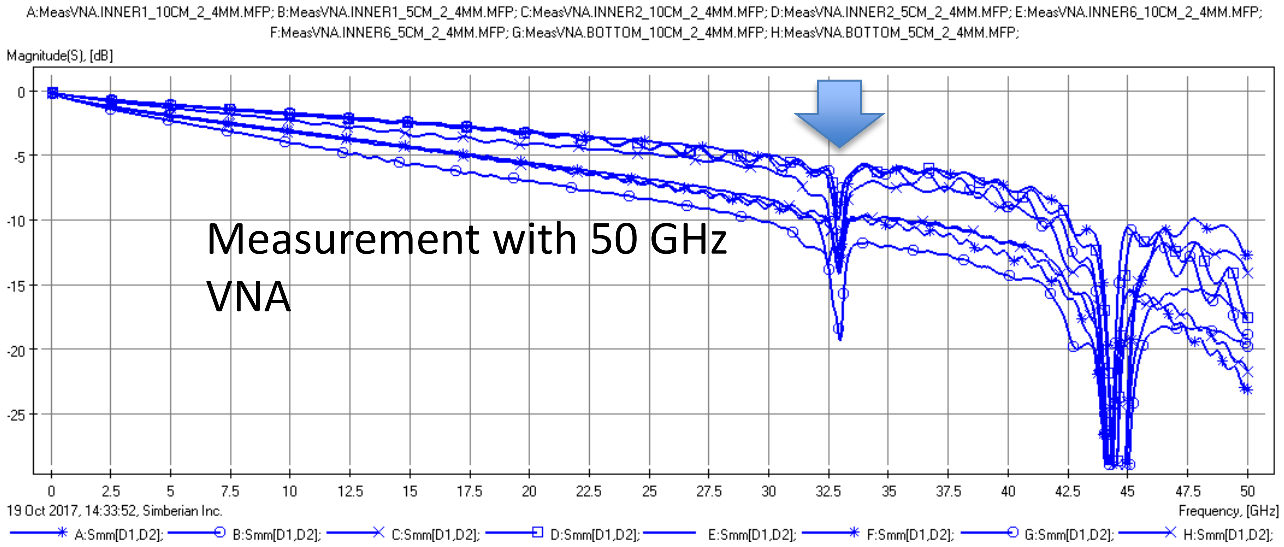
1. Fiber Weave Effect?
2. Connectors or adapters?
3. Launch localization?
4. Non of the above?

5 and 10 cm diff. traces in INNER1, INNER2, INNER6 and BOTTOM

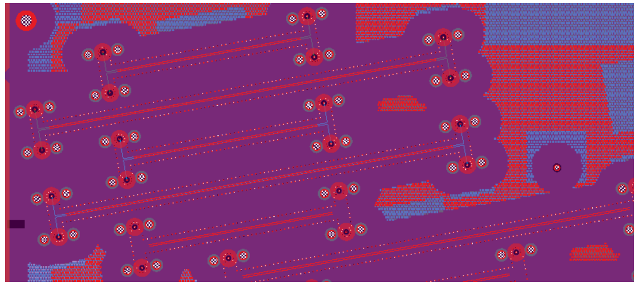




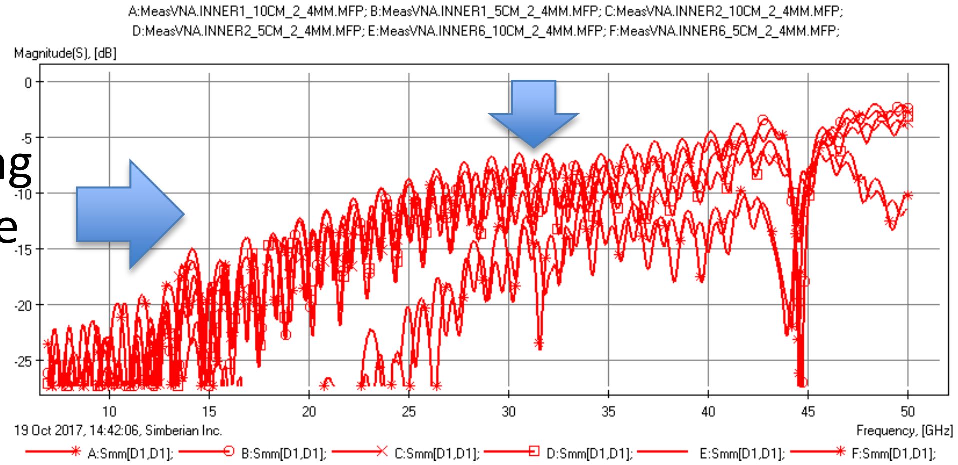
Reality: Resonance investigation



5 and 10 cm diff. traces in INNER1, INNER2, INNER6 and BOTTOM



No matching peaks in the reflections



Looks like NOT a fiber weave effect…

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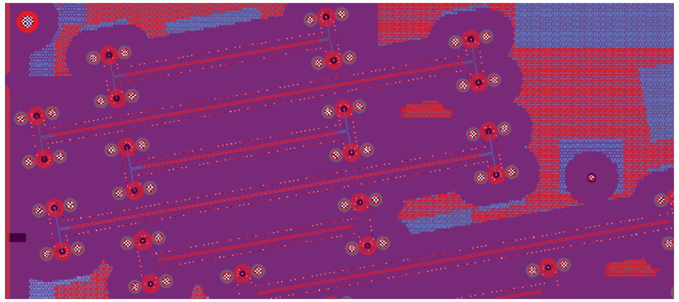
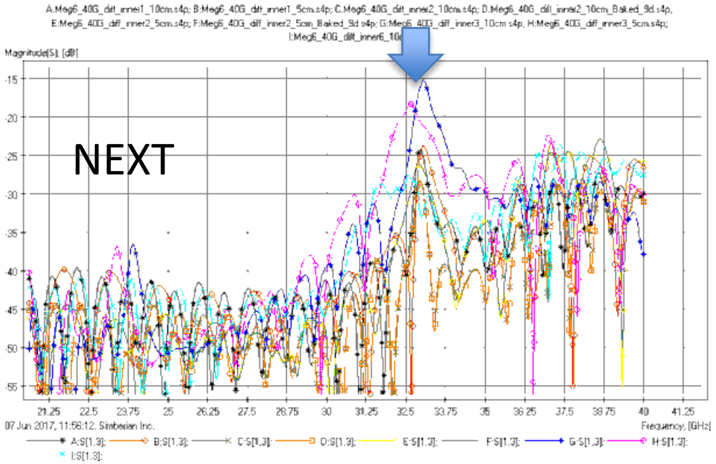
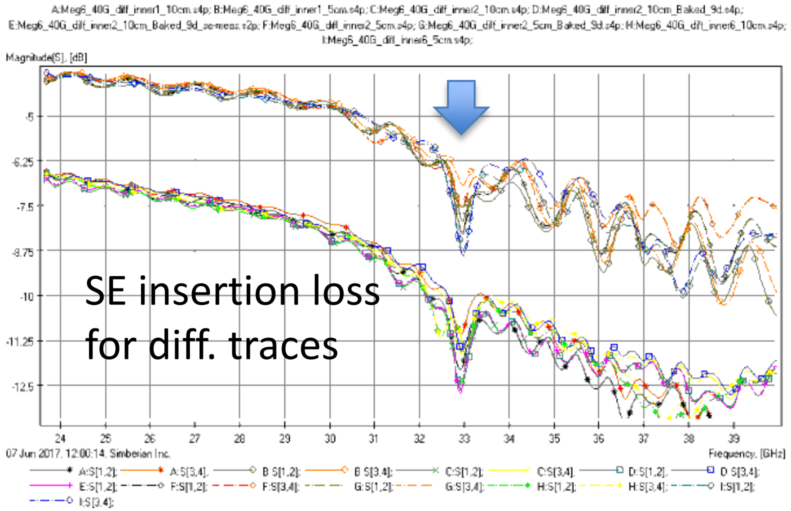
Reality: Resonance investigation

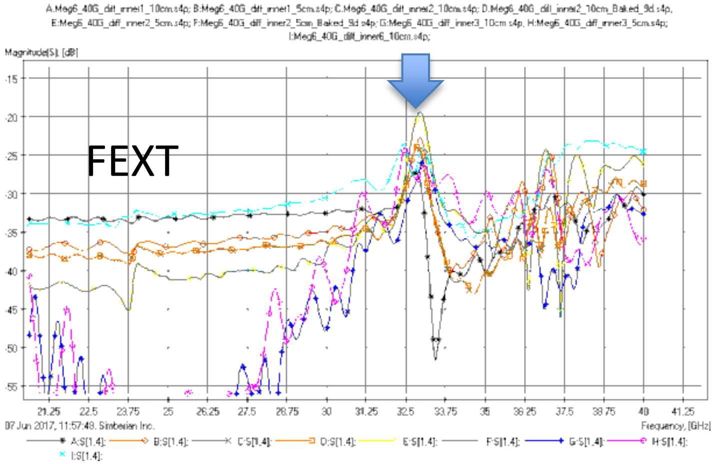
That is where the energy goes!

5 and 10 cm diff. traces in INNER1, INNER2, INNER6 and BOTTOM



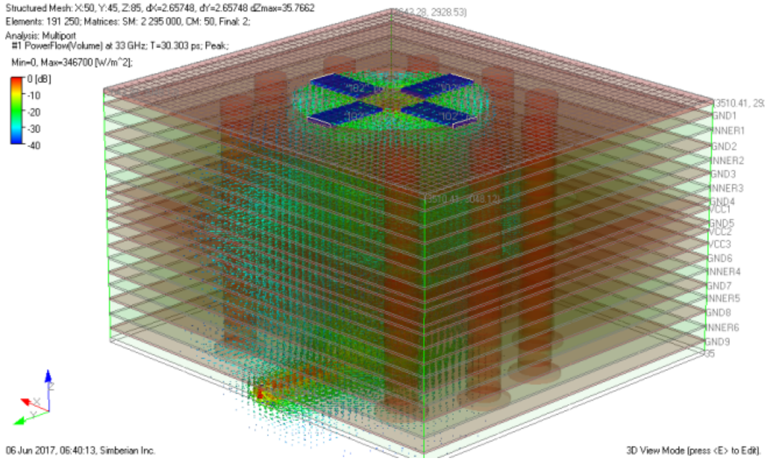


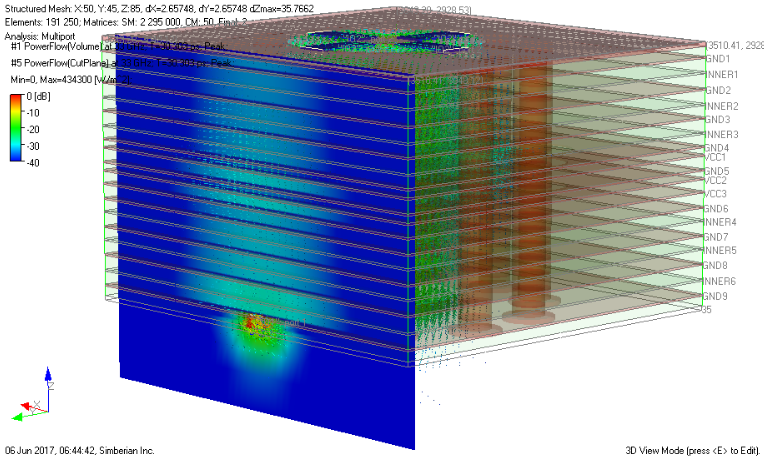




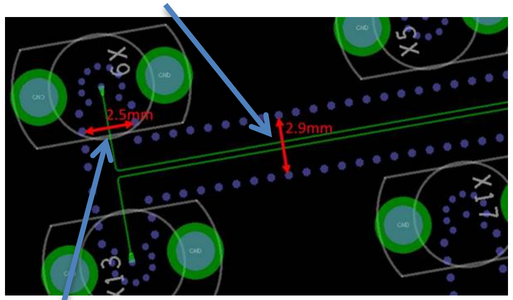
Launches are leaky above 30 GHz as designed!

Microstrip launch peak power flow density at 33 GHz



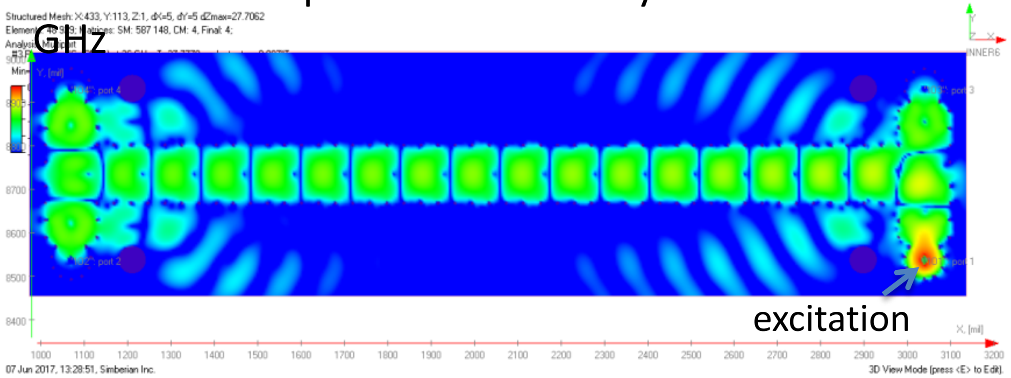


29 GHz cutoff frequency



32 GHz cutoff frequency

Instantaneous power flow density at 35 GHz



excitation

Energy leaked from the launches goes into Substrate Integrated Waveguide (SIW)

Simulated with Simbeor