UBM

A MATERIAL WORLD

Modeling dielectrics and conductors for interconnects operating at 10-50 Gbps

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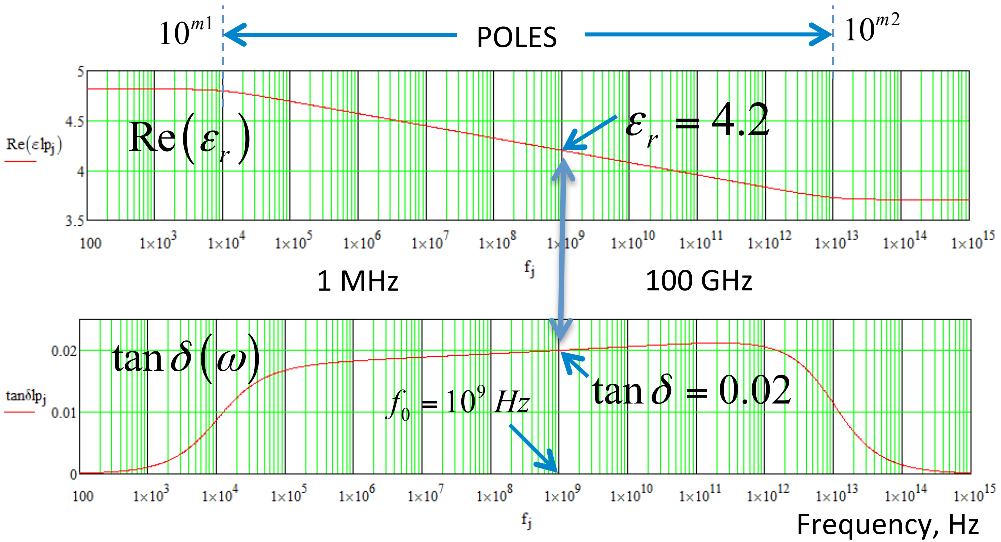
Practical PCB Material Identification Techniques

Wideband Debye model properties

Dk and LT at one point is sufficient to define the model!



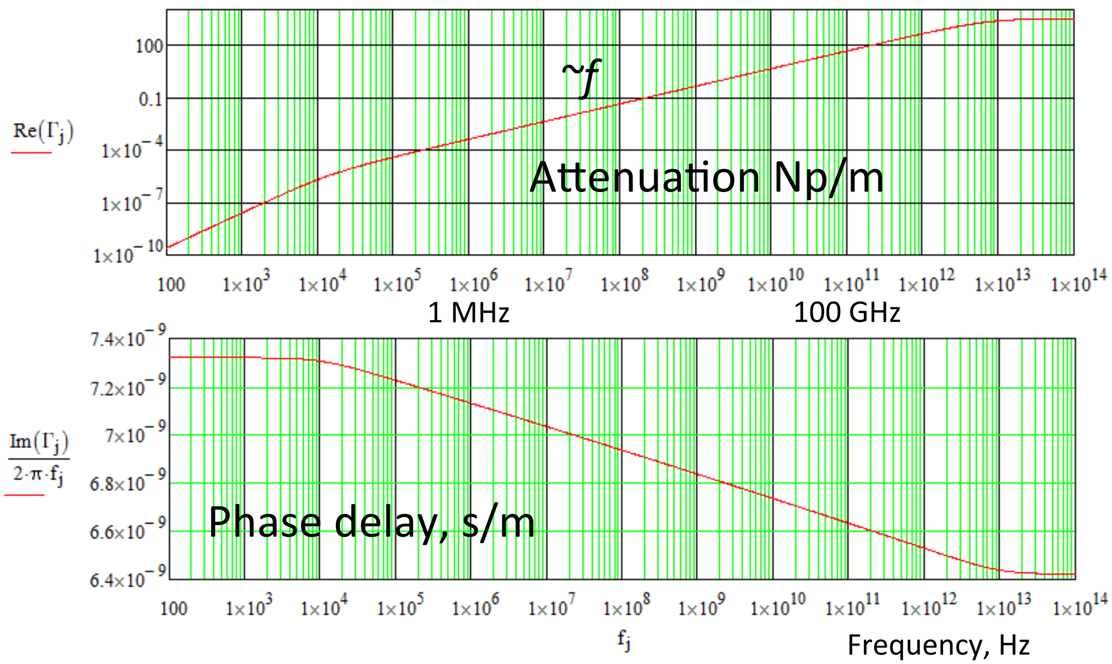
Djordjevic-Sarkar model assumptions

- Dielectric properties represent the behavior of two poles
    - **Low frequency pole (kHz)**
    - **High frequency pole (THz)**
    - **Well outside the frequency band that we want to characterize for data transmission.**

Djordjevic-Sarkar model advantages

- Describes most materials used in PCB/ Package/Cable
- Simple to adjust

Plane wave in Wideband Debye dielectric



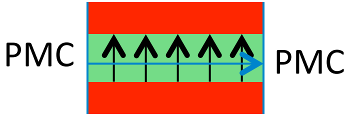
Both attenuation and phase delay provide the same information regarding the dielectric loss.

Slope of the phase delay is dependent upon loss tangent.

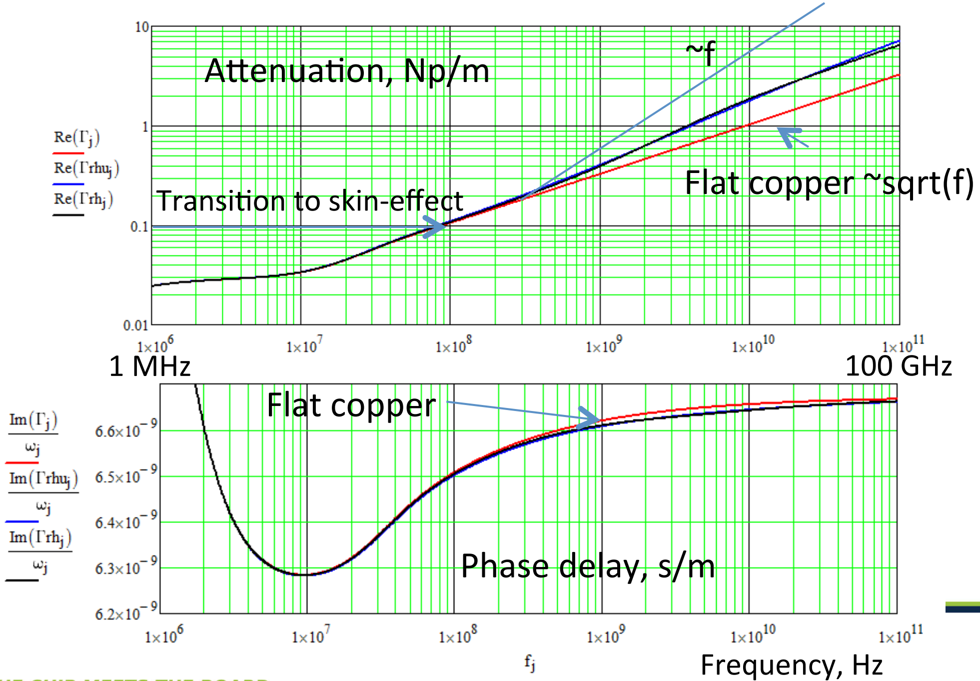
We can use this to identify dielectric, since there is a fairly sensitive slope.

Practical implication of rough conductors

"Oliner's waveguide – ideal to investigate RCCs



Copper: w=20 mil; t=1 mil; Rough;
Ideal dielectric: Dk=4; h=5.3 mil;



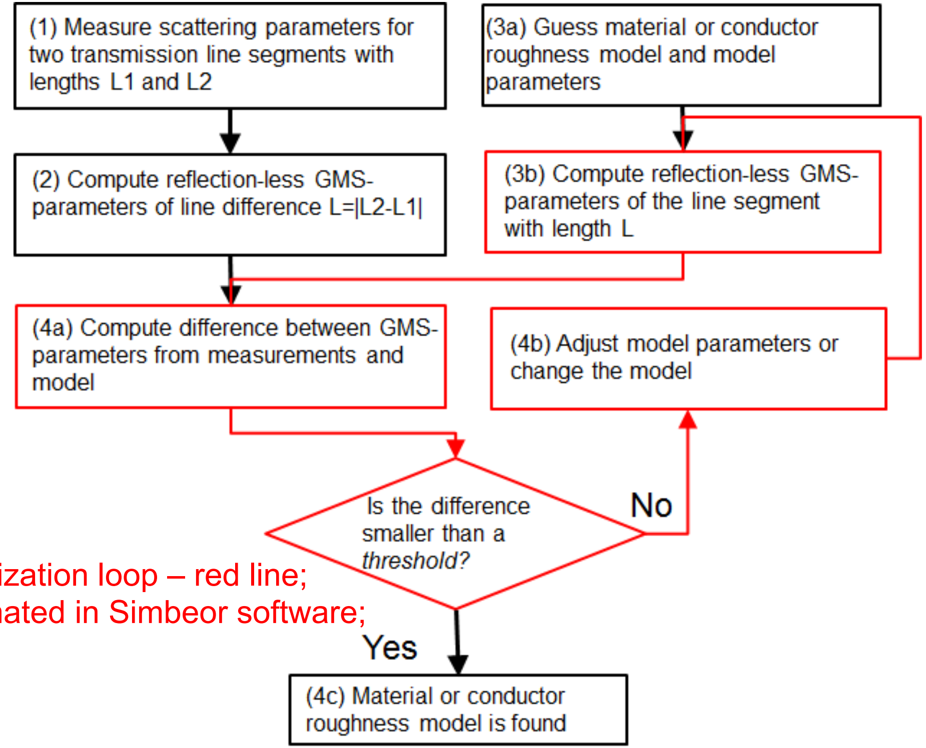
Roughness has a large impact on loss.

Roughness has a very small impact on phase delay.

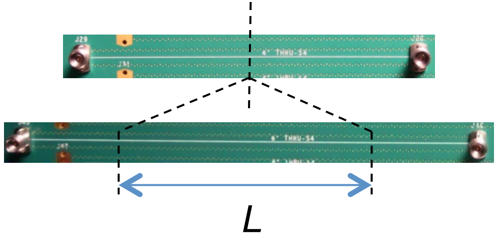
We can use this in the final tuning of overall interconnect loss.

We can neglect roughness for the purpose of identifying Dk and Df.

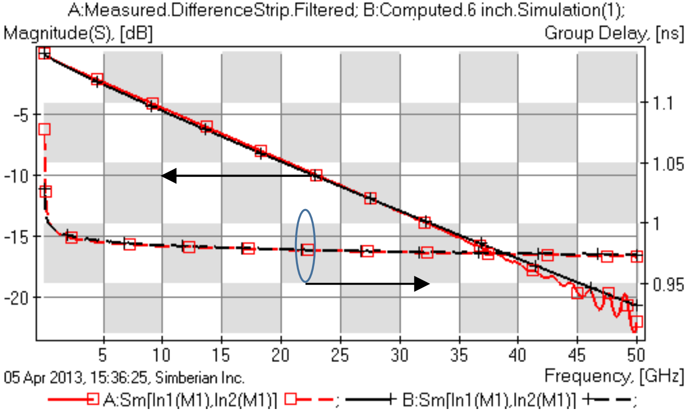
GMS-Parameters



Optimization loop – red line;
Automated in Simbeor software;



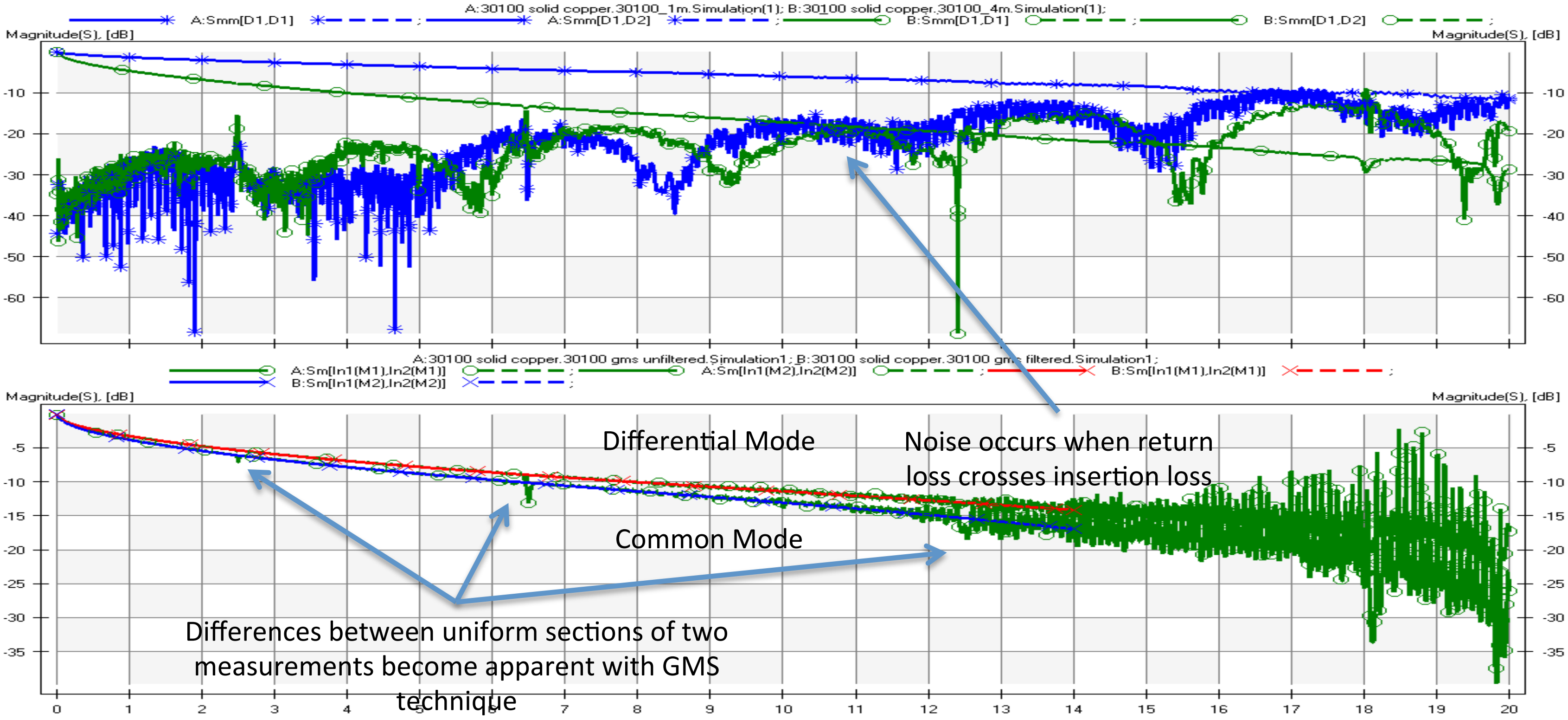
$$GMSc = \begin{bmatrix} 0 & \exp(-\Gamma \cdot L) \\ \exp(-\Gamma \cdot L) & 0 \end{bmatrix}$$



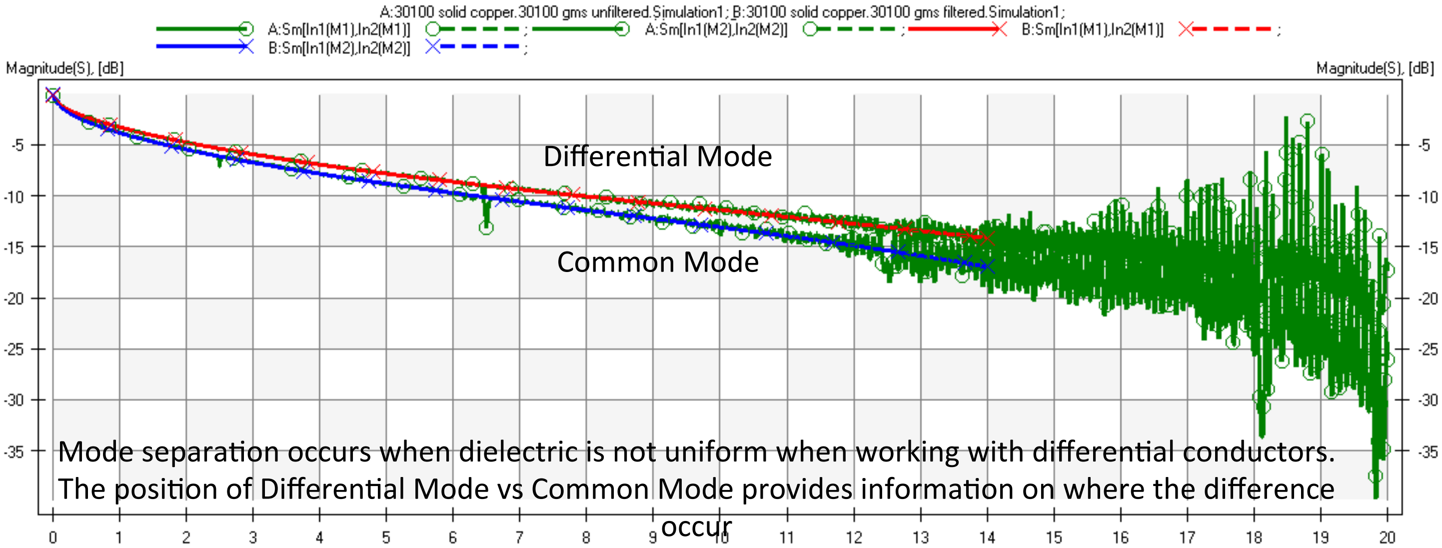
See details at: Y. Shlepnev, A. Neves, T. Dagostino, S. McMorrow, Practical identification of dispersive dielectric models with generalized modal S-parameters for analysis of interconnects in 6-100 Gb/s applications, DesignCon 2009, available at www.simberian.com

Y. Shlepnev, PCB and package design up to 50 GHz: Identifying dielectric and conductor roughness models, The PCB Design Magazine, February 2014, p. 12-28

Raw vs. GMS

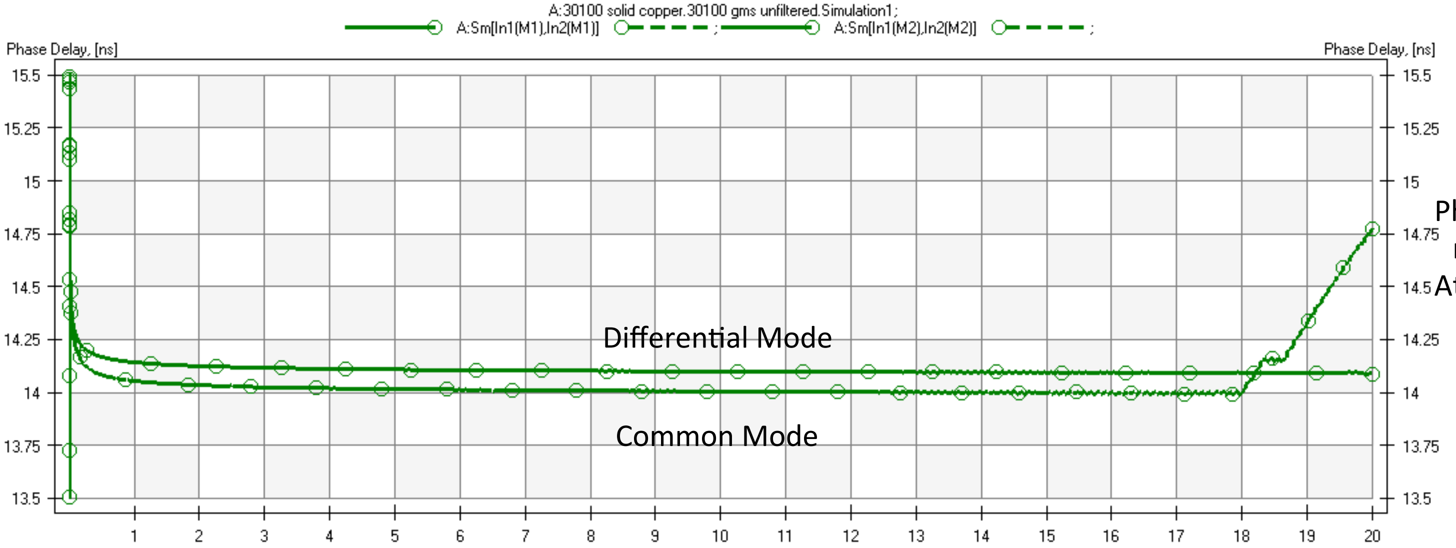

A:30100 solid copper.30100_1m.Simulation(1); B:30100 solid copper.30100_4m.Simulation(1);
A:Smm[D1,D1]
A:Smm[D1,D2]
B:Smm[D1,D1]
B:Smm[D1,D2]
Magnitude(S), [dB]
A:30100 solid copper.30100 gms unfiltered.Simulation1; B:30100 solid copper.30100 gms filtered.Simulation1;
A:Sm[In1(M1),In2(M1)]
A:Sm[In1(M2),In2(M2)]
B:Sm[In1(M1),In2(M1)]
B:Sm[In1(M2),In2(M2)]
Differential Mode
Noise occurs when return loss crosses insertion loss
Common Mode
Differences between uniform sections of two measurements become apparent with GMS technique

Filtered vs. Unfiltered Attenuation



Mode separation occurs when dielectric is not uniform when working with differential conductors. The position of Differential Mode vs Common Mode provides information on where the difference occur

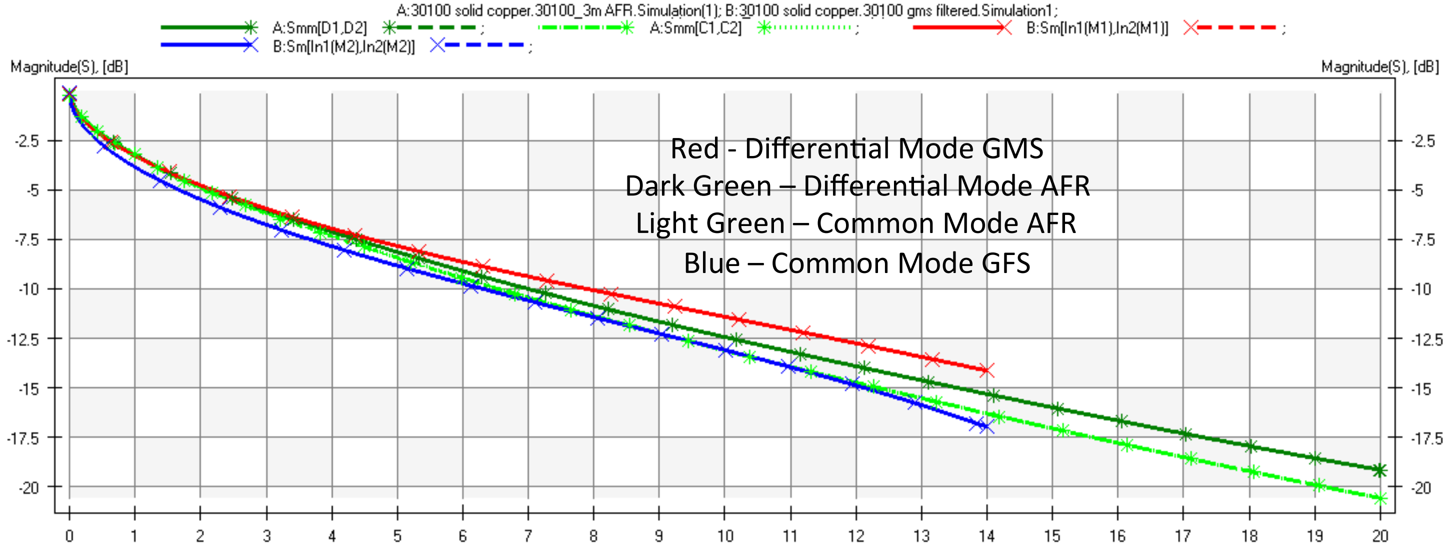
Unfiltered Phase Delay



Phase Delay is always much cleaner than Attenuation or Group Delay

Mode separation occurs when dielectric is not uniform when working with differential conductors. The position of Differential Mode vs Common Mode provides information on where the difference occurs. Faster Common Mode indicates common mode fields are exposed to a lower Dk dielectric.

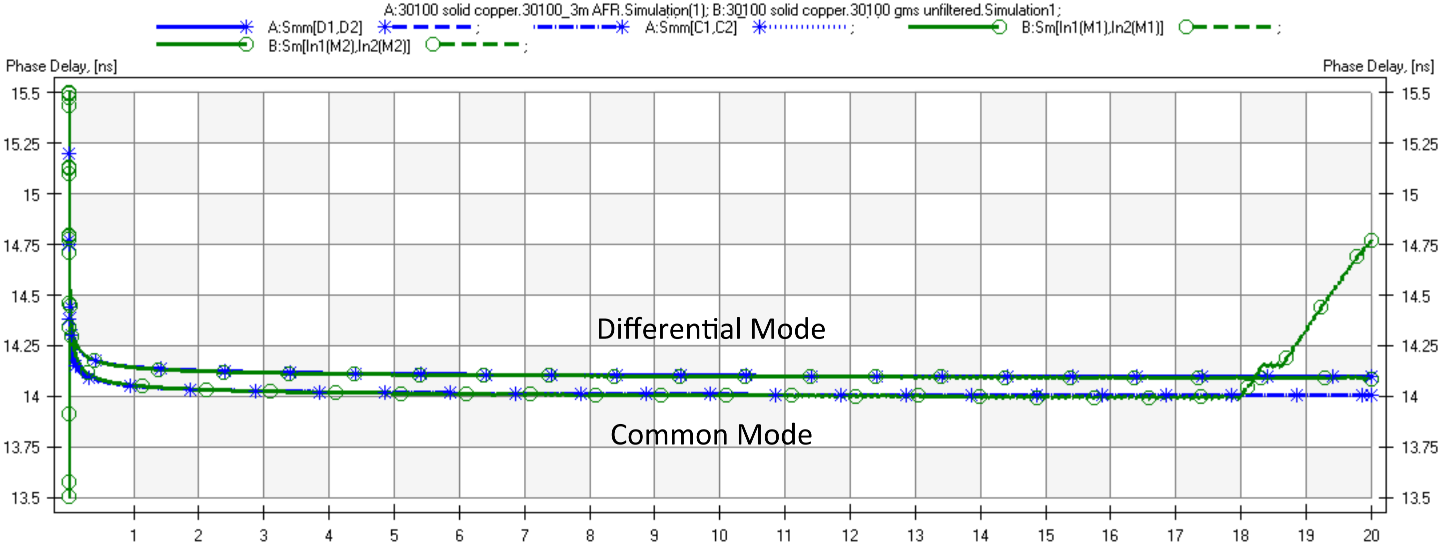
Comparison of GMS and AFR



GMS-parameter method is designed to remove losses due to impedance mismatch by normalizing to a perfectly matched condition at every frequency point.

Other methods are designed to create faithful models of the actual delta-length interconnect. This may introduce additional losses as mismatch increases.

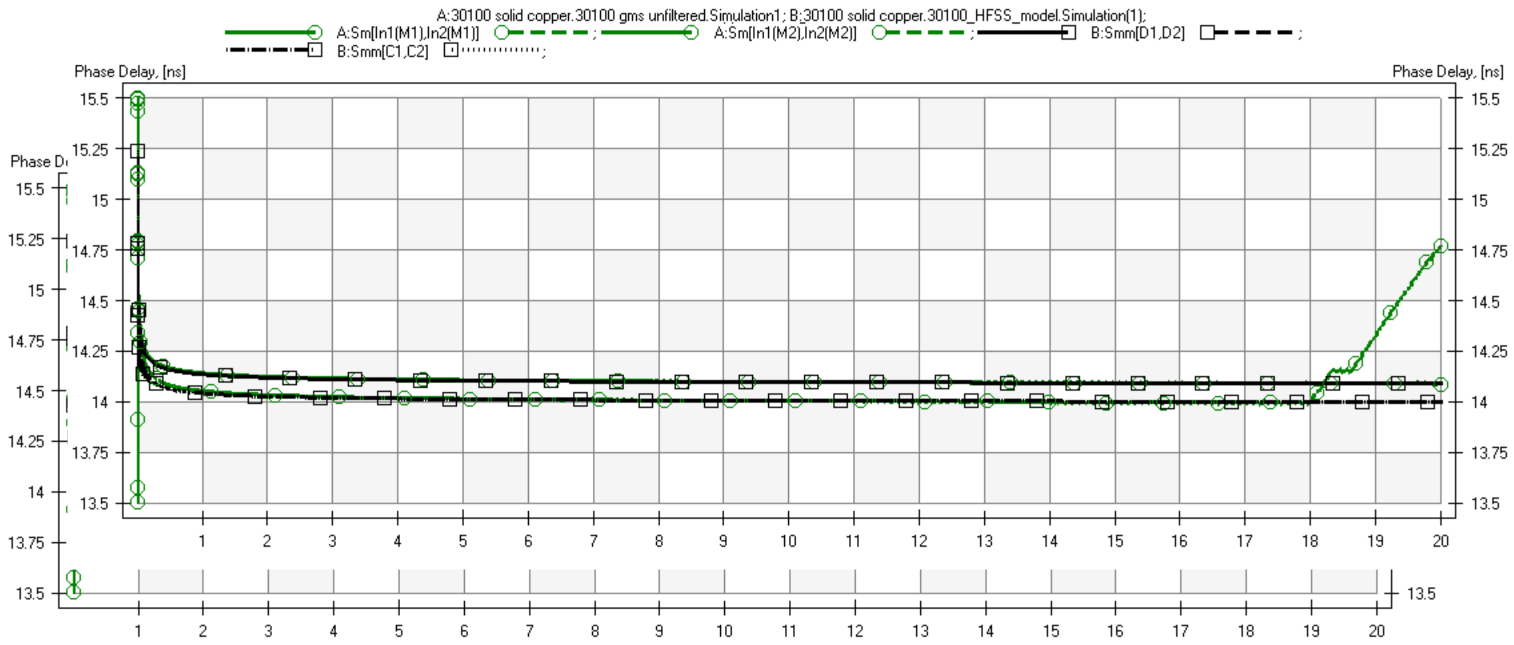
Comparison of GMS and AFR Phase Delay



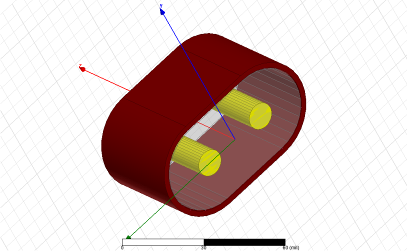
Essentially identical delay between GMS and AFR methods.

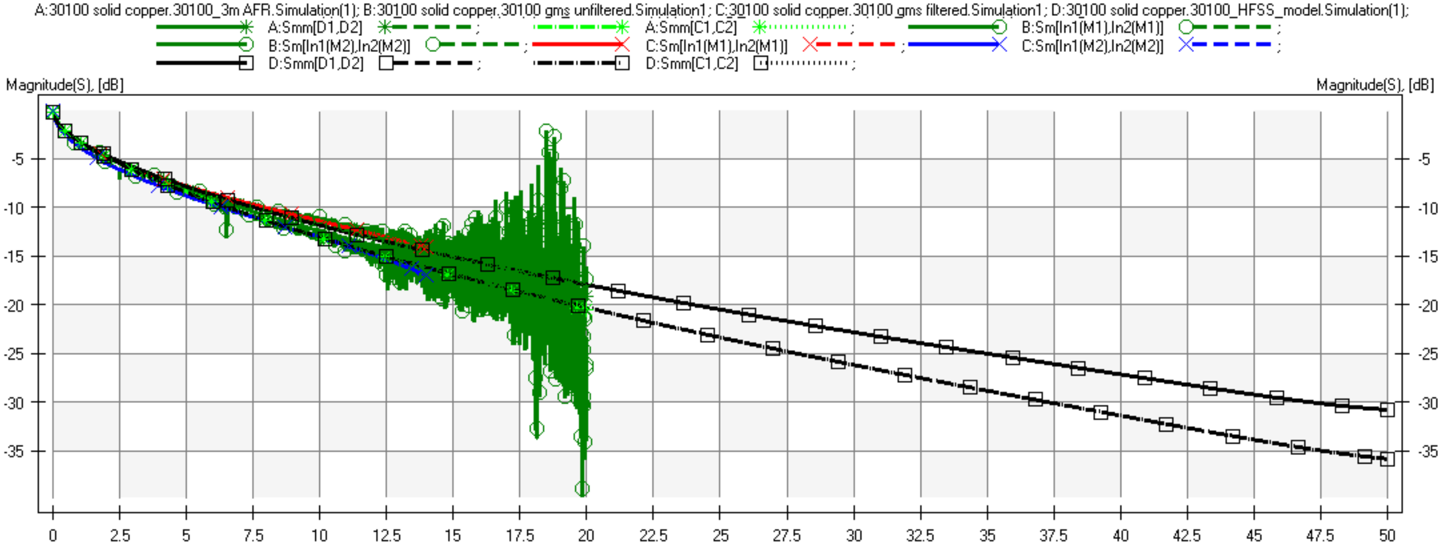
Phase or Phase delay is generally the most stable method for identifying dielectric properties.

Modeled vs. Measured Phase Delay



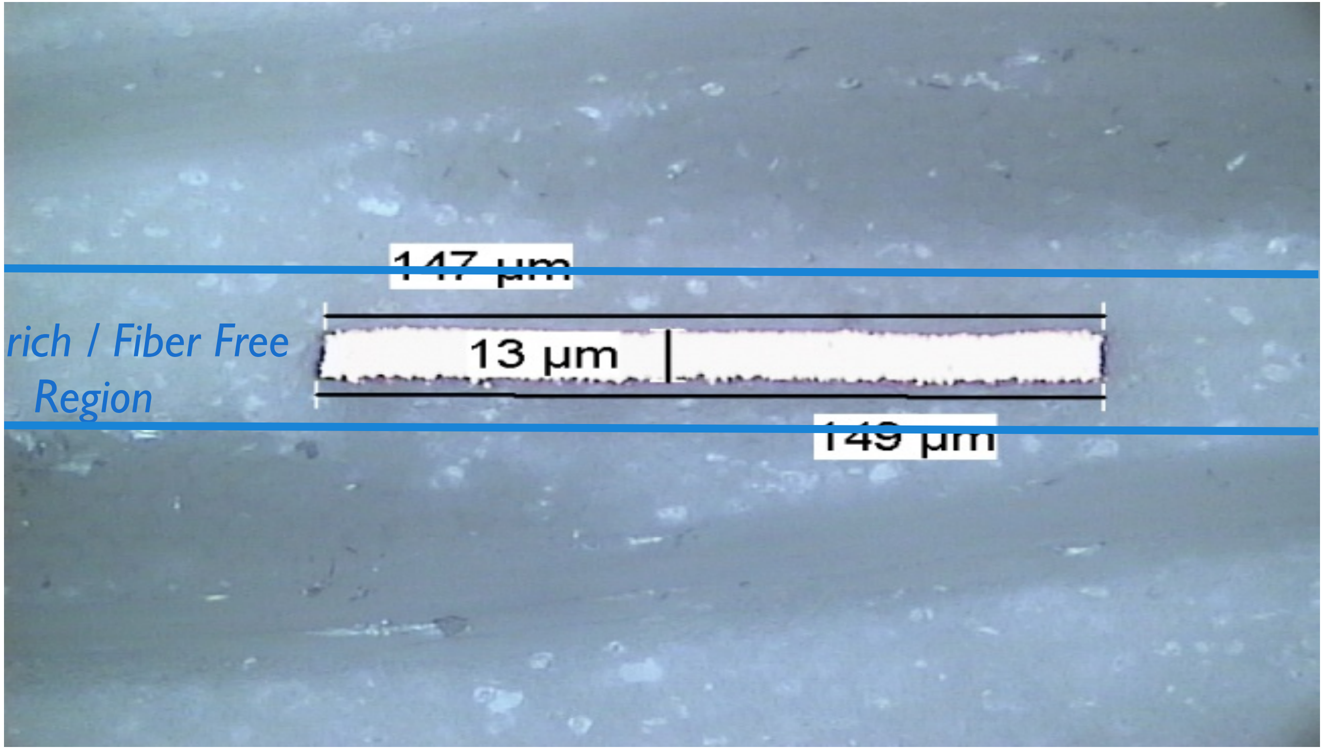
Modeled vs. Measured Attenuation



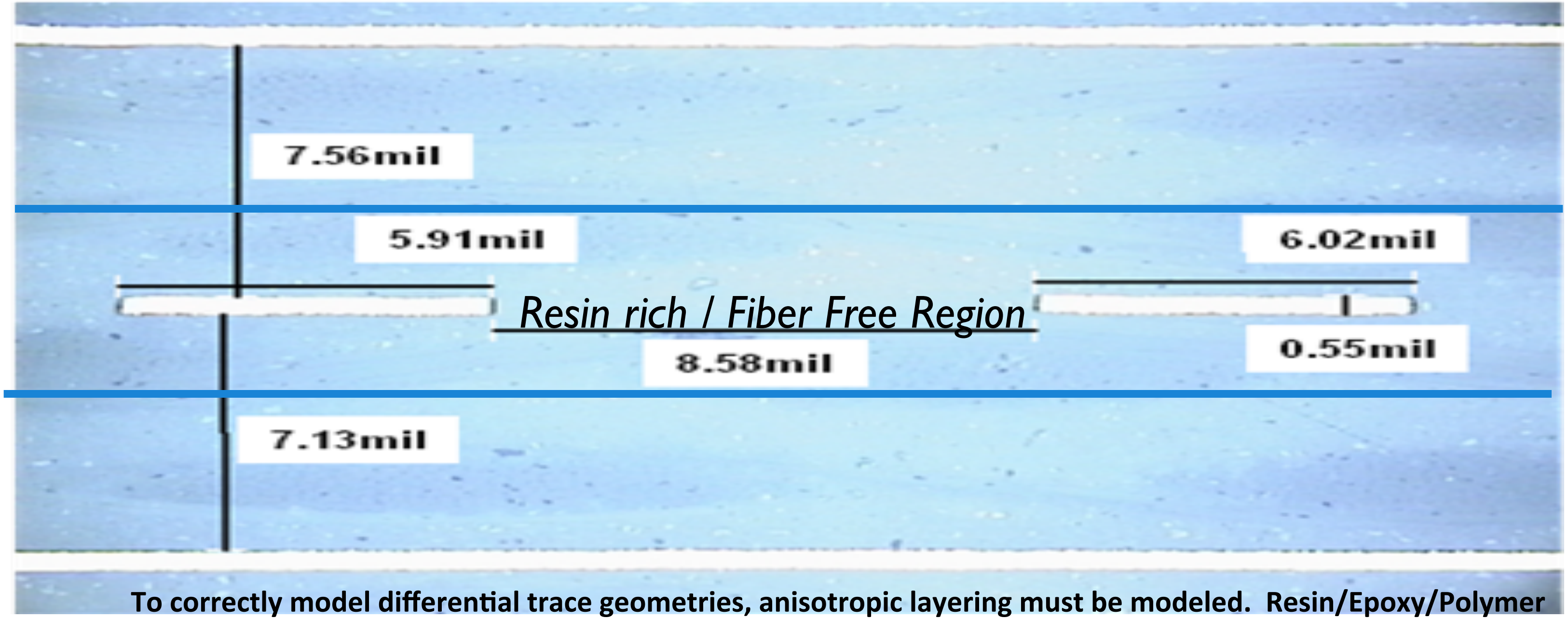


Trace Geometry Cross Section

Resin rich / Fiber Free Region



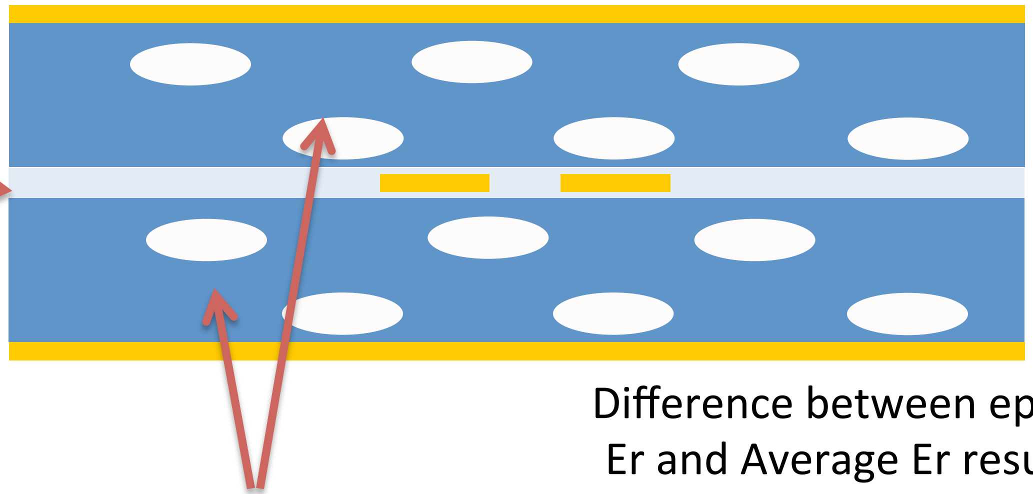
Differential Pair Geometry



To correctly model differential trace geometries, anisotropic layering must be modeled. Resin/Epoxy/Polymer regions are always lower Dk than mixed dielectric regions. Laminate weave skew is identified and bounded through measurements and then incorporated into channel models as a post process step.

Dielectric Mixture Modeling

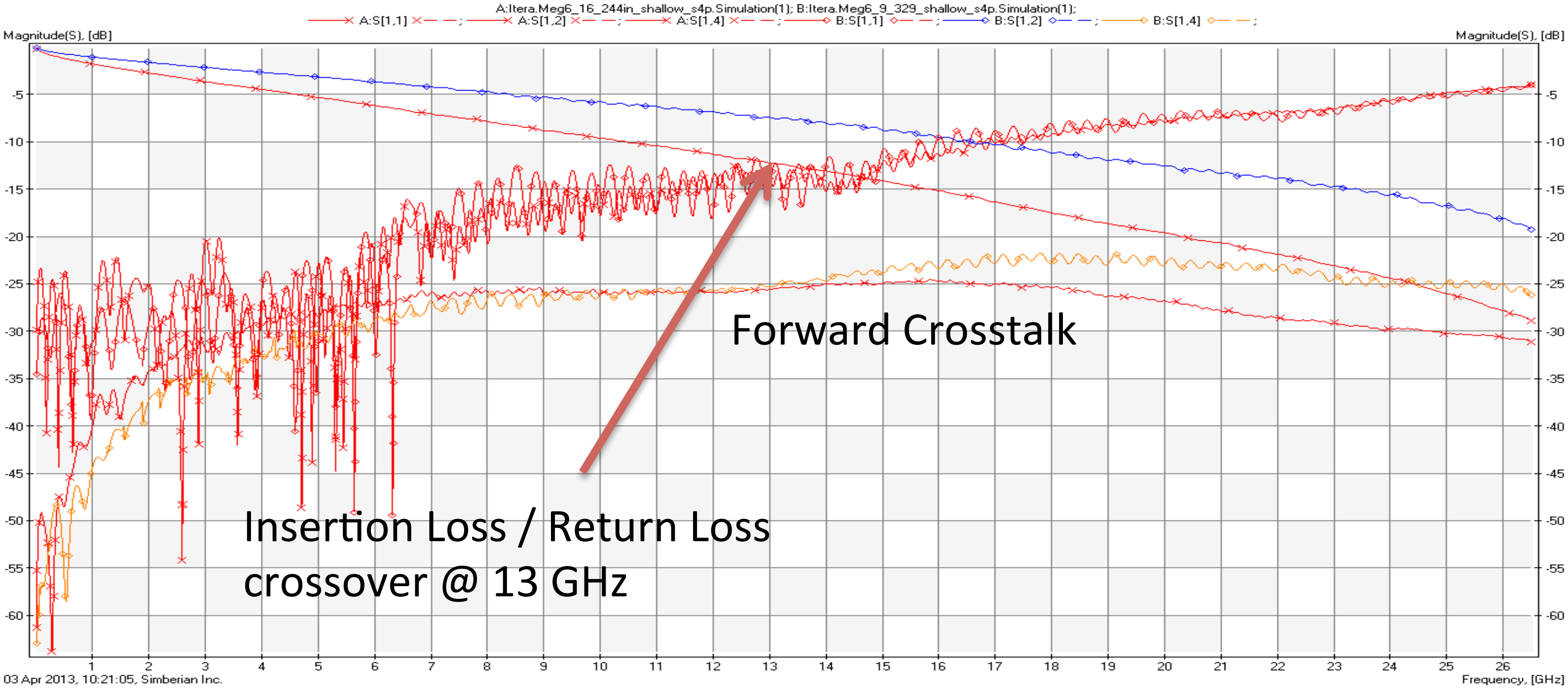
Pure epoxy



Dielectric average of epoxy and glass

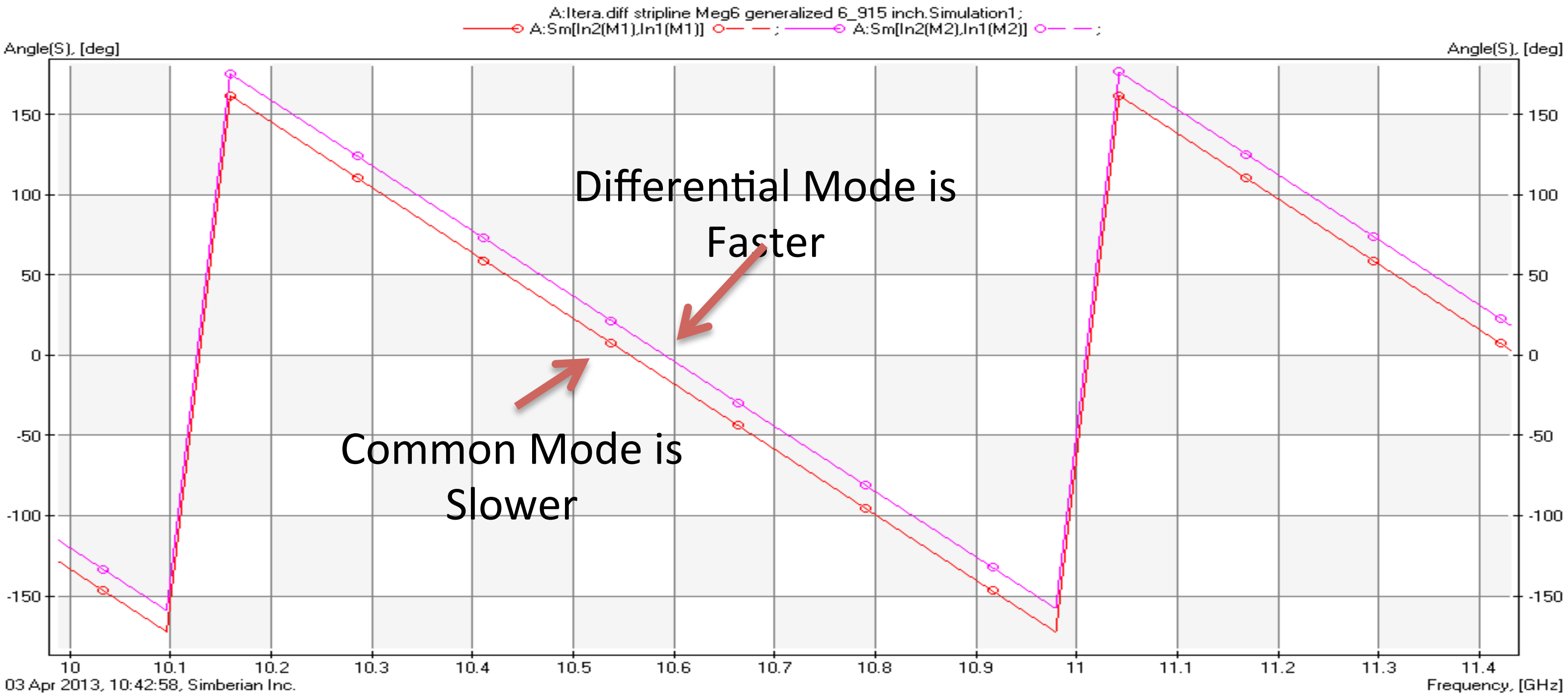
Difference between epoxy Er and Average Er results in separation of common and differential propagation modes.

Measured Meg6 Diff Stripline



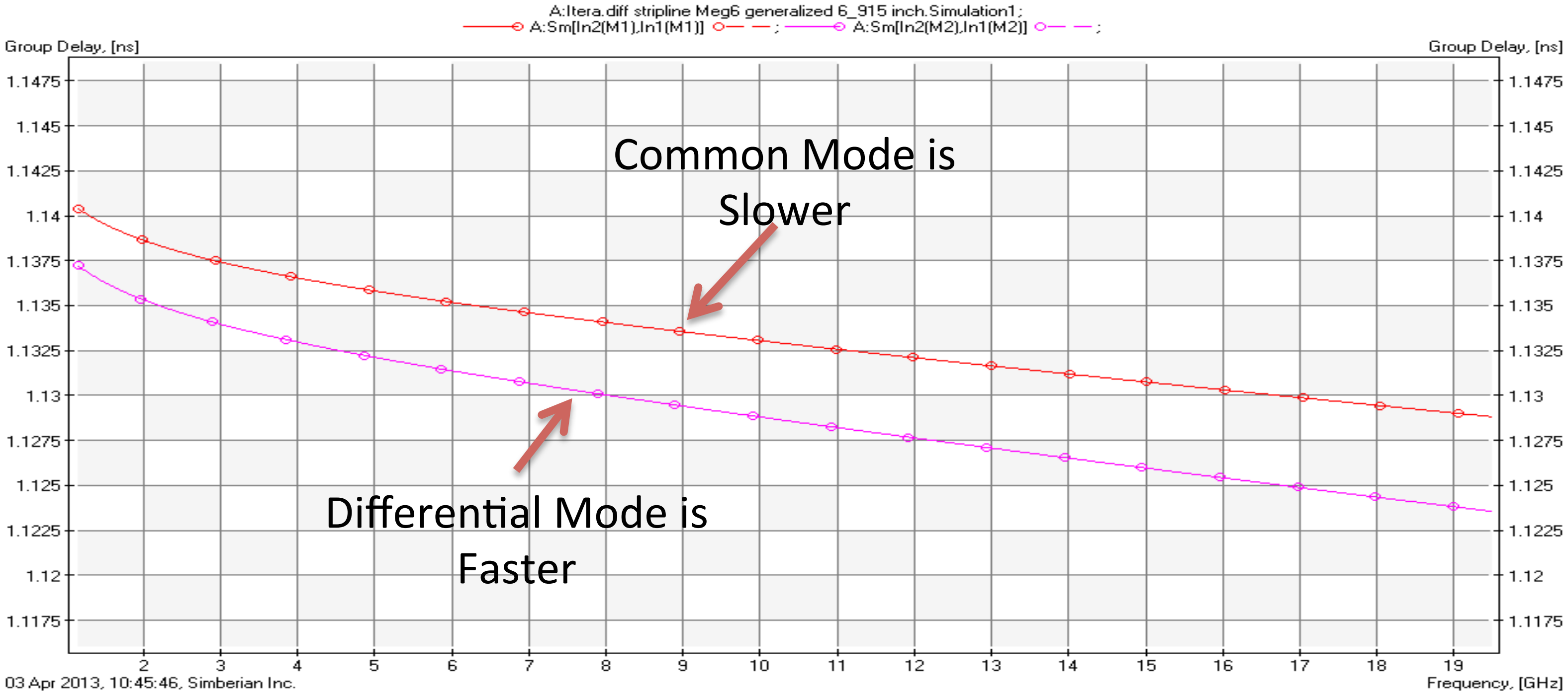
Measured data is often limited by Signal-to-Noise ratio at the insertion loss / return loss crossover point. But even this data can produce good model correlation if parameters are extracted between DC and 13 GHz.

Meg 6 Mode Separation Phase



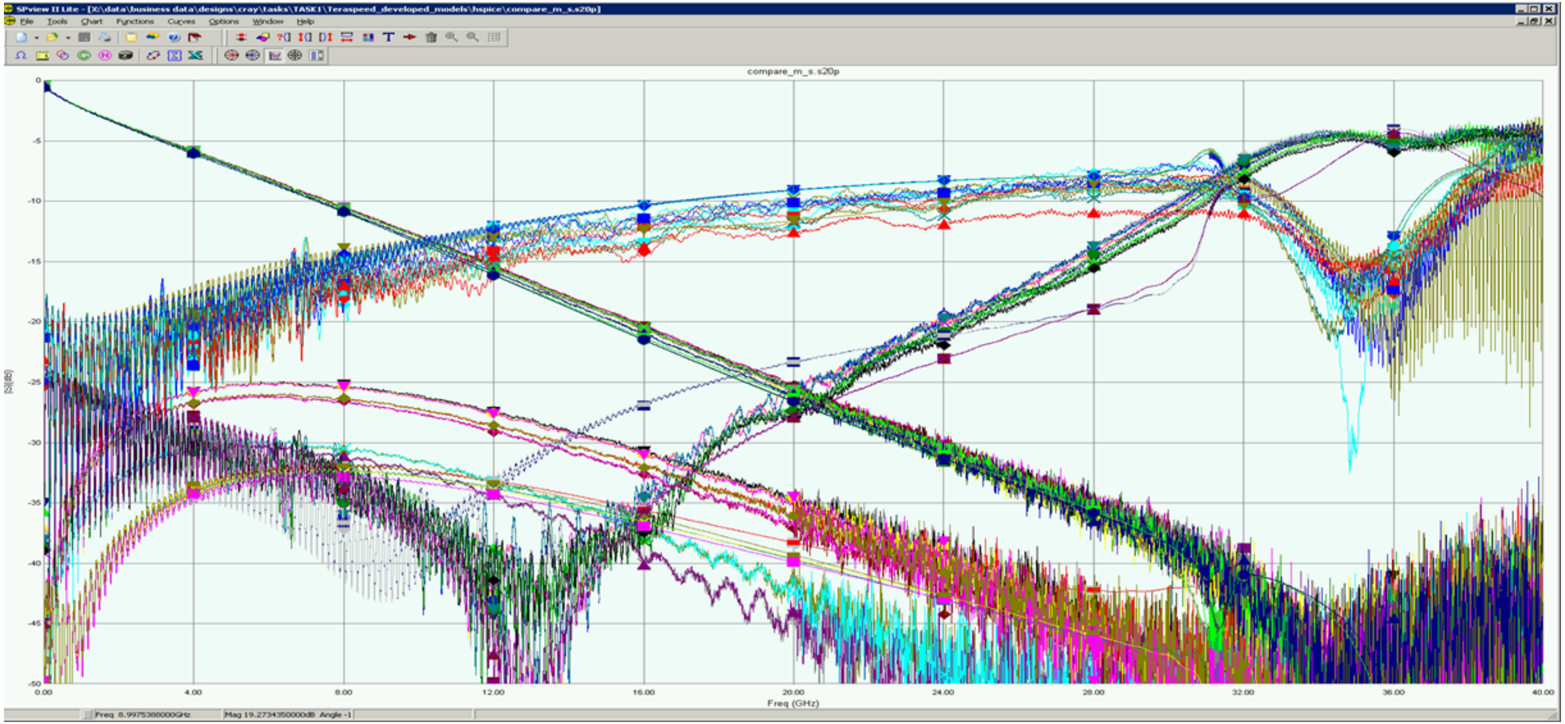
Mode separation due to layered anisotropy of epoxy and fiber rich areas in laminate system

Meg 6 Mode Separation Group Delay



Mode separation due to layered anisotropy of epoy and fiber rich areas in laminate system.

Megtron 6 20" Differential Pair Modeled vs. Measured Single-ended S-parameters



Practical Material Identification

- Step 1 – Use group/phase 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
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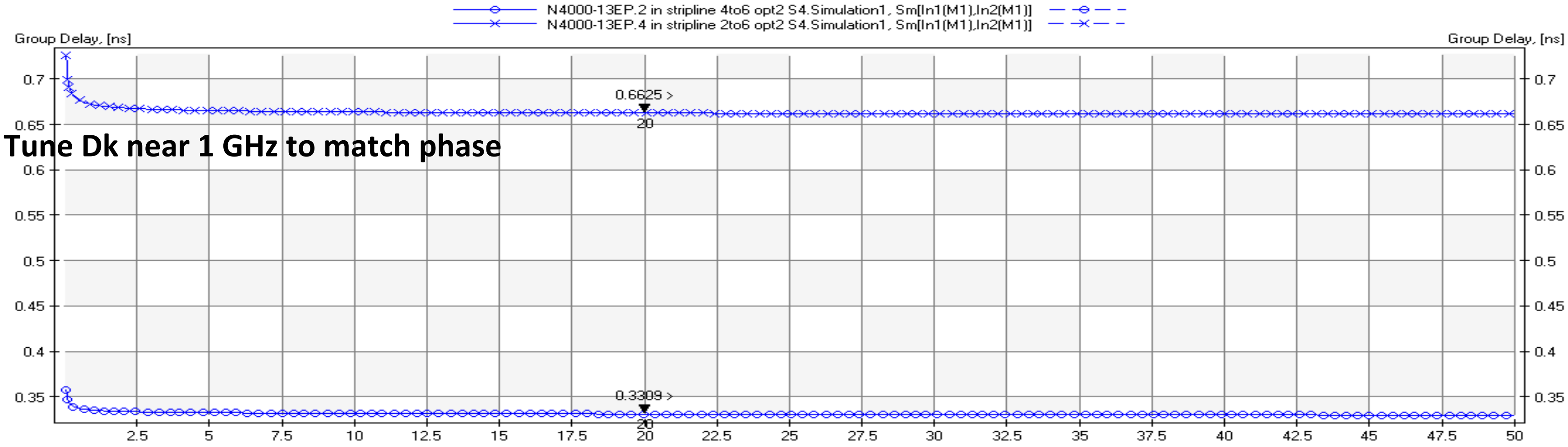
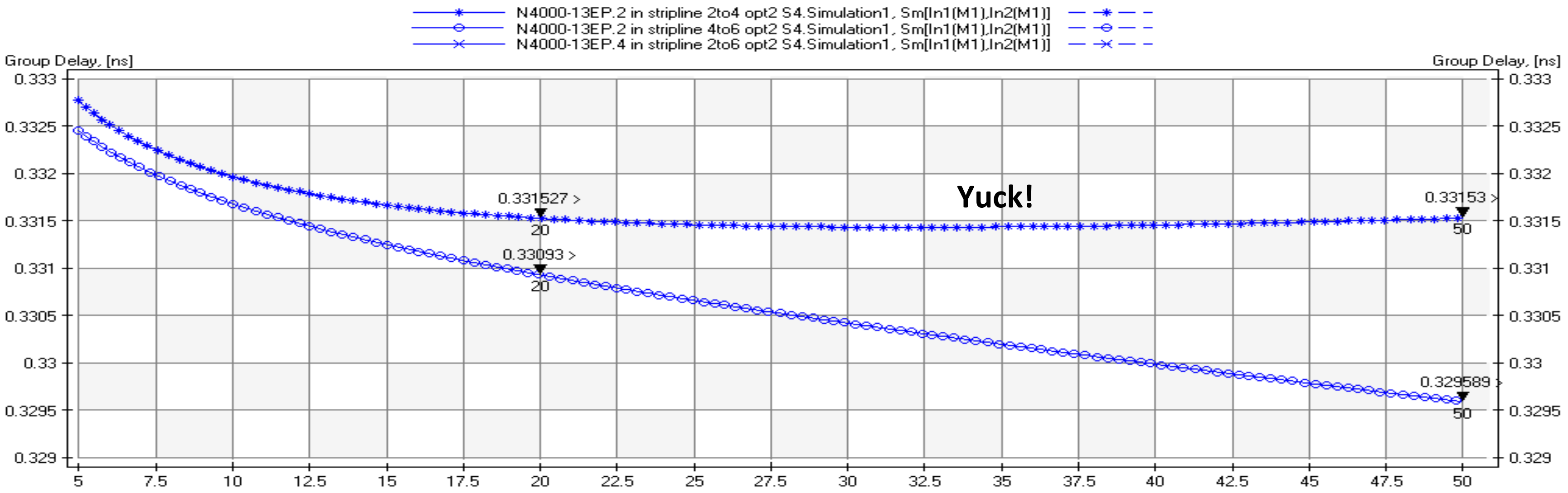
Practical Material Identification Step 1 – Group Delay Preliminary Er Identification

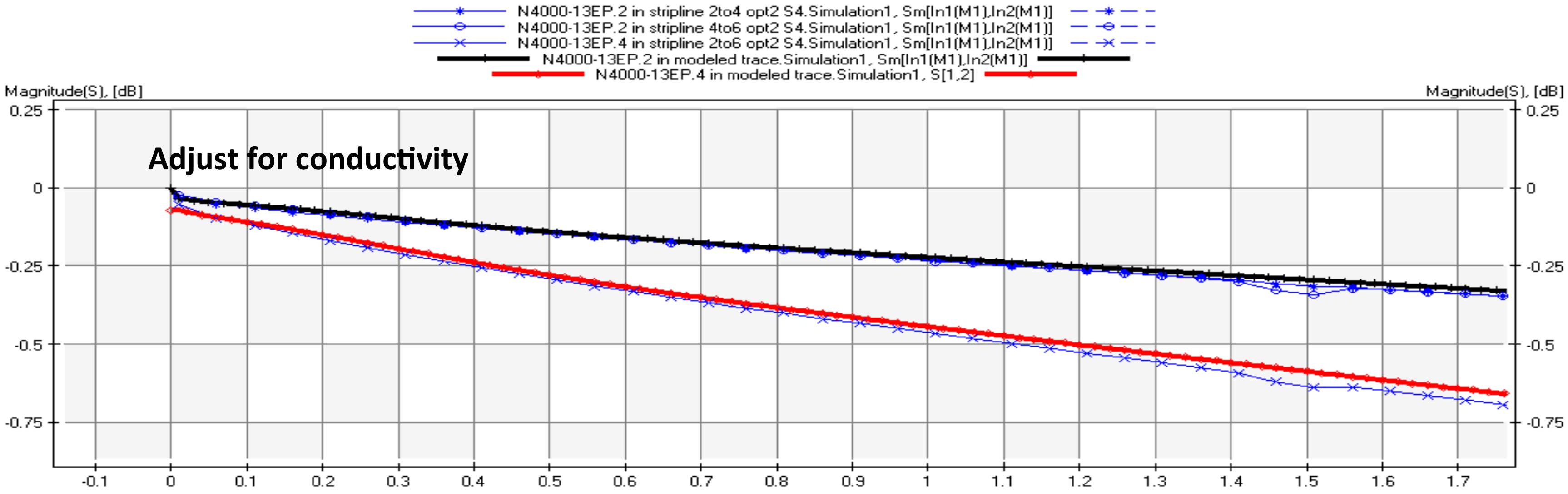


Tune Dk near 1 GHz to match phase

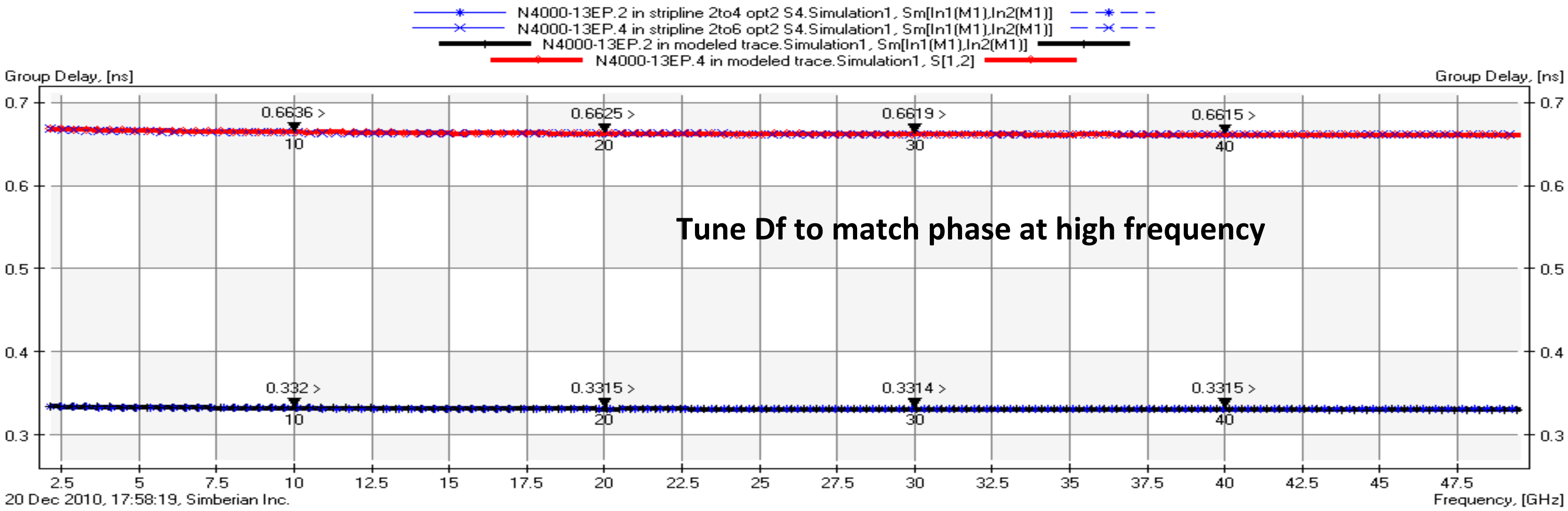
Practical Material Identification
Step 2 – Evaluate variation



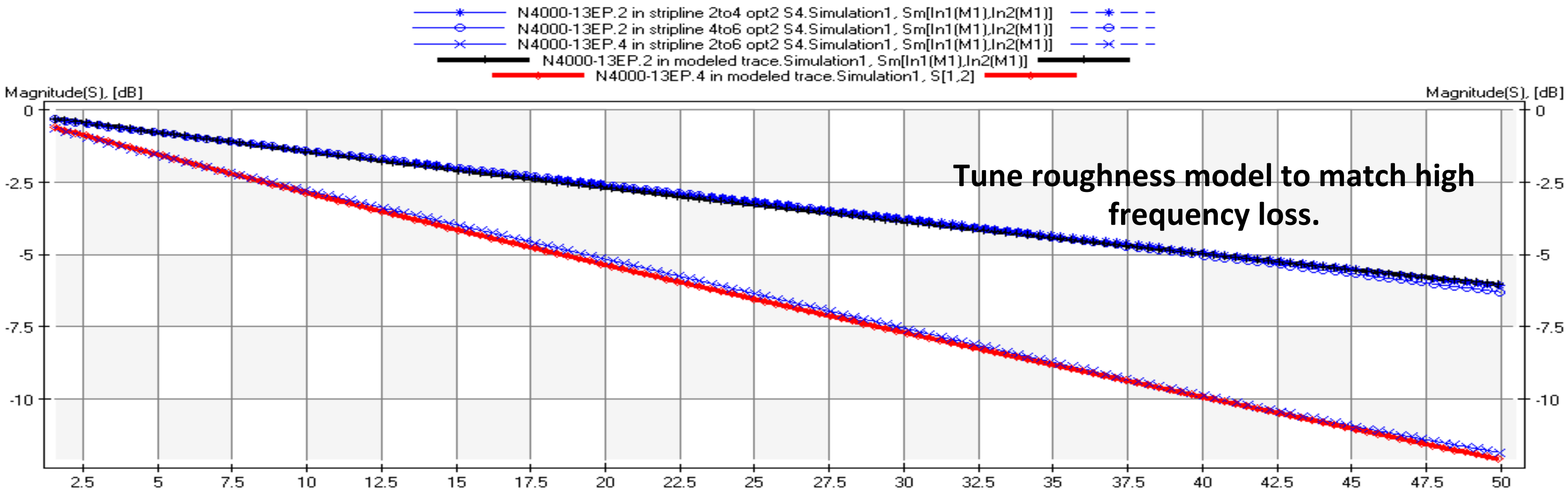
Practical Material Identification
Step 3 – Identify Low Frequency Characteristics



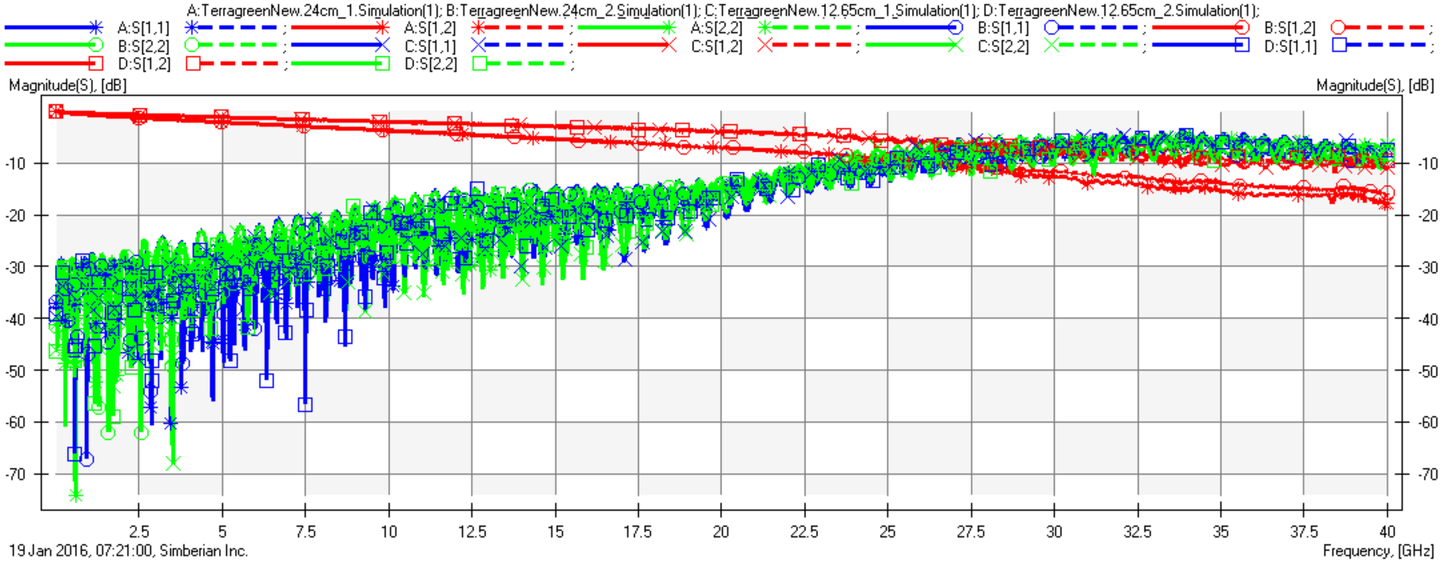
Practical Material Identification
Step 4 – Adjustment for Dielectric Loss



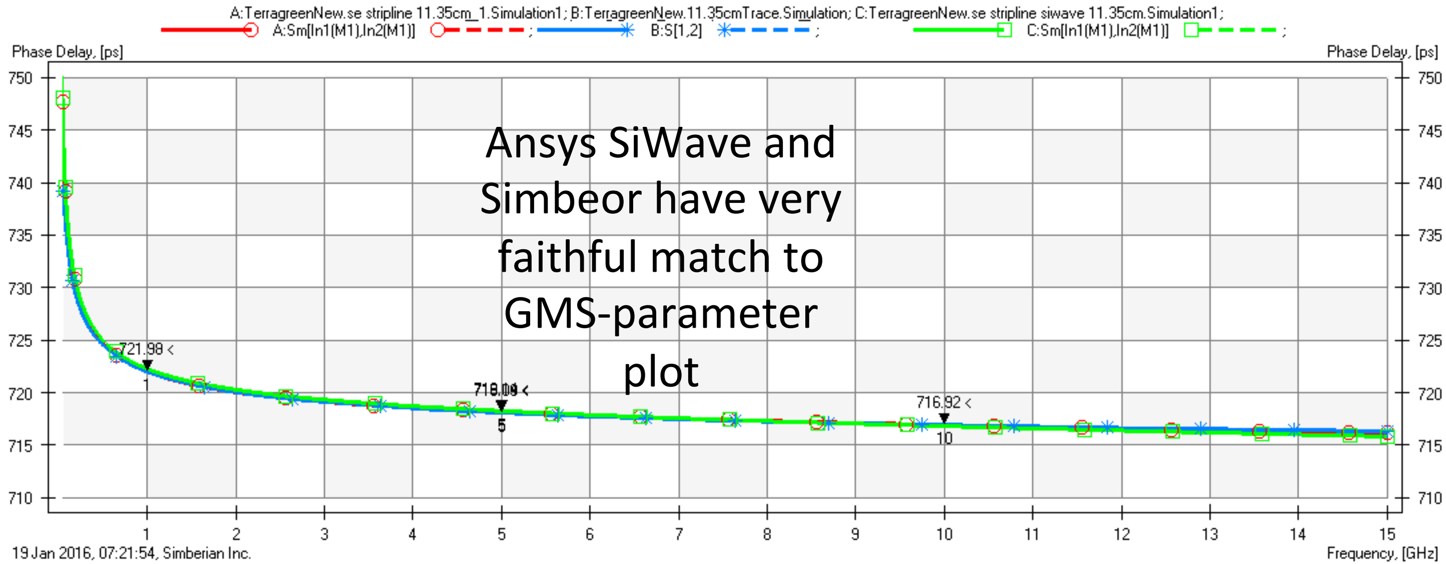
Practical Material Identification
Step 5 – Final Adjustment for Conductor Roughness



Terragreen Raw Measurements

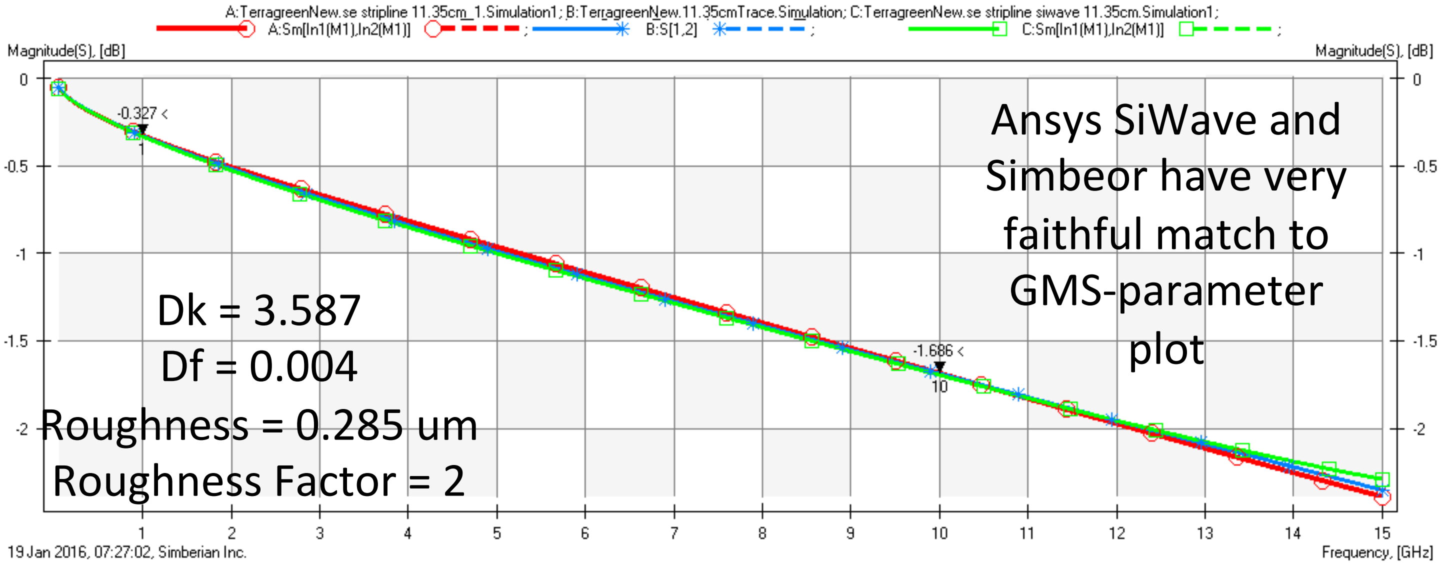


Terragreen Phase Delay
GMS vs Modeled

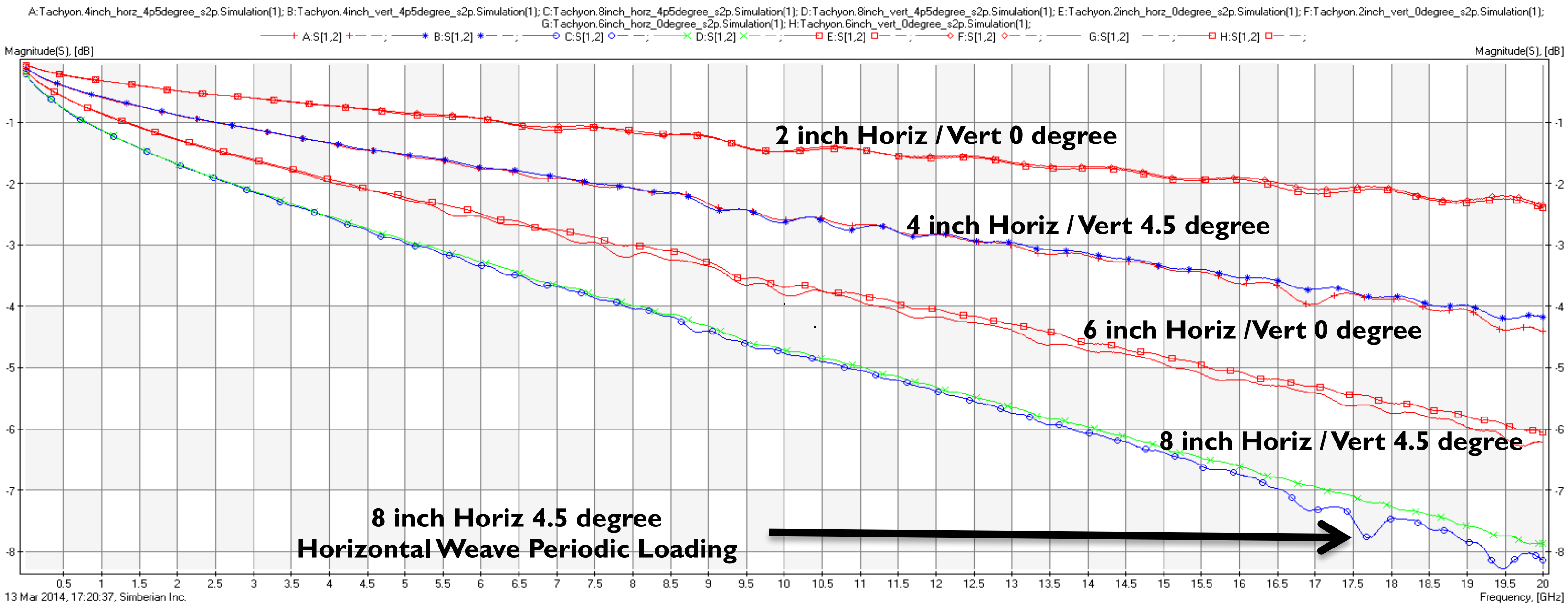


Ansys SiWave and Simbeor have very faithful match to GMS-parameter plot

Terragreen Attenuation GMS vs Modeled

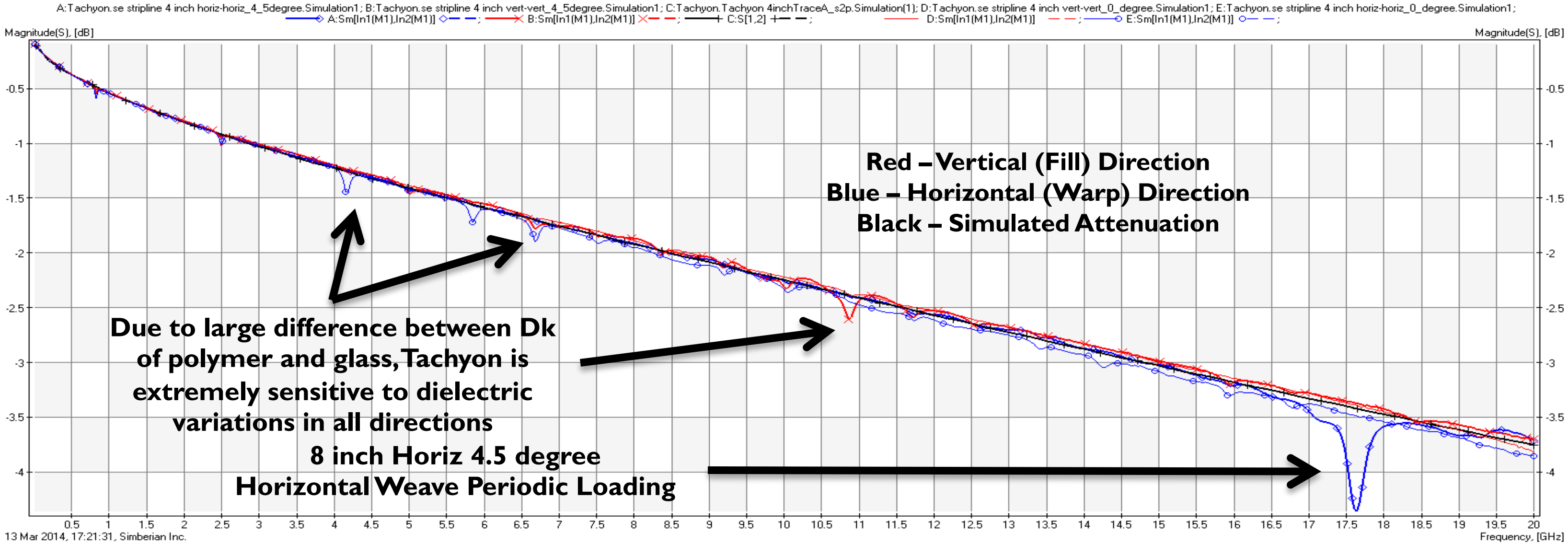


Tachyon 100G Measured Insertion Loss



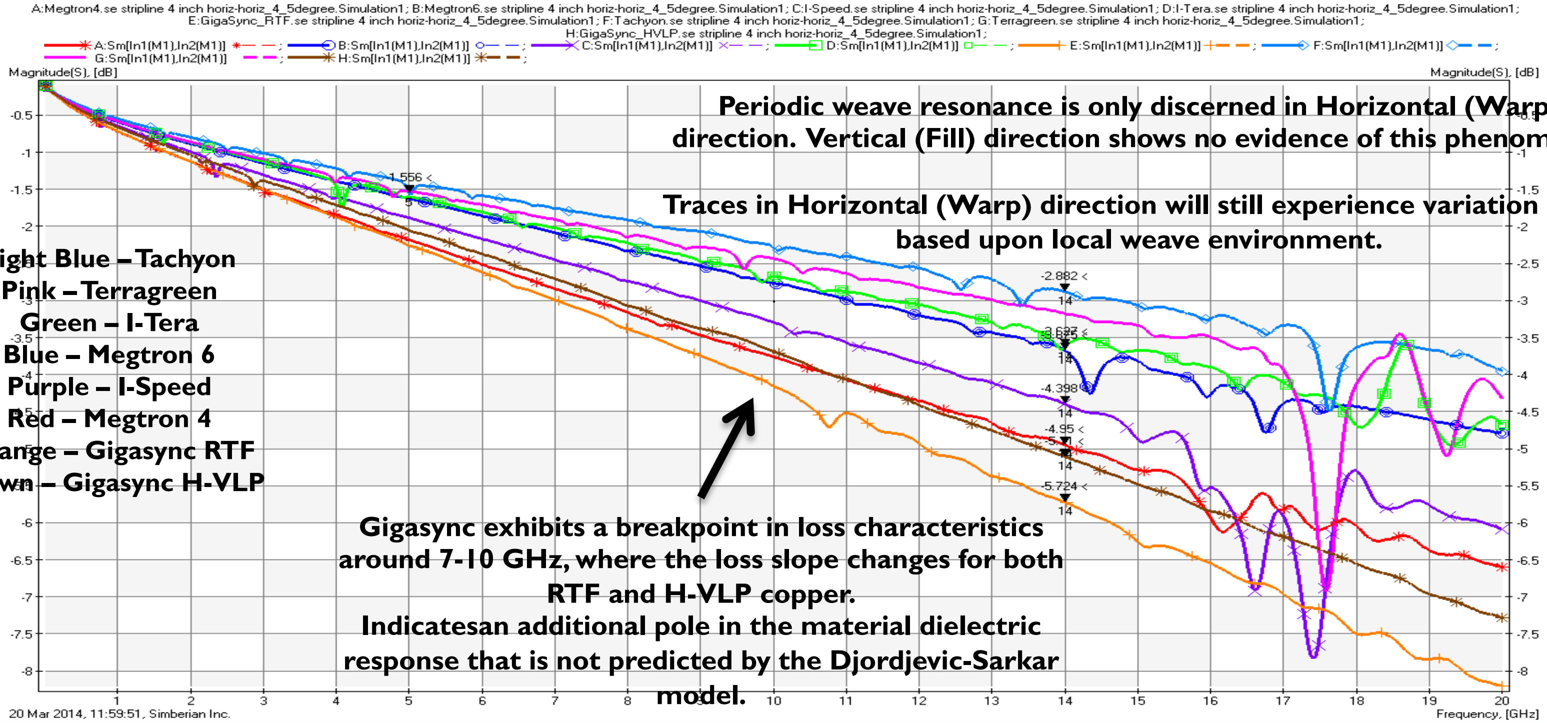
Variation of Dk in horizontal weave direction is discerned by 4.5 degree periodic weave loading, which causes a ½ wave resonance at ½ the crossing frequency

Tachyon 100G 4" Generalized De-embedded Attenuation Match



Cu Conductivity – 5.6 e^7 S/M
Cu Roughness – 0.4 micron (Hamerstadt-Jensen)
Dk – 3.06 @ 1 GHz (Djordjevic-Sarkar)
Df - .0025 @ 1 Ghz (Djordjevic-Sarkar)

Material Comparison
De-embedded Periodic Weave Resonance



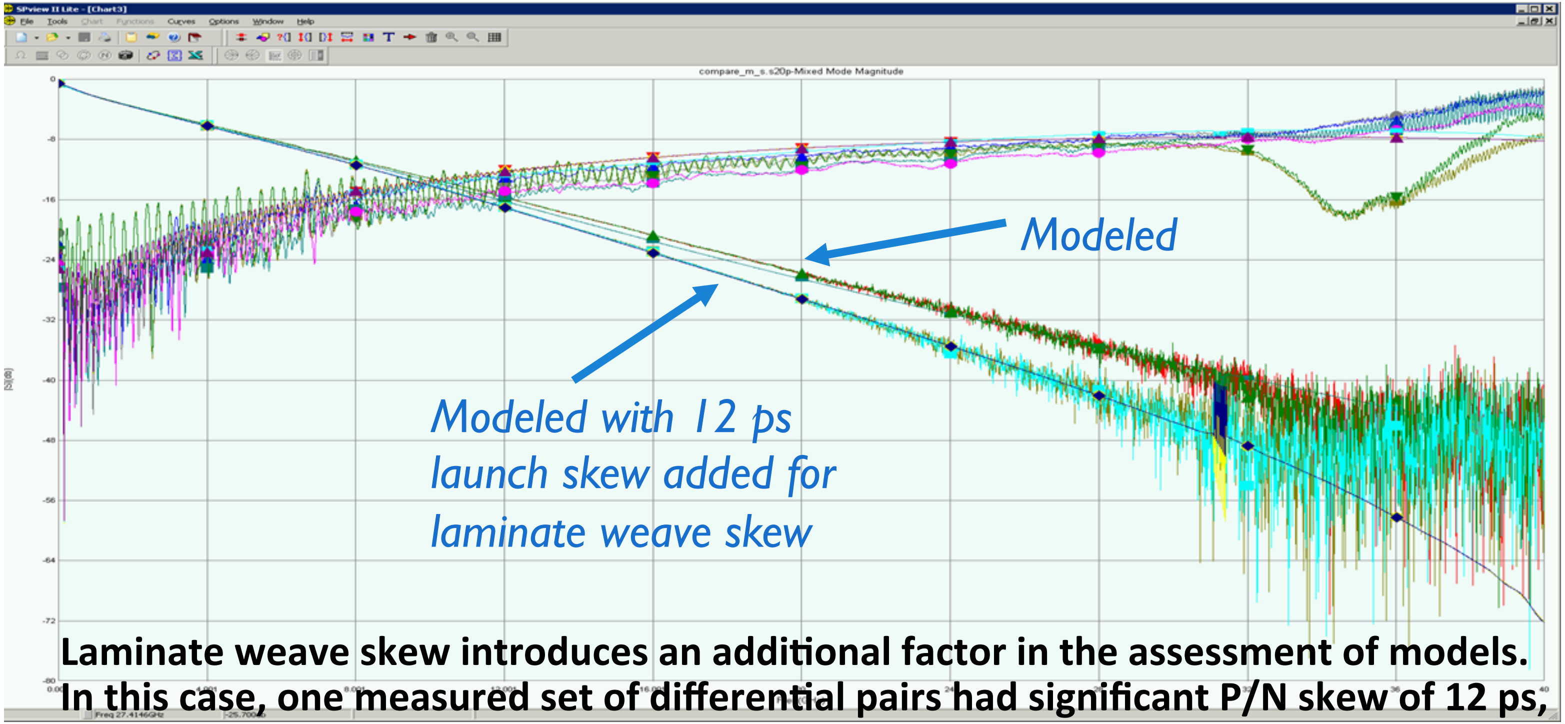
Periodic weave resonance is only discerned in Horizontal (Warp) direction. Vertical (Fill) direction shows no evidence of this phenomena.

Traces in Horizontal (Warp) direction will still experience variation in Dk based upon local weave environment.

Light Blue – Tachyon
Pink – Terragreen
Green – I-Tera
Blue – Megtron 6
Purple – I-Speed
Red – Megtron 4
Orange – Gigasync RTF
Brown – Gigasync H-VLP

Gigasync exhibits a breakpoint in loss characteristics around 7-10 GHz, where the loss slope changes for both RTF and H-VLP copper.
Indicatesan additional pole in the material dielectric response that is not predicted by the Djordjevic-Sarkar model.

Megtron 6 20" Differential Pair Modeled vs. Measured Differential S-parameters



Laminate weave skew introduces an additional factor in the assessment of models. In this case, one measured set of differential pairs had significant P/N skew of 12 ps, identified in group delay and phase plots.

Thank you!

QUESTIONS?

MORE INFORMATION:

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