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

(1) Measure scattering parameters for two transmission line segments with lengths L1 and L2

(2) Compute reflection-less GMS-parameters of line difference L=|L2-L1|

(3a) Guess material or conductor roughness model and model parameters

(3b) Compute reflection-less GMS-parameters of the line segment with length L

(4a) Compute difference between GMS-parameters from measurements and model

(4b) Adjust model parameters or change the model

(4c) Material or conductor roughness model is found

Is the difference smaller than a threshold?

No

Optimization loop – red line; Automated in Simbeor software;

Yes

GMSC = \[
\begin{bmatrix}
0 & \exp(-\Gamma \cdot L) \\
\exp(-\Gamma \cdot L) & 0
\end{bmatrix}
\]


Raw vs. GMS

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

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

13 µm

147 µm

149 µm
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

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

Differential Mode is Faster
Common Mode is Slower

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

**Common Mode is Slower**

**Differential Mode is Faster**

**Meg 6 Mode Separation Group Delay**
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
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

Yuck!
Practical Material Identification
Step 3 - Identify Low Frequency Characteristics

Adjust for conductivity
Practical Material Identification
Step 4 - Adjustment for Dielectric Loss

Tune $D_f$ to match phase at high frequency
Practical Material Identification
Step 5 – Final Adjustment for Conductor Roughness

Tune roughness model to match high frequency loss.
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

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

Dk = 3.587
Df = 0.004
Roughness = 0.285 um
Roughness Factor = 2
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

Red – Vertical (Fill) Direction
Blue – Horizontal (Warp) Direction
Black – Simulated Attenuation

Due to large difference between $Dk$ of polymer and glass, Tachyon is extremely sensitive to dielectric variations in all directions.

8 inch Horiz 4.5 degree
Horizontal Weave Periodic Loading

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.

Gigasync exhibits a breakpoint in loss characteristics around 7-10 GHz, where the loss slope changes for both RTF and H-VLP copper. Indicates an 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?

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