Design Insights from Electromagnetic Analysis of Interconnects

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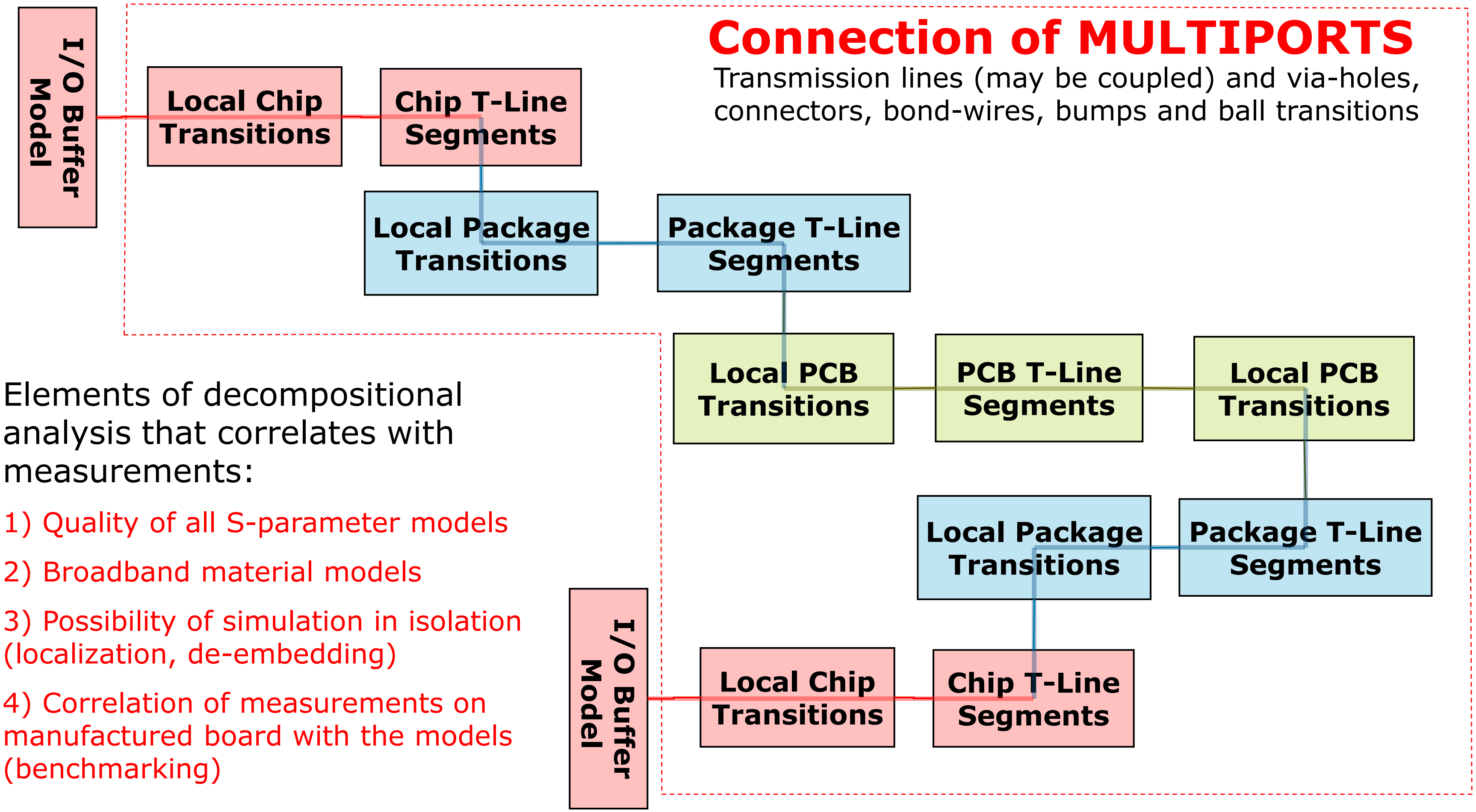
Outline

- Introduction
- Decompositional electromagnetic analysis
- Broadband material models
  - Dielectric and roughness models and model identification
  - Nickel model in ENIG plated traces
- Modeling discontinuities
  - Planar transitions - control of impedance and skew
  - Vertical transitions – localization and crosstalk
- Conclusion
- References and contacts

Introduction

- Data links running at bitrates 10-30 Gbps and beyond are becoming the mainstream in the communication and other electronic systems
- Why is design of PCB and packaging interconnects for such systems is a challenging problem?
  - It requires electromagnetic analysis over extremely broad frequency bandwidth from DC to 20-50 GHz
  - No frequency-continuous dielectric models available from laminate manufactures
  - No roughness models available from manufacturers
  - Boards are routed in old-style ways based on rules and approximate models and not on EM analysis
  - Boards are not manufactured as designed – large variations and manipulations by manufacturer
- Is it possible to design and build interconnects and have acceptable analysis to measurement correlation from DC to 20-50 GHz systematically?
  - Obviously yes, but only if some conditions are satisfied
  - The conditions are partially covered here and discussed in detail in my tutorial at DesignCon 2013 and in paper presented at EMC 2013 symposium (both available at www.simberian.com)
  - This presentation provides practical examples illustrating how to make decisions on the base of EM analysis
  - Some examples may look counter-intuitive ☺

Decompositional analysis of a channel



Elements of decompositional analysis that correlates with measurements:

1) Quality of all S-parameter models

2) Broadband material models

3) Possibility of simulation in isolation (localization, de-embedding)

4) Correlation of measurements on manufactured board with the models (benchmarking)

Quality of S-parameter models

- Multiports are usually described with S-parameter models
  - Produced by circuit or electromagnetic simulators, VNAs and TDNAs in forms of Touchstone or BB SPICE models
- Very often such models have issues and may be not suitable for consistent frequency and time domain analyses
  - Not sufficient bandwidth and sampling
  - Passivity, reciprocity and causality conditions may be violated
- How to make sure that a model is suitable for analysis?
  - The answer is one of the key elements for design success
  - To make the decision easier, Passivity, Reciprocity and Causality quality metrics has been introduced in 2010 and implemented in Simbeor software
  - See references on quality of S-parameters at the end of presentation
- All models for this presentation are created with Simbeor software
  - Adaptively sampled, reciprocal, passive and causal
  - With bandwidth 50 GHz for 30 Gbps, 16 ps rise time

Broadband material models

- The largest part of interconnects are transmission line segments
- Models for transmission lines are usually constructed with a quasi-static or electromagnetic field solvers
  - T-lines with homogeneous dielectrics (strip lines) can be effectively analysed with quasi-static field solvers
  - T-lines with inhomogeneous dielectric may require analysis with a full-wave solver to account for the high-frequency dispersion
- Accuracy of transmission line models is mostly defined by **availability of broadband dielectric and conductor roughness models**
- This is the most important elements for design success

Causal dielectric models for PCB and PKG

- Multi-pole Debye-Lorentz (real and complex poles)

$$\varepsilon(f) = \varepsilon(\infty) + \sum_{n=1}^{N} \frac{\Delta\varepsilon_n}{1 + i\frac{f}{fr_n}} + \sum_{k=1}^{K} \frac{\Delta\varepsilon_k \cdot fr_k^2}{fr_k^2 + 2i \cdot f \cdot \frac{\delta_k}{2\pi} - f^2}$$

Requires specification of value at infinity and poles/residues/damping or DK and LT at multiple frequency points

- Wideband Debye (Djordjevic-Sarkar)

$$\varepsilon(f) = \varepsilon_r(\infty) + \frac{\varepsilon_{rd}}{(m_2 - m_1)\cdot \ln(10)} \cdot \ln\left[\frac{10^{m2} + if}{10^{m1} + if}\right]$$

Continuous-spectrum model
Requires specification of DK and LT at one frequency point

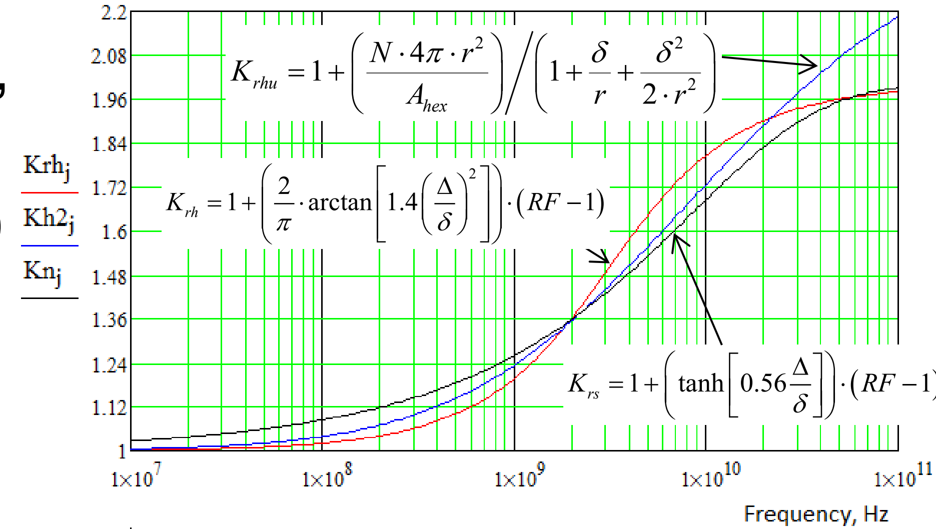
- Models for dielectric mixtures (Wiener, Maxwell-Garnet, …)
- Models for anisotropic dielectrics (separate definition of Z, and XY-plane components of permittivity tensor)

Parameters of the causal models are not available from manufacturers!

Causal roughness models

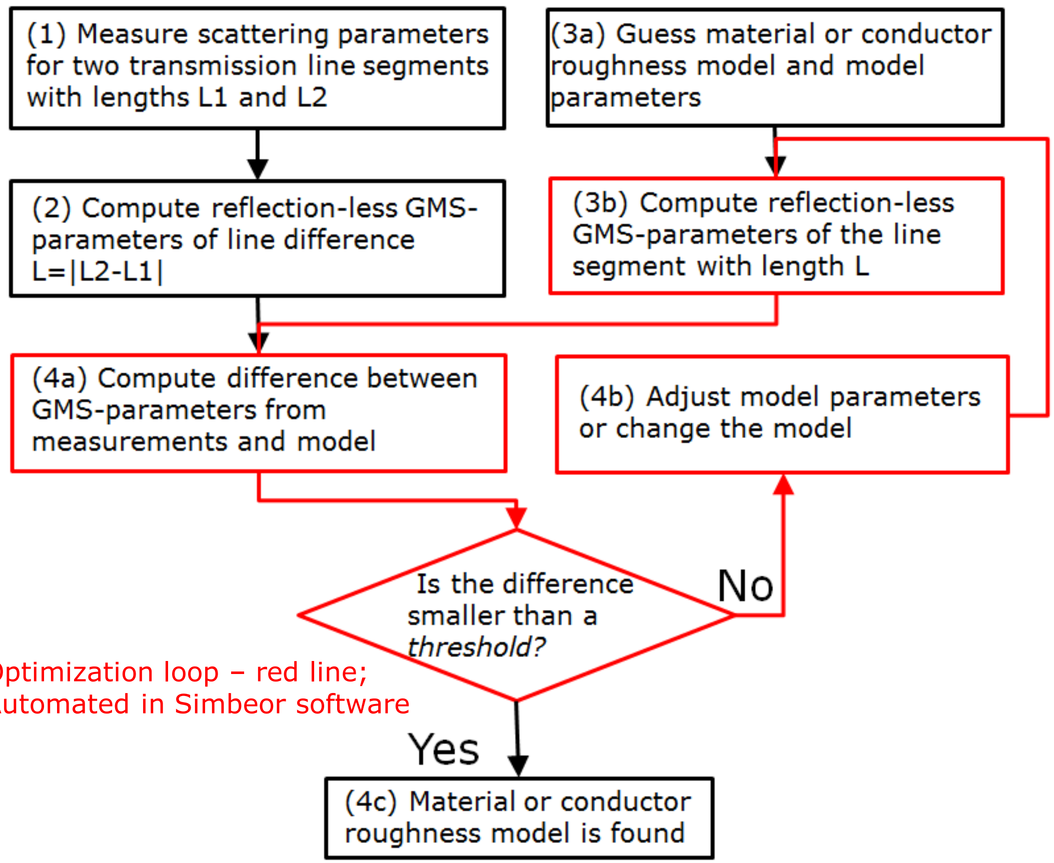
- Modified Hammerstad (red), Simbeor (black) and Huray's snowball (blue) models (RTF/TWS foil example)

See references in the papers (Shlepnev, EMC2012 and DC2012)

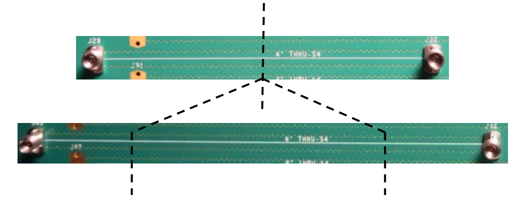


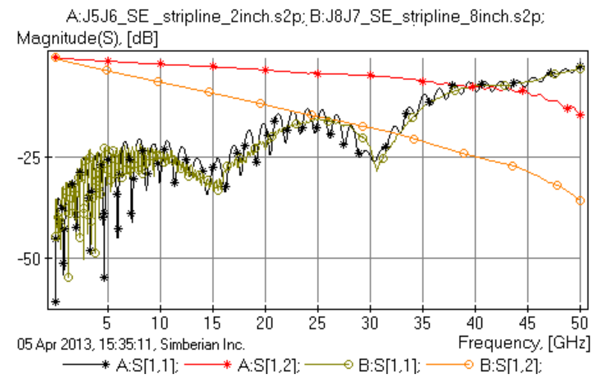
- Causal if correction is applied to conductor surface impedance operator
- Where to get the model parameters?
  - SR (delta) and RF for Simbeor and MHCC
  - Number of balls, ball size and tile area for Huray's model

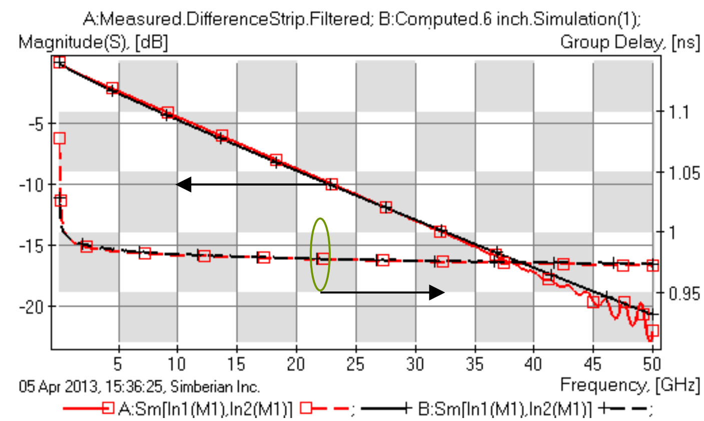
Material parameters identification with generalized modal S-parameters (GMS-parameters)



Optimization loop – red line;
Automated in Simbeor software



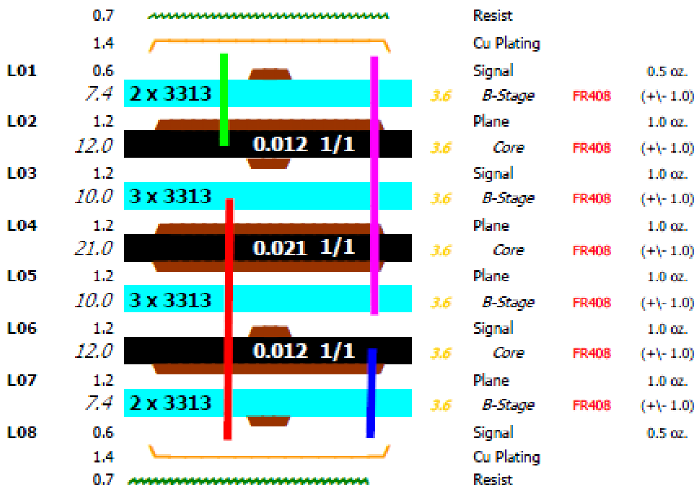




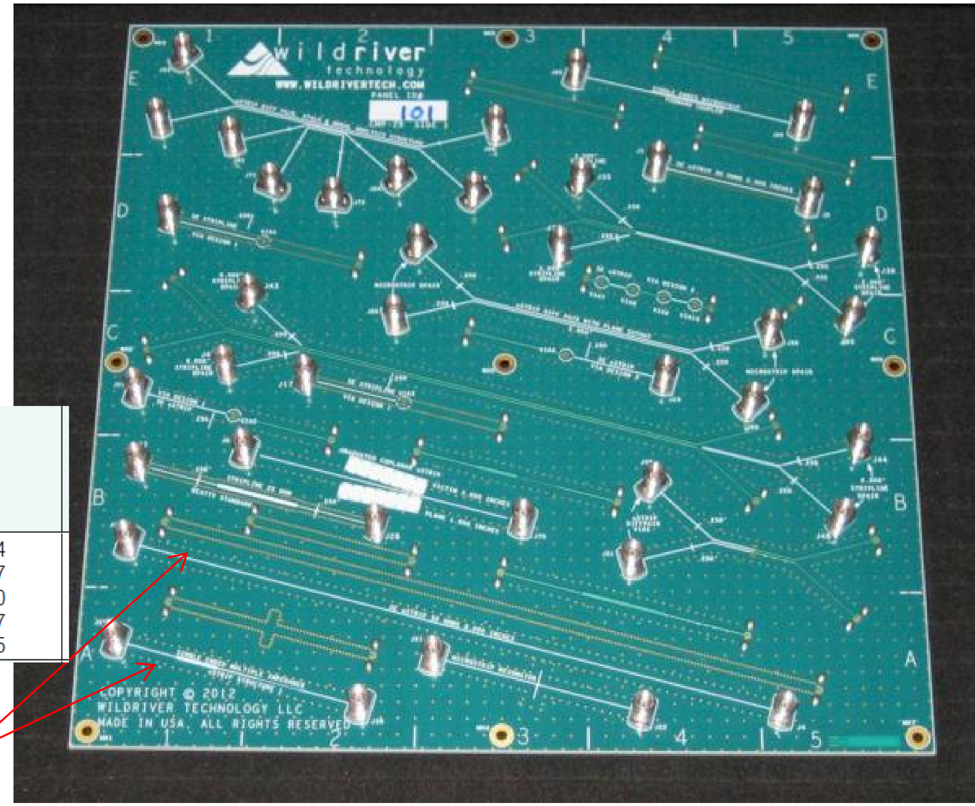
Can be used to identify both dielectric and conductor roughness models

Simberian's patents pending **#13/009,541** and **#14/045,392**

Board for material models identification example



CMP-28 validation board designed and investigated by Wild River Technology http://wildrivertech.com/

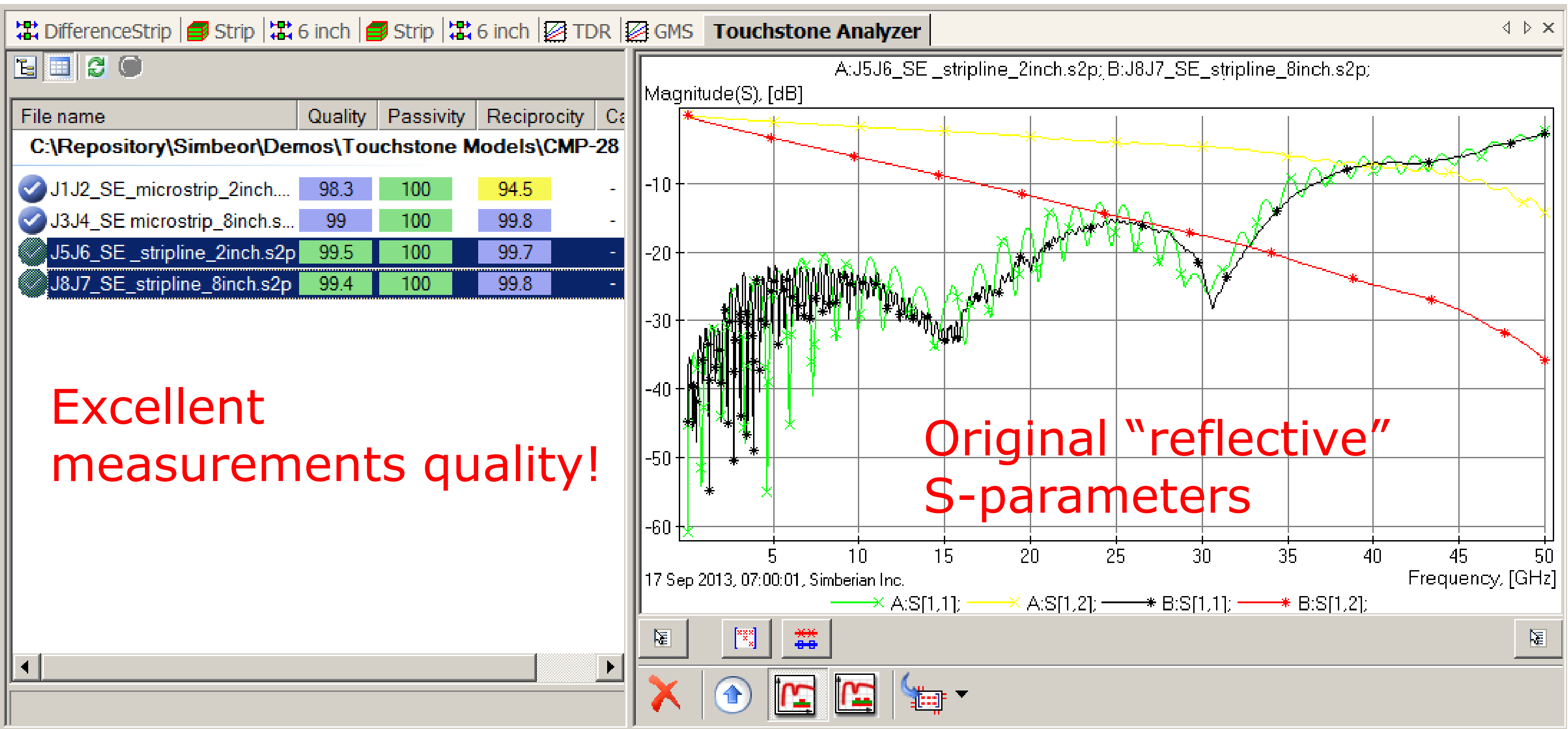


From Isola FR408 specifications

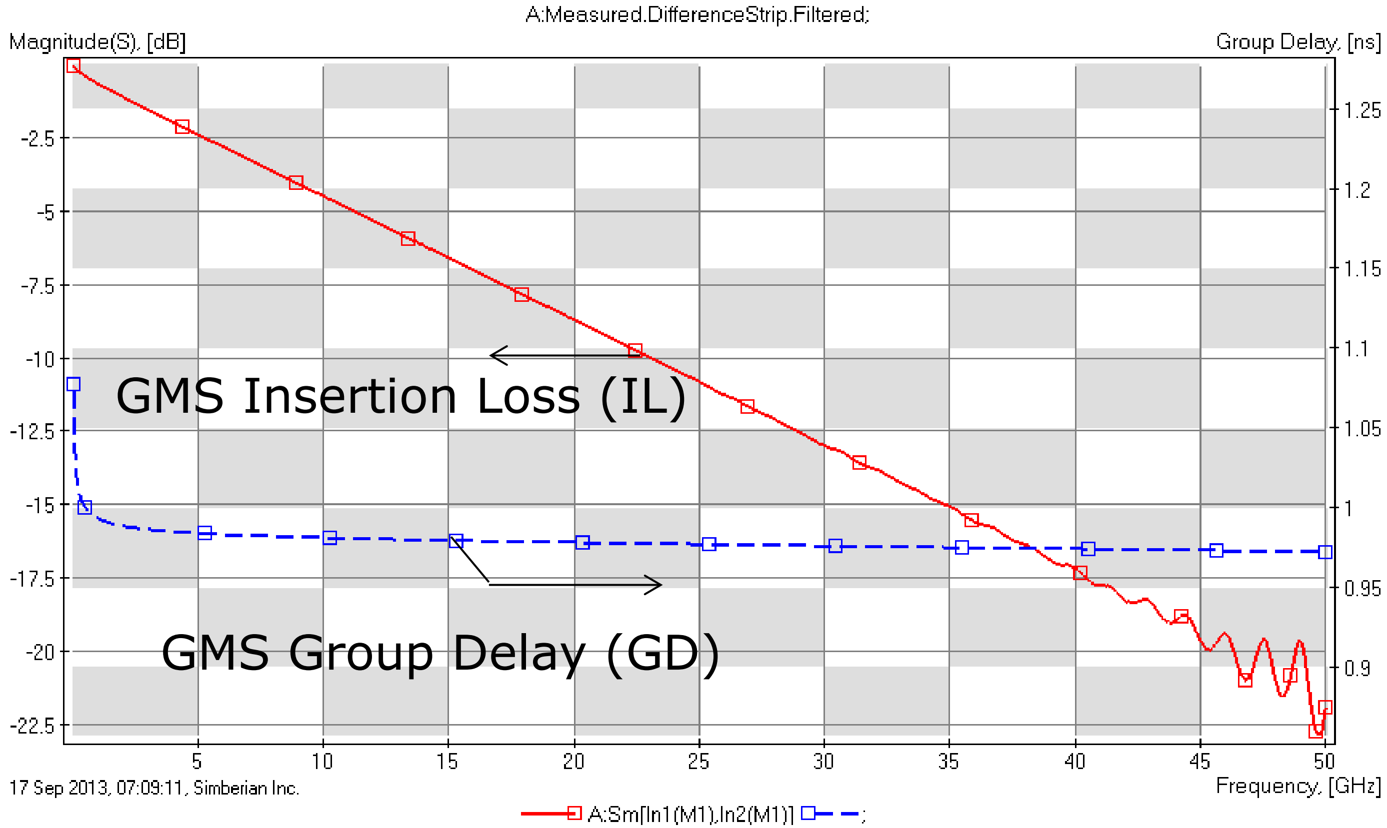
Dk, Permittivity (Laminate & prepreg as laminated) Tested at 56% resin	A. @ 100 MHz (HP4285A) B. @ 1 GHz (HP4291A) C. @ 2 GHz (Bereskin Stripline) D. @ 5 GHz (Bereskin Stripline) E. @ 10 GHz (Bereskin Stripline)	3.69 3.66 3.67 3.66 3.65
Df, Loss Tangent (Laminate & prepreg as laminated) Tested at 56% resin	A. @ 100 MHz (HP4285A) B. @ 1 GHz (HP4291A) C. @ 2 GHz (Bereskin Stripline) D. @ 5 GHz (Bereskin Stripline) E. @ 10 GHz (Bereskin Stripline)	0.0094 0.0117 0.0120 0.0127 0.0125

10.5-11 mil wide strip lines,
Use measured S-parameters for 2 segments (2 inch and 8 inch)

Measured S-parameters for 2 and 8 inch segments



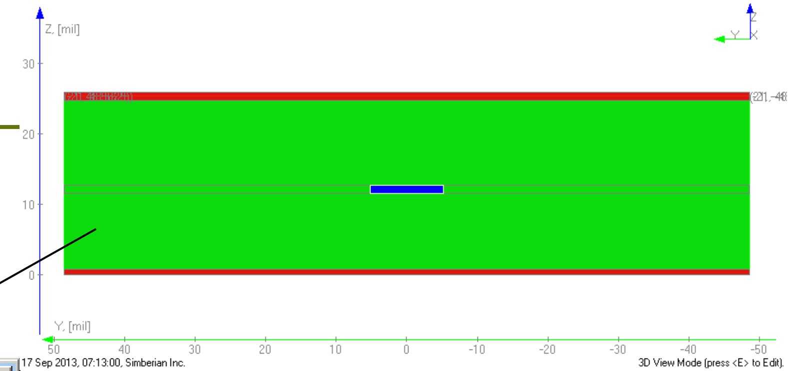
GMS-parameters computed from the original S-parameters

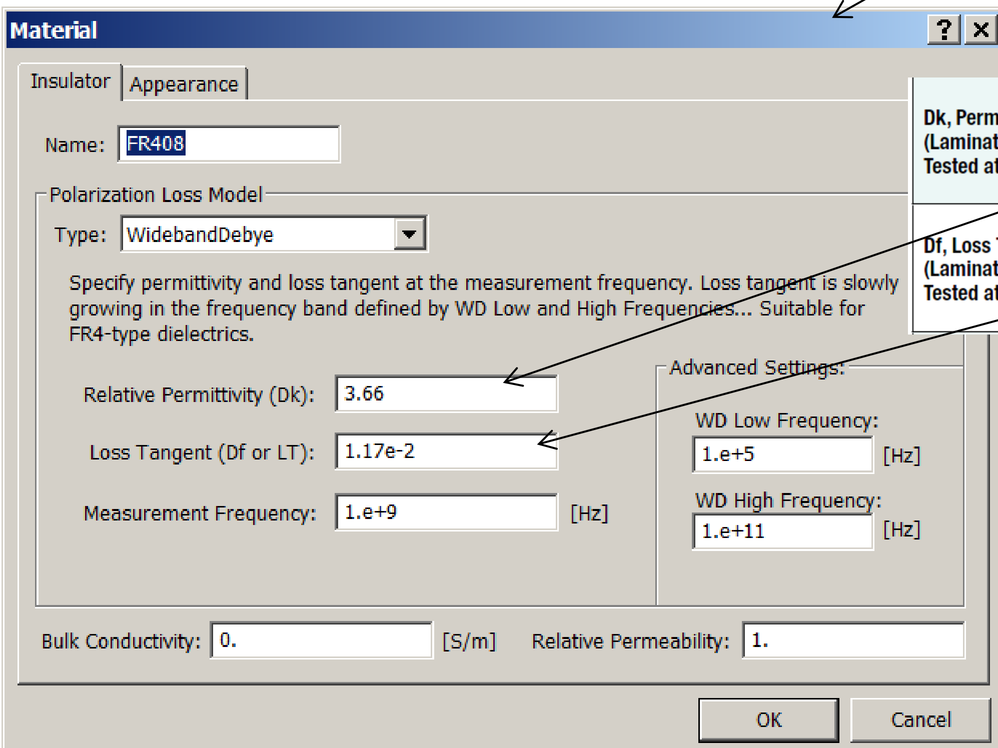


Reflection in generalized modal S-parameters is exactly zero – makes material model identification much easier!

Material models for strip line analysis - definition

First, try to use material parameters from specs





Dk, Permittivity (Laminate & prepreg as laminated) Tested at 56% resin	A. @ 100 MHz (HP4285A)	3.69
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	D. @ 5 GHz (Bereskin Stripline)	0.0127
	E. @ 10 GHz (Bereskin Stripline)	0.0125

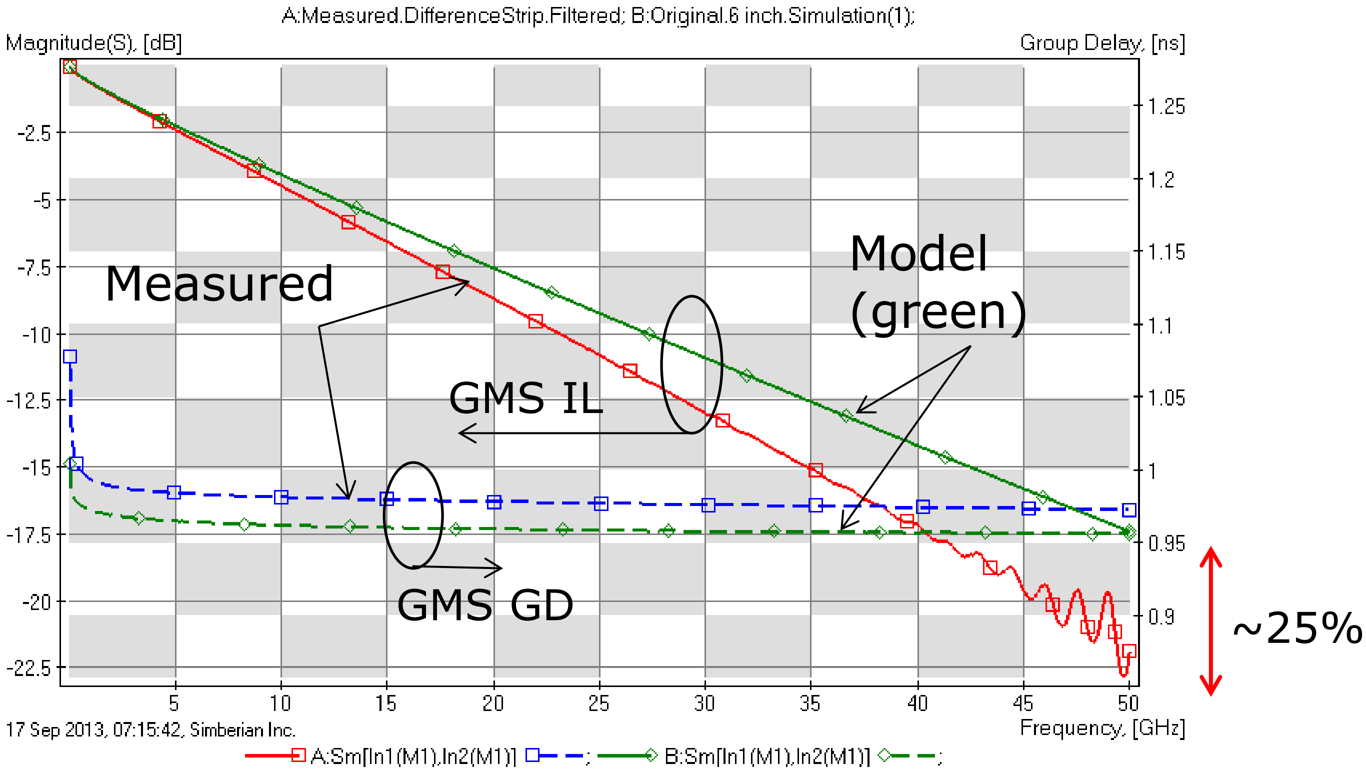
Wideband Debye model can be described with just one Dk and LT

$$\varepsilon(f) = \varepsilon_r(\infty) + \frac{\varepsilon_{rd}}{(m_2 - m_1)\cdot \ln(10)} \cdot \ln\left[\frac{10^{m2} + if}{10^{m1} + if}\right]$$

Conductor is copper, no roughness in specs

Results with the original material models

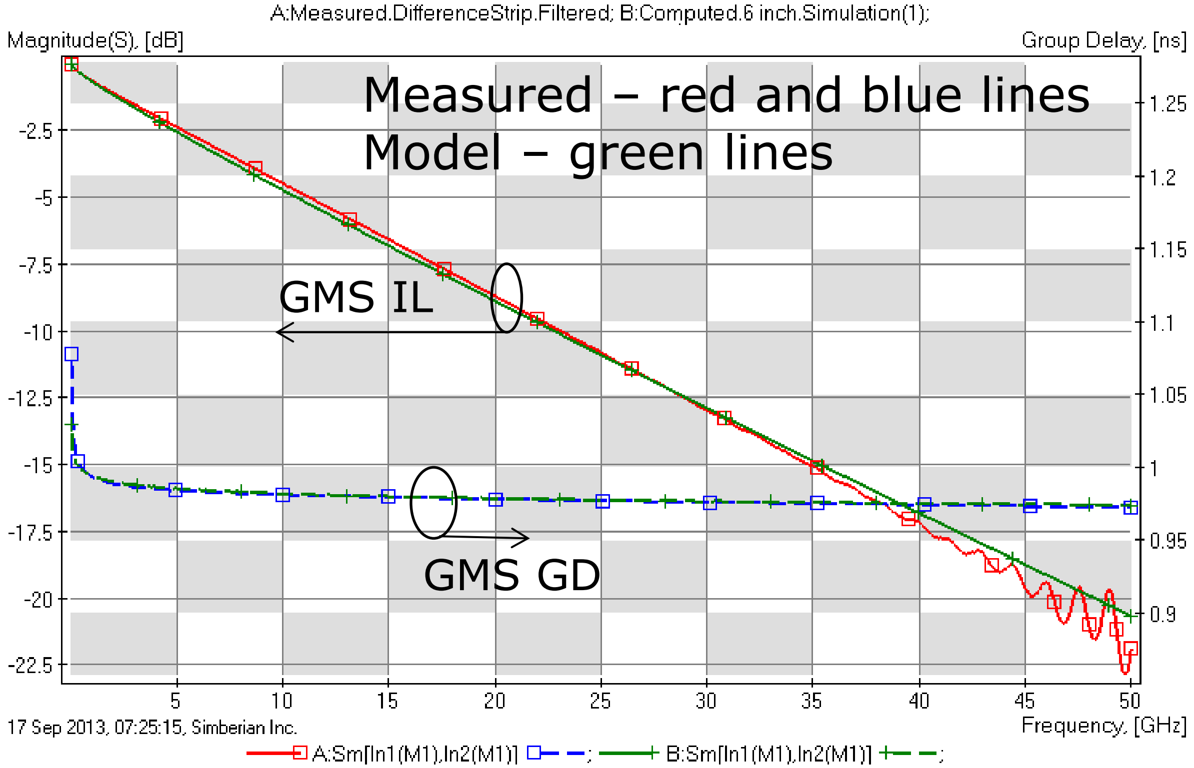
The original model produces considerably lower insertion losses (GMS IL) above 5 GHz and smaller group delay (GMS GD) at all frequencies:



Two options: 1) Increase Dk and LT in the dielectric model;
2) Increase Dk in dielectric model and model conductor roughness

Option 1: Increase Dk and LT in dielectric model (no conductor roughness)

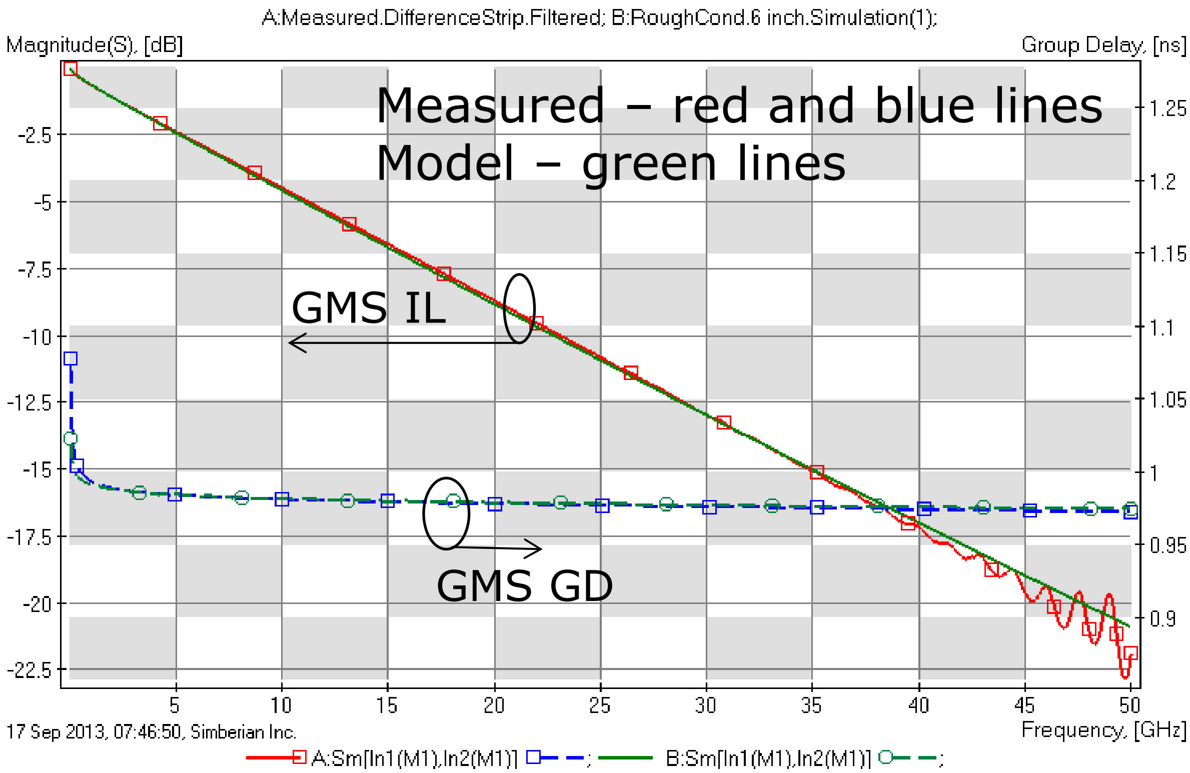
Good match with: Dk=3.83 (4.6% increase), LT=0.0138 (18% increase), Wideband Debye model



Good match, but what if conductors are actually rough?

Option 2: Increase Dk and model conductor roughness (proper modeling)

Dielectric: Dk=3.8 (3.8% increase), LT=0.0117 (no change), Wideband Debye model
Conductor: Modified Hammerstadt model with SR=0.32 um, RF=3.3

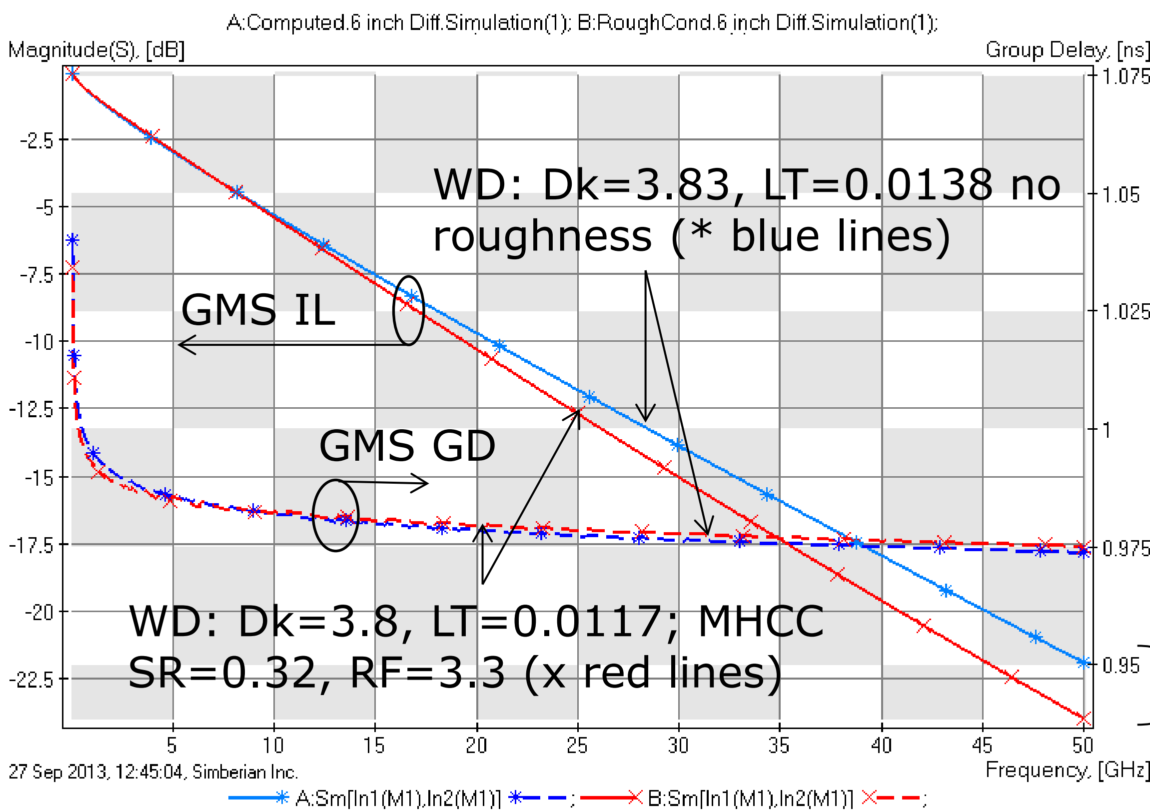


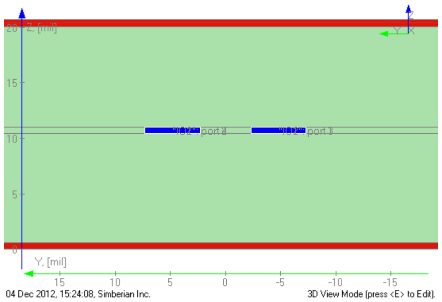
Excellent match and proper dispersion and loss separation!
This model is expected to work for strips with different widths

Can we use models for another cross-section?

- Differential 6 mil strips, 7.5 mil distance

GD is close, but the loss is different:





Which one is better?

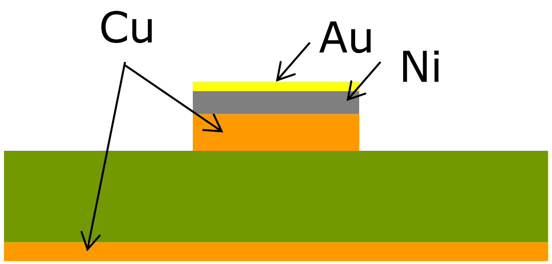
About 10% difference for medium-loss dielectric

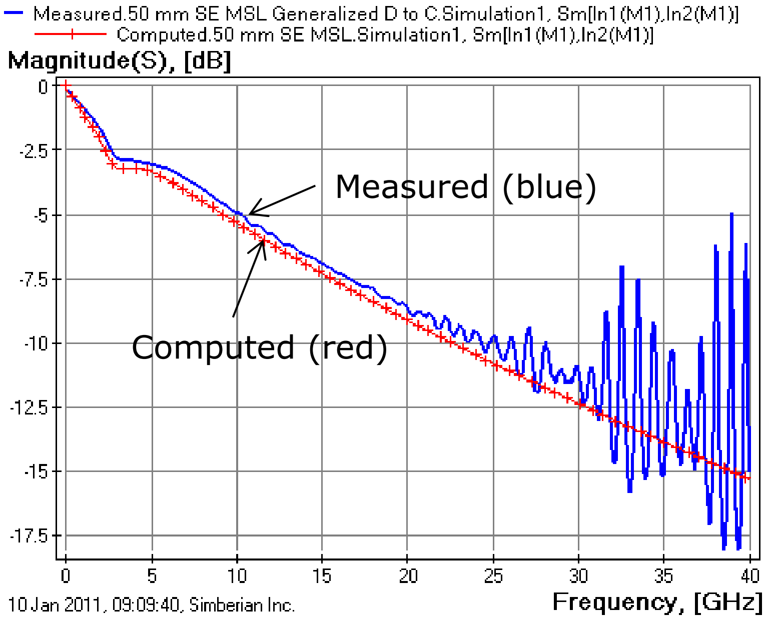
Simberian Electromagnetic Solutions

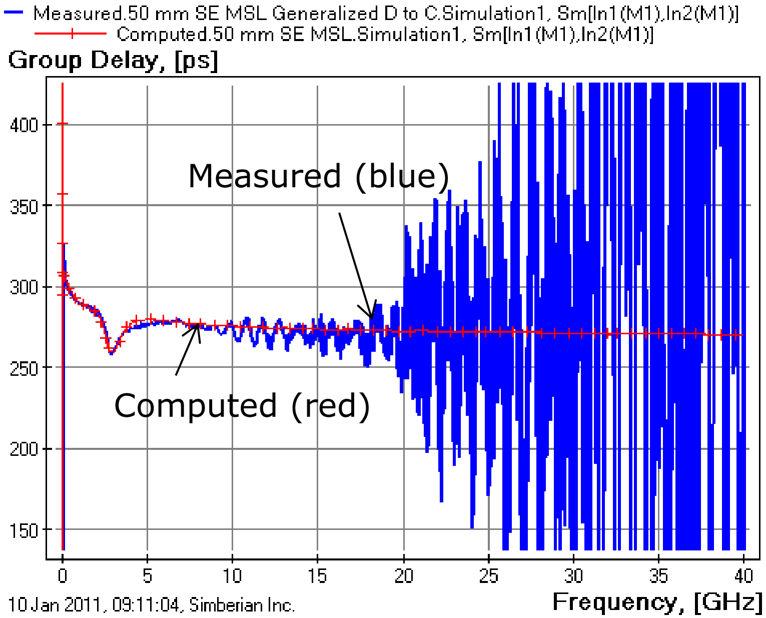
Plated nickel model identification

- Adjust Ni model parameters to match measured and computed GMS-parameters for 50 mm segment of microstrip line, strip width 69 um, thickness 12 um

ENIG finish with about 0.05 um of Au and about 6 um of Ni over the copper
Substrate dielectric DK=3.x and LT=0.01x at 1 GHz, wideband Debye model
Landau-Lifshits model for Nickel: Mul=5.7, Muh=1.4, f0=2.5, dc/f0=0.22, relative resistivity 3.75

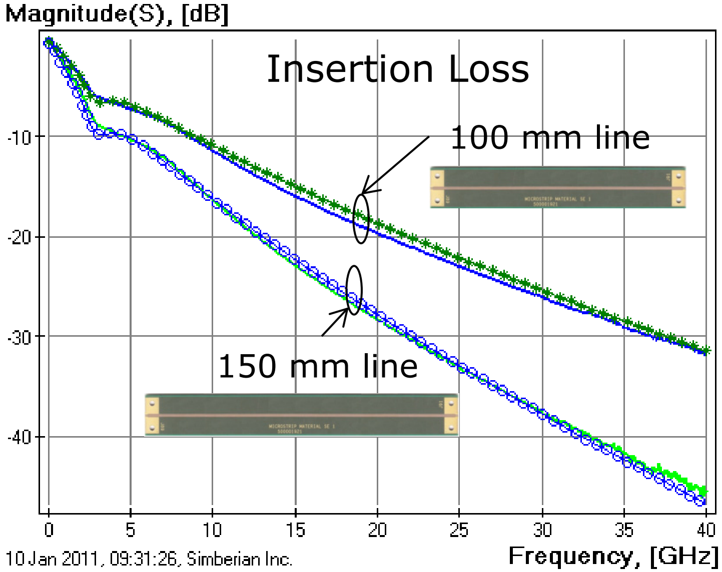


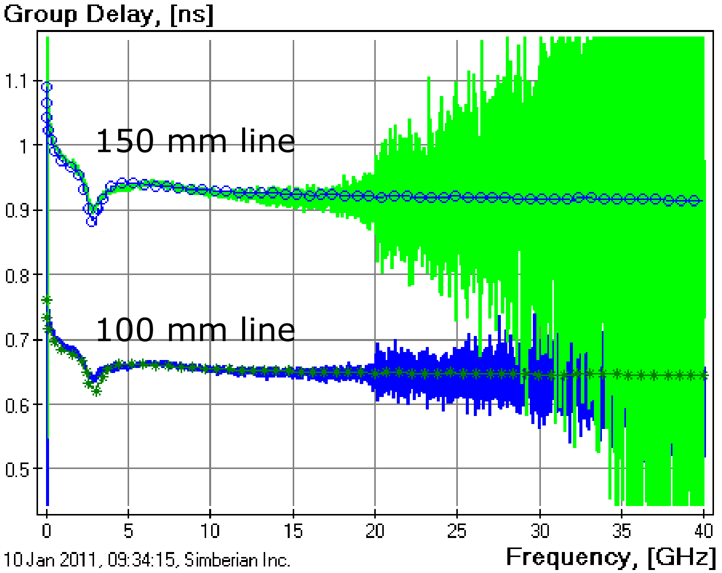




S-parameters of test structures

- Nickel: resistivity 6.46e-8 Ohm*meter, Landau-Lifshits Permeability Model: Mul=5.7, Muh=1.4, f0=2.5, dc/f0=0.22

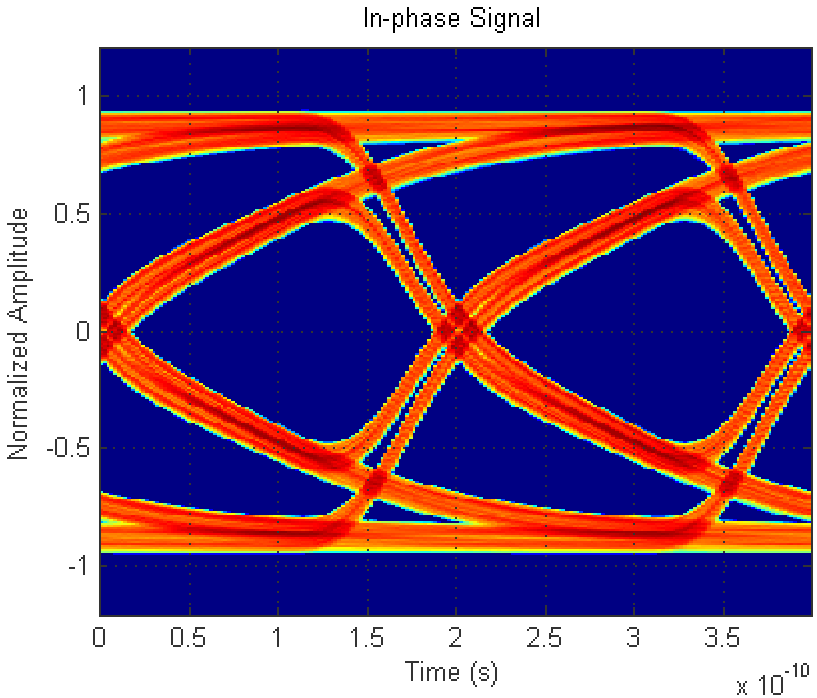




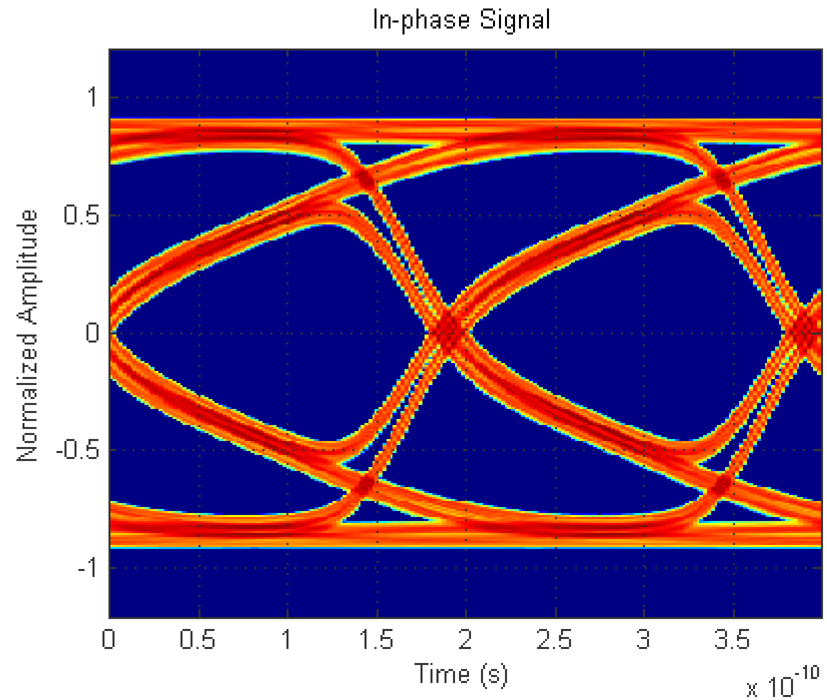
Measured – solid lines
Modeled – stars and circles

5 Gbps signal in structure with 150 mm line

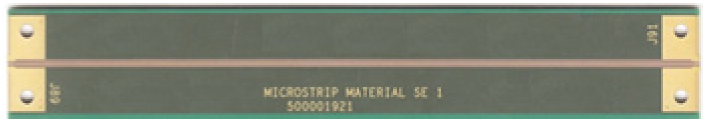
Measured



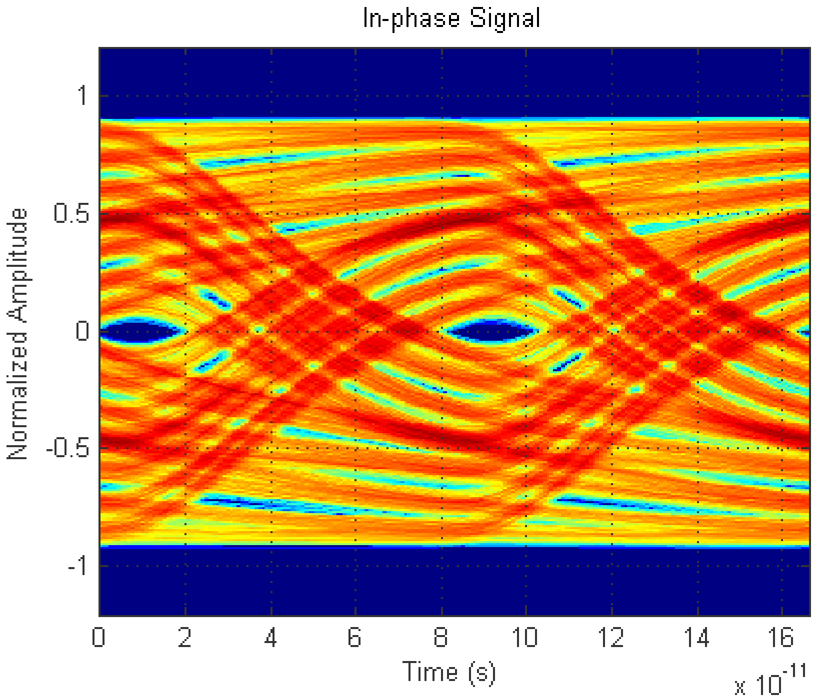
Modeled



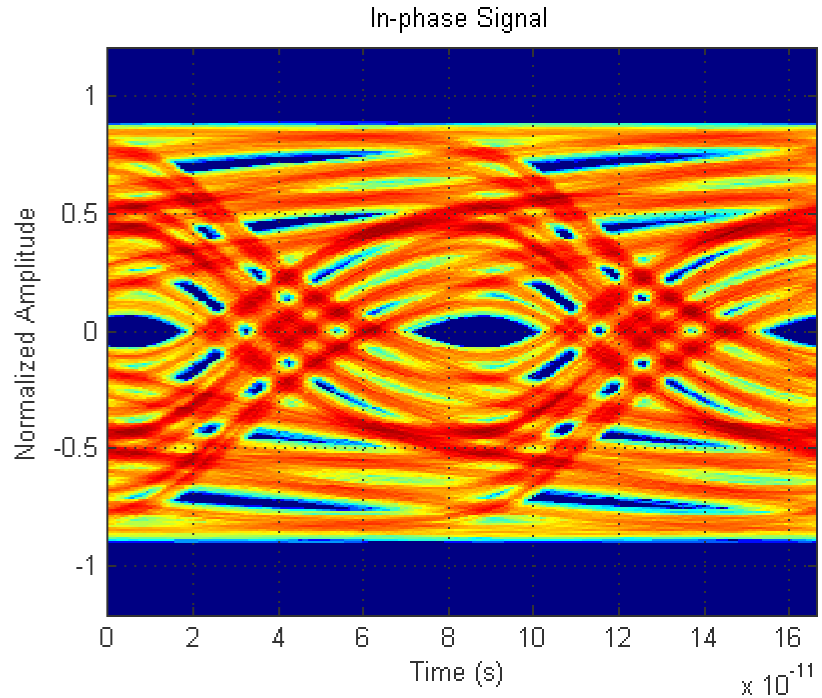
12 Gbps signal in structure with 150 mm line



Measured



Modeled



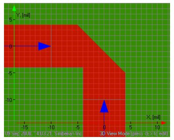
See more in Y. Shlepnev, S. McMorrow, Nickel characterization for interconnect analysis. - Proc. of the 2011 IEEE International Symposium on Electromagnetic Compatibility, Long Beach, CA, USA, August, 2011, p. 524-529. (also available at www.simberian.com)

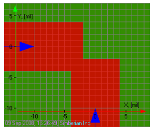
Summary on material models

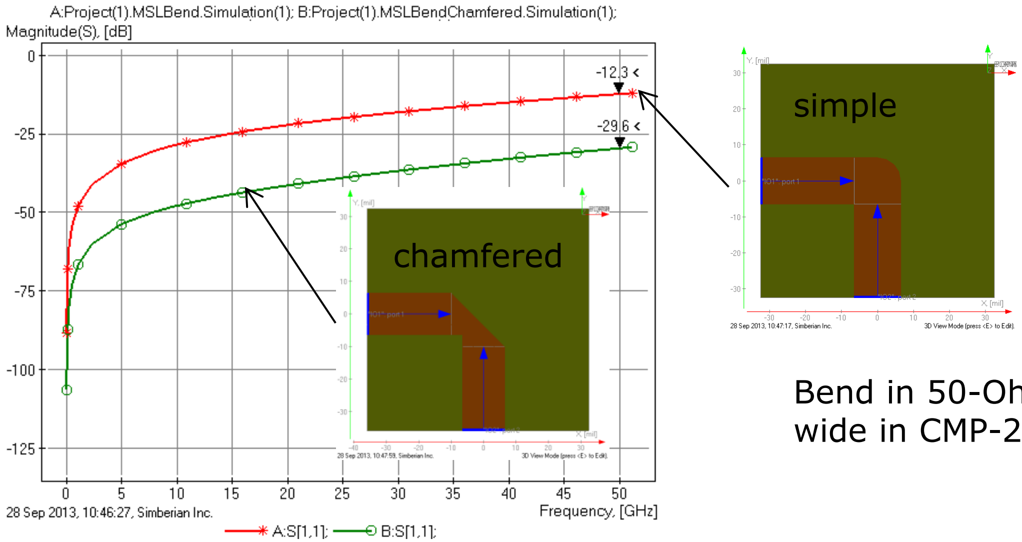
- Provided example illustrates typical situation and importance of the dielectric and conductor models identification
- Proper separation of loss and dispersion effects between dielectric and conductor models is very important, but not easy task
  - Without proper roughness model, dielectric models is dependent on strip width
  - If strip width is changed, difference in insertion loss predicted by different models may have up to 20-30% for low-loss dielectrics
  - See examples for Panasonic Megtron 6 and Nelco 4000 EP at “Which one is better?...” presentation and “Elements of decompositional analysis…” tutorial from DesignCon 2013 (available at www.simberian.com)
- In addition, PCB materials are composed of glass fibber and resin and have layered structure
  - Anisotropy: difference between the vertical and horizontal components of the effective dielectric constant
  - Weave effect: resonances and skew
  - All that properties can be modelled in Simbeor software

Planar transitions: Bends

- Design goal is to minimize the reflection loss |Sii|
- Have additional capacitance and inductance, uncertainty in trace length
- It is difficult to make them as bad as some other discontinuities
- Potentially multiple bends may cause problems
- Remove of excessive metallization helps to reduce the risks
- See more in App Note #2008_05 at http://www.simberian.com/AppNotes.php



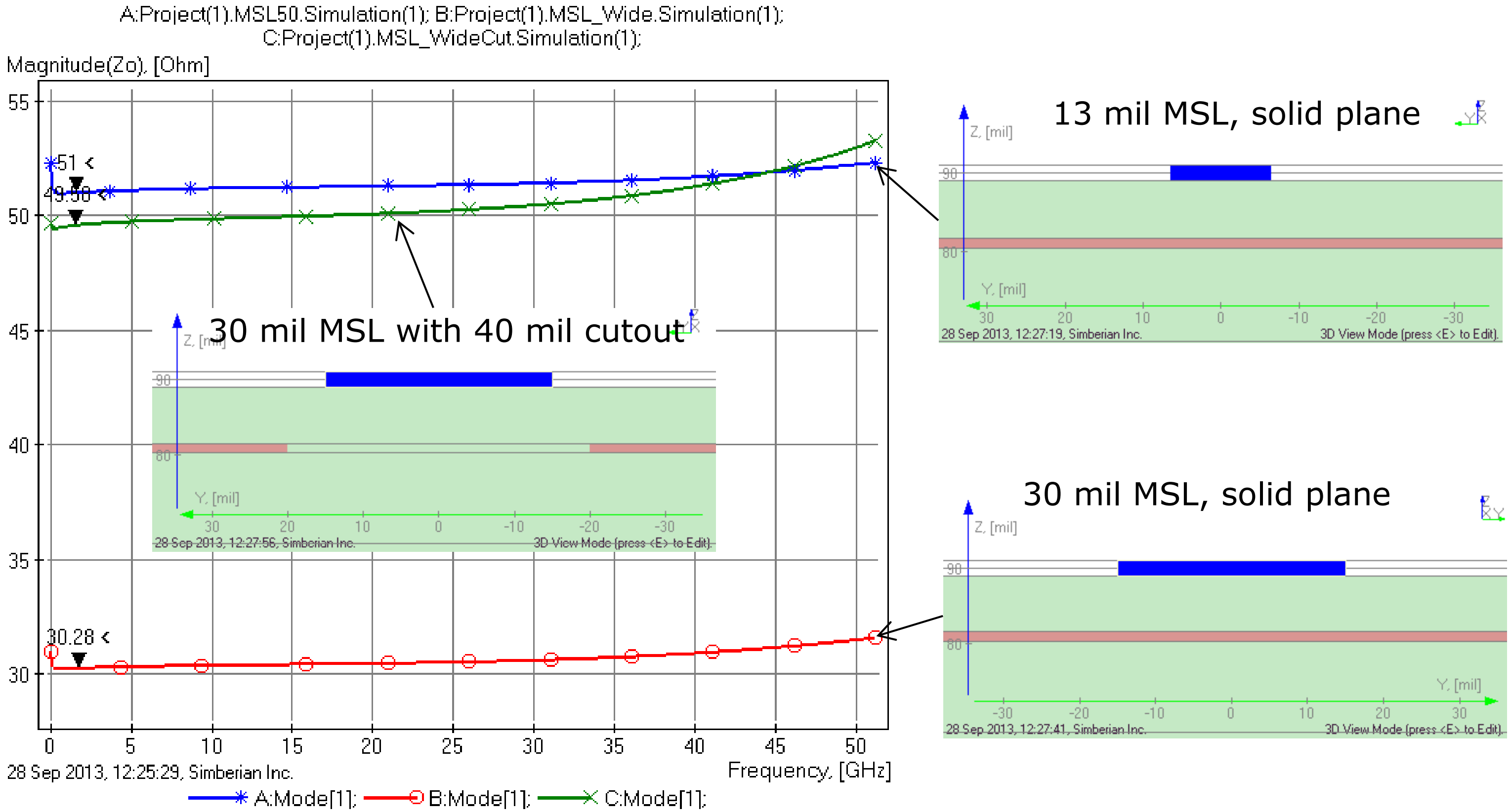




Bend in 50-Ohm MSL (13 mil wide in CMP-28 stackup)

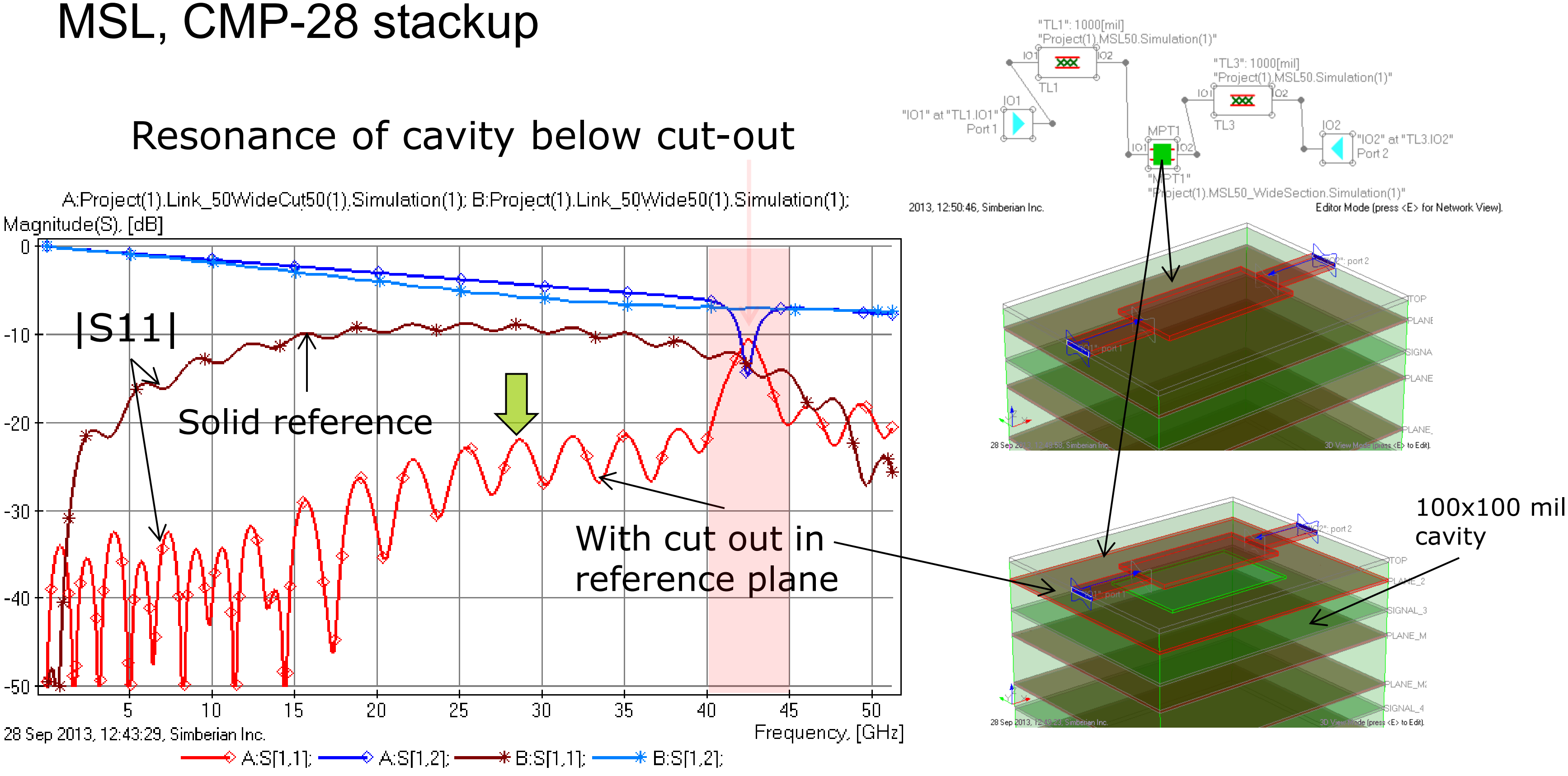
Planar transitions to wider strips or pads

- Optimize to have target characteristic impedance at wider section
- Example of transition from 13 mil (~50 Ohm) to 30 mil wide microstrip
  - Create 30 mil wide 50 Ohm transmission line:



Transition to wide strip 3D analysis

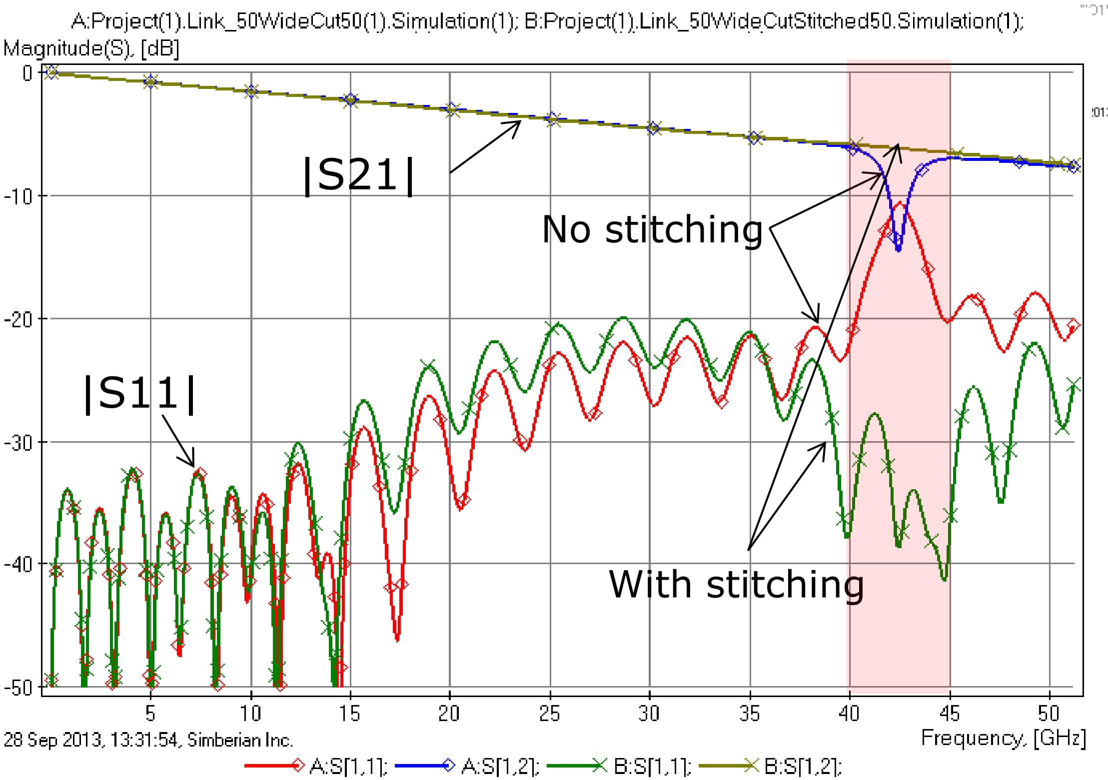
- Transition from 13 mil MSL to 60 mil long section of 30 mil wide MSL, CMP-28 stackup

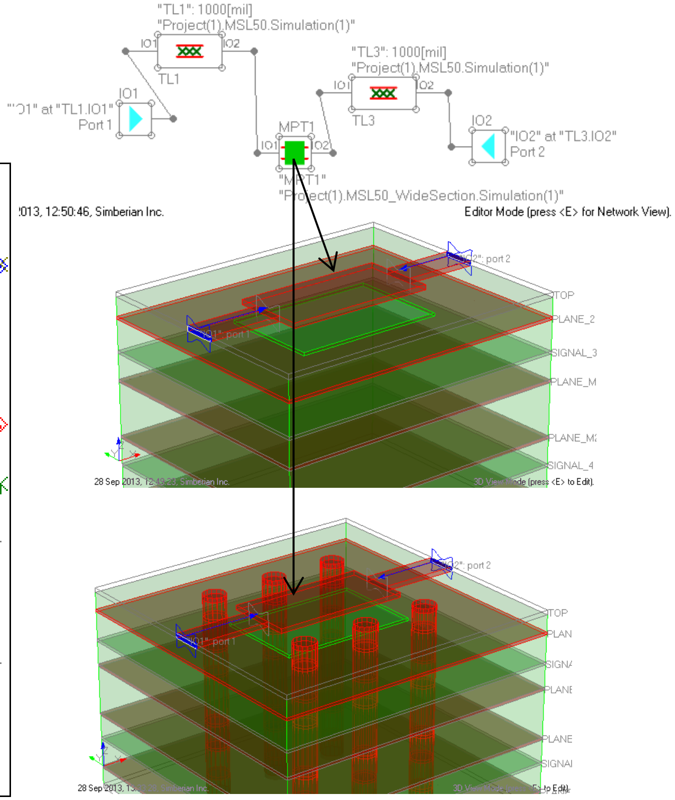


Cut-out reduced the reflection as expected, but may create another problem – possible coupling to the cavity below (SI and EMI); How to deal with that?

Localizing the cavity below the cut-out

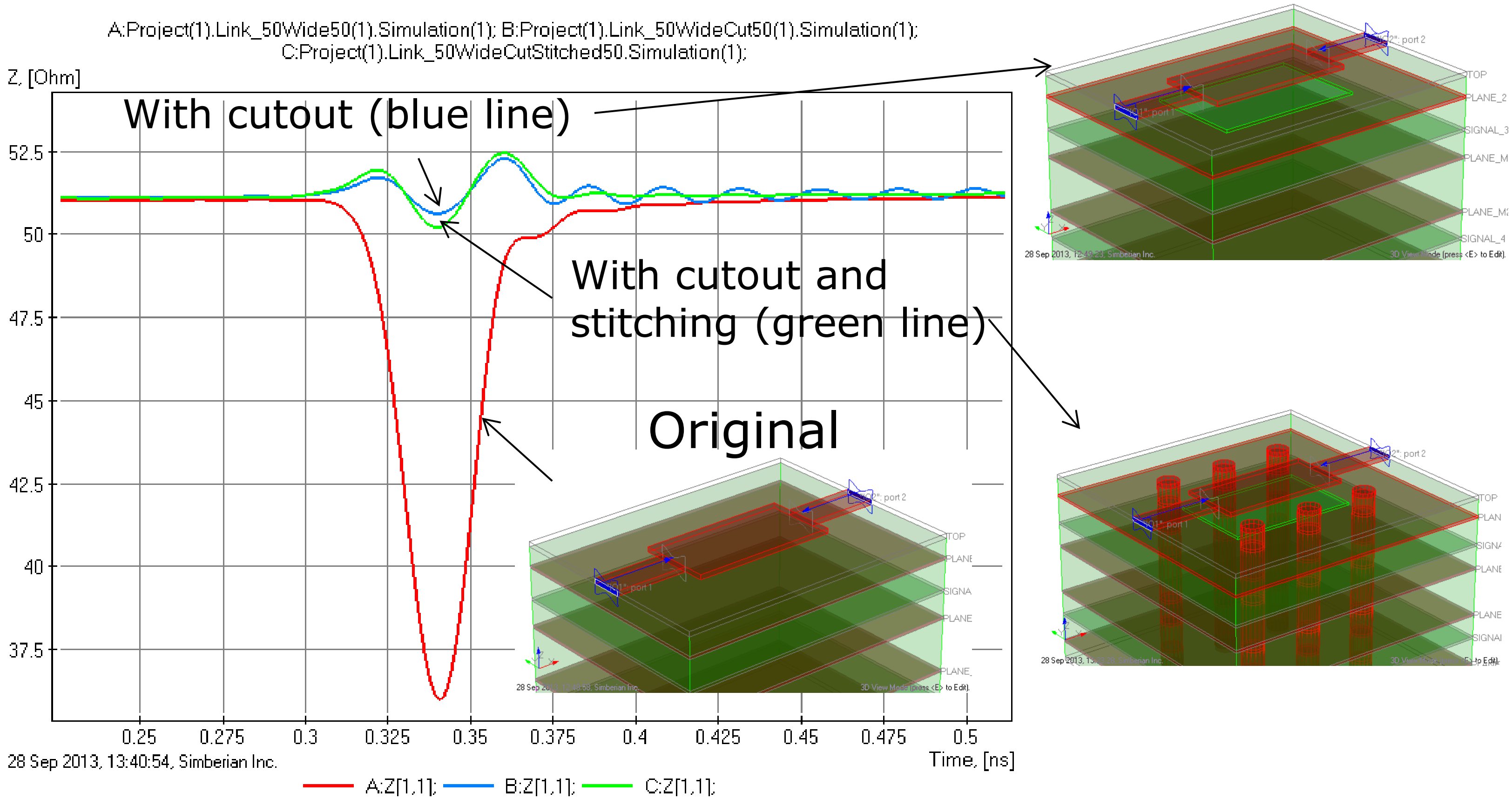
- 6 vias 30 mil apart, stitching the reference plane with the next plane





Transition to wider strip: TDR

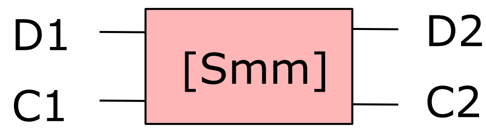
16 ps Gaussian step, 1 inch of 50-Ohm MSL on each side



See more on optimization of transitions for AC coupling caps in App Notes #2008_02 and 2008_04 at http://www.simberian.com/AppNotes.php

Differential transitions

Transitions Design Goals:
Minimize S[D1,D1], NEMT, FEMT
Maximize |S[D1,D2]| and make GD flat



Notation used here (reciprocal):

Block DD, Block DC, Block CC

$$Smm = \begin{bmatrix} S_{D1,D1} & S_{D1,D2} & S_{D1,C1} & S_{D1,C2} \\ S_{D1,D2} & S_{D2,D2} & S_{D2,C1} & S_{D2,C2} \\ S_{D1,C1} & S_{D2,C1} & S_{C1,C1} & S_{C1,C2} \\ S_{D1,C2} & S_{D2,C2} & S_{C1,C2} & S_{C2,C2} \end{bmatrix}$$

Alternative forms:

$$Smm = \begin{bmatrix} S_{DD11} & S_{DD12} & S_{DC11} & S_{DC12} \\ S_{DD12} & S_{DD22} & S_{DC21} & S_{DC22} \\ S_{DC11} & S_{DC21} & S_{CC11} & S_{CC12} \\ S_{DC12} & S_{DC22} & S_{CC12} & S_{CC22} \end{bmatrix}$$

$$Smm = \begin{bmatrix} S_{1,1}^{dd} & S_{1,2}^{dd} & S_{1,1}^{dc} & S_{1,2}^{dc} \\ S_{1,2}^{dd} & S_{2,2}^{dd} & S_{2,1}^{dc} & S_{2,2}^{dc} \\ S_{1,1}^{dc} & S_{2,1}^{dc} & S_{1,1}^{cc} & S_{1,2}^{cc} \\ S_{1,2}^{dc} & S_{2,2}^{dc} & S_{1,2}^{cc} & S_{2,2}^{cc} \end{bmatrix}$$

S[D1,D1] and S[D1,D2] – **differential mode reflection and transmission**

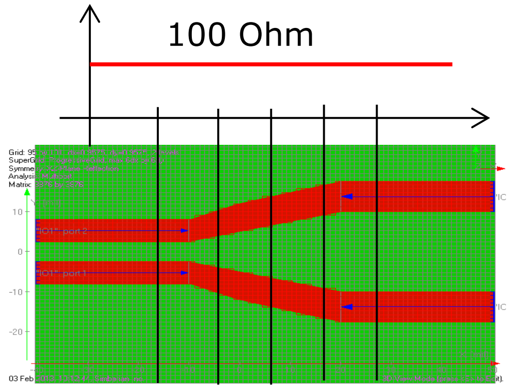
S[D1,C1], S[D2,C2] – **near end mode transformation (NEMT)** or transformation from differential to common mode at the same side of the multiport

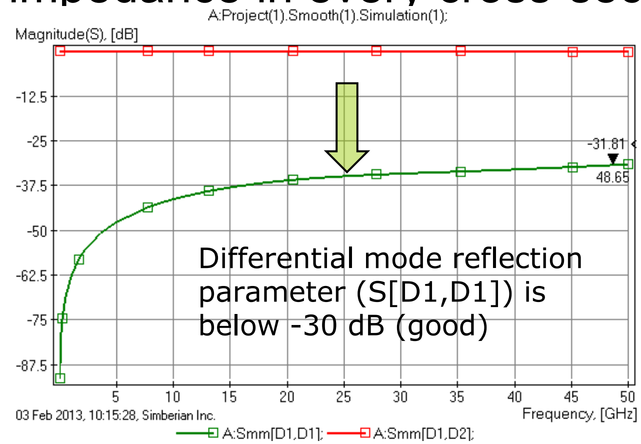
S[D1,C2], S[D2,C1] – **far end mode transformation (FEMT)** or transformation from differential mode on one side to the common mode on the opposite side of the multiport

See more on definitions in Simberian App Note #2009_01

Transitions from differential to single

- Maintain the target differential impedance in every cross-section



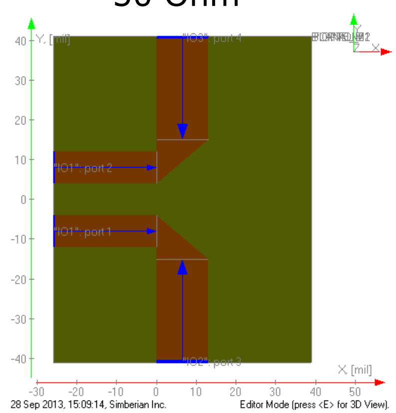


See more on transitions in App Note #2013_04

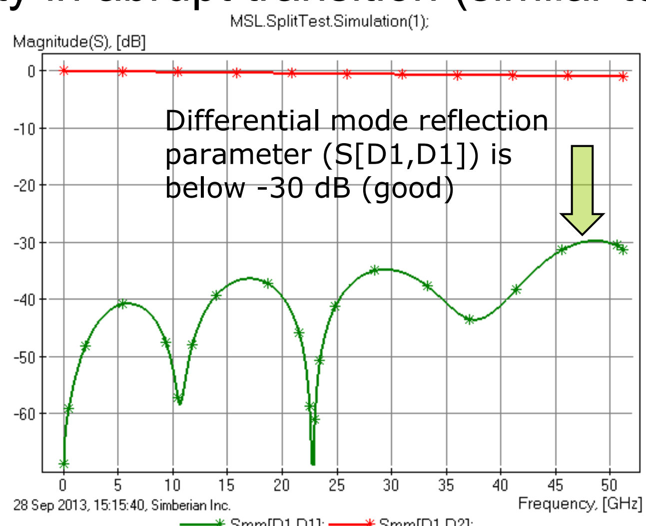
- Or minimize the discontinuity in abrupt transition (similar to single bend)

50 Ohm

~100 Ohm



50 Ohm

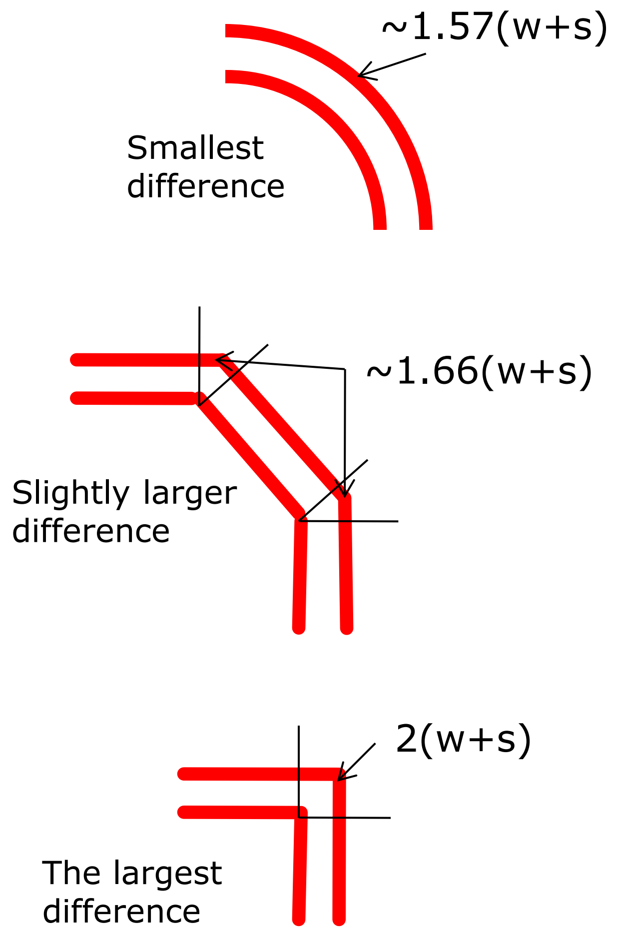


CMP-28 stackup, also used in skew analysis

100 mil diff MSL + split + 2 100 mil SE MSL + split + 100 mil diff MSL

Differential bends: Qualitative analysis

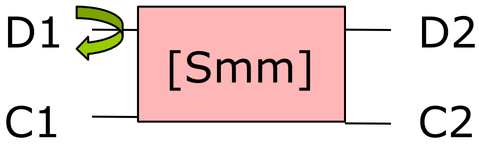
- Skew or mode transformation in bends is usually attributed to differences in lengths of the traces
  - That is how it is usually modeled in traditional SI software that uses static field solvers to extract t-line parameters and ignore the discontinuities like bends
- According to that measure the arched bend is better than two 45-degree and two 45-degree bend is better than 90-degree bend
- Is this correct statement?
  - Investigation is provided in App Note #2009_02 and here are some results…



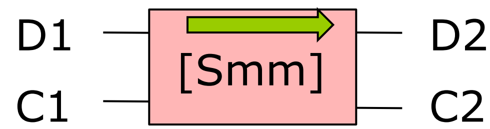
w is strip width and s is separation

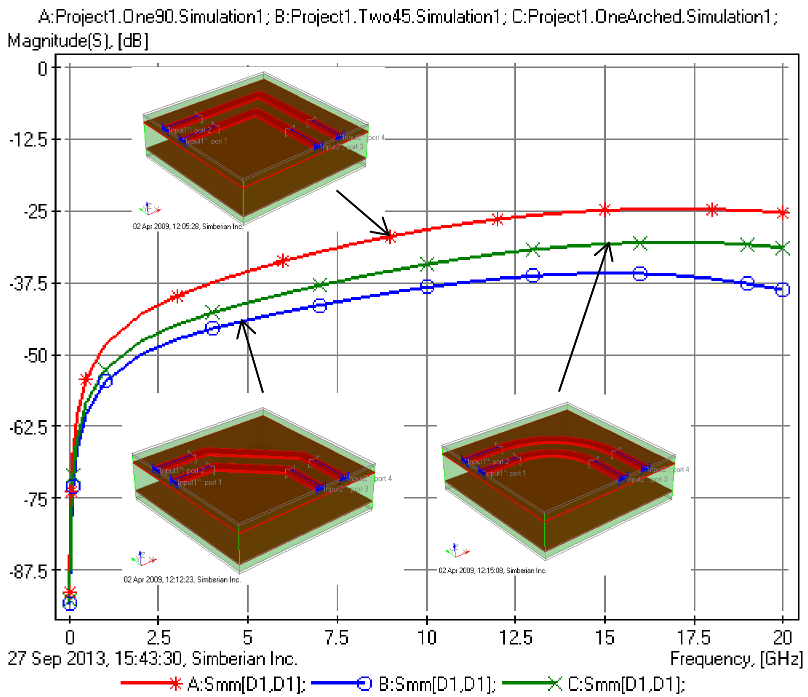
Differential reflection and transmission

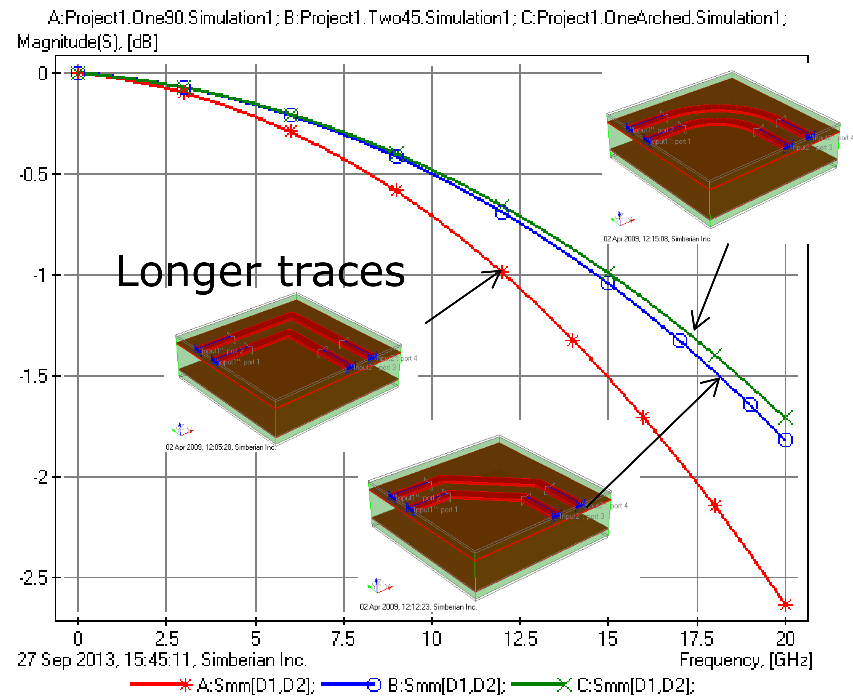
Differential reflection S[D1,D1]



Differential transmission S[D2,D1]



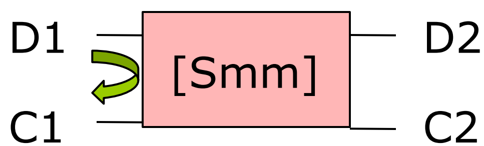




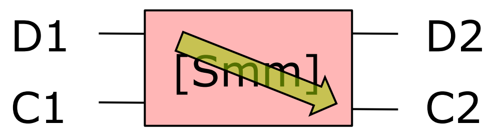
No difference for practical applications!

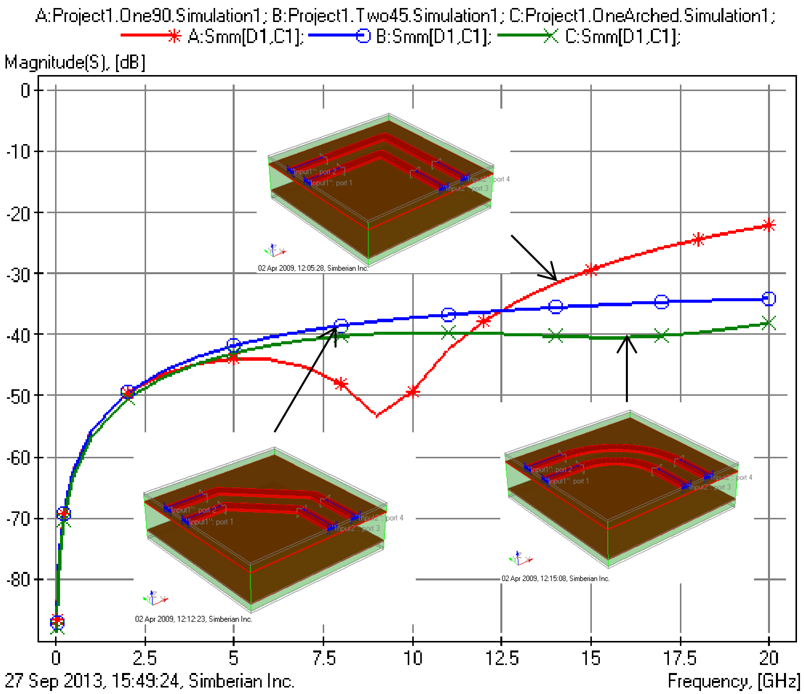
Mode transformation (skew and EMI)

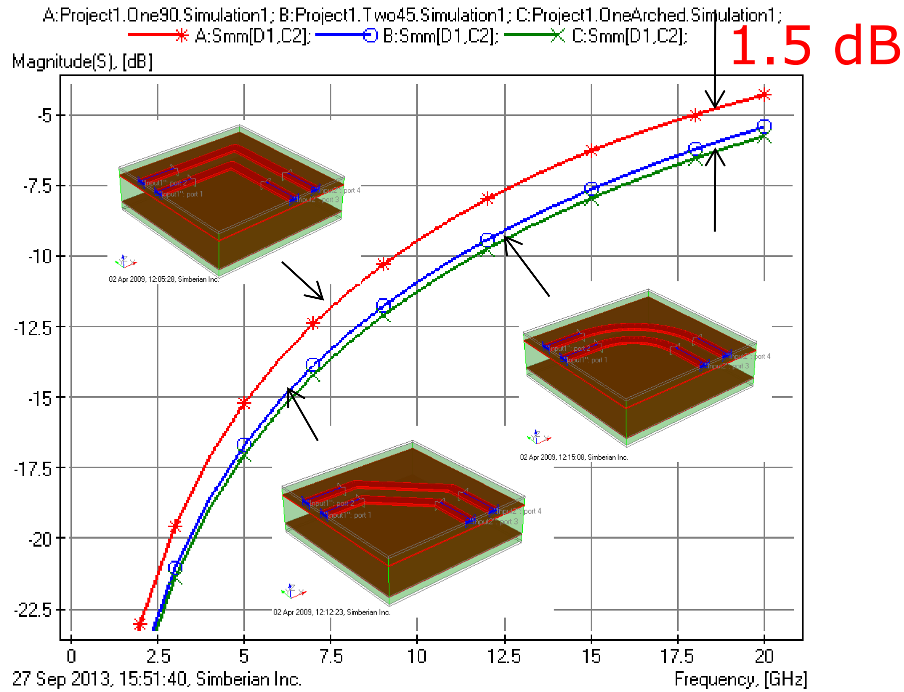
NEMT S[D1,C1]



FEMT S[D1,C2]



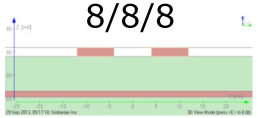




More modal transformations at 90-degree bend!

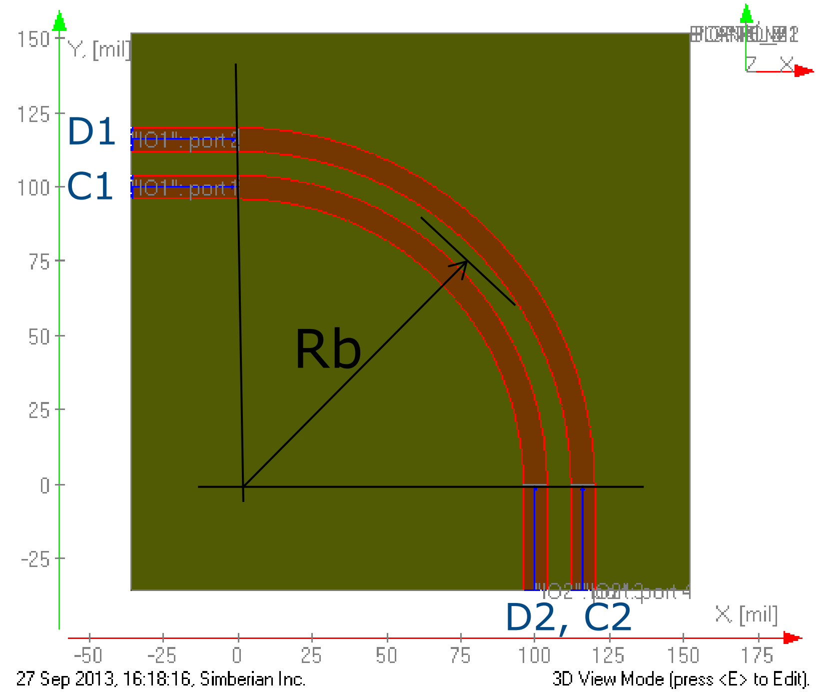
Practical example of skew analysis for nets with microstrip (MSL) arched bends

- 8-layer stackup from CMP-28 benchmark board from Wild River Technology, http://wildrivertech.com
- Material models are identified with GMS-parameters
- Two 8 mil strips 8 mil apart in layer TOP (microstrip)



Materials: T=20[°C],...
- "1OZ_COPPER", RR=1, SR=0.32, RF=3.3, RM=Original
- "PLATED_1OZ_COPPER", RR=1, SR=0.32, RF=3.3, RM=MHCC
- "FR-408HR", Dk=3.83, LT=0.0117, PLM=WD, Dk(0)=4.29, Dk(inf)=3.63
- "Air"
- "Soldermask", Dk=3.7, LT=0.02, PLM=WD, Dk(0)=4.46, Dk(inf)=3.37

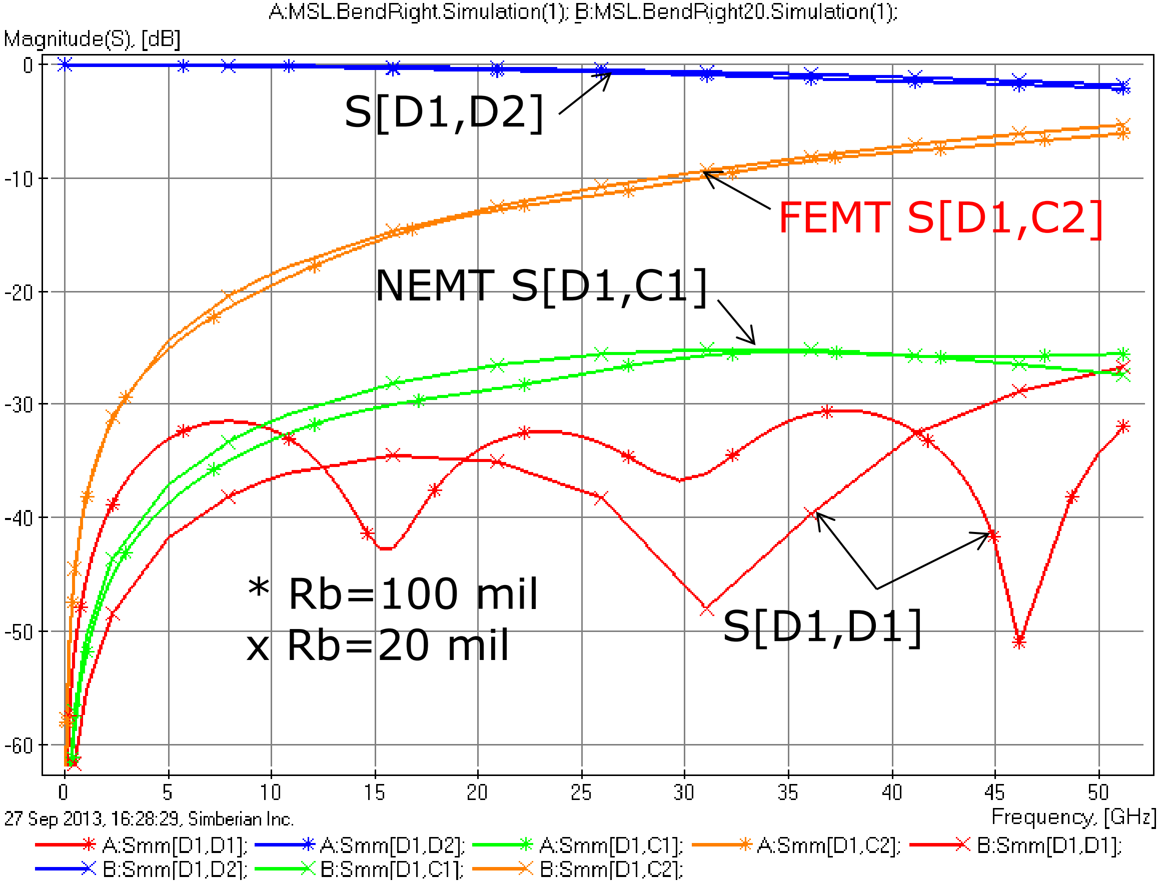
StackUp: LU=[mil], NL=8, T=91[mil], CSM=("Soldermask", 1.75[mil])
- 1| Signal: "TOP", T=2, Ins="Air", Cond="PLATED_1OZ_COPPER"
- 2| Medium: T=7.4, Ins="FR-408HR", DIE_003
- 3| Plane: "PLANE_2", Cond="1OZ_COPPER", T=1.2, Ins="FR-408HR"
- 4| Medium: T=12, Ins="FR-408HR", DIE_005
- 5| Signal: "SIGNAL_3", T=1.2, Ins="FR-408HR", Cond="1OZ_COPPER"
- 6| Medium: T=10, Ins="FR-408HR", DIE_007
- 7| Plane: "PLANE_M1", Cond="1OZ_COPPER", T=1.2, Ins="FR-408HR"
- 8| Medium: T=21, Ins="FR-408HR", DIE_008
- 9| Plane: "PLANE_M2", Cond="1OZ_COPPER", T=1.2, Ins="FR-408HR"
- 10| Medium: T=10, Ins="FR-408HR", DIE_009
- 11| Signal: "SIGNAL_4", T=1.2, Ins="FR-408HR", Cond="1OZ_COPPER"
- 12| Medium: T=12, Ins="FR-408HR", DIE_011
- 13| Plane: "PLANE_5", Cond="1OZ_COPPER", T=1.2, Ins="FR-408HR"
- 14| Medium: T=7.4, Ins="FR-408HR", DIE_013
- 15| Signal: "BOTTOM", T=2, Ins="Air", Cond="PLATED_1OZ_COPPER"



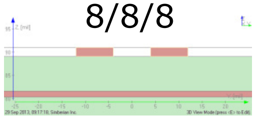
We investigate two bends with
Rb=108 mil and Rb=28 mil (center line)
Both bends have identical 25 mil difference in strip lengths

Effect of bend radius

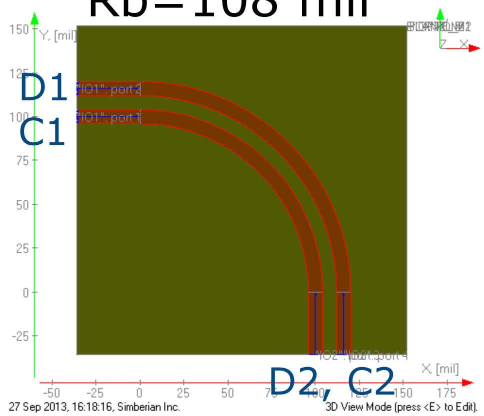
- Very similar modal transformations in larger and smaller bends!



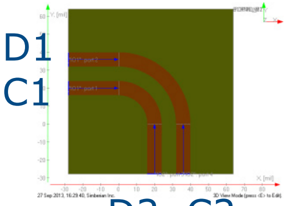
8/8/8



Rb=108 mil

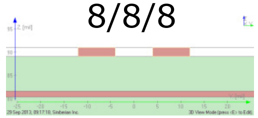


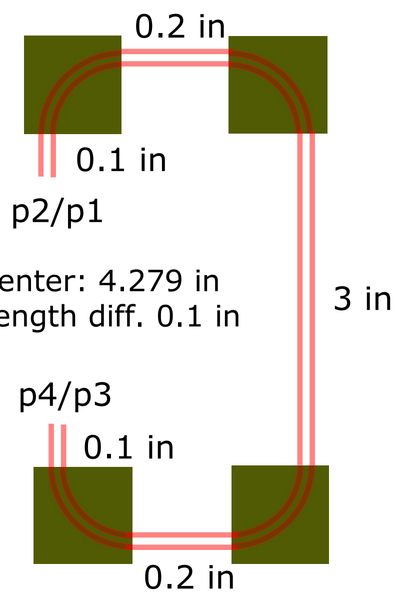
Rb=28 mil



FEMT is definitely a problem (skew, EMI)!

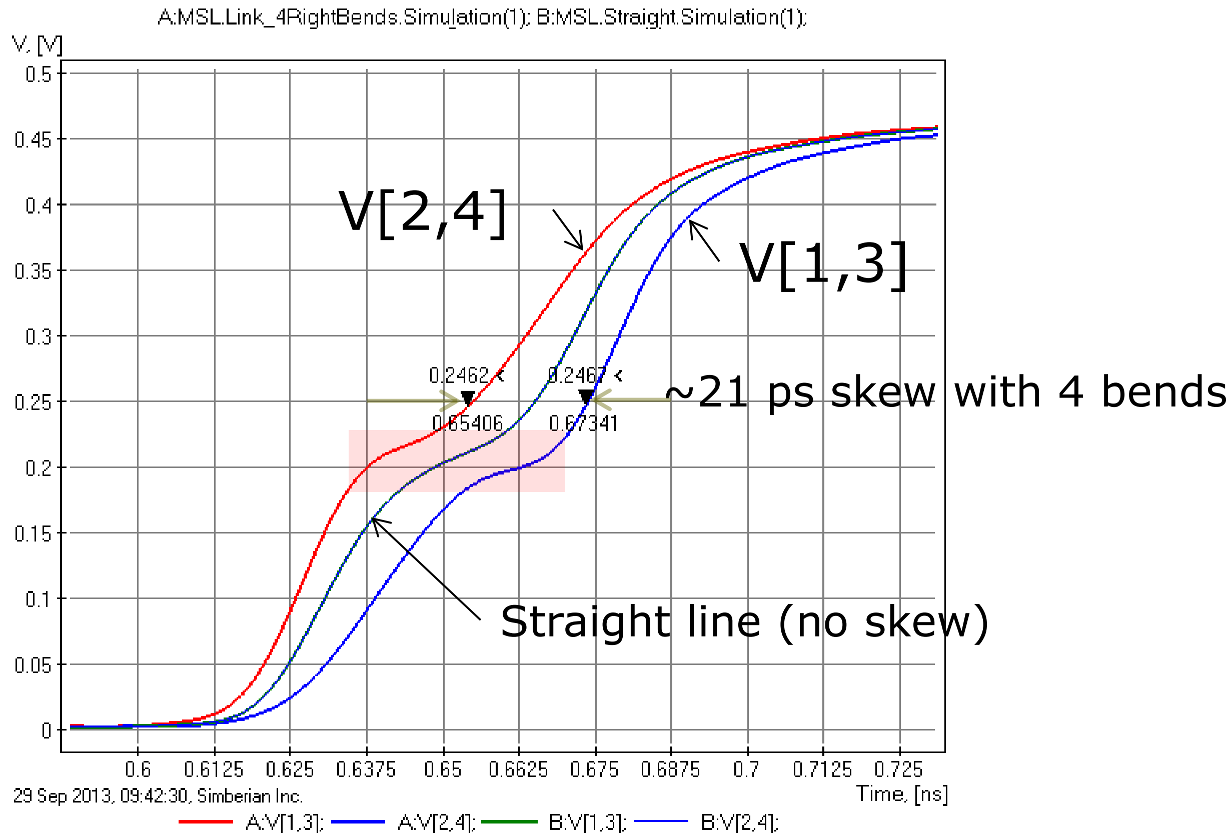
MSL link with 4 right bends – SE TDT





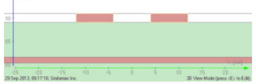
Center: 4.279 in
Length diff. 0.1 in

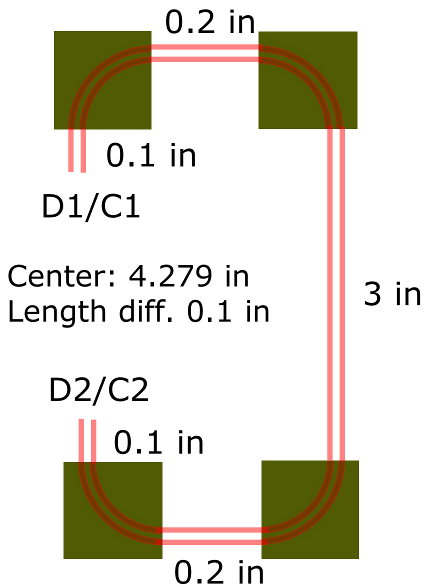
Single-ended TDT, 0.5 V 16 ps Gaussian step



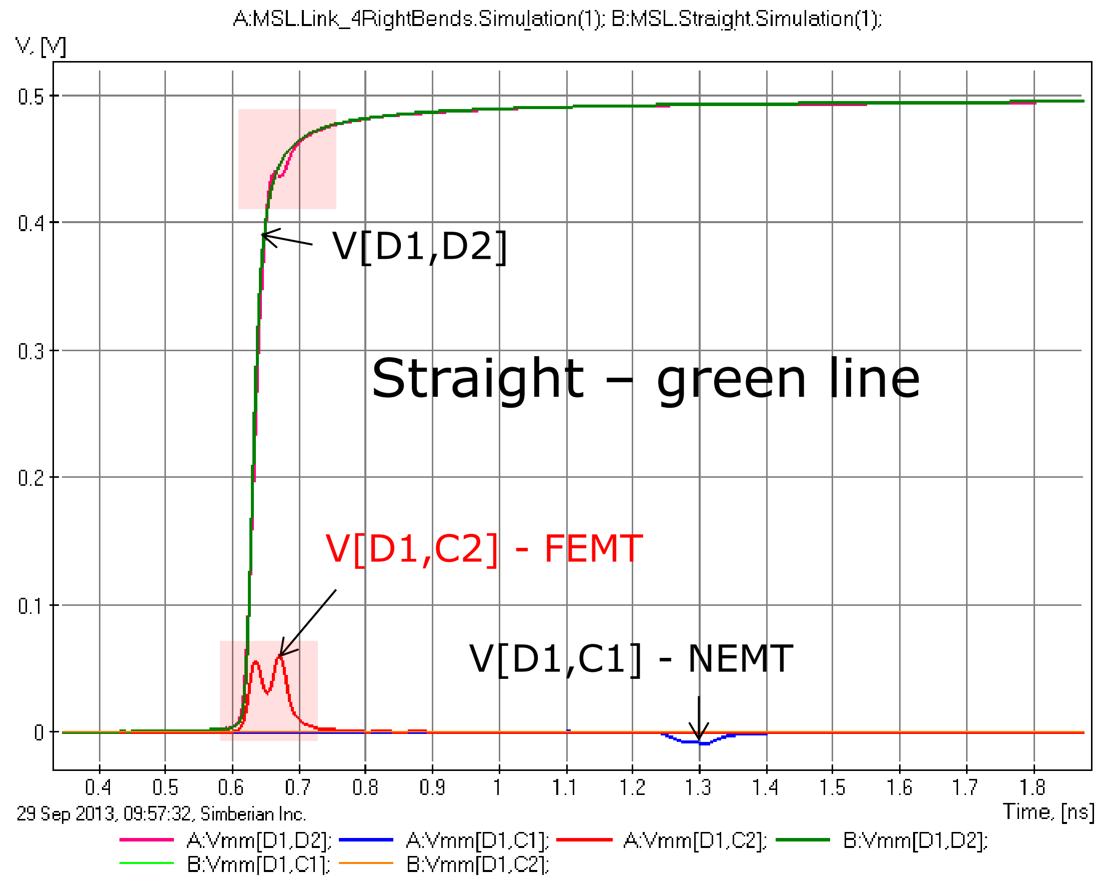
MSL link with 4 right bends – MM TDT

8/8/8



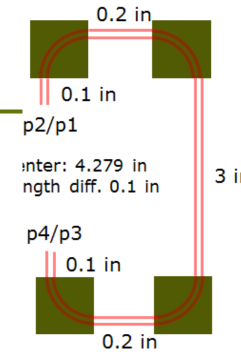


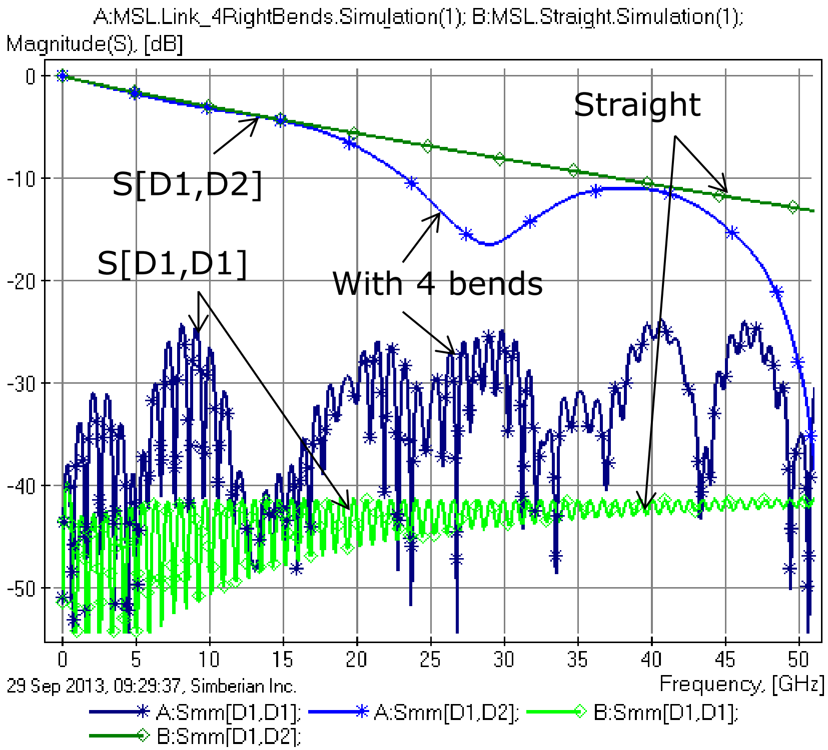
Mixed-mode TDT, 0.5 V 16 ps Gaussian step

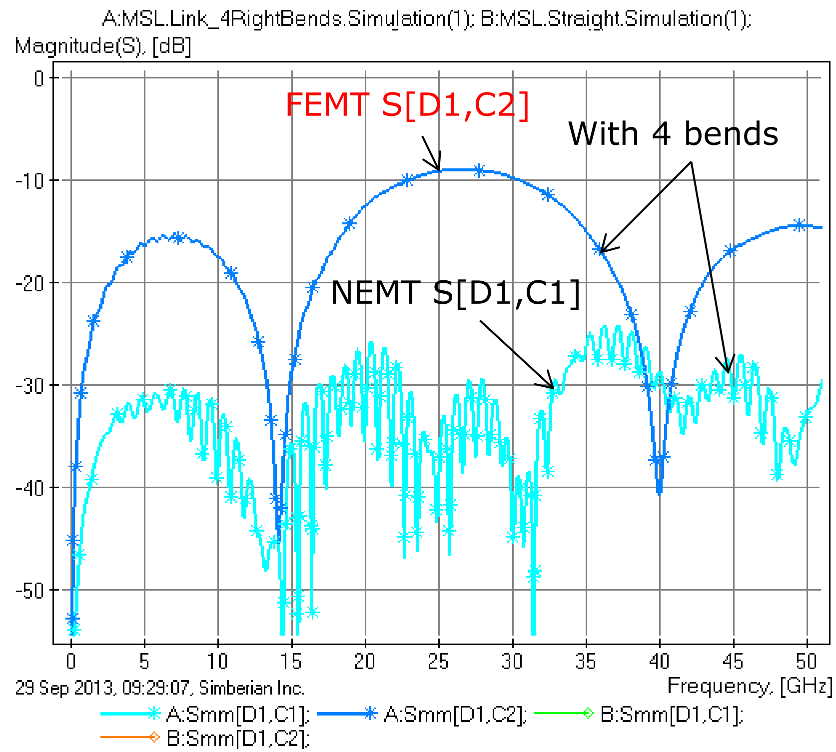


MSL link with 4 right bends: “Skew” view on S-parameters

- How to fix it? – match length?

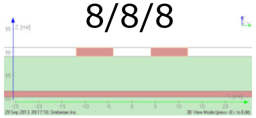


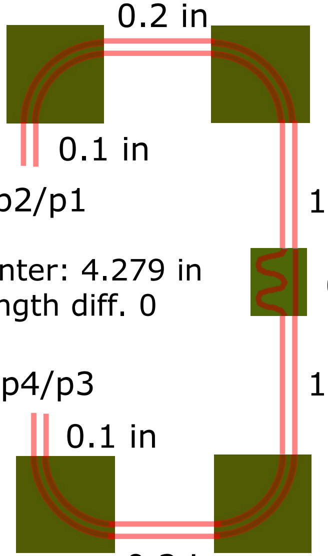




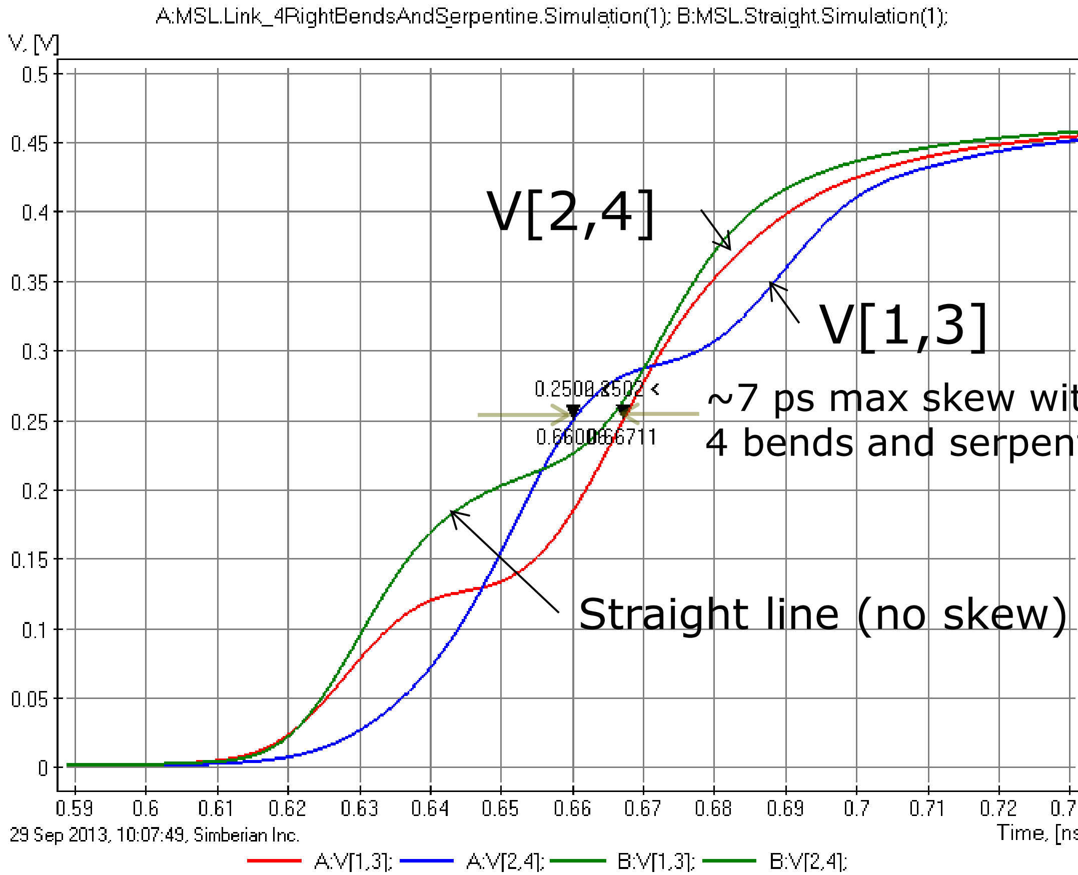
MSL link with 4 right bends and serpentine – SE TDT

8/8/8



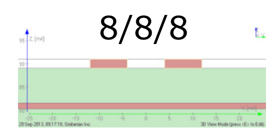


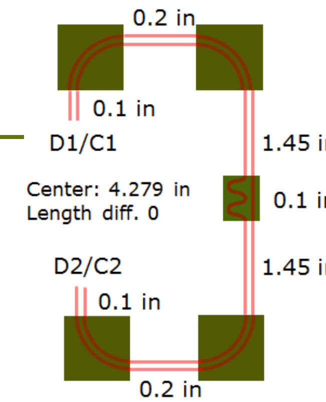
Mixed-mode TDT, 0.5 V 16 ps Gaussian step

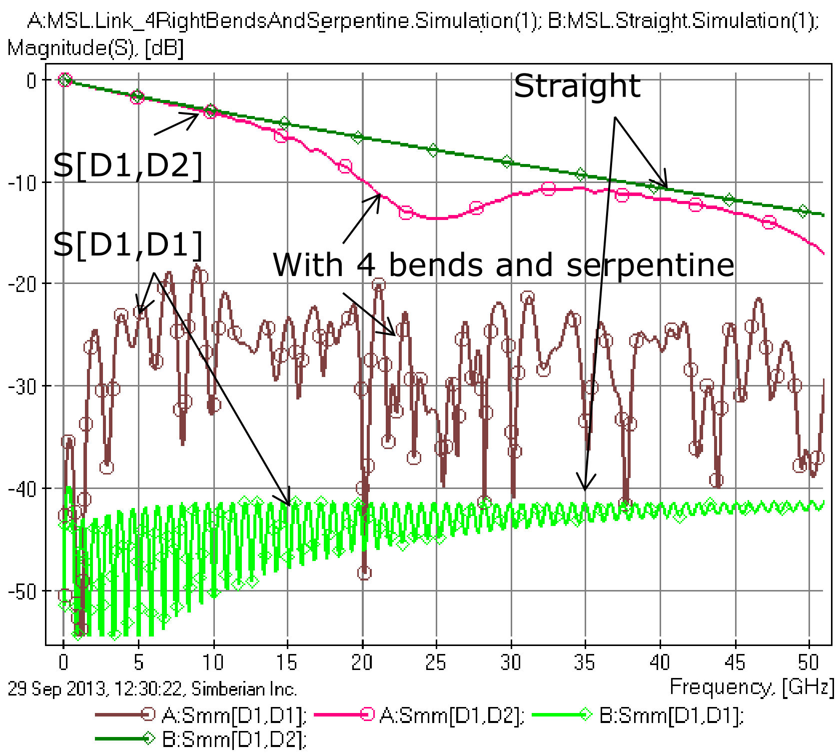


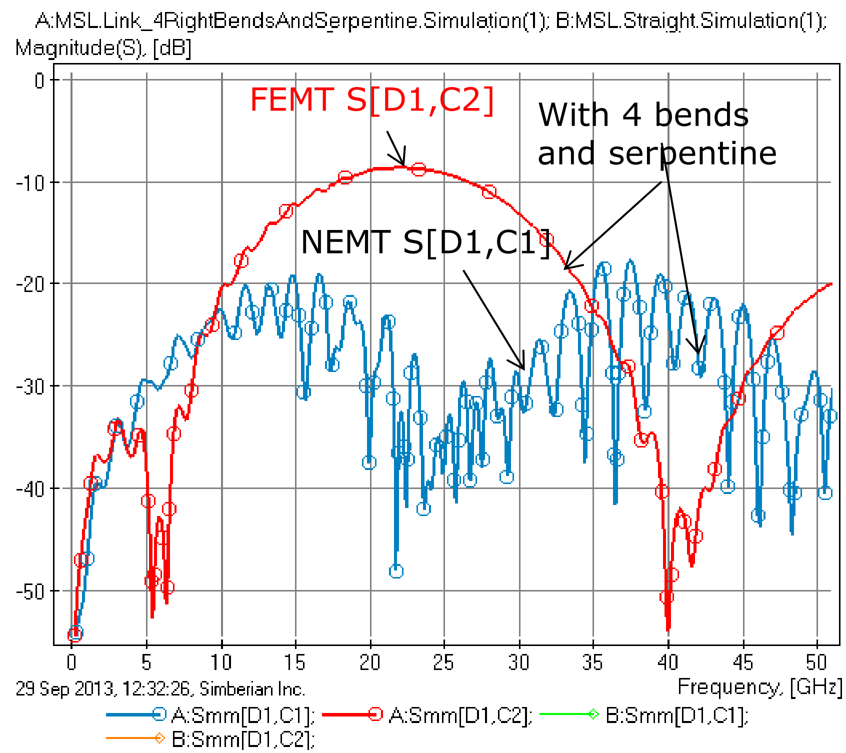
MSL link with 4 right bends and serpentine: "Skew" view on S-parameters

- Length match did not fix the problem!

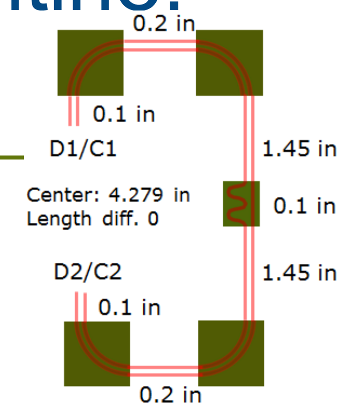




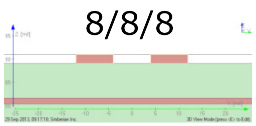


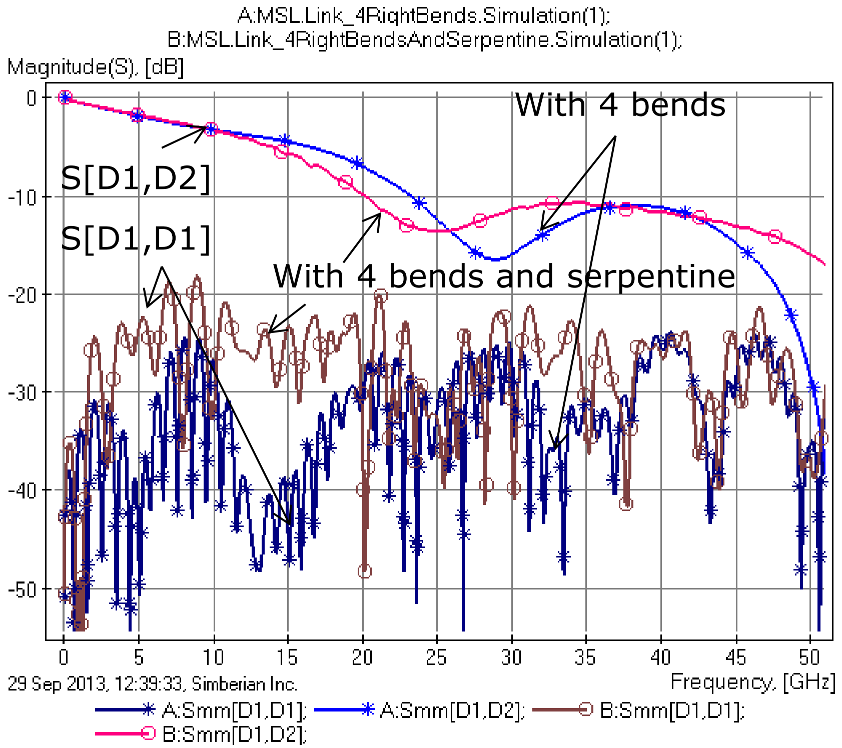


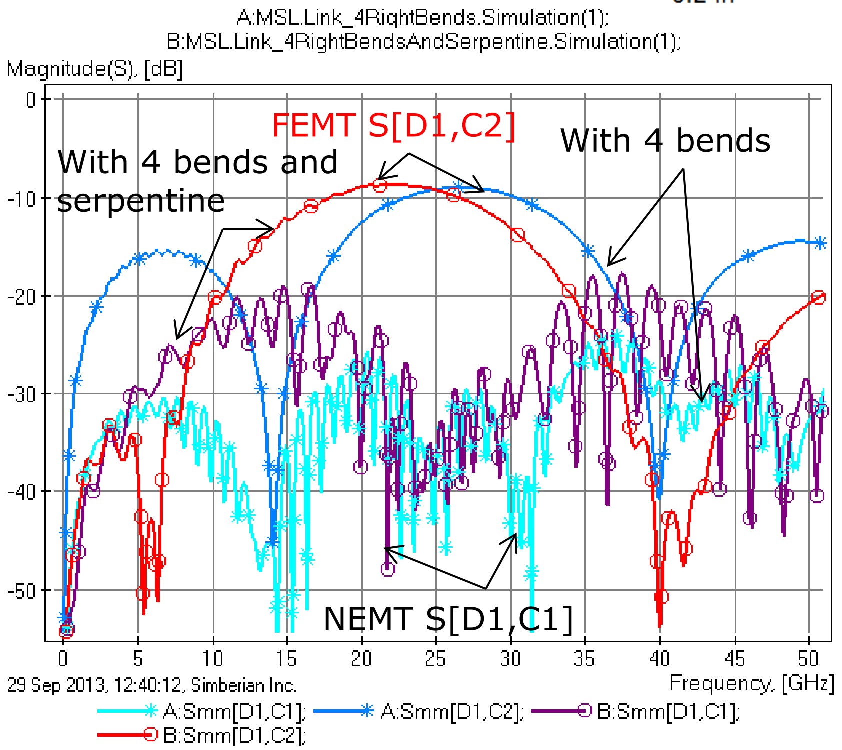
MSL link with 4 right bends and serpentine: "Skew" view on S-parameters



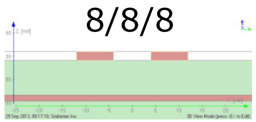
- Actually made it worse: MT at lower frequencies

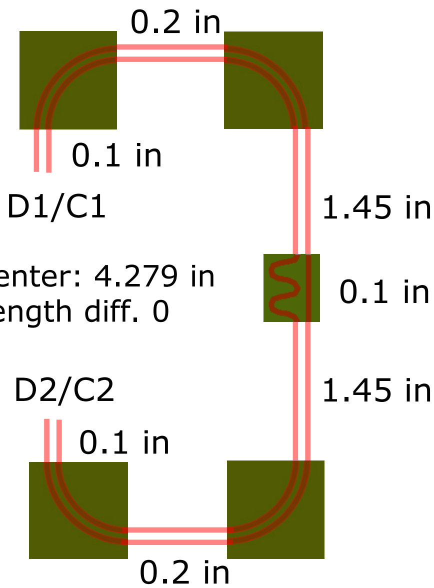




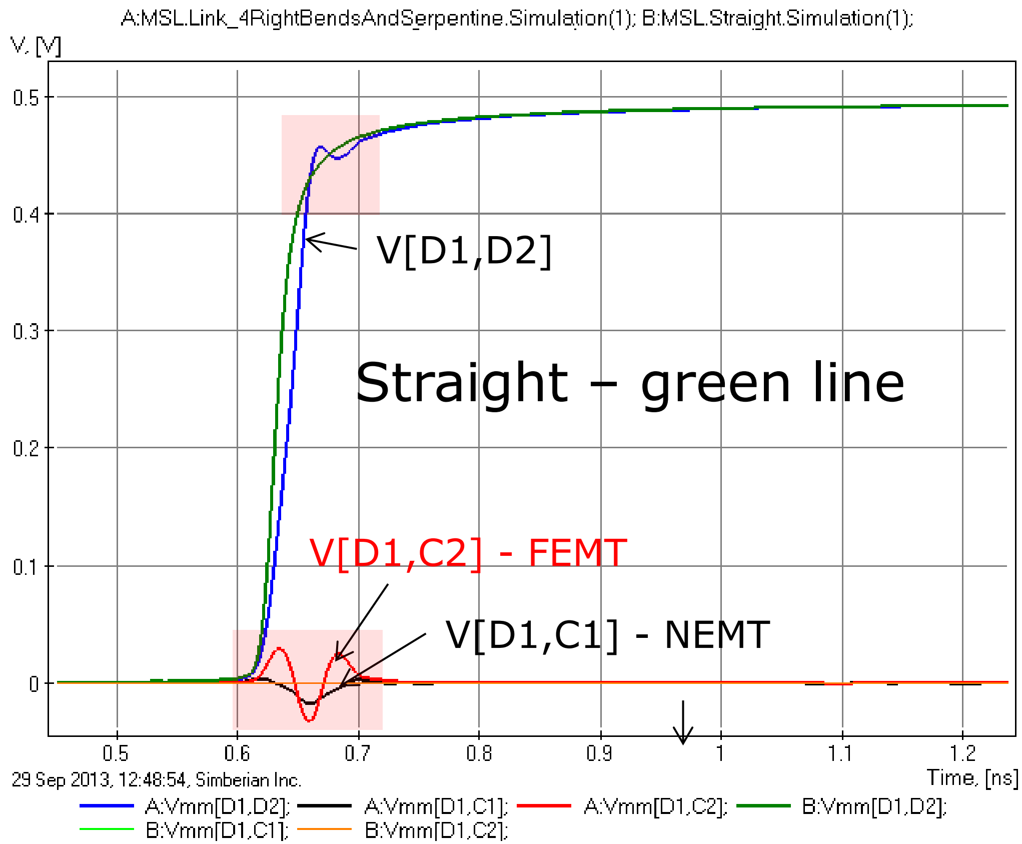


MSL link with 4 right bends and serpentine – MM TDT



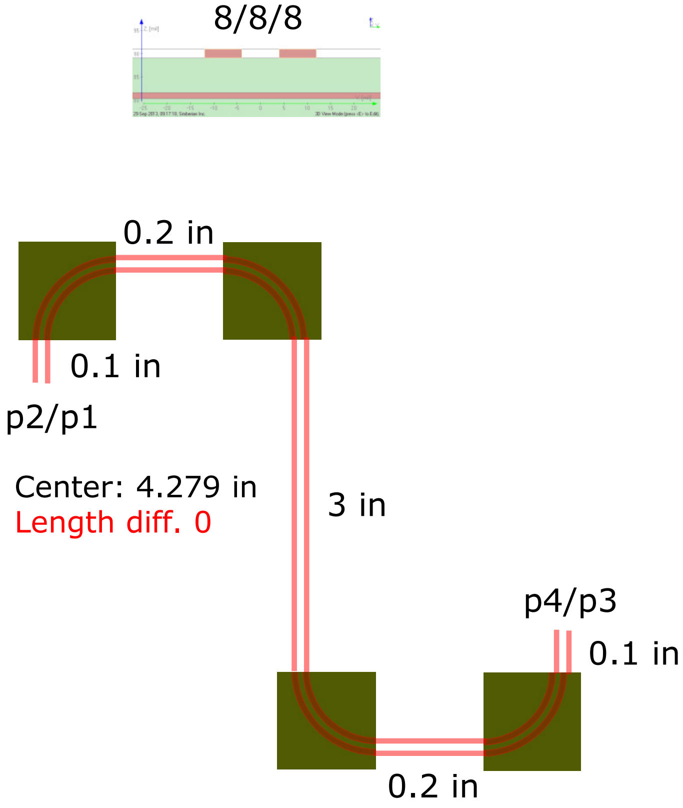


Mixed-mode TDT, 0.5 V 16 ps Gaussian step

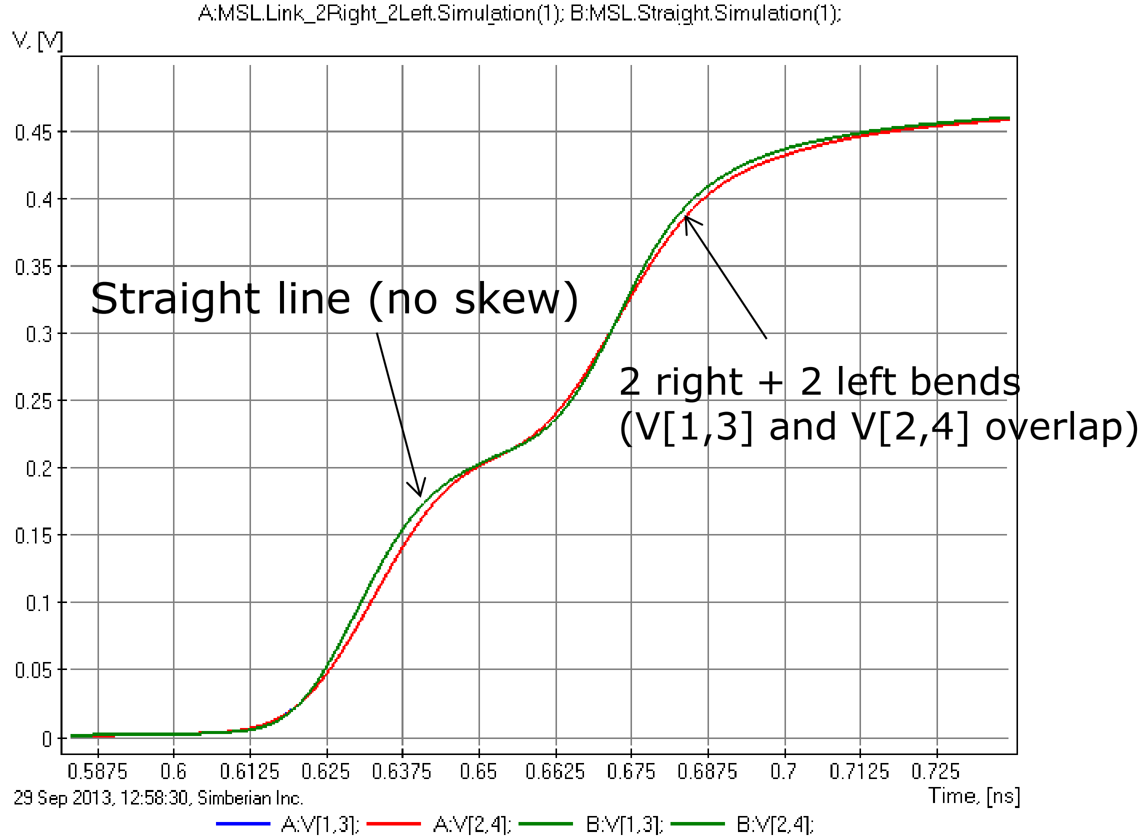


Length match in microstrip link clearly did not work!
May be it was not done properly?

MSL link with 2 right and 2 left bends – SE TDT



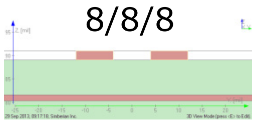
Single-ended TDT, 0.5 V 16 ps Gaussian step

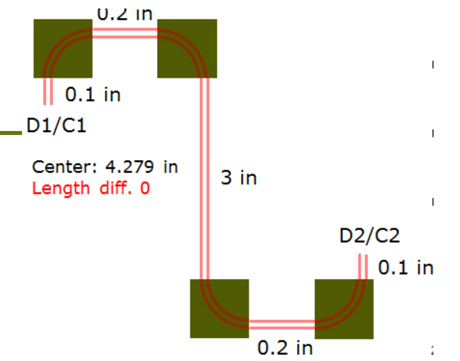


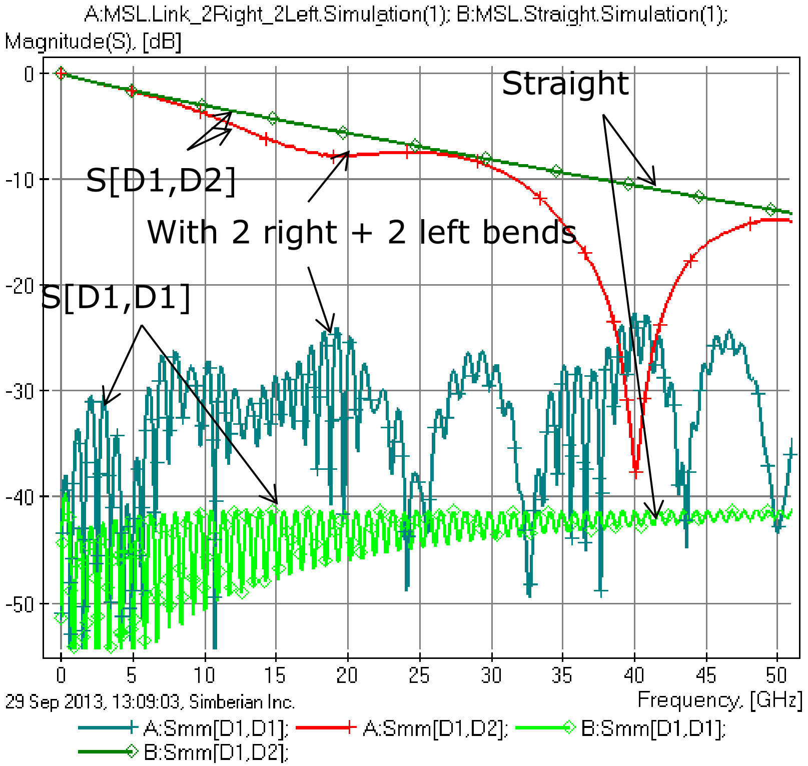
The best we can do, but did it solver the problem?

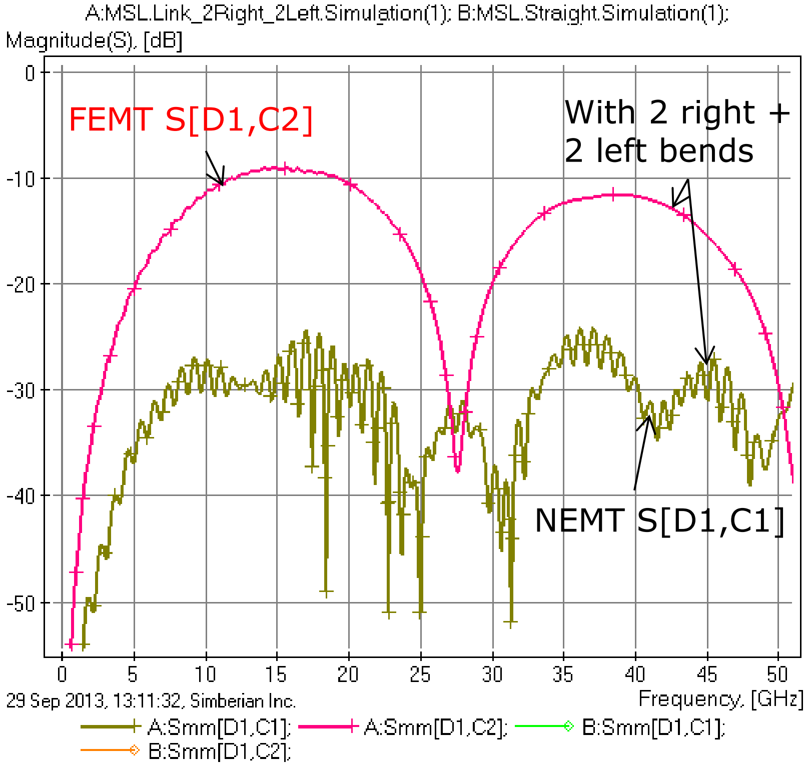
MSL link with 2 right + 2 left bends: "Skew" view on S-parameters

- Still problem with insertion loss and mode transformation!

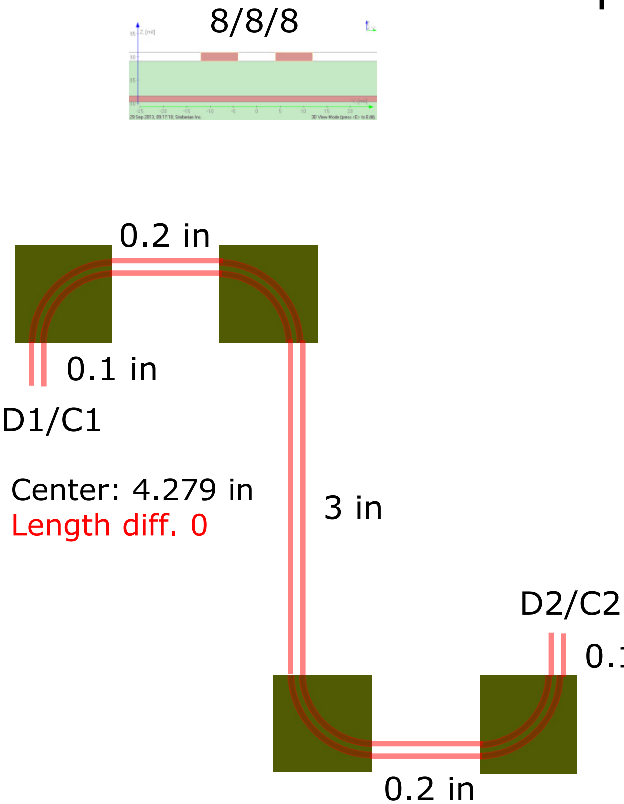




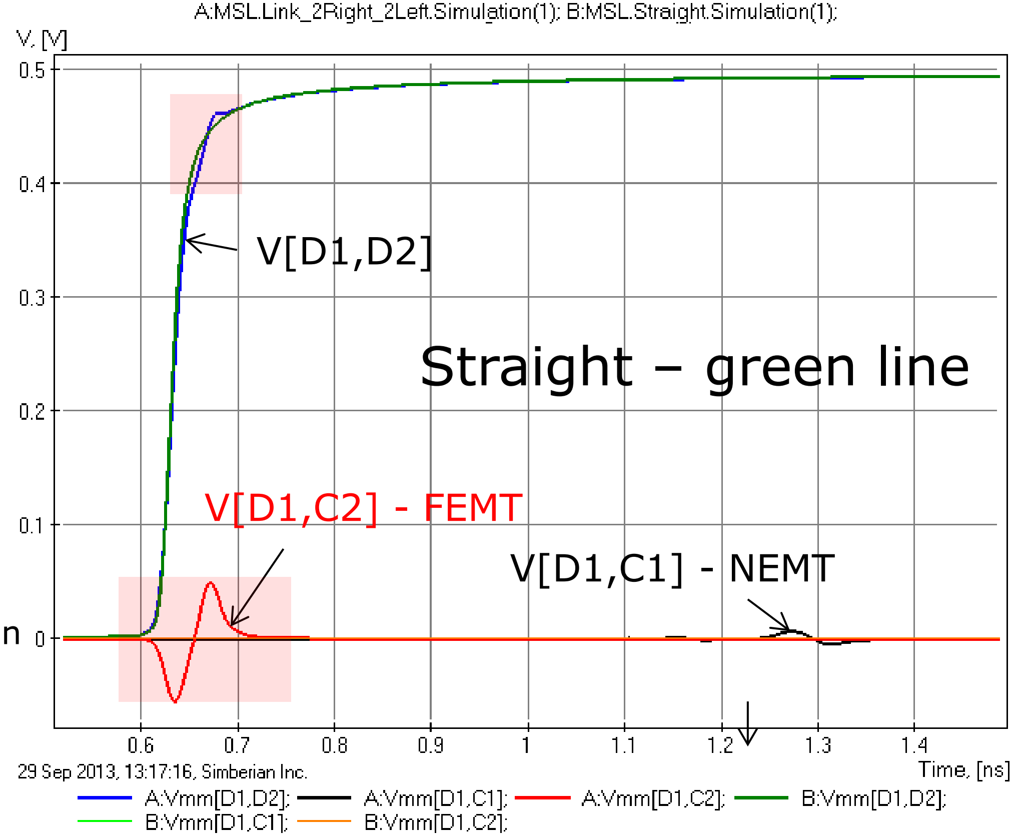




MSL link with 2 right + 2 left bends and serpentine – MM TDT

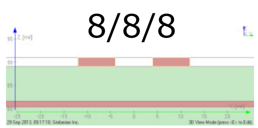


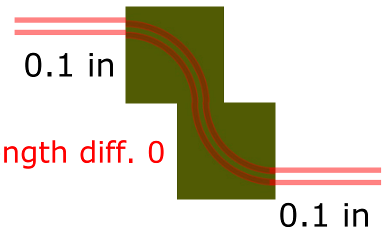
Mixed-mode TDT, 0.5 V 16 ps Gaussian step



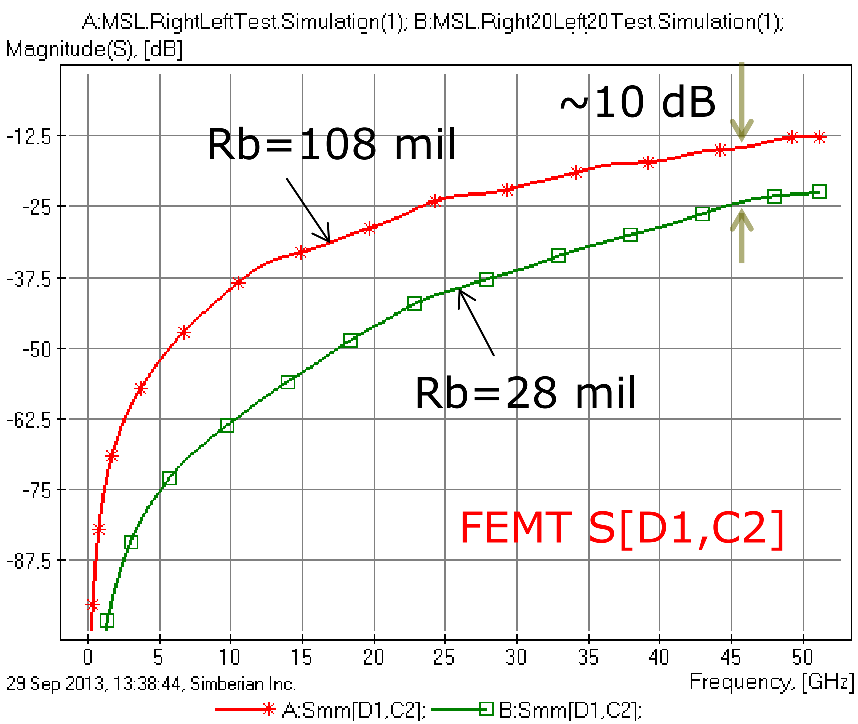
Length match in microstrip link does not work?
Let's try to figure out why…

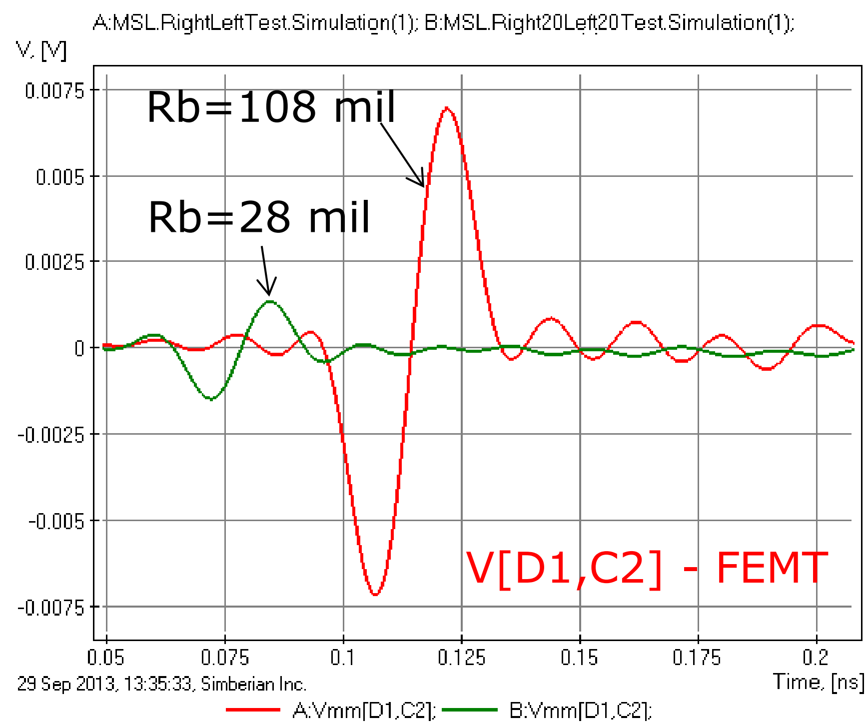
MSL back-to-back right and left bends





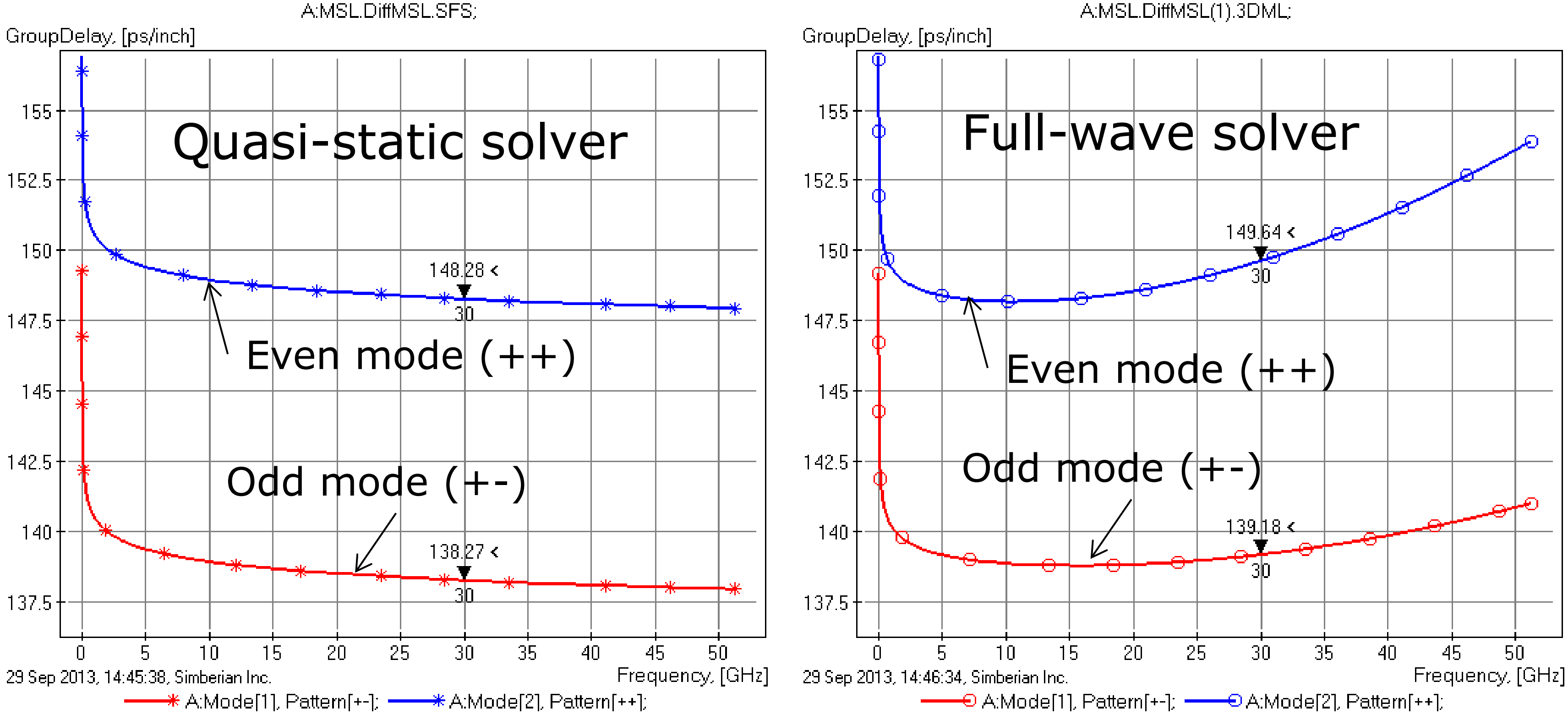
Only small close complimentary bends reduce the mode transformation and skew and EMI!





Why length matching does not work for microstrip lines?

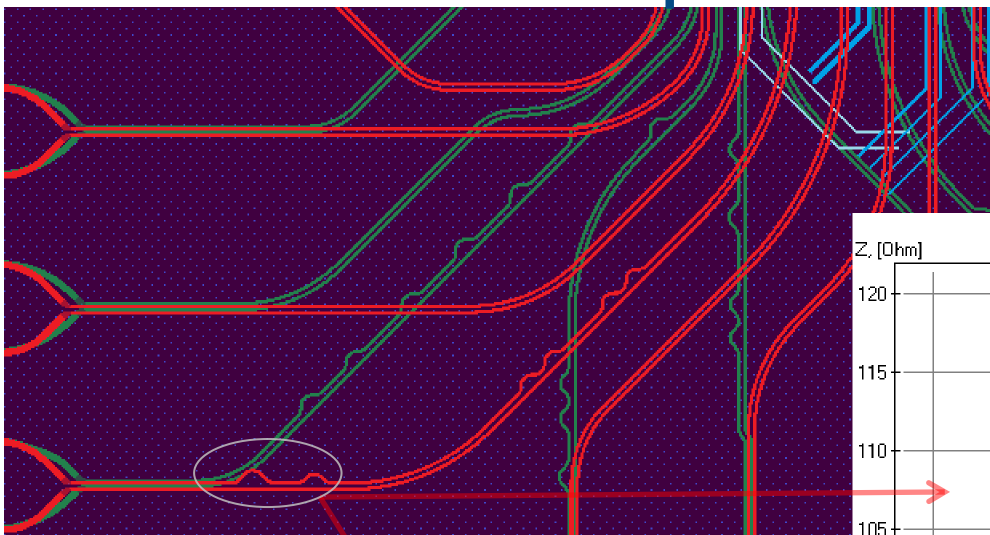
- Energy along the coupled MSL propagate in even and odd modes and they have different propagation velocity or group delay:

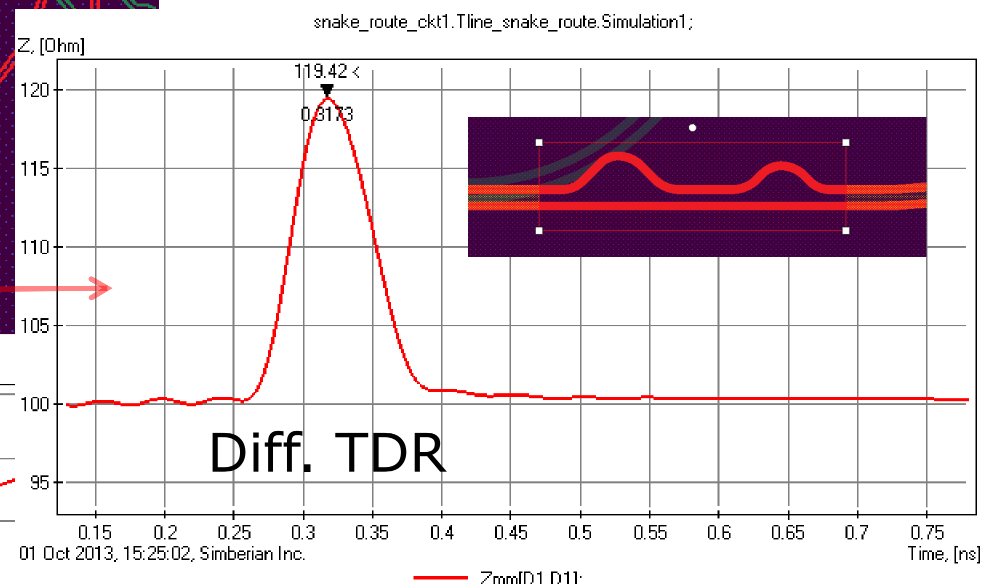


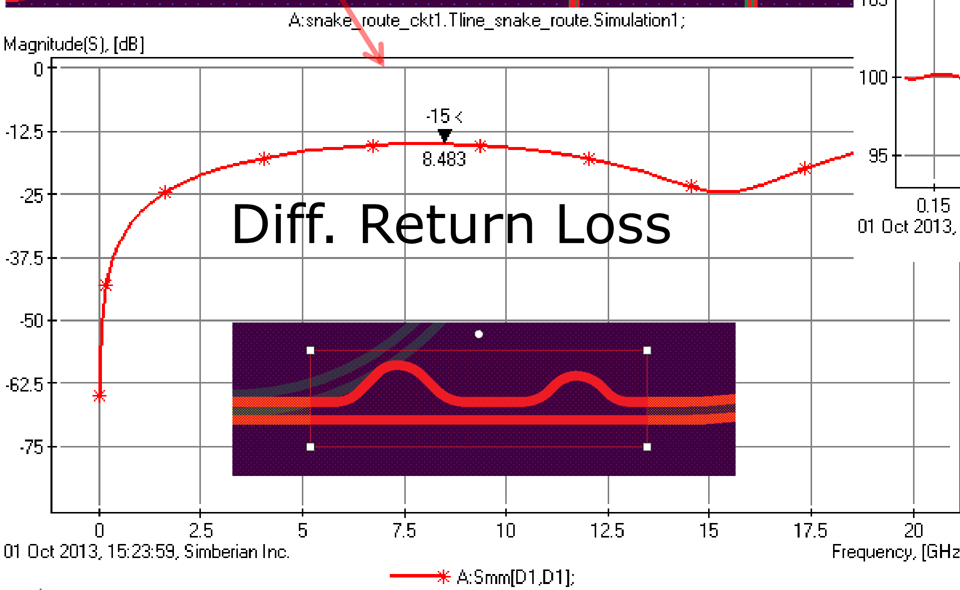
Will length compensation work if no difference in mode velocity (strip lines)? …
Depends on how you do it – see Simbeor FRSI examples on skew in diff strips…

Practical example of length matching

Serpentines may be worse then vias!





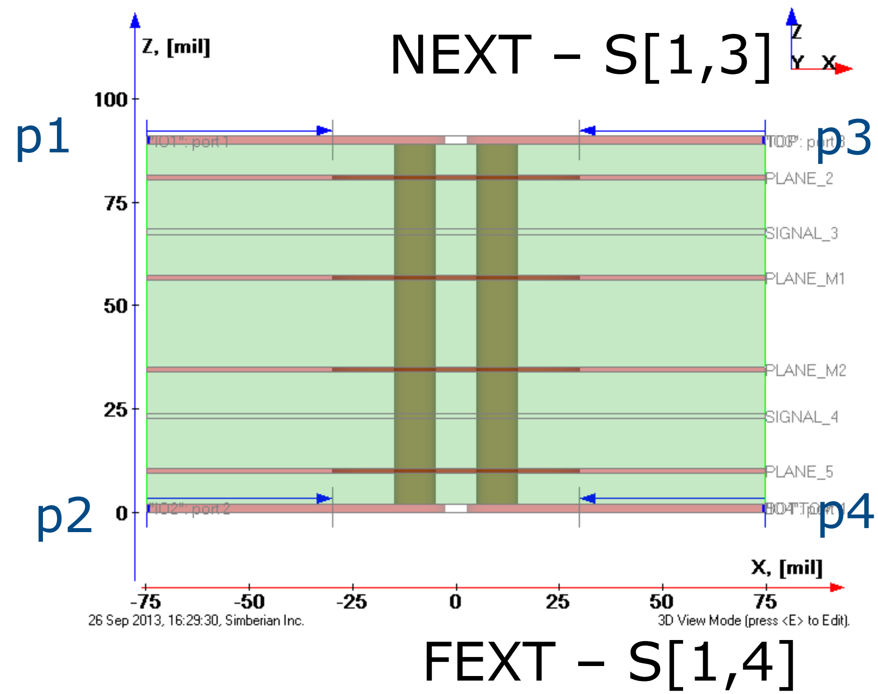


Cross-talk in vias

- 8-layer stackup from CMP-28 benchmark board from Wild River Technology, http://wildrivertech.com
- Dielectric and conductor models are identified with GMS-parameters

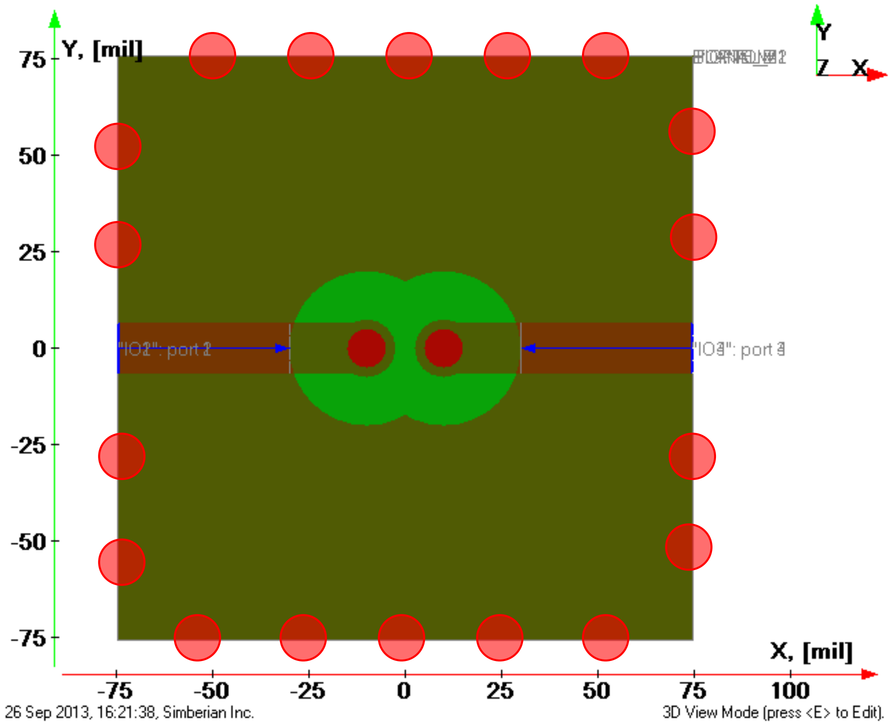
Materials: T=20[°C],...
- "1OZ_COPPER", RR=1, SR=0.32, RF=3.3, RM=Original
- "PLATED_1OZ_COPPER", RR=1, SR=0.32, RF=3.3, RM=MHCC
- "FR-408HR", Dk=3.83, LT=0.0117, PLM=WD, Dk(0)=4.29, Dk(inf)=3.63
- "Air"
- "Soldermask", Dk=3.7, LT=0.02, PLM=WD, Dk(0)=4.46, Dk(inf)=3.37

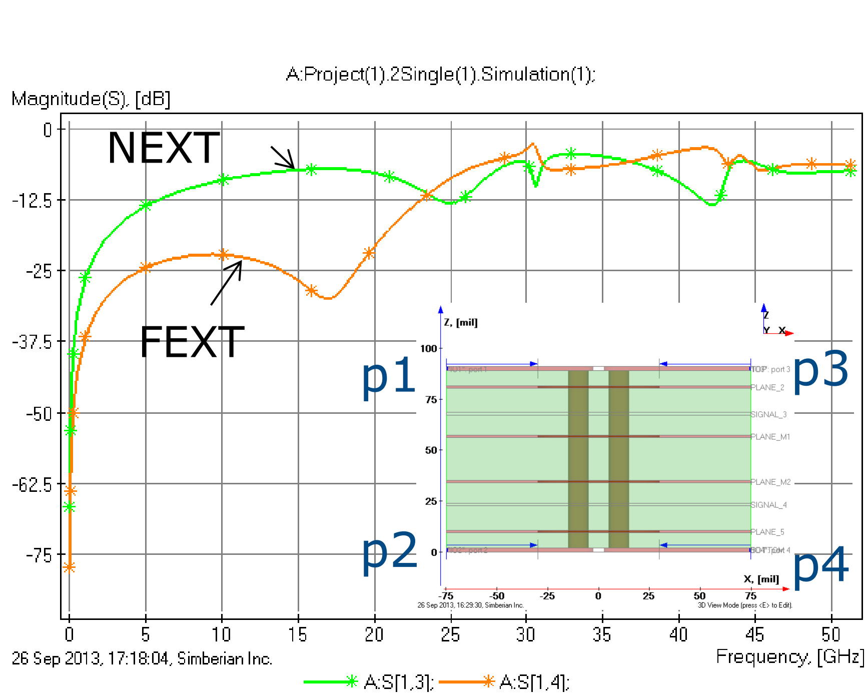
StackUp: LU=[mil], NL=8, T=91[mil], CSM=("Soldermask", 1.75[mil])
- 1| Signal: "TOP", T=2, Ins="Air", Cond="PLATED_1OZ_COPPER"
- 2| Medium: T=7.4, Ins="FR-408HR", DIE_003
- 3| Plane: "PLANE_2", Cond="1OZ_COPPER", T=1.2, Ins="FR-408HR"
- 4| Medium: T=12, Ins="FR-408HR", DIE_005
- 5| Signal: "SIGNAL_3", T=1.2, Ins="FR-408HR", Cond="1OZ_COPPER"
- 6| Medium: T=10, Ins="FR-408HR", DIE_007
- 7| Plane: "PLANE_M1", Cond="1OZ_COPPER", T=1.2, Ins="FR-408HR"
- 8| Medium: T=21, Ins="FR-408HR", DIE_008
- 9| Plane: "PLANE_M2", Cond="1OZ_COPPER", T=1.2, Ins="FR-408HR"
- 10| Medium: T=10, Ins="FR-408HR", DIE_009
- 11| Signal: "SIGNAL_4", T=1.2, Ins="FR-408HR", Cond="1OZ_COPPER"
- 12| Medium: T=12, Ins="FR-408HR", DIE_011
- 13| Plane: "PLANE_5", Cond="1OZ_COPPER", T=1.2, Ins="FR-408HR"
- 14| Medium: T=7.4, Ins="FR-408HR", DIE_013
- 15| Signal: "BOTTOM", T=2, Ins="Air", Cond="PLATED_1OZ_COPPER"



Single-ended vias – case 1

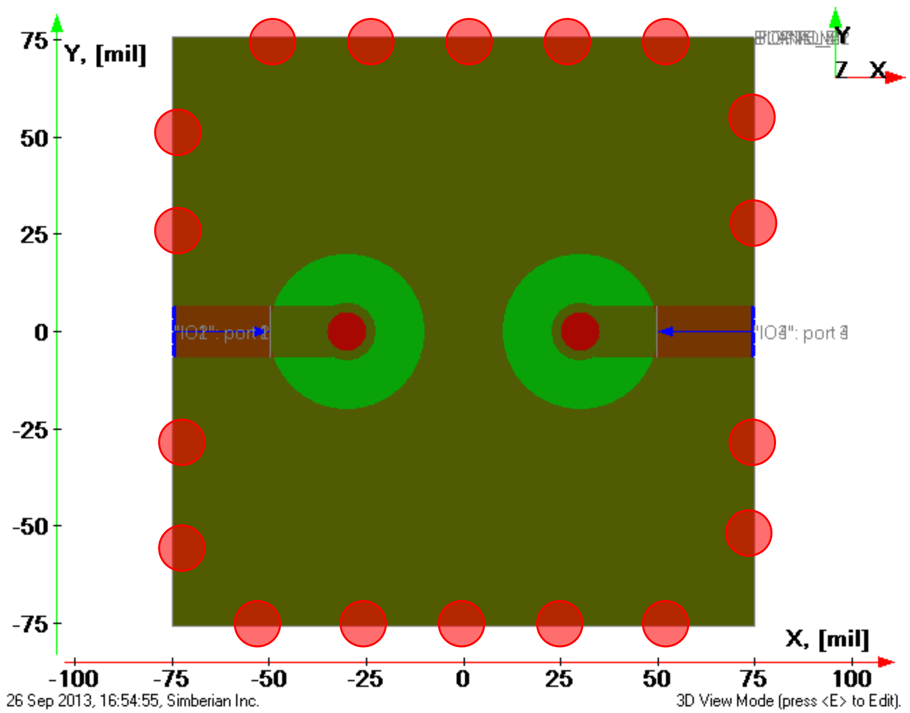
- Two coupled vias in a 150 x 150 mil area caged with PEC wall (stitching vias)
- Vias are 20 mil apart, antipad diameters 40 mil, 13 mil MSL;
- The first cage resonance is at about 10 GHz (half wavelength in dielectric)

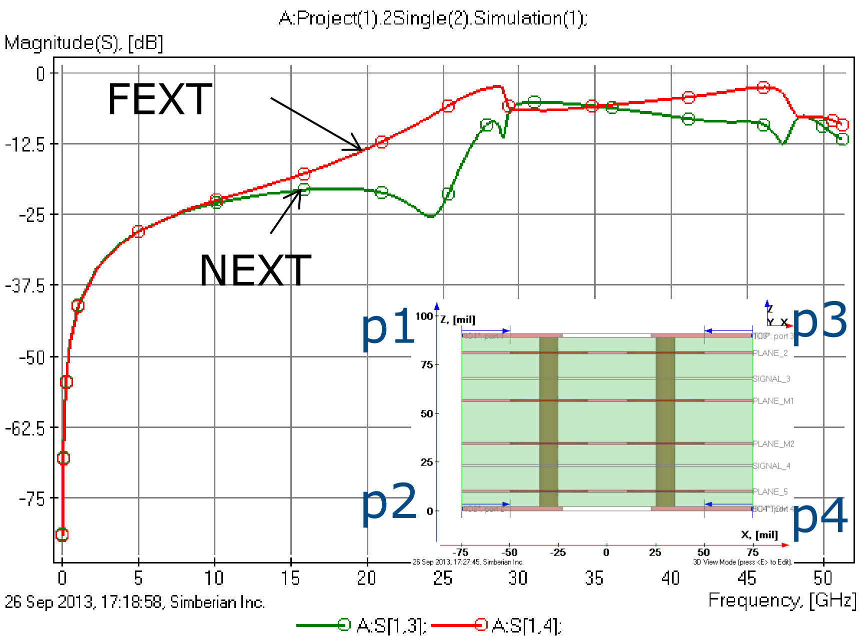




Single-ended vias – case 2

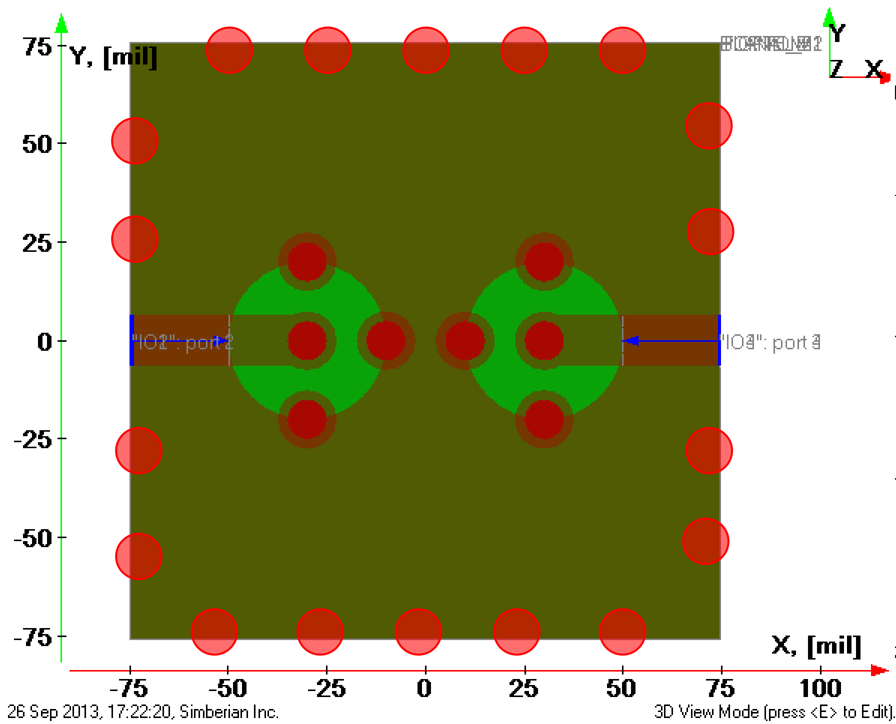
- Two un-coupled vias in a 150 x 150 mil area caged with PEC wall (stitching vias)
- Vias are 60 mil apart, antipad diameters 40 mil
- Separation reduced NEXT below 25 GHz, but FEXT is increased above 10 GHz – vias are coupled through the cavity (may be the whole board)!

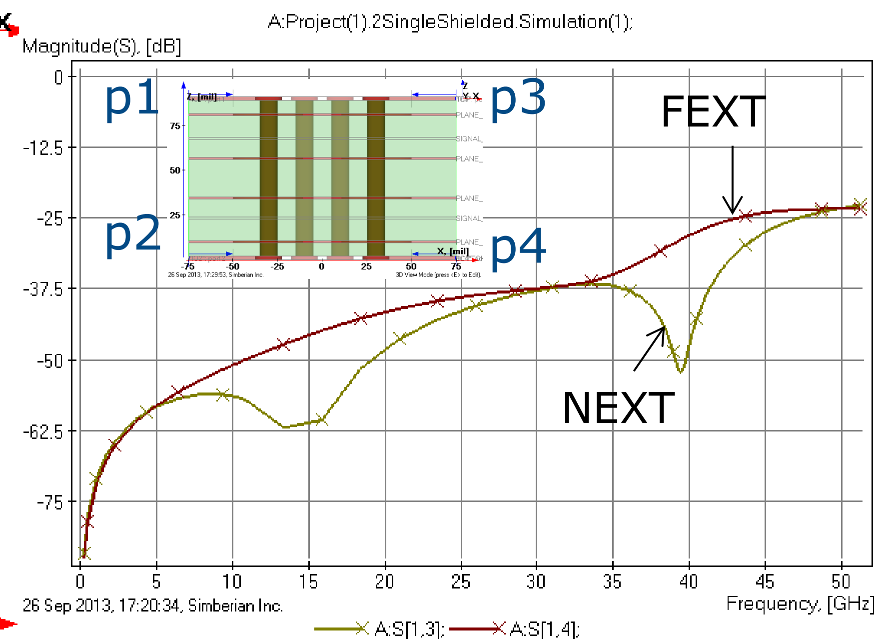




Single-ended vias – case 3

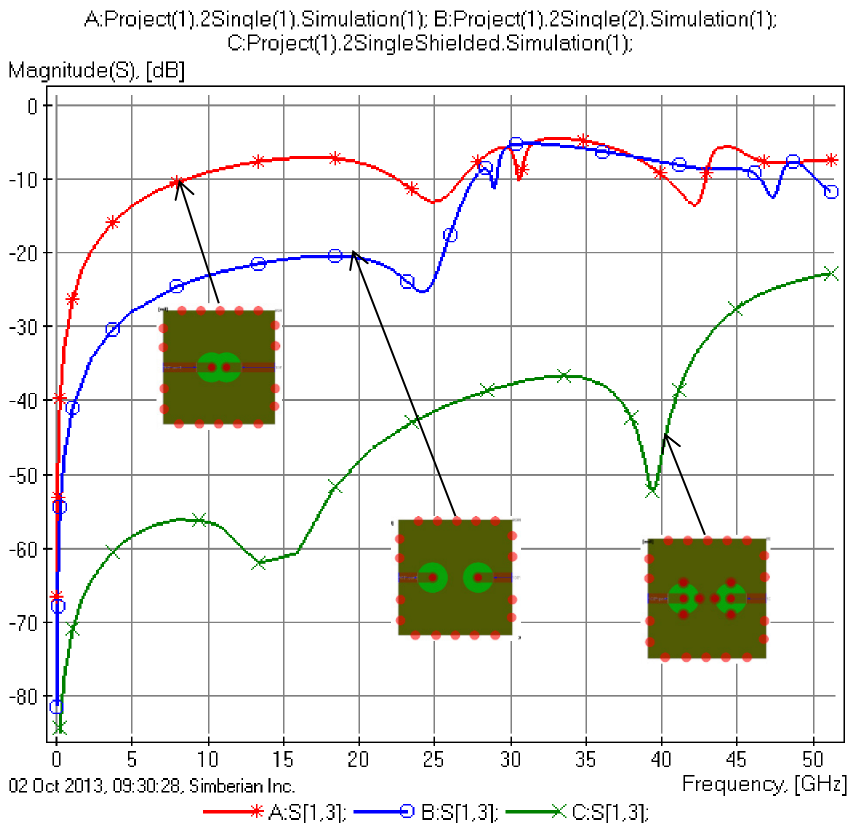
- Two shielded vias in a 150 x 150 mil area caged with PEC wall (stitching vias)
- Vias are 60 mil apart, antipad diameters 40 mil, stitching vias are 20 mil from the signal vias – localized up to about 30 GHz
- No cross-talk due to the localization – also models for such vias do not depend on the caging or simulation area!



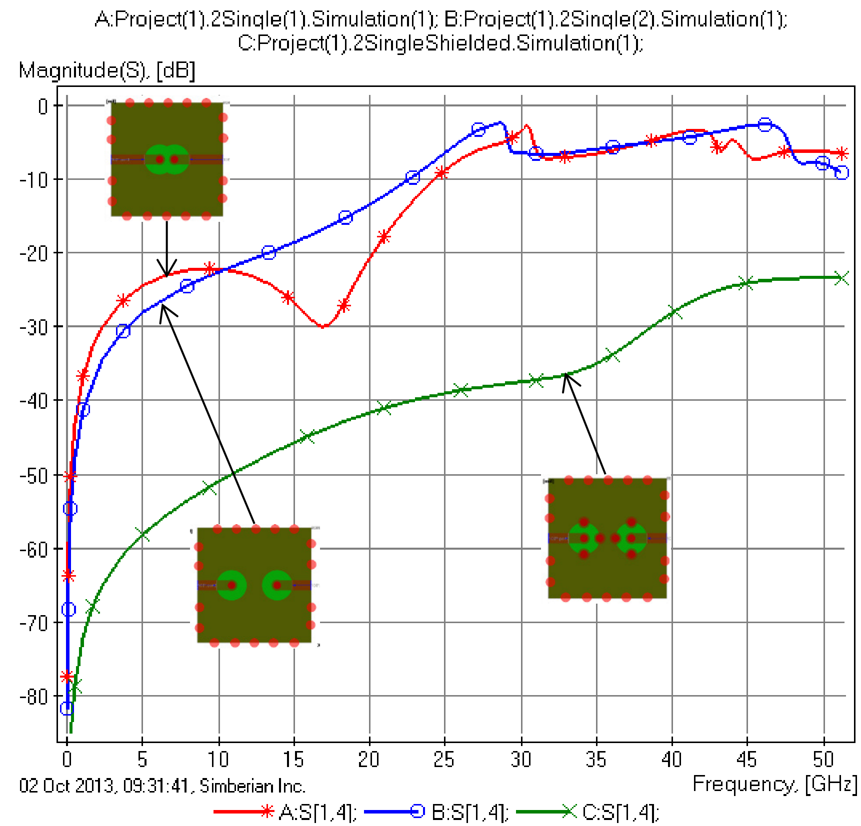


Cross-talk in single-ended vias

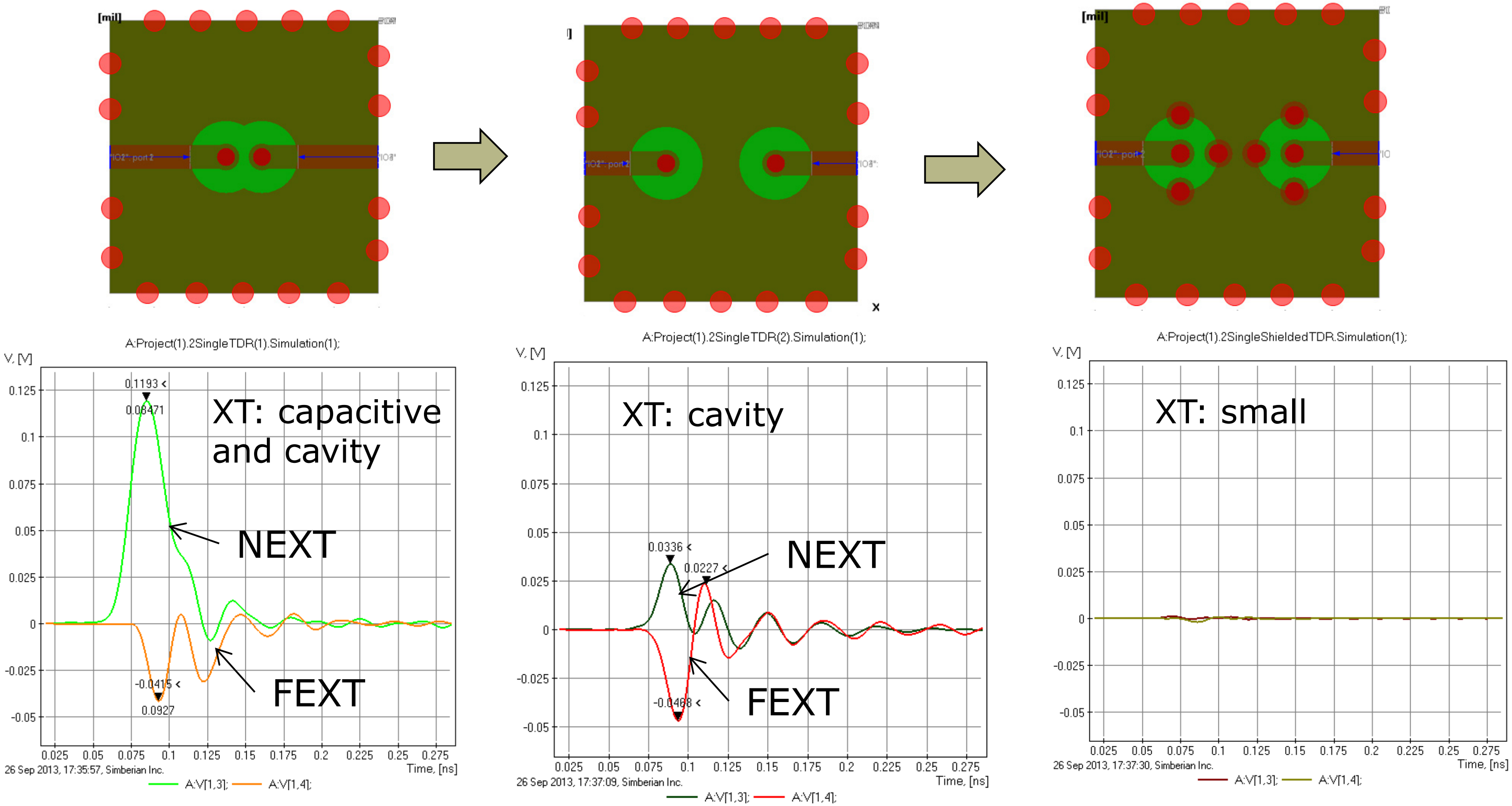
NEXT



FEXT



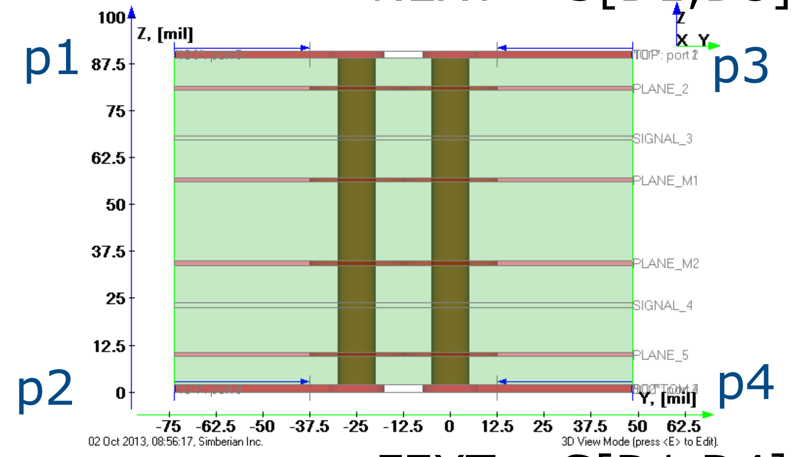
SE vias cross-talk on TDT: 0.5 V, 16 ps Gaussian step



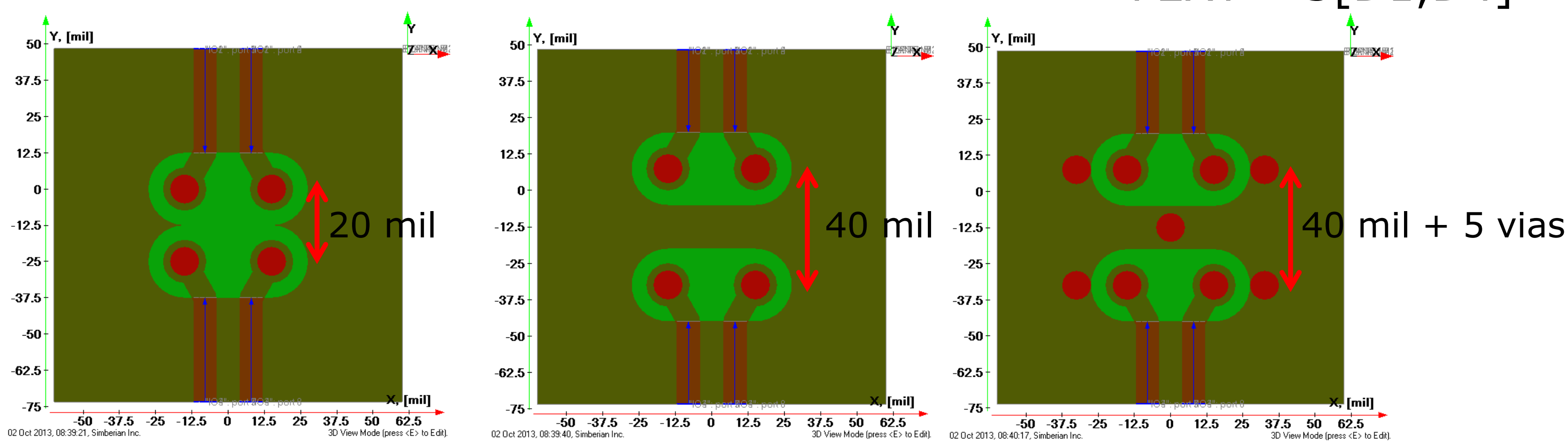
Are localized vias also optimal? – see FRSI via x-talk example at www.kb.simberian.com

Cross-talk in differential vias

Two coupled differential vias in a 120 x 120 mil area caged with PEC wall
Vias are 30 mil apart, antipad 25x55 mil, traces 8 mil MSL, 8 mil separation;
The first cage resonance is at about 12 GHz (half wavelength in dielectric)
Stackup from CMP-28 board, Wild River Technology http://wildrivertech.com

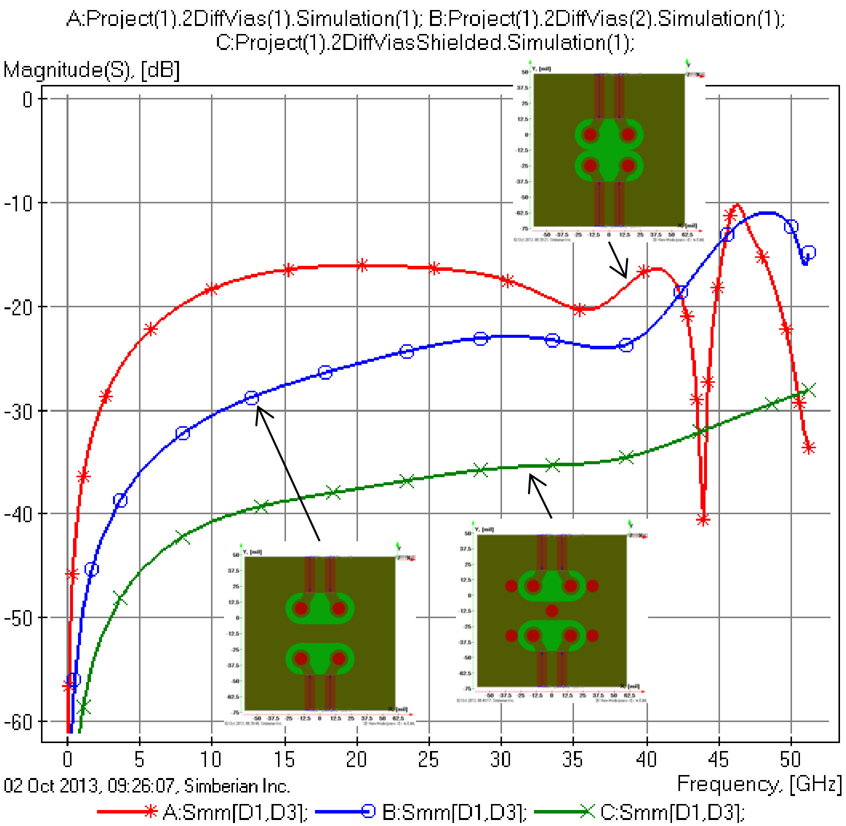


Three cases:

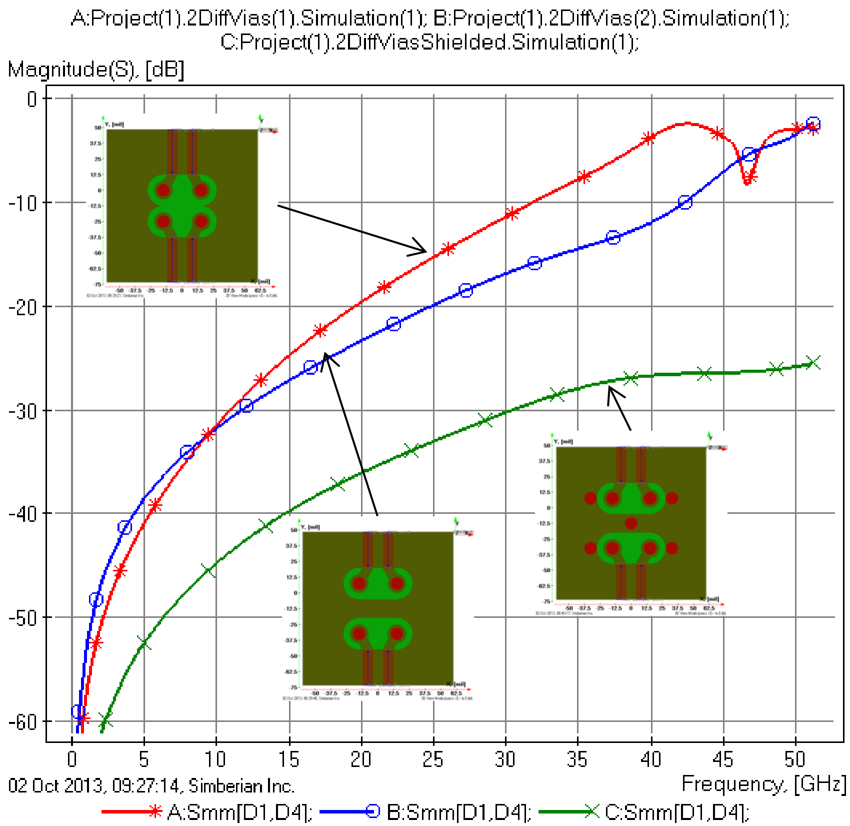


Cross-talk in differential vias

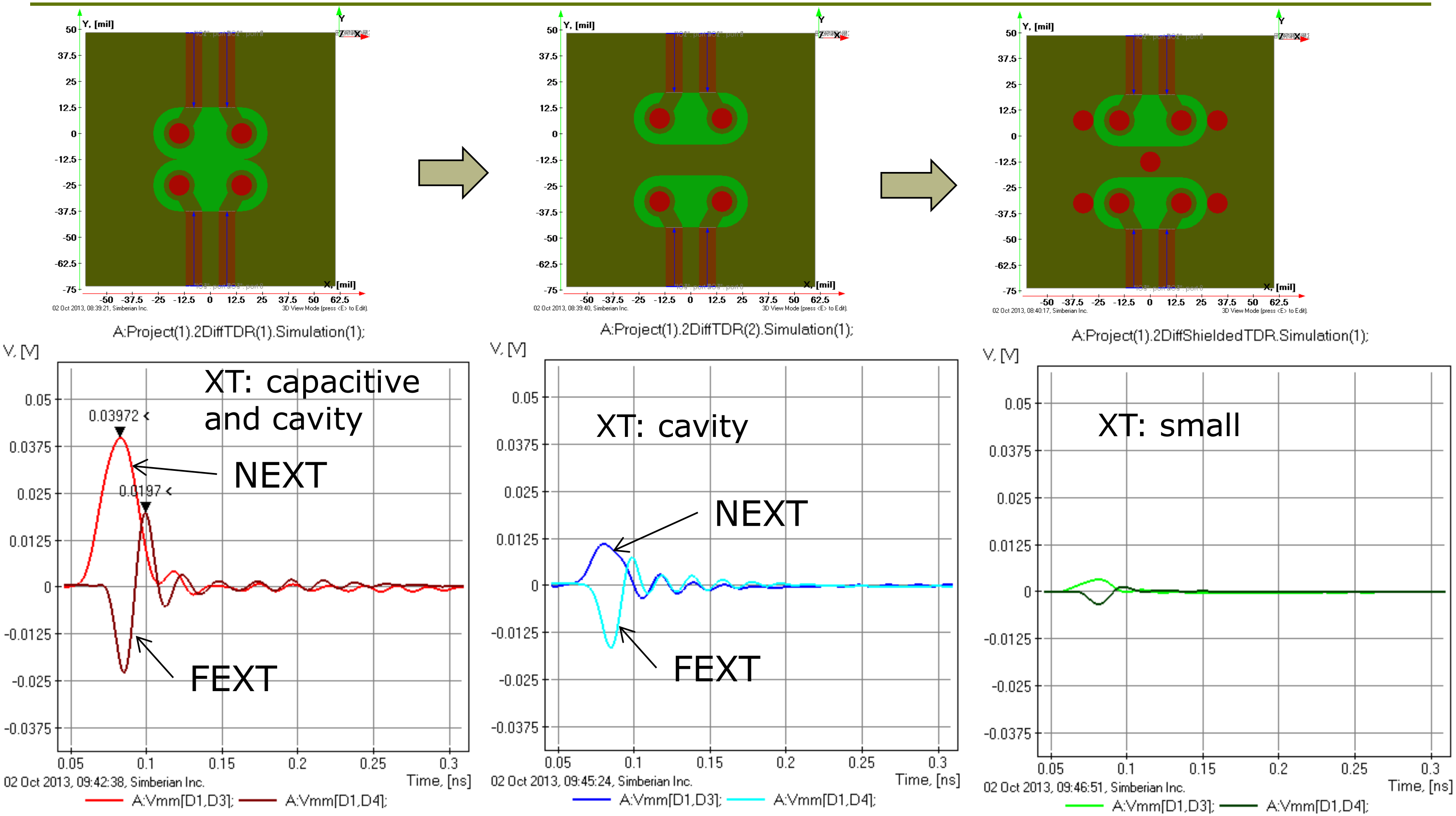
NEXT



FEXT



Differential vias cross-talk on TDT: 0.5 V, 16 ps Gaussian step



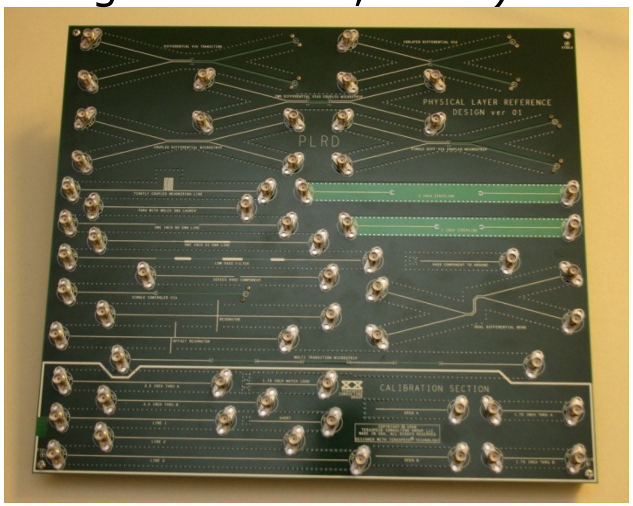
Are localized vias also optimal? – see FRSI via x-talk example at www.kb.simberian.com

Benchmarking or validation

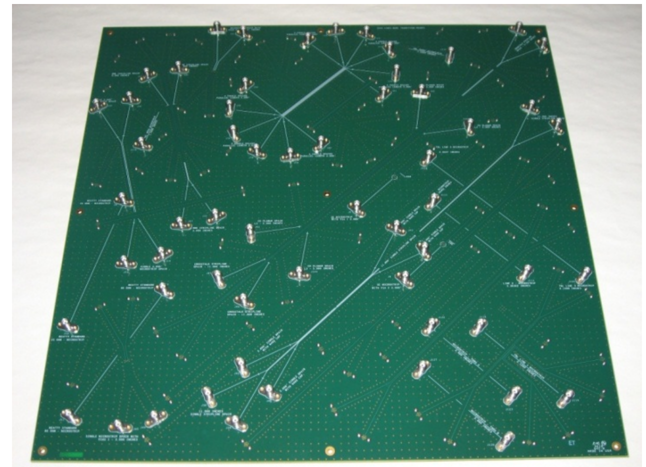
- How to make sure that the analysis works? – Validation boards!
- Consistent board manufacturing is the key for success
  - Fiber type, resin content, copper roughness must be strictly specified or fixed!!!
- Include a set of structures to identify one material model at a time
  - Solder mask, core and prepreg, resin and glass, roughness, plating,…
- Include a set of structures to identify accuracy for transmission lines and typical discontinuities
  - Use identified material models for all structures on the board consistently
  - No tweaking - discrepancies should be investigated
- Use VNA/TDNA measurements and compare both magnitude and phase (or group delay) of all S-parameters

Example of benchmarking boards

PLRD-1 (Teraspeed Consulting, DesignCon 2009, 2010)

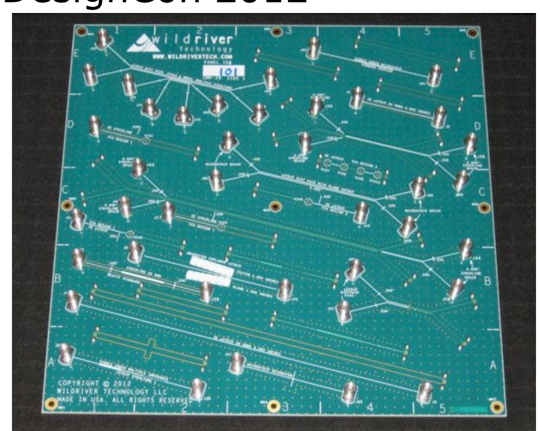


CMP-08 (Wild River Technology & Teraspeed Consulting, DesignCon 2011)



Isola, EMC 2011, DesignCon 2012

CMP-28, Wild River Technology, DesignCon 2012



Conclusion

- Validate all ideas with EM analysis
- Build only things that can be reliably analyzed!
- Decompositional analysis is the fastest and most accurate way to simulate interconnects ONLY IF
  - All S-parameter models in the link are qualified
  - Material parameters are properly identified
  - Interconnects are designed as localized waveguides
  - Manufacturer, measurements and models are benchmarked
- Examples created for this presentation are available at www.kb.simberian.com (use FRSI keyword)

Contact and resources

- Yuriy Shlepnev, Simberian Inc.,
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  Tel: 206-409-2368
- **Webinars on decompositional analysis, S-parameters quality and material identification http://www.simberian.com/Webinars.php**
- Simberian web site and contacts www.simberian.com
- Demo-videos http://www.simberian.com/ScreenCasts.php
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