IEEE SW Test Workshop

Semiconductor Wafer Test Workshop

June 9 - 12, 2013 | San Diego, California

High Frequency PCB Material Characterization and Simulation

Jason Mroczkowski

Signal Integrity Product Development Manager

Overview

- **Background**
  - Characterization, Simulation
- **PCB Material Project**
  - Overview and Results
- **Discuss leading loss drivers**
  - Dielectric properties
  - Copper Roughness
- **Summary**

Background

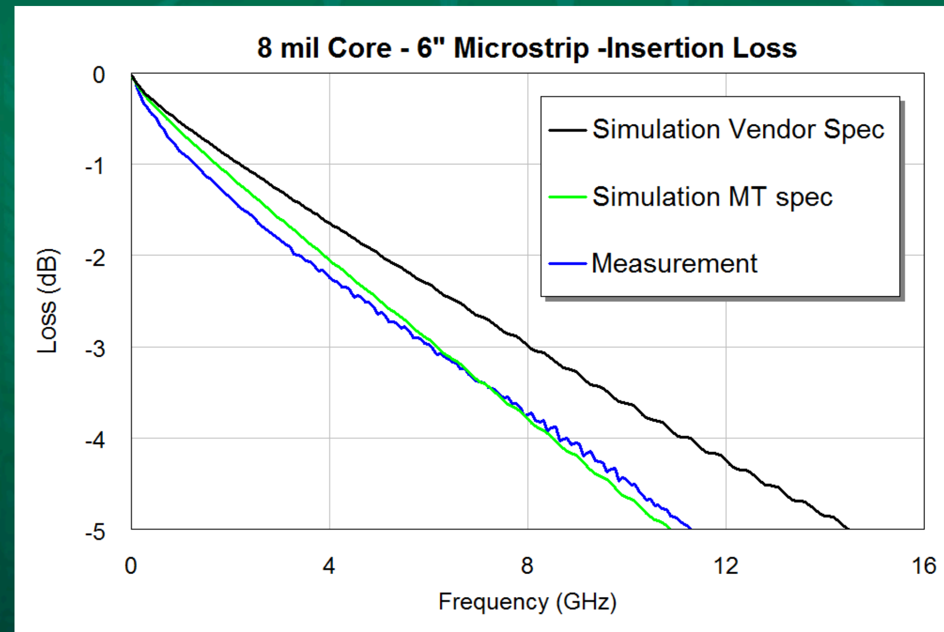
- **Previously PCB vendors asked to control impedance**
  - 50 Ohms +/- 5%
  - 100 Ohms +/- 10%
- **Today PCB vendors asked to control loss**
  - More involved
  - Er, etch, core thickness, roughness, discontinuities, weave, etc
- **Need to understand PCB characteristics to detail not previously required to predict PCB performance**

Simulation

- Multitest has run test interface simulations for about a decade
- Simulation provides confidence that the interface is designed correctly the first time
- Simulations include any or all of the following:
  - PCB (vias, components)
  - Contactor
  - Package
  - Device

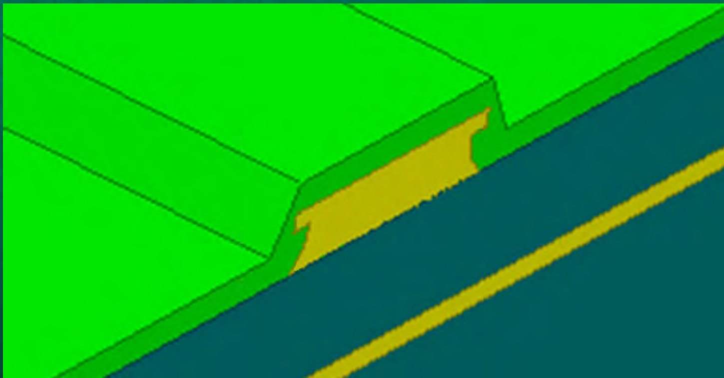
Simulation vs. Measurement

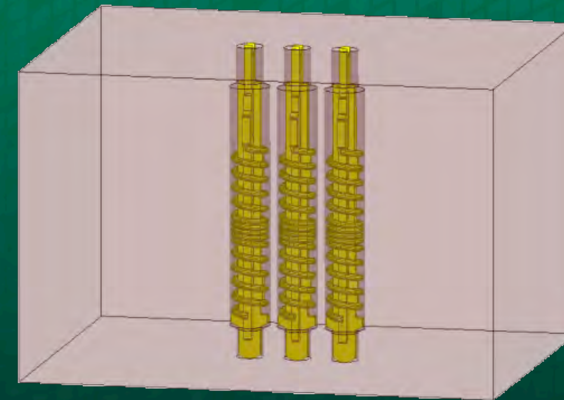
- **Results show importance of characterization to correlate simulation and measurement**
  - ~1dB difference at 10GHz



Importance of Characterization

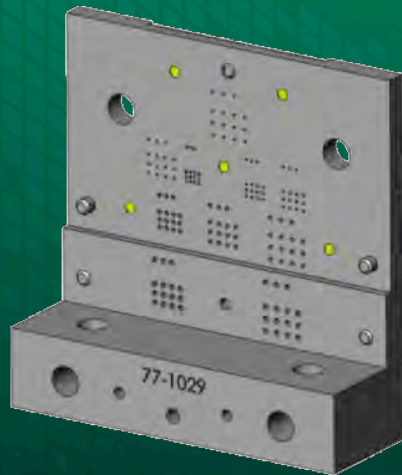
- Reliable simulation results require accurate models
- Extensive simulation-to-measurement correlation for both PCBs and contactors is critical
- Correlation ensures models accurately represent physical design





Characterization

- Test vehicles required to confirm model accuracy
- Vehicles must be created by target fabricator
- Hardware is fabricated using same techniques as end products
- Multitest manufactures both PCBs and contactors
- Test vehicles can be created quickly and easily

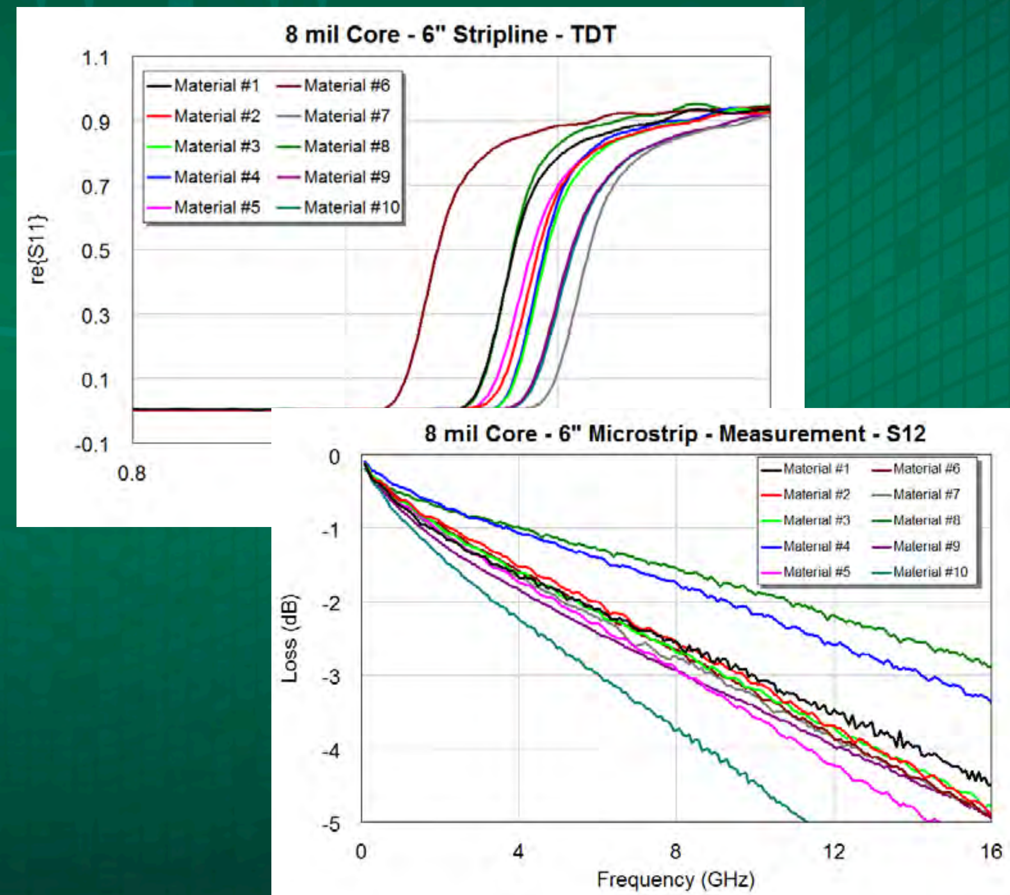


Characterization Project

- Fabricate boards from ten different PCB materials
- Each board includes:
  - Two Core Thicknesses
  - Microstrip and stripline
  - One, four, and six-inch traces
- Via and pad geometries optimized through simulation

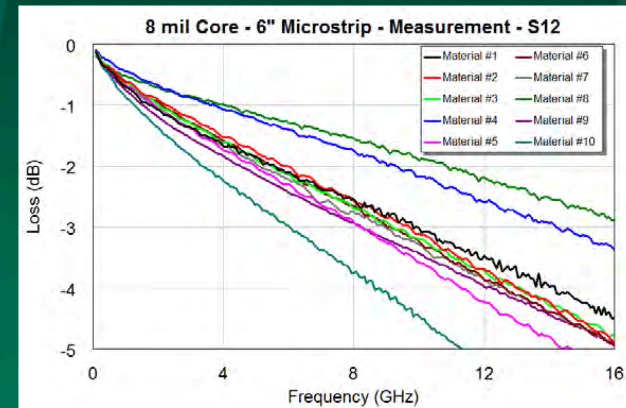
Material Comparisons

- **Material characteristics studied:**
  - Insertion loss
  - Loss tangent
  - Dielectric Constant
  - Solder Mask
  - Repeatability
  - Copper Roughness
  - plating



Results

- **Insertion Loss**
  - Difference from data sheet specifications:
    - 1 dB @ 10 GHz
    - 2.5 dB @ 20 GHz

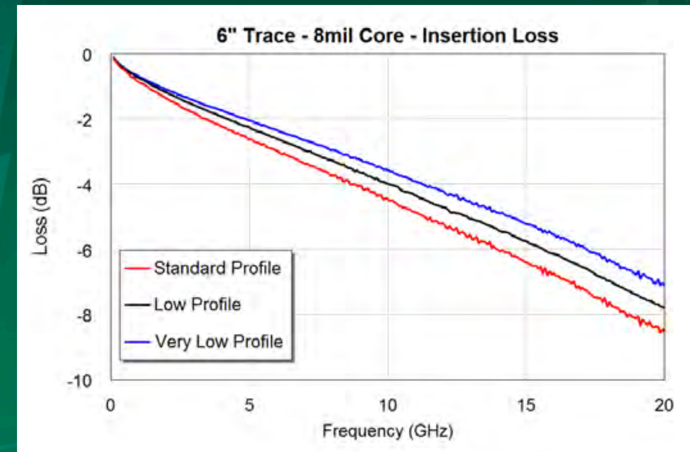


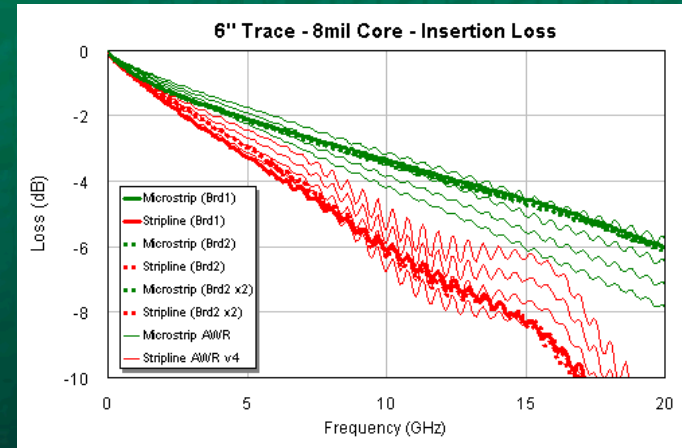
- **Dielectric Constant**
  - Measured εR and datasheet εR are different
    - $|\text{Difference}|_{AVG}$ = 0.12 (3%)
    - Results in up to 2 ohm difference in impedance
  - Thicker cores typically have a higher εR
    - 4 mil vs. 8 mil $|\text{Difference}|_{AVG}$ = 0.19 (5%)

Measured ε_R	
Deviation from Spec	
Material #1	0.16
Material #2	-0.18
Material #3	-0.12
Material #4	-0.06
Material #5	0.02
Material #6	-0.04
Material #7	0.13
Material #8	-0.03
Material #9	0.36
Material #10	-0.07

Results

- **Copper Roughness**
  - Difference from copper profiles
    - 0.5dB @ 10GHz
    - 1.5 dB @ 20 GHz
    - As much as 3-4 dB up to 40 GHz
- **Loss Tangent**
  - Loss tangent higher than datasheet specifications
    - $|\text{Difference}|_{AVG}$ = 0.005 (42%)
  - Thinner core materials will typically have a larger simulated loss tangent
    - $|\text{Difference}|_{AVG}$ = 0.002 (16%)





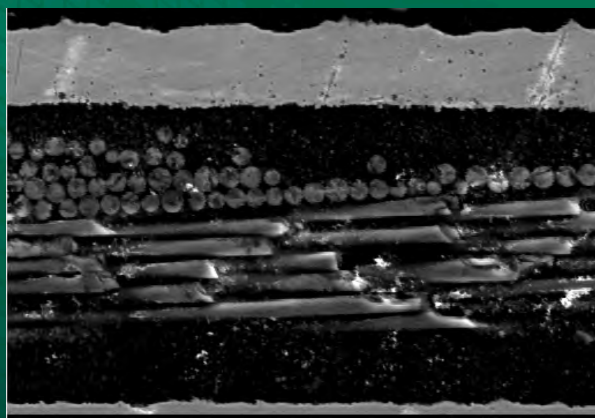
Material Specifications

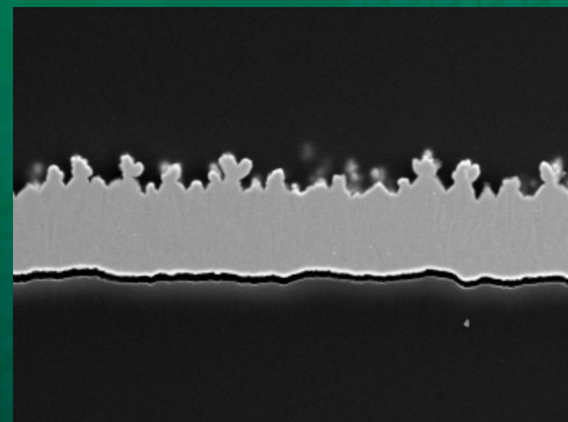
- **Problems with Material specifications for practical use in Simulation**
  - Ideal conditions – no moisture or processing effects
  - Does not account for impact of conductor losses

- **Need to quantify effects using manufacturing process that will be used for end product**

Drivers of Spec vs. Measurement Variation

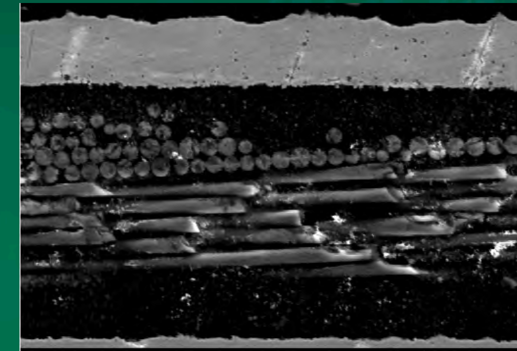
- **1) Anisotropic behavior of materials**
  - Fiberglass (glass) and Resin (epoxy)
- **2) Copper effects**
  - Roughness impacts dielectric constant and loss



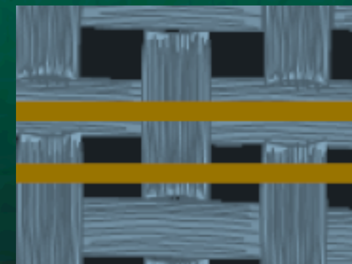


Anisotropic Materials

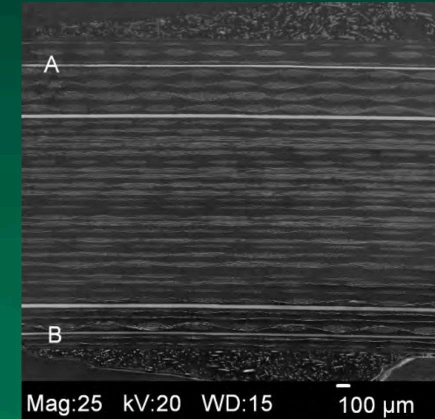
- **PCB Ɛr is a combination of Epoxy Ɛr and Glass Ɛr**
  - Ɛr = Ɛrepoxy*%+Ɛrglass*%
  - Epoxy Ɛr is lower than Glass Ɛr



- **Glass types**
  - E-Glass – Most common "Fiberglass"
  - NE-Glass – improved electrical characteristics, lower Ɛr closer to epoxy Ɛr
- **Ɛr varies up to 0.32 due to Location of Trace above Weave (8%)**
  - Weave will also impact skew



Anisotropic Materials



- **Impact of Layer thickness**
  - 4 mil (A) vs. 8 mil (B) $|\text{Difference}|_{AVG}$ = 0.19 (5%)
  - Glass has higher Dk and slower speed
  - Ɛr = Ɛrepoxy*%+Ɛrglass*%
  - Information is important to get from the PCB manufacturers

Material	Core Thickness	Resin %
Material #1	0.004	75
Material #2	0.004	68.7
Material #3	0.004	66
Material #4	0.004	65
Material #5	0.004	57
Material #6	0.004	74.5
Material #7	0.004	68
Material #8	0.004	70
Material #9	0.004	68
Material #10	0.004	56
Average	0.004	66.82

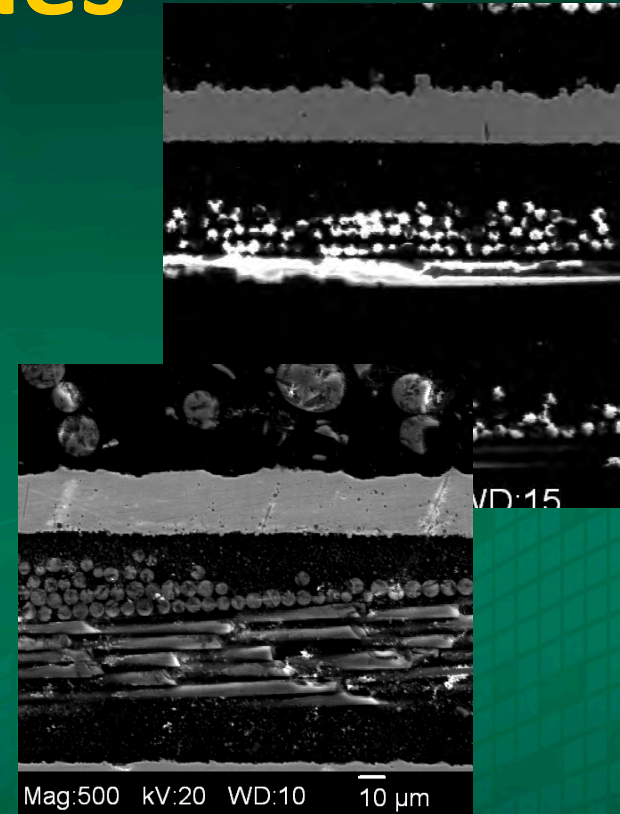
Material	Core Thickness	Resin %
Material #1	0.008	58
Material #2	0.008	46
Material #3	0.008	57
Material #4	0.008	54
Material #5	0.008	43
Material #6	0.008	45
Material #7	0.008	50
Material #8	0.008	48
Material #9	0.008	46
Material #10	0.008	56
Average	0.008	50.3

Copper effects

- **Paradigm shift**
  - For years PCB vendors have been requested to increase surface roughness to improve peel strength
  - Today they are being requested to reduce surface roughness to improve signal integrity
  - Copper roughness is not specified by many PCB vendors
- **Profiles**
  - Electrodeposited copper
    - High Profile, Standard Profile, Low Profile and Very Low Profile
  - Rolled – smoothest option, but poorest adhesion

Copper Profiles

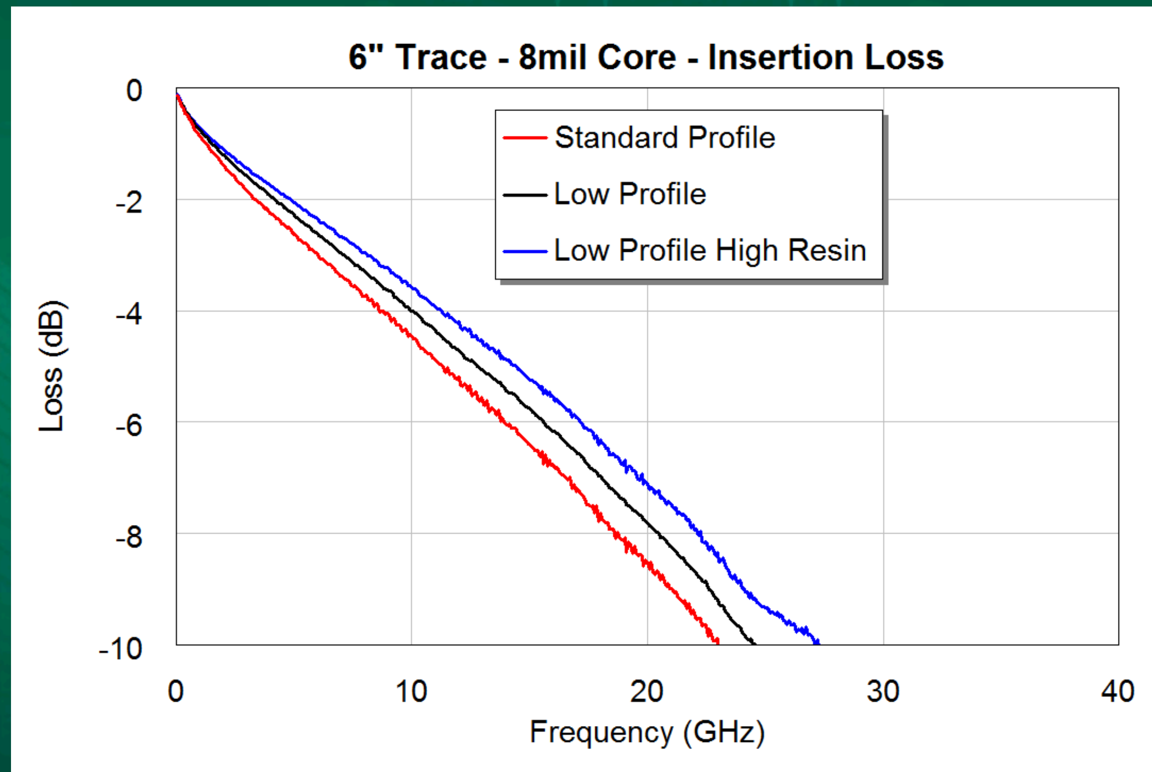
- **Standard Profile – 8-10um**
- **Low Profile – 4-7um**
- **Very Low Profile – 1-3um**



?

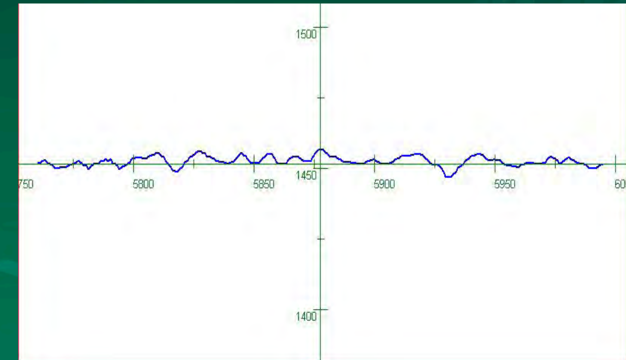
Surface Roughness

- Comparing Profile impact on Insertion loss



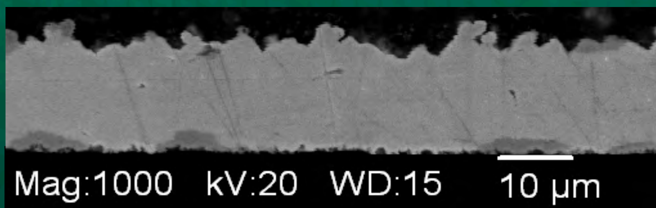
Copper Profiles

- **Internal measurement comparison**
  - 4 mil core 0.5 oz copper thickness
  - Nikon x1083 Magnification
  - Scanning Electron Microscope



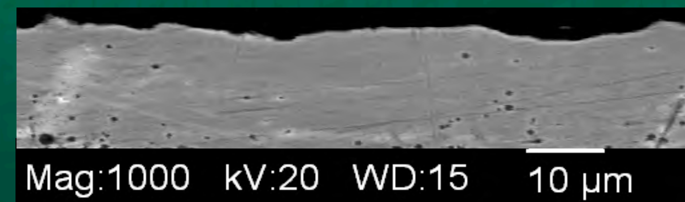
Standard Profile

8-10um



Low Profile

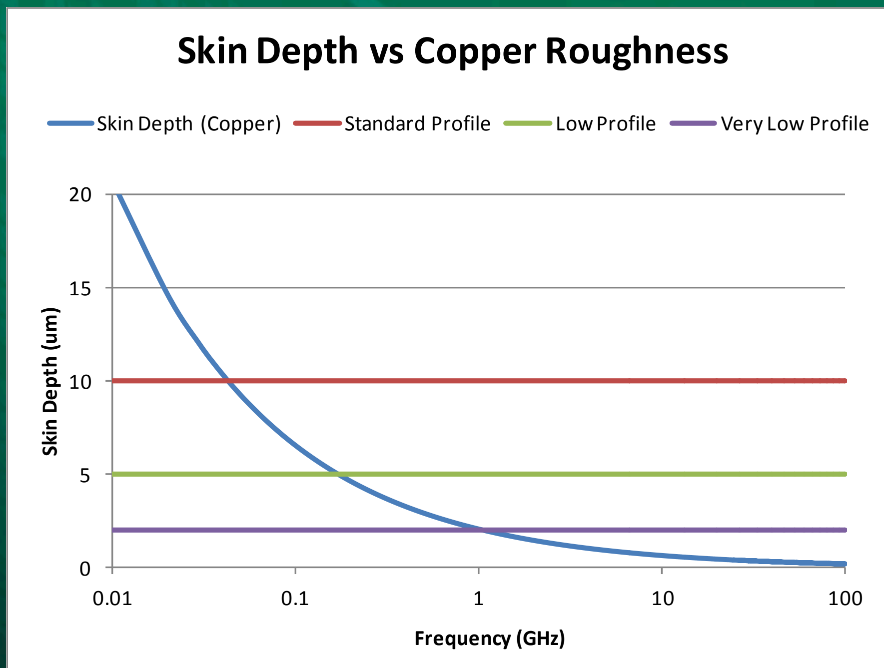
4-5um

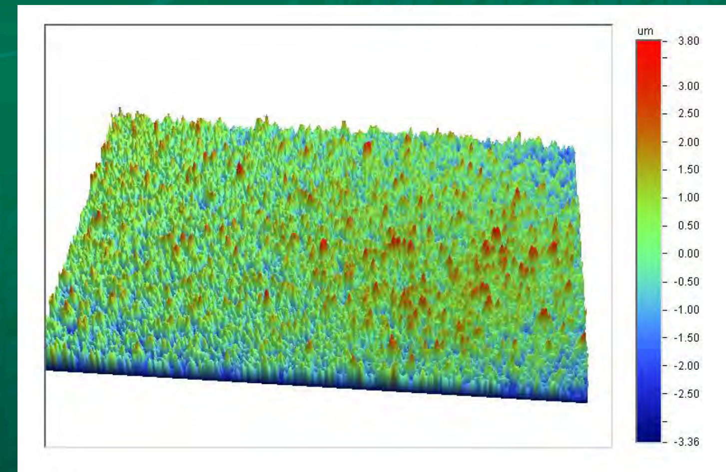


SWTW

Conductor Losses

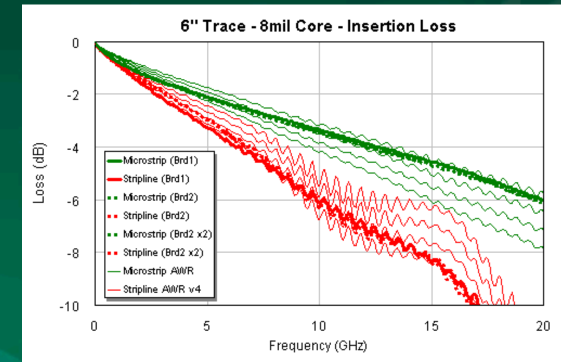
- As Frequency increases beyond a couple GHz Surface roughness becomes significant factor of loss
- Skin effect causes signal to travel nearer surface as frequency increases
- Above 2 GHz Standard Surface Roughness is greater than skin depth of signal
- Causes significantly more loss than traditional models suggest





Picture Courtesy of Rogers Corporation

Conductor Loss Modeling



- **Conductor Loss Model Options**
  - Increased Loss Tangent
    - Differs by line width and copper roughness
  - Curve fit skin depth equation
    - Differs by line width and copper roughness
  - Hammerstad and Jensen
    - Additional loss constant added to classical model
    - Only differs with differing roughness

$$\alpha_{COND,ROUGH} = \alpha_{COND,SMOOTH} * K_{SR}$$

$$K_{SR} = 1 + \frac{2}{\pi}\tan^{-1}\left(1.4\left[\frac{R_{RMS}}{\delta}\right]^2\right)$$

Summary

- Defined major contributors to variations between simulation and measurement of PCB material
- Increased simulation accuracy
- Developed Internal ε_R, and loss tangent values to use in simulation models
- Developed process to do apples-to-apples comparison of PCB material high frequency characteristics

Conclusions

- Datasheet specifications are insufficient for accurate high frequency PCB design
- Modeling must include impact of copper roughness and ratio of epoxy to glass content – Need to get from PCB material vendors
- Confidence in high frequency predictions requires extensive material characterization and correlation

Future Work

- Improve understanding of surface roughness impact
- Implement surface roughness into simulation models

Thanks

- **References:**
  - Rogers Corporation
  - HIGH FREQUENCY PCB MATERIAL CHARACTERIZATION AND SIMULATION Part 1, Ryan Satrom, BITS Workshop
  - Non-Classical Conductor Losses due to Copper Foil Roughness and Treatment, Intel, Gould Electronics
  - Understanding the Variables of Dielectric Constant for PCB Materials used at Microwave Frequencies, Rogers Corporation
  - Practical Fiber Weave Effect Modeling, Lamsim Enterprises