Design and Optimization of a Novel 2.4 mm Coaxial Field Replaceable Connector Suitable for 25 Gbps System and Material Characterization up to 50 GHz

Course Number: 13-WA4

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2.4mm Abstract

- With Data rates climbing to 10-12.5 Gb/s and plans for 28 Gb/s , it becomes important to increase PCB fixtures from the typical 20 GHz to 50 GHz. There are several vendor Vector Network Analyzers that will sweep this high, but not many PCB launch connectors that can accurately launch these high frequencies.

- This paper will:
  - Present modeling and validate data for a novel compression launch 2.4mm coaxial connector, functional up to 50GHz
  - Introduce methods for analytical modeling and measurements for optimizing the PCB launch and escape, under the 2.4 mm connector.
  - Demonstrate accurate broadband material characterization, using the method of generalized modal S-parameters, out to 50 GHz.

- The 2.4mm design includes a compression attach center conductor that does not require a solder attach to the PCB. The 2.4mm coax design meets all the standard 2.4mm mechanical interface standards, with a VSWR of <1.2 @ 50 GHz back to back test method.
- This paper will review EDA analytically modeling methodology and results for the integrated 2.4mm coaxial connector with, several PCB layout designs.
- The final optimized PCB design was fabricated, measured and correlated to the analytical model.

Paper Overview

- This DesignCon paper will be presented in several parts
  - Review of 2.4mm coaxial design and optimization modeling and results
  - Two pcb optimization patterns have been modeled and measured.
    - Optimization 1: Review of analytical models, results. Review of optimization 1 test board fab, test results and model to data correlation
    - Optimization 1: Review of analytical models, results. Review of optimization 1 test board fab, test results and model to data correlation
  - Practical material characterization and identification of dielectric loss and copper surface roughness

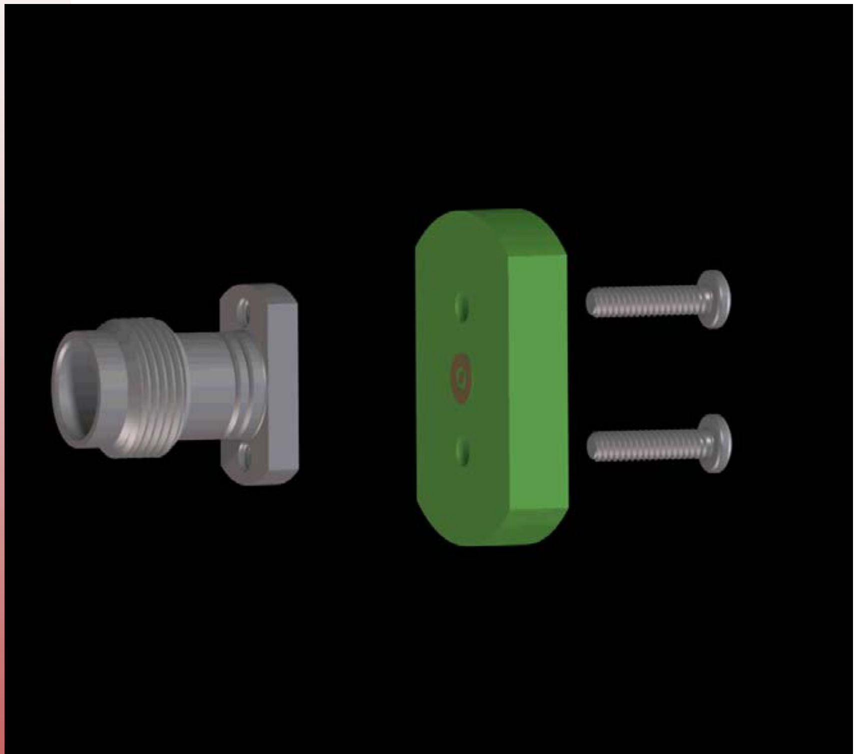
2.4mm Coaxial Design

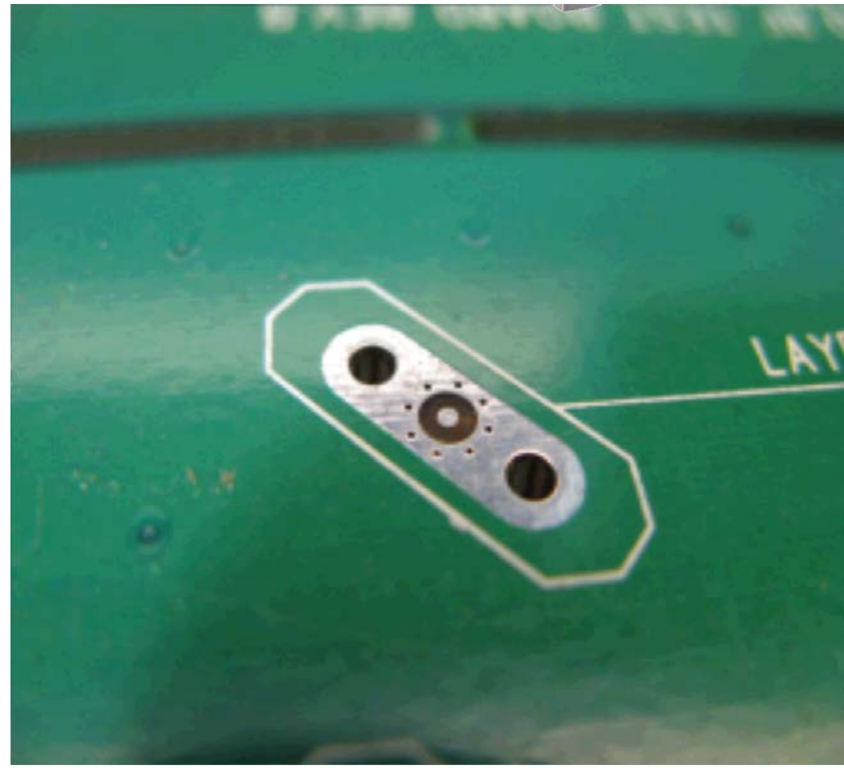
2.4mm Coaxial Design

2.4MM CONNECTOR OVERVIEW

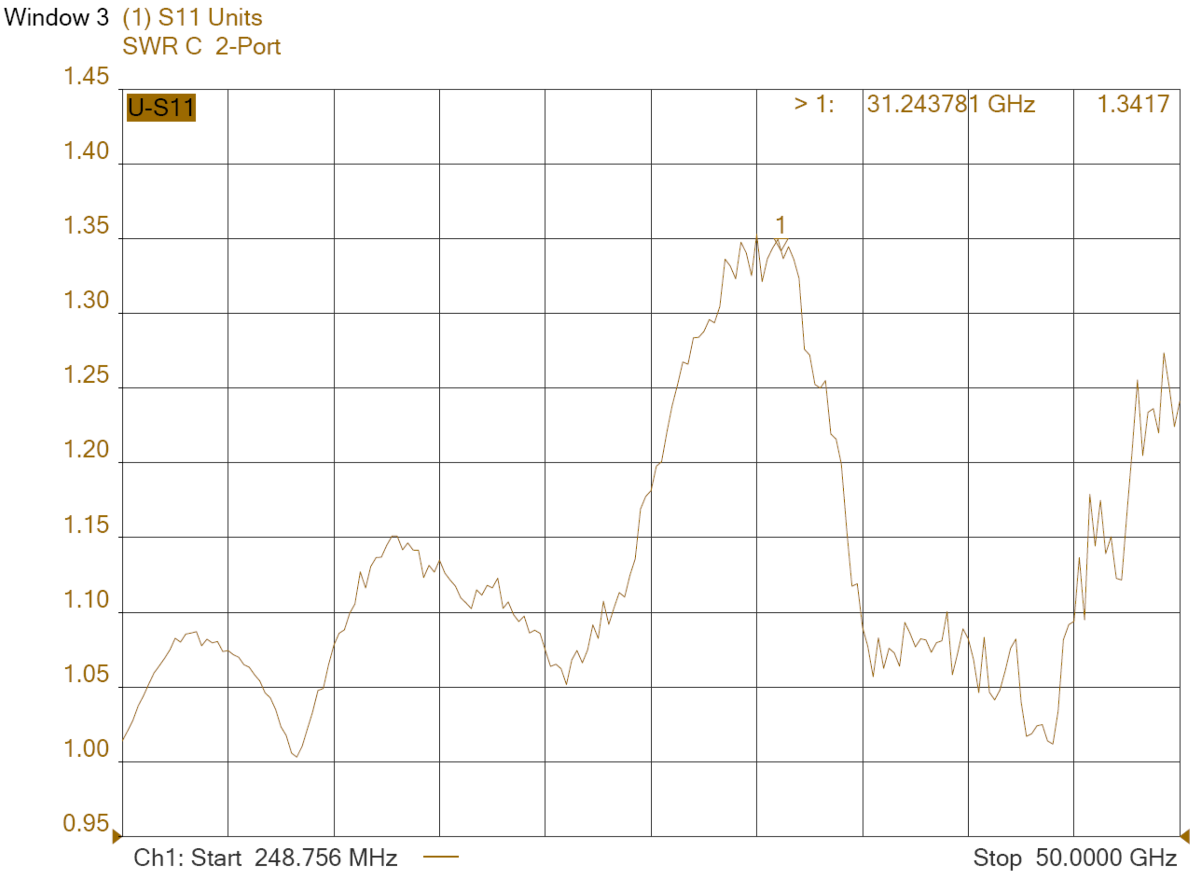
•Standard 2.4mm coaxial design using pressure contact attachment to the board.
•Uses two 0-80 UNF screws to mount the connector to the PCB with no solder requirement.
•Integrated center pin design which is capable to 1.2:1 VSWR at 50 GHz using back to back test method.

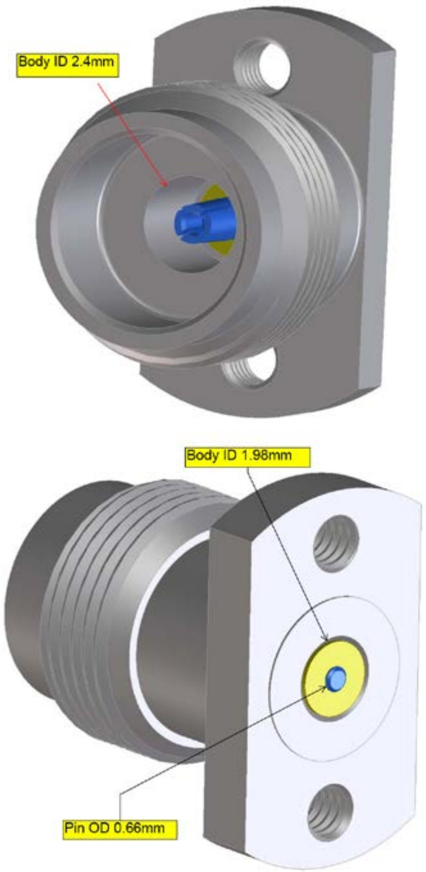
2.4mm Coaxial Design



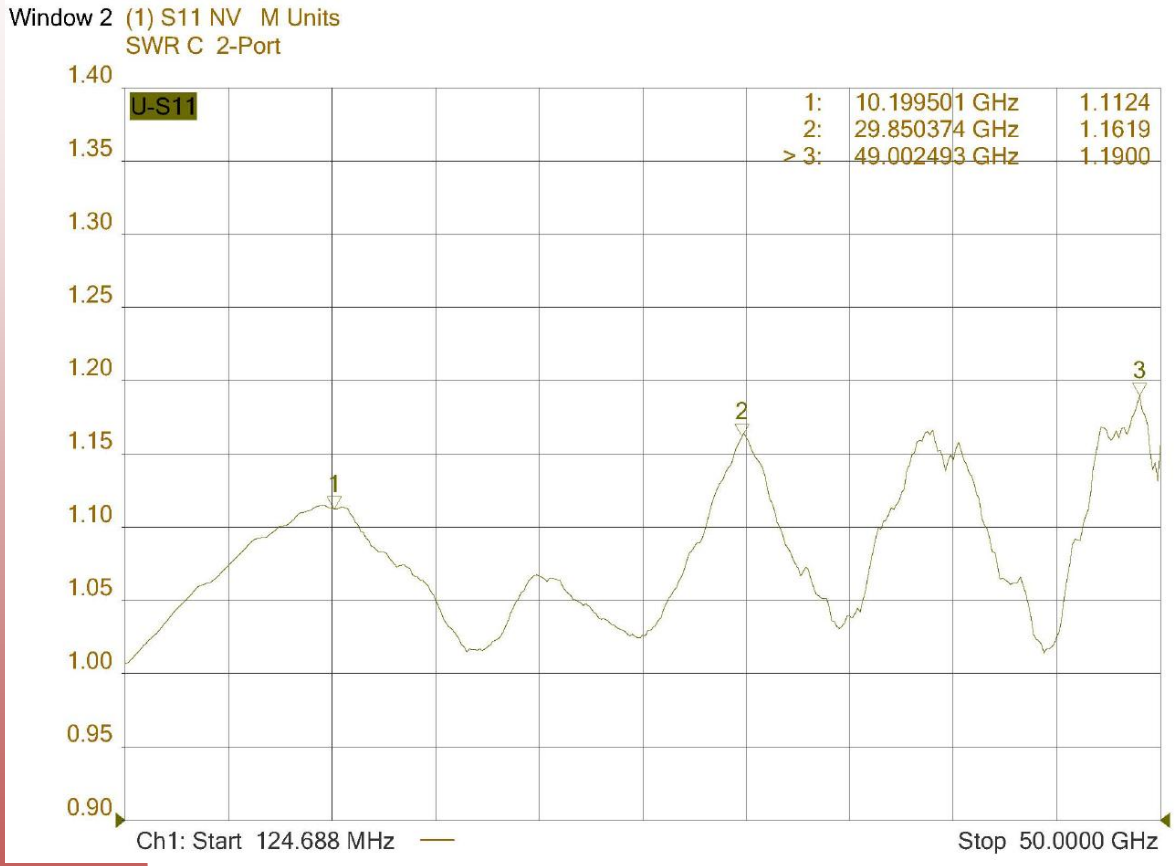


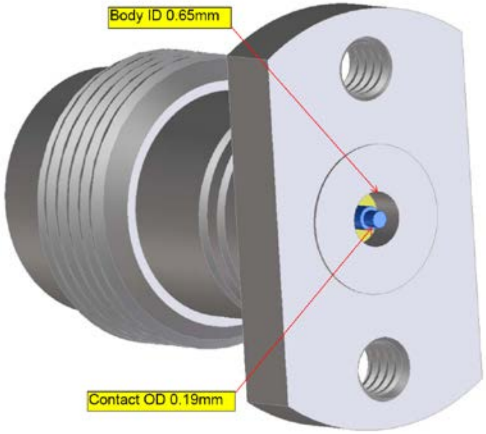
2.4mm Coaxial Initial Design

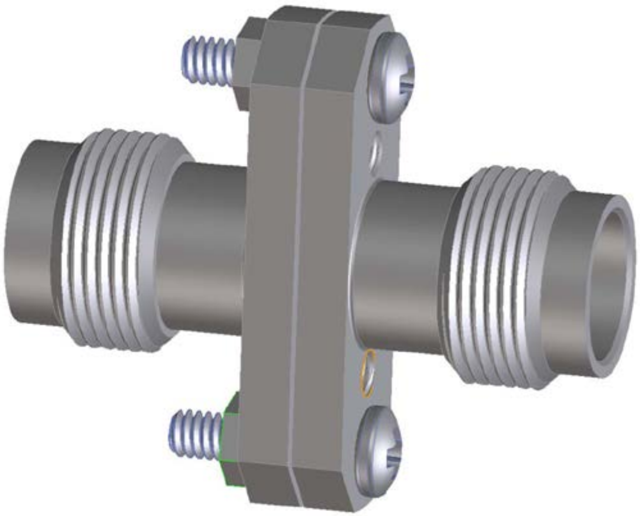




2.4mm Coaxial Optimized Design







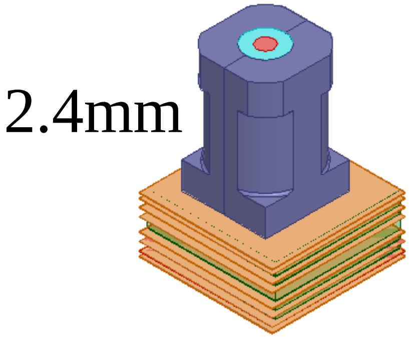
Optimization 1

Measure S-parameters of test fixture with 4”length of line segment.

Optimization 1 has a simplified gnd pcb launch pattern

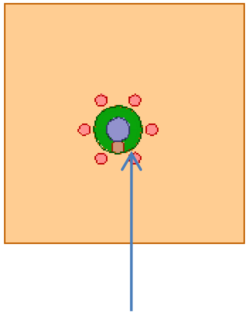
Optimization 1

- Model review



PCB Launch

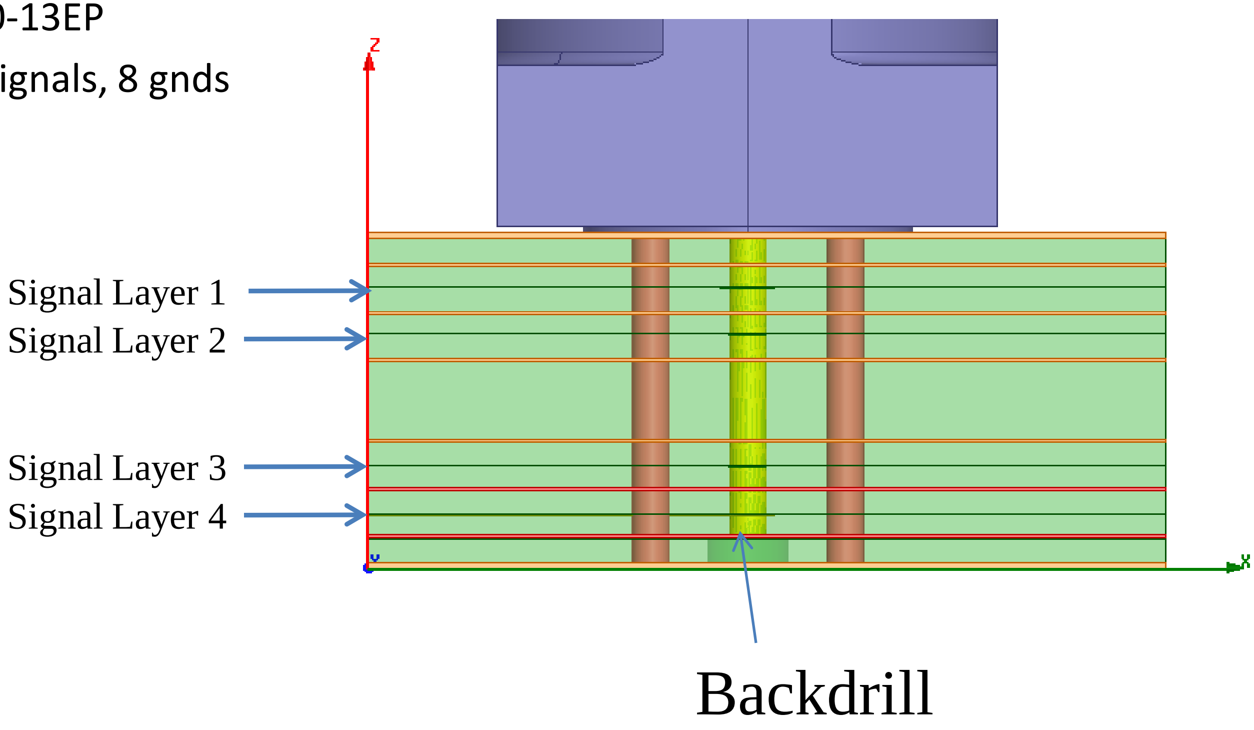
PCB Pattern



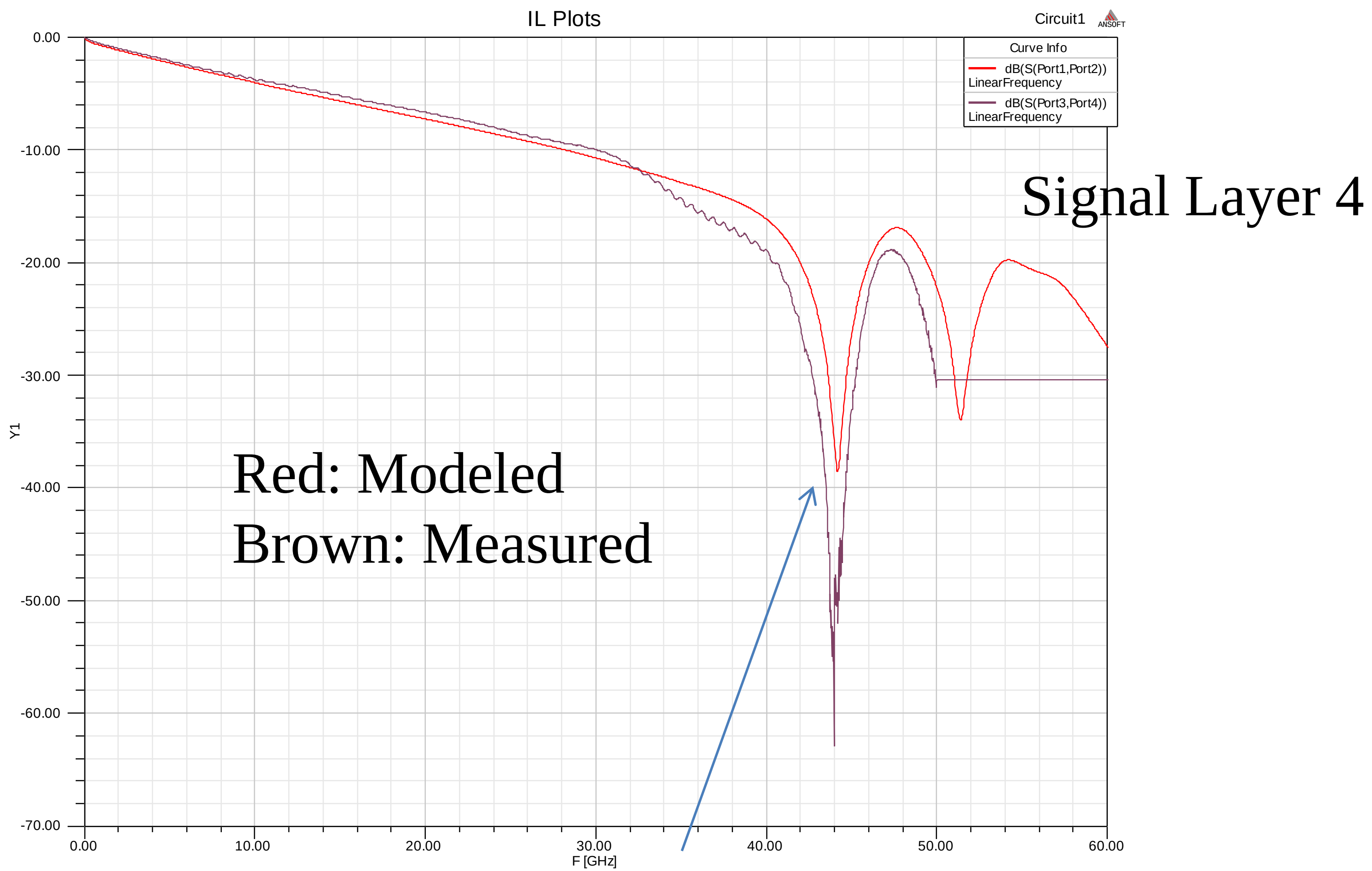
Simplified Gnd Pattern

Optimization 1: Model Review

- PCB Stack
  - 135mil Nelco 4000-13EP
  - Copper layers : 4 signals, 8 gnds

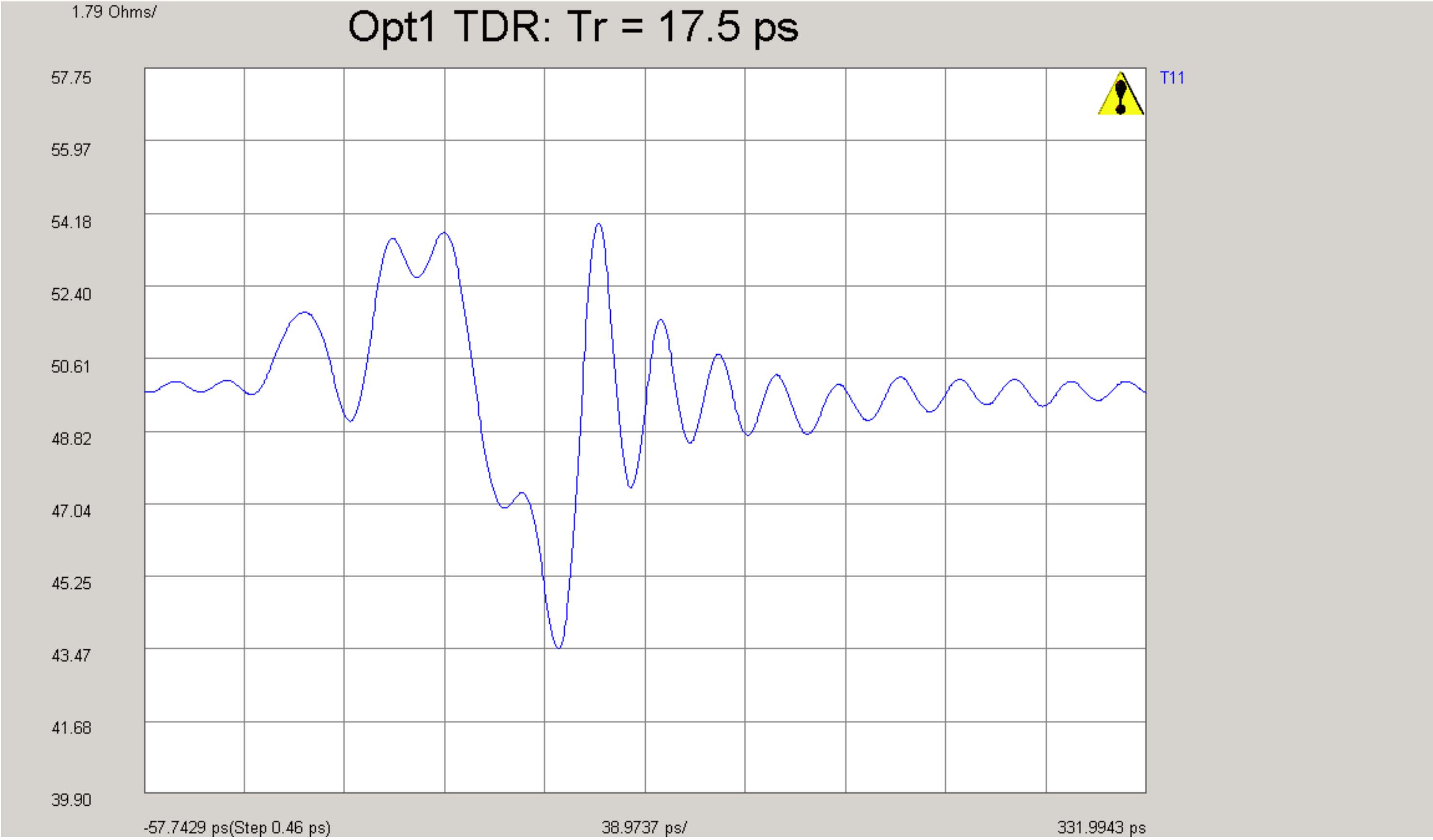


Optimization 1: Modeled to Measured Results



Signal Layer 4: Cavity Mode Resonance due to non optimized PCB via pattern

Optimization 1: TDR Results

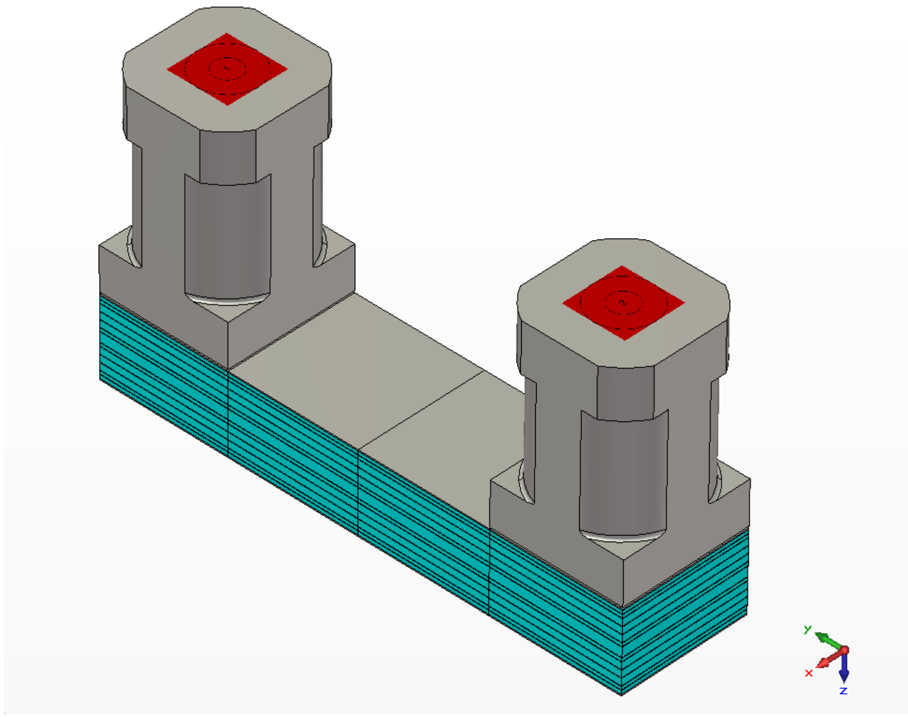


Optimization 1 Observations

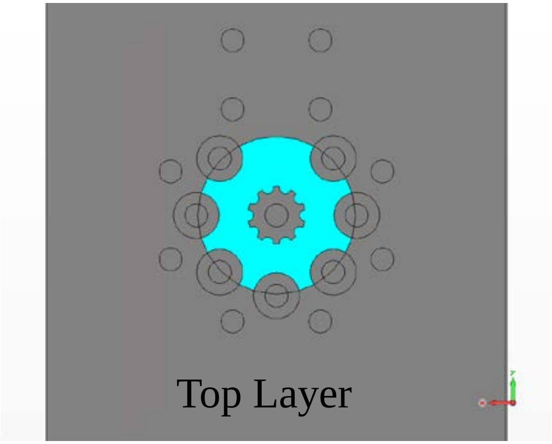
Due to the high frequency bandwidth of this design it becomes very difficult to optimize both Frequency and Time domain capabilities. Optimization 1 tunes the TDR, leaving higher frequency resonances.

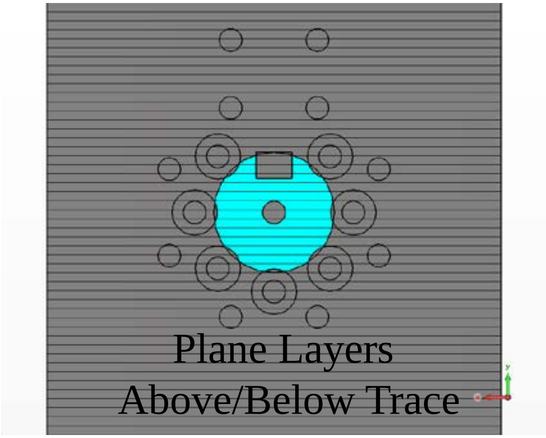
Optimization 2 Goals

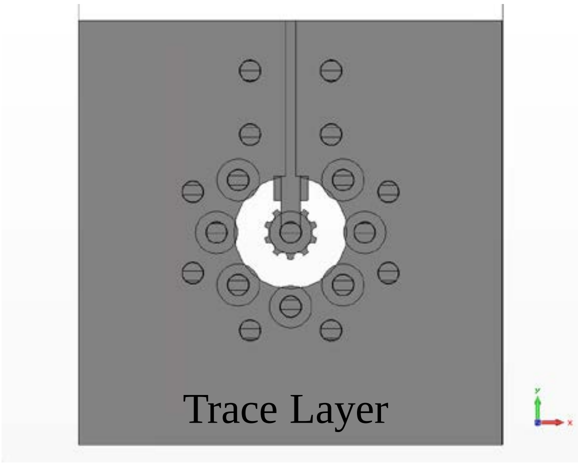
- More aggressive optimization.
  - Push cavity modes far above 50 GHz.
  - Increase launch "localization" by providing better cavity ground containment.
  - Optimize two connectors on trace to minimize half-wave end-to-end resonances.
  - Provide complex internal compensation structures.

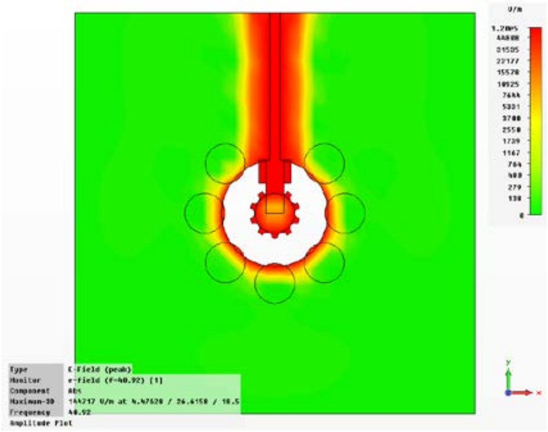


Areas of Optimization

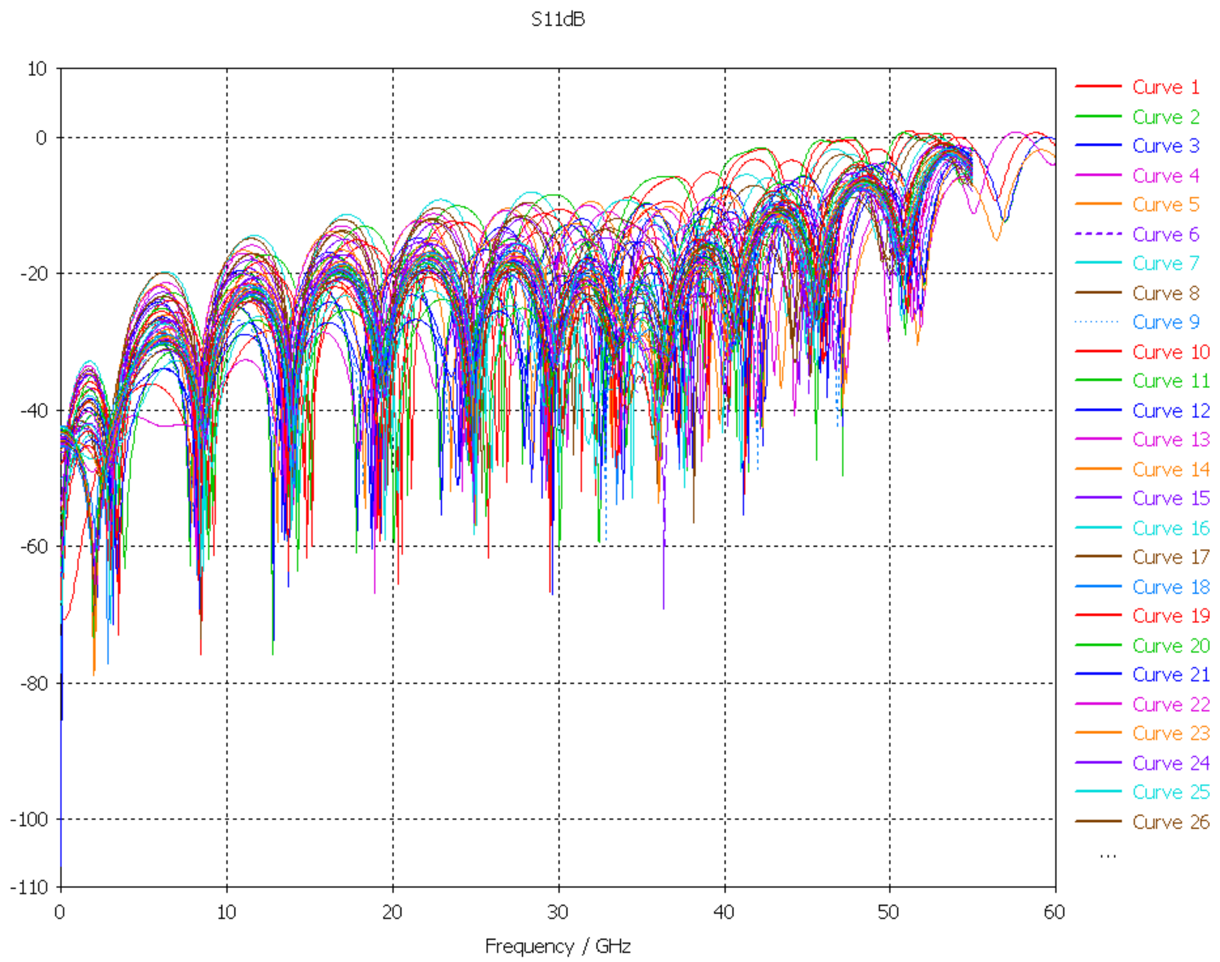




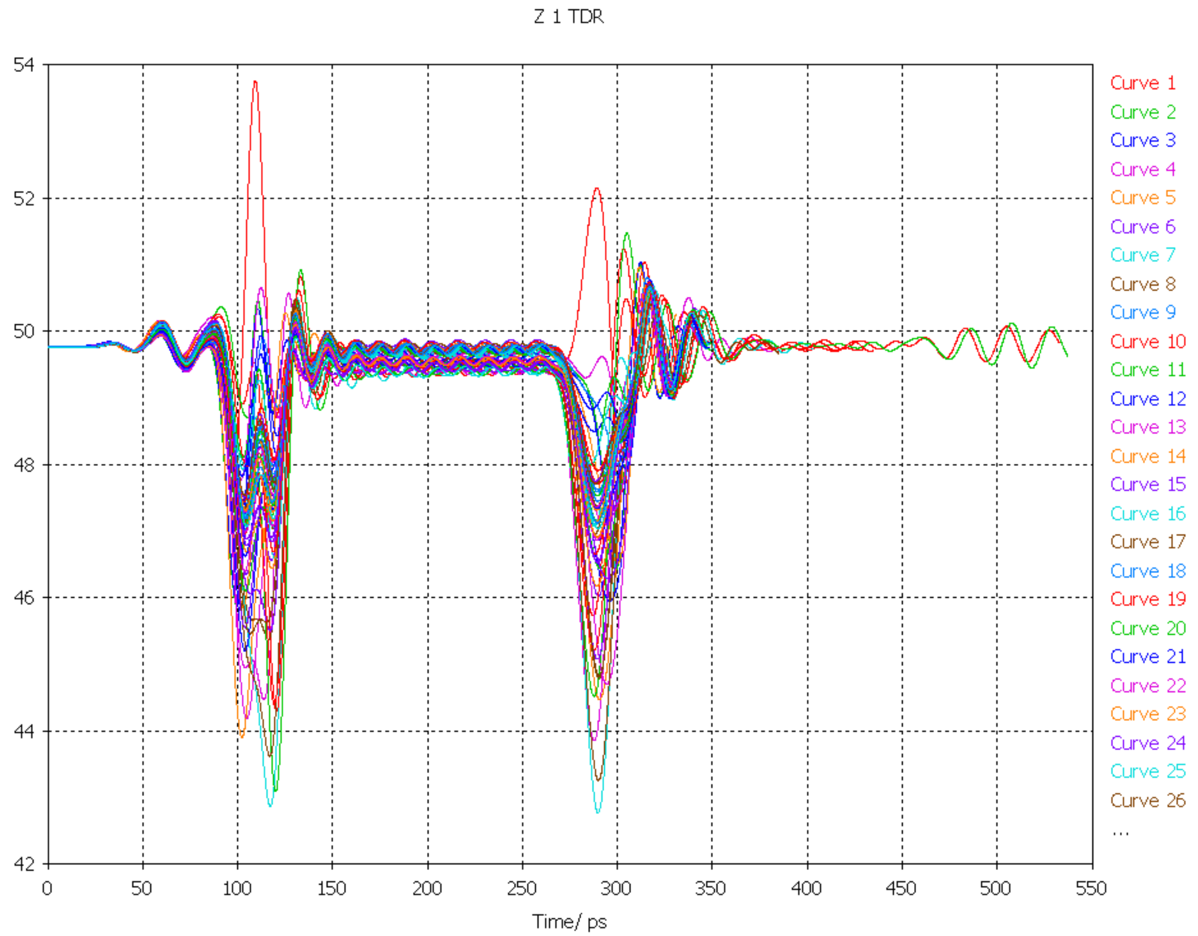




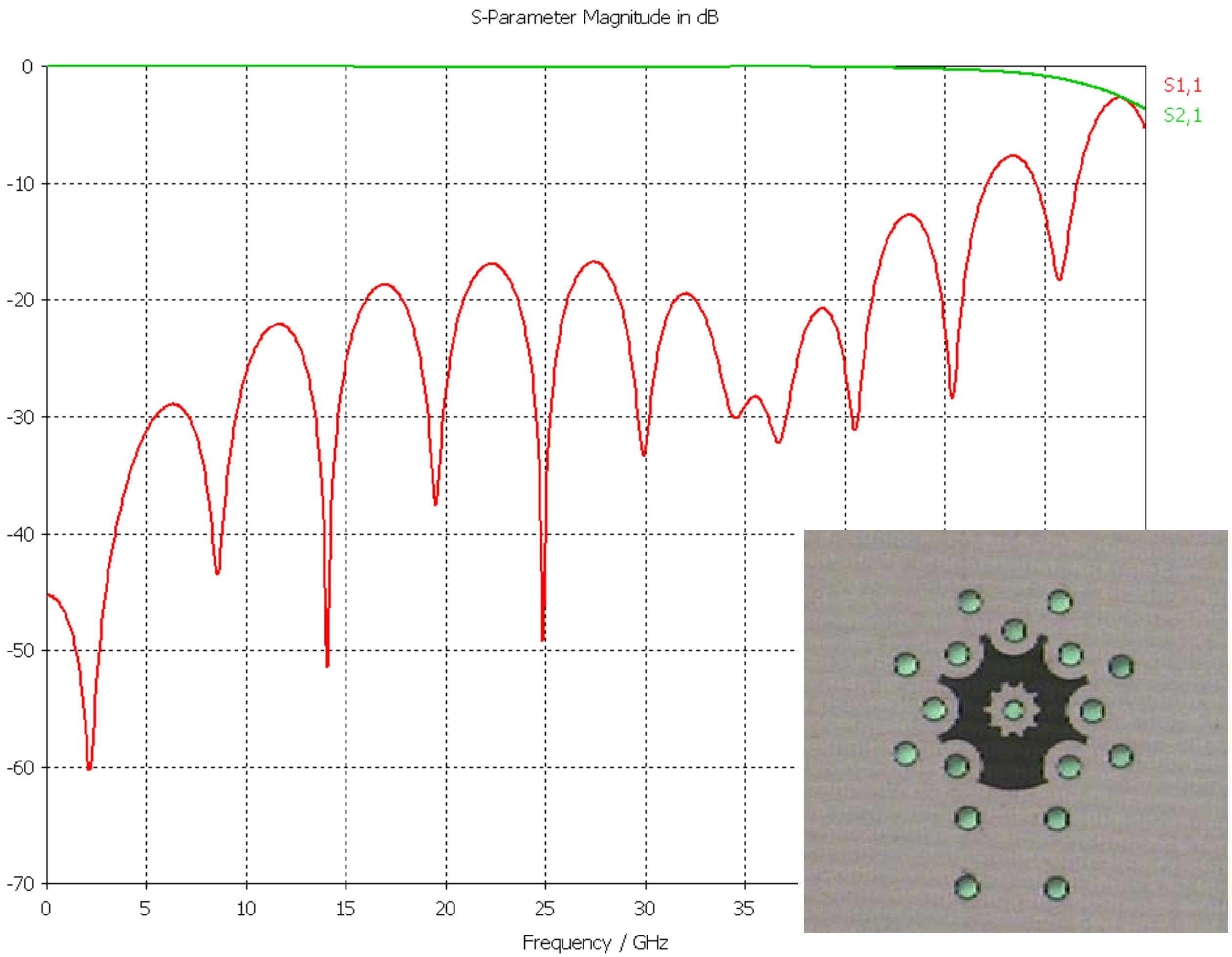
Return Loss Optimization Runs



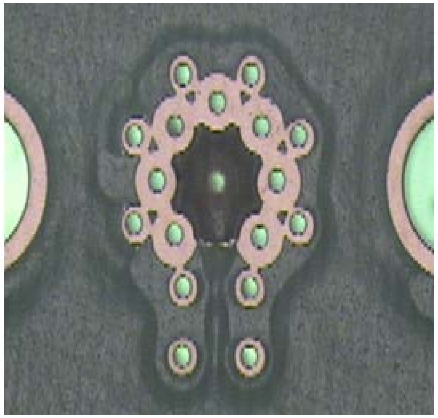
TDR Results Across Sweeps



Optimization 2 Design Results



Optimization results of two connectors separated by 300 mil of stripline trace to extend performance above 30 GHz.



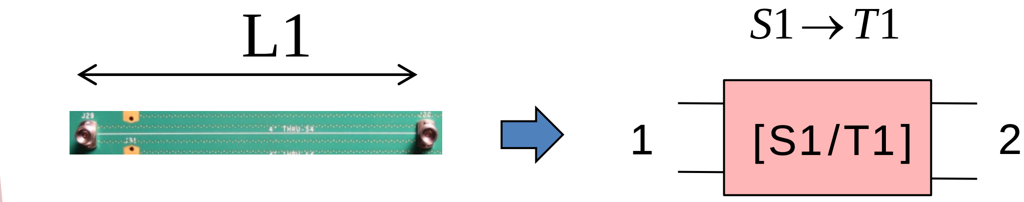
Material parameters identification with GMS-parameters

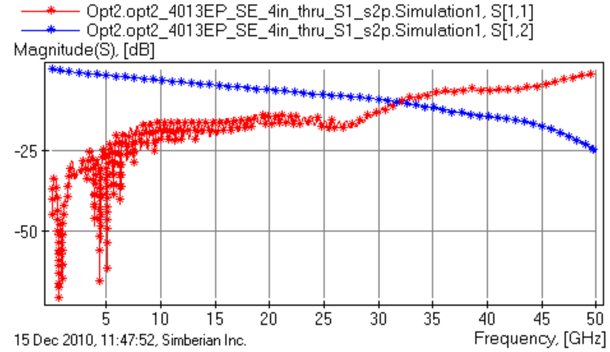
- Measure S-parameters of two test fixtures with different length of line segments S1 and S2
- Transform S1 and S2 to the T-matrices T1 and T2, diagonalize the product of T1 and inversed T2 and compute GMS-parameters of the line difference
- Select material model and guess values of the model parameters
- Compute GMS-parameters of the line difference segment by solving Maxwell's equation for t-line cross-section (only propagation constants are needed)
- Adjust material parameters until computed GMS parameters fit measured GMS-parameters with the computed

Simberian's patent pending

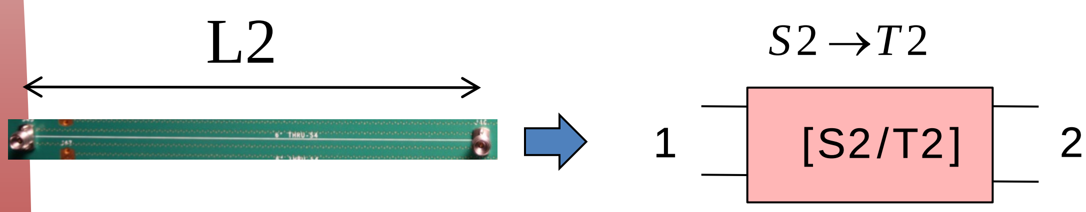
Measure S-parameters of two test fixtures with line segments (no calibration is required)

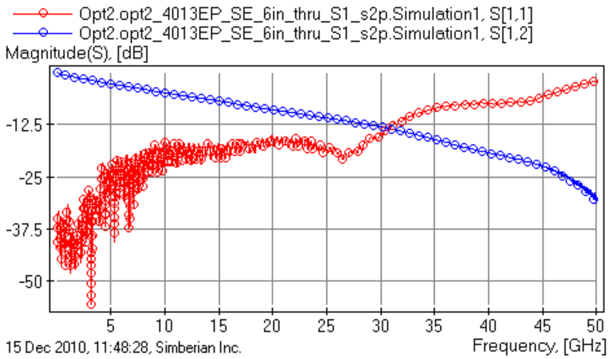
- S1 and T1 for line with length L1





- S2 and T2 for line with length L2

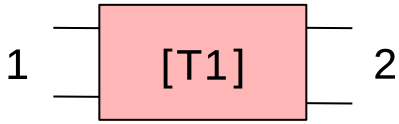


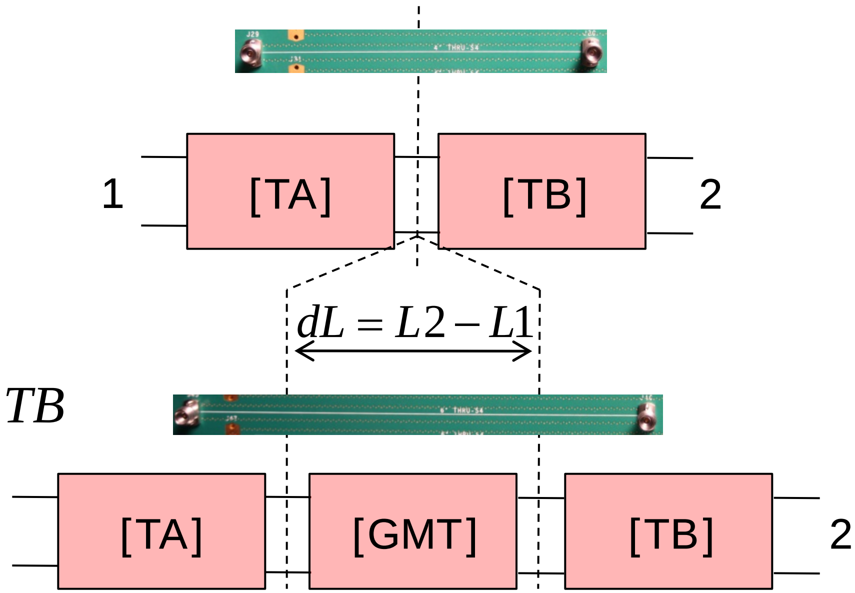


T1 and T2 matrices are scattering T-parameters (computed directly from S-parameters)

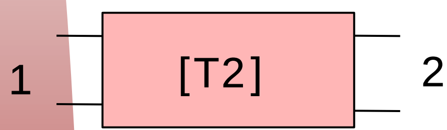
Extract Generalized Modal T-parameters (GMT) and then GMS-Parameters

Segment L1 $T1 = TA \cdot TB$





Segment L2 $T2 = TA \cdot GMT \cdot TB$



GMT is non-reflective modal T-matrix (normalized to the unknown characteristic impedances of the modes)

$$T2 \cdot T1^{-1} = TA \cdot GMT \cdot TA^{-1}$$

$$\Downarrow$$

$$GMT = eigenvals\left(T2 \cdot T1^{-1}\right)$$

Easy to compute!

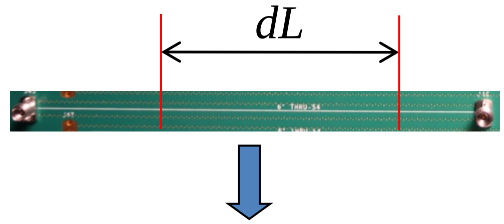
For 1-conductor line we get:

$$GMT = \begin{bmatrix} T_{11} & 0 \\ 0 & T_{11}^{-1} \end{bmatrix} \Rightarrow GMSm = \begin{bmatrix} 0 & T_{11} \\ T_{11} & 0 \end{bmatrix}$$

Just 1 complex function!

Identifying dielectrics by fitting GMS-parameters

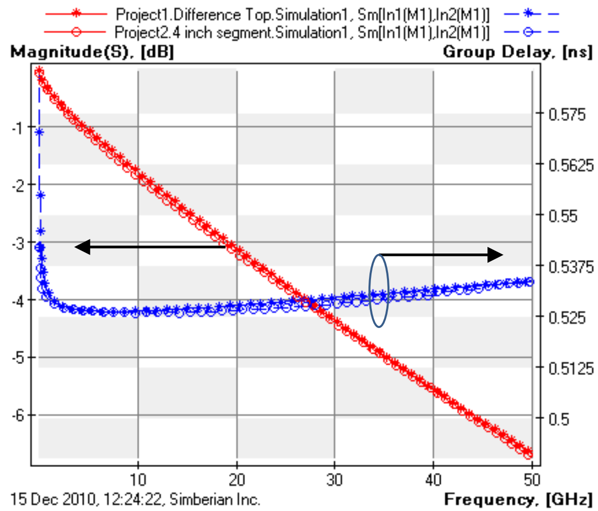
- Solve Maxwell's equations for 1-conductor line:



$$GMSc = \begin{bmatrix} 0 & \exp(-\Gamma \cdot dL) \\ \exp(-\Gamma \cdot dL) & 0 \end{bmatrix}$$

- Fit measured data: *Only 1 complex function!*

$$GMSm = \begin{bmatrix} 0 & T_{11} \\ T_{11} & 0 \end{bmatrix}$$



- Measured GMS-parameters of the segment can be directly fitted with the calculated GMS-parameters for material parameters identification
- Phase or group delay can be used to identify DK and insertion loss to identify LT or conductor roughness!

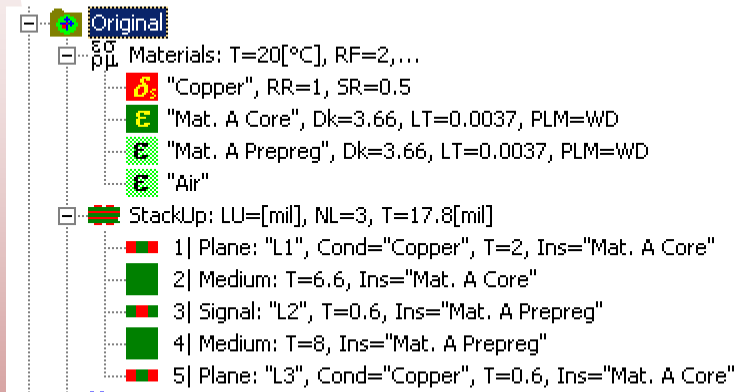
The GMS-parameters technique is the simplest possible

- Needs un-calibrated measurements for 2 t-lines with any geometry of cross-section and transitions
  - No extraction of propagation constants (Gamma) from measured data (difficult, error-prone)
  - No de-embedding of connectors and launches (difficult, error-prone)
- Needs the simplest numerical model
  - Requires computation of only propagation constants
  - No 3D electromagnetic models of the transitions
- Minimal number of smooth complex functions to match
  - One parameter for single and two parameters for differential
  - All reflection and modal transformation parameters are exactly zeros

What if launches or connectors in test fixtures are not identical?

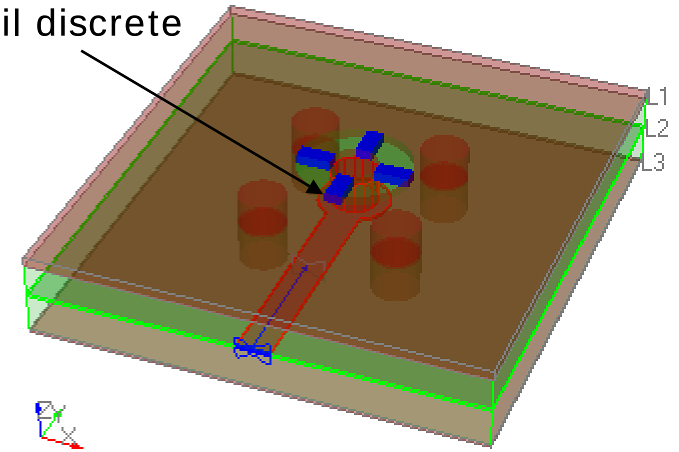
- Numerical experiment to investigate the consequences of the non-identity

Materials & Stackup



Simple transition to 7-mil strip-line with pad (in L2) diameter changing from 8 to 22 mil with 3.5 mil discrete

T0 – 8 mil
T1 – 11.5 mil
T2 – 15 mil
T3 – 18.5 mil
T4 – 22 mil



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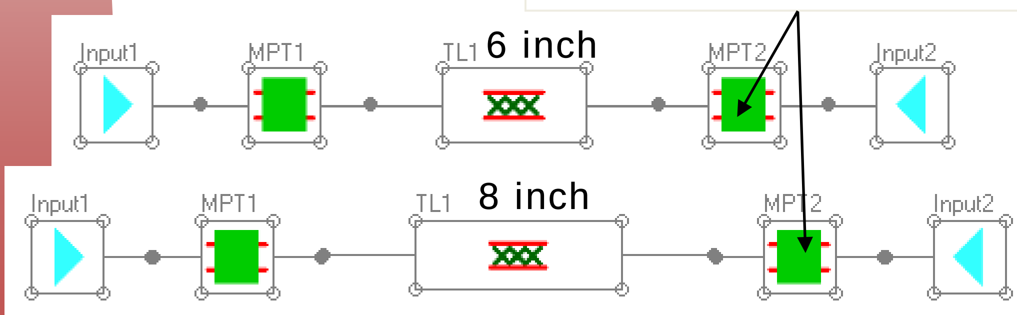
Models of the launches – different between 2 structures



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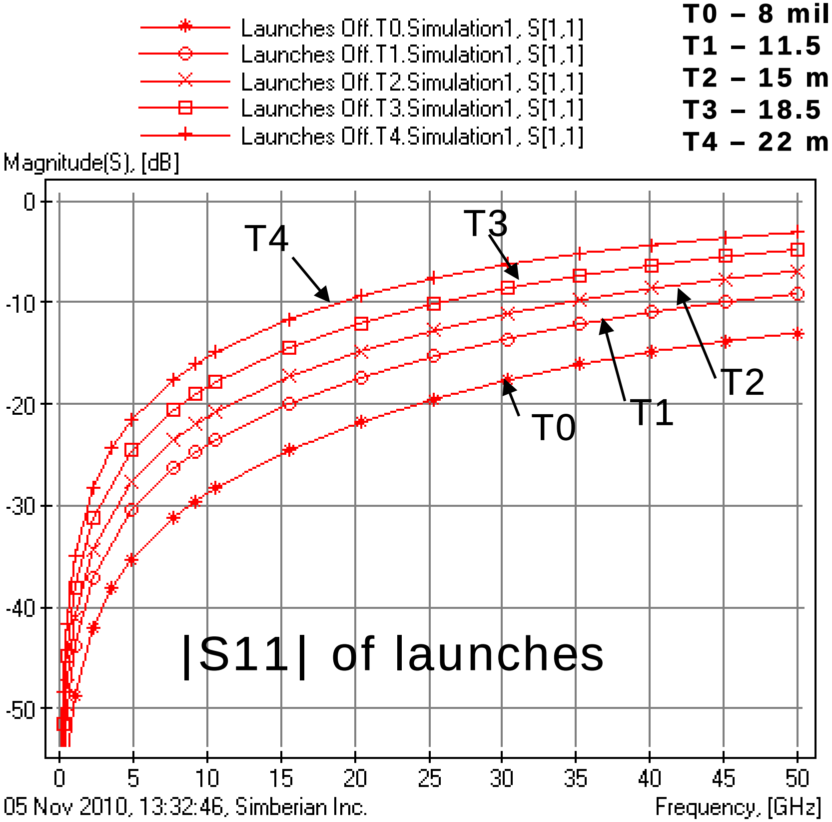
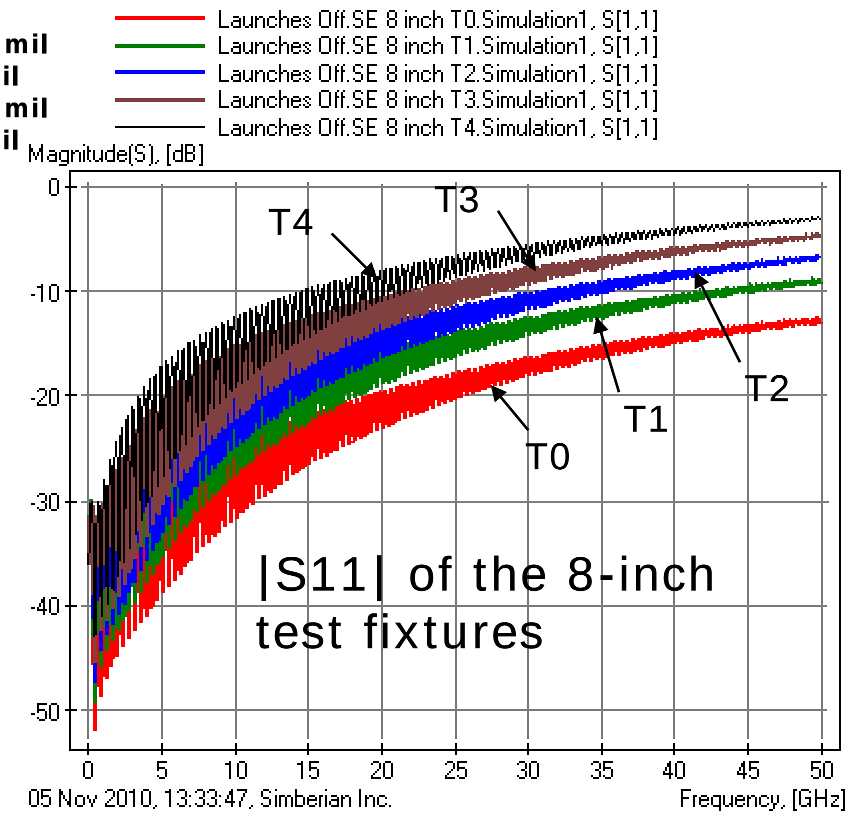
From simulated S-parameters of 2 structures with varying pad diameters we extract GMS-parameters of 2-inch segment and compare it with the GMS-parameters of 2-inch segment computed directly

Effect of launch pad diameter on reflection from 8-inch test fixture

- In case of the t-line impedance close to 50-Ohm, the envelop of the reflection parameters is mostly defined by the reflection from the transition



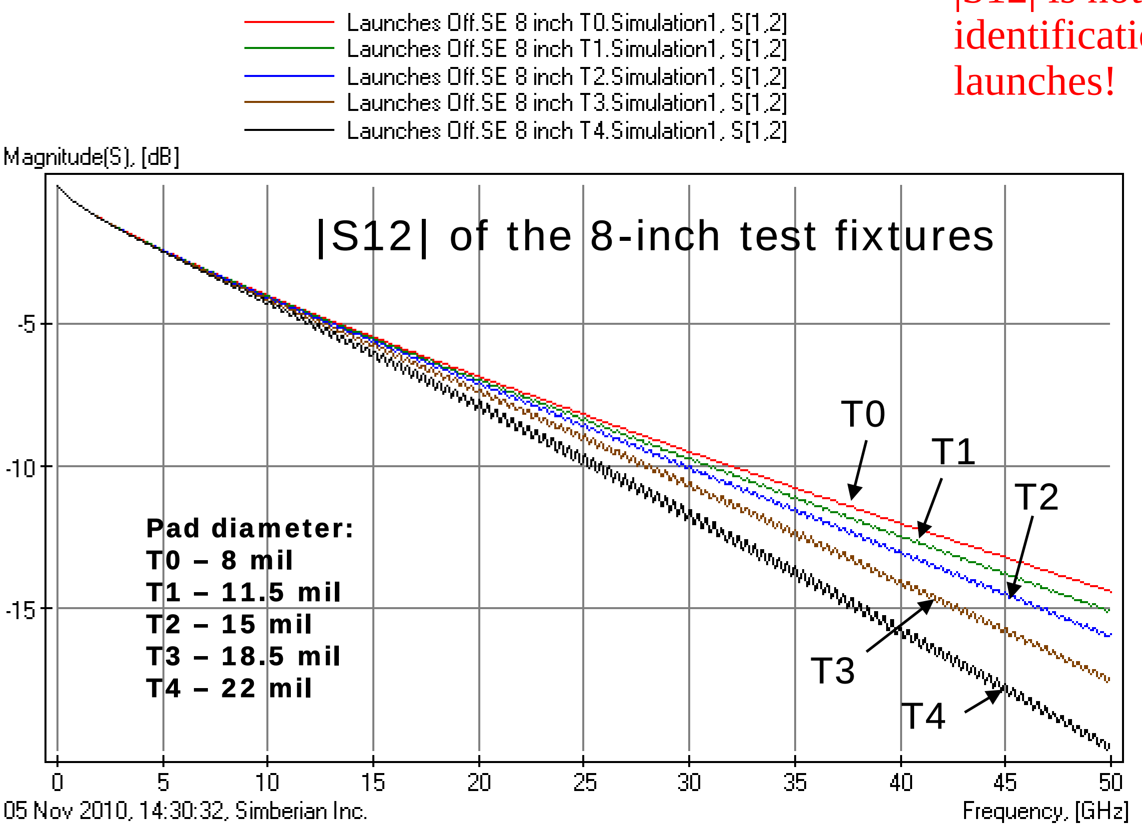
Pad diameter:
T0 – 8 mil
T1 – 11.5 mil
T2 – 15 mil
T3 – 18.5 mil
T4 – 22 mil



Effect of launch pad diameter on transmission through 8-inch test fixture

- Reflective launch lead to substantial difference in the insertion loss |S12| of the test fixture

|S12| is not suitable for the material identification, even with relatively good launches!



Phases are practically identical

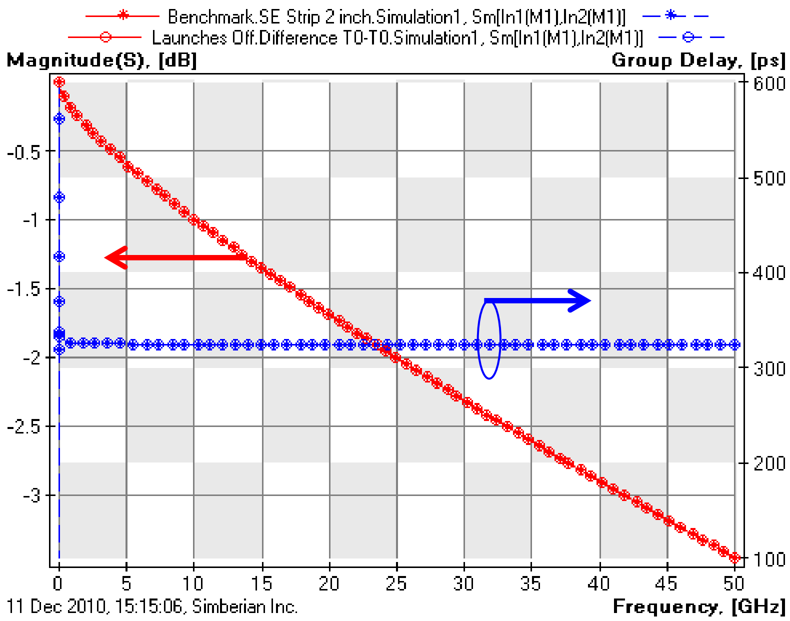
Group delays are substantially different due to reflections

The result is similar for the 6-inch structure

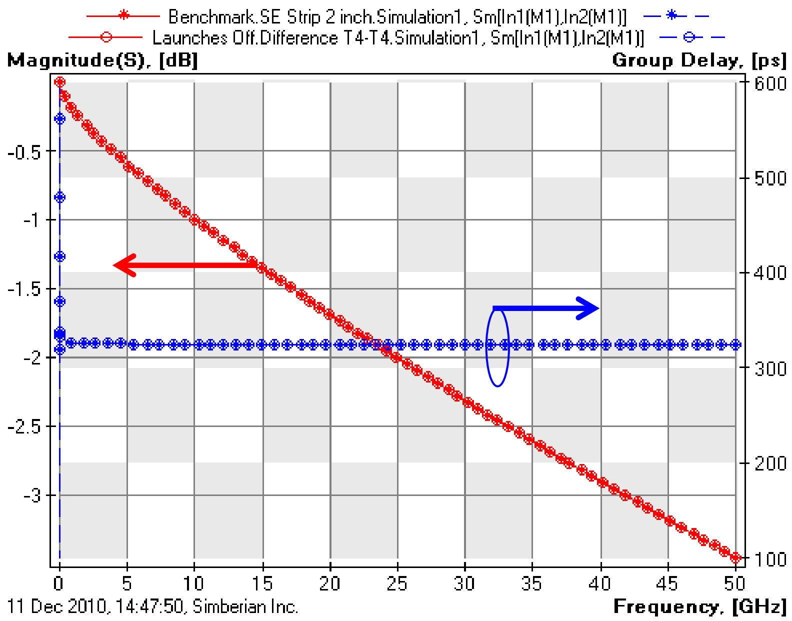
GMS-parameters in case of identical launches

- Extracted GM transmission parameters of 2-inch segment are independent of the launch geometry as long as all 4 launches on 2 test fixtures are identical

Launch with 8 mil pad



Launch with 22 mil pad

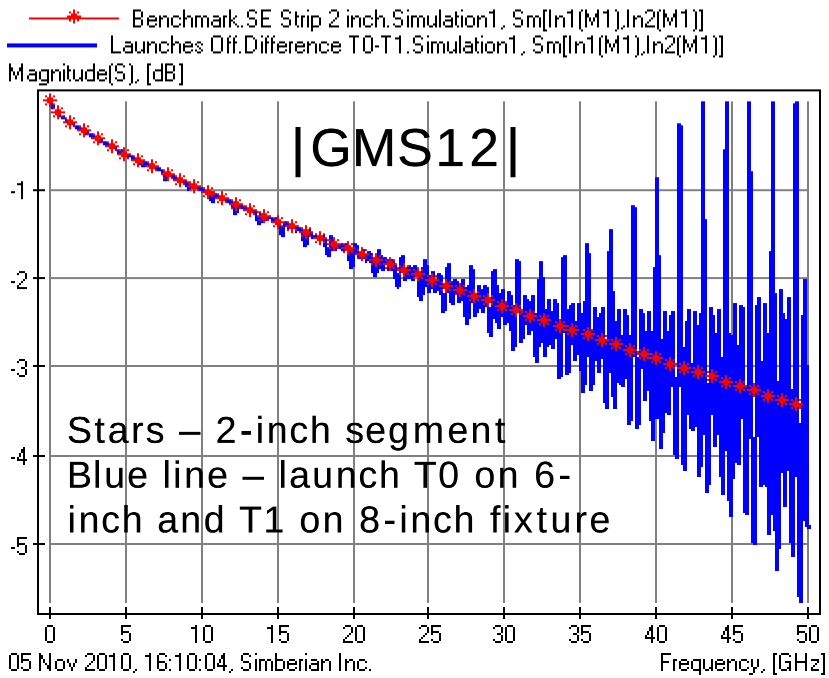


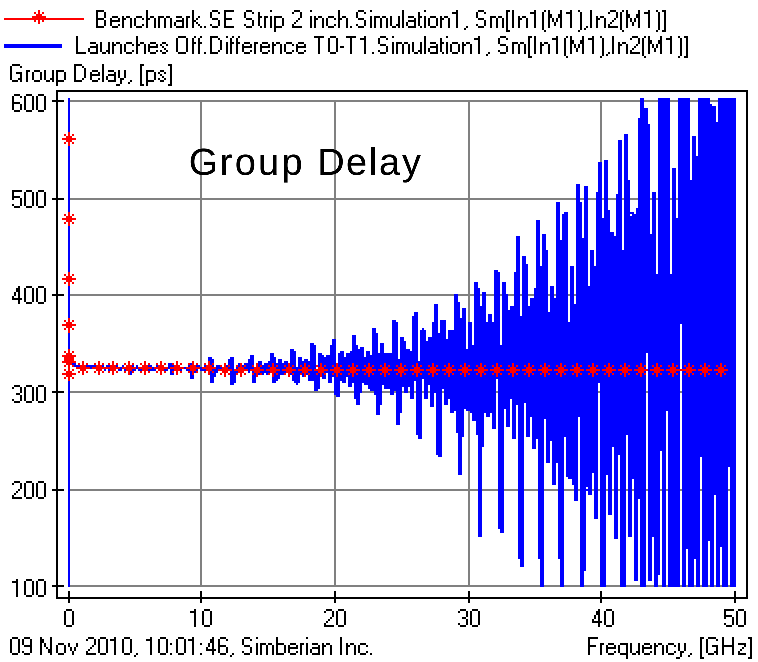
Stars – 2-inch exact, circles – computed from 2 test fixtures

What if launches on 6-inch fixture are different from launches on 8-inch fixture?

- Magnitude of Generalized Modal transmission and group delay look “noisy”
- Material identification may be possible only up to 20-25 GHz

Pad diameter: T0 – 8 mil; T1 – 11.5 mil





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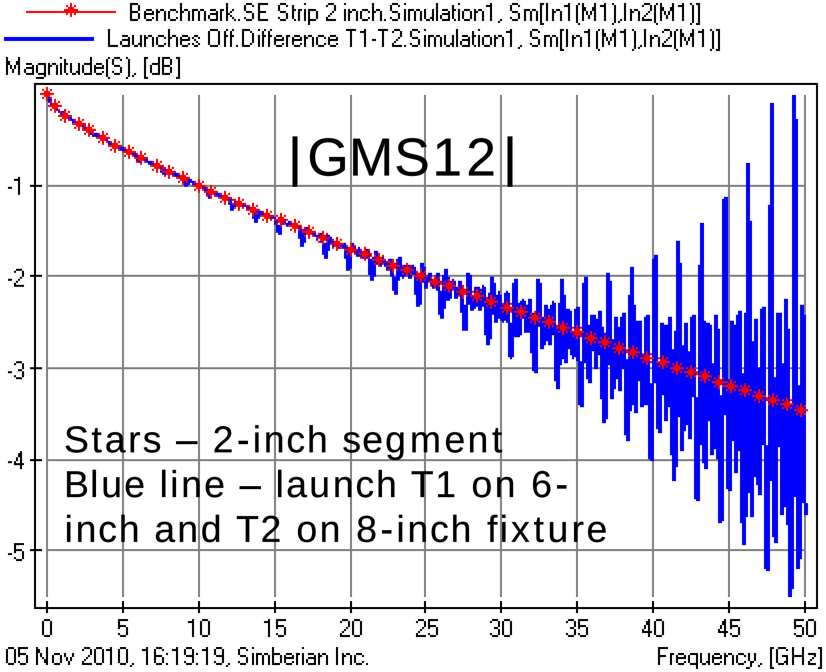
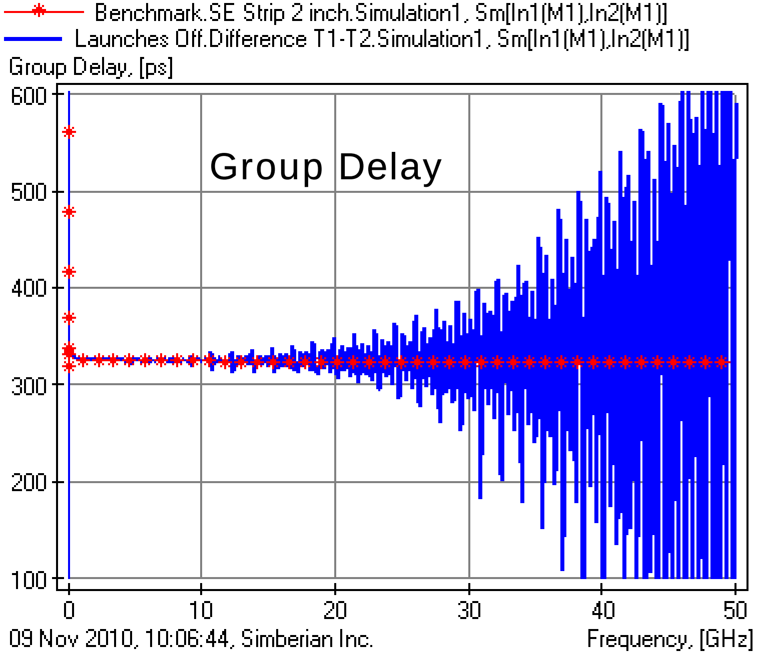
Another pair of launches (better)

- Generalized Modal transmission and group delay looks “noisy”
- Material identification may be possible only up to 20-25 GHz

Pad diameter: T1 – 11.5 mil;T2 – 15 mil

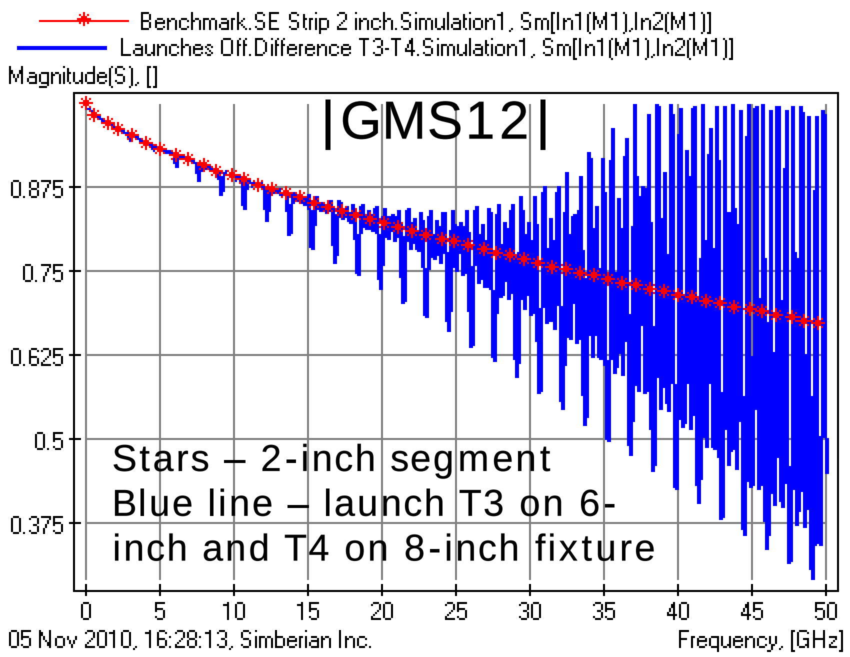


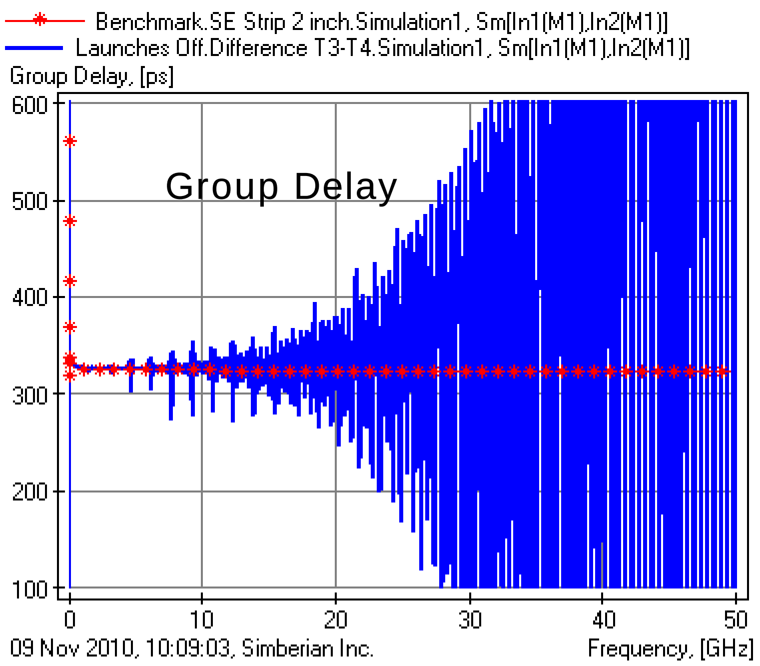


Worst pair of launches

- Generalized Modal transmission and group delay are extremely “noisy”
- Material identification may be possible only up to about 5-10 GHz

Pad diameter: T3 – 18.5 mil; T4 – 22 mil

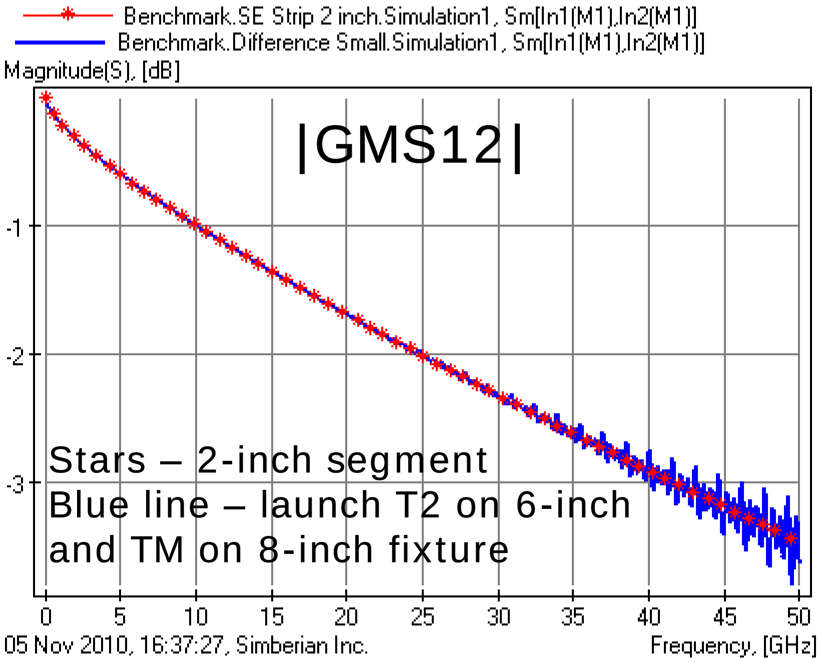


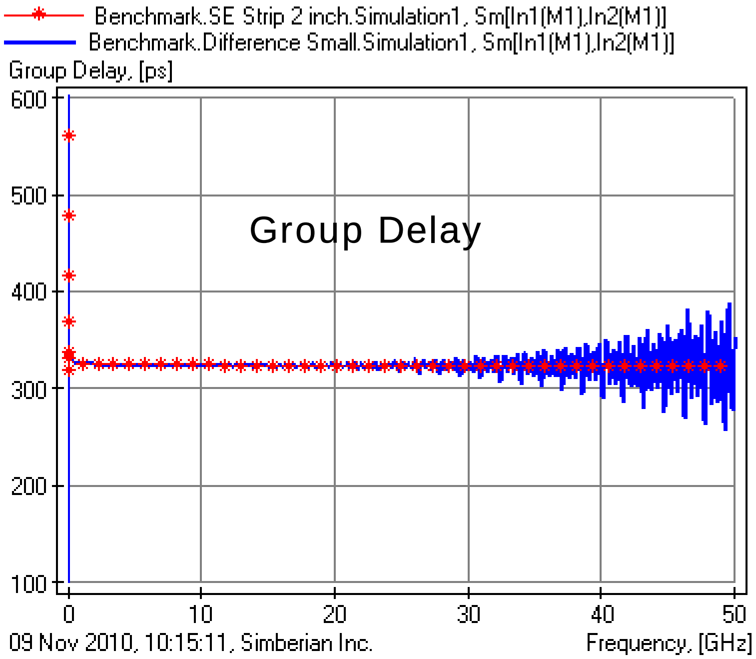


Example with acceptable difference in pad diameters

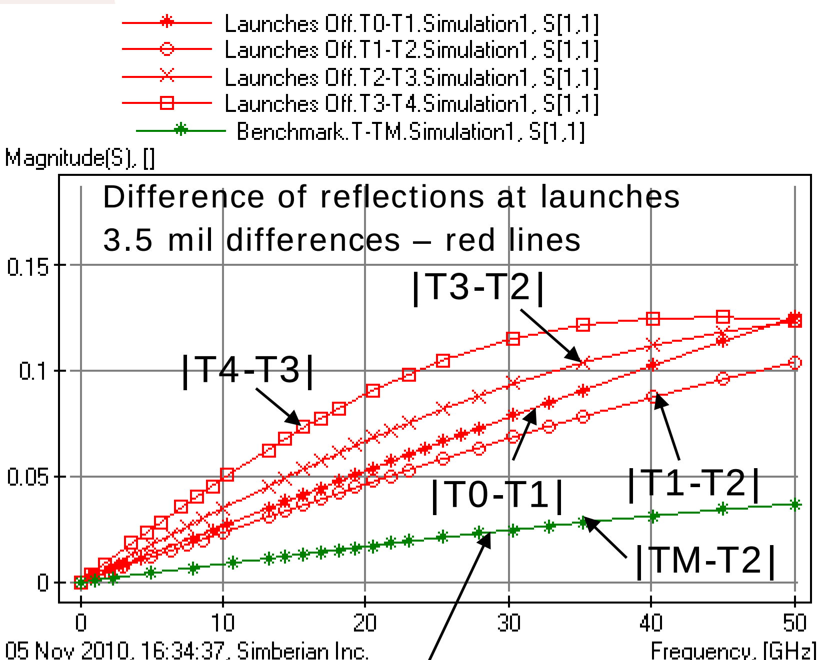
- Suitable for material identification up to 50 GHz

Pad diameter: T2 – 15 mil; TM – 13 mil

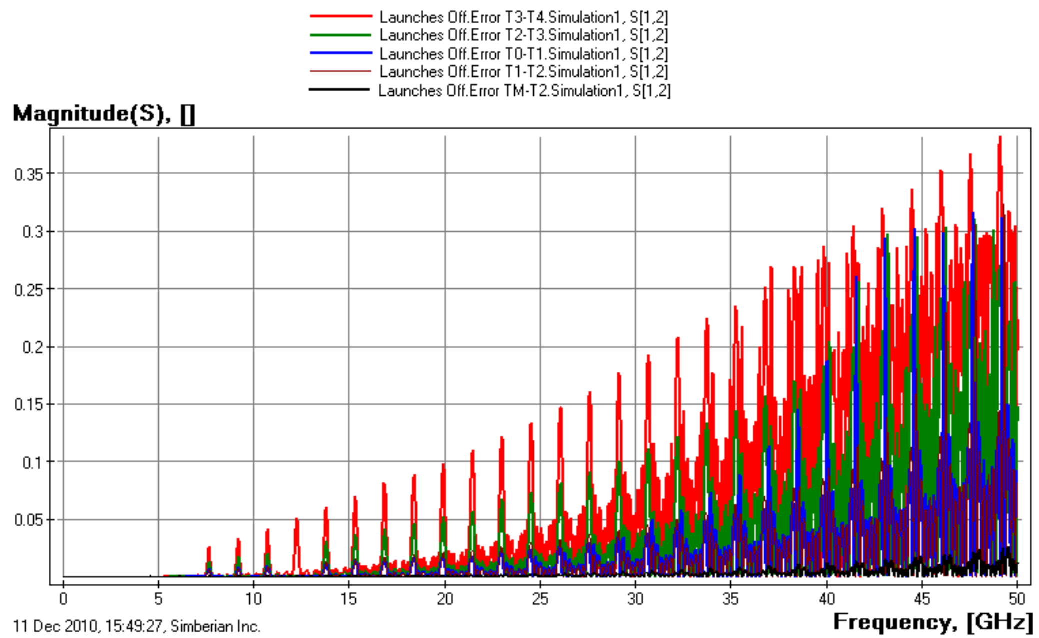




Differences in S-parameters of launches and GMS-parameters extraction error



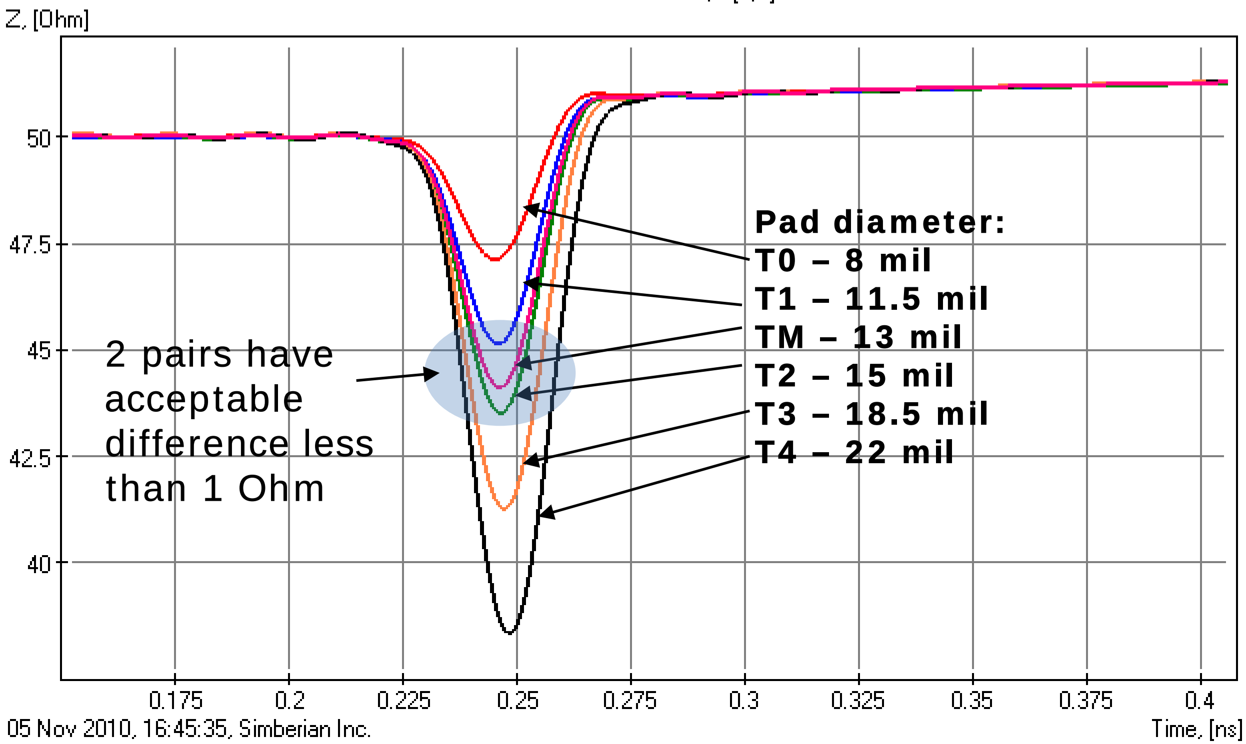
2-mil difference: 13 and 15 mil



The larger the difference in the launches, the larger the deviation of the extracted GMS-parameters from the GMS-parameters of 2-inch line

TDR of the test fixture can provide practical measure of non-identity for pre-qualification

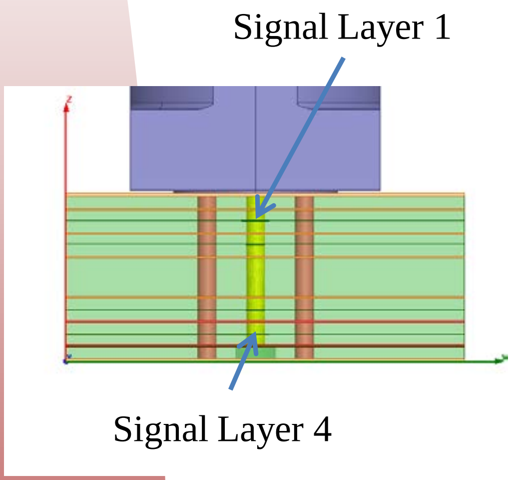
TDRs are computed with the rational macro-models and 20 ps (0.1-0.9) Gaussian step

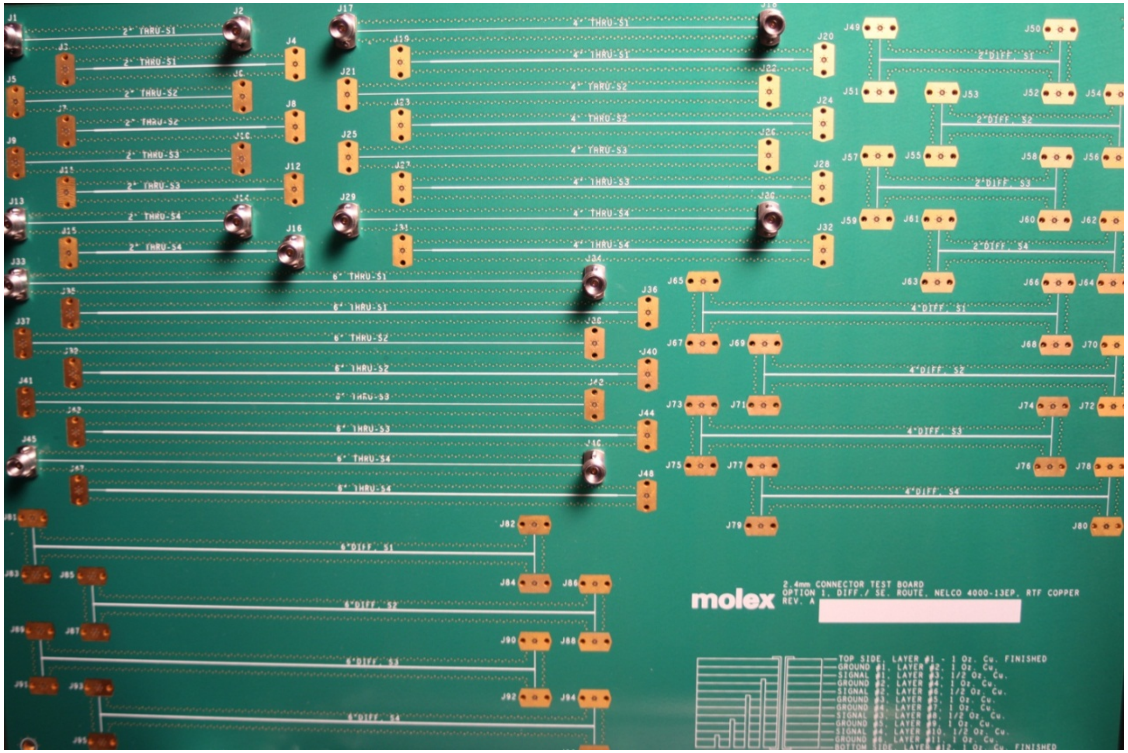


The difference in the launch impedances should be less than 1 Ohm for material identification up to 50 GHz

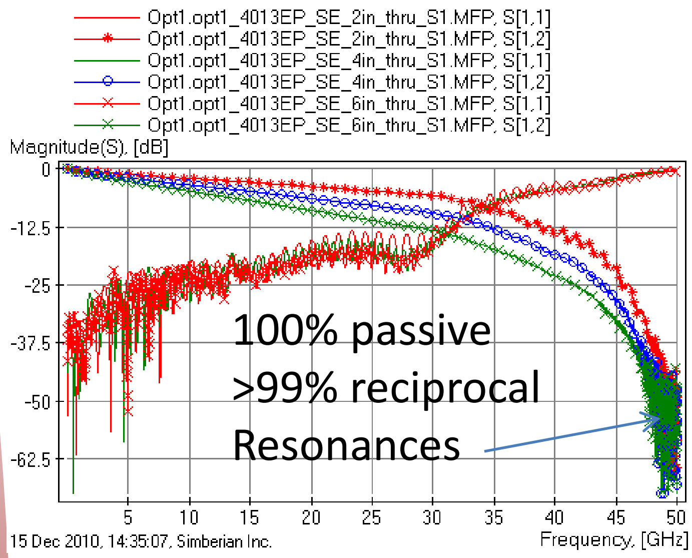
Material extraction structures at 4000-13EP boards

2 board with the same stackup (4 signal & 8 GNDs), but different launches
6 test fixtures with 2, 4 and 6 inch strip line segments in Layer 1 and Layer 4

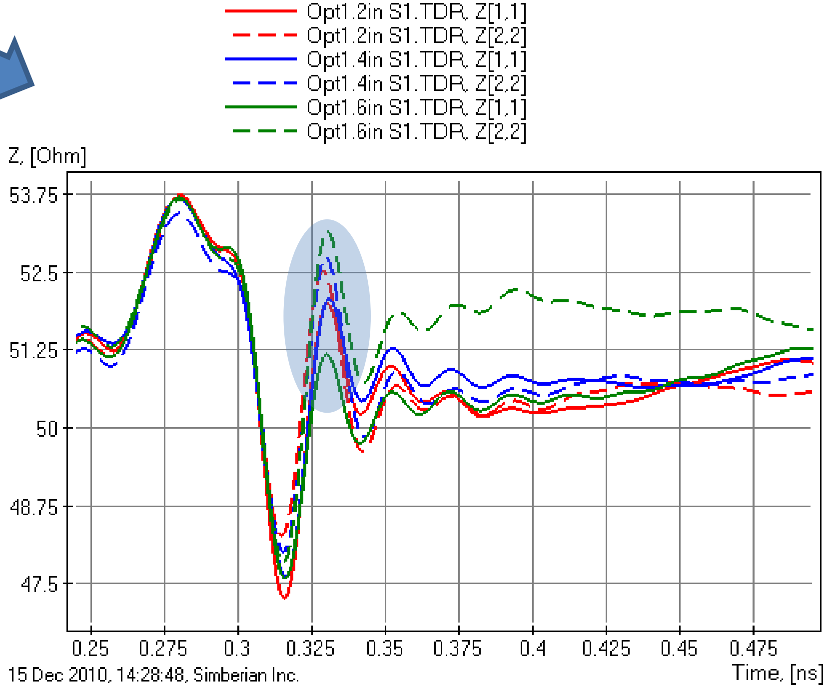




Pre-qualification of launches on 4000-13EP test board – Launch 1, layer S1



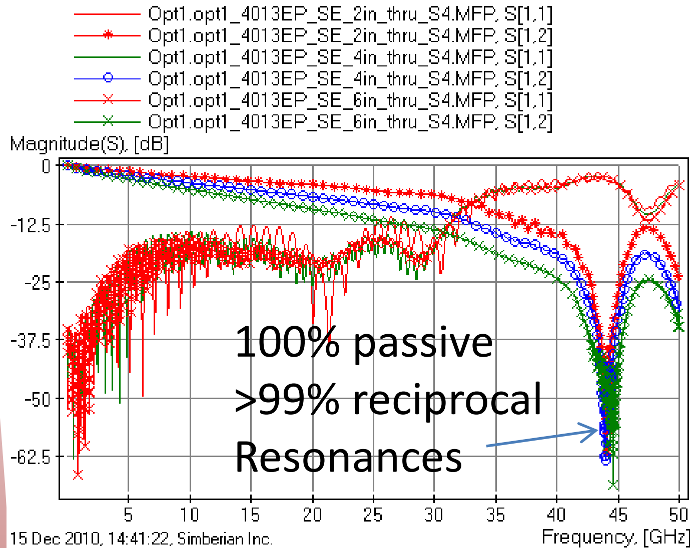
TDR computed with rational macro-models (RMSE<0.005) and Gaussian step with 20 ps rise time



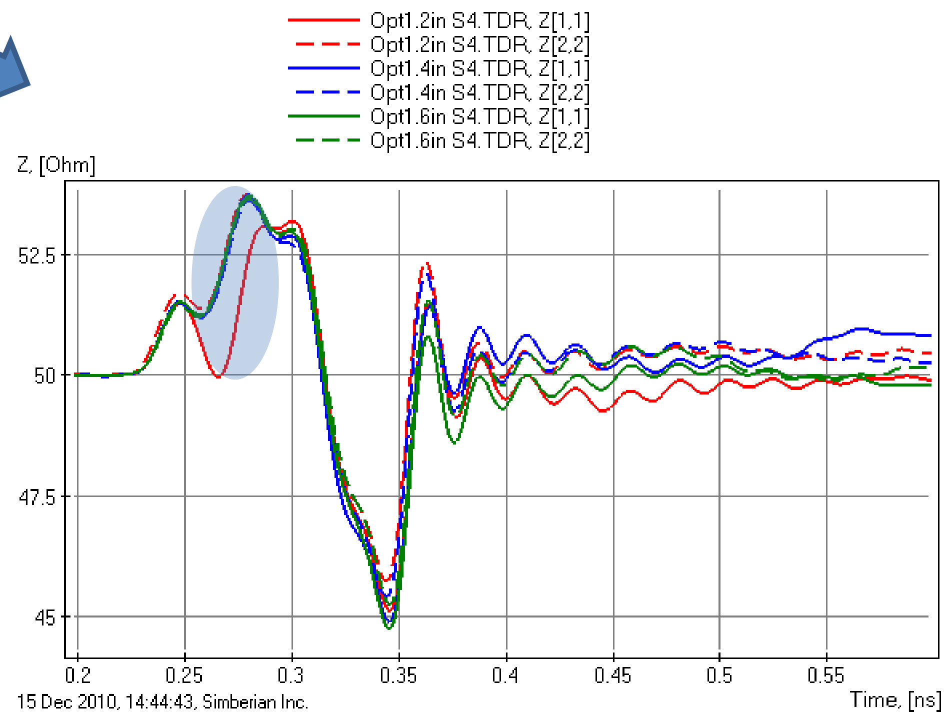
6-inch fixture (green lines) has large variation in the impedance

2 and 4 inch structures are within 1 Ohm - suitable for the identification

Pre-qualification of launches on 4000-13EP test board – Launch 1, layer S4



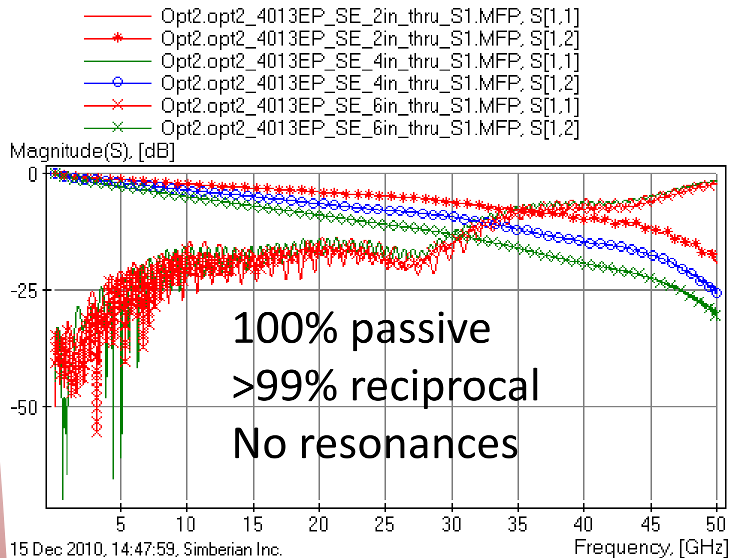
TDR computed with rational macro-models (RMSE<0.005) and Gaussian step with 20 ps rise time



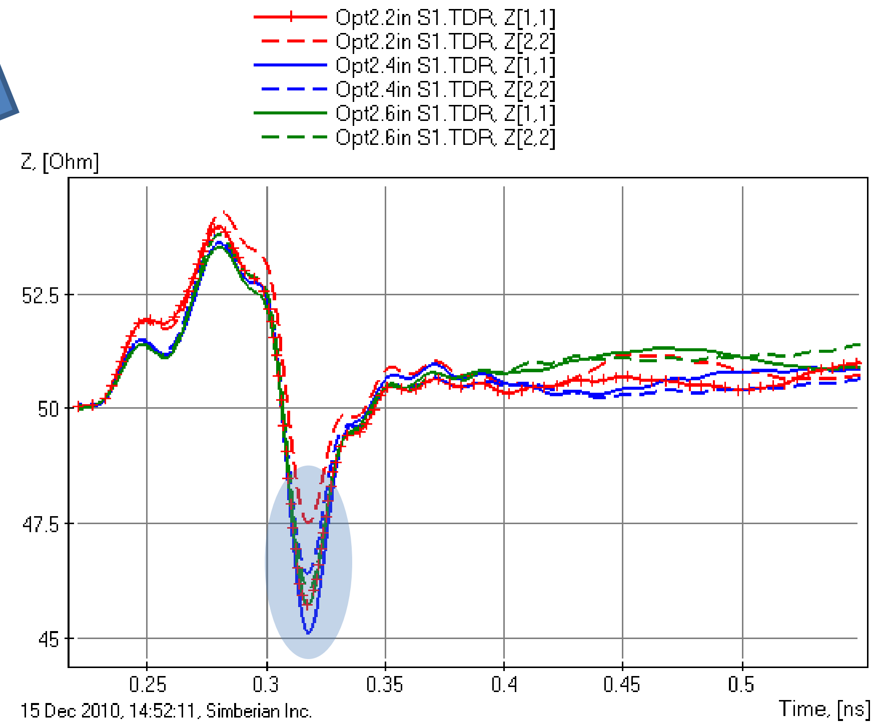
2-inch fixture (red lines) has large variation in the impedance

4 and 6 inch structures are within 1 Ohm - suitable for the identification

Pre-qualification of launches on 4000-13EP test board – Launch 2, layer S1



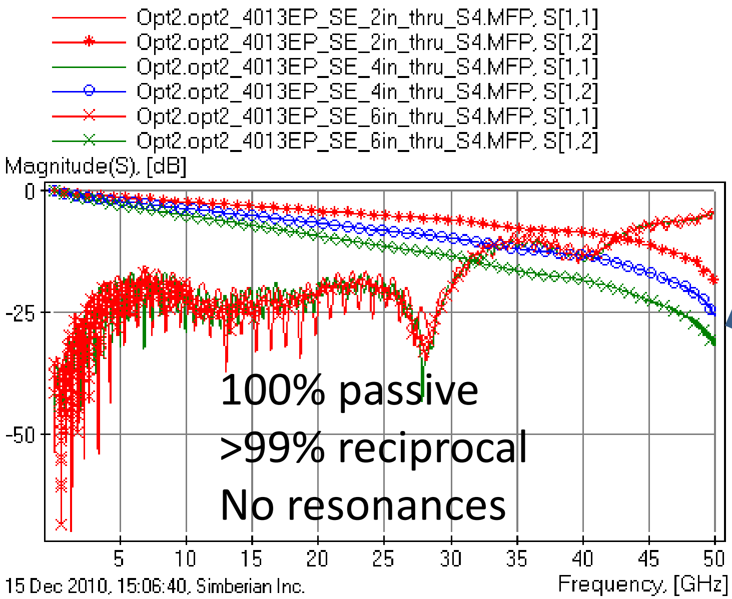
TDR computed with rational macro-models (RMSE<0.005) and Gaussian step with 20 ps rise time



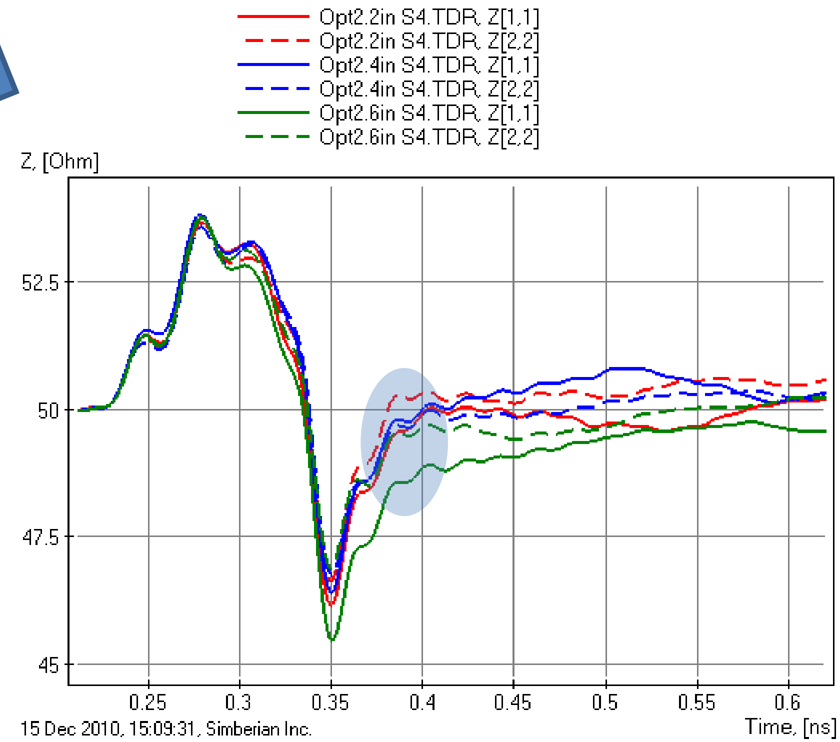
2-inch fixture (red lines) has large variation in the impedance

4 and 6 inch structures are within 1 Ohm - suitable for the identification

Pre-qualification of launches on 4000-13EP test board – Launch 2, layer S4



TDR computed with rational macro-models (RMSE<0.005) and Gaussian step with 20 ps rise time



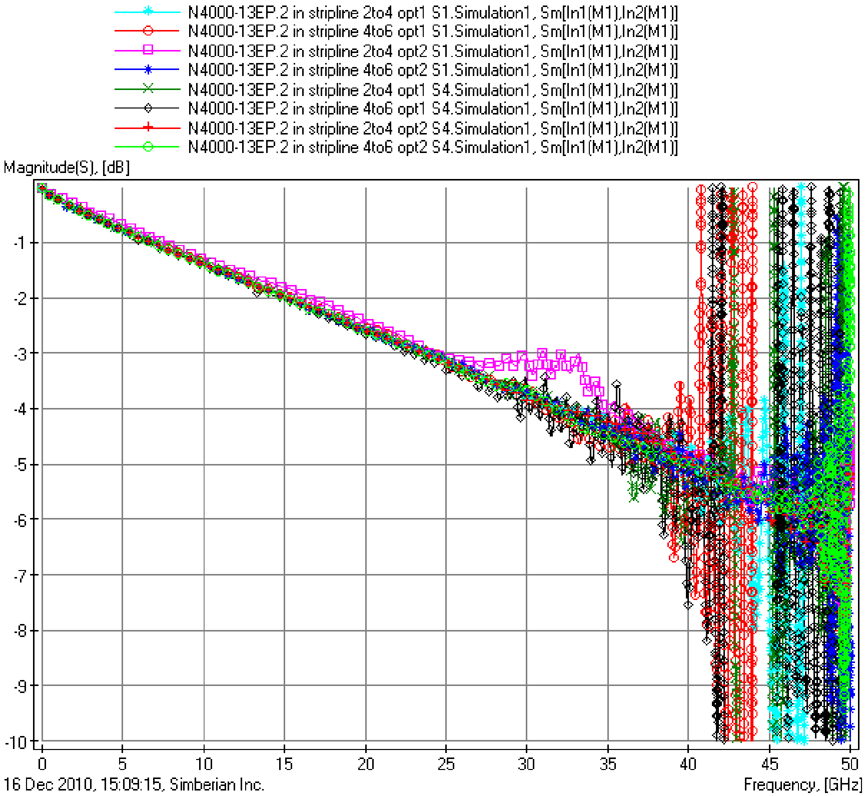
6-inch fixture (green lines) is questionable (near launch)

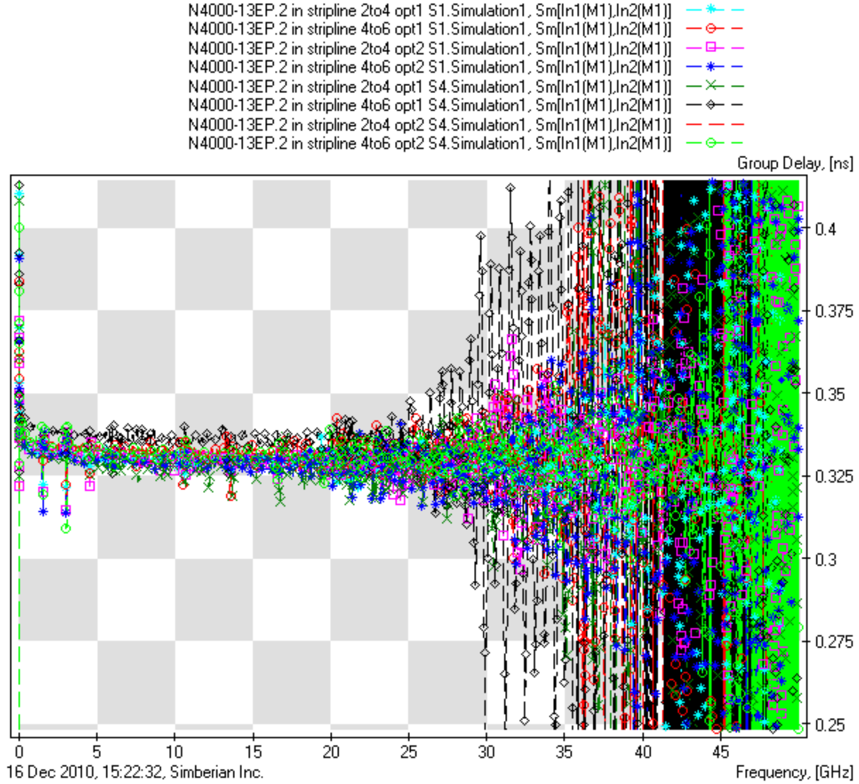
2 and 4 inch structures are within 1 Ohm - suitable for the identification

GMS-parameters of 2-in line

Extracted from different combinations of S-parameters measured for 2, 4 and 6 inch strip lines in layers S1 and S4

Bad launches & resonance blows off data above 30-35 GHz

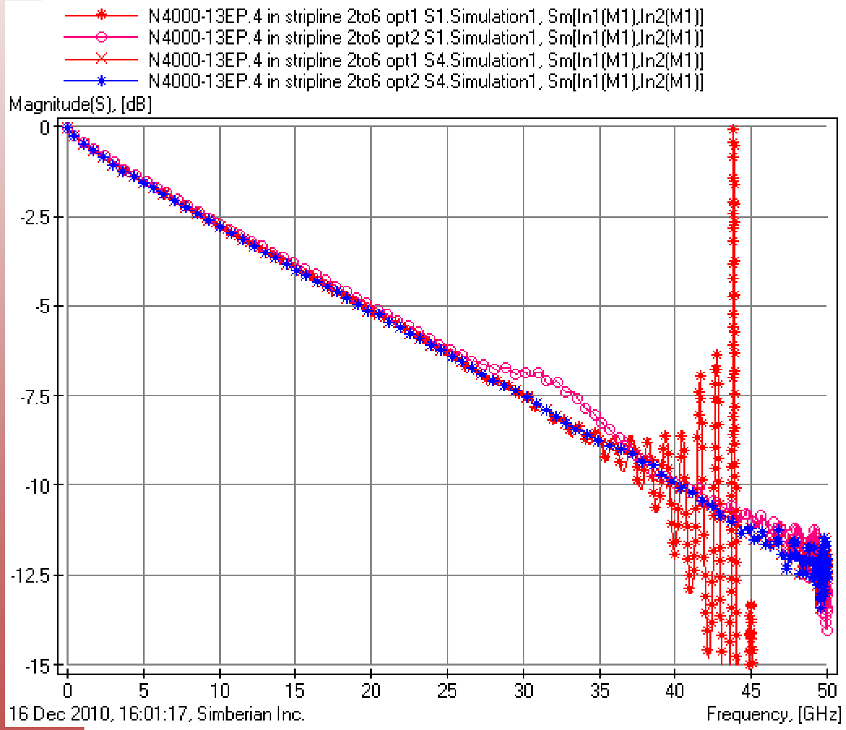


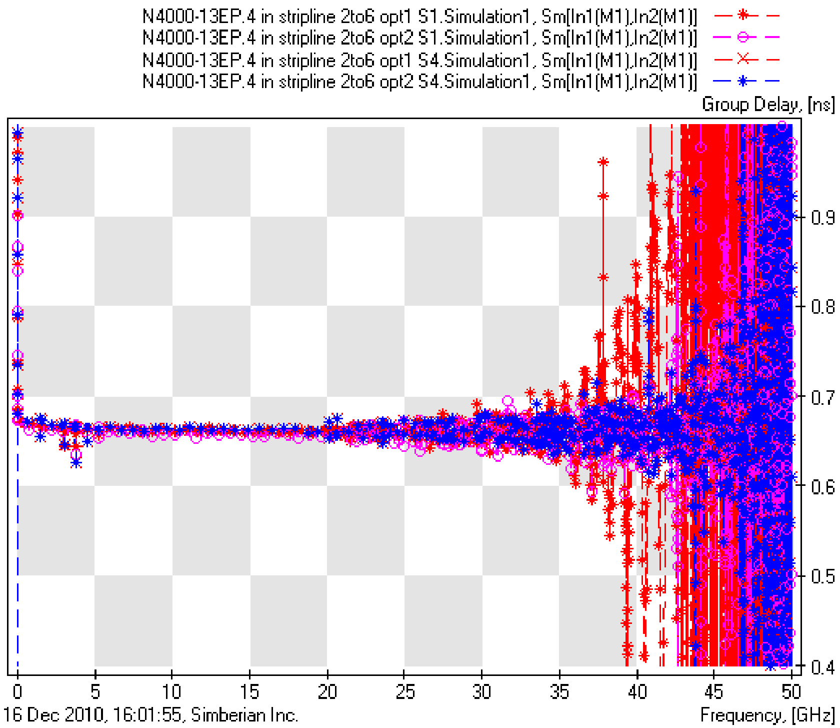


GMS-parameters of 4-in line

Extracted from different combinations of S-parameters measured for 2 and 6 inch strip lines in layers S1 and S4

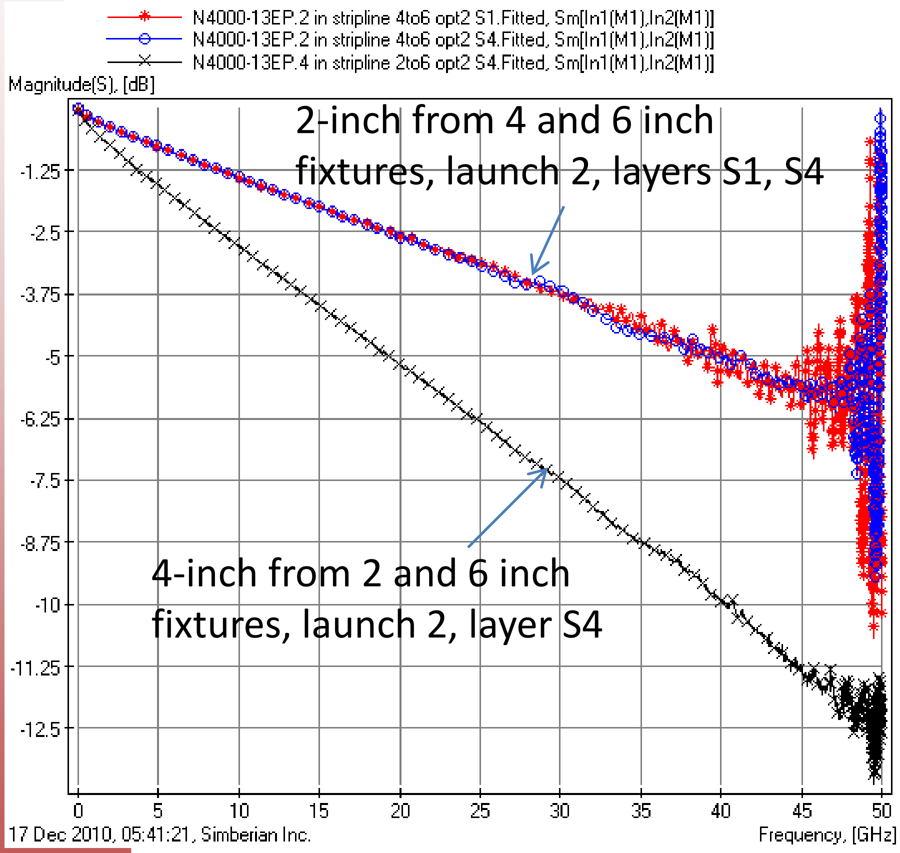
Bad launches & resonance blows off data above 30-35 GHz



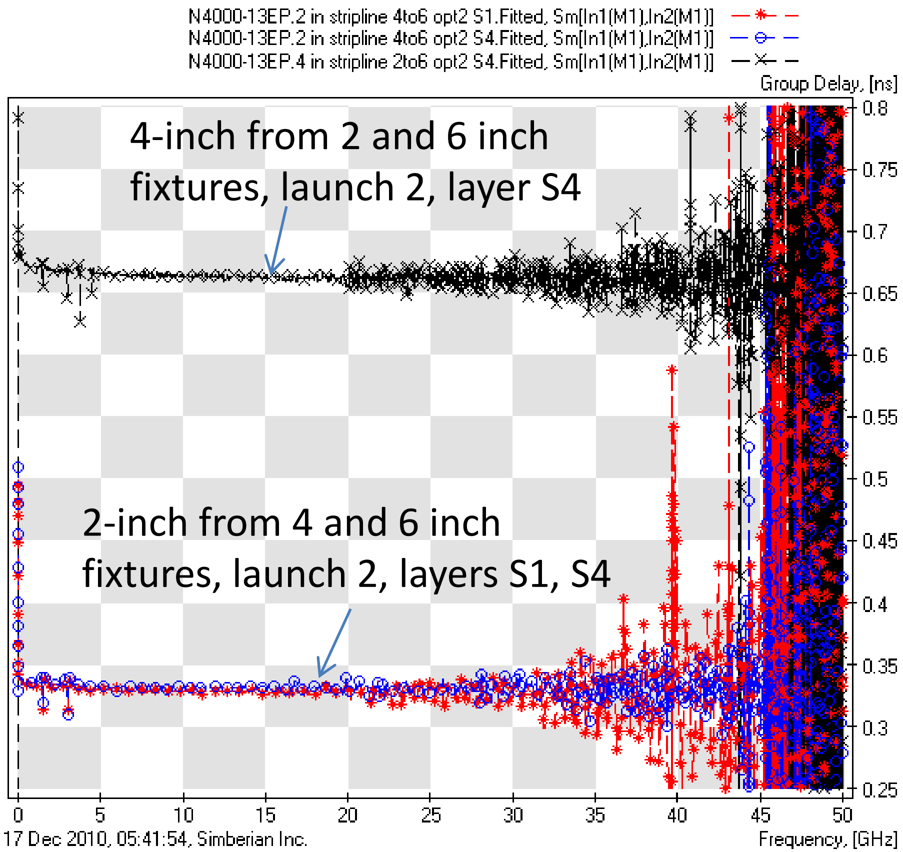


GMS-parameters from 3 best pairs

Generalized Insertion Loss



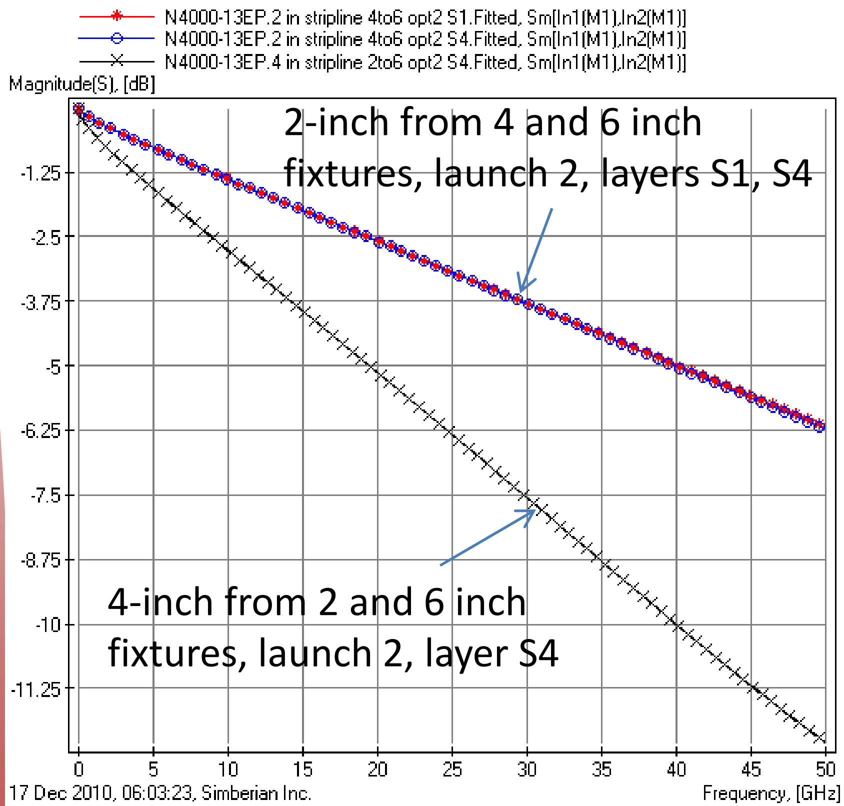
Generalized Group Delay



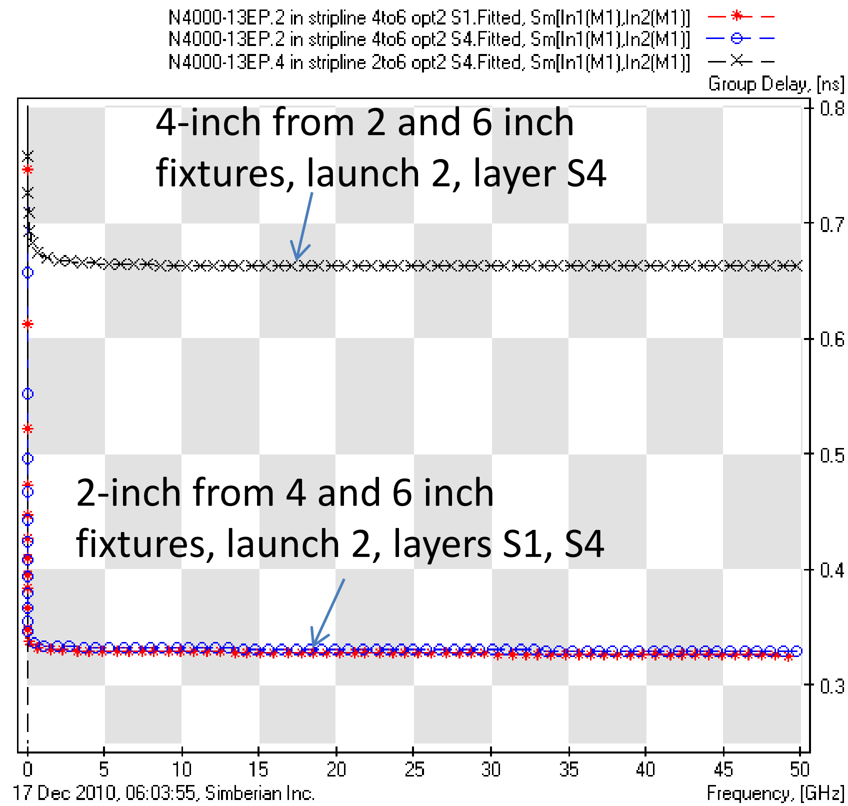
Already suitable for the identification, but can be further improved with post-processing

Fitted GMS-parameters from 3 best pairs

Generalized Insertion Loss



Generalized Group Delay



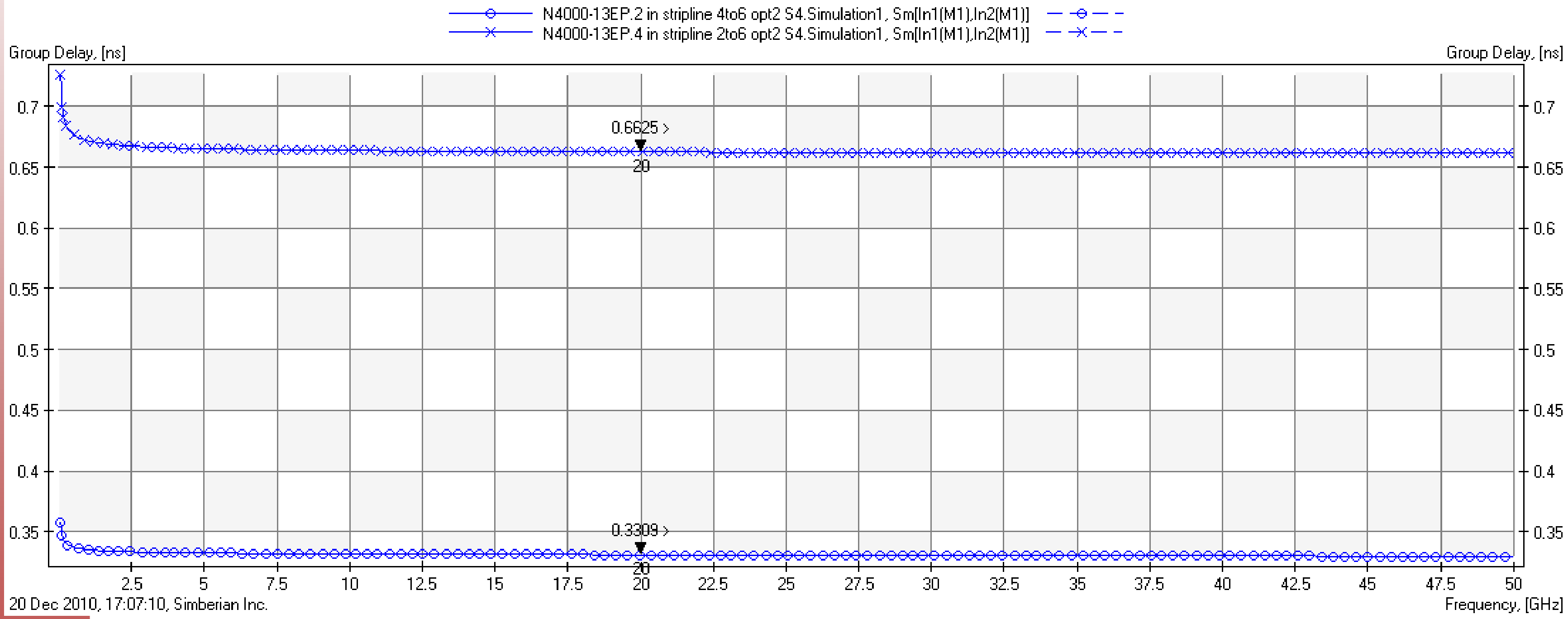
Now data are suitable for precise characterization of materials!

Practical Material Identification

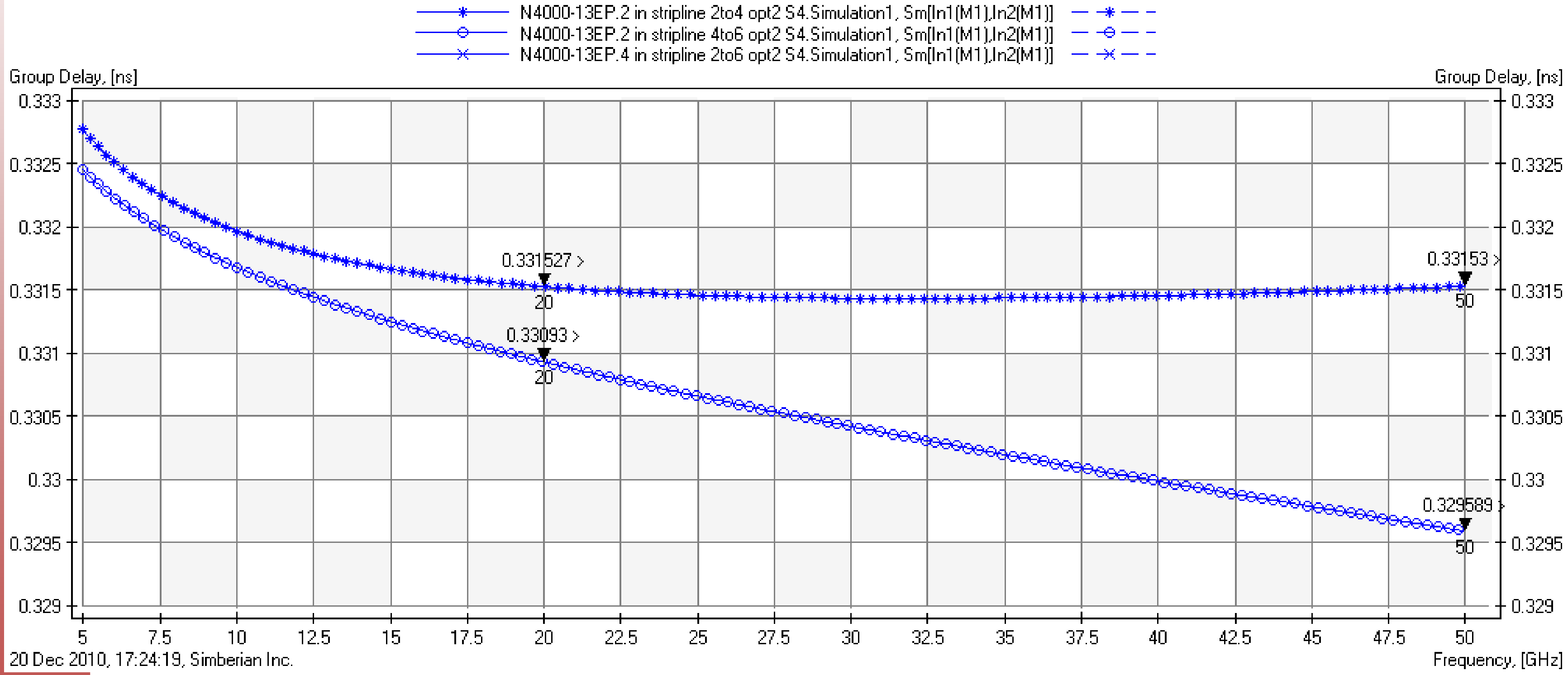
- Step 1 – Use group delay for preliminary Er
- Step 2 – Evaluate potential variation
- Step 3 – Identify low frequency characteristics
- Step 4 – Adjust for dielectric loss
- Step 5 – Final adjustment for conductor roughness

Practical Material Identification

Step 1 – Group Delay Preliminary Er Identification

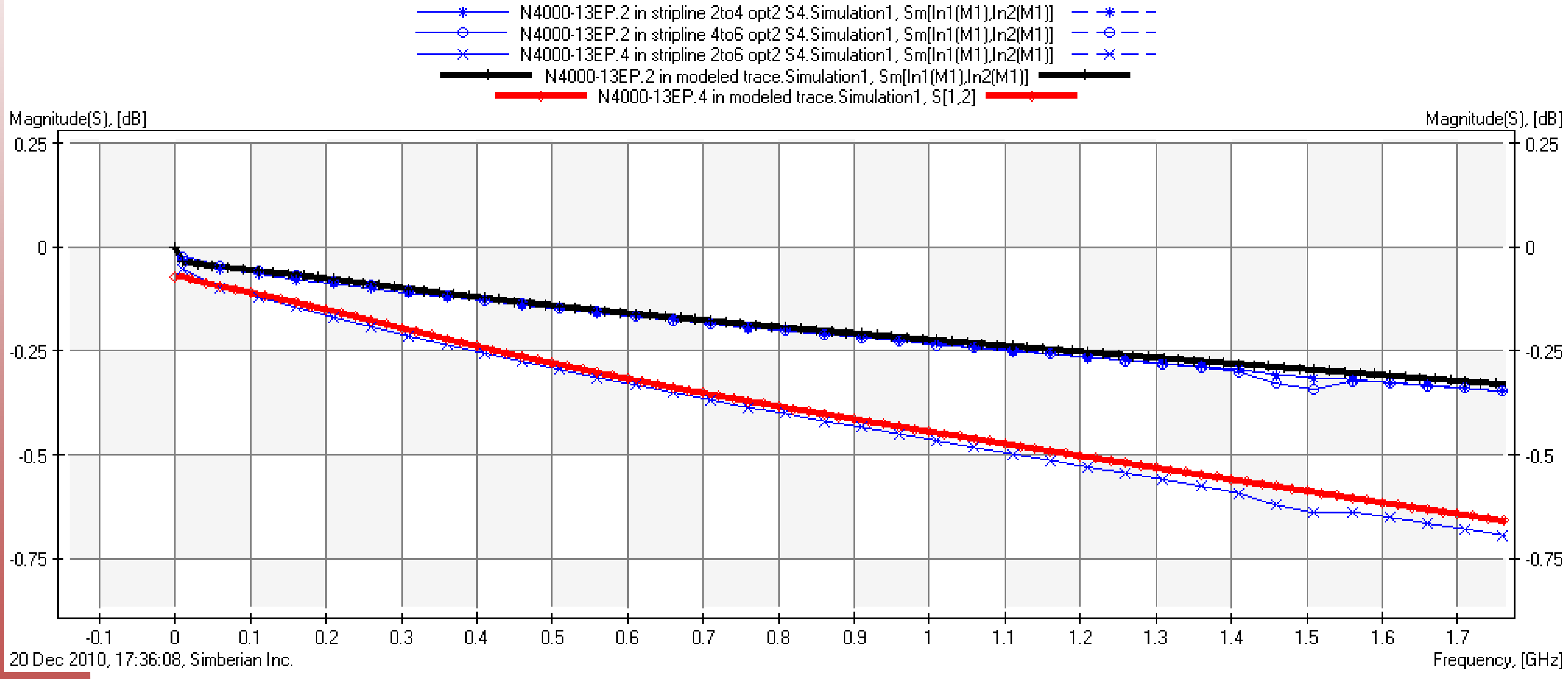


Practical Material Identification
Step 2 – Evaluate variation

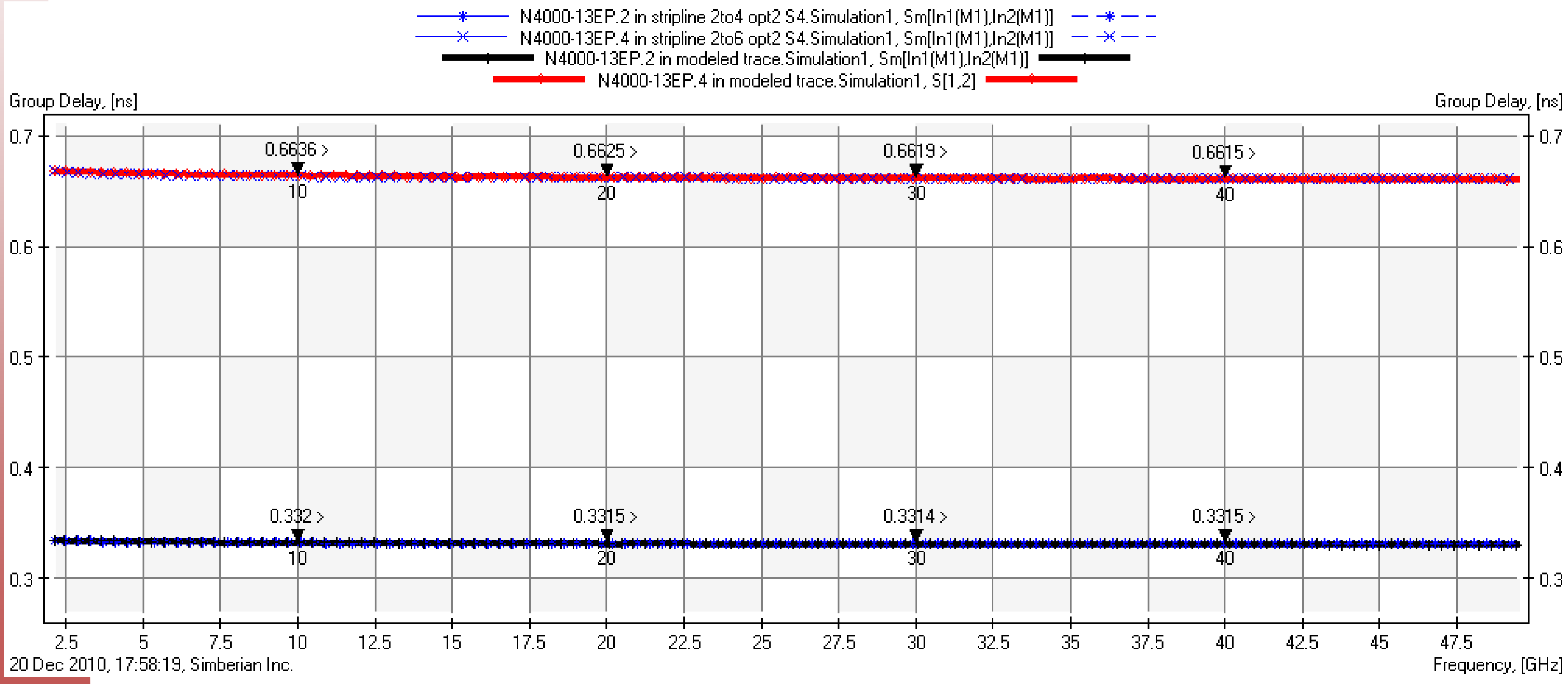


Practical Material Identification

Step 3 – Identify Low Frequency Characeristics

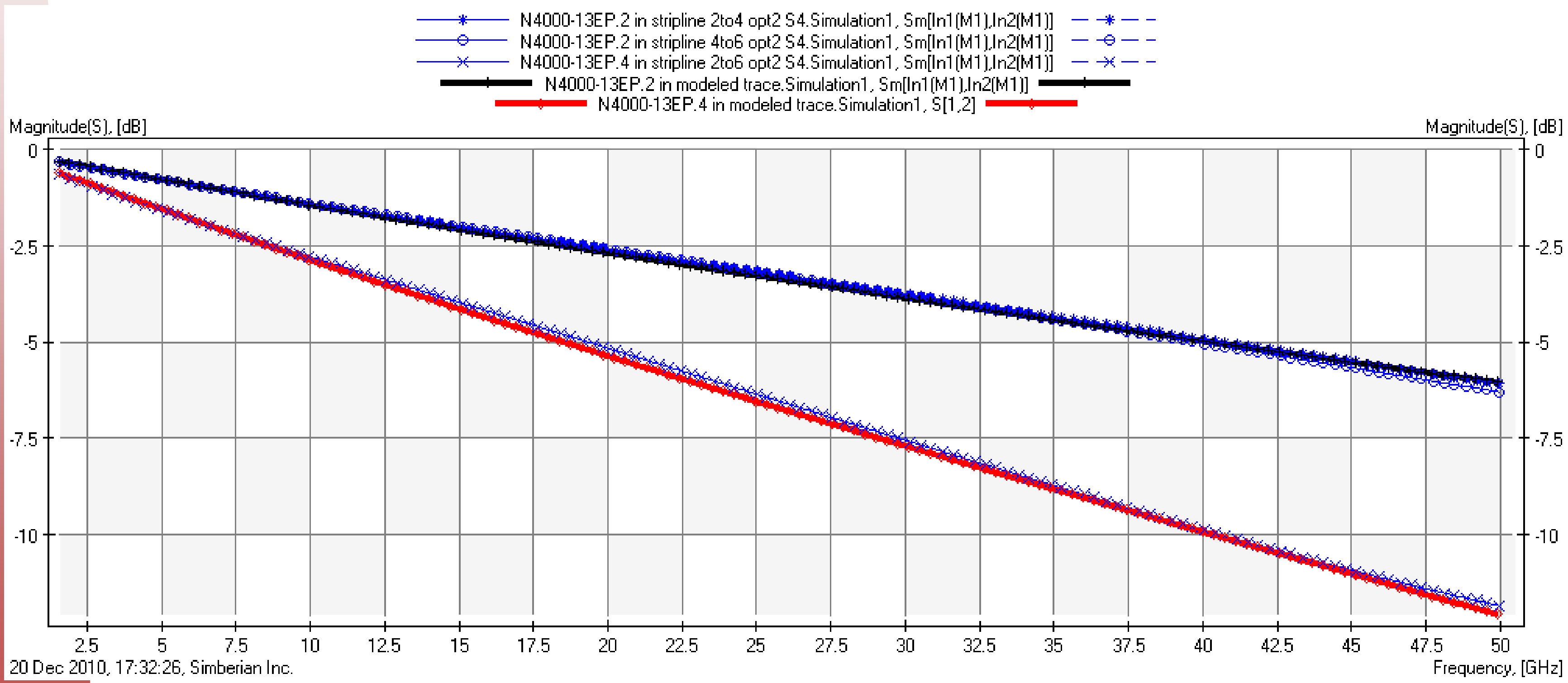


Practical Material Identification
Step 4 – Adjustment for Dielectric Loss



Practical Material Identification

Step 5 – Final Adjustment for Conductor Roughness



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Conclusion

- A novel compression-launch 2.4mm coaxial connector, functional up to 50GHz, has been designed
- Methodology and design of optimal PCB launch and escape under the 2.4 mm connector are presented
- GMS-based material identification procedure is outlined and illustrated with practical examples
- Sensitivity of material identification to non-identities of the launches geometries is investigated theoretically and with practical examples
- Materials of a test board are identified from DC to 50 GHz

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