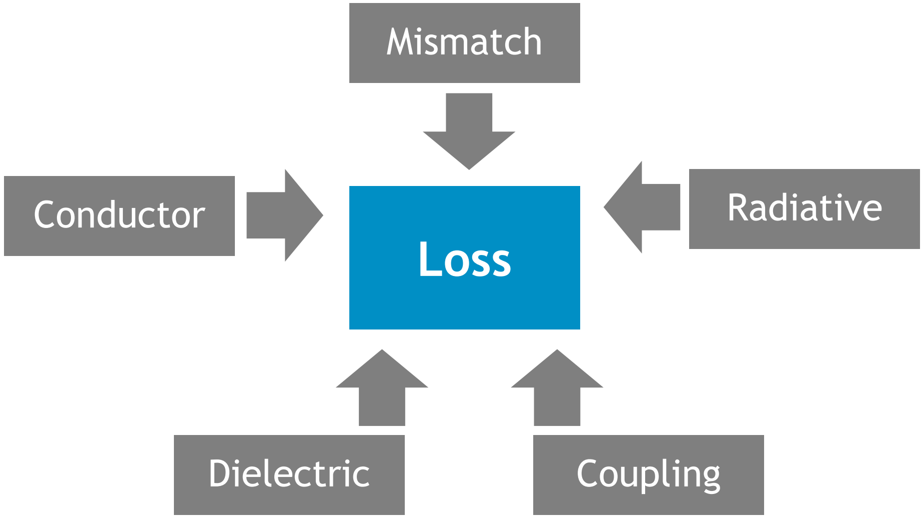
Signal integrity simulation strategies for accurate and fast results
Correct Material Properties that simulate quickly

Tracey Vincent

Loss Components



Overview

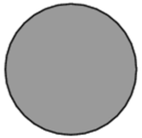
- Loss components
  - **Conductor**:
    - Skin effect
    - Simulating surface roughness:
      - Tabulated surface impedance: Hammerstad, Huray
      - 3D models- Periodic surface, random surface
      - DERM - Effective Dielectric method – (Dr. M. Koledintseva)
    - Edge effects: case studies
  - **Dielectric** :
    - Theory and parameters
      - N^{th} order curve fitting
    - Material properties modeling/extraction based on measured data
      - Popular Techniques
        - CST Extraction Macro
          - Two Transmission Line
          - NIST Multiline TRL
  - Discussion and conclusion

Conductor Loss

Skin Effect Theory

Current density increases at extremities at RF frequencies

Cross-sectional area of round conductor

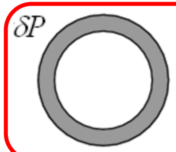


At DC
Current density fills cross-section

$$R_{DC} = \frac{1}{\sigma S} \text{ ohms/meter}$$

S is the cross-section area of the conductor.
σ is the volume conductivity.
Current is homogenous.

At AC
Current density moves toward extremities



At GHz frequencies
Current density concentrated at extremities

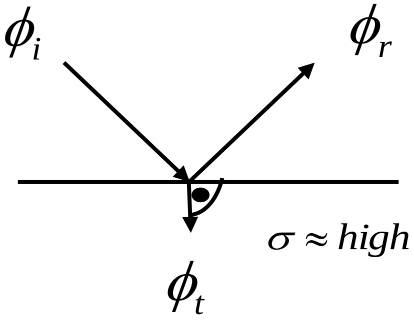
$$R_{AC} = \frac{1}{\sigma \delta P} \text{ ohms/meter}$$

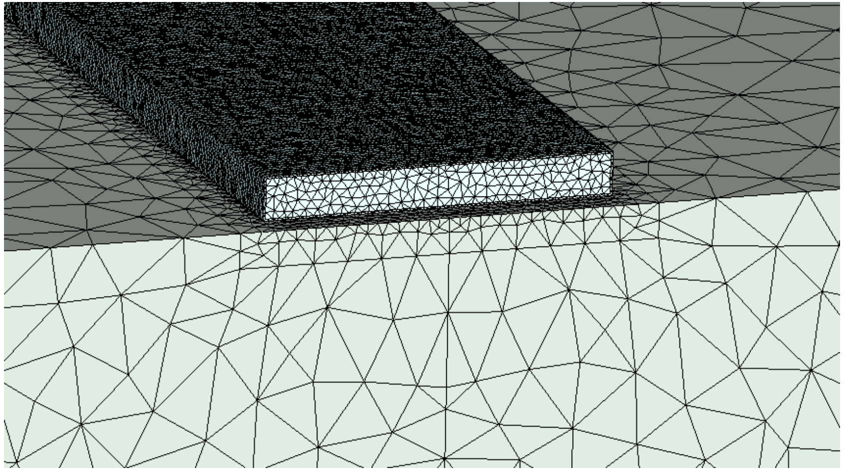
$$= \frac{R_S}{P} \text{ ohms/meter}$$

P is the *circumference* of the conductor, δ is skin depth. The δP is the equivalent cross-section area.

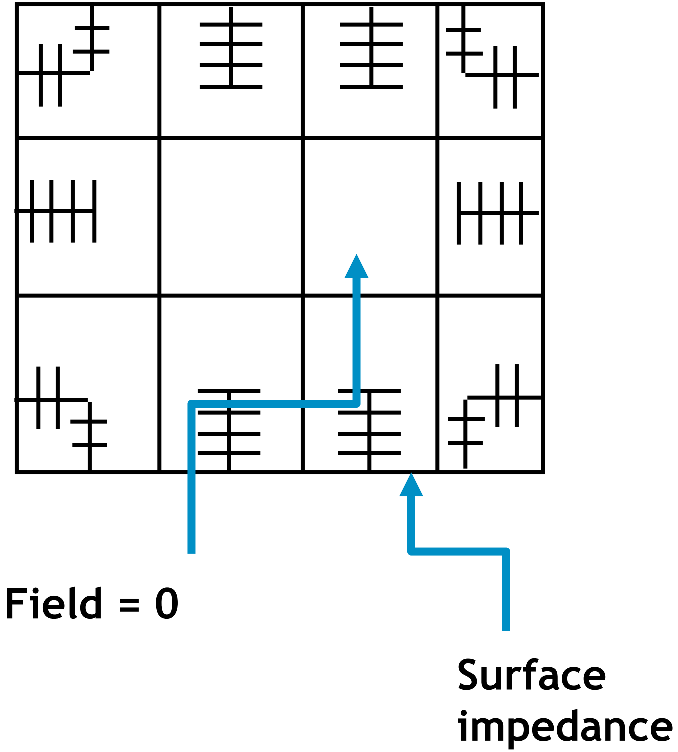
$$\delta = \sqrt{\left(\frac{2}{\omega \mu_o \sigma}\right)}$$

Skin Effect - Lossy Metal



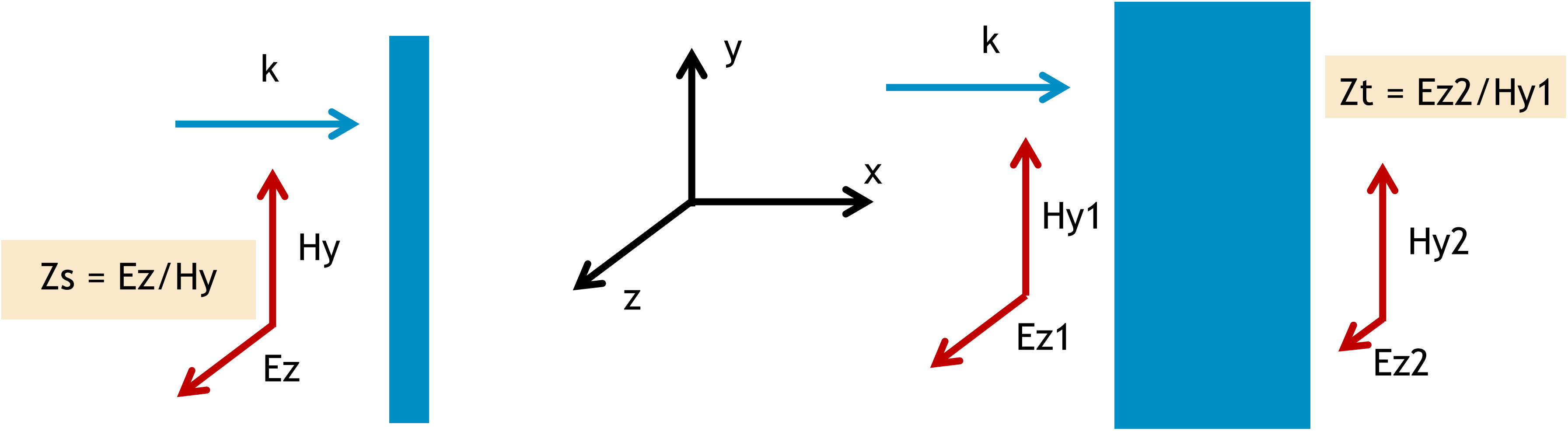


Alternative



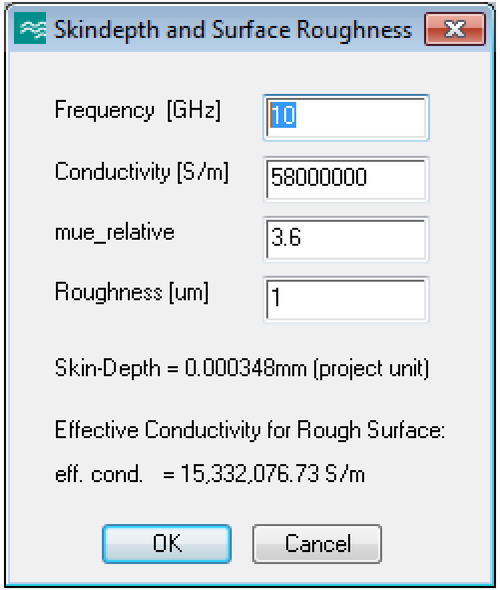
Surface Impedance Materials

- In principle, a classical dispersive material could be used
- However, an excessively fine mesh might be needed:
  - If the object made of that material is too thin
  - If the penetration depth of the field into the object is very small
- The surface impedance model is a way to avoid a very fine mesh

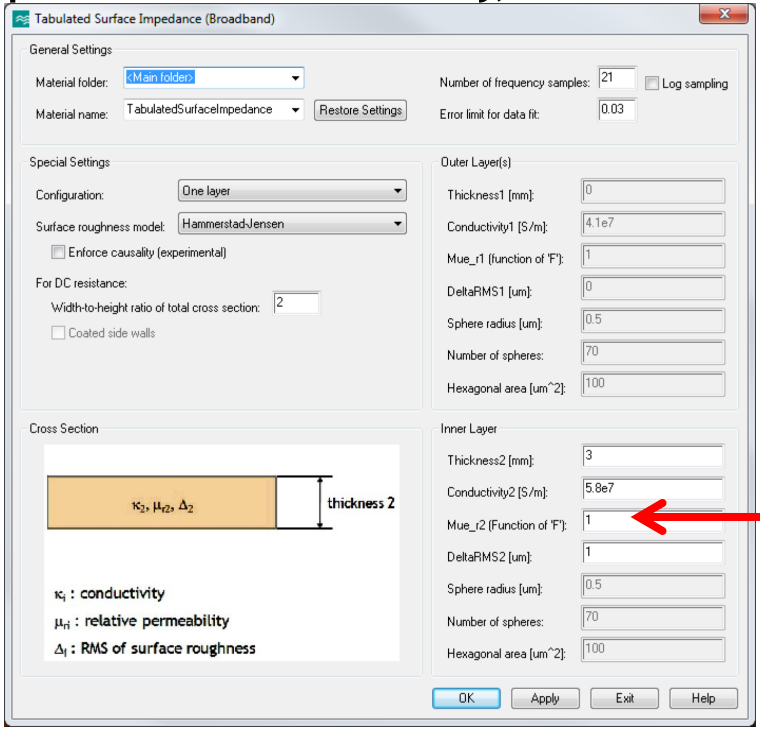


Surface Roughness Parameterization

Narrow band "quick" parameterization

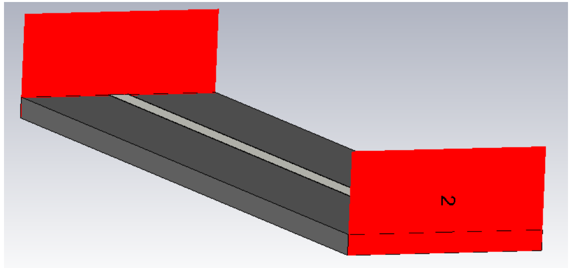


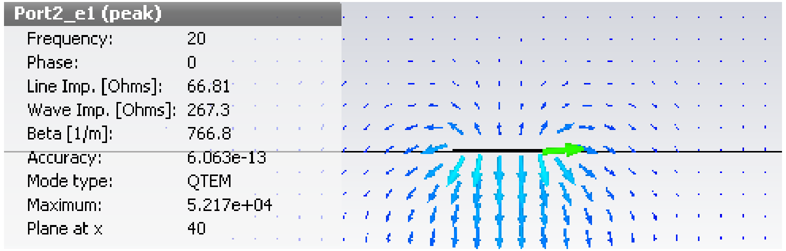
Broadband tabulated surface impedance parameterization: Huray, Hammerstad

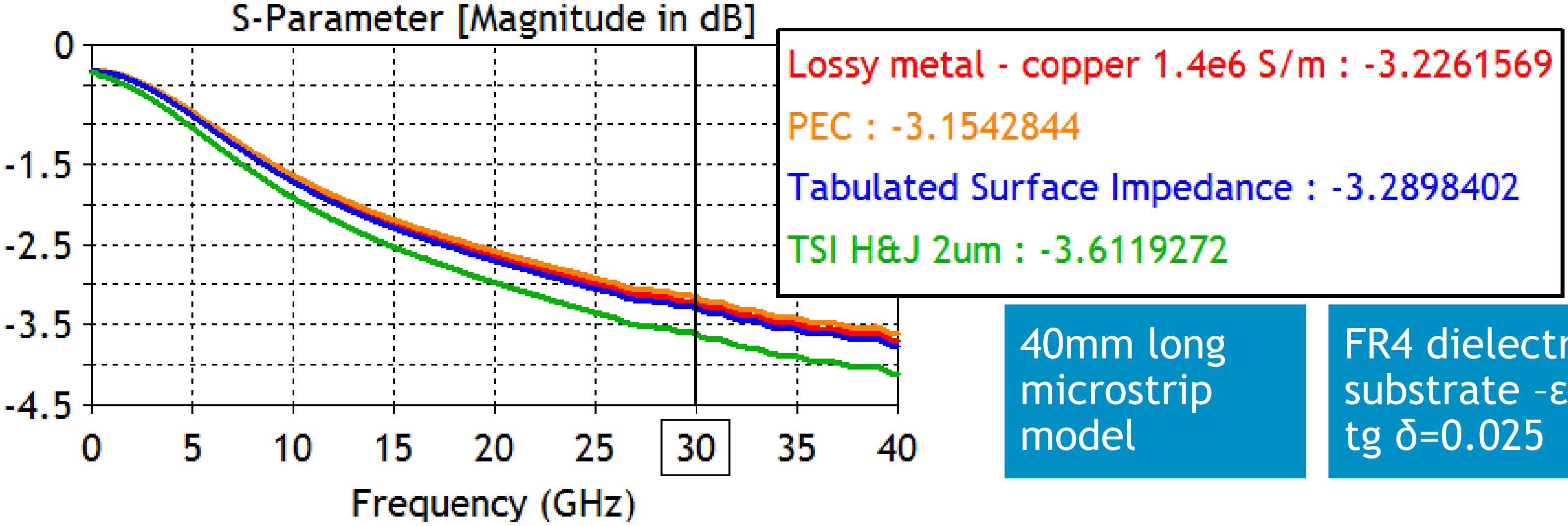


Option to Include nickel

Comparison of Results for Simple Model



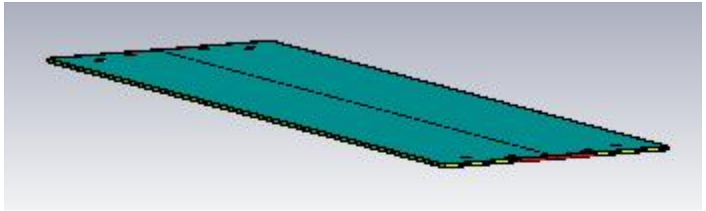


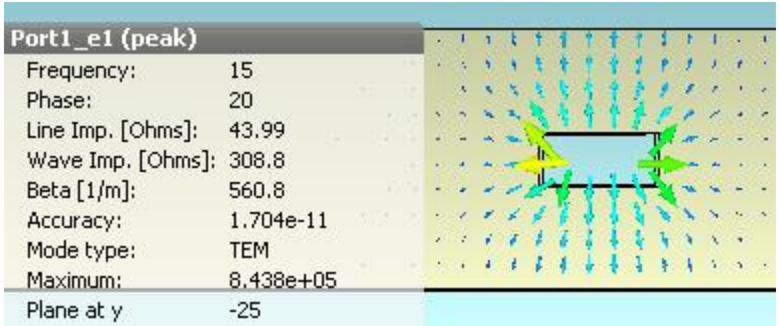


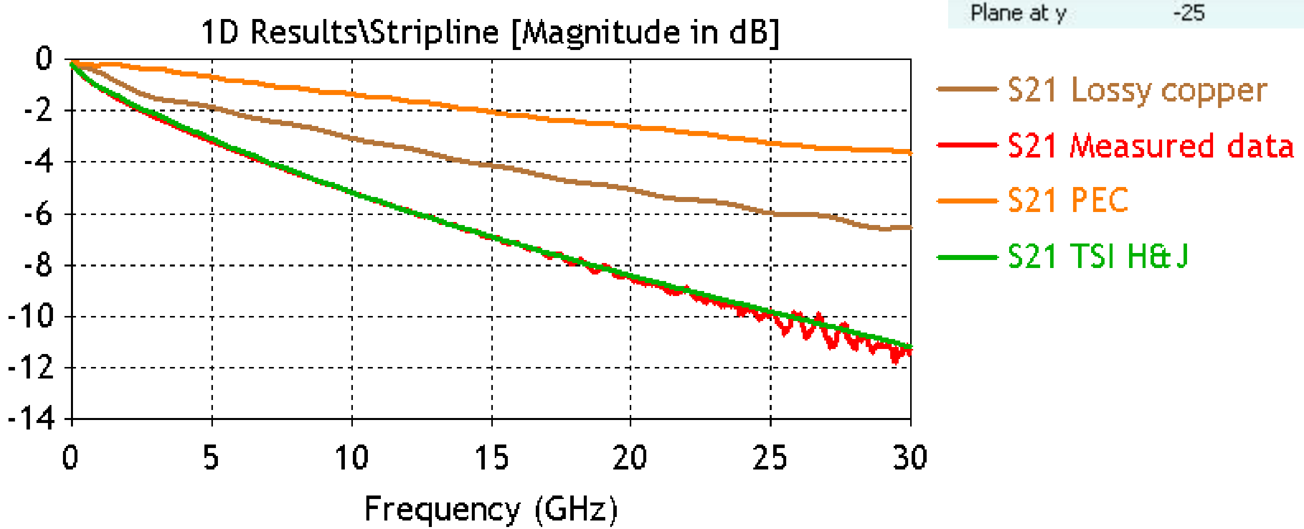
40mm long microstrip model

FR4 dielectric substrate –εr=4.3, tg δ=0.025

Measured and Simulated Data for Stripline



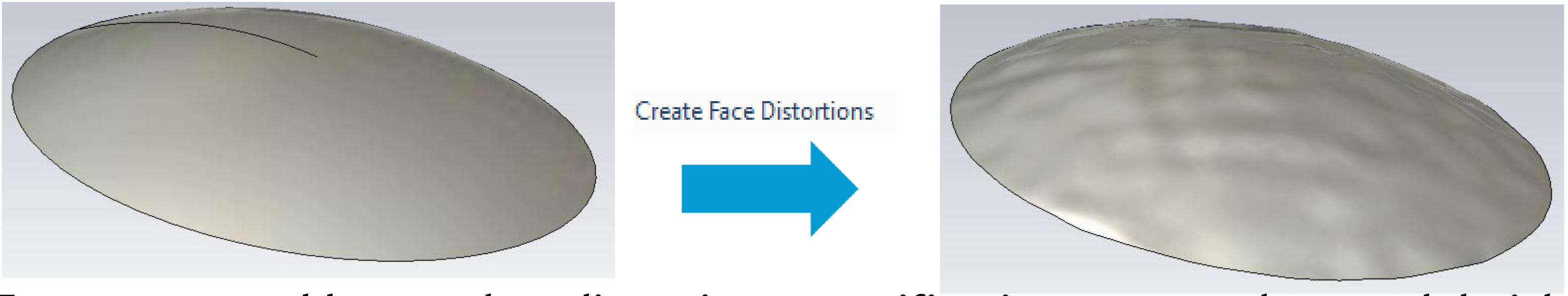




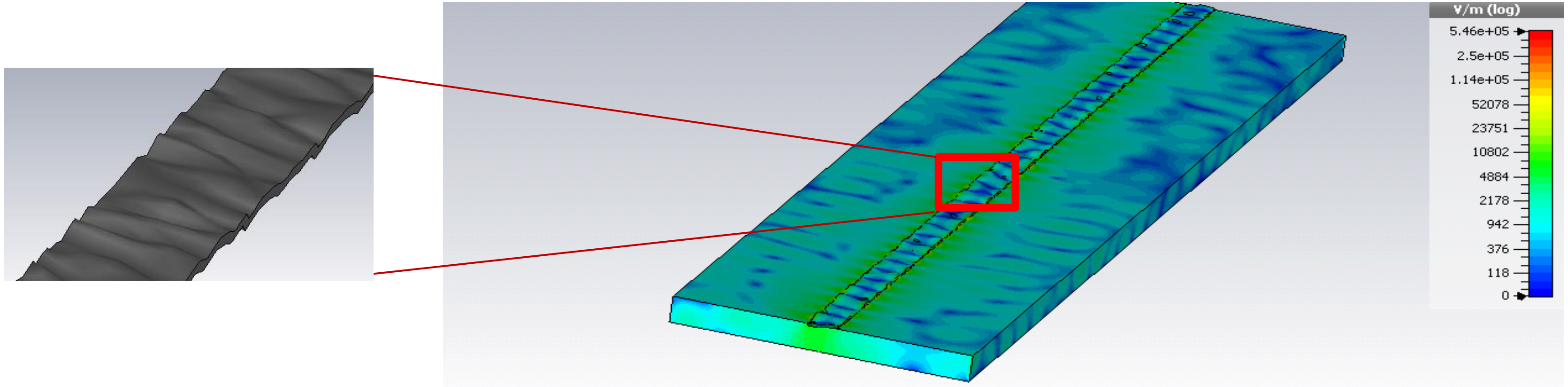
FR4 dielectric substrate –εr=3.5, tg δ=0.06

50mm long stripline model

Face Distortion Surface

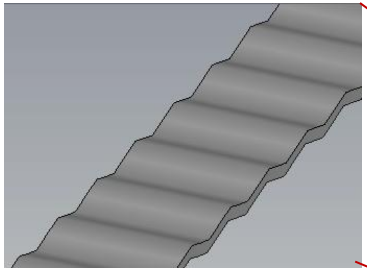


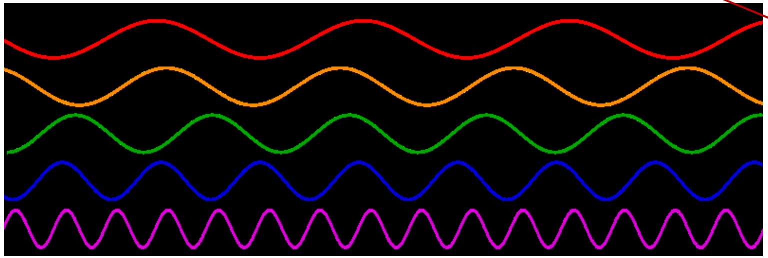
Trace generated has random distortions, specifications are: peak to peak height, average distance between peaks



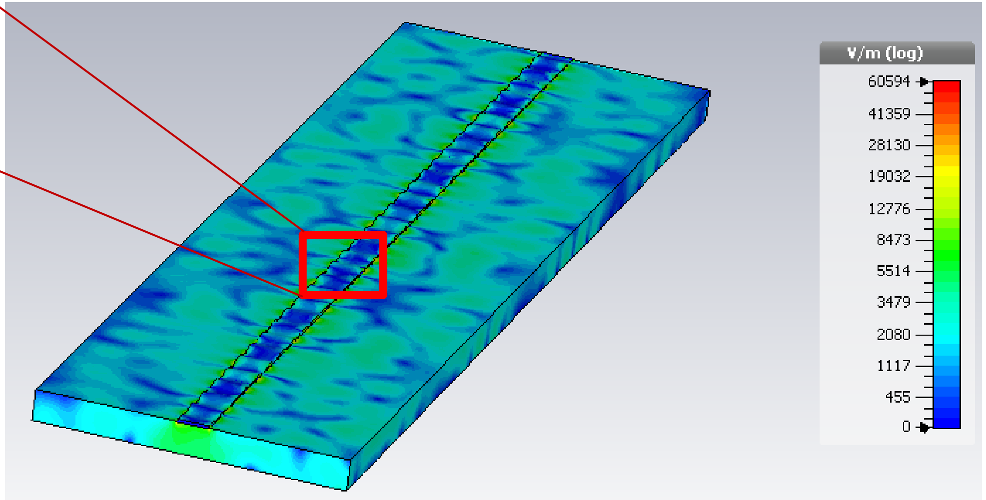
Analytical Face surface. Periodic example.

- Equation, such as polynomial can be used to generate non-smooth trace.
- Example is periodic trace: w=*Ra**sin(b00u).



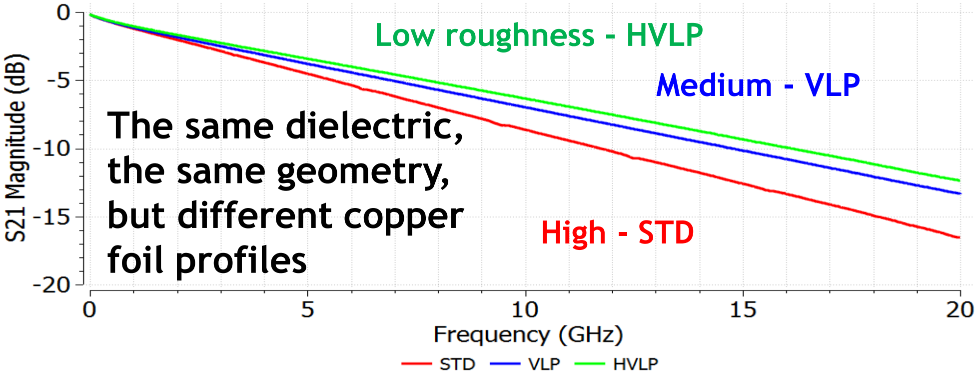


All of these waveforms have same average roughness Ra

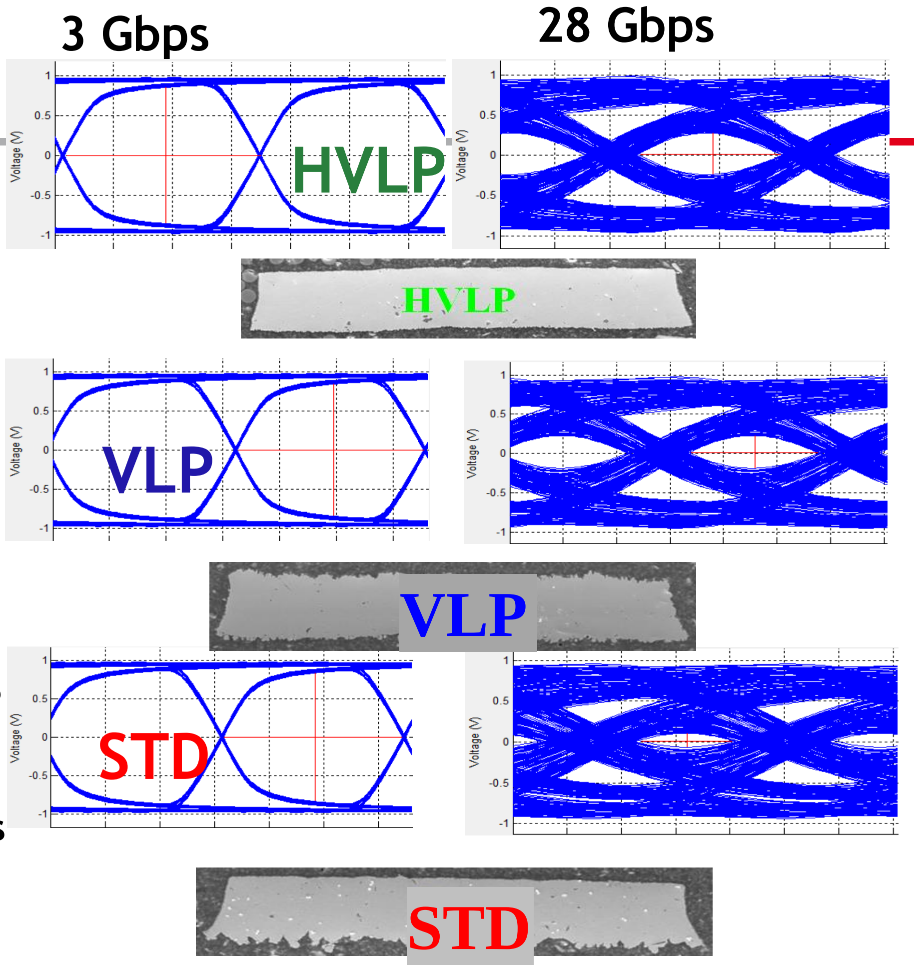


Motivation

- Conductor roughness affects both phase and loss constants in PCB transmission lines and results in eye diagram closure.



The same dielectric, the same geometry, but different copper foil profiles



- Conductor surface roughness lumps into laminate dielectric parameters.
- Surface roughness topography of printed circuit boards (PCBs) needs to be included in simulations in order to accurately predict wideband frequency behavior of designs for both SI and EMC/EMI purposes.

New Analytical Method “Roughness Dielectric”- Concept

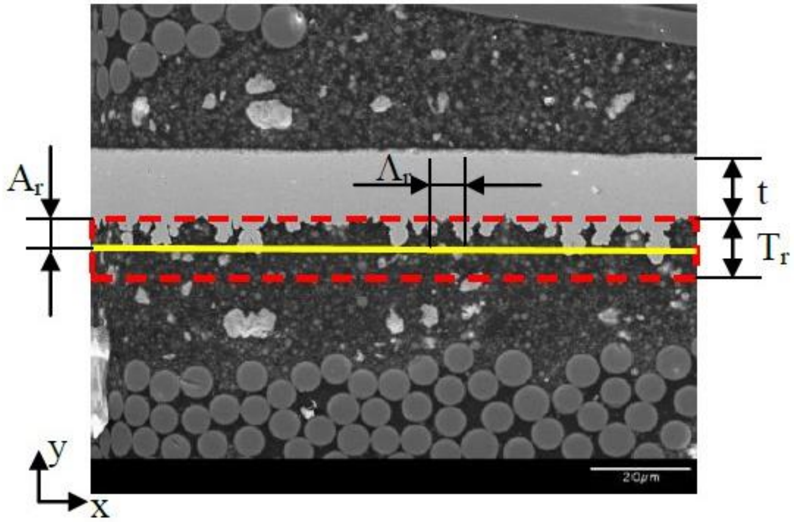
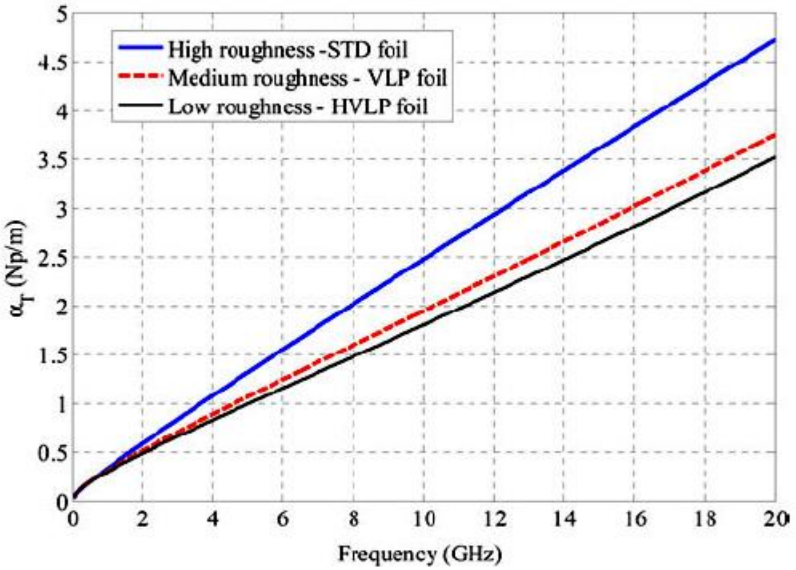


Fig. 6. Magnified section of the signal trace conductor in the SEM picture of the test line with STD foil. The region of the “roughness dielectric” is selected by a dashed line

	Ar (µm)	Λr (µm)	Ar/Λr	Ra (µm)	Rz (µm)	Rrms (µm)
STD	7.98	10.62	0.75	1.56	8.41	1.91
VLP	3.35	7.28	0.46	0.75	4.19	0.92
HVLP	1.65	4.69	0.35	0.35	2.29	0.44

Reference: Koledintseva, Razmadze, Gafarov, De, Drewniak, Hinaga “PCB Conductor Surface Roughness as a Layer with Effective Material Parameters” Electromagnetic Compatibility (EMC), 2012 IEEE International Symposium 2012

"Roughness Dielectric"- Extracting the parameters



Reference: Koul, Koledintseva, Hinaga, Drewniak "Differential Extrapolation Method for Separating Dielectric and Rough Conductor Losses in Printed Circuit Boards" IEEE Trans, 2012.

"smooth" conductor contribution /skin effect

Roughness contribution

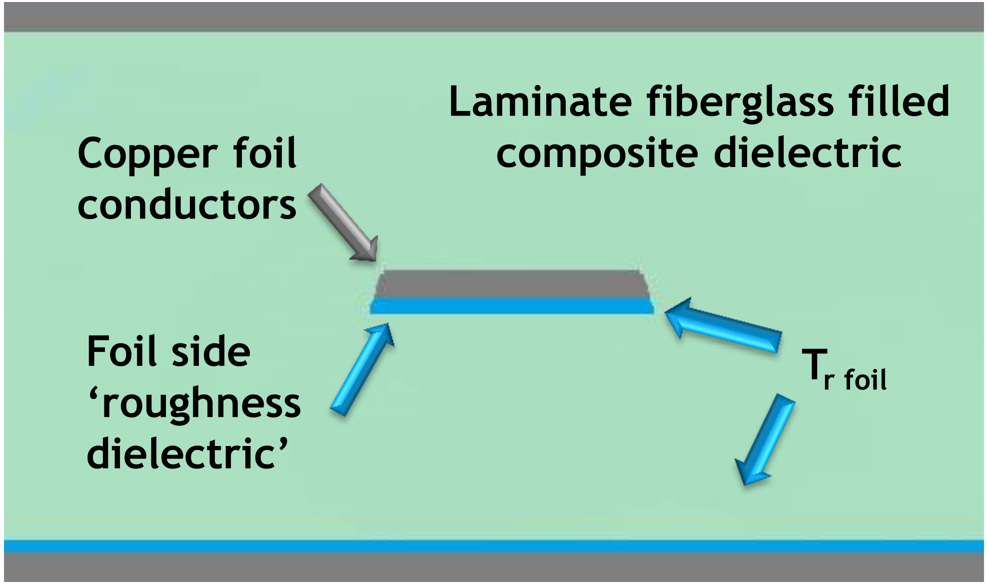
Dielectric contribution

$$\alpha_T = a\sqrt{\omega} + b\sqrt{\omega} + c\omega + d\omega^2 + e\omega + f\omega^2$$

a + b = K1 c + e = K2 d + f = K3

- Curve fitting co-efficients are generated K1 ~ √ω , K2 ~ ω, and K3 ~ ω²
- K1(0), K2(0), and K3(0) corresponds with smooth conductor, allow separation of surface roughness loss and dielectric loss. K co-efficients relate to Ar
- Dielectric material (smooth) 3D object with extracted "roughness" parameters can be included in simulation to simulate roughness impact

"Roughness Dielectric"- Concept

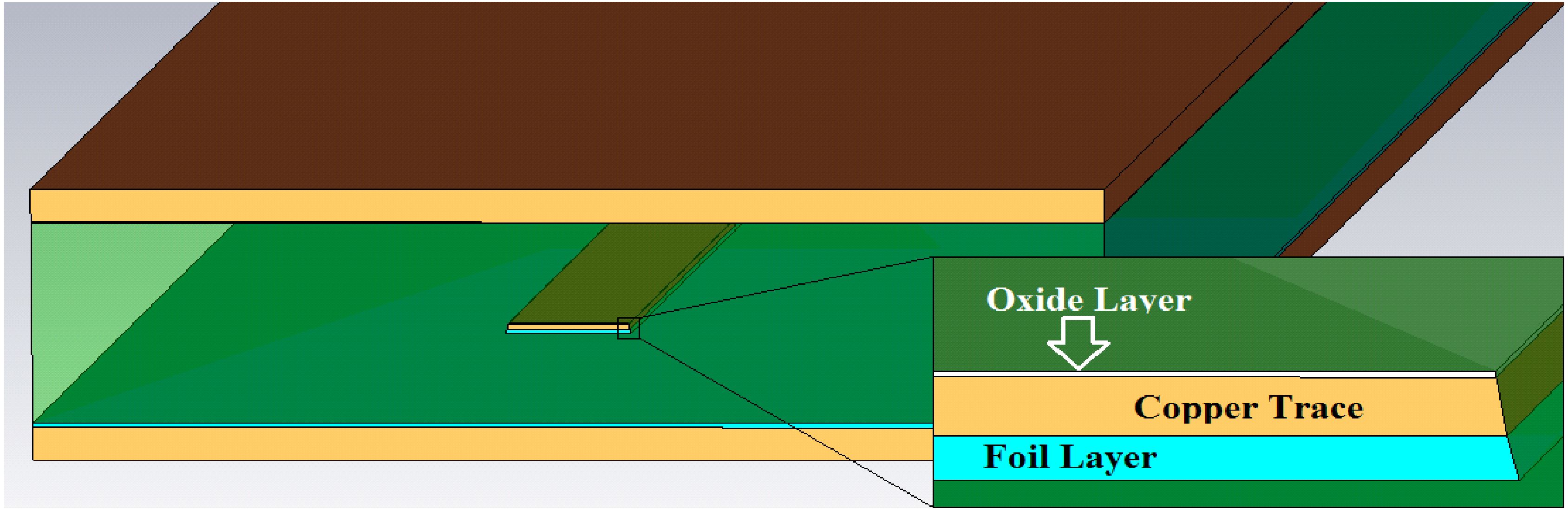


Cross section view - Not to scale for presentation purposes only

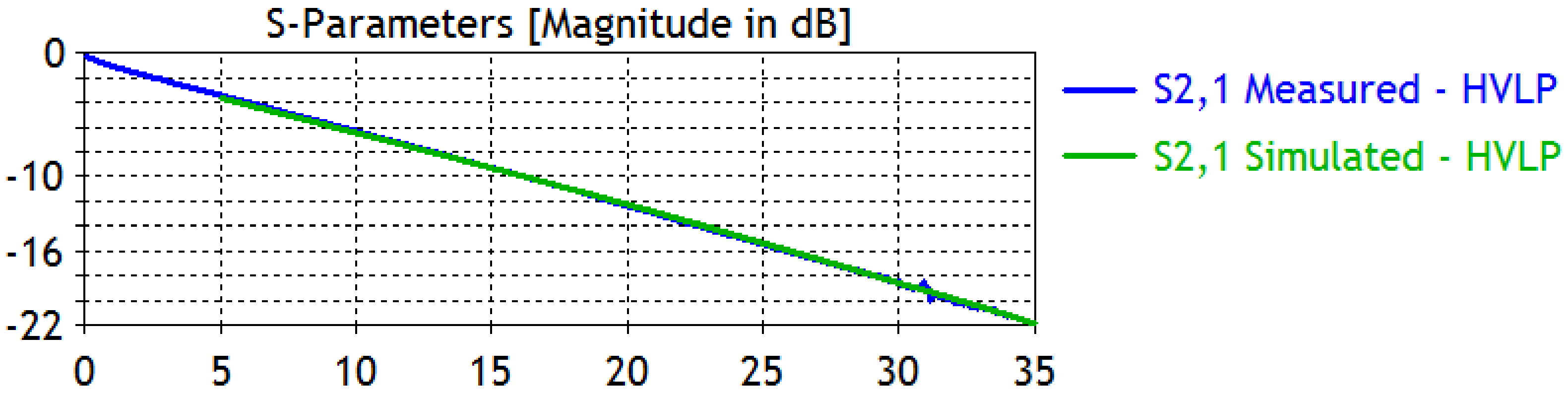
- Laminate dielectric parameters are extracted from DERM2 (for both α and β).
- Heights of ERD $T_{r\ foil}$ are taken $2A_{r\ foil}$, respectively.
- Line length for this model = 15,410 mils

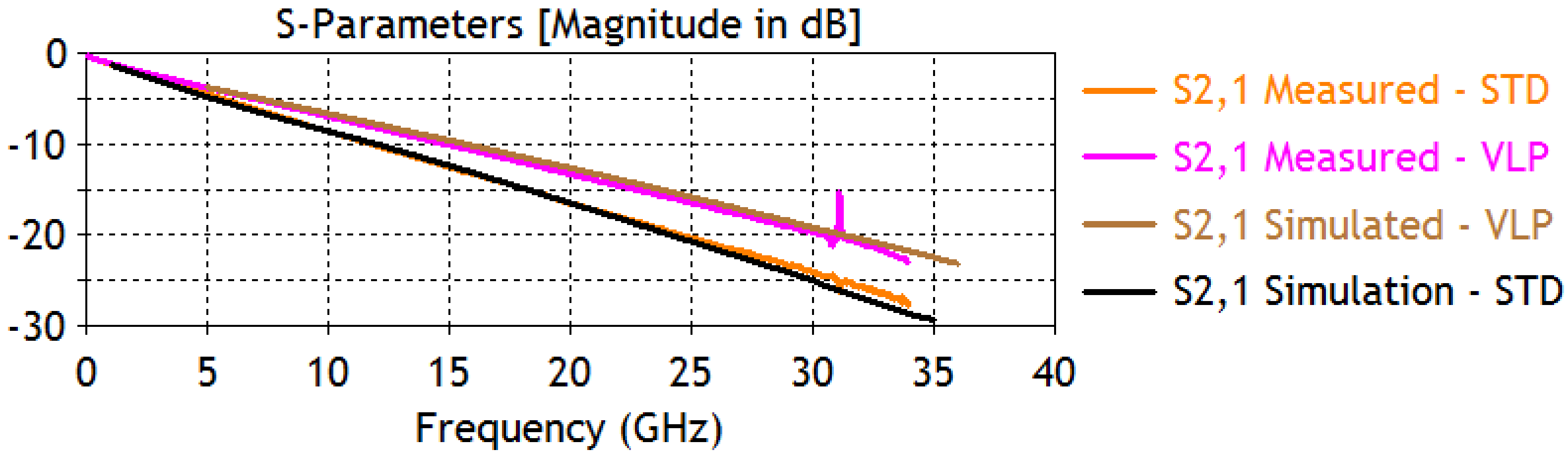
Validation Using Full-wave EM Numerical Simulations

CST Studio Suite 3D model is used for validation of the extracted ERD data



Comparison of S21 Results

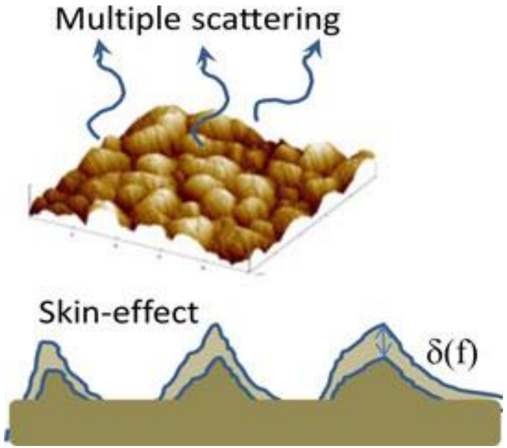


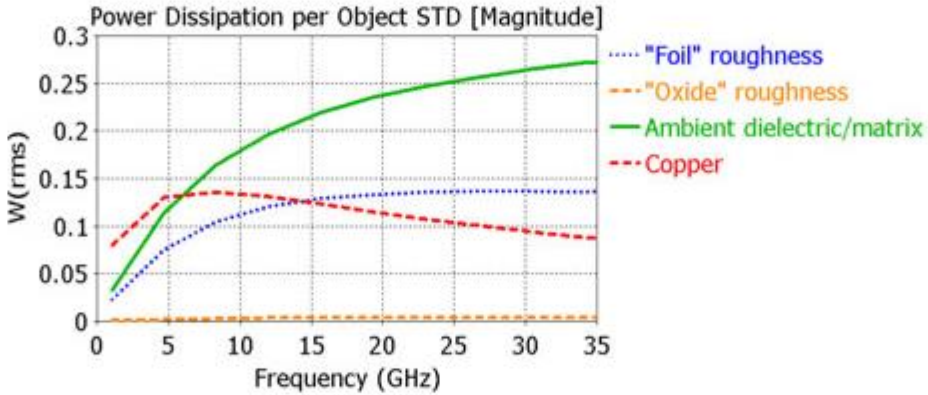


What is physically happening in the conductor foil?

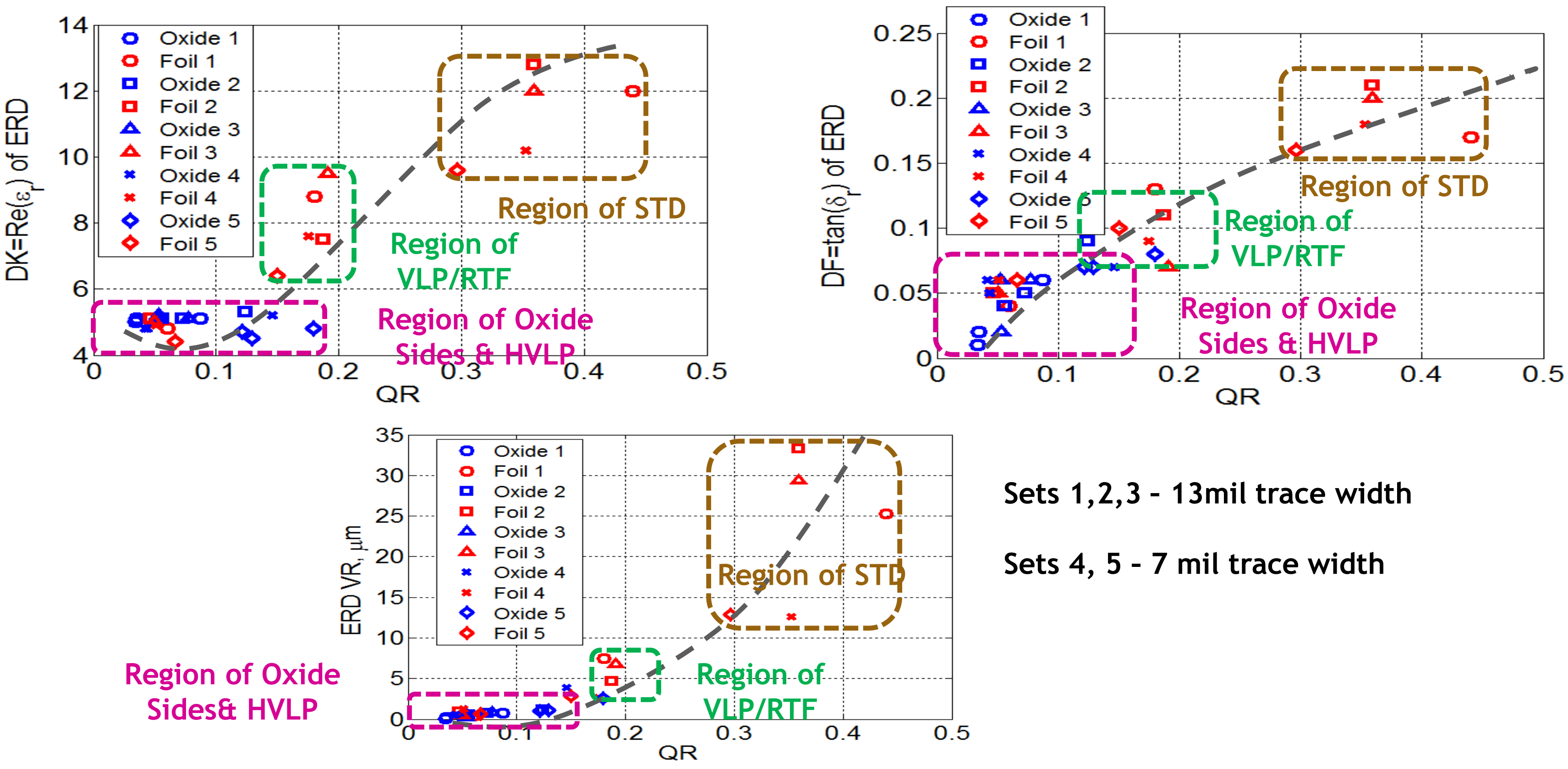
Sophisticated curve fitting but what is/are the underlying physics?

- Skin effect allows field to penetrate the foil at lower band. Multiple scattering pushes the fields out of the metallic “particles” causing a slight decrease in metal loss at higher band.
- <6GHz conductor loss dominates. >6GHz dielectric loss dominates –for STD “foil” roughness is significant (not for others!)





“Design Curves” - ERD Parameters as Functions of Roughness Factor

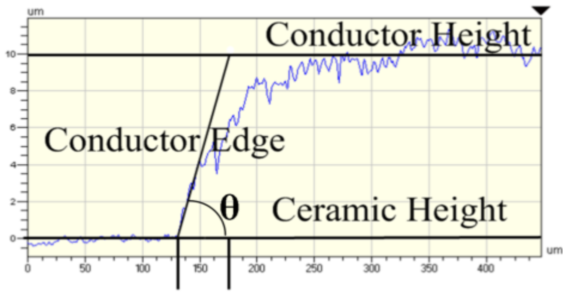


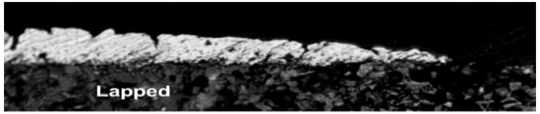
Sets 1,2,3 - 13mil trace width

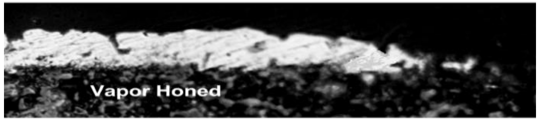
Sets 4, 5 - 7 mil trace width

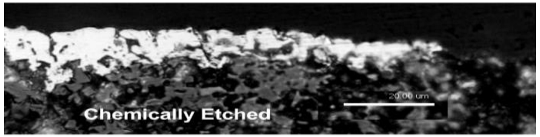
Trace Edge Cross-Section

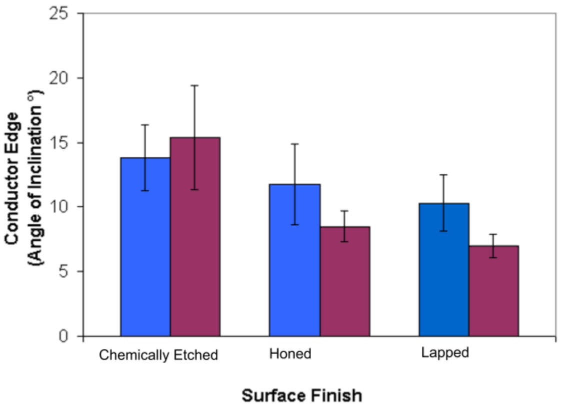
Thick-film print cross-section





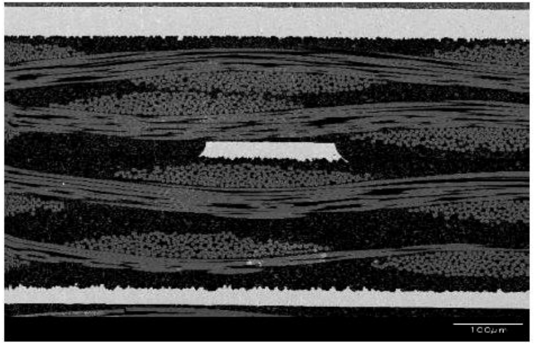




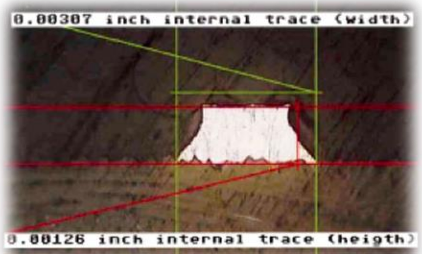


Thick film printed circuit have very sharp edges 7-15 degrees.
Results shown for 2 types of silver paste on 3 surfaces

Typical PCB cross-section



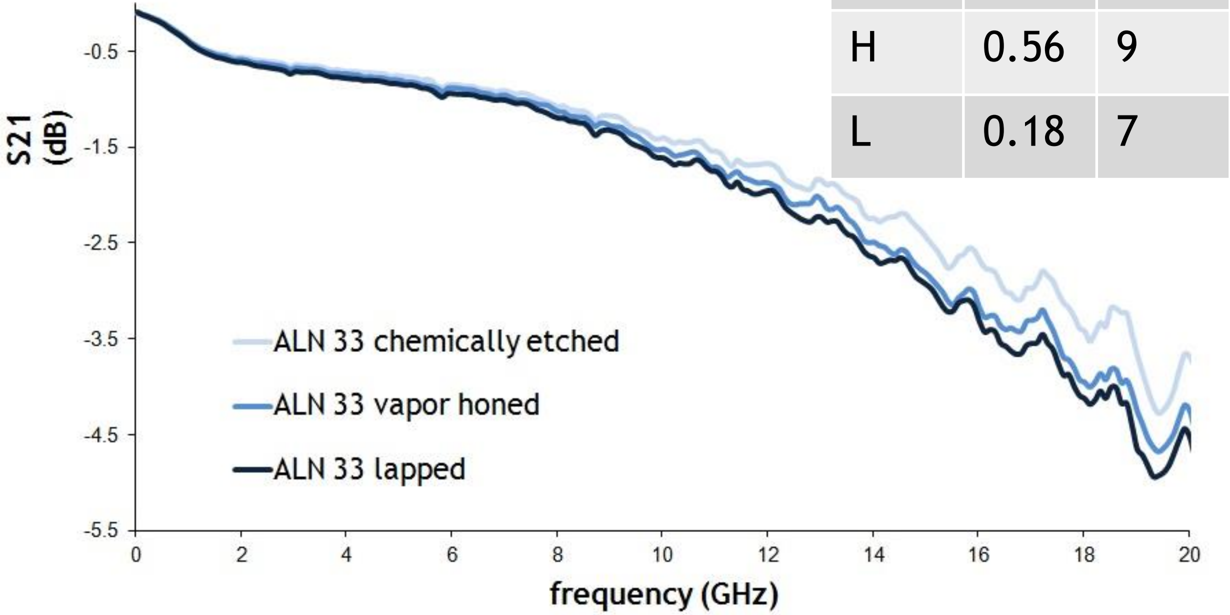
Etched circuits can have tapered edges ~45 degrees

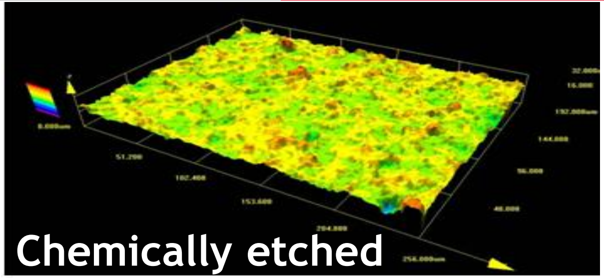


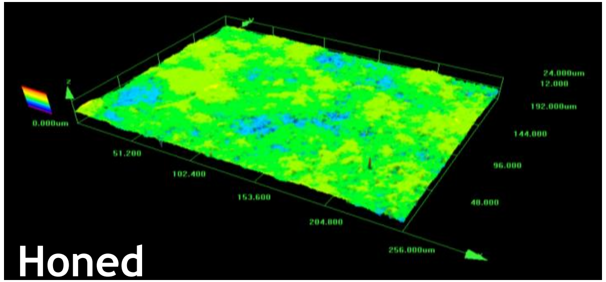
Measured Results with Sharp Edges (Printed)

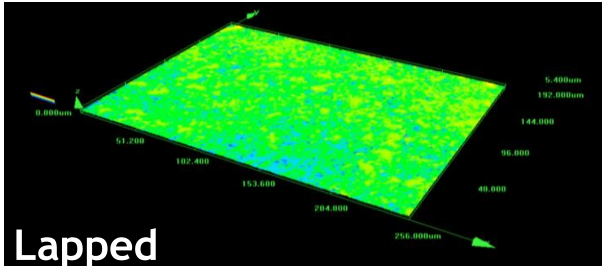
"roughest" surface has "best" loss, "smoothest" surface has "worst" loss.

	Ra um	A°
CE	1.09	15
H	0.56	9
L	0.18	7

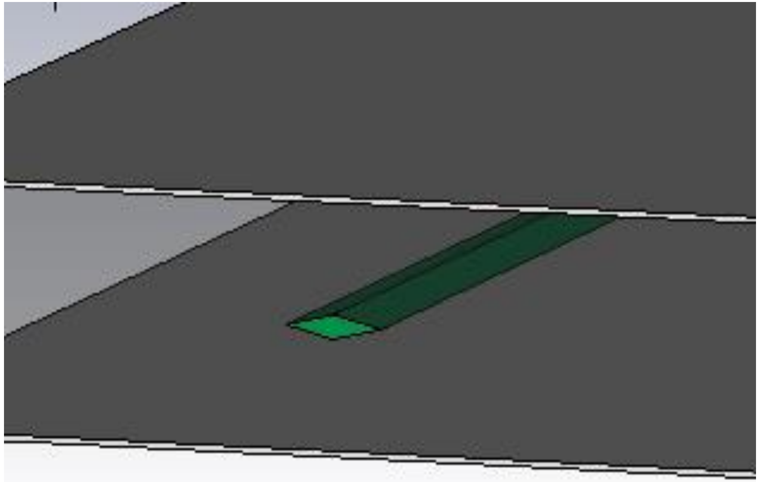




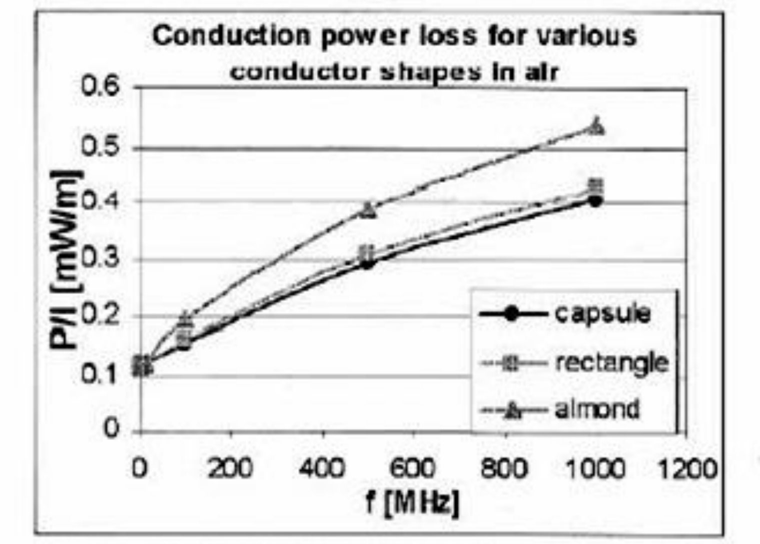




Edge Effect -“Almond Shape” vs Rectangular

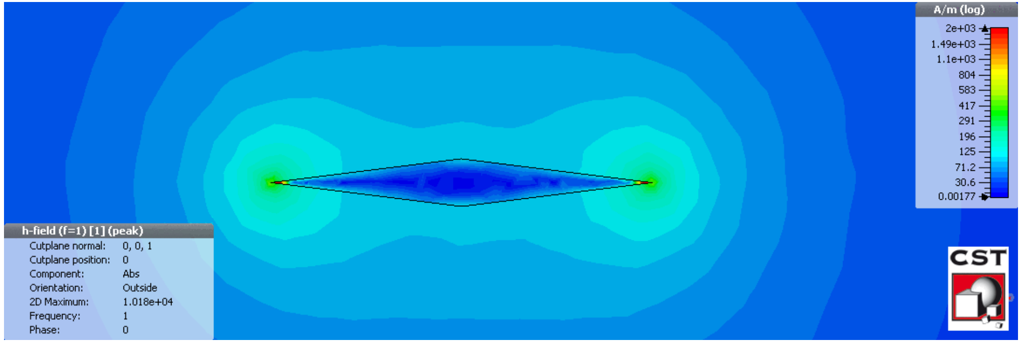


Reference: Lim, Wyk “Impact of Conductor Cross-Sectional Shape on Component Performance and Total Losses in a Microsystem” iMAPS 2006, demonstrated the increase in loss with simulated and measured conductor shapes in LTCC stripline topology



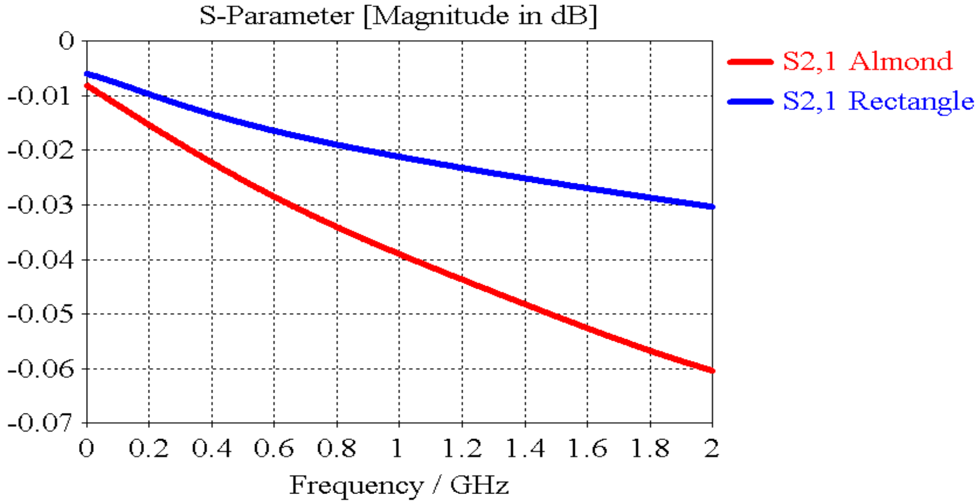
Power loss results comparing “Almond” and “Rectangle” shape with same cross-sectional area. Larger loss with “Almond” shape @ 1GHz, difference of ~38% conductor loss

Sharp Edges

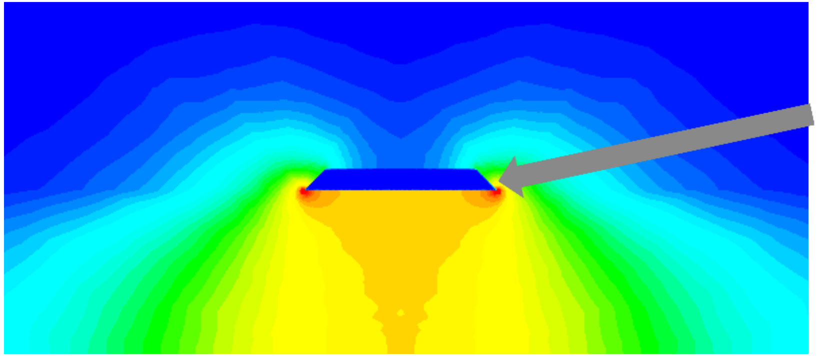


Field lines showing much stronger field at edges

S(2,1) results comparing "Almond" and "Rectangle" shape with same cross-sectional area larger loss with "Almond" shape @ 1GHz

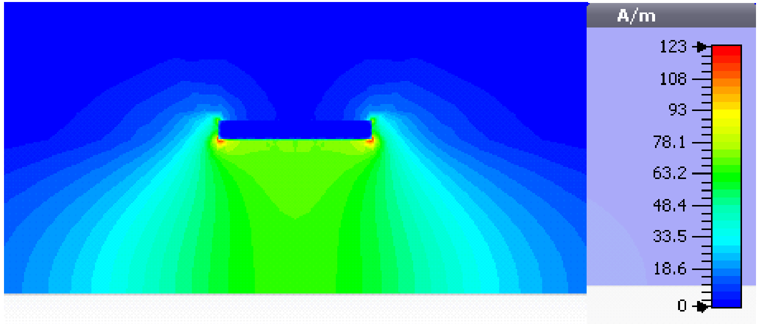


Trapezoidal Edge

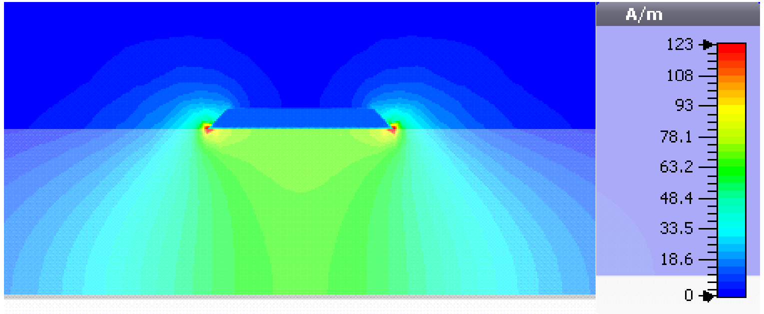


Increased peak H field at edges of trapezoidal shape

Reference: Guo, Glisson, Kajfez "Skin-effect Resistance of Conductors with a Trapezoidal Cross Section" Microwave and Optical Technology Letters, Vol. 18, No. 6, 1998. Analytical method* to predict the resistance of trapezoidal lines. For 45 degree taper Rac/Rac-trap=1.14 @1GHz, 1.22 @50GHz



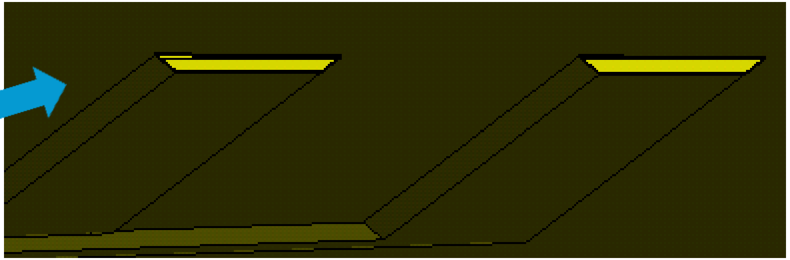
Attenuation coefficient=0.5163 @50GHz



Attenuation coefficient=0.8979 @50GHz

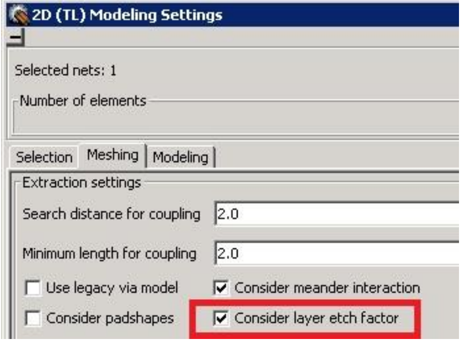
Simulation of Etch Factor

Material	Cond. / tan delta	Permittivity	Thickness	Elevation	Filling from	Etch undercut	Etch factor
COPPER	4.159e+07	0	2.9	147.4	above	bottom	0.8
FR-4	0.01@10GHz	3.6	4.2	143.2			
COPPER	4.159e+07	0	0.6	142.6	above	bottom	0.8
FR-4	0.01@10GHz	3.6	6	136.6			
COPPER	4.159e+07	0	0.9	135.7	above	bottom	0.8
FR-4	0.01@10GHz	3.6	9	126.7			
COPPER	4.159e+07	0	0.6	126.1	above	bottom	0.8
FR-4	0.01@10GHz	3.6	6	120.1			
COPPER	4.159e+07	0	0.6	119.5	above	bottom	0.8
FR-4	0.01@10GHz	3.6	9	110.5			
COPPER	4.159e+07	0	0.6	109.9	above	bottom	0.8
FR-4	0.01@10GHz	3.6	6	103.9			
COPPER	4.159e+07	0	0.6	103.3	above	bottom	0.8
FR-4	0.01@10GHz	3.6	9	94.3			
COPPER	4.159e+07	0	0.6	93.7	above	bottom	0.8
FR-4	0.01@10GHz	3.6	6	87.7			



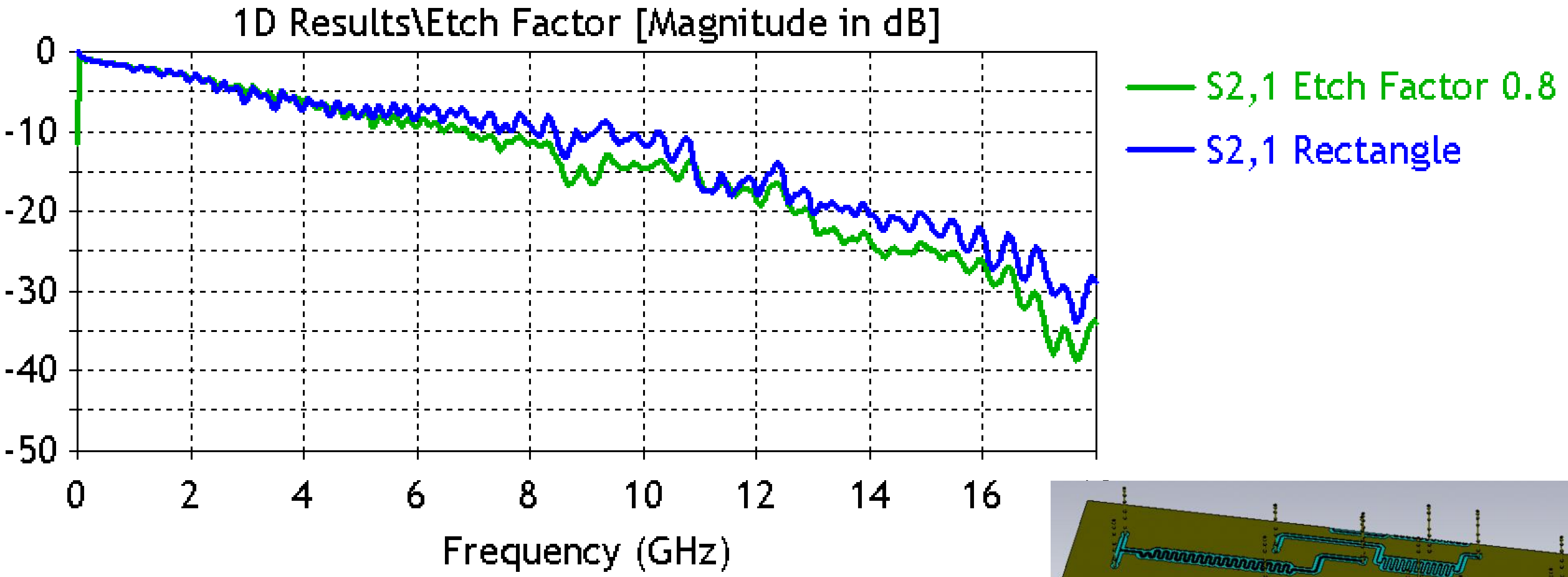
CST MICROWAVE STUDIO

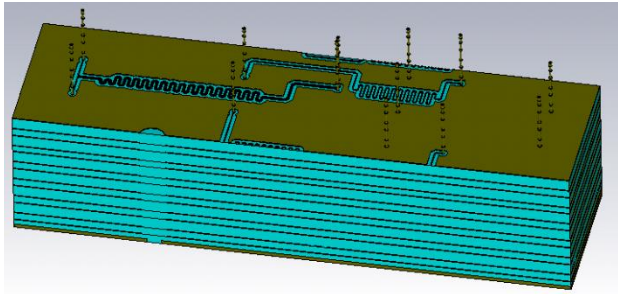
Etch factor implemented on import of EDA file



CST PCB STUDIO

Etch Factor


1D Results\Etch Factor [Magnitude in dB]
0
-10
-20
-30
-40
-50
0
2
4
6
8
10
12
14
16
Frequency (GHz)
S2,1 Etch Factor 0.8
S2,1 Rectangle



A couple of notes before moving on….

Bulk conductivity:

- Is the conductivity of the metal correct? Any slight alloying will drastically reduce the conductivity.
- Good news – bulk conductivity can, fairly easily, be tested.

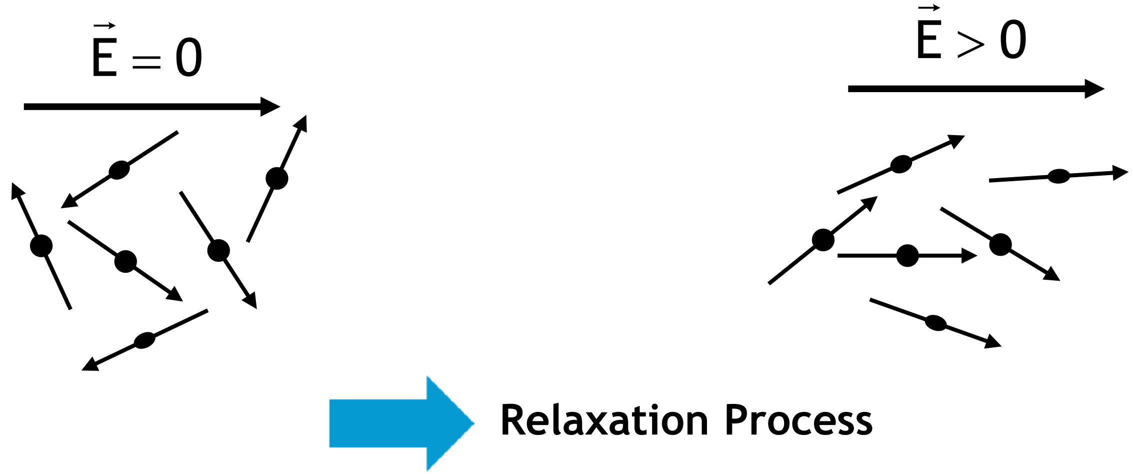
Nickel:

- Nickel can be mechanically desirable. The material characteristics of nickel can also be included in the TSI
- For example: 1+16*exp(-F2/15) [Hodsman, Eichholz, and Millership]

[Design Con 2012, EM modeling of Board Surface Finish Effect on High-Speed PCB Performance, Yuming, Scharf]

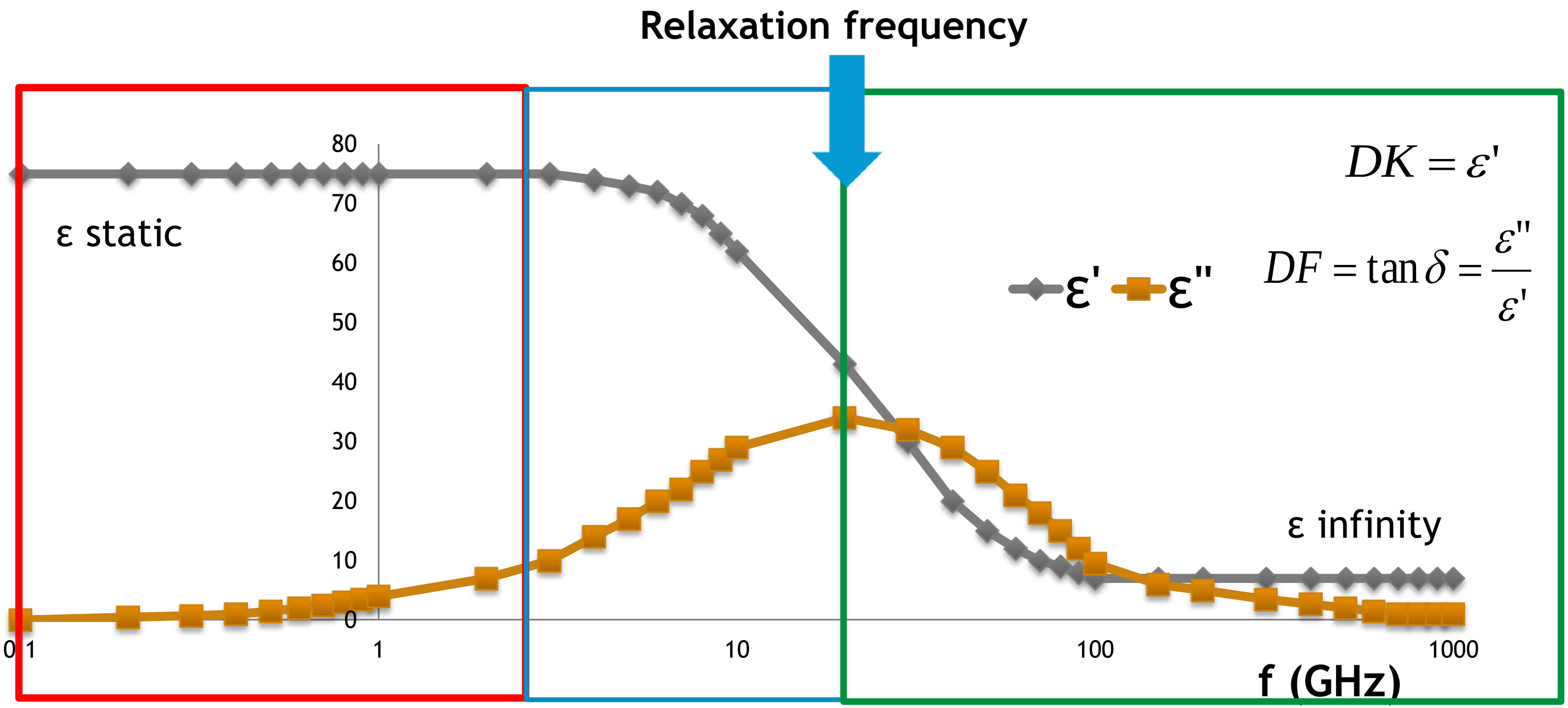
Dielectric Loss

Dielectric Material Theory



- Such dielectric behavior can be modeled by including many relaxation terms, each localized around different frequency.
- Common PCB/package dielectric materials exhibit gradual change in dielectric constant over a very broadband frequency range.

Dielectric Loss Theory - 1st Order Debye Dispersion



Dielectric Loss - Causality

Definition: in any passive circuit, the effect always has to follow the cause.

“The man who shoots faster than his shadow“

Or

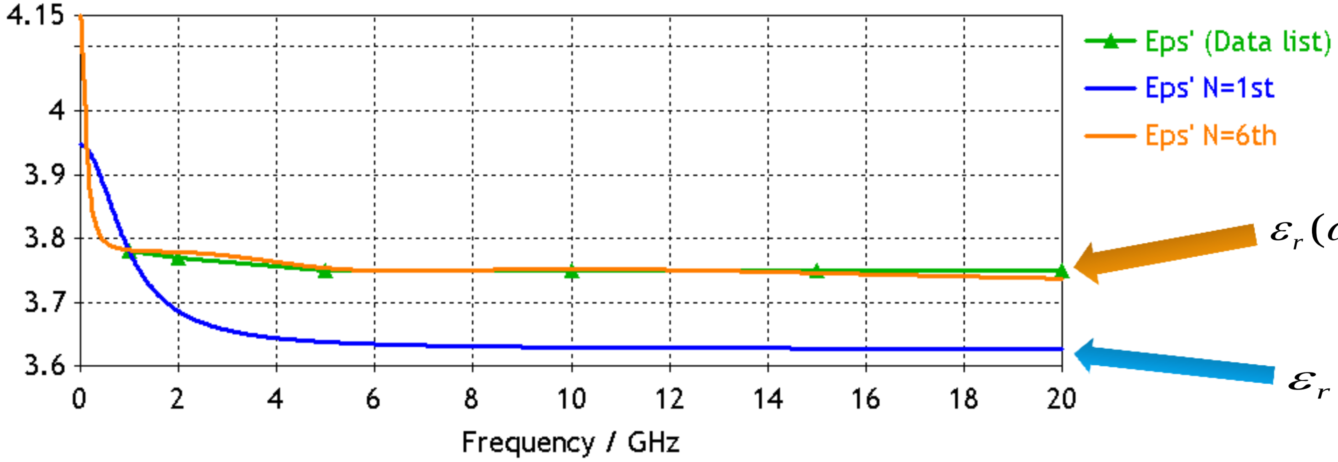
“The shadow shoots the man“!

Sources of non-causality: Measurement, simulation (resonance, round error, interpolation, and extrapolation), and data manipulation.

Time domain solvers are broadband, curve fitting will retain causality.

Dielectric Loss - Curve fitting Nth Orders

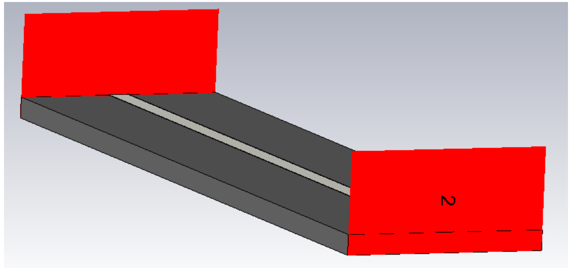
- Why nth order?
  - The transient solver is broadband (often more broadband that device modeled), dispersive materials: fit required.
  - nth order Debye/Lorentz fit more accurately than simple Debye or Lorentz models.



$$\varepsilon_r(\omega) = \varepsilon_\infty^{'} + \sum_i^N \frac{\Delta\varepsilon_i^{'}}{1 + j\dfrac{\omega}{\omega_i}} - j\frac{\sigma}{\omega\varepsilon_0}$$

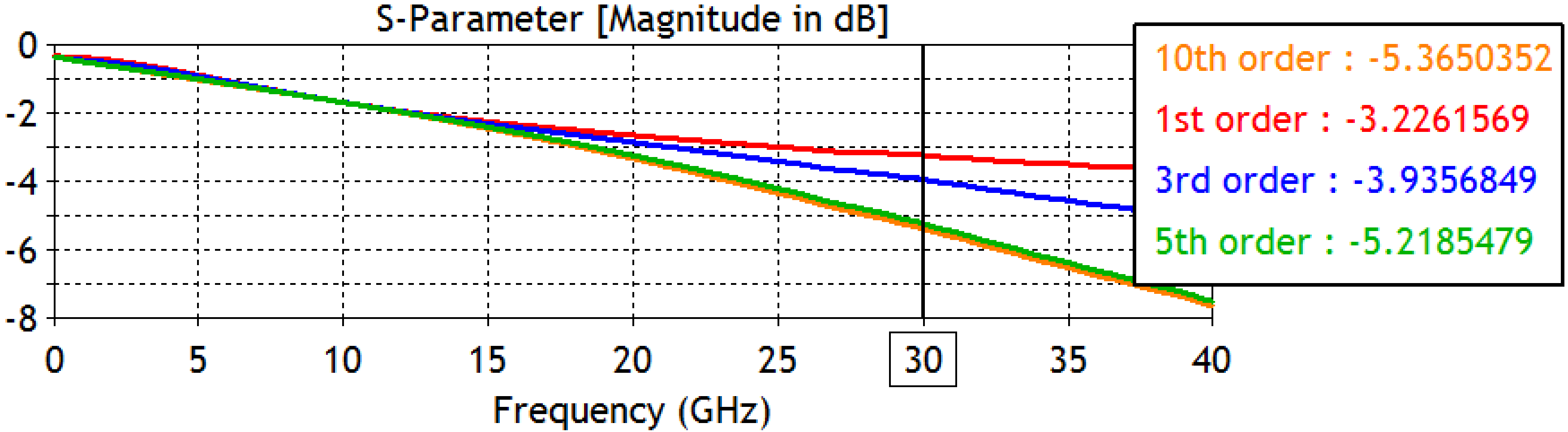
$$\varepsilon_r(\omega) = \varepsilon_\infty^{'} + \frac{\Delta\varepsilon^{'}}{1 + j\dfrac{\omega}{\omega_0}}$$

Curve Fitting Comparison - S21 Results

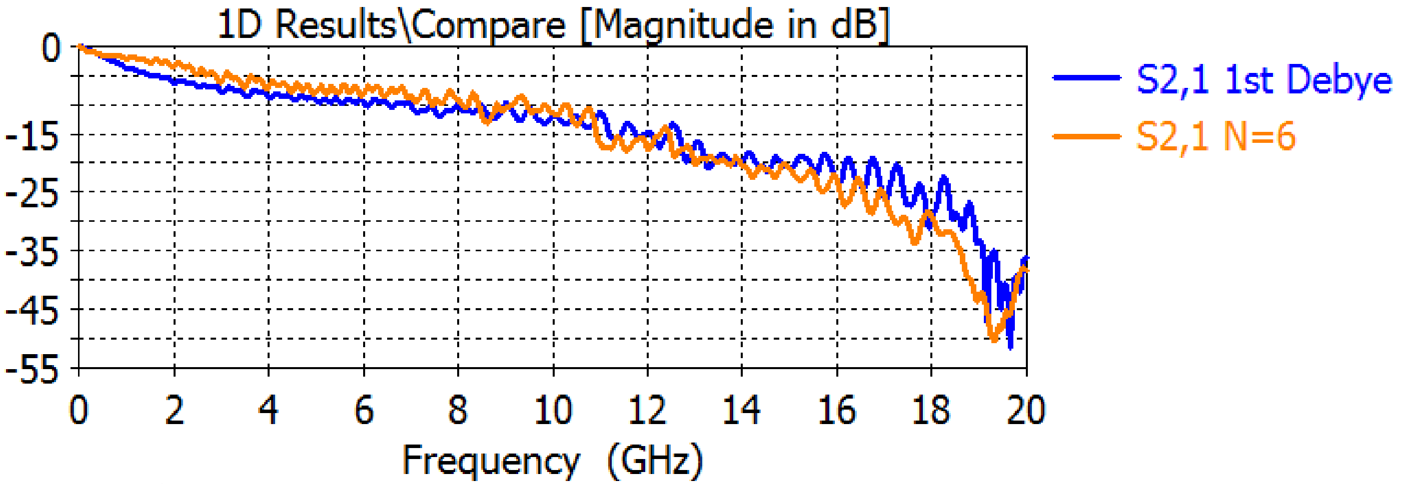


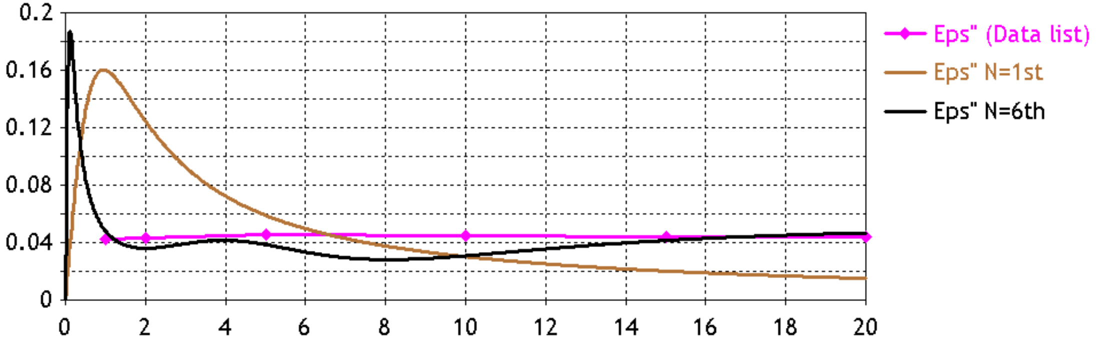
40mm long microstrip model

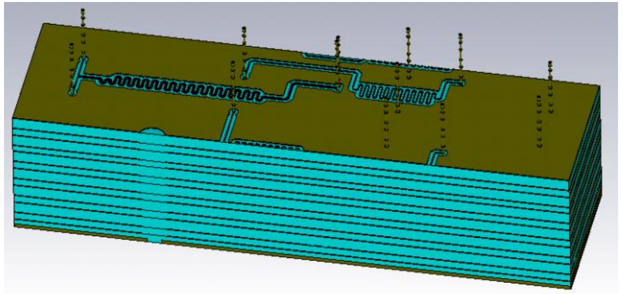
FR4 dielectric substrate –εr=4.3, tg δ=0.025



Dielectric Loss – Curve Fitting Nth Orders – S21 Results



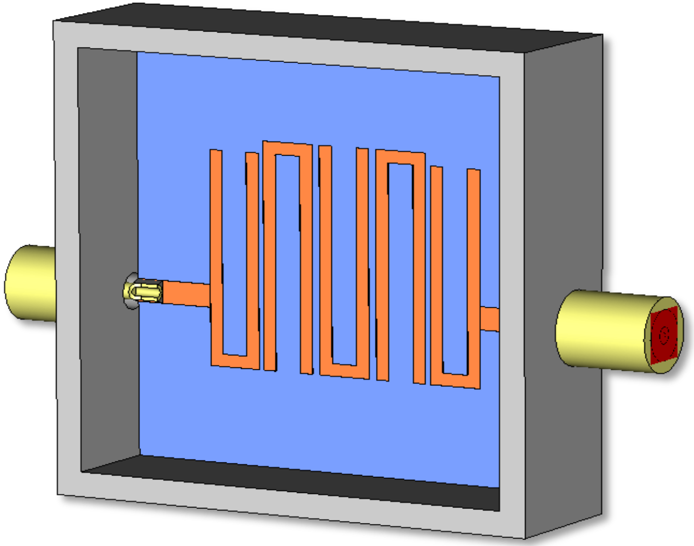


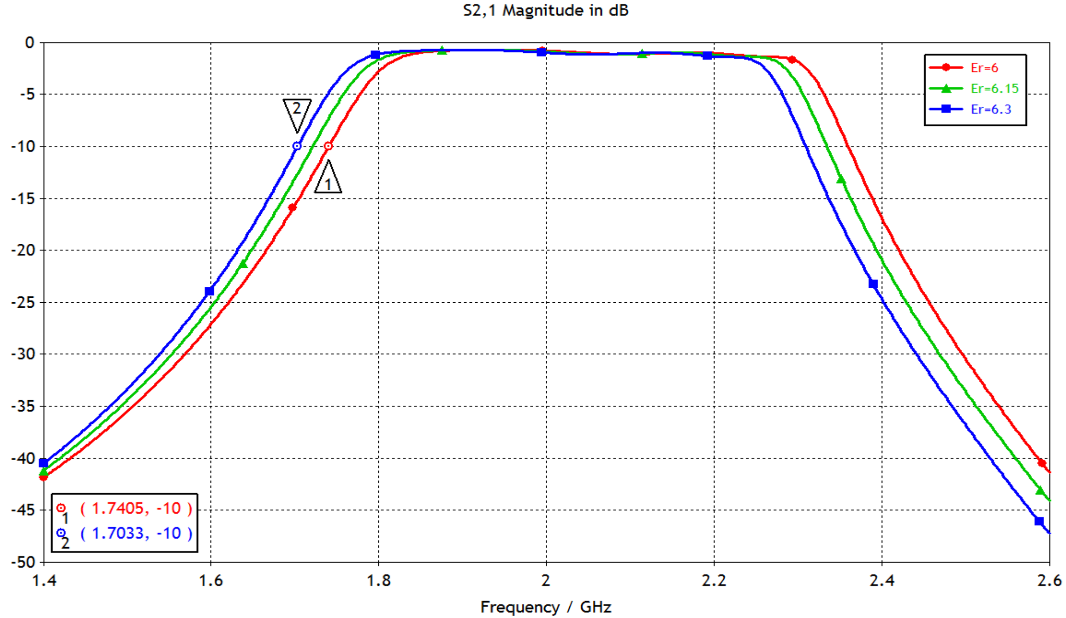


Dielectric material parameters extraction

Material Properties

Uncertainty in ε_r ...

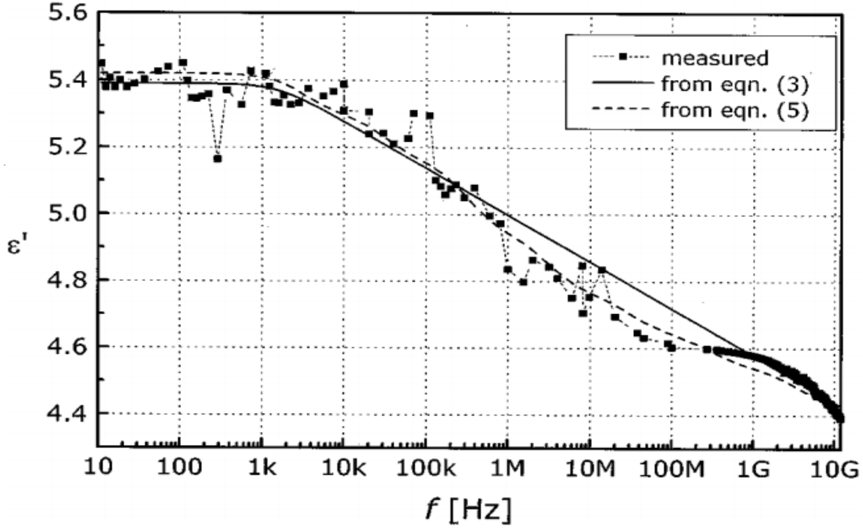


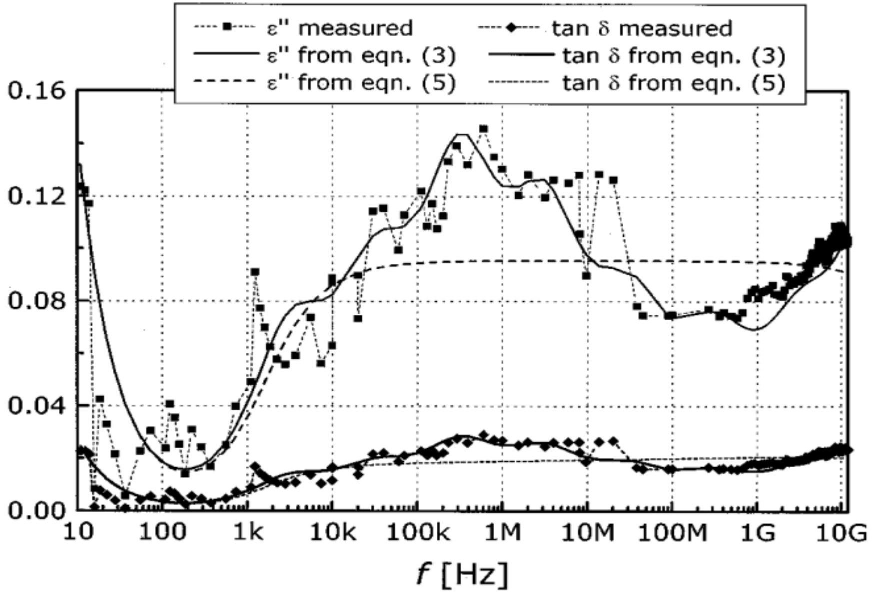


Material Properties

Uncertainty in dispersion of ε_r ...

“FR-4”?





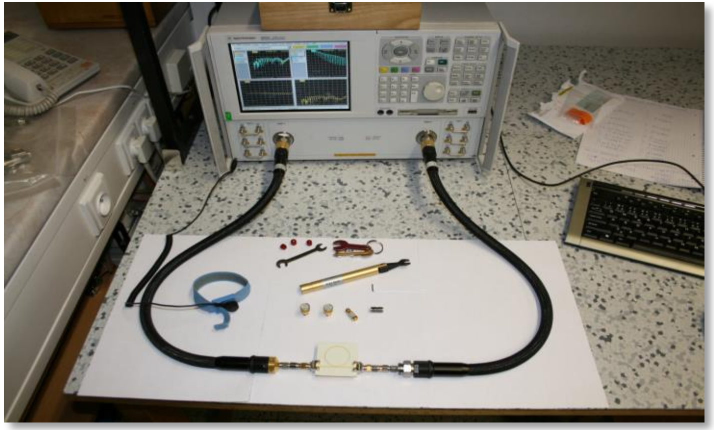
Djordjević, et al., IEEE T-EMC, Vol. 43, No. 4, pp. 662-667, Nov. 2001.

Where can I find properties?

- Datasheet
- Literature
- Measurement!

RO4000® Series High Frequency Circuit Materials

Property	Typical Value		Direction	Units	Condition	Test Method
	RO4003C	RO4350B				
Dielectric Constant, ε_r (Process specification)	3.38 ± 0.05	[1] 3.48 ± 0.05	Z	--	10 GHz/23°C	IPC-TM-650 2.5.5.5 [2]Clamped Stripline
[3] Dielectric Constant, ε_r (Recommended for use in circuit design)	3.55	3.66	Z	--	FSR/23°C	IPC-TM-650 2.5.5.6 Full Sheet Resonance
Dissipation Factor tan, δ	0.0027 0.0021	0.0037 0.0031	Z	--	10 GHz/23°C 2.5 GHz/23°C	IPC-TM-650 2.5.5.5



Wideband Frequency-Domain Characterization of FR-4 and Time-Domain Causality

Antonije R. Djordjević, Radivoje M. Biljić,
Vladana D. Likar-Smiljanić, and Tapan K. Sarkar

Abstract—FR-4 is one of the most widely used dielectric substrates in the fabrication of printed circuits for fast digital devices. This material exhibits substantial losses and the loss tangent is practically constant over a wide band of frequencies. This paper presents measured data for the complex permittivity of this material from power frequencies up to the microwave region. In addition it gives simple closed-form expressions that approximate the measured data and provide a causal response in the time domain.

Index Terms—Causality, dielectric losses, dielectric measurements, dispersive media.

Popular Techniques for dielectric materials extraction

Overview of various techniques

- Full Sheet Resonance (FSR) – only Eps', low freq. < 1 GHz
- Clamped Stripline Resonator – Eps' can be reported lower, moderate acc. for tgD
- Split Post Dielectric Resonator (SPDR) – sensitive to sample thickness, Eps'xy only
- "RA" resonator – Anisotropic permittivity, Eps' only, fixture freq. limit

- Cavity resonator – freq. limit, probe influence
- Ring resonator – only Eps'

focus of this presentation

- Modified ring resonator – probe influence on tgD
- Transmission line propagation constant – Eps' and tgD, probe influence eliminated, very wide frequency range, moderate accuracy for tgD at low freq.

Overview

- Full Sheet Resonance
- Clamped Stripline Resonator
- Split Post Dielectric Resonator
- “RA” resonator

- Cavity resonator
- Ring resonator

- Modified ring resonator
- Transmission Line (TL)

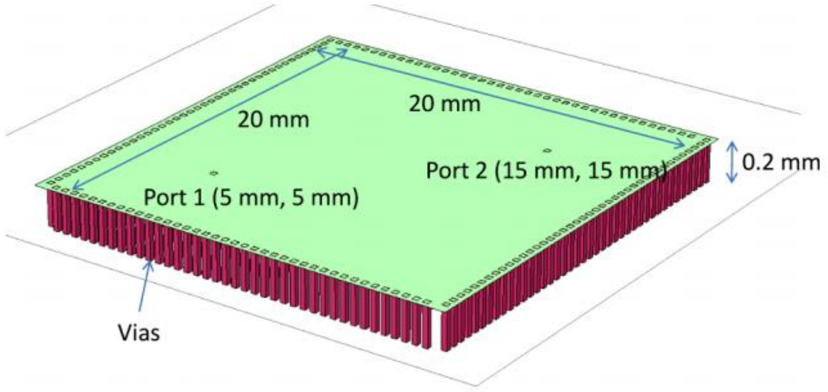
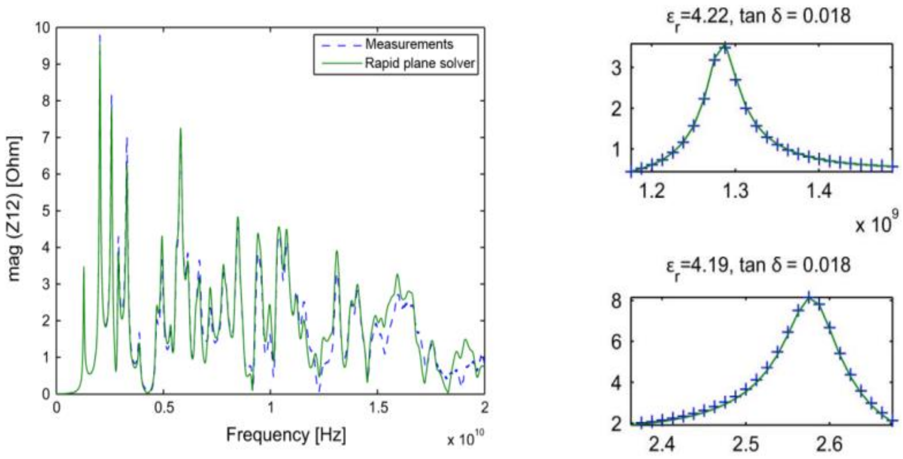


Fig. 5. Geometry of the shorted resonator simulated using Sonnet and the rapid plane solver.

A. Ege Engin, IEEE T-MTT, Vol. 58, No. 1, pp. 211-219, Jan. 2010.

Overview

- Full Sheet Resonance
- Clamped Stripline Resonator
- Split Post Dielectric Resonator
- “RA” resonator
- Cavity resonator
- Ring resonator
- Modified ring resonator
- Transmission Line (TL)



A. Ege Engin, IEEE T-MTT, Vol. 58, No. 1, pp. 211-219, Jan. 2010.

Overview

- Full Sheet Resonance
- Clamped Stripline Resonator
- Split Post Dielectric Resonator
- “RA” resonator

- Cavity resonator
- Ring resonator

- Modified ring resonator
- Transmission Line (TL)

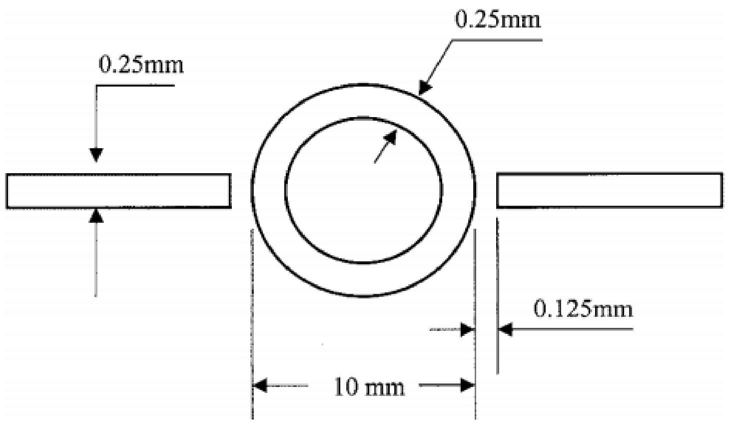


Figure 1 Ring resonator geometry

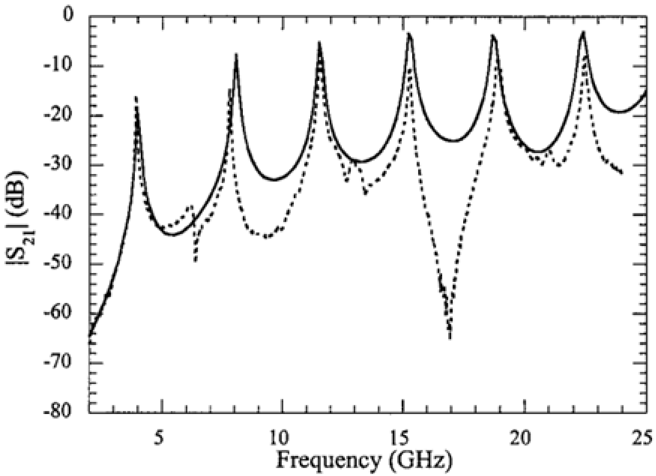
Semouchkina et al., MOT Lett., Vol. 29, No. 1, pp. 21-24, Apr. 2001.

Overview

- Full Sheet Resonance
- Clamped Stripline Resonator
- Split Post Dielectric Resonator
- "RA" resonator

- Cavity resonator
- Ring resonator

- Modified ring resonator
- Transmission Line (TL)



Semouchkina et al., MOT Lett., Vol. 29, No. 1, pp. 21-24, Apr. 2001.

Overview

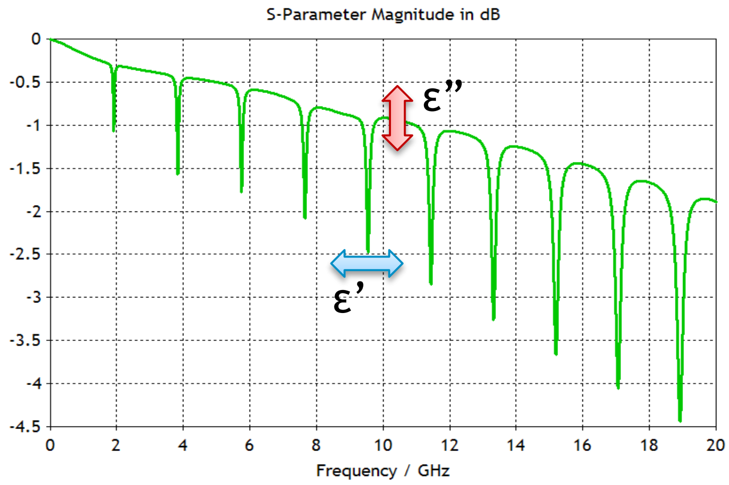
- Full Sheet Resonance
- Clamped Stripline Resonator
- Split Post Dielectric Resonator
- “RA” resonator

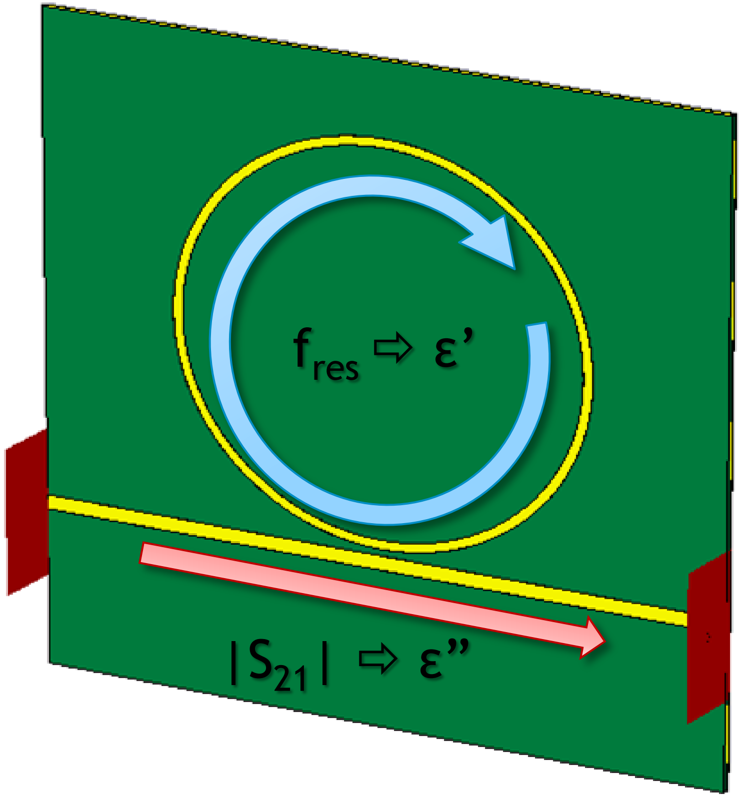
- Cavity resonator
- Ring resonator

- Modified ring resonator
- Transmission Line (TL)

Modified Ring Resonator

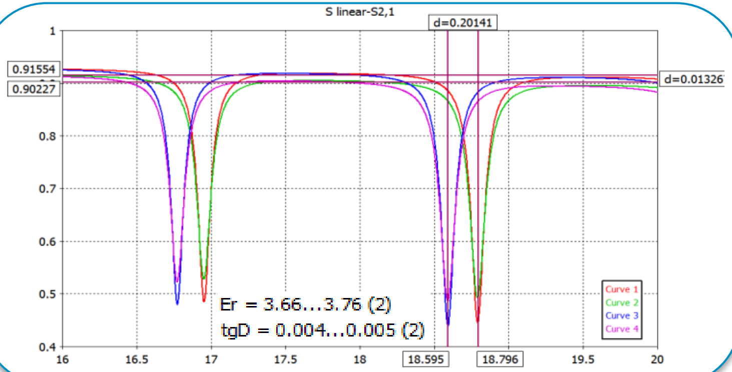
- Parallel coupling
  - $f_{res} \Rightarrow \varepsilon'$
  - $|S_{21}| \Rightarrow \varepsilon''$





Complex ε_r Extraction Algorithm

1. Parameter sweep of ε_r and tanδ



2. Sensitivity of freq. and S_{21}

$$sensf = \frac{\Delta f}{\Delta \varepsilon_r'}$$

$$sensS_{21} = \frac{\Delta |S_{21}|}{\Delta \varepsilon_r''}$$

3. "Correction" factor

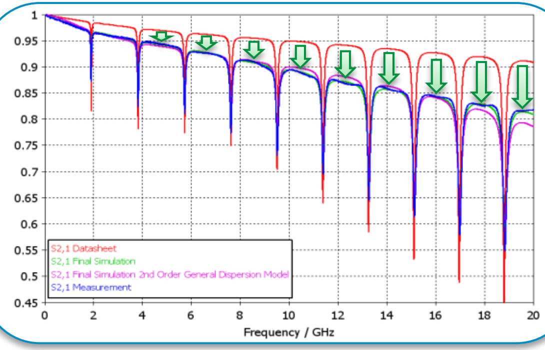
$$\Delta \varepsilon_r' = \frac{f_{sim} - f_{meas}}{sensf}$$

$$\Delta \varepsilon_r'' = \frac{|S_{21}|_{sim} - |S_{21}|_{meas}}{sensS_{21}}$$

NO

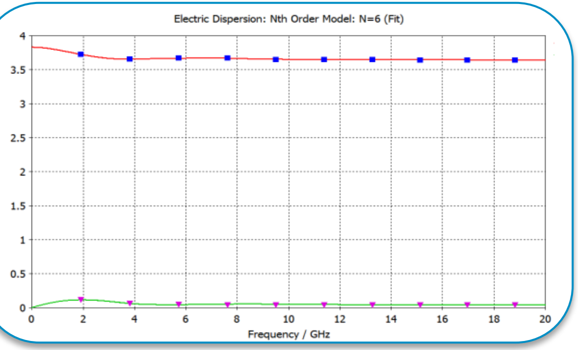
Freq. [GHz]	Eps'	Eps"
1.912788	3.72363	1.1403284e-1
3.8264725	3.6559328e+000	5.7550857e-002
5.7341705	3.6706356e+000	4.3679197e-002
7.6298955	3.6711876e+000	4.0248729e-002
9.515643	3.6489617e+000	3.8845006e-002
11.393409	3.6482667e+000	3.7751987e-002
13.263192	3.6448654e+000	3.7079645e-002
15.122998	3.6408623e+000	3.5987710e-002
16.972827	3.6387886e+000	3.7337948e-002
18.814673	3.6362939e+000	3.8063682e-002

4. Define materials



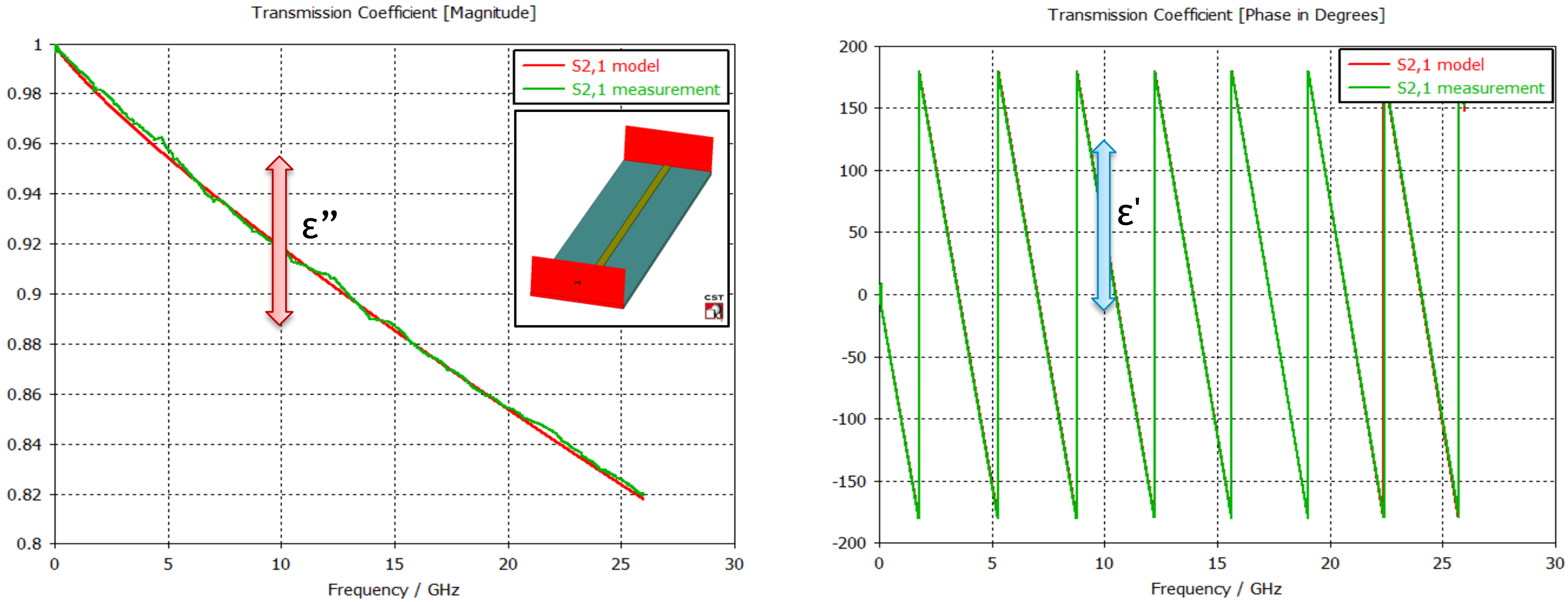
5. Simulation = Measurement?

YES



6. Dielectric properties

TL Propagation Constant Technique

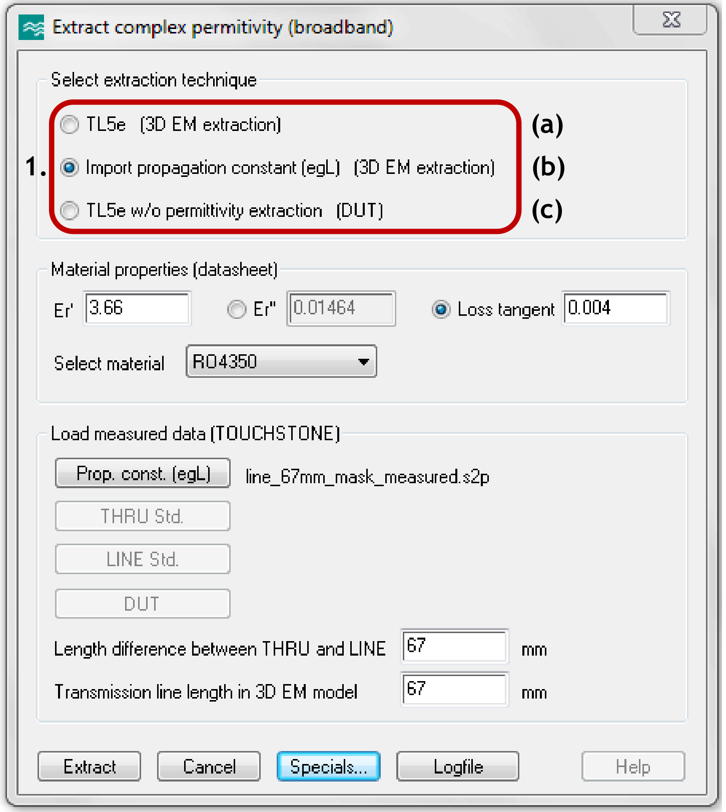


The measured S_{21} of homogeneous transmission line section is used for an extraction of substrate complex permittivity. Please note that transmission coefficient S_{21} is equal to exp(-*ΓL*) or “egL”, where Gamma is the propagation constant and L is the length of TL.

Automated Material Extraction Macro

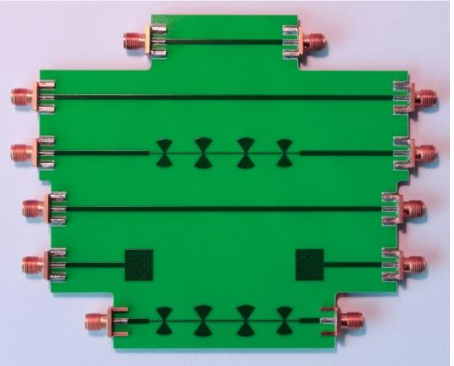
Automatic Extraction Macro

CST STUDIO SUITE®
New Feature 2015



1(a) Extracts complex permittivity from measurement of two lines* (Thru, Line) using 3D EM line model.

1(b) Extracts complex permittivity from directly measured S-parameters of a section of homogeneous transmission line (transmission coefficient egL) stored in Touchstone file using 3D EM line model. Multiline calkit and NIST Multiline TRL calibration technique is usually used for this option.

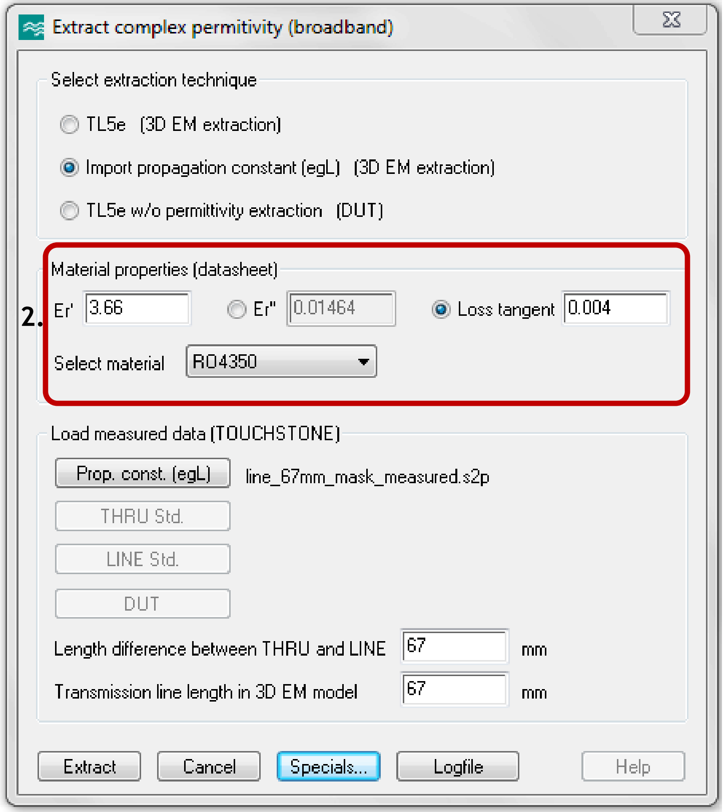


1(c) Extracts DUT S-parameters using just Thru and Line calibration standards*.

* 1st tier calibration at coaxial line is required.

Automatic Extraction Macro

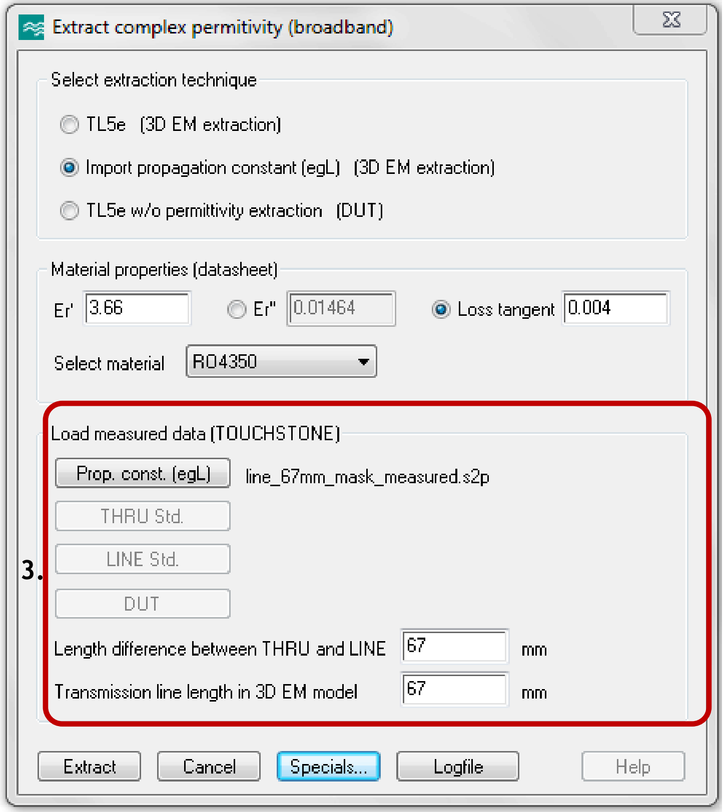
CST STUDIO SUITE®
New Feature 2015



2. Initial guess of the dielectric constant Er' and loss tangent tgD. Datasheet data are usually used.
Material to be used for the extraction in 3D EM model is selected in the drop list.

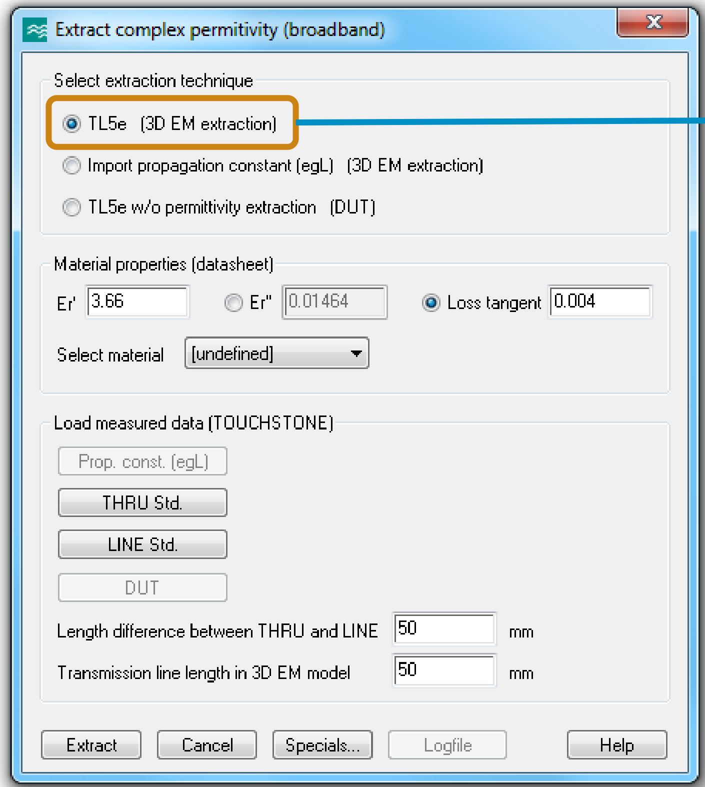
Automatic Extraction Macro

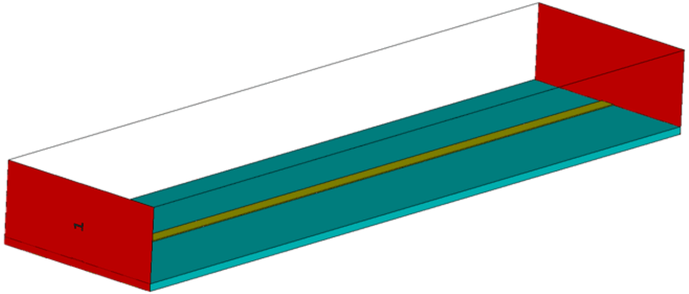
CST STUDIO SUITE®
New Feature 2015

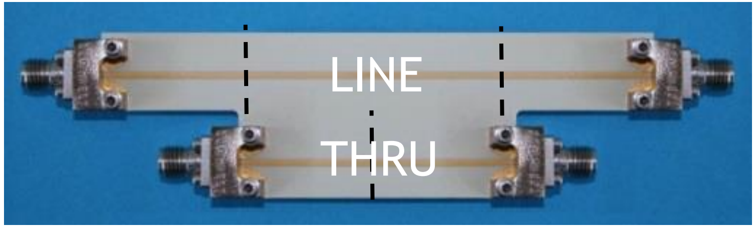


3. Measured S-parameters are loaded here as Touchstone files.
Transmission line length in 3D EM model can be reduced in case the length of the measured sample is too long. Then the measured transmission coefficient is scaled down to fit the length of the 3D EM model.

Two Transmission Line

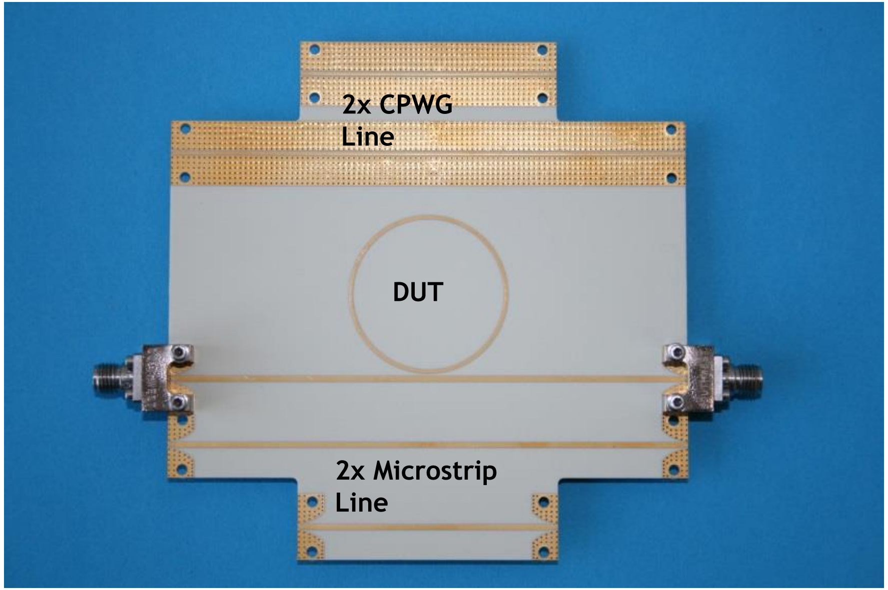


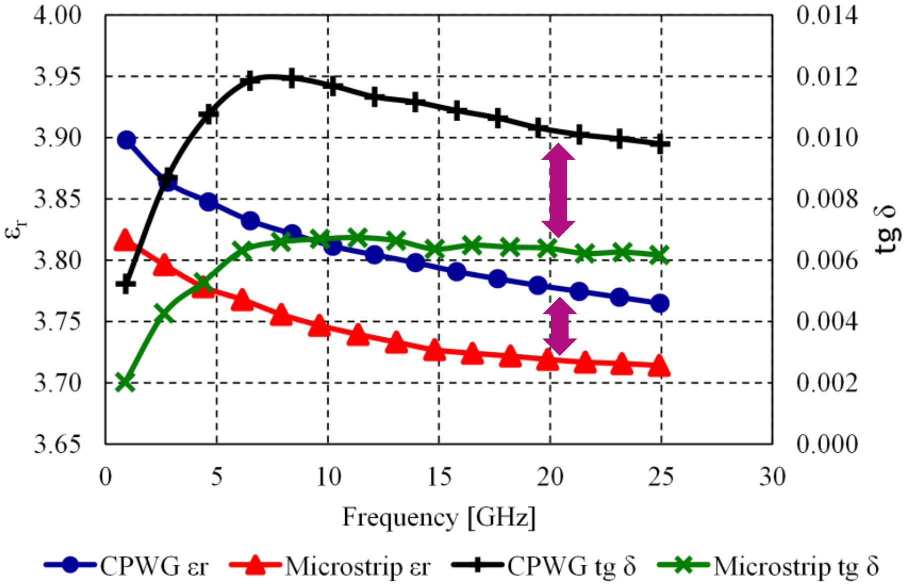




V. Sokol, J. Eichler, M.Rütschlin, 83rd ARFTG, 2014.

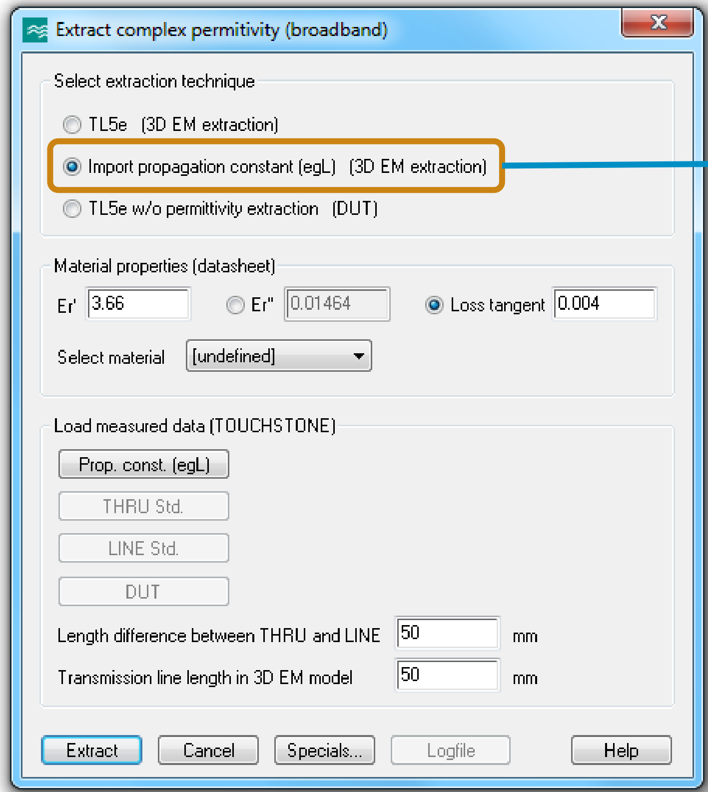
Two Transmission Line

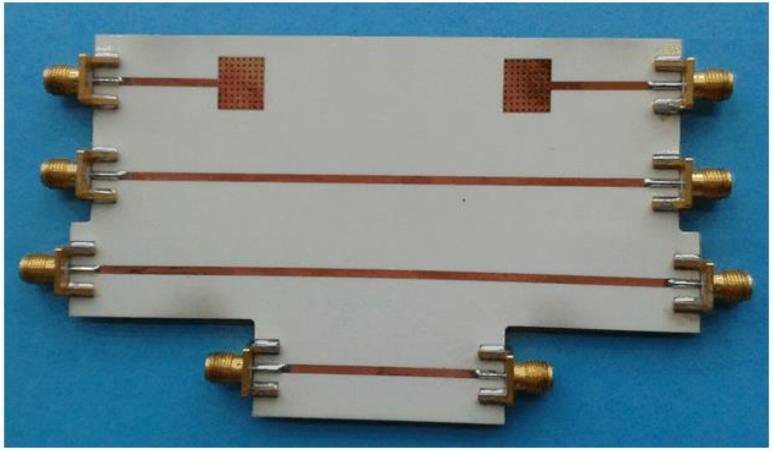




V. Sokol, J. Eichler, M.Rütschlin, 83rd ARFTG, 2014.

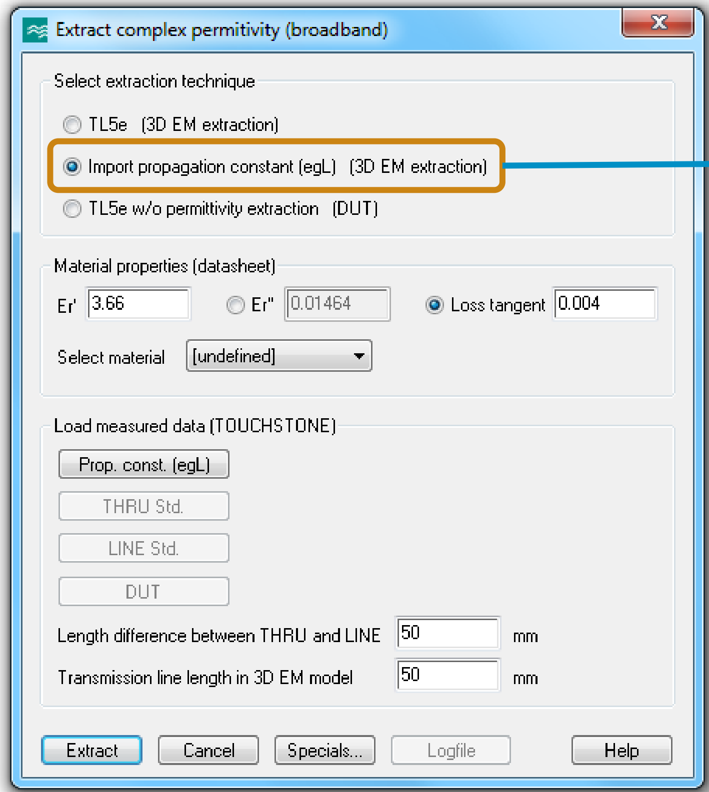
NIST Multiline TRL

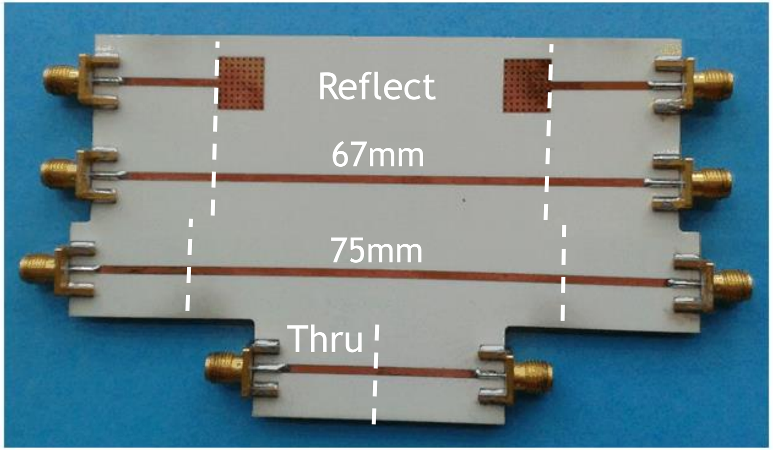




Marks, Roger B., "A multiline method of network analyzer calibration," *Microwave Theory and Techniques, IEEE Transactions on*, vol.39, no.7, pp.1205,1215, Jul 1991

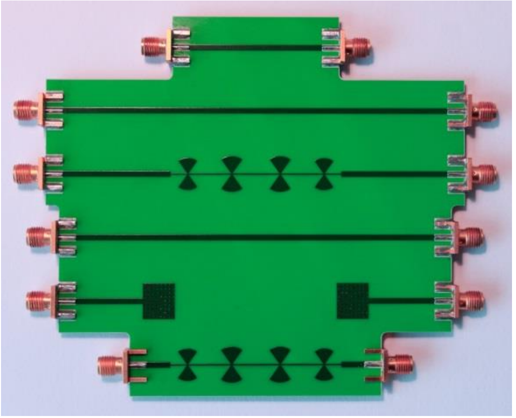
NIST Multiline TRL



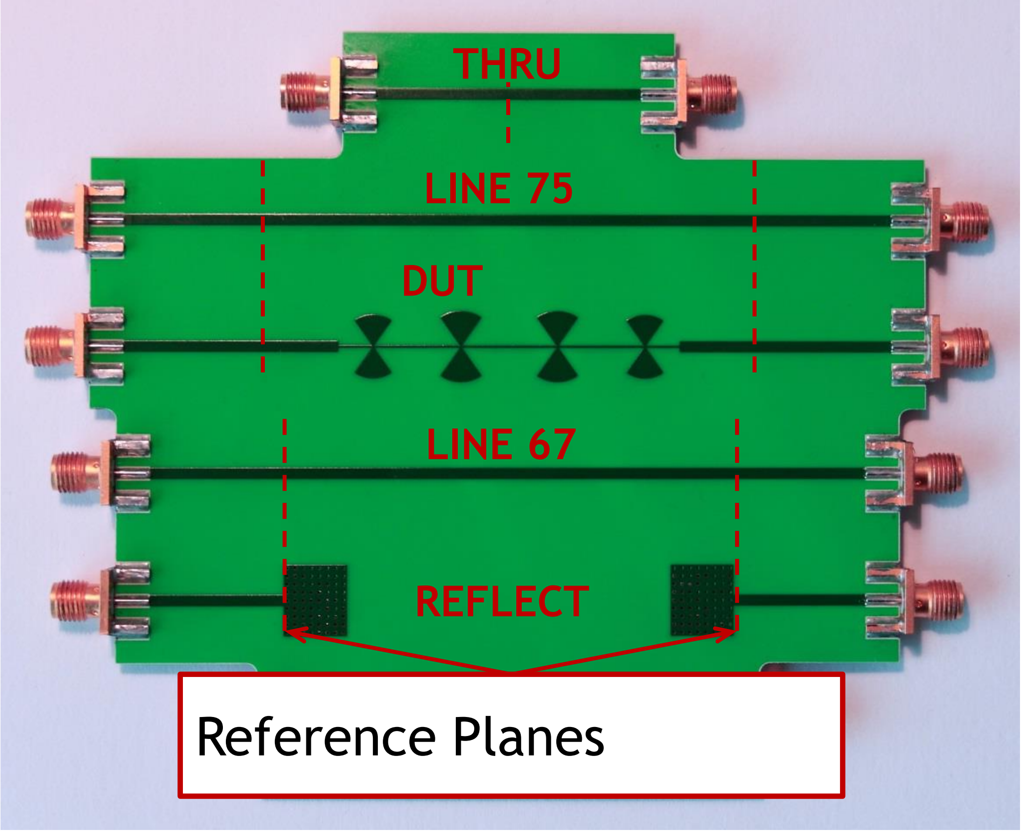


$$\tau = \frac{l}{c / \sqrt{\varepsilon_{ef}}}$$

Multiline TRL examples



Multiline TRL - Microstrip



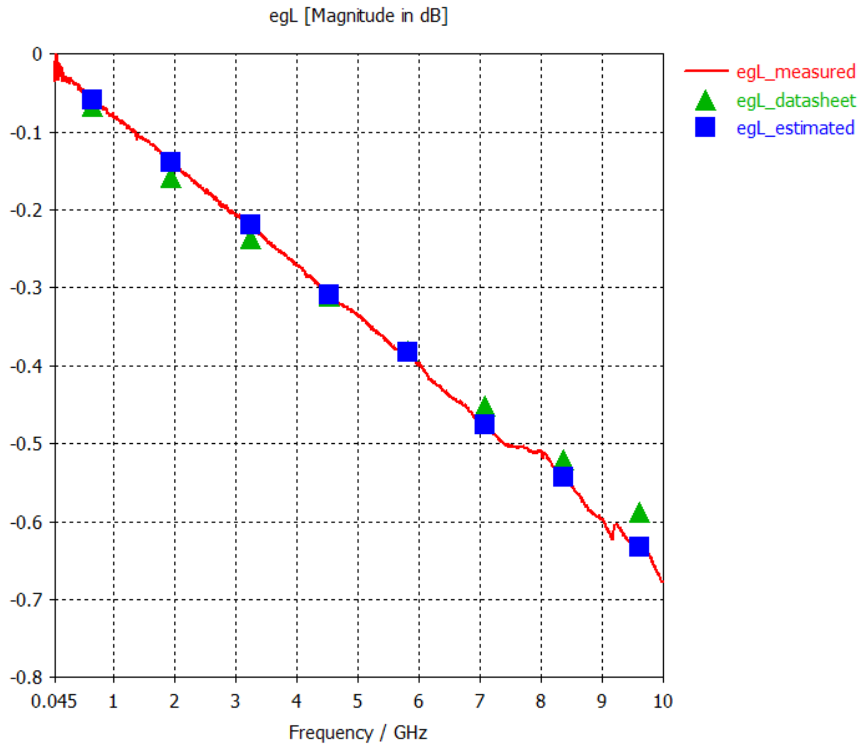
Time-delay calculation for LINE standards (67 and 75 mm):

$$\tau = \frac{l}{c/\sqrt{\varepsilon_{ef}}}$$

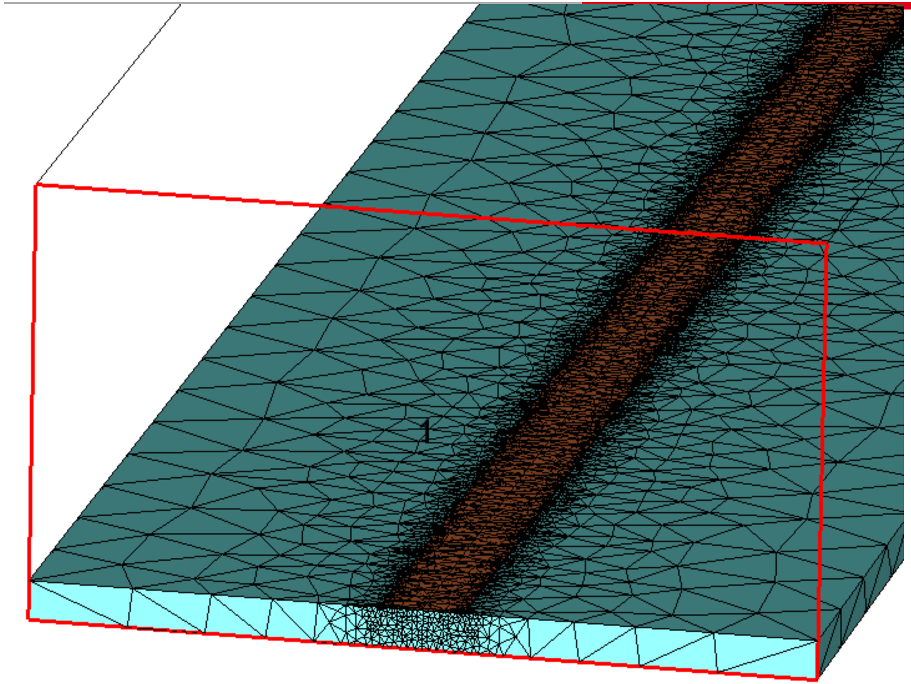
$$\tau_1 = \frac{0.067}{c/\sqrt{2.9}} = 381 \text{ ps}$$

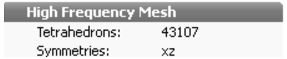
$$\tau_2 = \frac{0.075}{c/\sqrt{2.9}} = 427 \text{ ps}$$

Multiline TRL - Microstrip



Line 67 mm S21 (egL) is used for the extraction here.

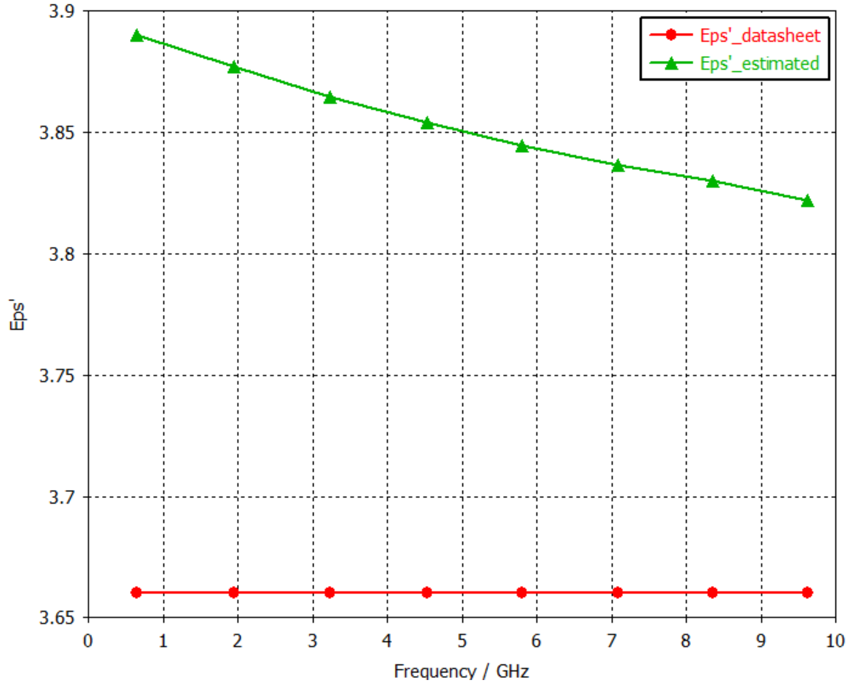




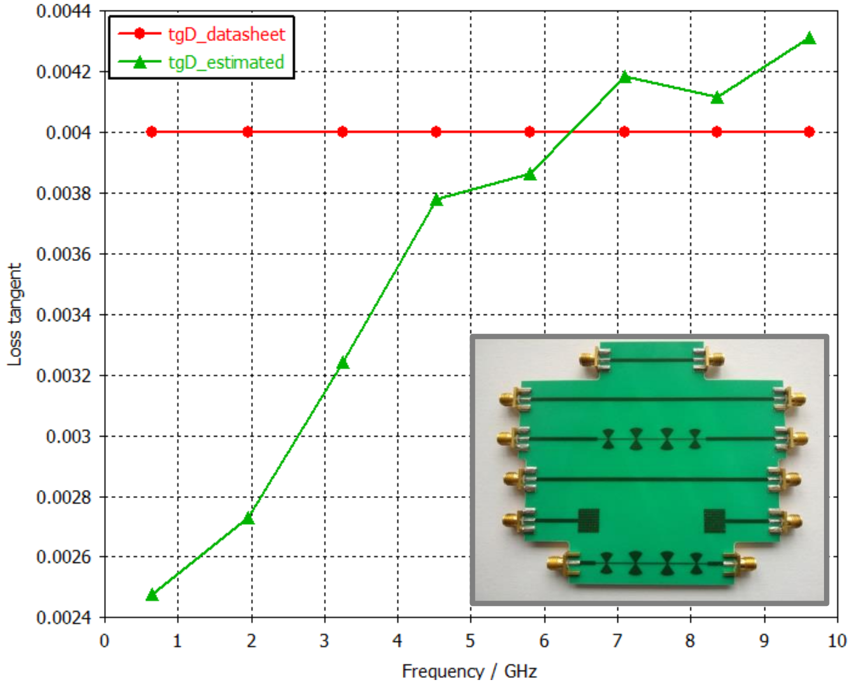
Max. phase deviation: 2.87529624441959e-1 deg
Max. magnitude deviation: 9.77502528792806e-5 (linear)
Extraction finished after 3 iterations in 8 min 55 s

Multiline TRL - Microstrip

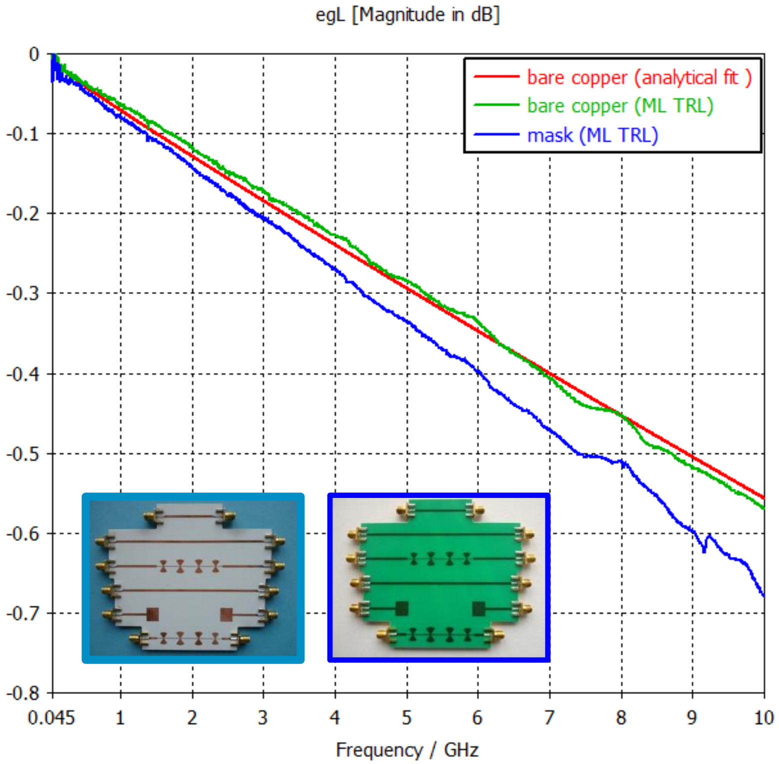
Eps’

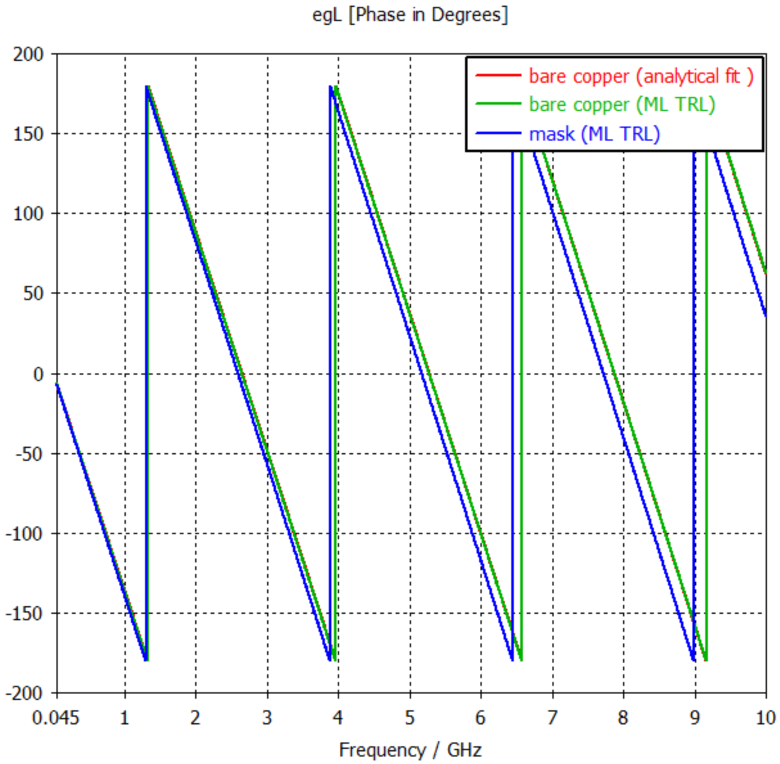


tgD

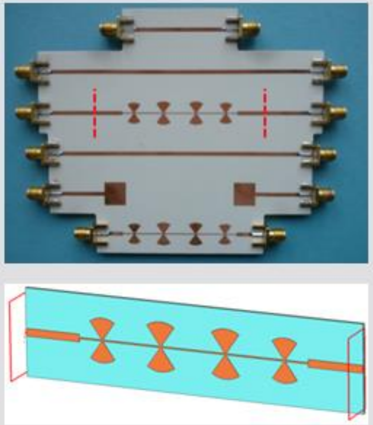
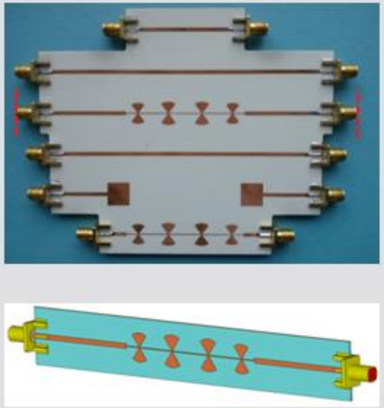
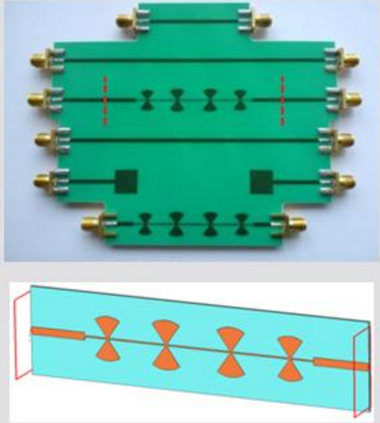
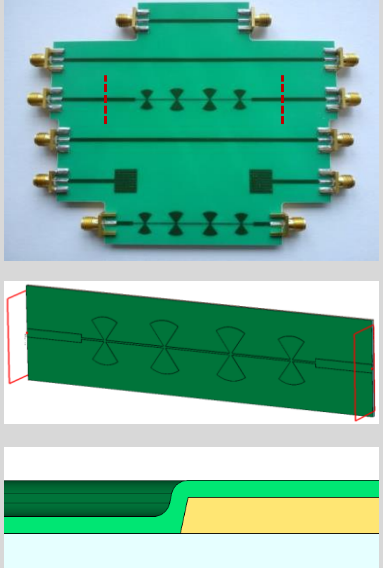


Bare Copper versus Solder Mask





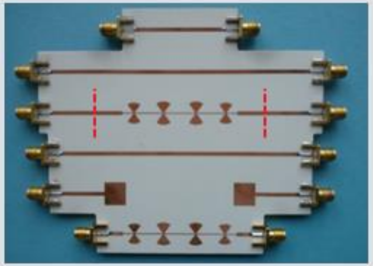
Low-Pass Filter

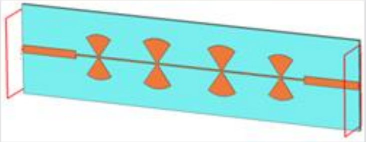
Bare copper PCB ref. planes	Bare copper SMA ref. planes	Solder mask (integrated) PCB ref. planes	Solder mask (extra layer) PCB ref. planes
			

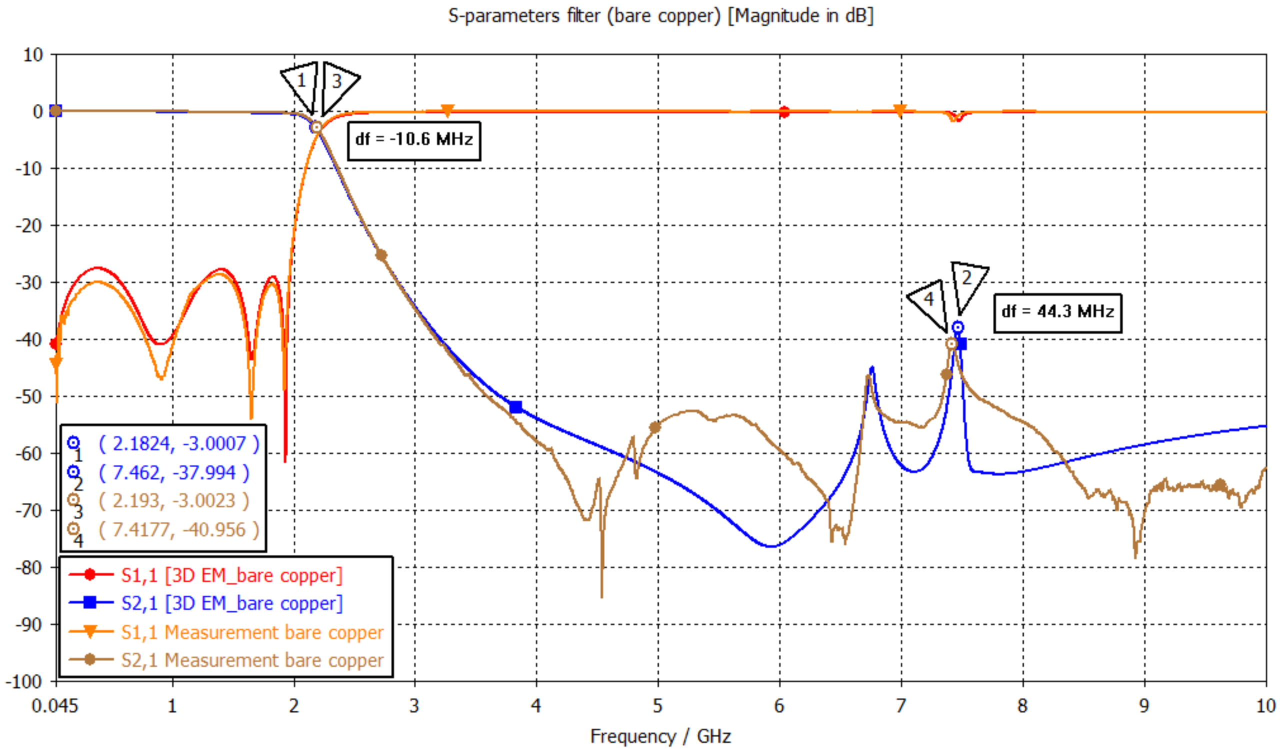
Low-Pass Filter (Bare Copper)

Bare copper

PCB ref. planes



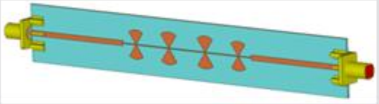


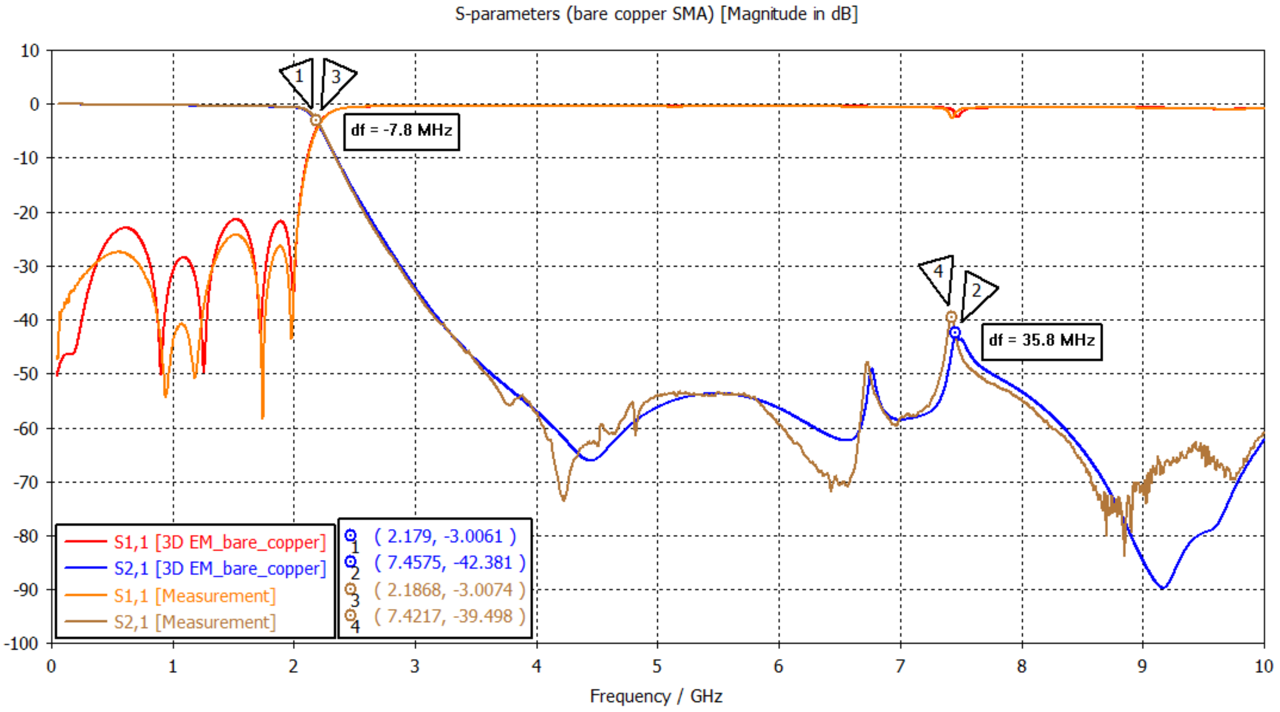


Low-Pass Filter (Bare Copper at SMA)

Bare copper

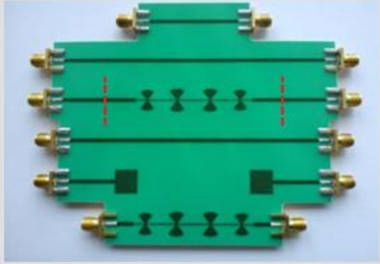
SMA ref. planes

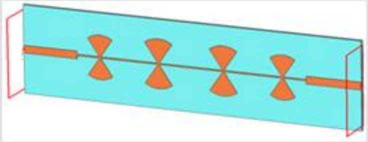


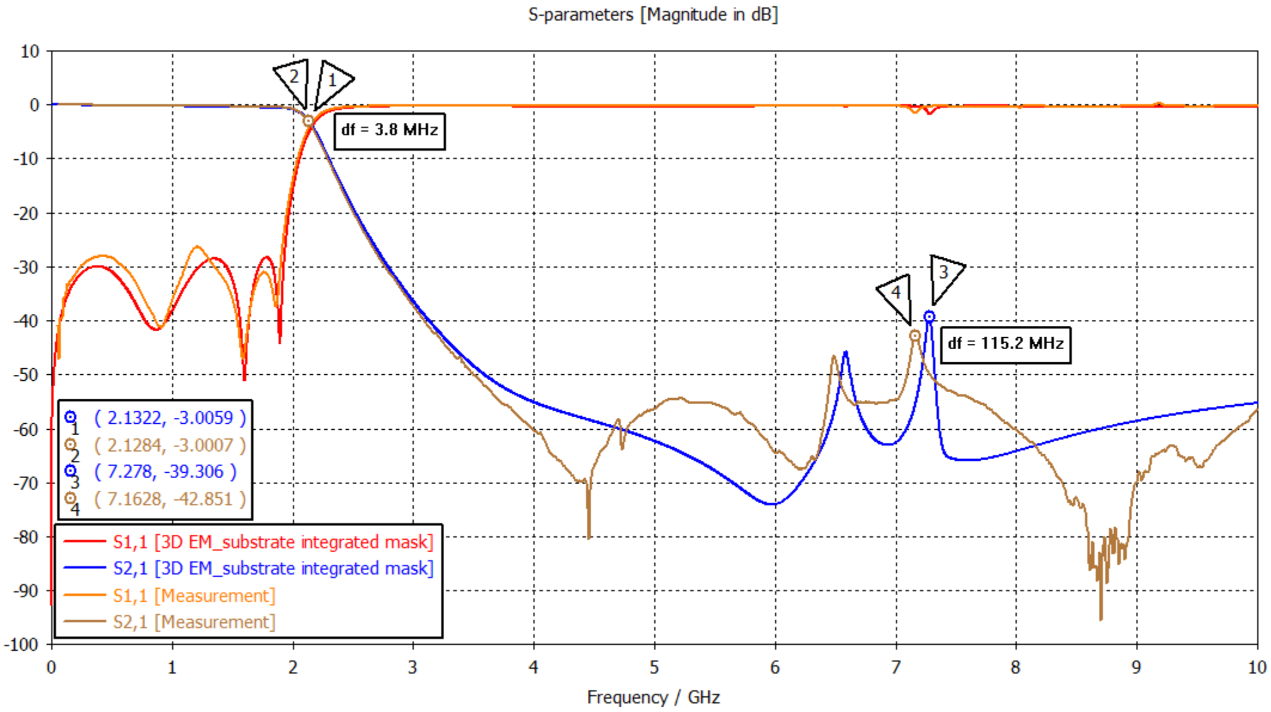


Low-Pass Filter (Integrated Mask)

Solder mask (integrated)
PCB ref. planes

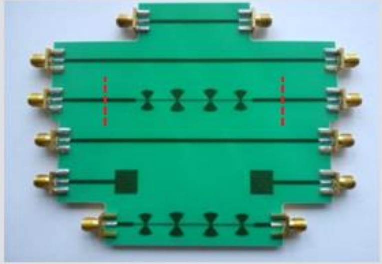


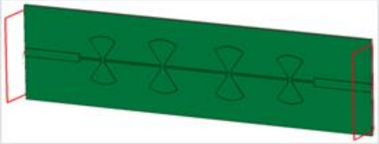


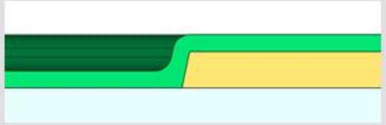


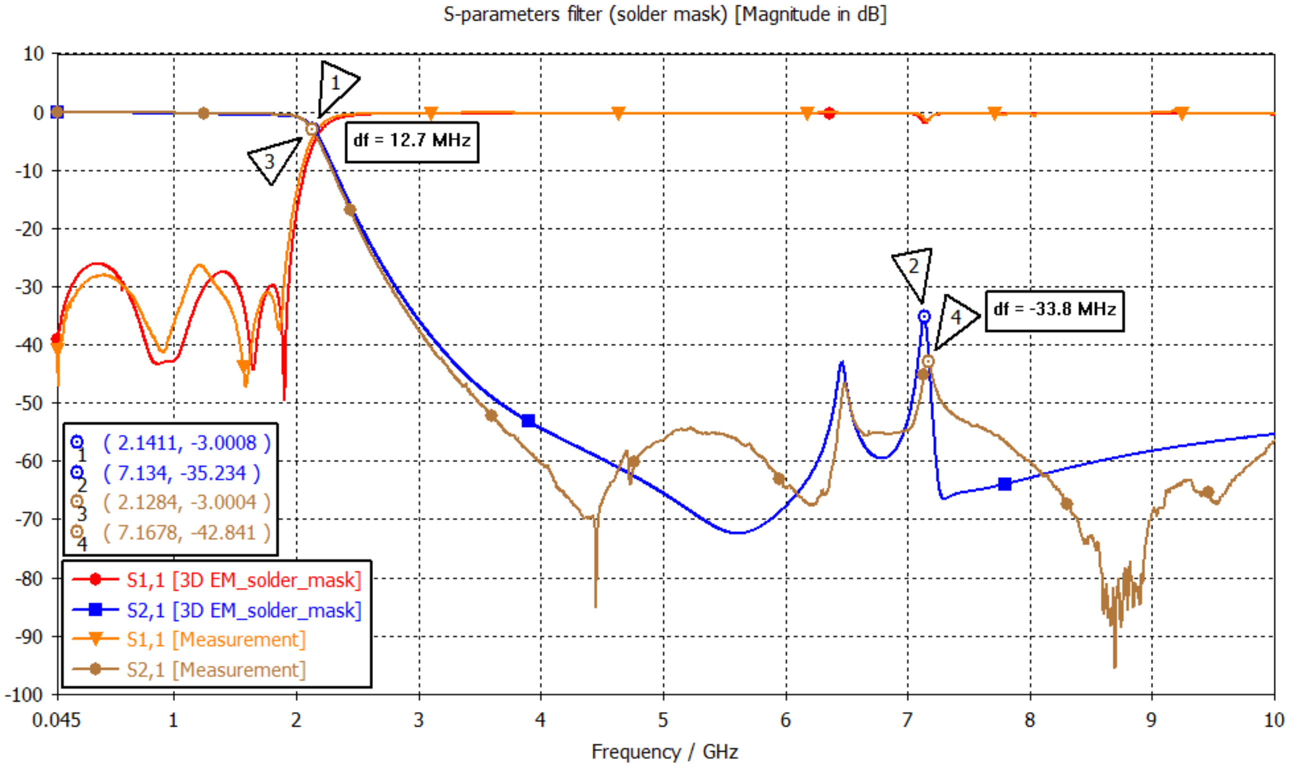
Low-Pass Filter (Mask As Extra Layer)

Solder mask
(extra layer)
PCB ref. planes

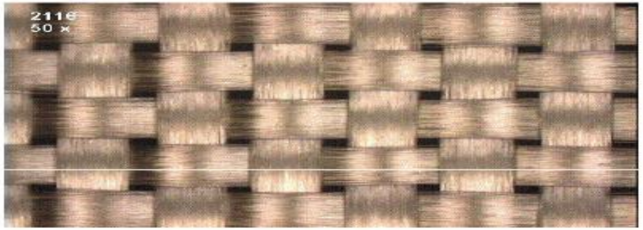


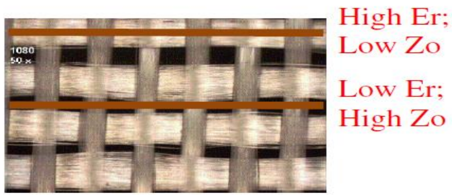


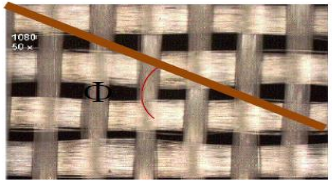




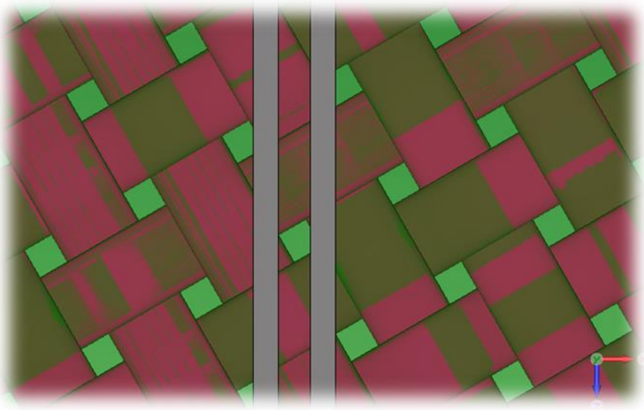
Composite Materials – Glass Weave







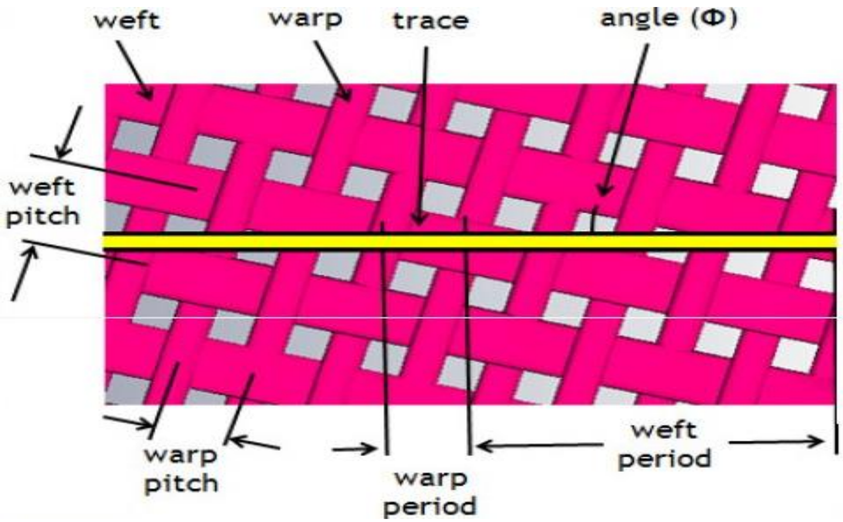
Effects originate from the inhomogeneous properties of PCB laminates



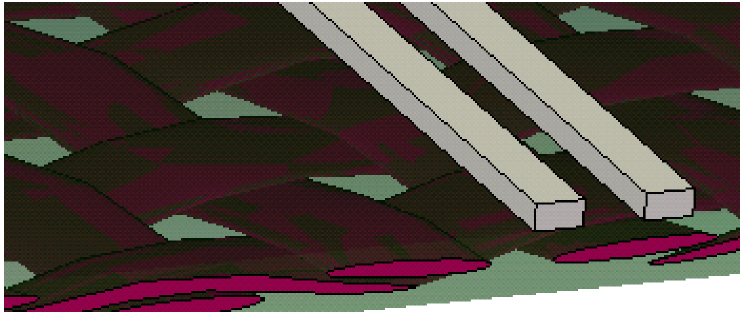
The location of trace versus fiber weave influences impedance,dielectric parameters, and can cause resonance.

Reference: G. Romo, M Schauer, et Al, "Stack-up and routing optimization by understanding micro-scale PCB Effects", presented at DesignCon 2011

Glass Weave



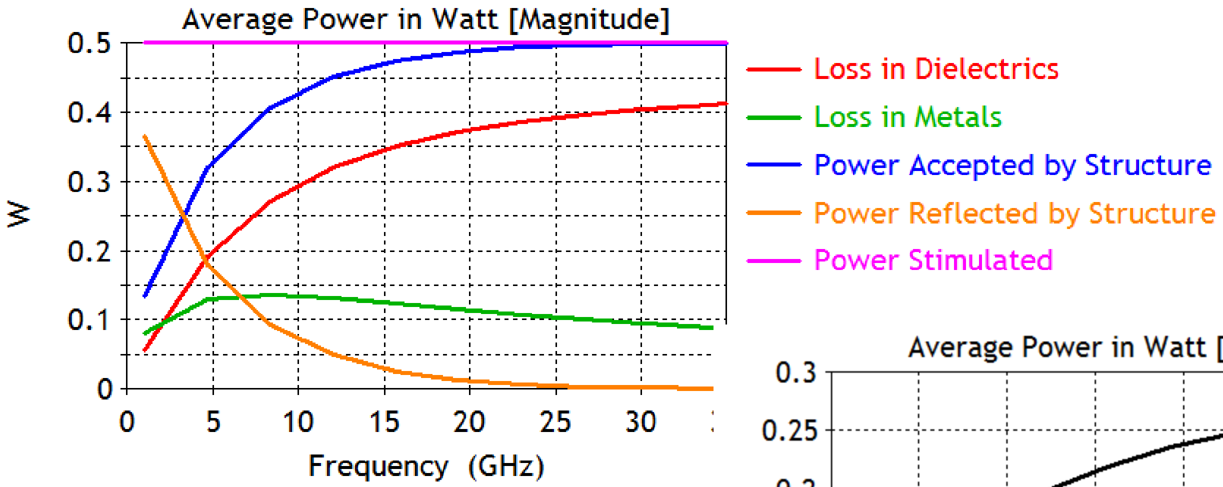
$$weftperiod = \sqrt{pitch^2\left(\frac{1}{[\tan\phi]^2}+1\right)}$$

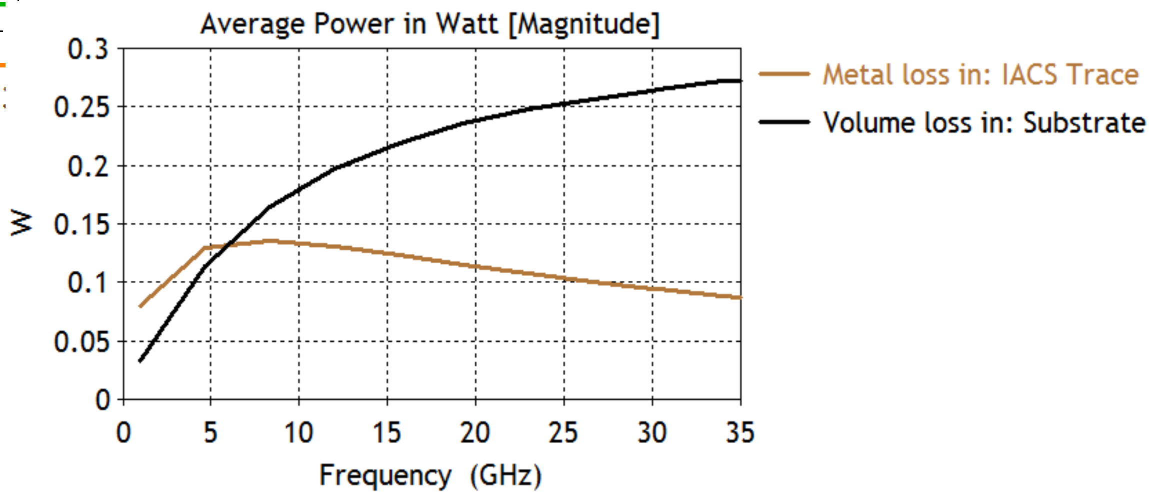


- Spatial period for sparse weave will impact effective permittivity and trace impedance
- Challenge to find spatial period; period depends on routing angle
- The Weft and Warp loading may have resonance effects

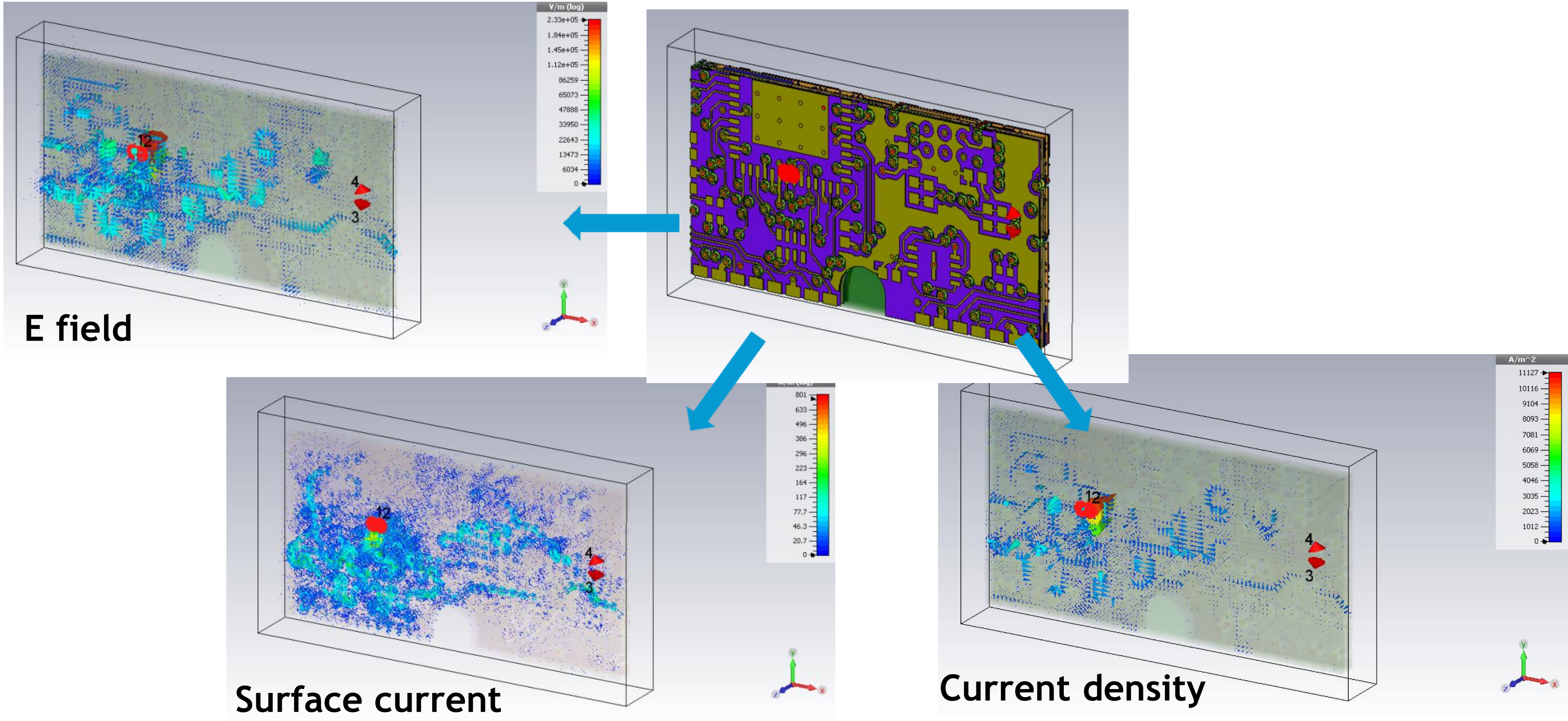
Extract parameters from detailed model

Where Does the Power go? Separating the Components

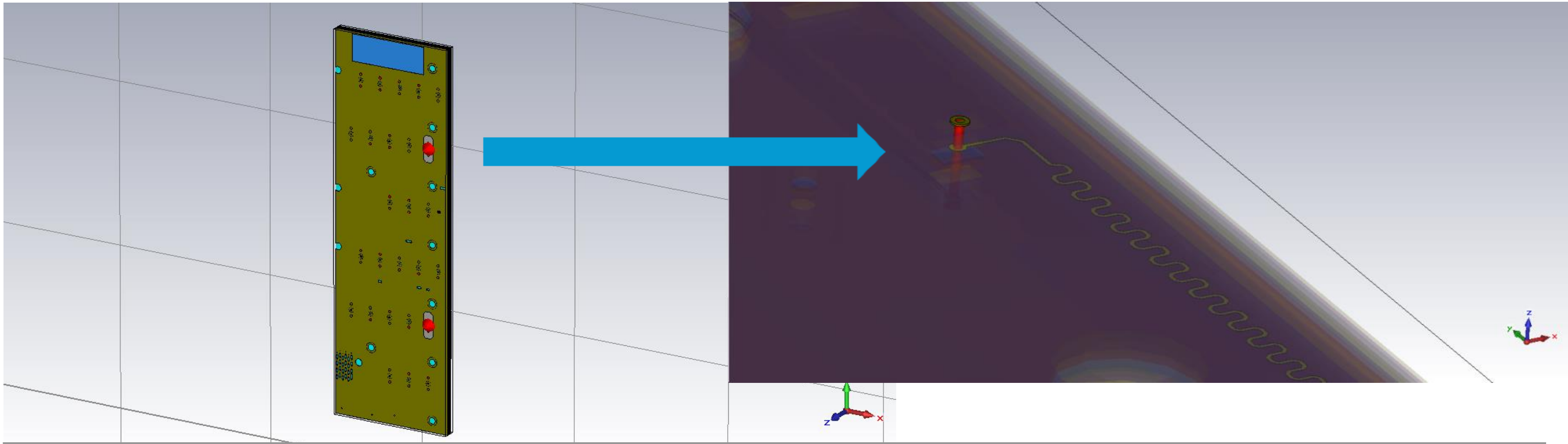




Where Does the Power go? Monitoring the Fields

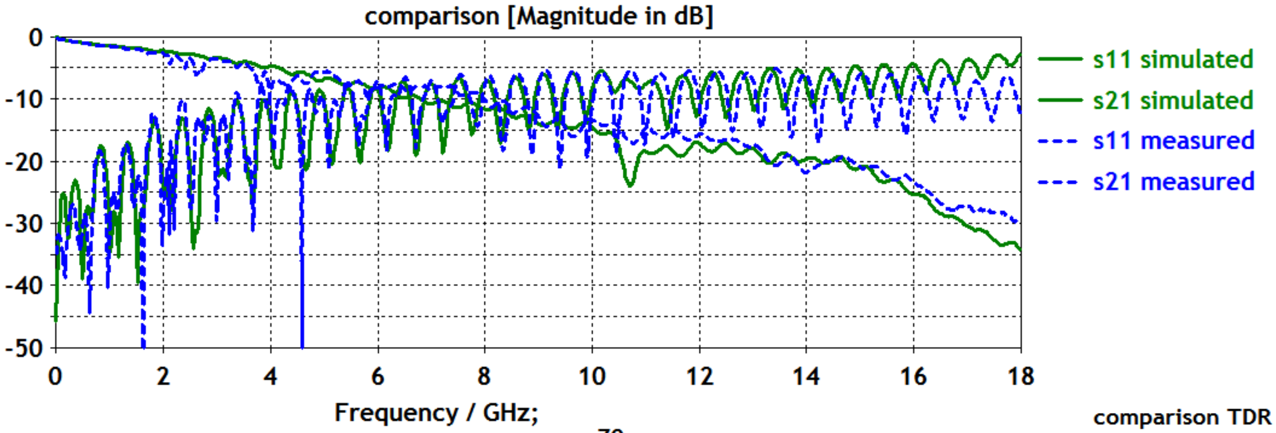


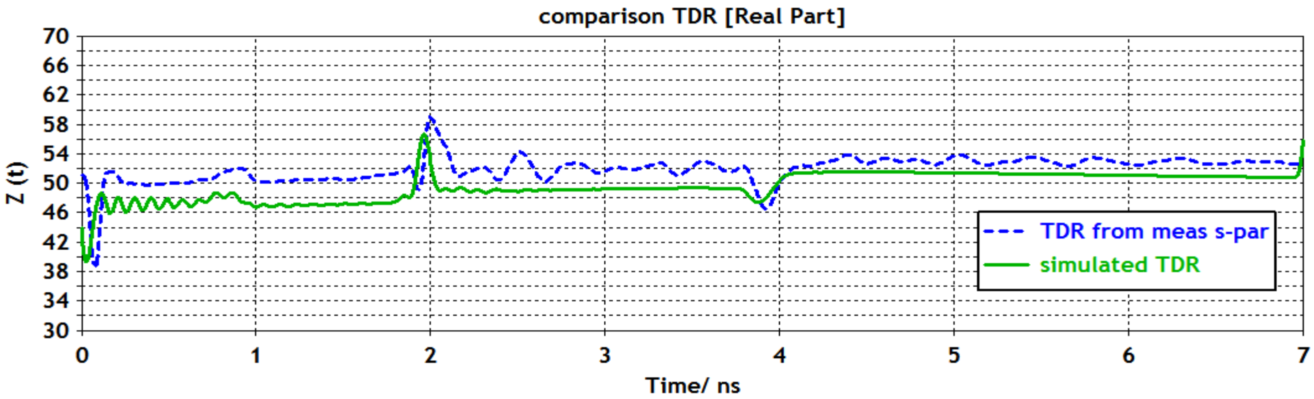
Real Case Example



Materials properties
Dielectric: eps=3.6, tgd=0.01 Debye 3rd order
Copper = 4.1e7 S/m with inclusion of surface roughness with TSI (H&J model)

S-Parameter and TDR Results





Discussion

Conductor loss characterization

…before going directly to surface roughness:

- Accurate conductivity? Rare that metal trace is from pure element.
- Edge consideration? Weave influence?
- Other process changing the material characteristics?
- Try to include surface roughness.

Dielectric material characterization

- Accurate “Nth order” curve fit for T solver simulations.
- Measure/characterize yourself?

Conclusion

- Conductor and dielectric loss components significant and require careful parameterization for simulation. If you want accurate results.
- Simulation can help separate loss components and help the characterization process.
- Several strategies are available for the simulation of surface roughness. TSI good in some cases. Other strategies being developed.
- Knowledge really is power. Know your materials.
- Microscopic effects: surface roughness, nickel, glass weave etc, can be extracted from detailed models and parameterized for larger/faster models.

Thank you for your attention

Questions?