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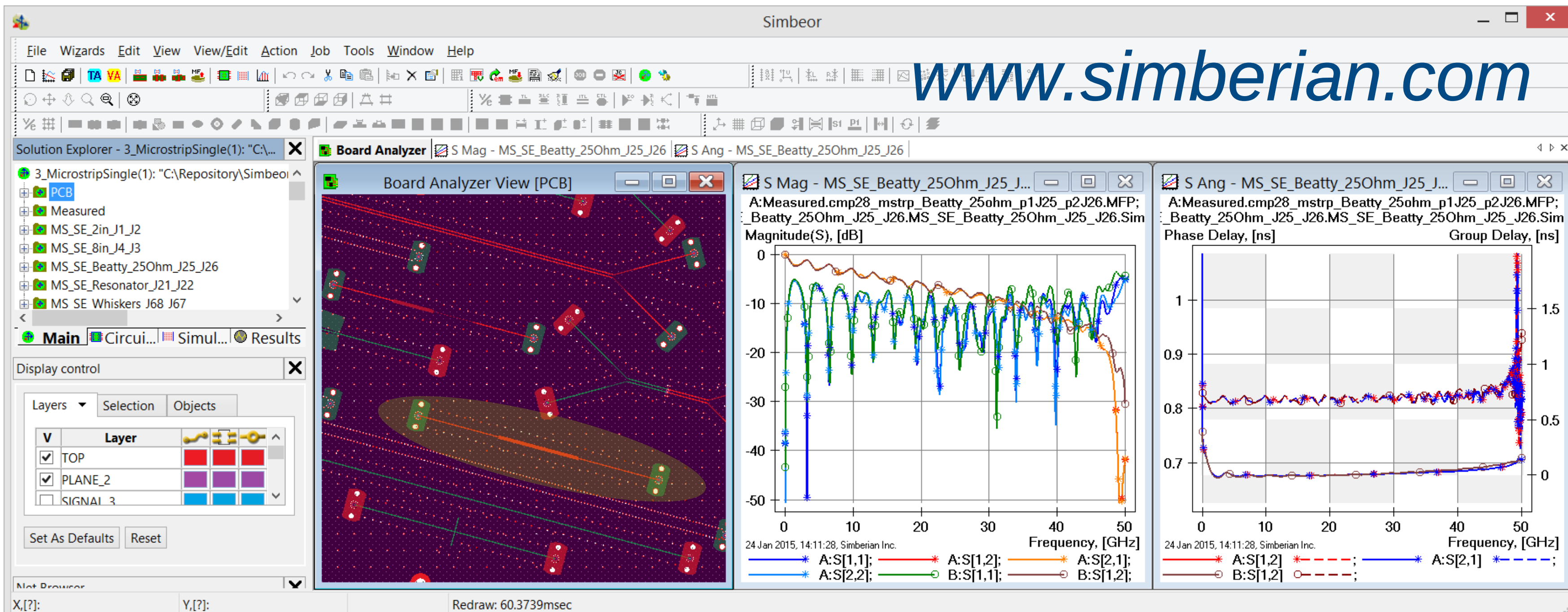
Simberian Electromagnetic Solutions

Simbeor Application Note #2017_03, August 2017

Identification of dielectric and conductor roughness models with differential lines



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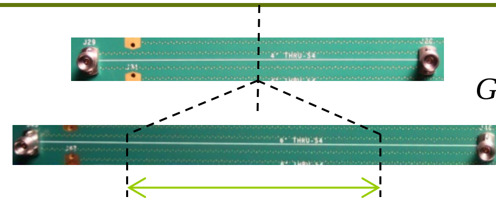
Outline

- Model identification with GMS-parameters
  - Step 1: Measure S-parameters for 2 line segment and ensure quality and consistency
  - Step2: Extract GMS-parameters
  - Step 3: Create model of line segment and compute GMS-parameters
  - Step 4: Identify dielectric and conductor roughness parameters
- Create model with two dielectrics (FEXT)
- Appendix: Results with causal Huray-Bracken roughness model

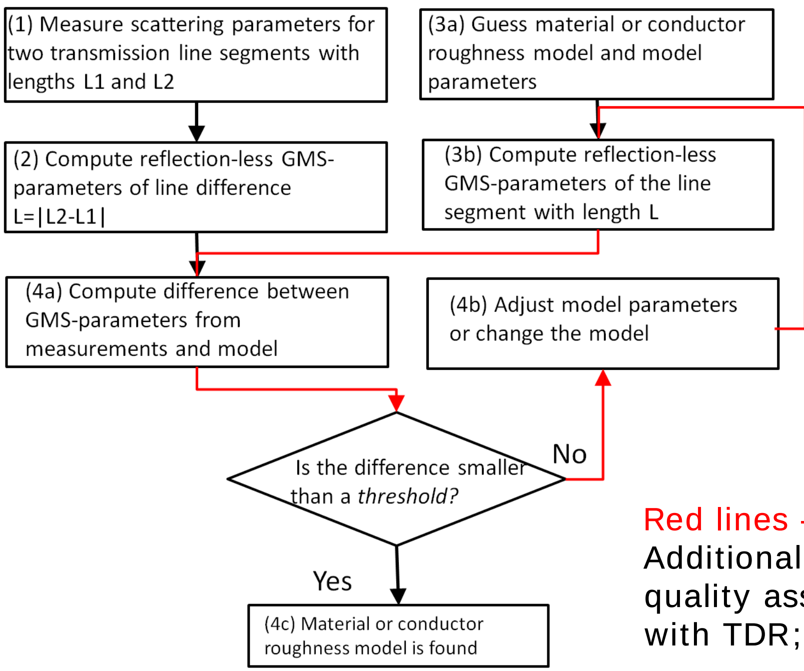
Identification with GMS or SPP techniques

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

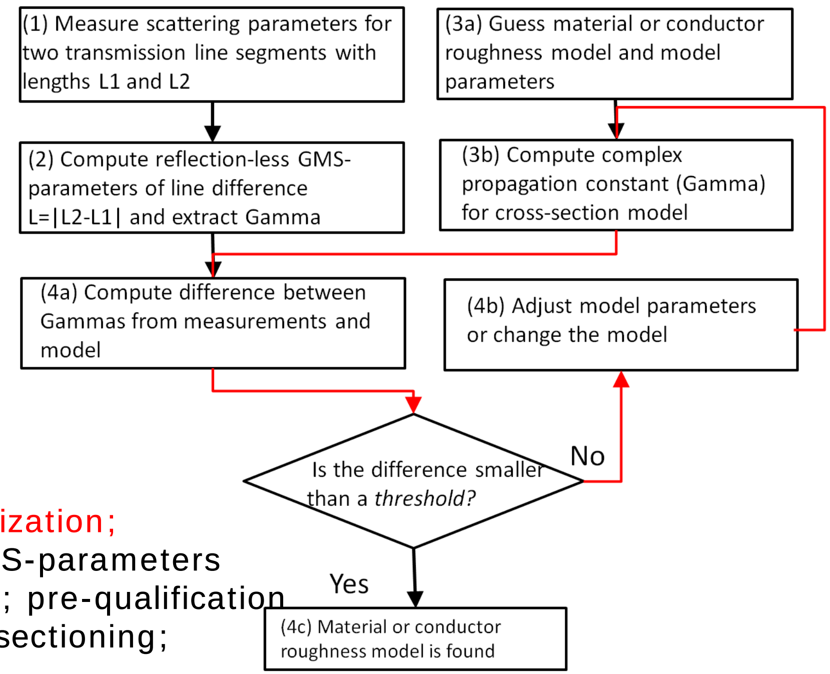


$$GMT = eigenvals\left(T2 \cdot T1^{-1}\right) = \begin{pmatrix} \exp(-\Gamma \cdot L) & 0 \\ 0 & \exp(\Gamma \cdot L) \end{pmatrix}$$

Use of raw GMS-parameters



Gamma extraction – "SPP Light"

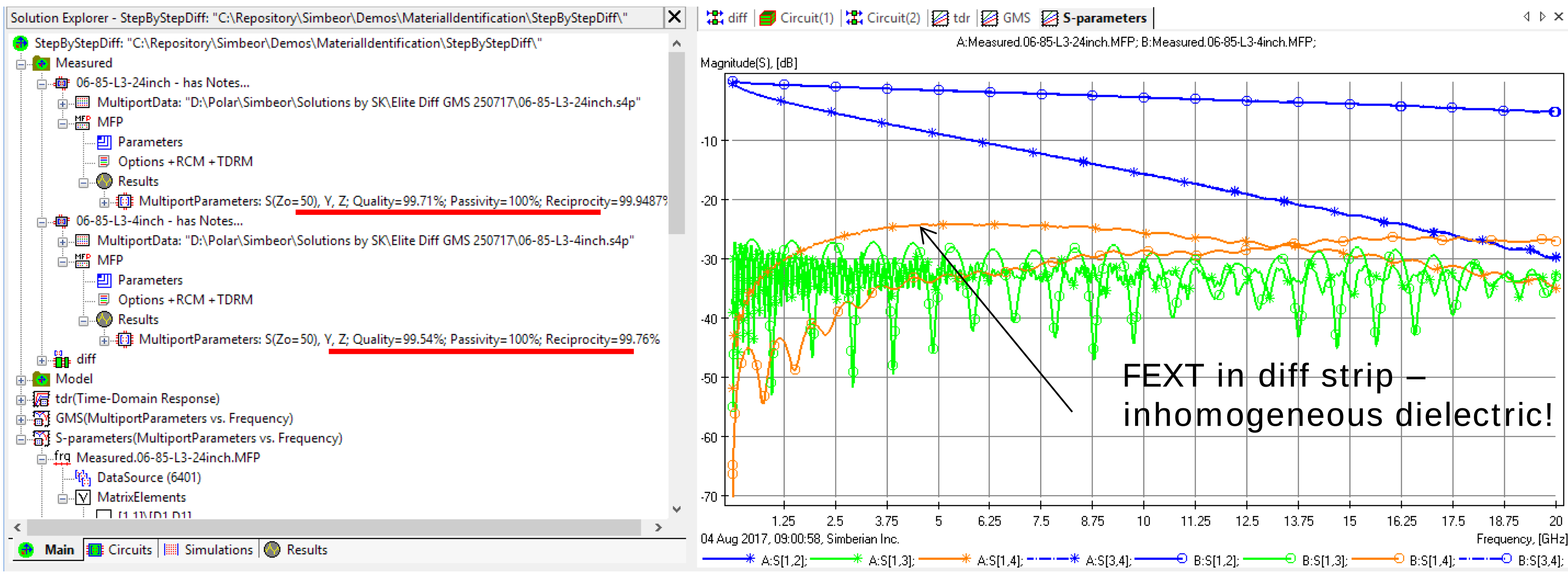


Red lines – optimization;
Additional steps: S-parameters quality assurance; pre-qualification with TDR; Cross-sectioning;

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.

Step 1a: Measure S-parameters of 2 line segments, import into Simbeor and ensure quality

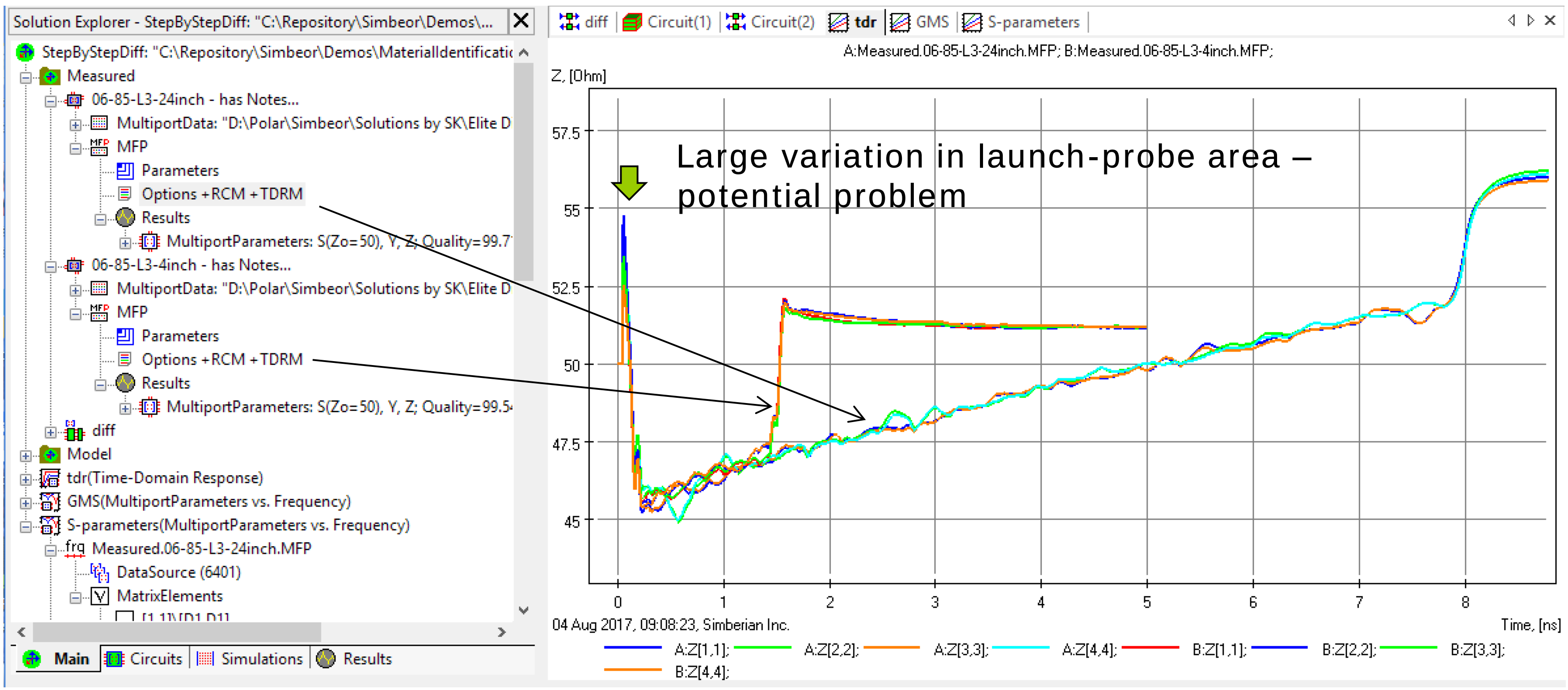
Quality of S-parameters of 24 inch in and 4 inch segment is good



See more on the import of S-parameters and quality assurance at
http://kb.simberian.com/browse_item.php?id=775
http://kb.simberian.com/browse_item.php?id=240

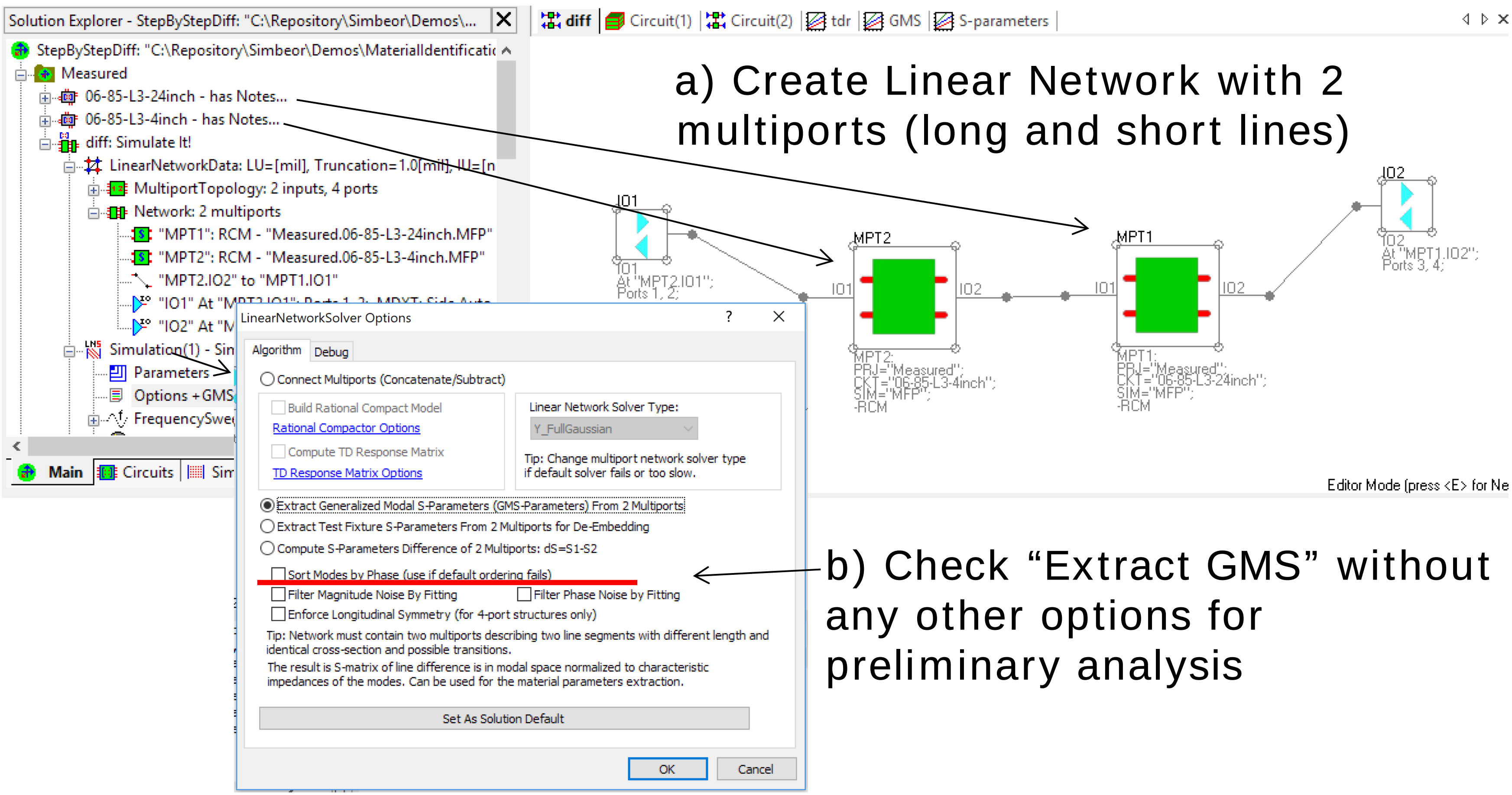
Step 1b: Ensure quality of test fixtures with TDR computed from S-parameters

TDRs of short and long segments are consistent, except the launch area
Traces are about 46 Ohm



See more on TDR computation at
http://kb.simberian.com/browse_item.php?id=202

Step 2: Extract GMS-parameters

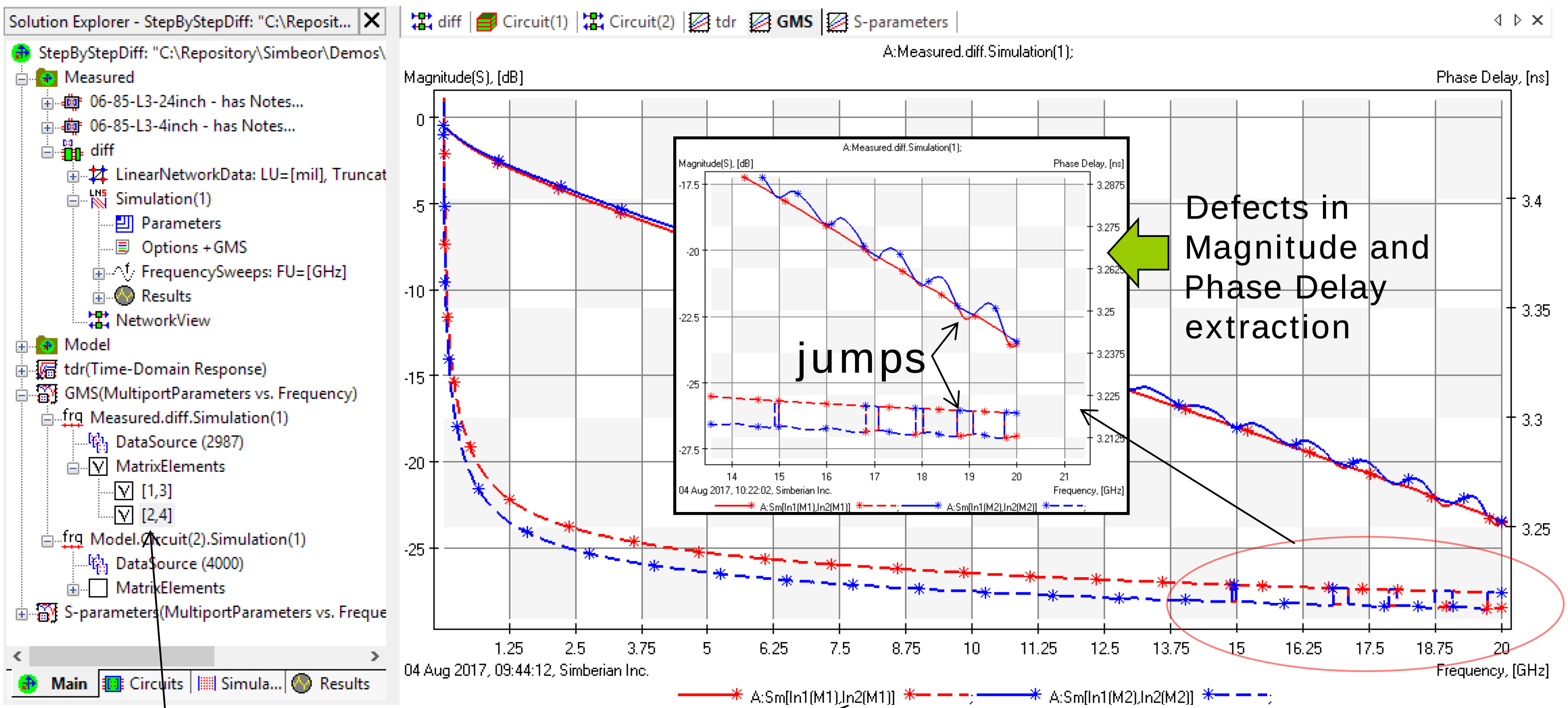


a) Create Linear Network with 2 multiports (long and short lines)

b) Check “Extract GMS” without any other options for preliminary analysis

See details and recommendations at
http://kb.simberian.com/browse_item.php?id=846

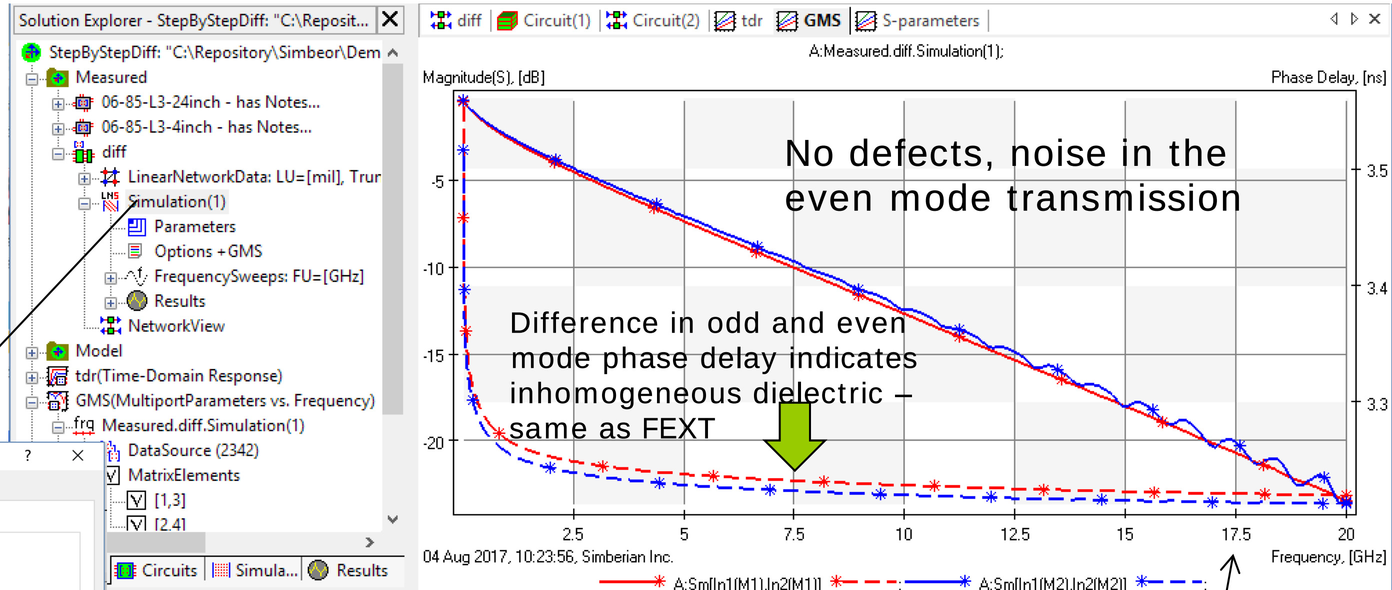
Step 2: Extract GMS-parameters – plot Magnitude and Phase Delay

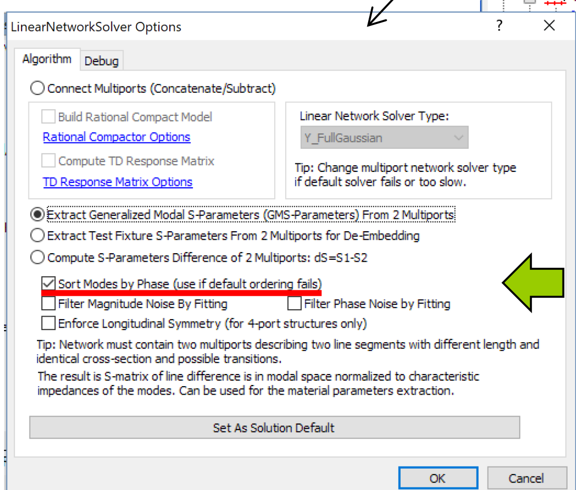


Elements GMS[1,3] – odd or differential mode transmission, GMS[2,4] – even or common mode transmission

Mode M1 is odd, mode M2 is even

Step2: Extract GMS-parameters – use options to fix problems

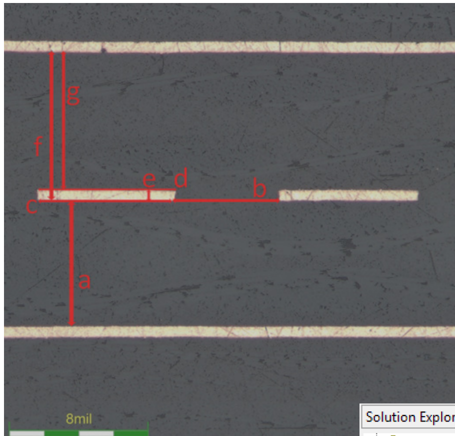




a) Check "Sort modes by phase" and optionally "Enforce Longitudinal Symmetry"
Filtering options are not recommended for noisy data – it distorts the results

b) re-run the analysis and observe GMS-parameters

Step 3a: Compute GMS-parameters of line segment – cross section

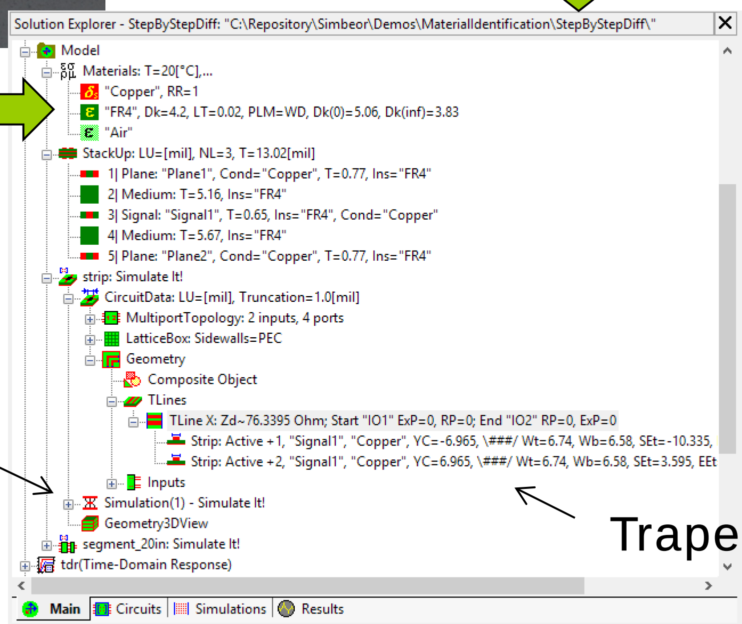


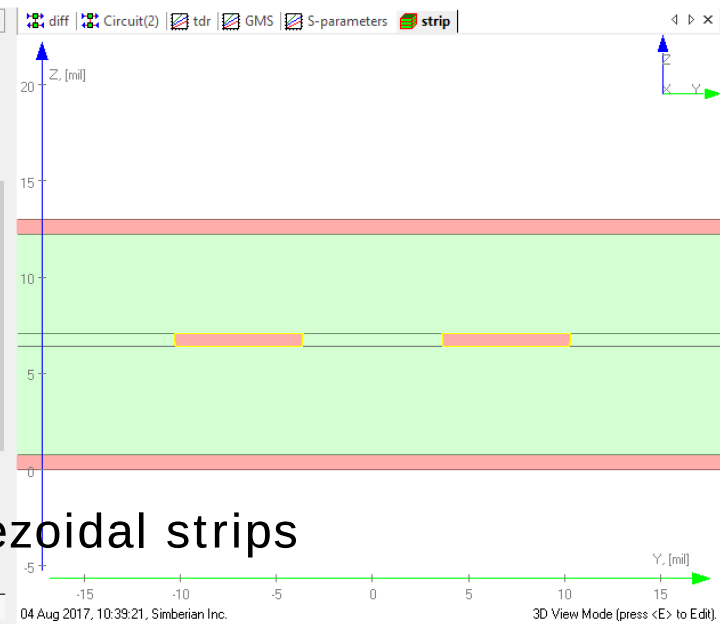
	85-L3-4inch	85-L3-24inch
Parameter	Avg.	Avg.
a	5.66	5.67
b	7.41	7.35
c	6.51	6.58
d	6.67	6.74
e	0.65	0.65
f	5.80	5.82
g	5.15	5.16

Create model of differential strip cross-section – Wizards -> Create TLine Model…

Preliminary material models

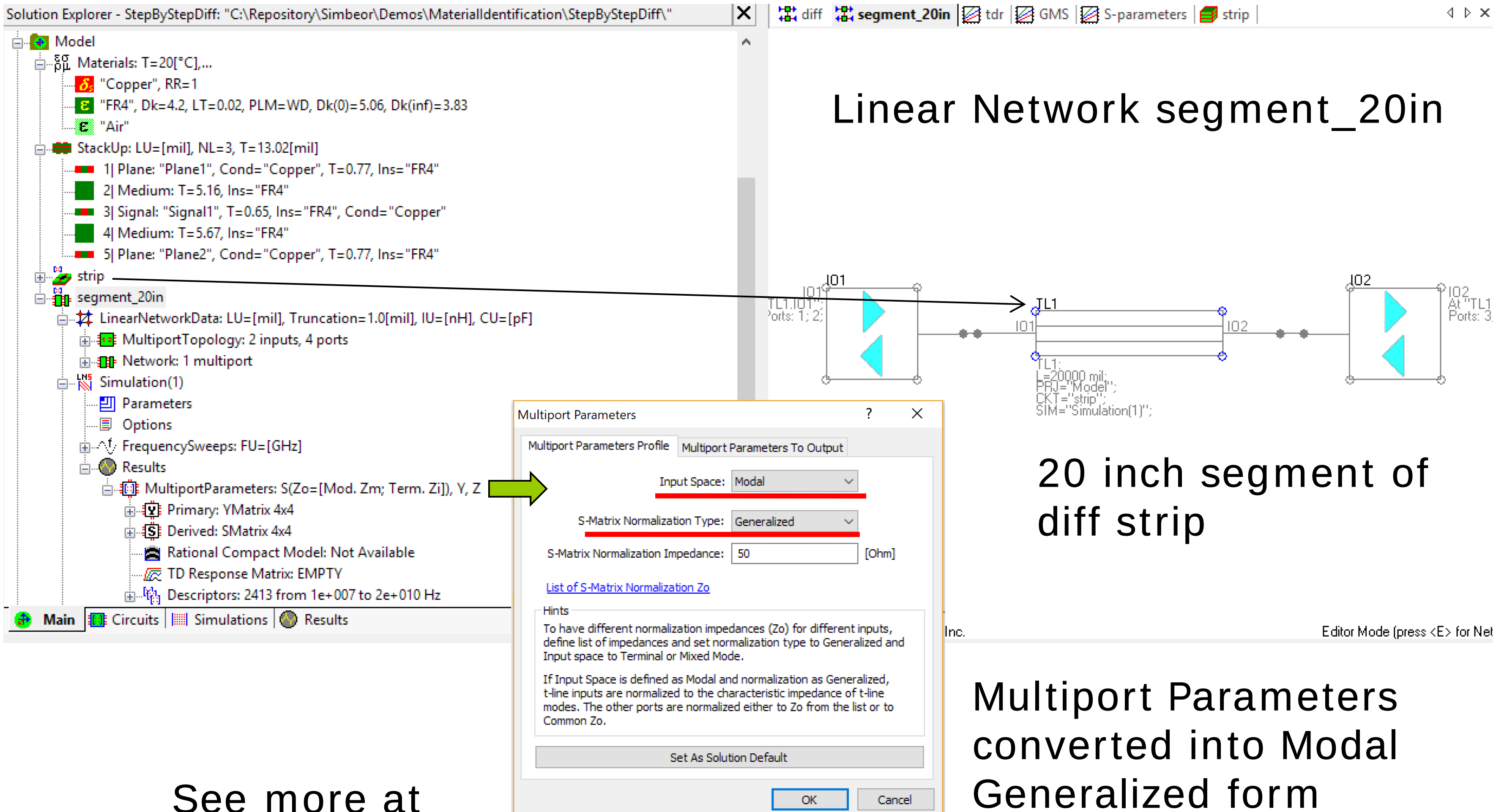
Simbeor SFS solver is used for strips





Trapezoidal strips

Step 3b: Compute GMS-parameters of line segment – model 20 inch diff strip segment



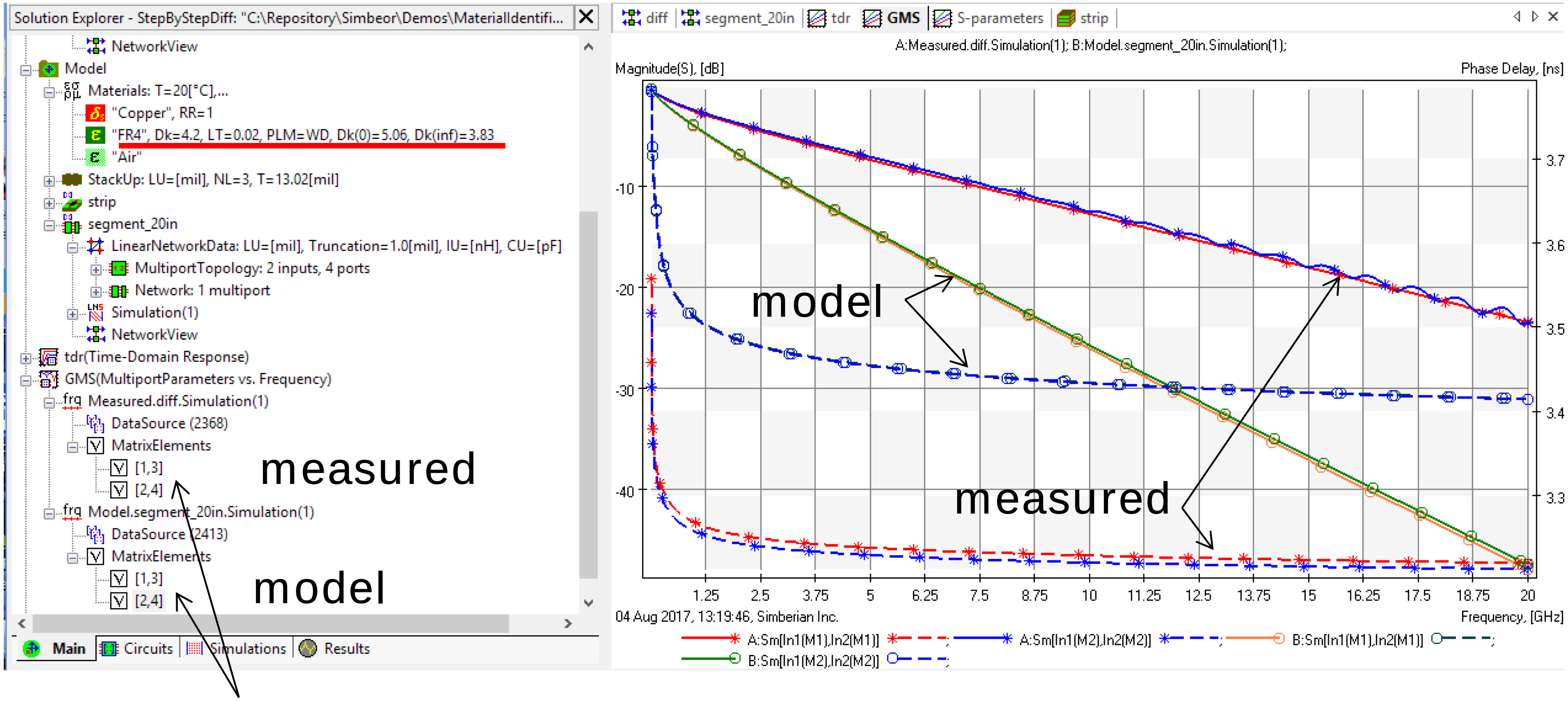
Linear Network segment_20in

20 inch segment of diff strip

Multiport Parameters converted into Modal Generalized form

See more at http://kb.simberian.com/browse_item.php?id=847

Step 3c: Plot GMS-parameters of the model



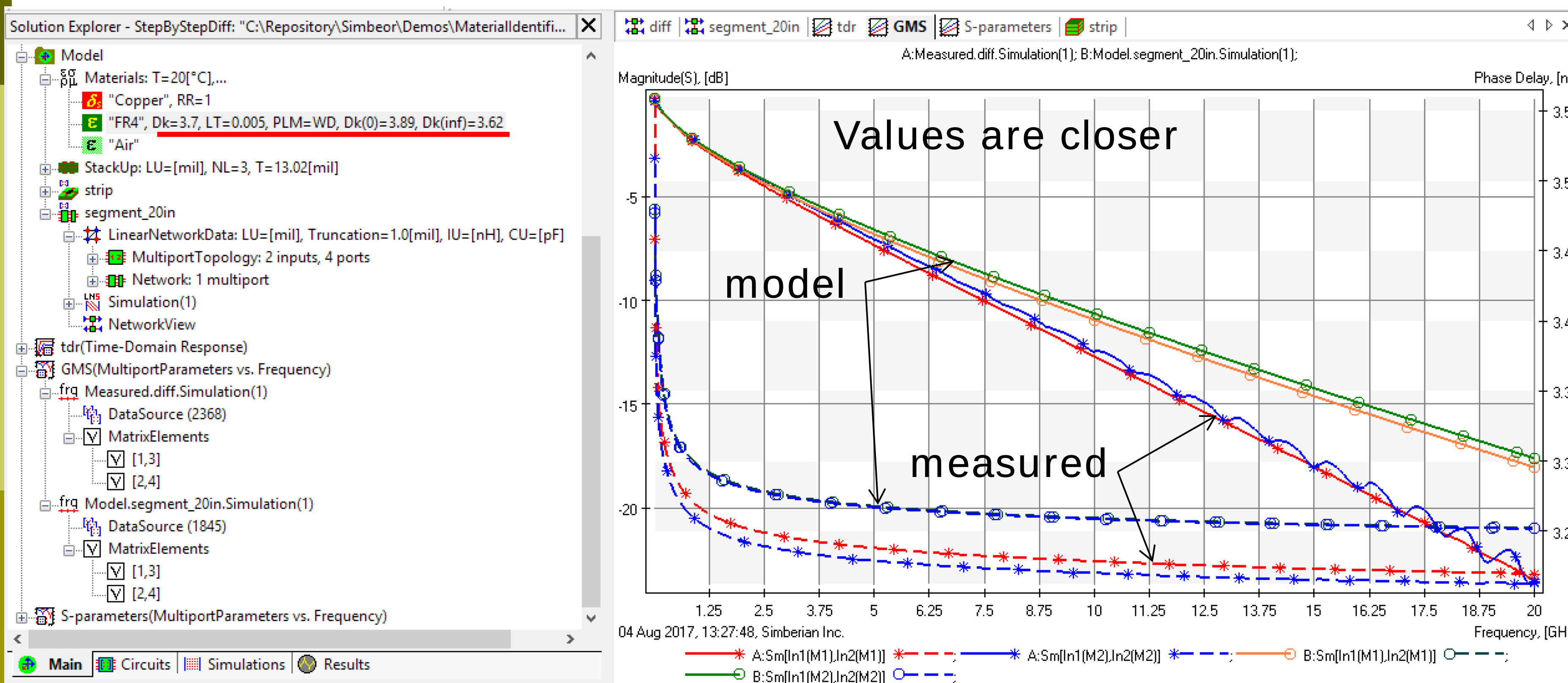
Elements GMS[1,3] – odd or differential mode transmission, GMS[2,4] – even or common mode transmission

Mode M1 is odd, mode M2 is even

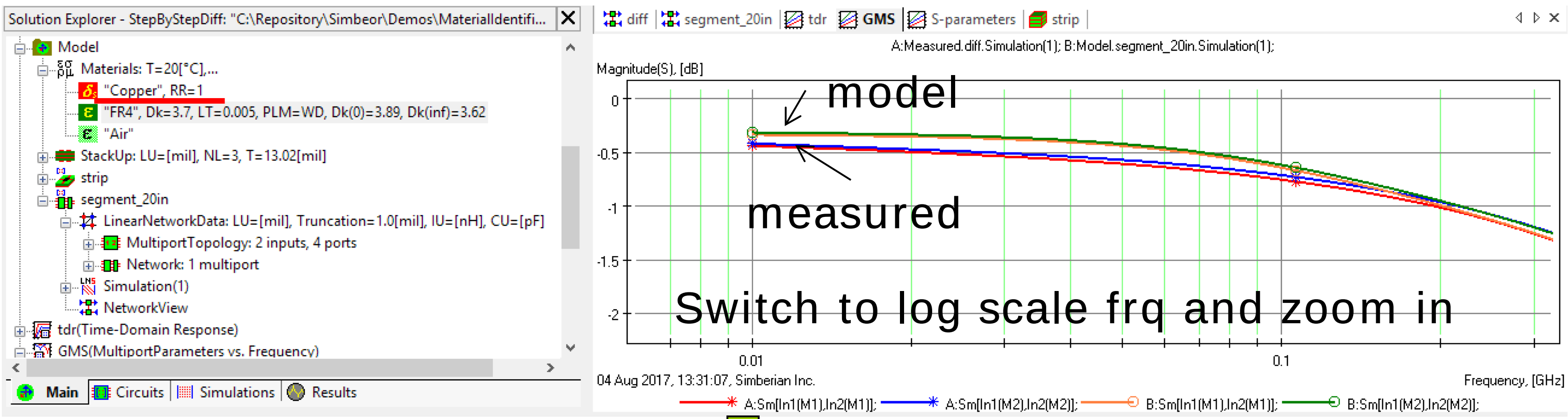
The first adjustment can be done without SiTune – from the Phase Delay we can see that the Dk and LT should be much lower (4.2 and 0.02@ 1 GHz are specified as the starting point)

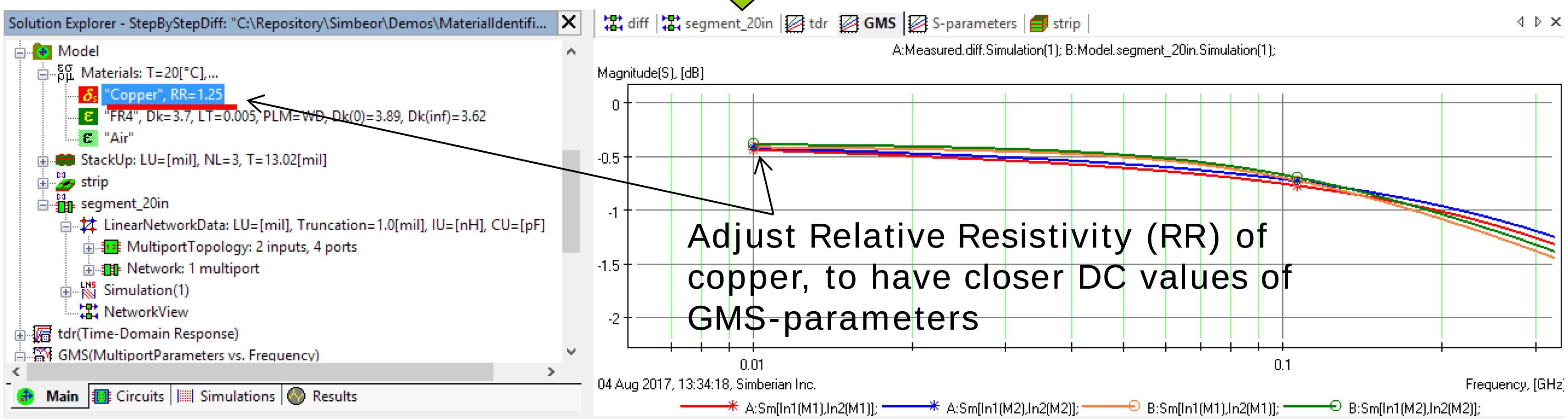
Step 4a: Manually adjust Dk and LT to have model GMS-parameters closer to measured

For instance, adjust Dk to 3.7 and LT to 0.005 and re-run the analysis



Step 4b: Manual adjustment of resistivity



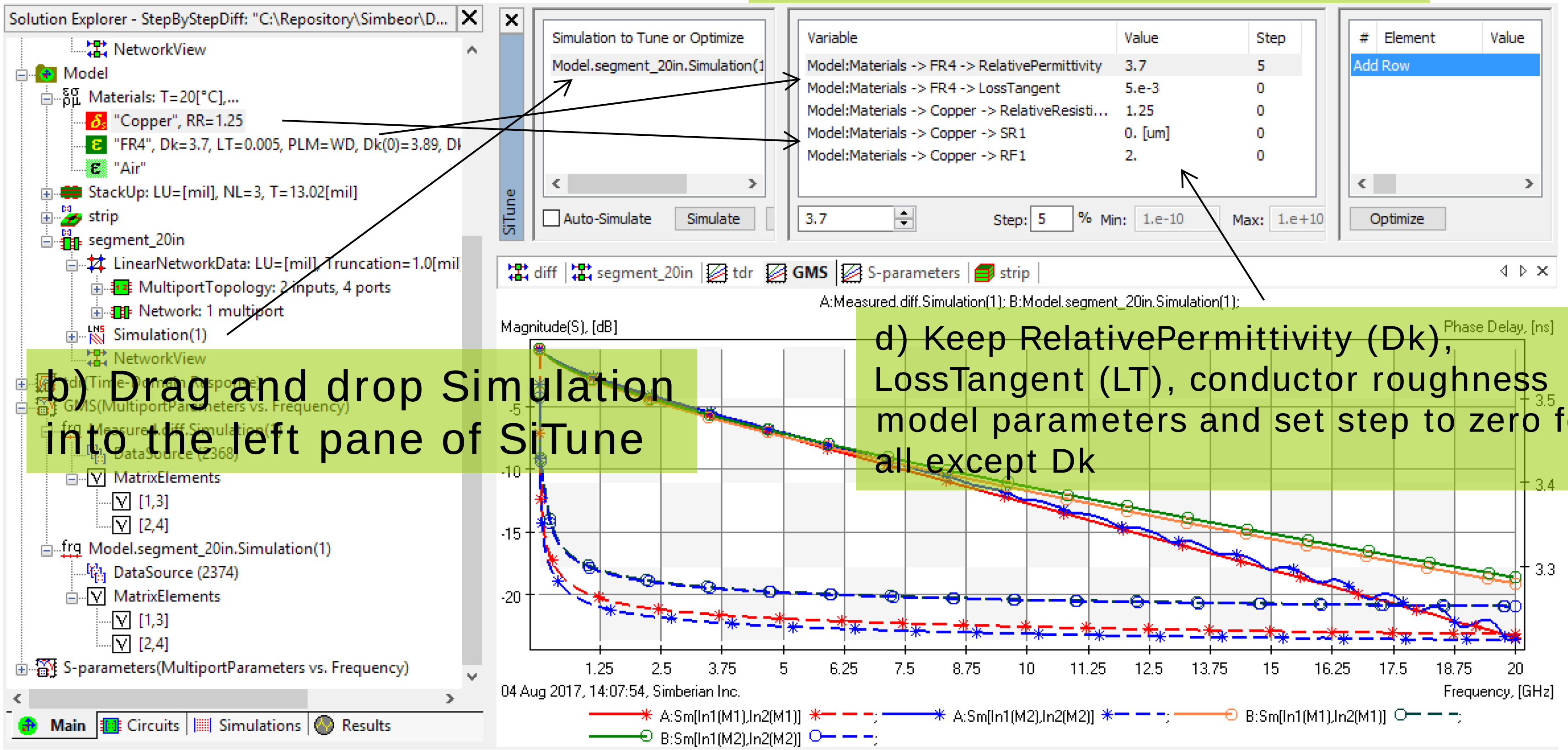


RR=1.25 gives better DC match, but this is questionable adjustment!

Step 4c: Bring model parameters into SiTune for the optimization

a) Open SiTune from Tools menu

c) Drag and drop Copper and FR4 into variable pane



b) Drag and drop Simulation into the left pane of SiTune

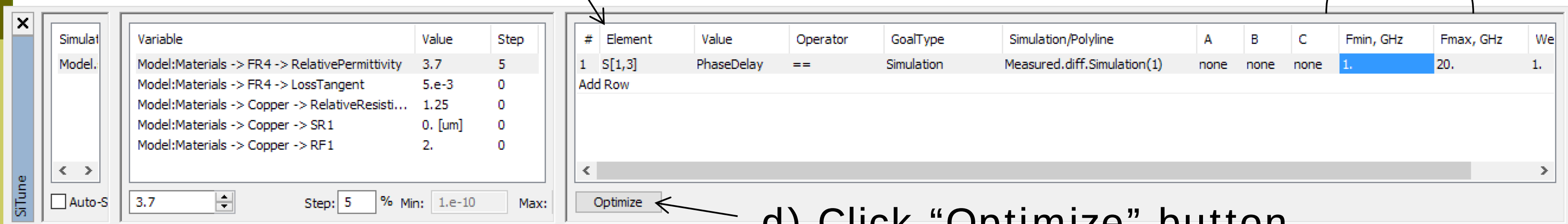
d) Keep RelativePermittivity (Dk), LossTangent (LT), conductor roughness model parameters and set step to zero for all except Dk

Step 4c: Set up goal for Dk

a) For GMS odd mode transmission parameter

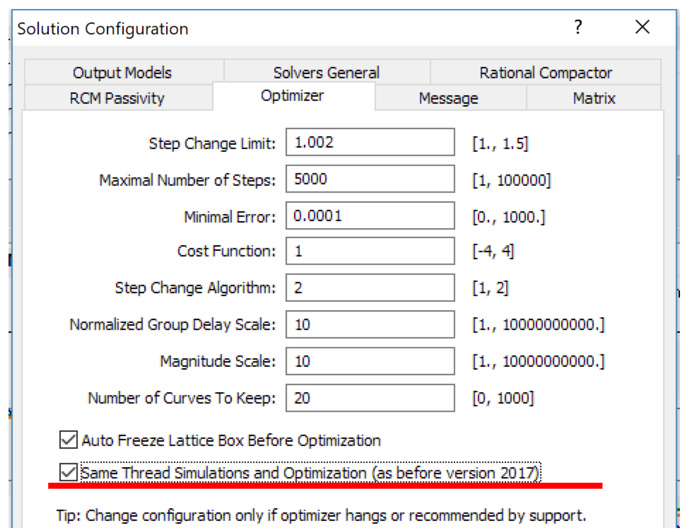
b) Match Phase Delay to Measured GMS-par.

c) From 1 to max frequency (20 GHz in this case)



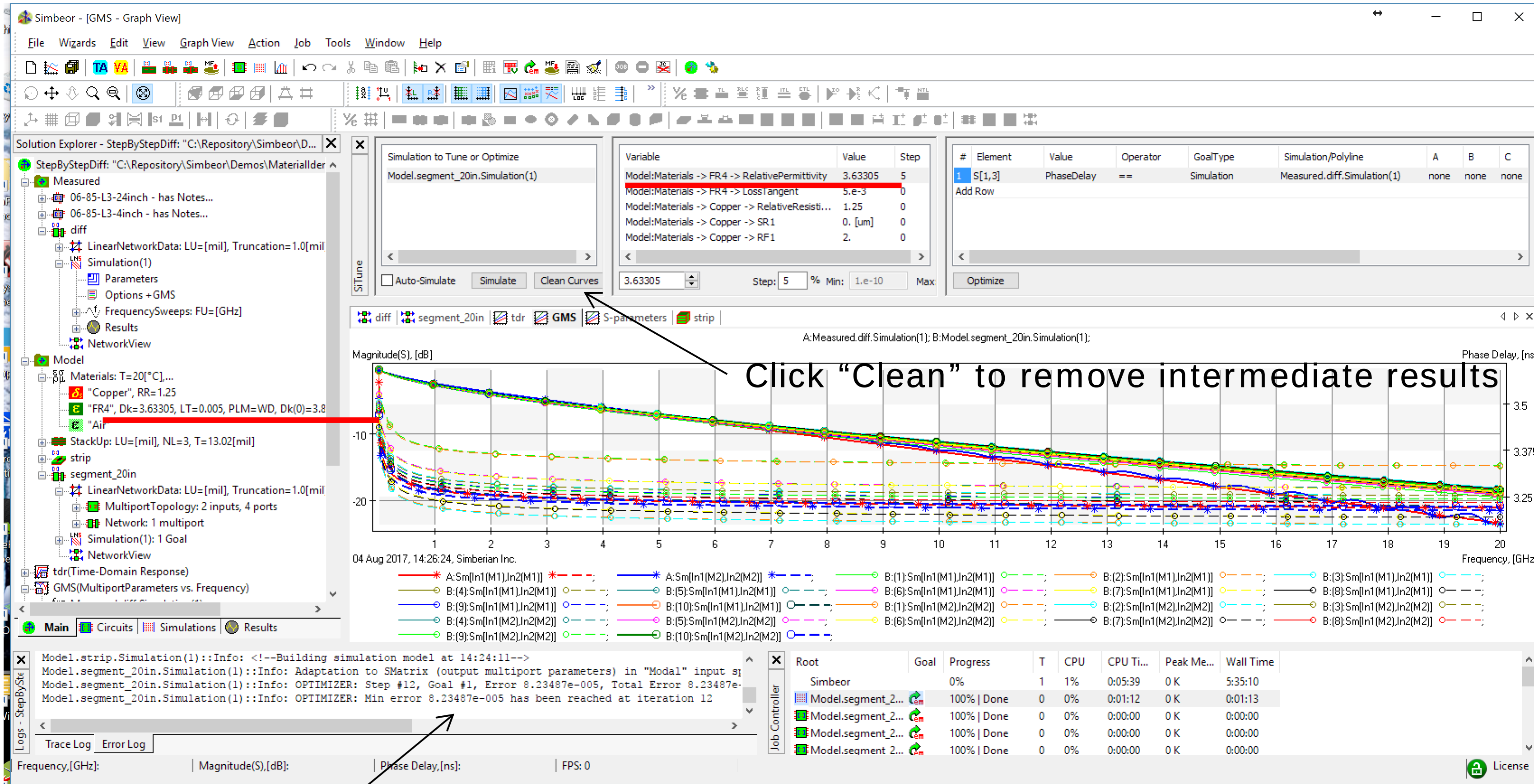
d) Click “Optimize” button

Optionally, check “Same Thread Simulation” in Solution -> Configuration -> Optimizer, to run all simulations during the optimization in one thread (each simulation will be parallelized if necessary)



Step 4c: Dk optimization result

Dk value matching measured and simulated GMS Phase delay



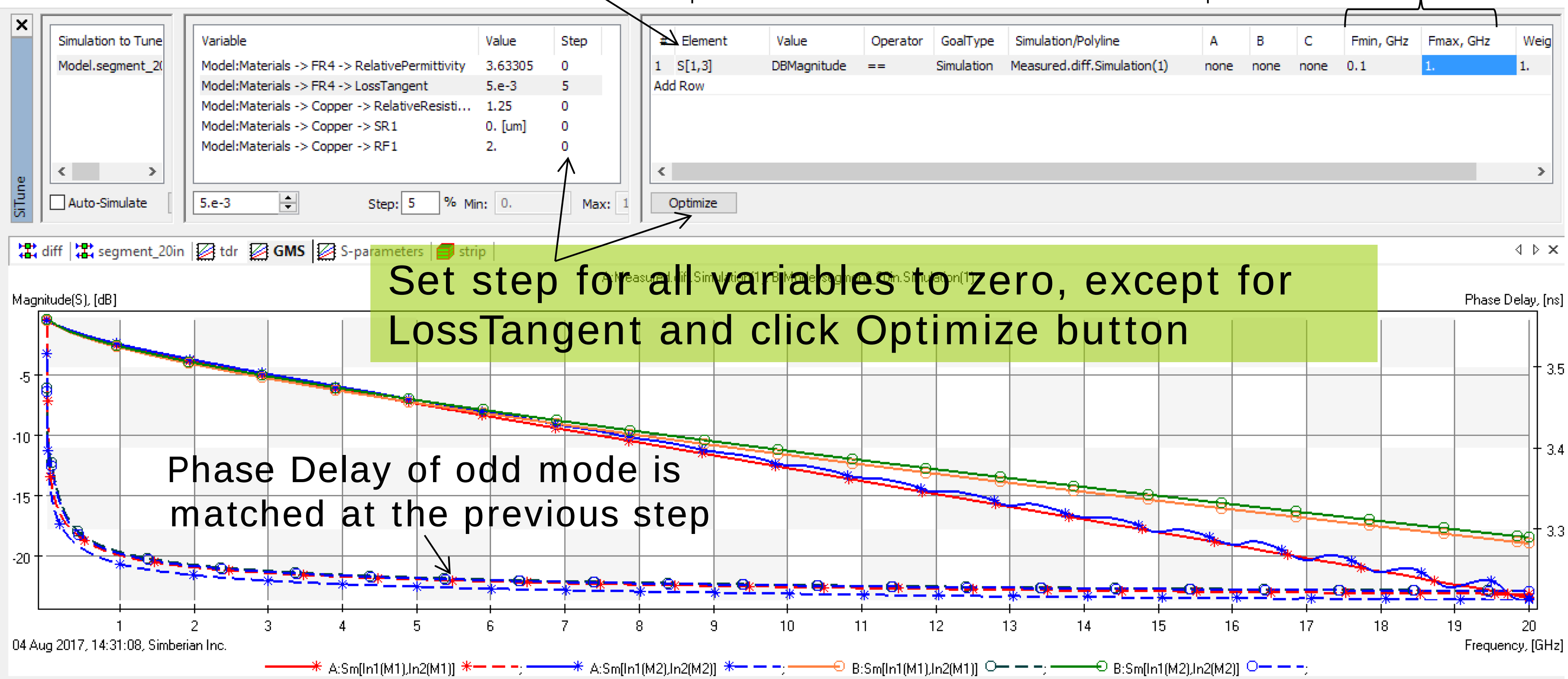
Final RMS Error

Step 4d: Set up goad for LT

a) For GMS odd mode transmission parameter

b) Match DBMagnitude to Measured GMS-par.

c) From 0.1 to 1-2 GHz



Set step for all variables to zero, except for LossTangent and click Optimize button

Phase Delay of odd mode is matched at the previous step

d) Run Optimization, Clean Curves

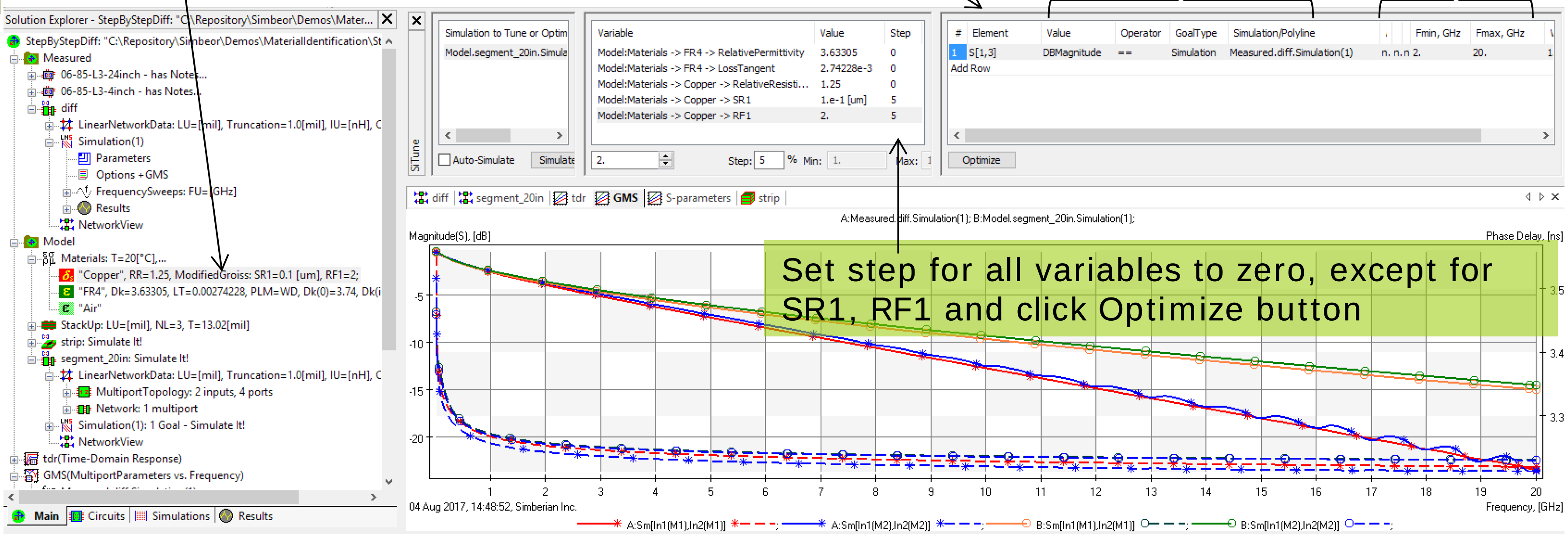
Step 4e: Identify conductor roughness model

First set Copper Roughness model type (Groiss in this case) and non-zero initial value for SR1

a) For GMS odd mode transmission parameter

b) Match DBMagnitude to Measured GMS-par.

c) From 2 to max frq. (20 GHz here)

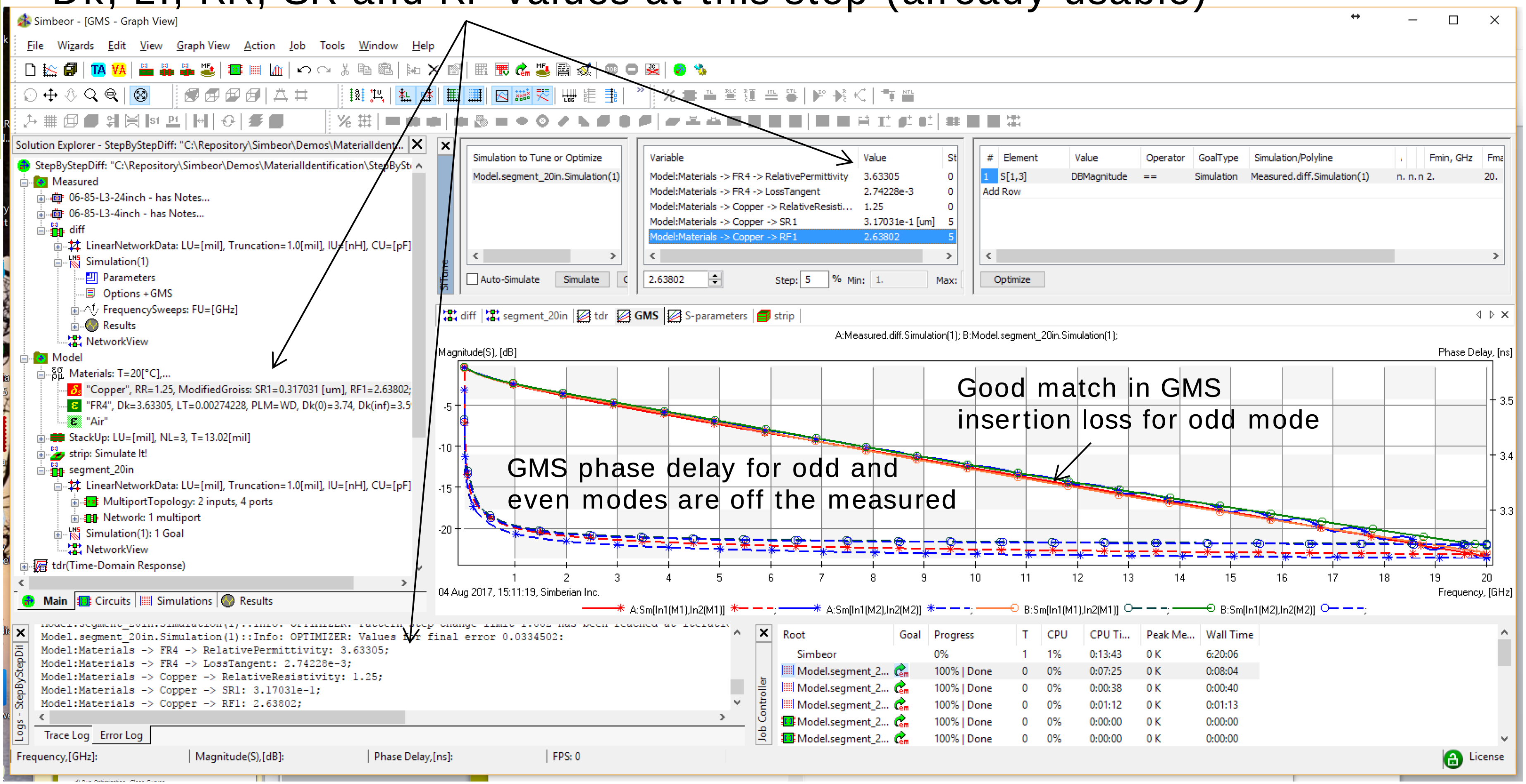


Set step for all variables to zero, except for SR1, RF1 and click Optimize button

d) Run Optimization, Clean Curves

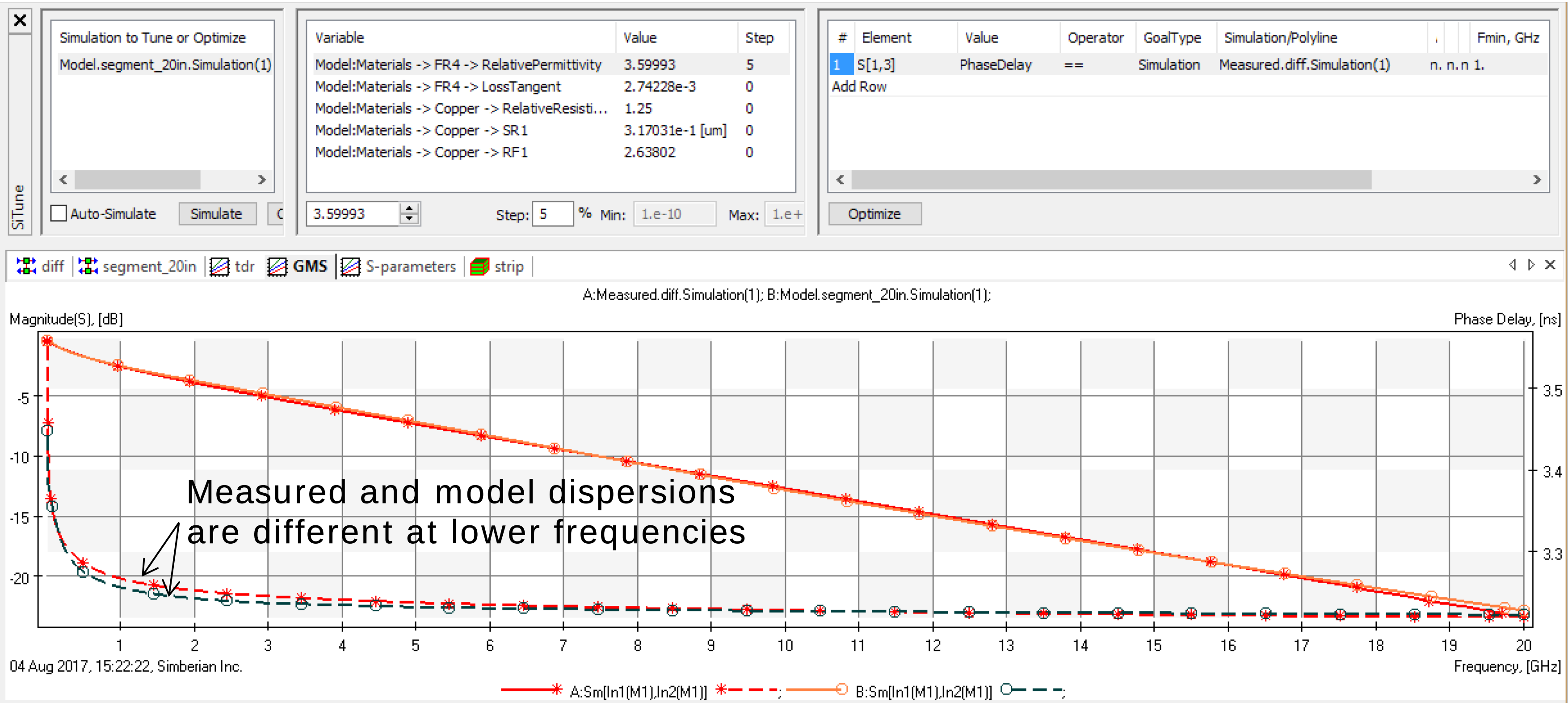
Step 4e: Analysis of preliminary results

Dk, LT, RR, SR and RF values at this step (already usable)



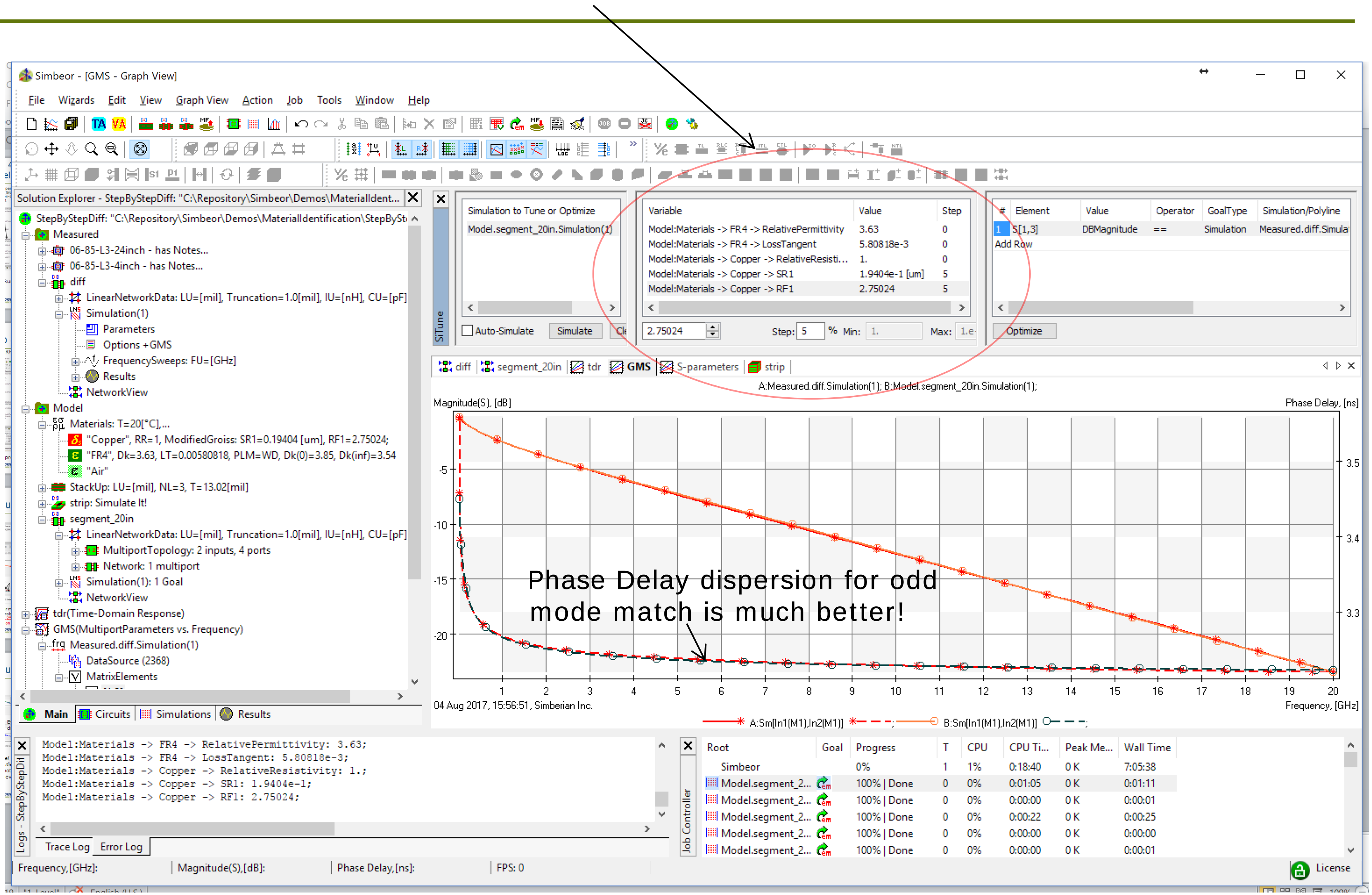
To improve accuracy, repeat step 4c

Results are acceptable, but not perfect

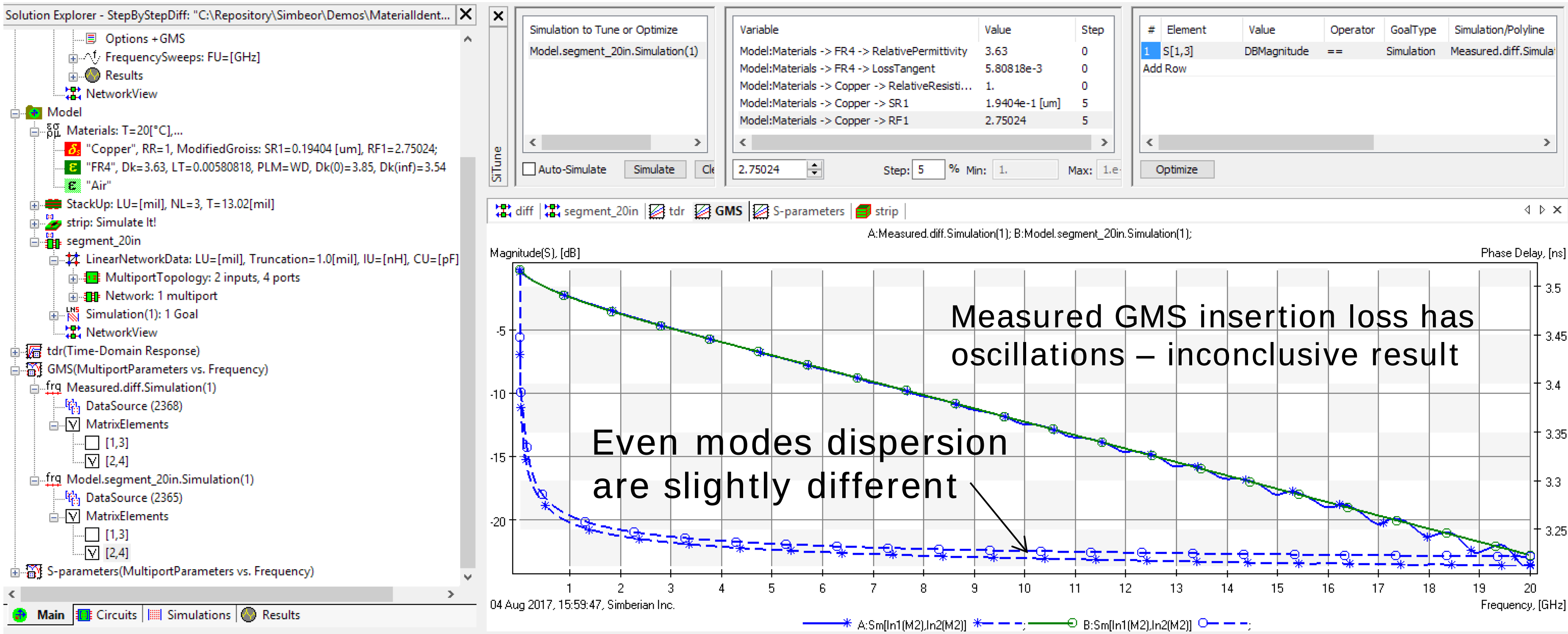


Higher measured dispersion in Phase Delay indicates that LT should be larger (dispersion)
The problem is with the matching RR at DC that resulted in larger value of resistance
RR=1.25 – this is questionable result (resistance 25% of annealed copper)!
Solution – set RR back to 1 (annealed copper) and redo the matching...

New results with RR=1



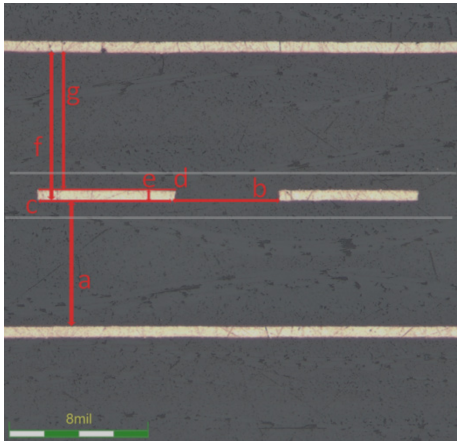
What about the even mode?



Problem: Model contains only one dielectric – cannot match simultaneously odd and even mode – though, it may be acceptable if FEXT is not large

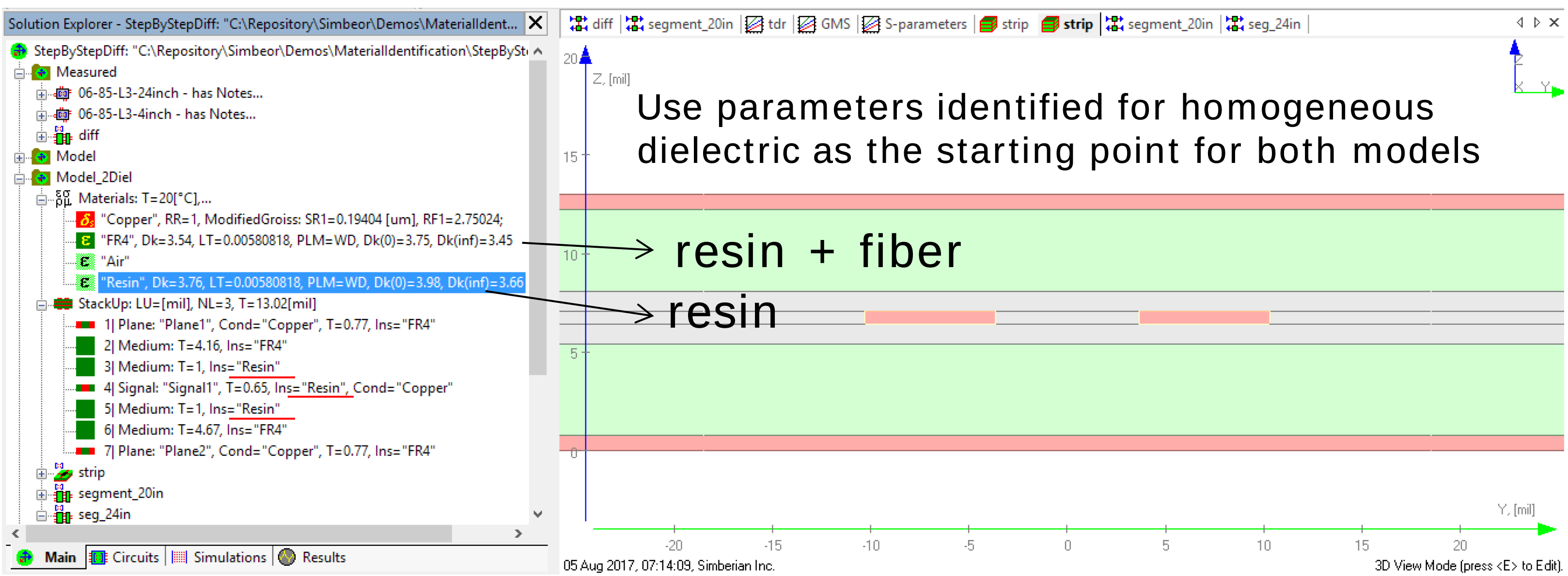
Solution: Create model with the additional layer of dielectric around the strips – see next slides…

Model with inhomogeneous dielectric



Predominantly resin

	85-L3-4inch	85-L3-24inch
Parameter	Avg.	Avg.
a	5.66	5.67
b	7.41	7.35
c	6.51	6.58
d	6.67	6.74
e	0.65	0.65
f	5.80	5.82
g	5.15	5.16

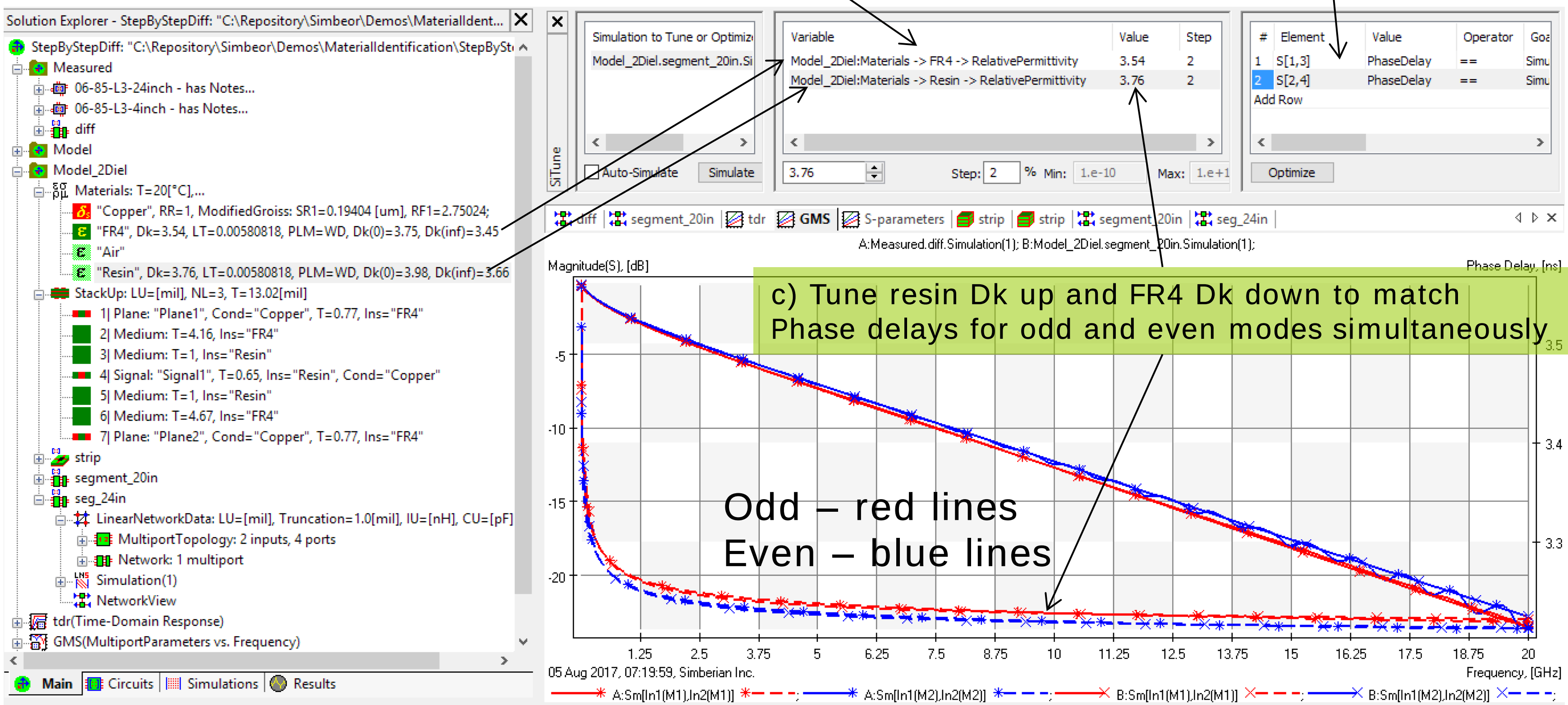


Simultaneously match odd and even mode GMS-parameters

a) Use parameters identified for homogeneous dielectric as the starting point

b) Bring relative permittivities of the base material (FR4) and fill material (resin) to Variable pane to optimize or tune

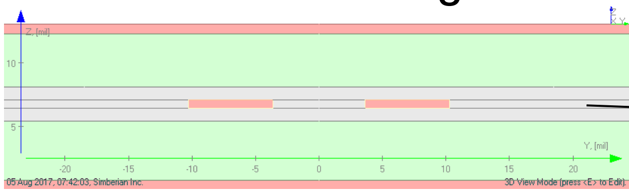
c) Alternatively set goals for Phase delays for 2 modes and optimize

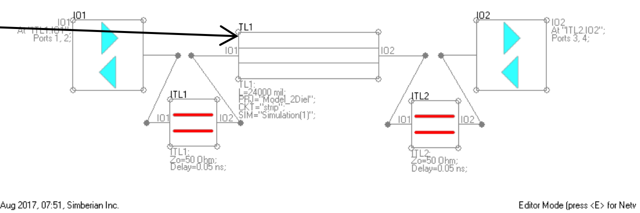


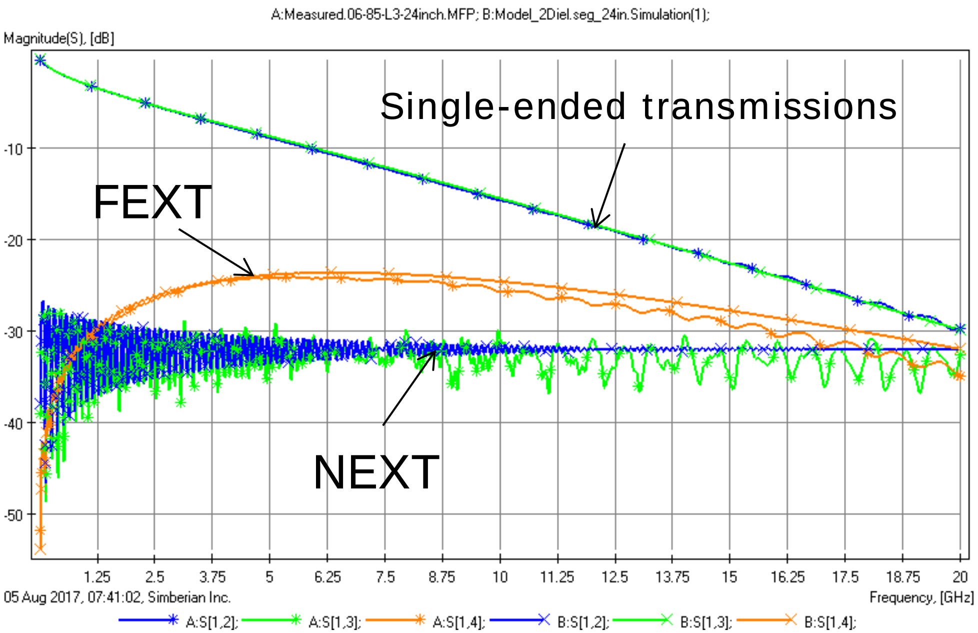
Final dielectric models: Wideband Debye FR4 Dk=3.54, LT=0.0058 @ 1 GHz; Resin Dk=3.76, LT=0.0058 @ 1 GHz; Copper roughness model: Groiss SR=0.19 um, RF=2.75

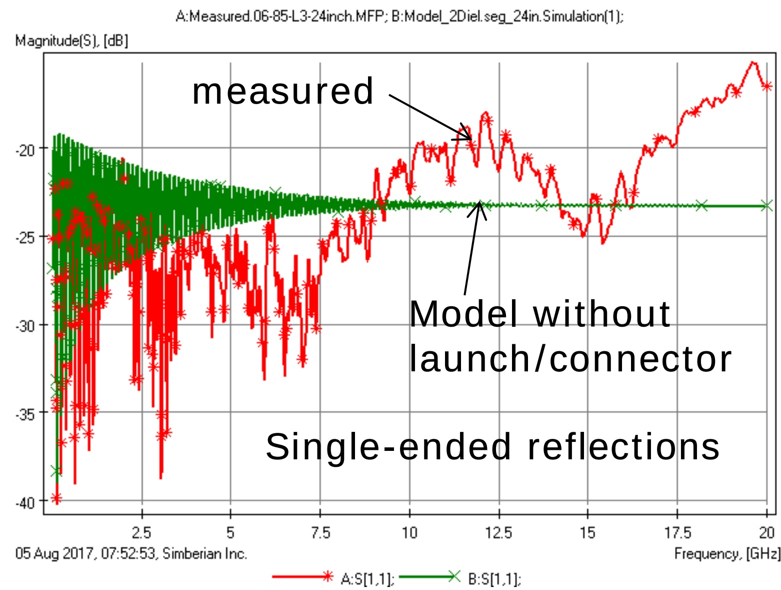
Compare raw single-ended S-parameters for 24 inch segment

24-inch segment model with ideal 100 Ohm connector model



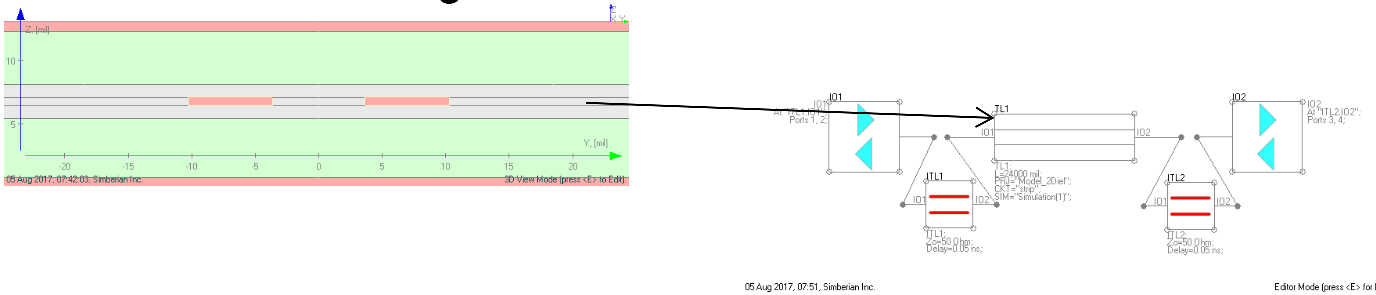


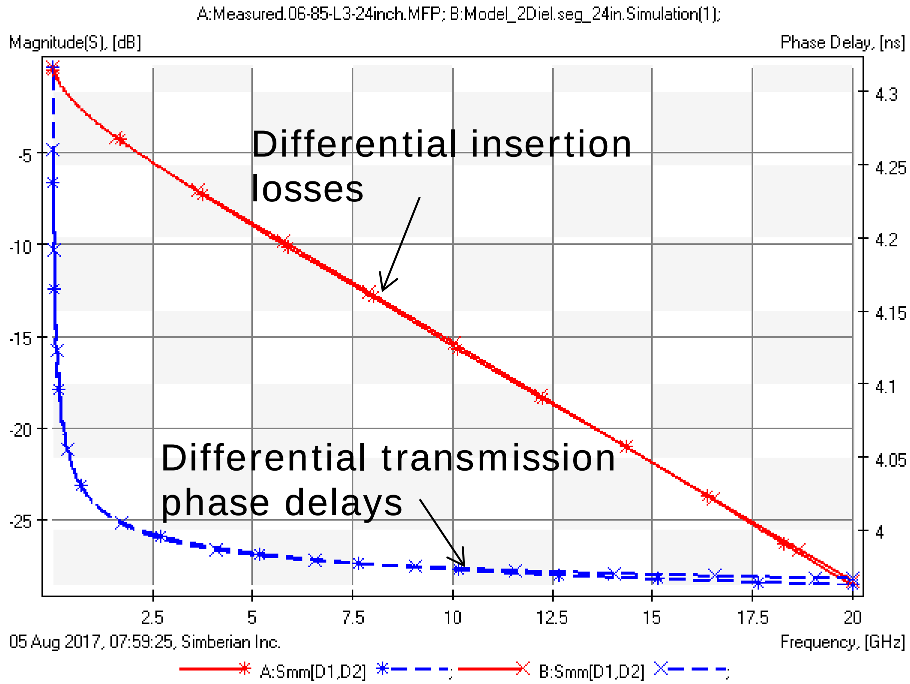


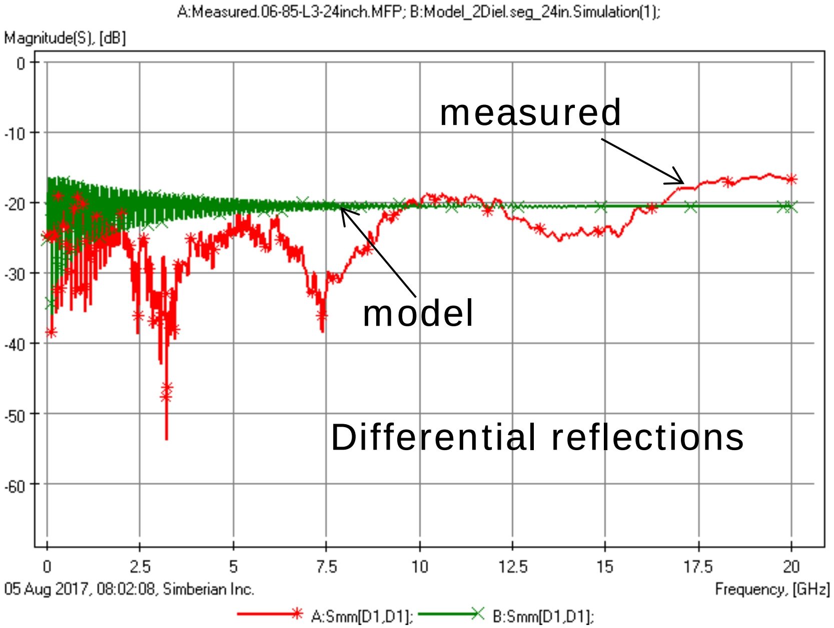


Compare raw differential S-parameters for 24 inch segment

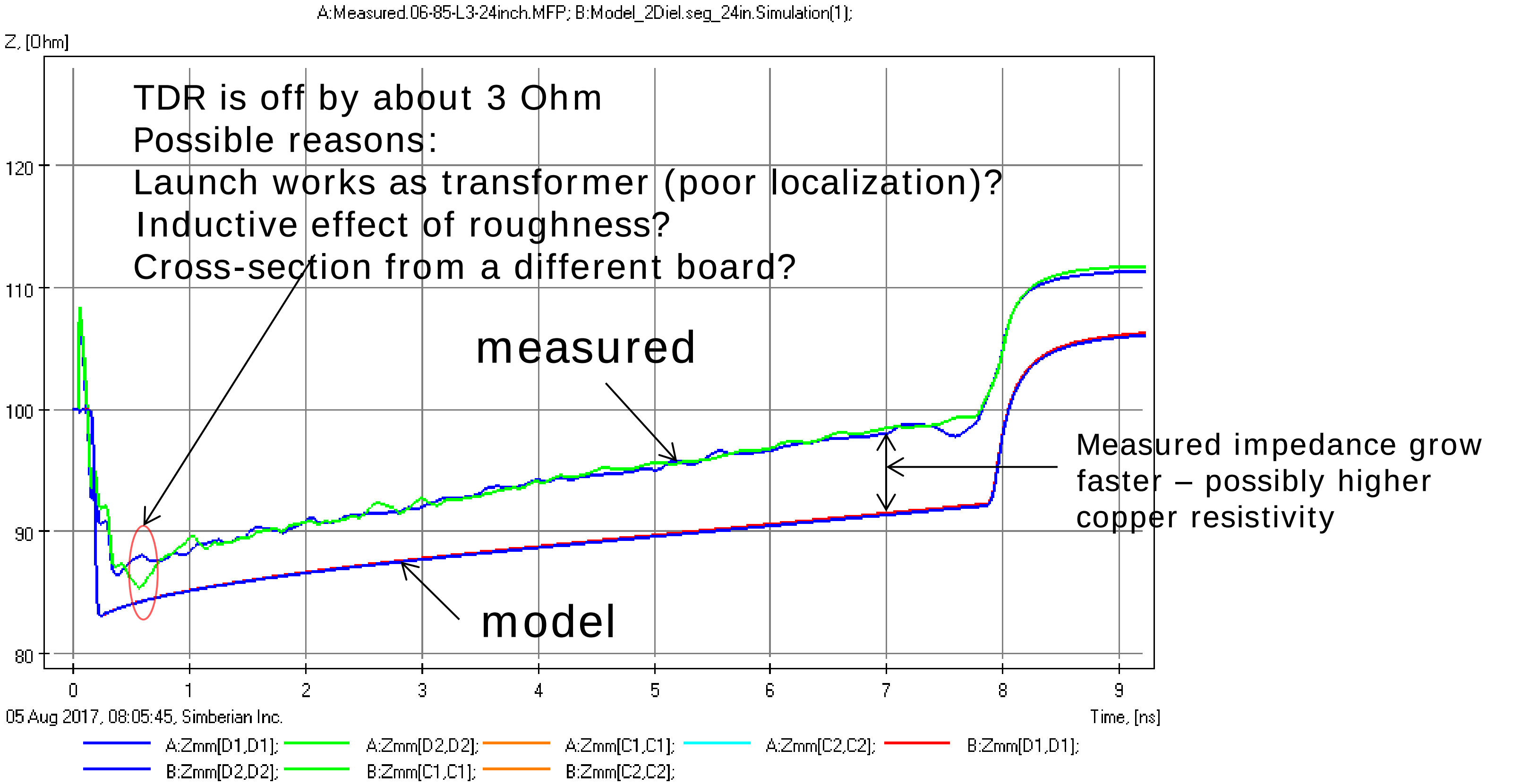
24-inch segment model with ideal 100 Ohm connector model







Compare TDR for 24 inch segment



Requires further investigation – see appendix…

Conclusion

- Always identify or validate dielectric, conductor and conductor roughness models
- Use of GMS-parameters is simplest and most accurate technique for the material model identification
- Differential strip is useful to identify dielectric inhomogeneity and fit 2 dielectric models simultaneously
- Use homogeneous dielectric if no FEXT observed or FEXT is not a part of design
- Use two dielectric models to match phase delay of two modes – it leads to match in the FEXT

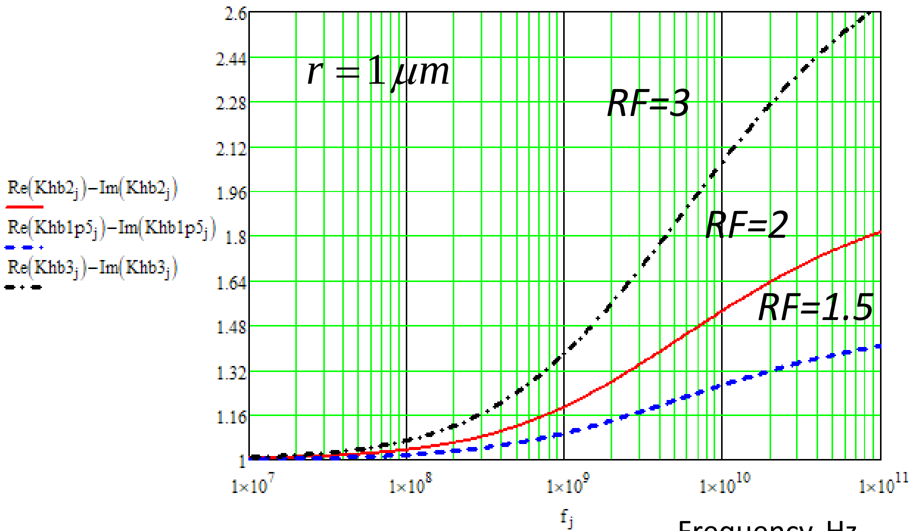
Appendix: Causal Huray-Bracken roughness model

$$K_{sr} = 1 + \sum_k \left((RF_k - 1) \cdot \left(1 + (1-i)\frac{\delta_s}{2r_i} \right)^{-1} \right) \qquad \delta_s = \sqrt{\frac{1}{\pi \cdot f \cdot \mu \cdot \sigma}} \qquad Z_{rough} = K_{sr} \cdot (1+i) \cdot \delta_s$$

RFi - roughness factor, defines maximal growth of losses due to all balls with radius ri;
ri – ball radius (SRi parameter in Simbeor);

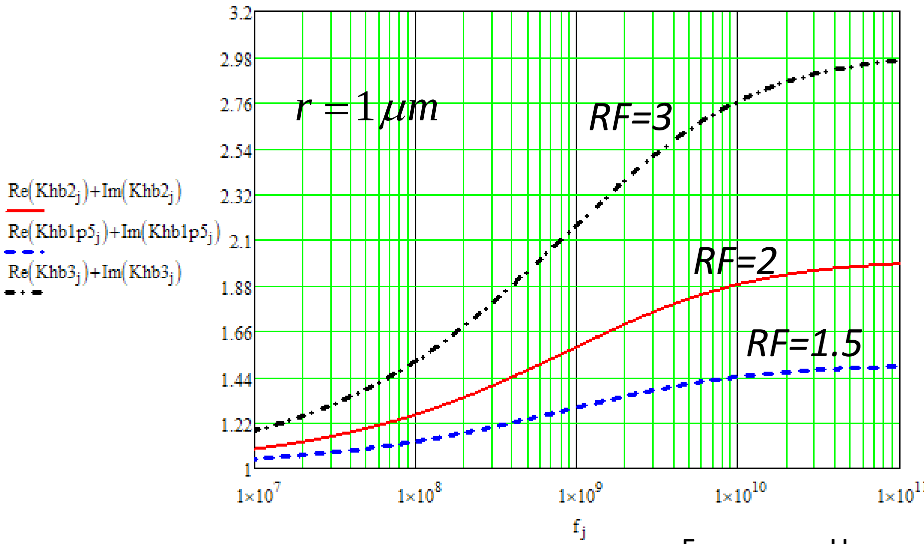
Conductor losses (same as in Huray model)

$$\mathrm{Re}(Z_{rough}) = \left[\mathrm{Re}(H_{sr}) - \mathrm{Im}(H_{sr}) \right] \cdot \delta_s$$



Additional conductor inductance

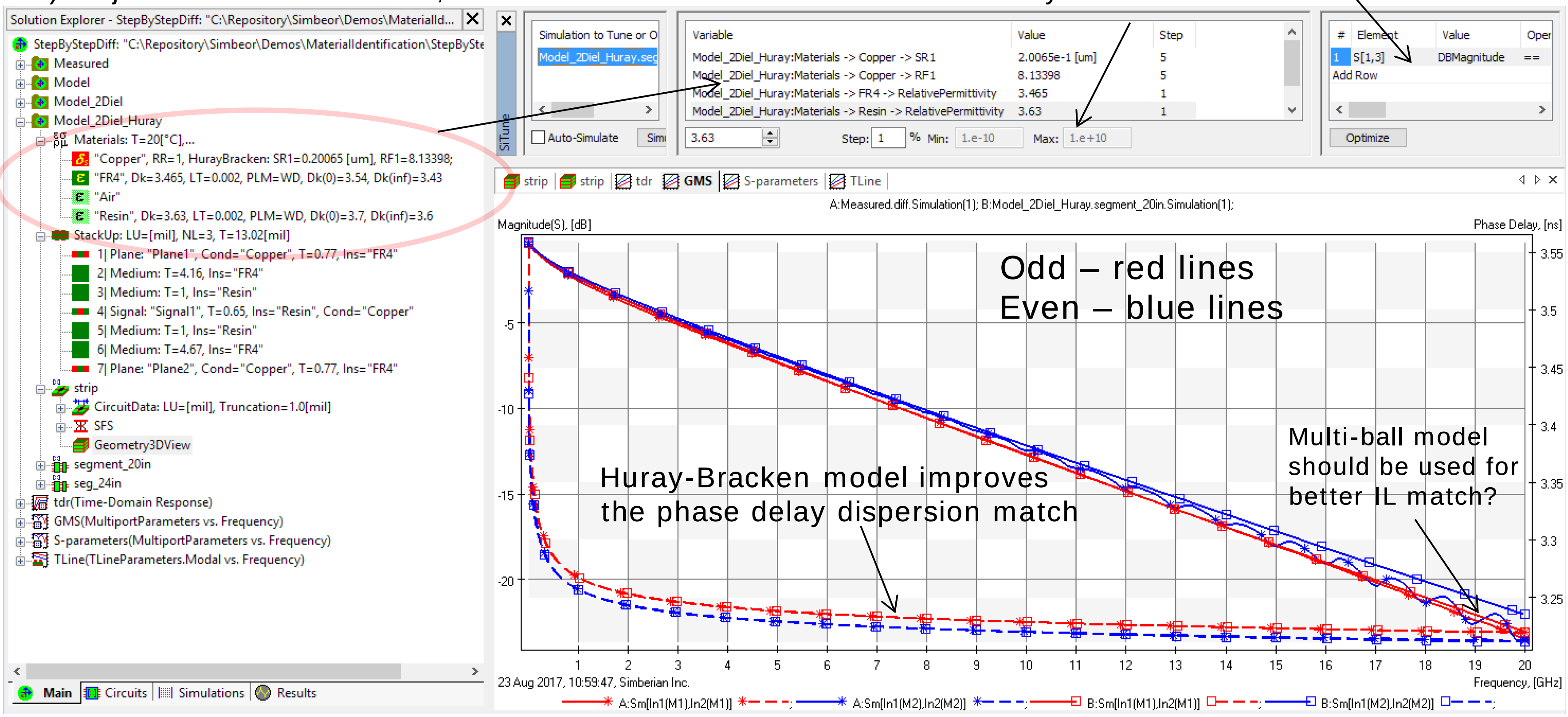
$$\mathrm{Im}(Z_{rough}) = \left[\mathrm{Re}(H_{sr}) + \mathrm{Im}(H_{sr}) \right] \cdot \delta_s$$



J. E. Bracken, A Causal Huray Model for Surface Roughness, DesignCon 2012

Appendix: Results with causal Huray-Bracken model

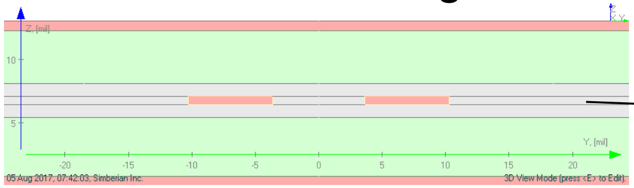
a) Use parameters identified for inhomogeneous dielectric as the starting point, set LT to 0.002 (specs);
b) Optimize roughness model parameters (SR1, RF1), to match GMS IL from 2 to 20 GHz
c) Adjust Dk of FR4 and Resin, to match the even and odd mode Phase Delay

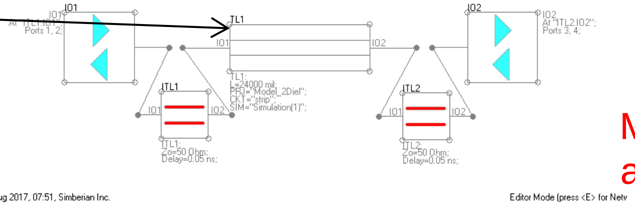


Final dielectric models: Wideband Debye FR4 Dk=3.465, LT=0.002 @ 1 GHz; Resin Dk=3.63, LT=0.002 @ 1 GHz; Copper roughness model (RR=1): Huray-Bracken SR=0.2 um, RF=8.134
If copper relative resistance is adjusted to RR=1.2, Huray-Bracken model is SR=0.2, RF=7.75

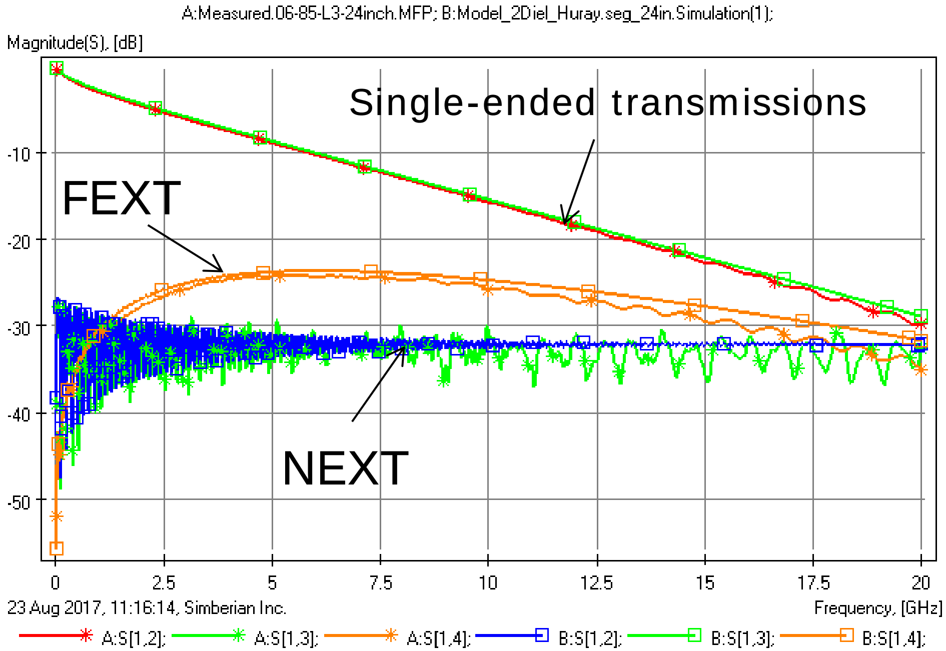
Appendix: Validation with causal Huray-Bracken model

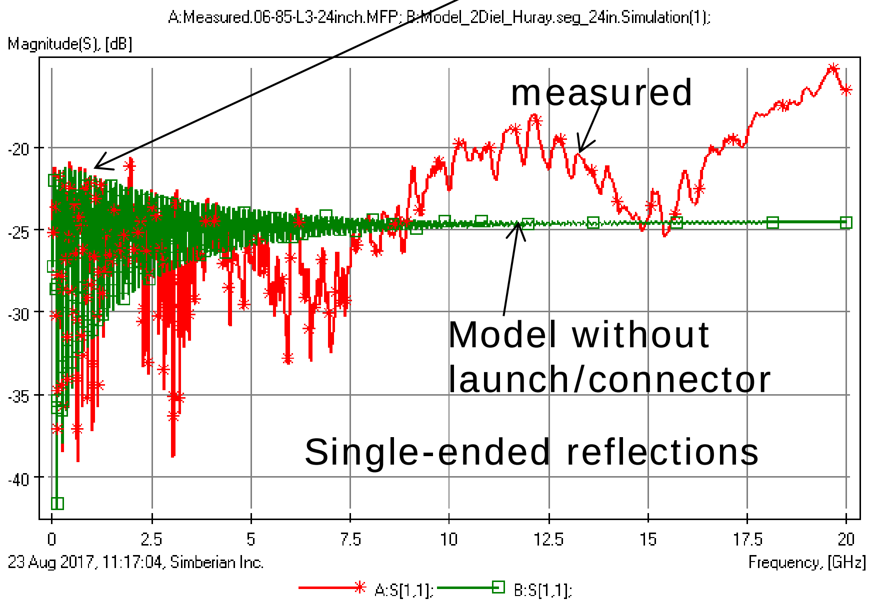
24-inch segment model with ideal 100 Ohm connector model





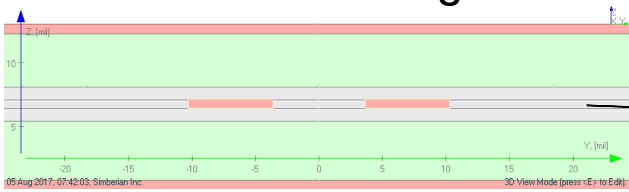
Much better correlation at lower frequencies

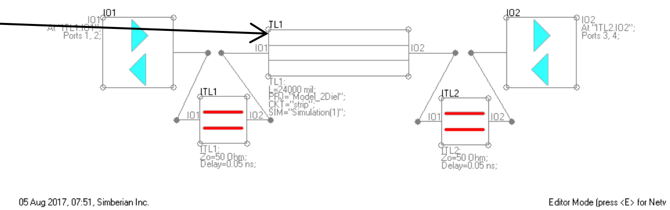


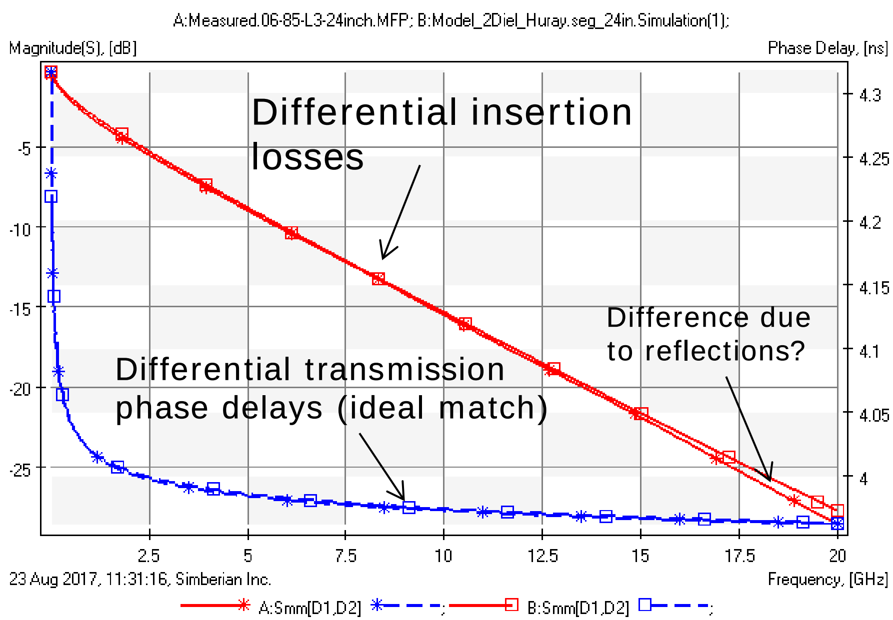


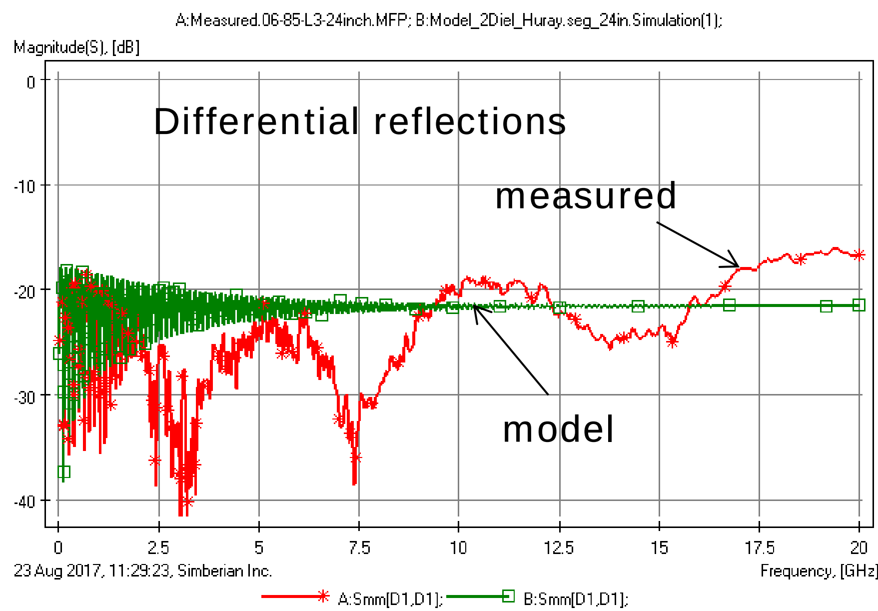
Appendix: Validation with causal Huray-Bracken model

24-inch segment model with ideal 100 Ohm connector model

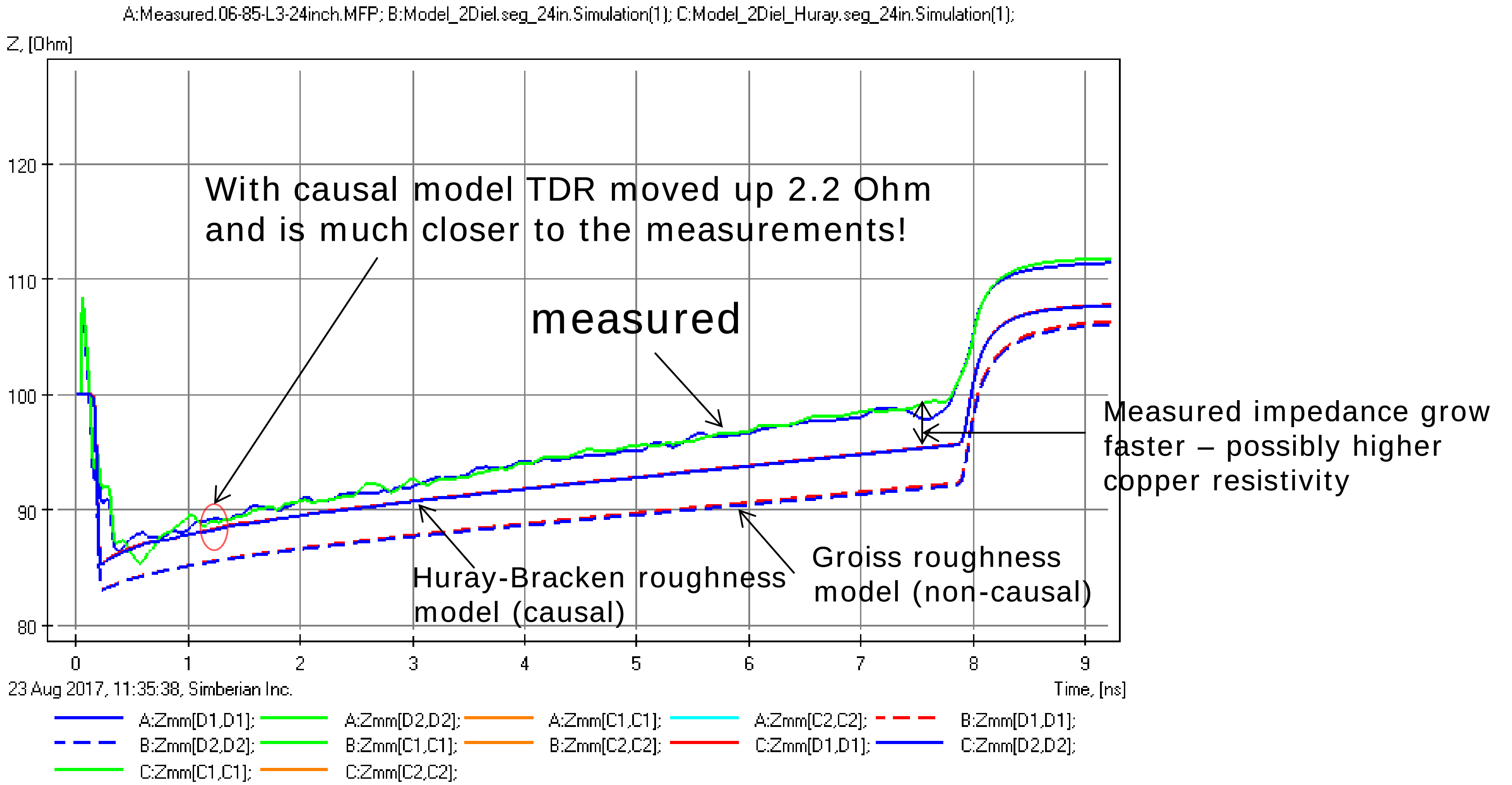






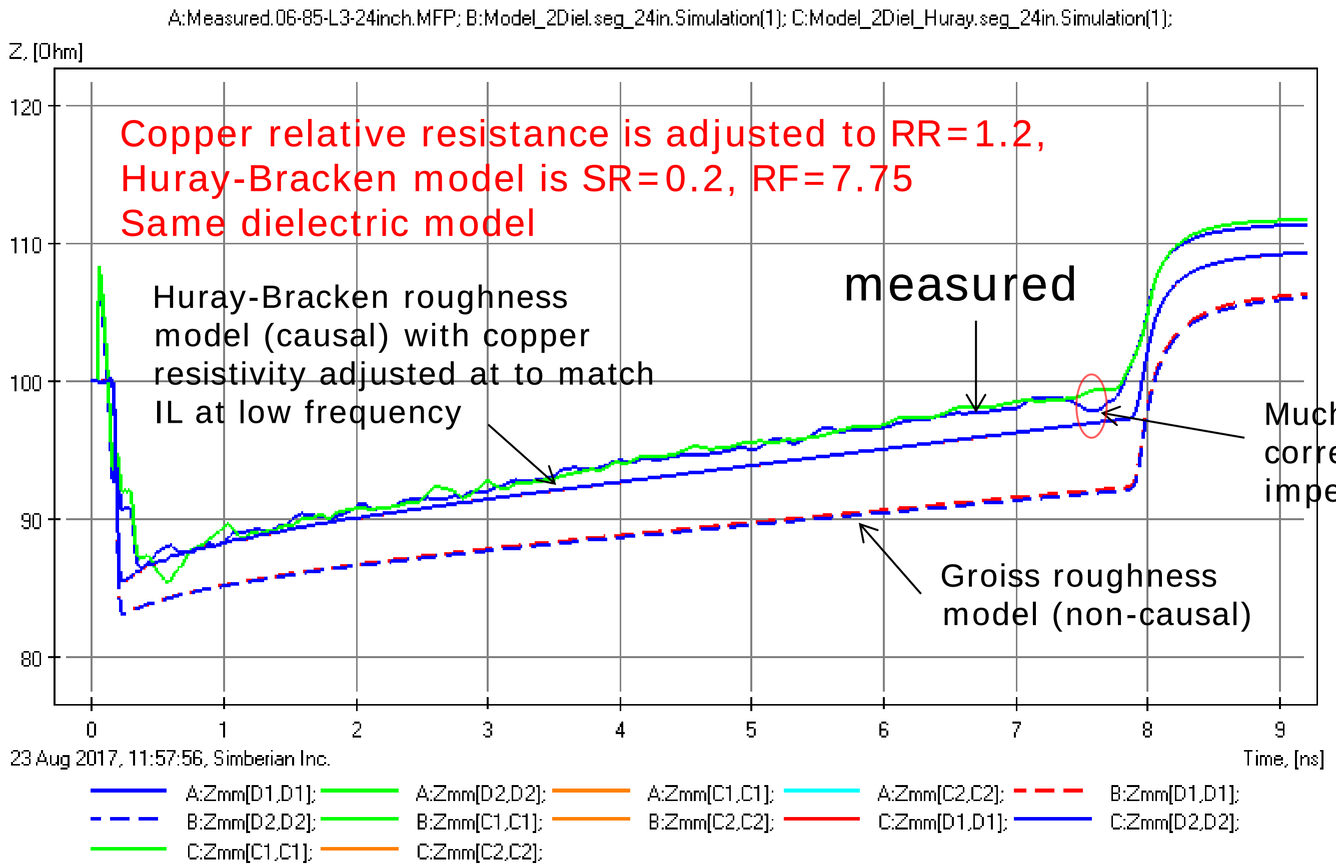


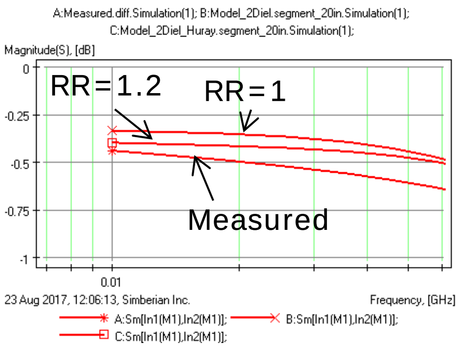
Appendix: TDR for 24 inch segment with Huray-Bracken roughness model



...the impedance mystery solved!

Appendix: TDR for 24 inch segment with Huray-Bracken roughness model





TDR can be used to validate the relative resistivity in addition to matching GMS IL at the lowest frequency…

Simberian Inc.

- Mission
  - Build accurate, easy-to-use, and cost-effective electromagnetic software for high-speed electronic design automation
- Incorporated in USA on February 28, 2006
  - Founder and President Yuriy Shlepnev
    - PhD in in computational electromagnetics
    - 25-years experience in building electromagnetic software
- Development in Westlake Village, USA, St. Petersburg and Voronezh Russia
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