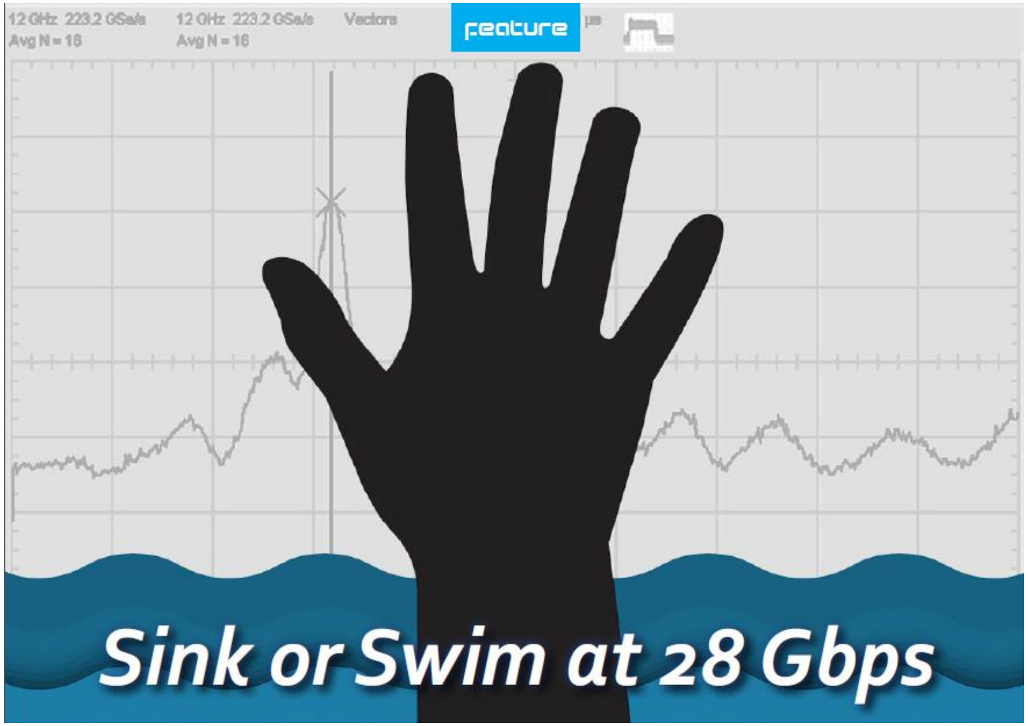

PCB Design Magazine, Oct. 2014, p. 12-23

How to validate interconnect analysis software for 28 Gbps data links

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In collaboration with Wild River Technology LLC
DesignCon IBIS Summit, Santa Clara, January 30, 2015

Outline

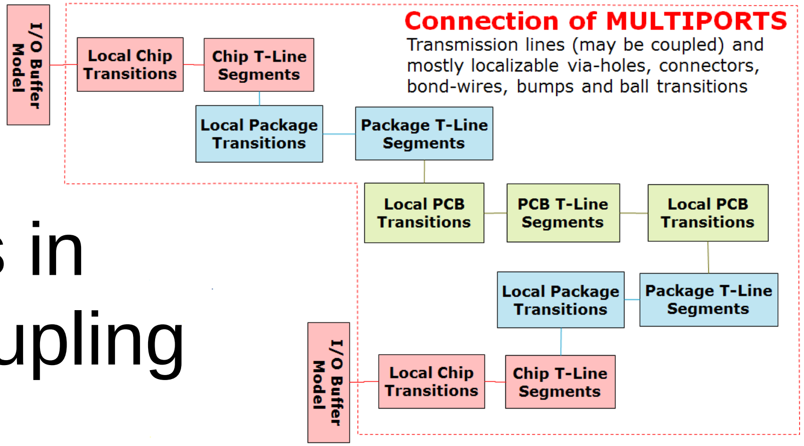
- Introduction
- Validation process overview
- Example of analysis to measurement validation
  - Measured S-parameters pre-qualification
  - Geometry adjustments
  - Material models identification
  - Comparing analysis to measurements
- Conclusion

Introduction

- Design of PCB and packaging interconnects for data links running at bitrates 28-32 Gbps and beyond is a challenging problem:
  - It requires electromagnetic analysis over extremely broad frequency bandwidth from DC to 40-50 GHz
  - No frequency-continuous dielectric models available from manufactures
  - No conductor roughness models available from manufacturers
  - Boards are not manufactured as designed – large variations and manipulations by manufacturers
  - Making accurate measurements over this bandwidth is very difficult
- Is it possible to design interconnects and have acceptable analysis to measurement correlation from DC up to 40-50 GHz systematically?

Analysis correlates with measurements if…

1) Quality of S-parameter models is ensured



2) Simulation of all elements in isolation is possible or coupling is properly accounted

3) Broadband material models are identified or confirmed

4) Models are validated with measurements

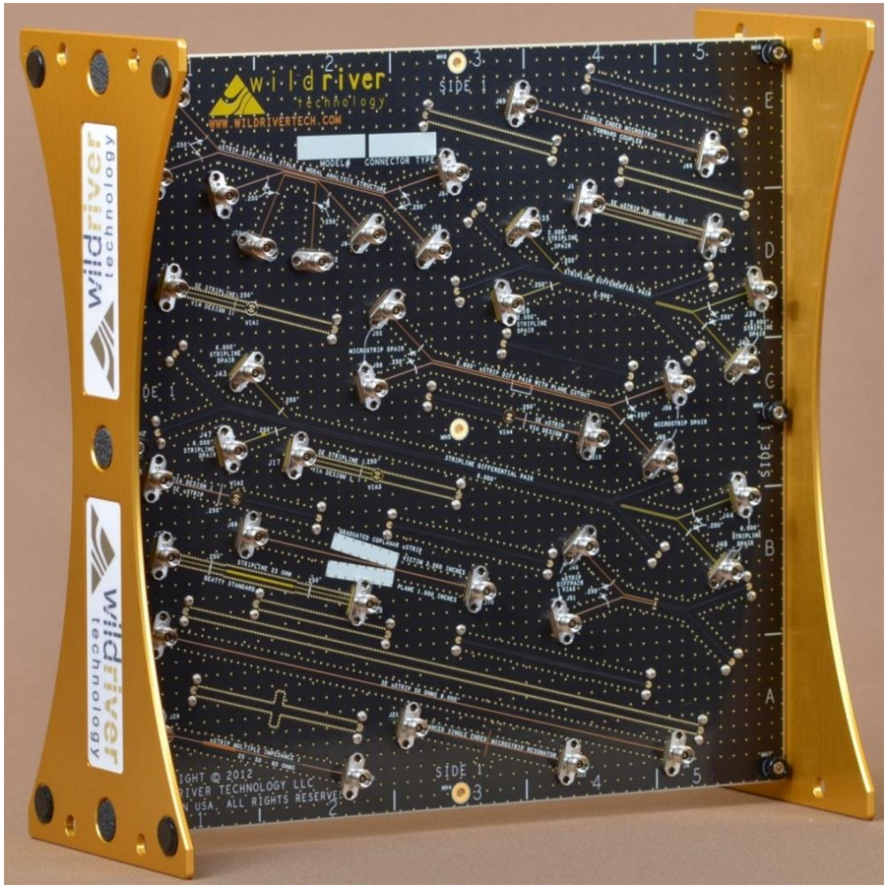
4 elements of design success – see App Notes #2013_03 and #2013_05 at http://www.simberian.com/AppNotes.php

Analysis to measurement validation process for 28-32 Gbps interconnects

- **Design and manufacture** a board with a set of typical or useful interconnect links
- **Measure S-parameters** up to 40-50 GHz
- Load board design into EDA tool, and **compute S-parameters** of the links
- **Compare S-parameters** magnitudes and phases
- Optionally compare TDR/TDT and eye diagrams
- As simple as that…☺

Validation platforms simplify the process!

- Channel modeling platform was developed by Wild River Technology to promote systematic approach to interconnect analysis to measurement validation up to 40/50 GHz or up to 28/32 Gbps
  - **Contains 27 micro-strip and strip-line interconnect structures** equipped with 2.92 mm or 2.4 mm connectors and can be used to validate signal integrity simulations, models, and measurement technique
- Electromagnetic signal integrity software from Simberian is used here to illustrate all elements of the analysis to measurement validation



Complete description of the platform with all validation results are available here.

Example of analysis to measurement validation

1. Use VNA to measure S-parameters and validate quality of the measurements
2. Get board geometry adjustments (stackup and trace widths) from manufacturer (if any) and use consistently in the material identification and the analysis (use cross-sectioning if no data provided)
3. Identify broad-band dielectric and conductor roughness models with Generalized Modal S-parameters (GMS-parameters)
4. Simulate all structures with the identified or validated material models and confirmed adjustments consistently and compare with the measurements (no further manipulations with data)

4 steps with live demo are covered in webinar #4 at http://www.simberian.com/Webinars.php

Step 1: Ensure S-parameters quality

- Accuracy of discrete S-parameters approximation with frequency-continuous macro-model, passive from DC to infinity

$$RMSE = \max_{i,j}\left[\sqrt{\frac{1}{N}\sum_{n=1}^{N}\left|S_{ij}(n) - S_{ij}(\omega_n)\right|^2}\right]$$

original tabulated data

$$S_{i,j}(i\omega) = \left[d_{ij} + \sum_{n=1}^{N_{ij}}\left(\frac{r_{ij,n}}{i\omega - p_{ij,n}} + \frac{r_{ij,n}^{*}}{i\omega - p_{ij,n}^{*}}\right)\right]\cdot e^{-s\cdot T_{ij}}$$

- Can be used to estimate quality of the original data

$$Q = 100\cdot\max\left(1 - RMSE, 0\right)\%$$

Model Icon/Quality	Quality Metric	RMSE
- good	[99, 100]	[0, 0.01]
- acceptable	[90, 99)	(0.01, 0.1]
- inconclusive	[50, 90)	(0.1, 0.5]
- bad	[0, 50)	> 0.5
- uncertain	[0,100], not passive or not reciprocal	

Rational model can be used for FD and TD analysis instead of the original data

Introduced at IBIS forum in 2010

Quality estimation theory is covered in webinar #1 at http://www.simberian.com/Webinars.php

Example of S-parameter quality estimation with rational compact model (RCM)

S-parameters are measured by expert; Models include connectors and adapters;
RCM are built with options: “Extrapolate to infinity” and “Extract Delay” and “Auto-adjust” are OFF)

Touchstone Analyzer

File name	Quality	Passivity	Reciprocity	Causality
C:\Repository\Simbeor\CMP-28_Simbeor_Kit_Rev4\CMP-28_Rev4\Touchstone_Files\1stc...				
cmp28_gnd_voids_p1J74_p2J75.s2p	99.5	100	99.4	-
cmp28_graduated_coplanar_p1J70_p2J69.s2p	99.7	100	99.5	-
cmp28_mstrp_2in_p1J1_p2J2.s2p	99.5	100	99.7	-
cmp28_mstrp_8inch_p1J4_p2J3.s2p	99.7	100	99.8	-
cmp28_mstrp_Beatty_25ohm_p1J25_p2J26.s2p	99.6	100	99.4	-
cmp28_mstrp_multiZ_p1J31_p2J32.s2p	99.6	100	99.3	-
cmp28_mstrp_p1J30_p2J29.s2p	99.6	100	99.8	-
cmp28_mstrp_resonator_p1J22_p2J22.s2p	99.7	100	99.7	-
cmp28_mstrp_whiskers_p1J68_p2J67.s2p	99.5	100	99.8	-
cmp28_strpl_2in_50ohm_p1J6_p2J5.s2p	99.6	100	99.1	-
cmp28_strpl_2in_Capacitive_p1J10_p2J09.s2p	99.5	100	99.5	-
cmp28_strpl_2in_Inductive_p1J12_p2J11.s2p	99.5	100	99.4	-
cmp28_strpl_8inch_p1J7_p2J8.s2p	99.6	100	99.7	-
cmp28_strpl_Beatty_25ohm_p1J28_p2J27.s2p	99.7	100	99.4	-
cmp28_strpl_resonator_p1J23_p2J24.s2p	99.6	100	99.4	-
cmp28_via_pathology_p1J65_p2J66.s2p	99.6	100	99.8	-

Touchstone Analyzer

File name				
cmp28_strpl_via_backdrilled_p1J14_p2J13.s2p	97.7	100	99.4	-
cmp28_strpl_via_capacitive_p1J18_p2J17.s2p	93.4	100	99.7	-

ALL PASSED!

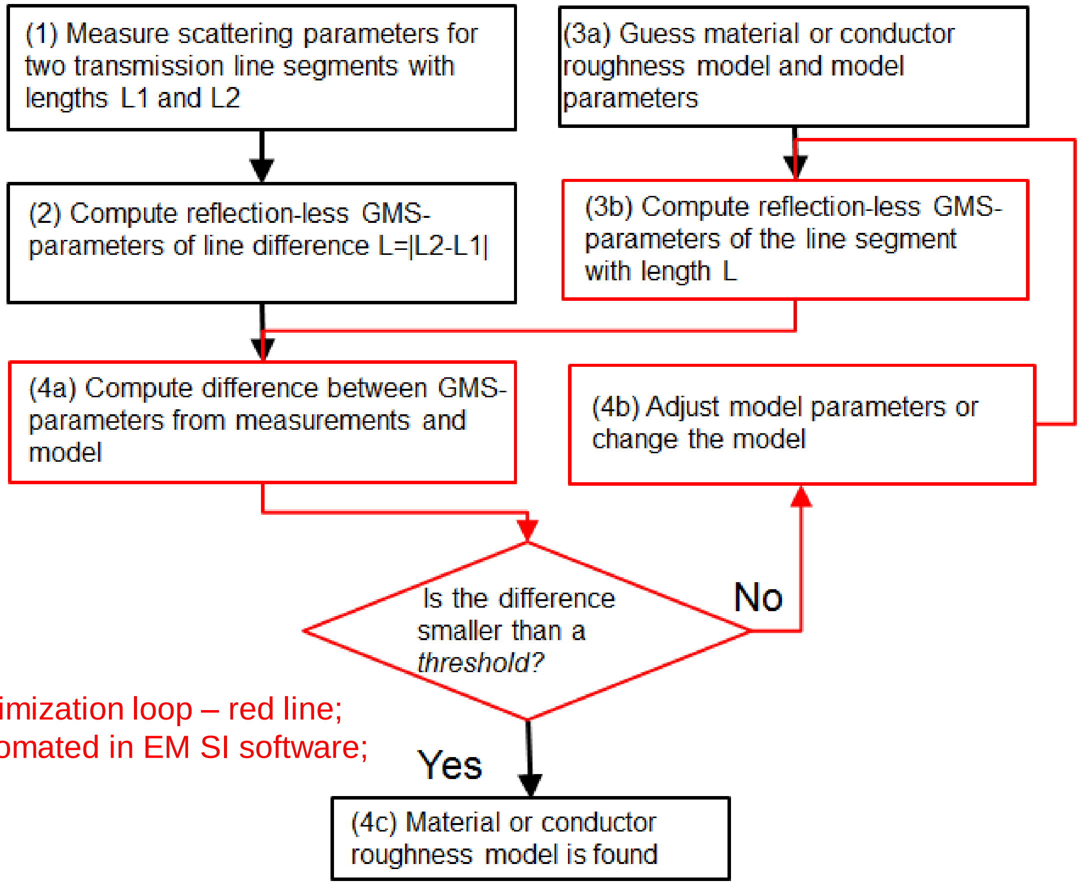
See how to do it in demo-videos #2011_01 and 2011_02 at http://www.simberian.com/ScreenCasts.php

…

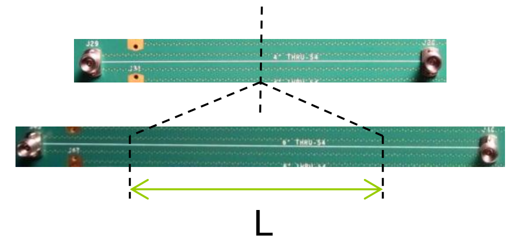
Step 2: Board geometry adjustments

- Stackup is adjusted from data provided by manufacturer
- Width adjustments before analysis to match the impedance observed on TDR:
  - Micro-strip single-ended line widths are adjusted from 14.5 to 13.5 mil
  - Strip line single-ended widths are adjusted from 11.0 to 10.5 mil
  - All other widths and dimensions are exactly as in the board design (may need consistent adjustments as follows from the validation)
- Cross-sectioning may be needed to investigate all adjustments

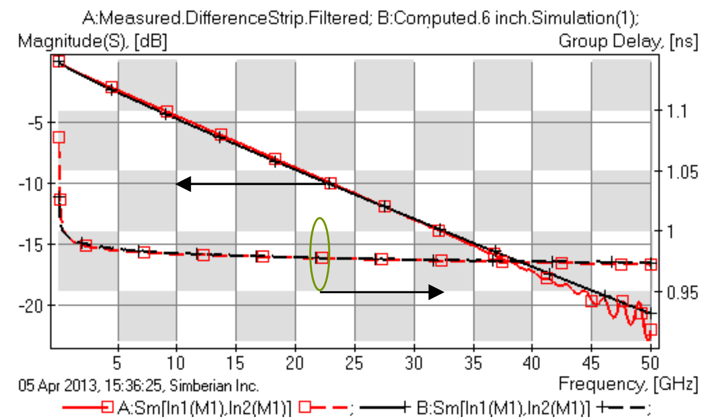
Step 3: Identify material models with Generalized Modal S-parameters (GMS-parameters)



Optimization loop – red line;
Automated in EM SI software;

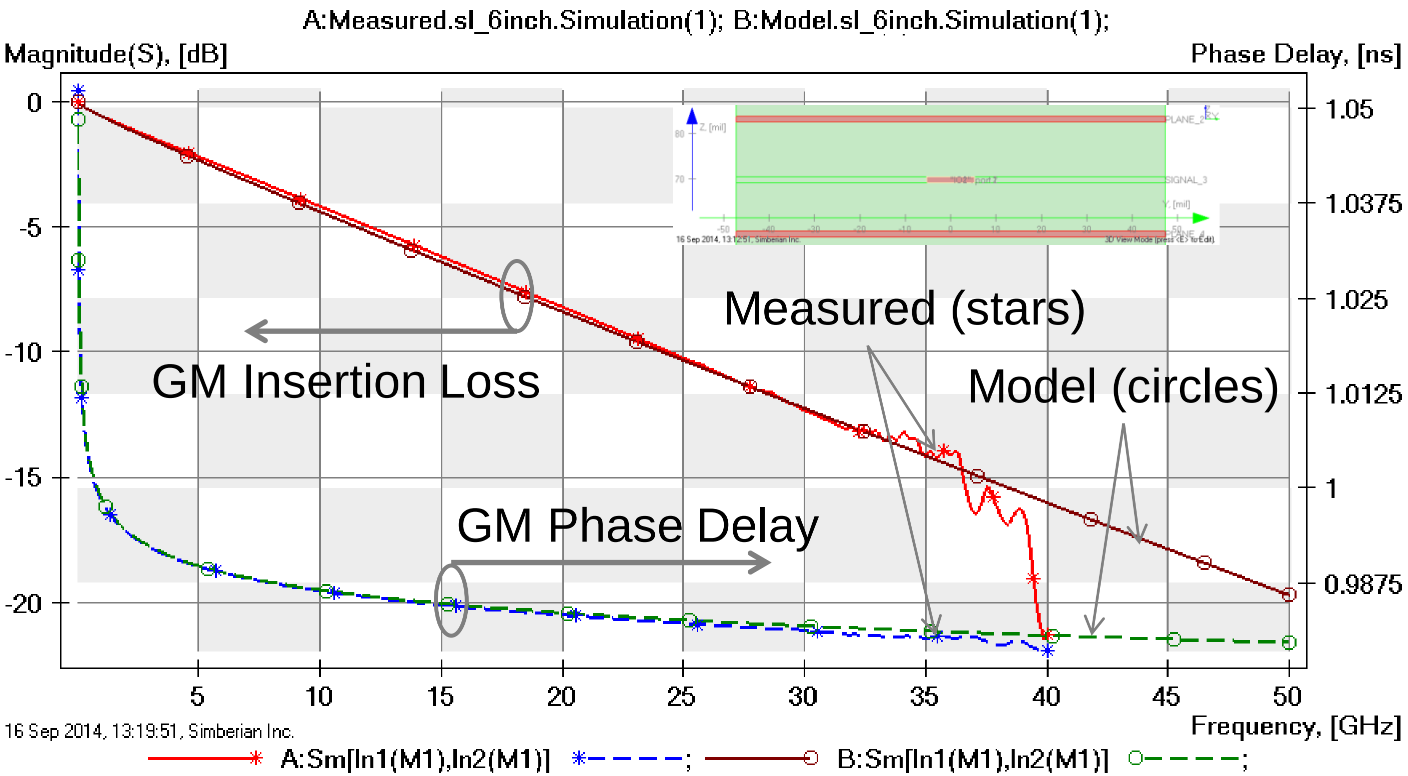


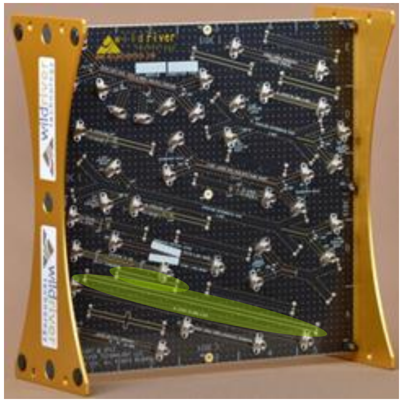
GMS-parameters have zero reflection and mode transformation;
Applicable to dielectric and conductor roughness models;



See App Notes #2014_02 and 2014_03 for details on identification with GMS-parameters at http://www.simberian.com/AppNotes.php and webinar #2 at http://www.simberian.com/Webinars.php

Step 3: Dielectric and conductor roughness model identification with strip line





GM - Generalized Modal (reflection-less);

About 35 GHz useful bandwidth from the measured data due to mechanical differences;

Models are usable up to 50 GHz!

GMS parameters computed from S-parameters measured for 2 and 8 inch strip line segments (red and blue lines) and modeled for 6 inch strip line segment (brown and green lines):

FR408HR model: Wideband Debye, Dk=3.815 (3.66), LT=0.0117 @ 1 GHz;

Conductor roughness model: Modified Hammerstad, SR=0.4 um, RF=2;

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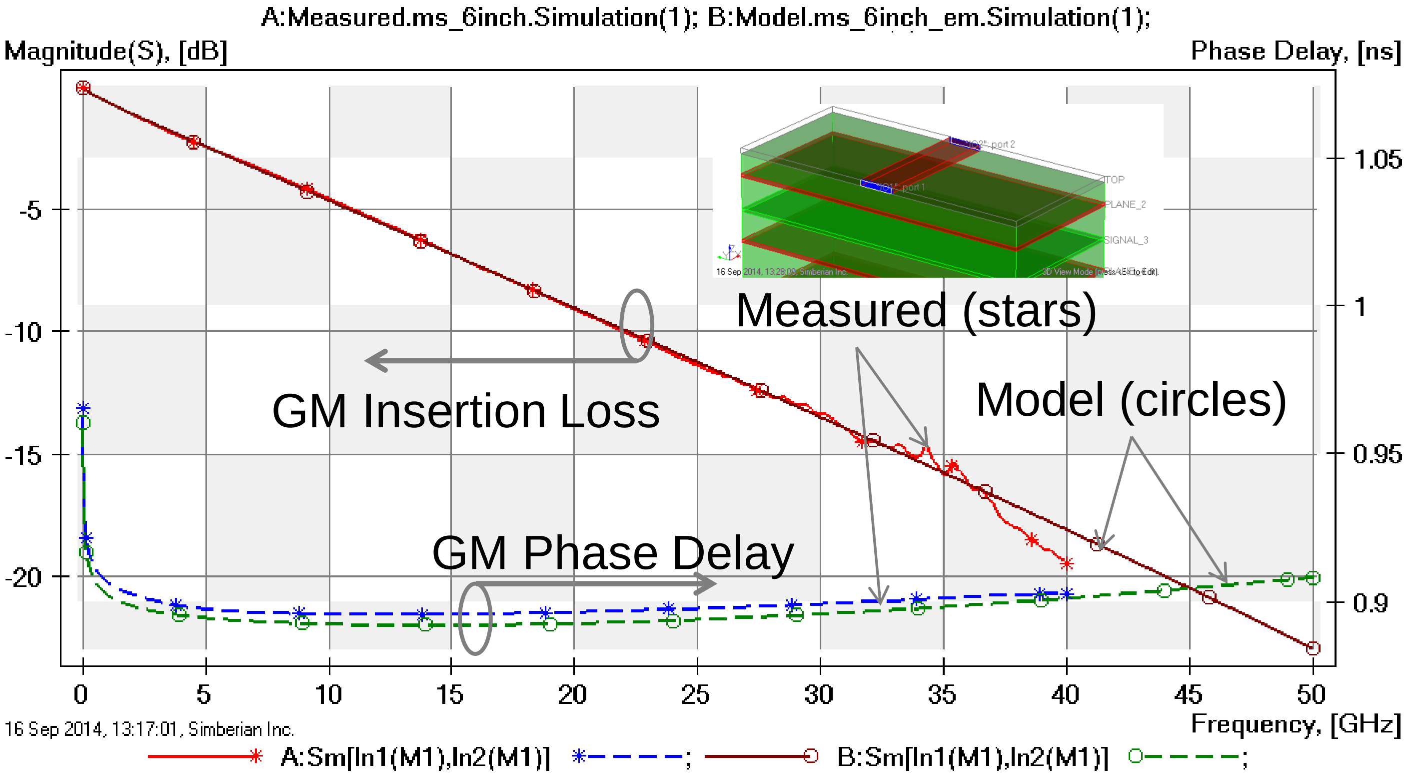
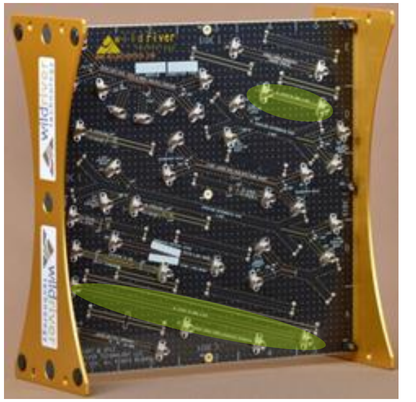
Step 3: Dielectric and conductor roughness model identification with micro-strip line





GM - Generalized Modal (reflection-less);

Models are usable up to 50 GHz!

GMS parameters computed from S-parameters measured for 2 and 8 inch micro-strip line segments (red and blue lines) and modeled for 6 inch micro-strip line segment (brown and green lines):
FR408HR model: Wideband Debye, Dk=3.815 (3.66), LT=0.0117 @ 1 GHz (same as for strip);
Taiyo solder mask model: Wideband Debye, Dk=3.85 (3.9), LT=0.02 @ 1 GHz;
Conductor roughness model: Modified Hammerstad, SR=0.4 um, RF=3.5;

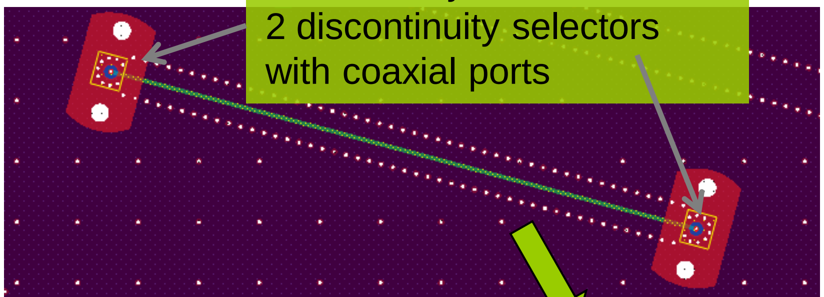
Step 4: Simulate all 27 structures and compare with the measurements

- Compute and compare S-parameters for all structures (complete adapter-to-adapter links or use de-embedding)
  - Compare simulated and measured magnitudes and phase/group delays in terminal and mixed-mode space up to 50 GHz
- Compute TDR from simulated and measured S-parameters and compare for all structures
  - Use rational compact models and Gaussian step with 20 ps 10-90% rise time
- Compute eye diagrams for 28 Gbps PRBS signals from simulated and measured S-parameters and compare for selected structures

Basics of the de-compositional analysis covered in webinar #3 at http://www.simberian.com/Webinars.php

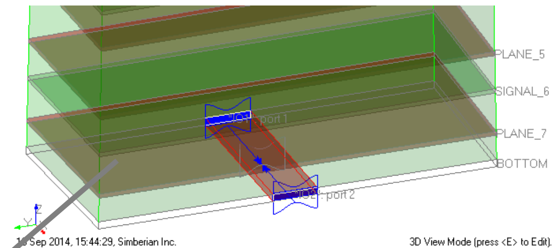
1) 2-inch microstrip line segment: De-compositional analysis

Board Analyzer:
2 discontinuity selectors
with coaxial ports

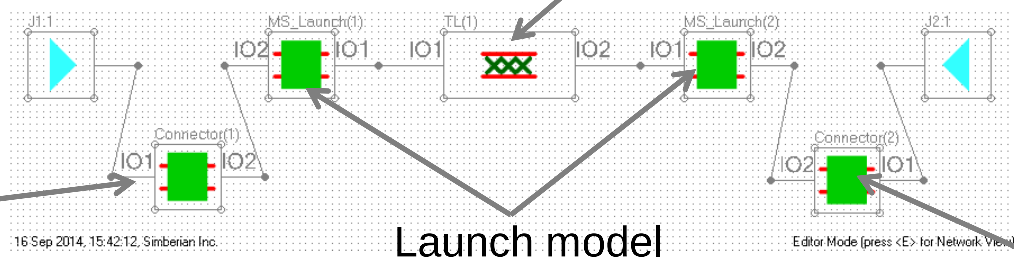


Auto-extraction

Trace width is adjusted in BA



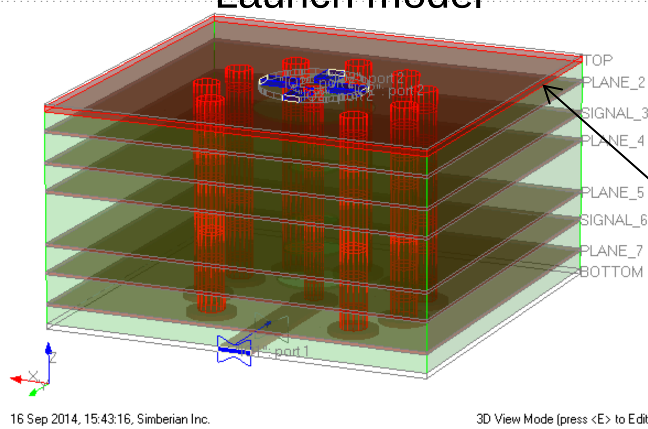
Built with 3D EM solver to include HF dispersion



Connector + adapter model (added)

Launch model

Connector + adapter model (added)

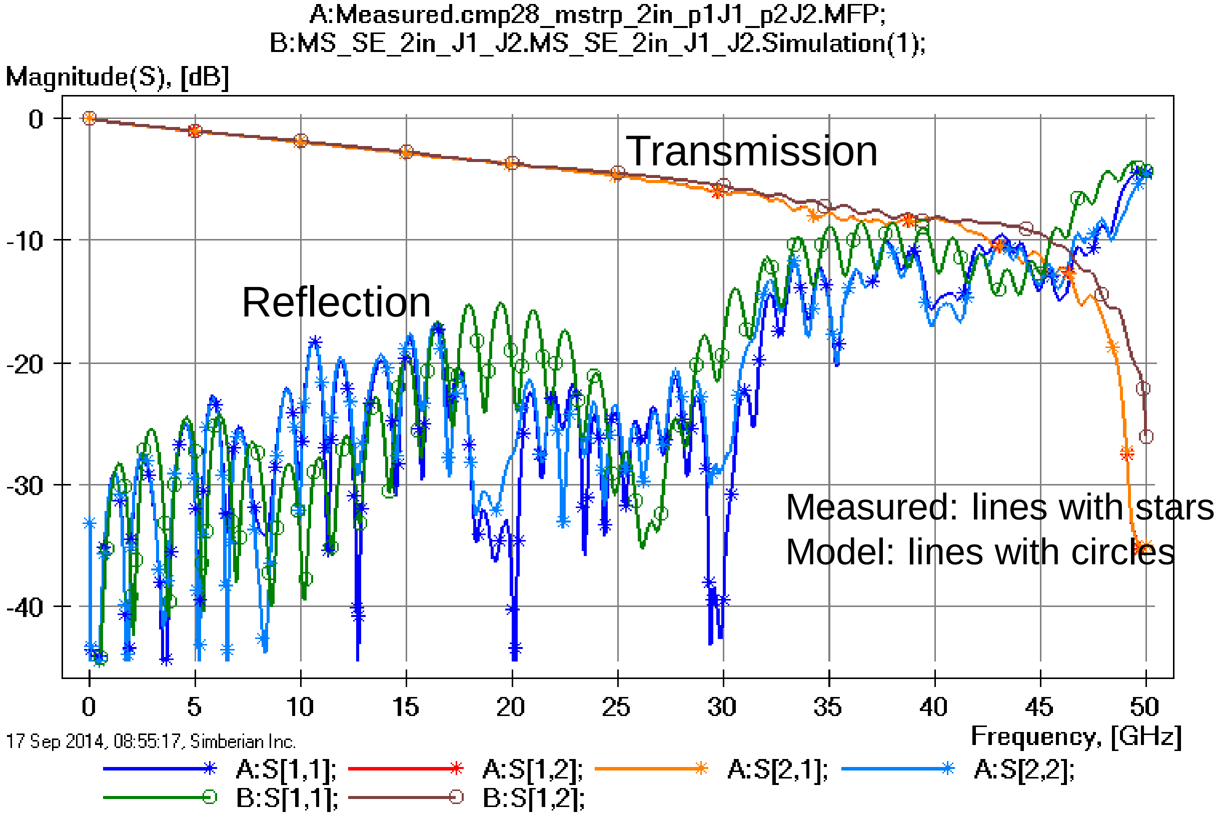


Built with 3D EM Solver

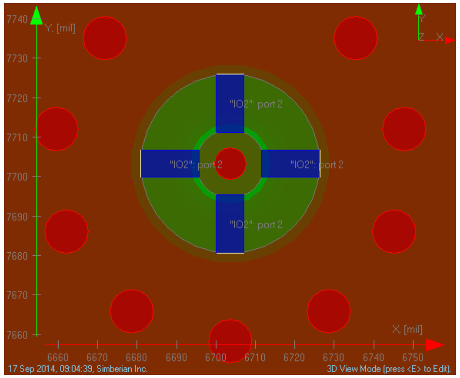
Connector + Launch are also simulated separately in PCB/MS_ConnectorAndLaunch for further reuse

Magnetic wall right above at the top layer to eliminate excessive capacitance

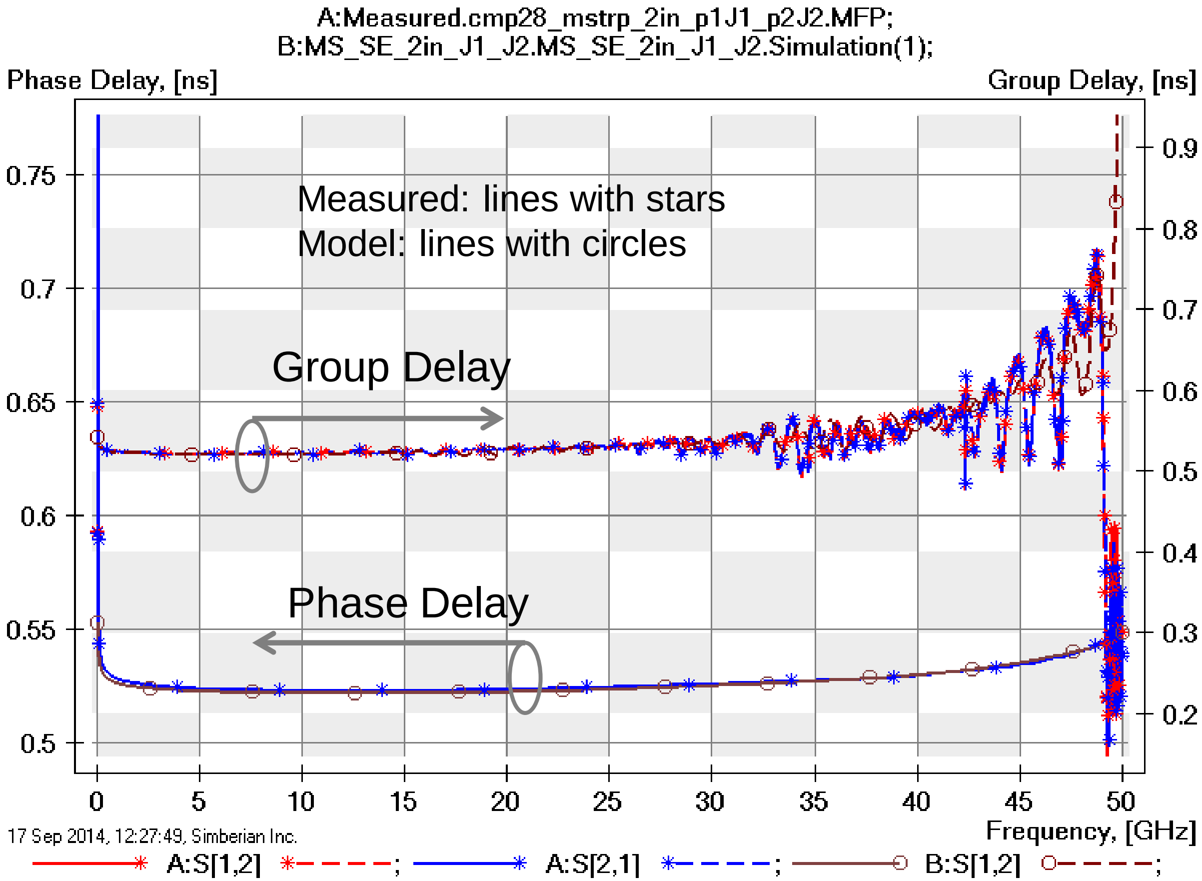
1) 2-inch microstrip line segment: Magnitude of S-parameters



MS Launch looses the localization at about 30 GHz: Distance from signal via to stitching vias is about quarter of wavelength at 30 GHz – we cannot expect correlation above that frequency! Though, the impedance of the return path remains low due to plenty of stitching vias.



1) 2-inch microstrip line segment: Transmission phase and group delay



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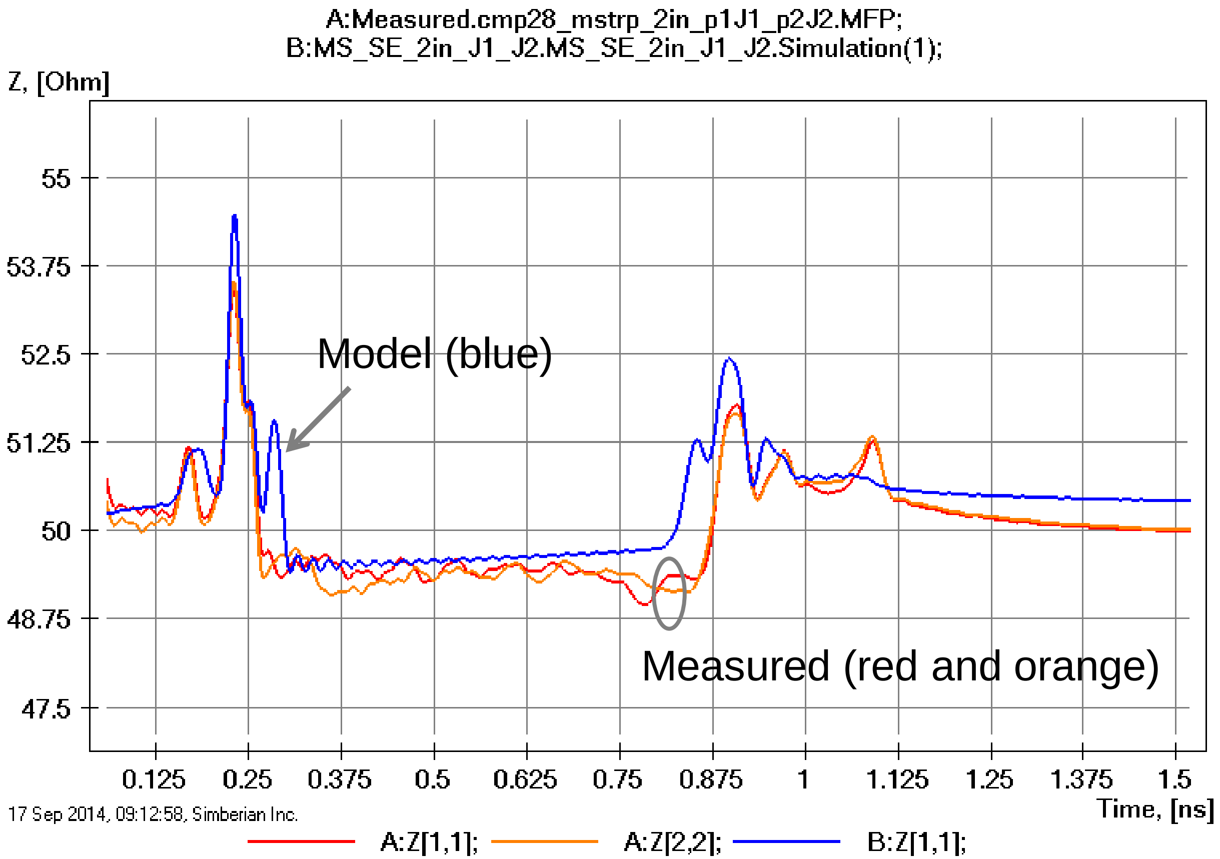
1) 2-inch microstrip line segment: TDR with 20 ps Gaussian step



Variations of impedance along the traces visible here indicates that either trace width is varying or dielectric is inhomogeneous (or both); This is not accounted for in the model and partially explains differences in the reflection.

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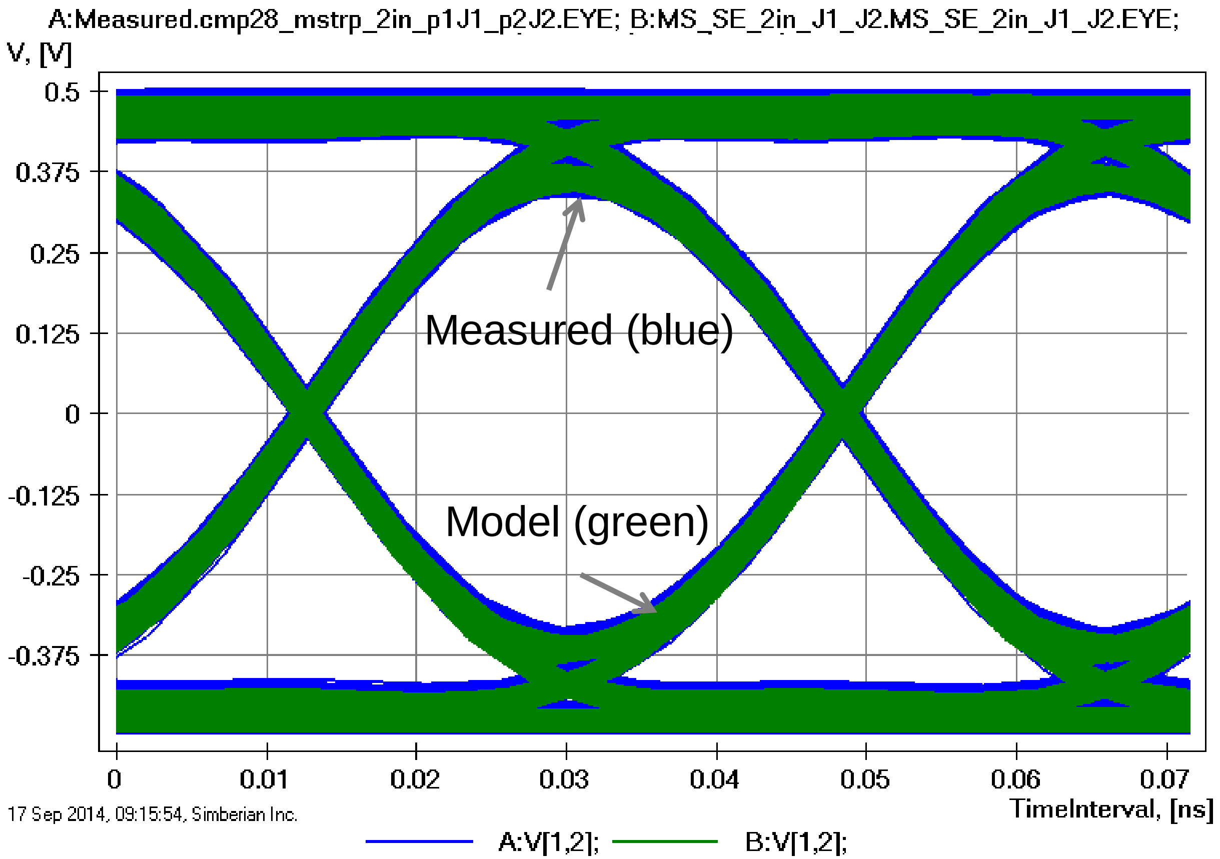
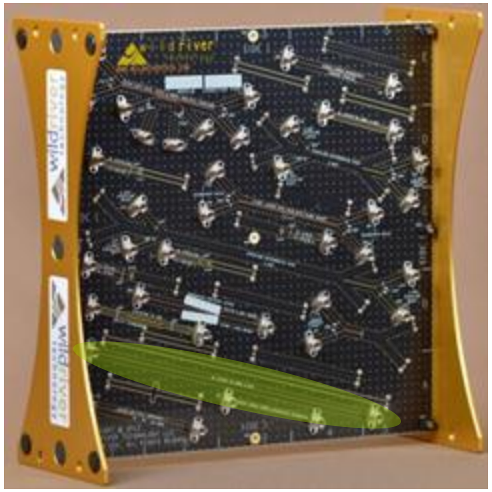
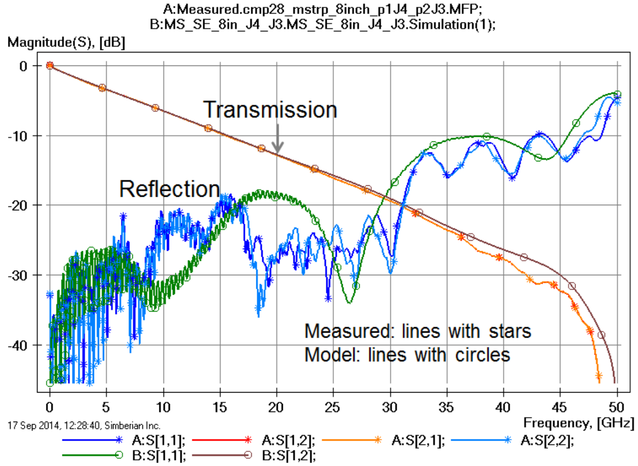
1) 2-inch microstrip line segment: 28 Gbps PRBS, 25 ps rise/fall time

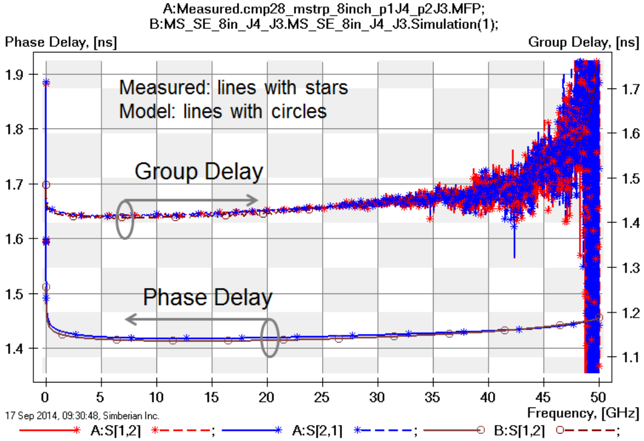


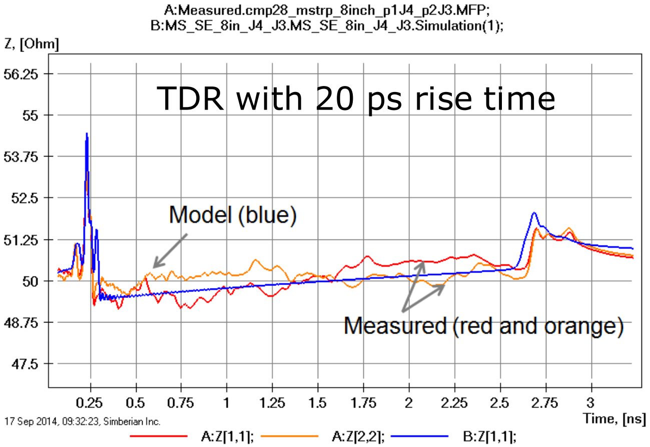
Eyes are on top of each other!

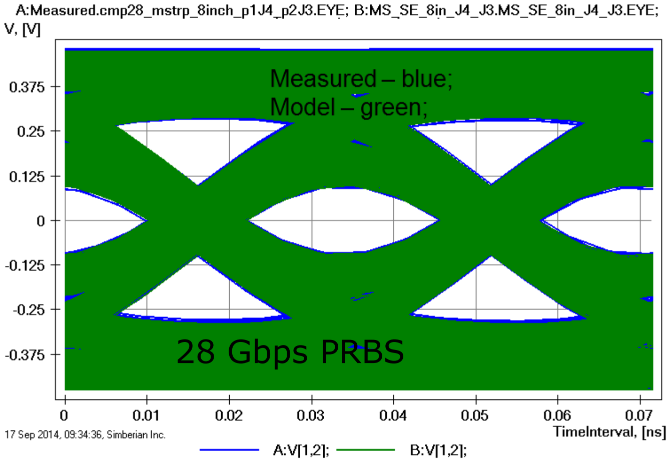
2) 8-inch microstrip line segment



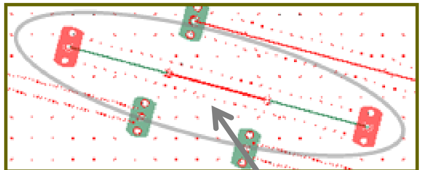


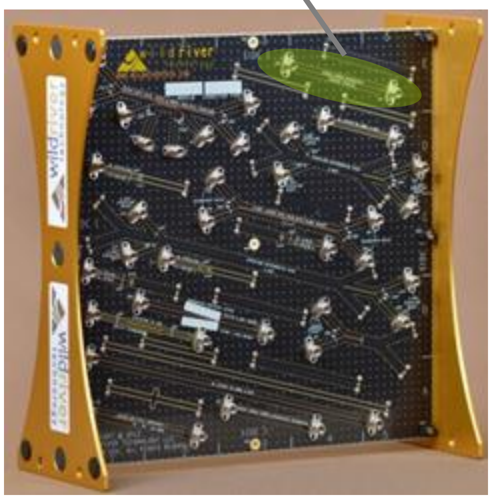




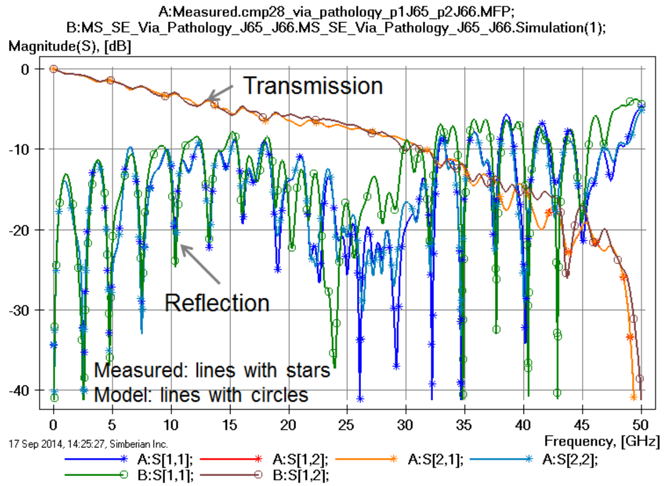


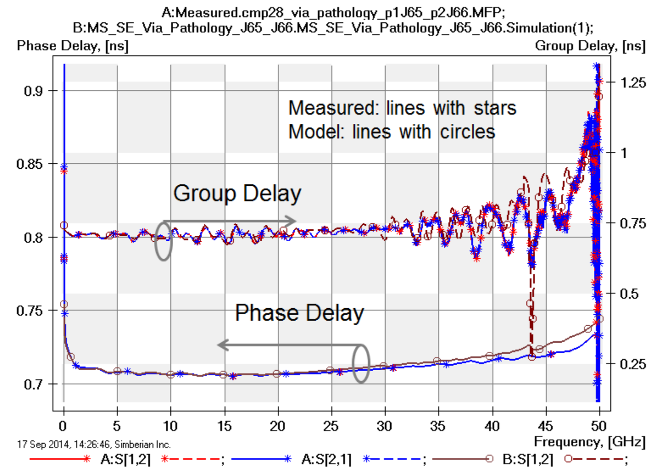
12) Microstrip line with two capacitive vias

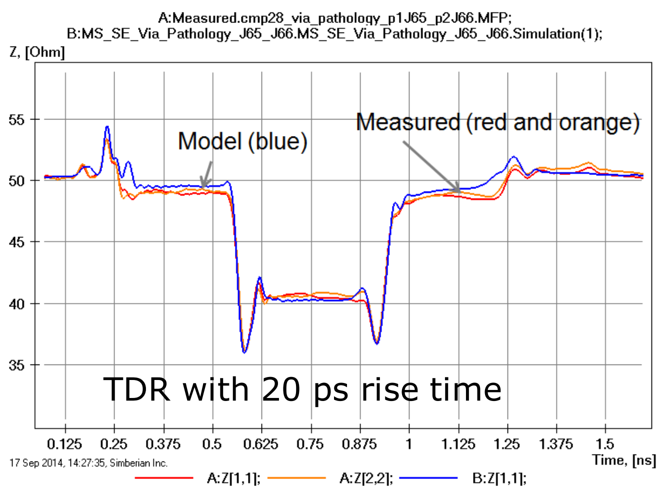


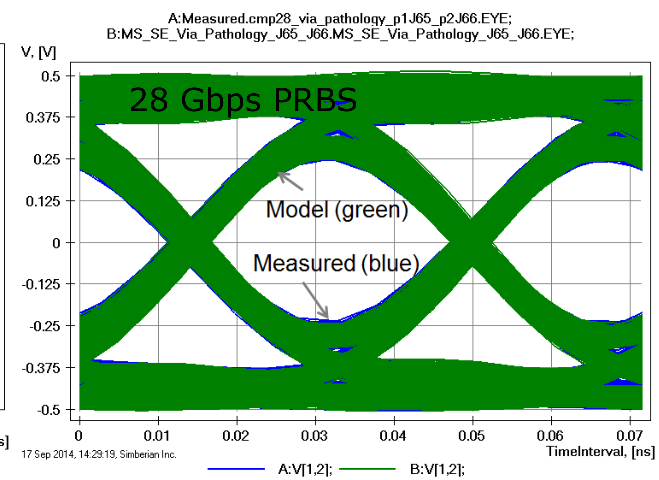


Both narrow and wider sections widths are reduced by 1mil

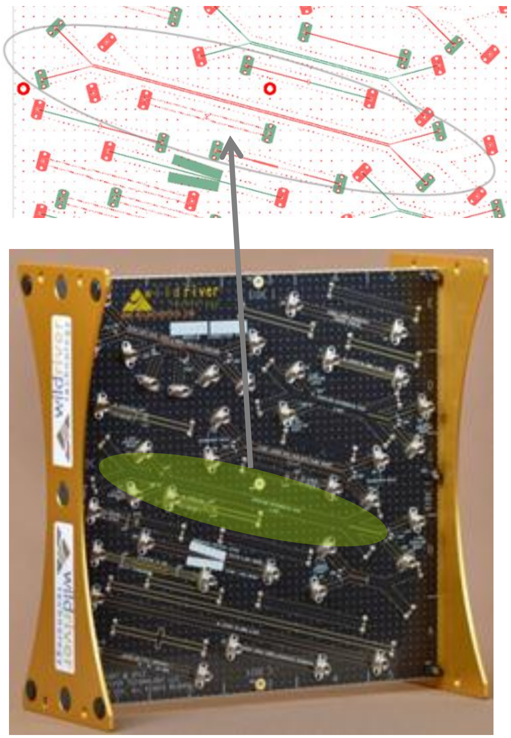


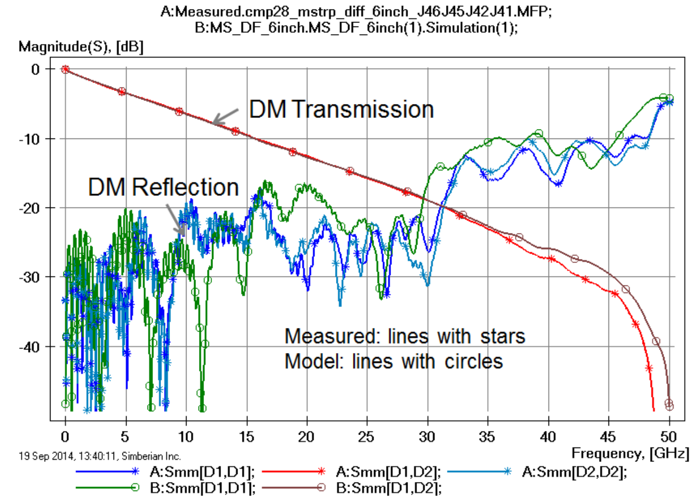


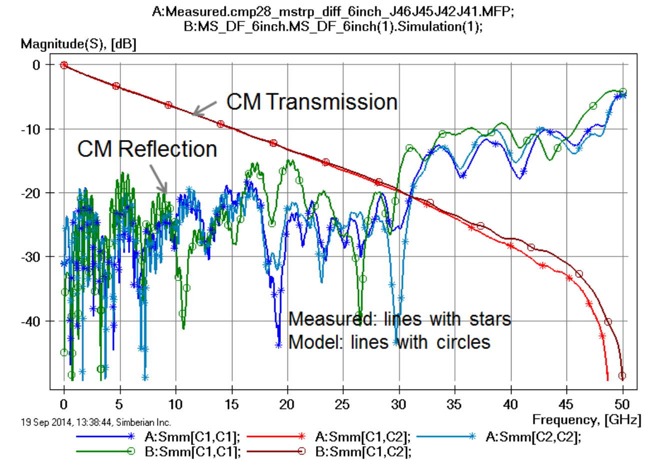


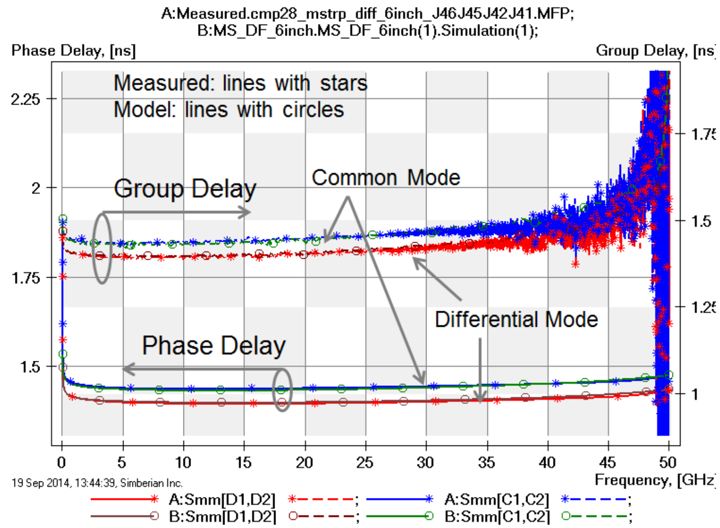


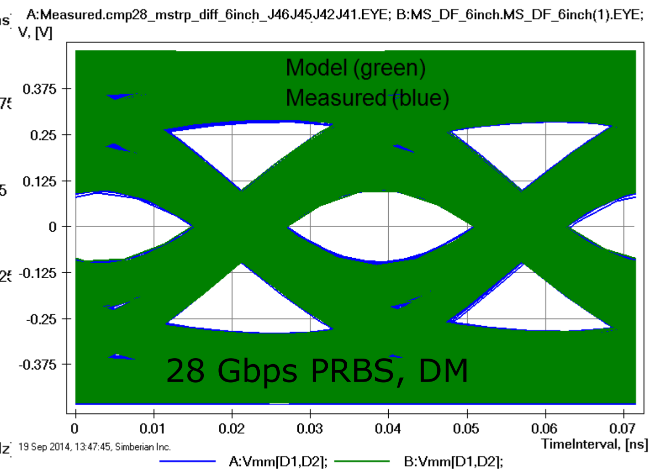
14) 6-inch microstrip differential line





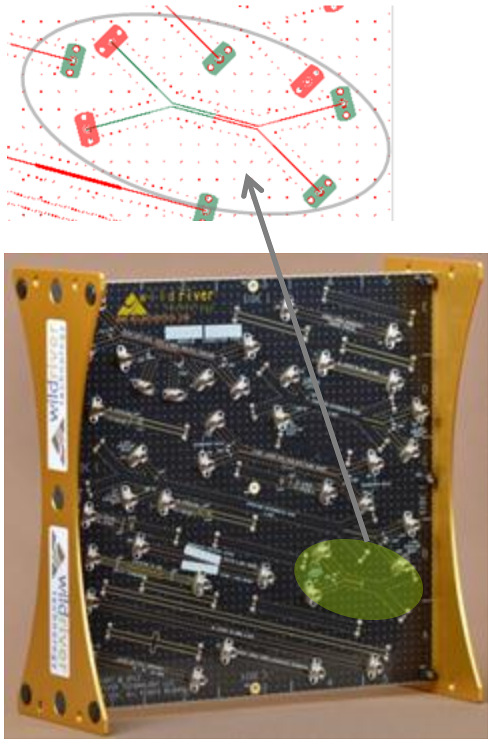


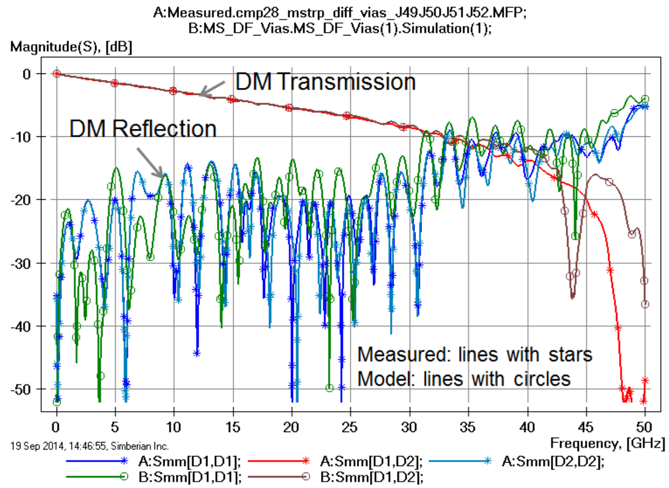


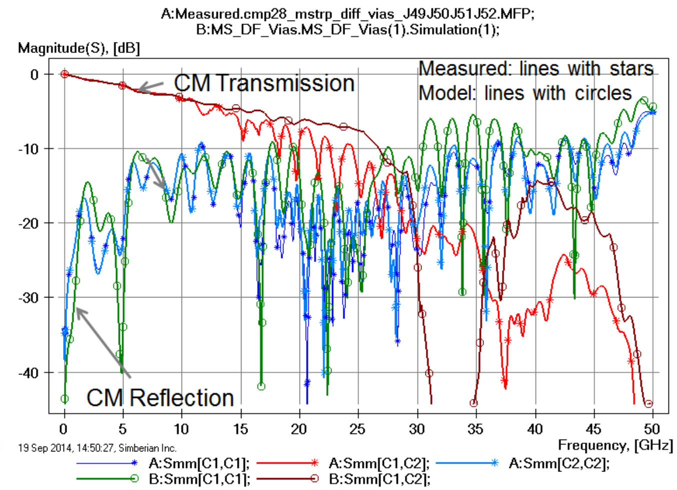


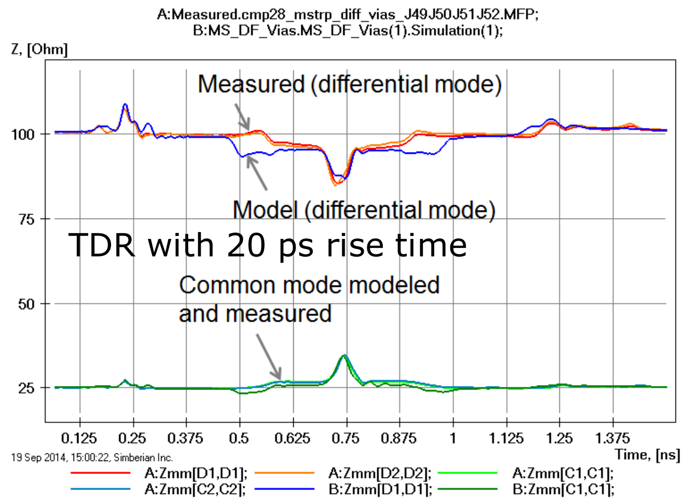
DM – Differential Mode
CM – Common Mode

16) Microstrip differential line with vias

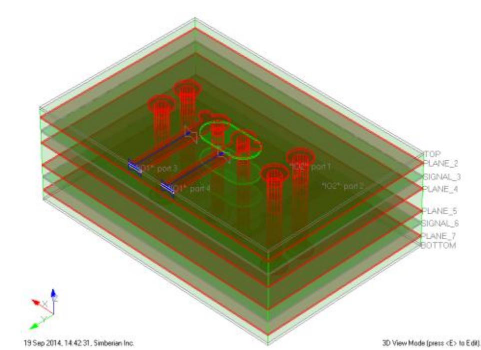








Loss of the localization for Common mode at about 15-10 GHz



DM – Differential Mode
CM – Common Mode

Discrepancies in geometry of the transitions from SE to DF

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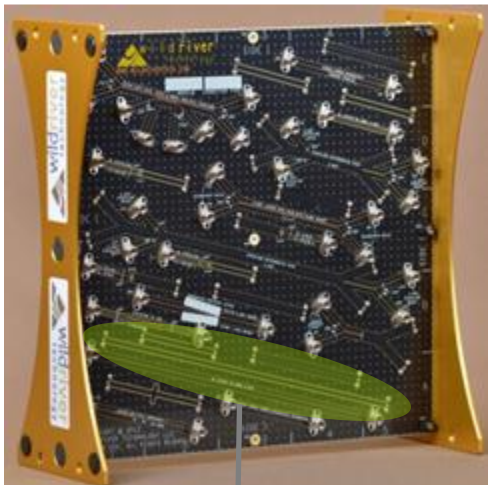
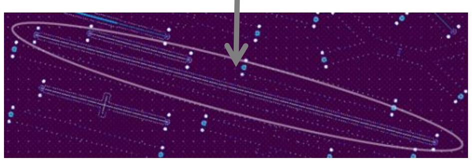
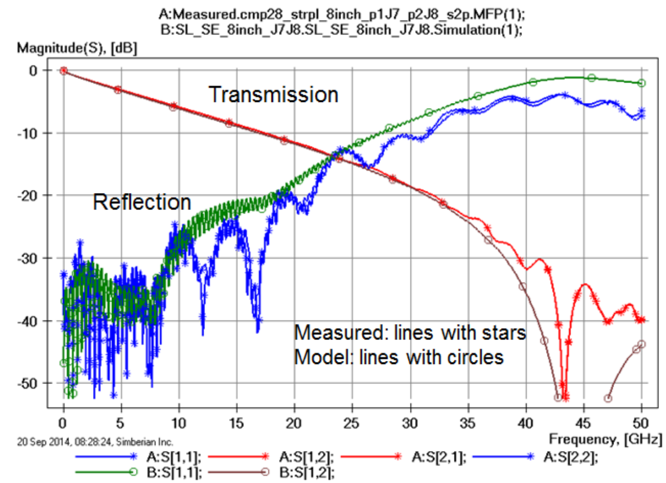
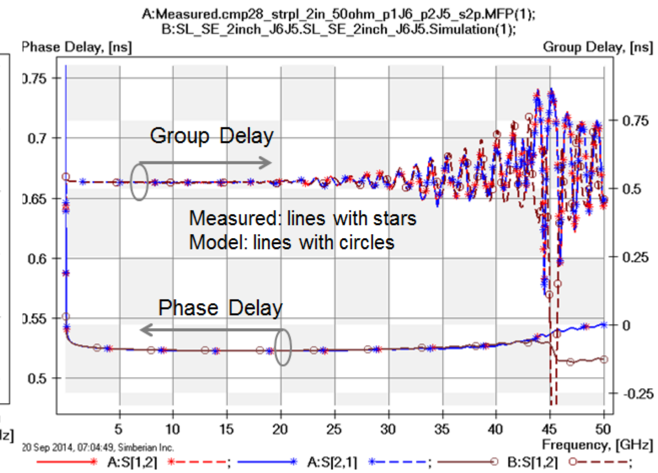
19) 8-inch single-ended strip line

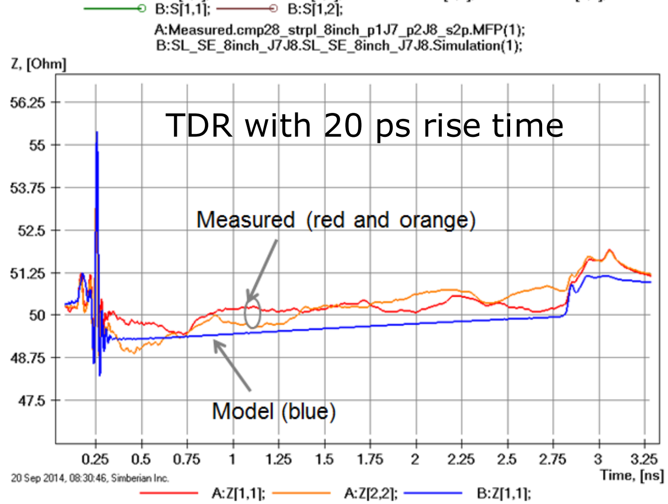


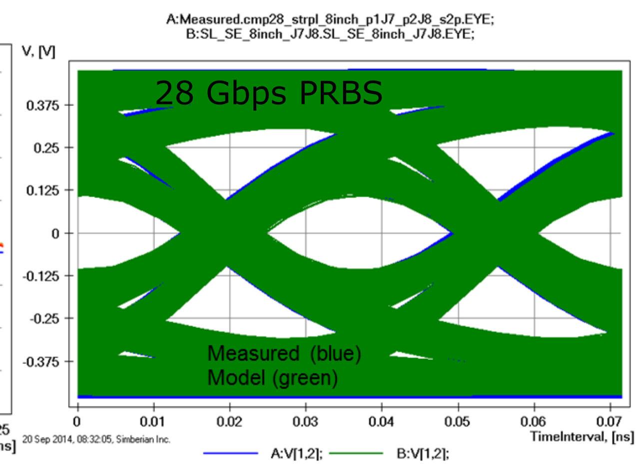


Launch model is the worst case;
Localization problem;









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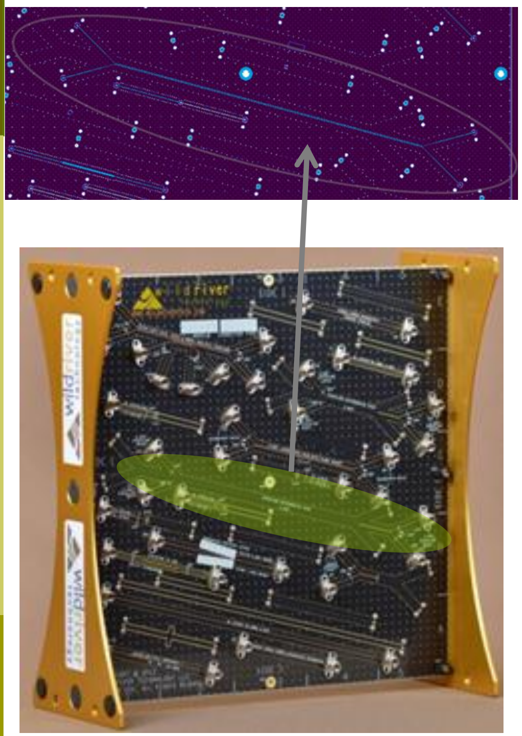
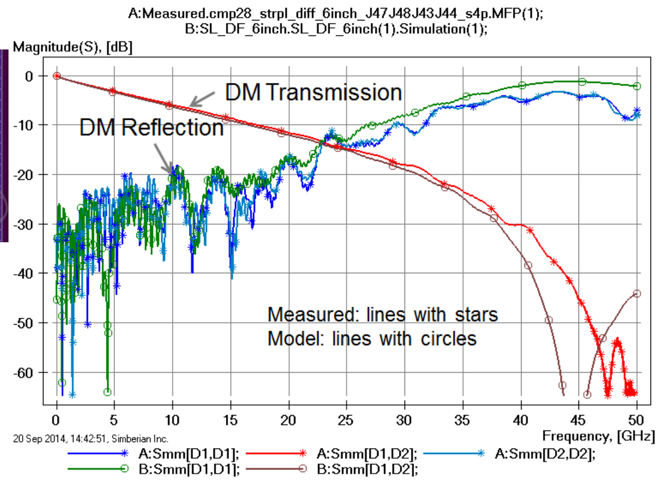
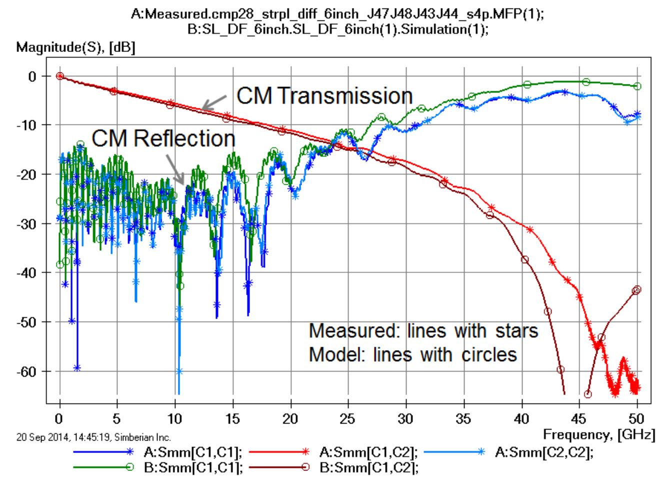
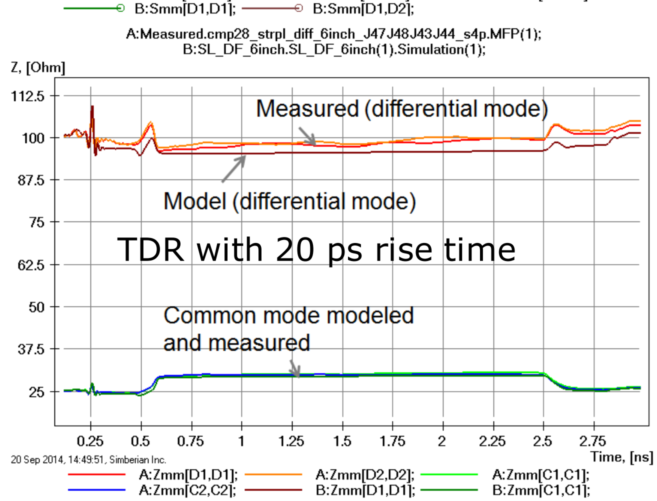
Electromagnetic Solutions

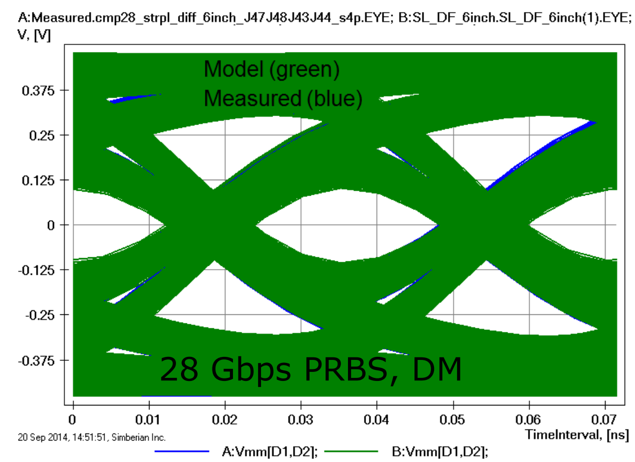
26) 6-inch strip differential line











DM – Differential Mode
CM – Common Mode

Conclusion

- Systematic process of the interconnect analysis-to-measurement validation up to 50 GHz is introduced – such process should be standardized
- Readily available validation platforms represent a critical SI tool for the manufacturing, measurement and software benchmarking
- The process is illustrated with channel modeling platform from Wild River Technology and electromagnetic signal integrity software from Simberian
- Following the process one can qualify or reveal problems in any signal integrity software and compare accuracy, productivity and cost…
- Contacts and further resources:
  - Simberian web site and contacts: *www.simberian.com*
  - Wild River Technology web site and contacts: *www.wildrivertech.com*