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FRIEDRICH-ALEXANDER
UNIVERSITÄT
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Generation of Porous and Rough Surfaces for Electromagnetic Analysis

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Making Bits Fly

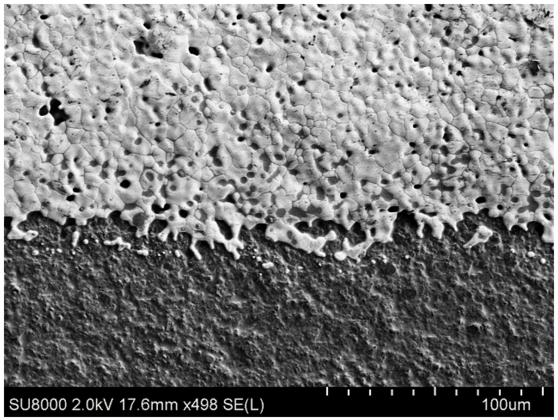
euc 2014

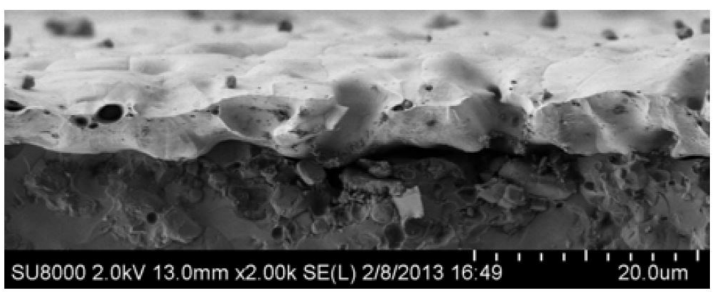
Outline

- Motivation
- Rebuilding Measured Surfaces
- Generation of Random Structures
- Basic Conditions for subsequent Simulation
- Fringed Microstrip Lines on porous LTCC
  - Measurement
  - Model
- Simulation Results
- Outlook & Conclusion

Motivation

Cofired Gold Conductor



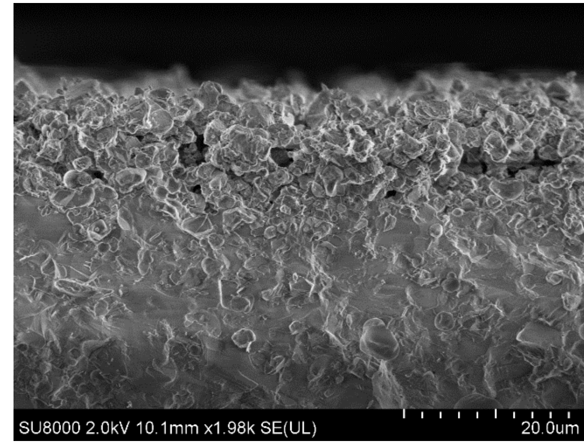


Substrate &

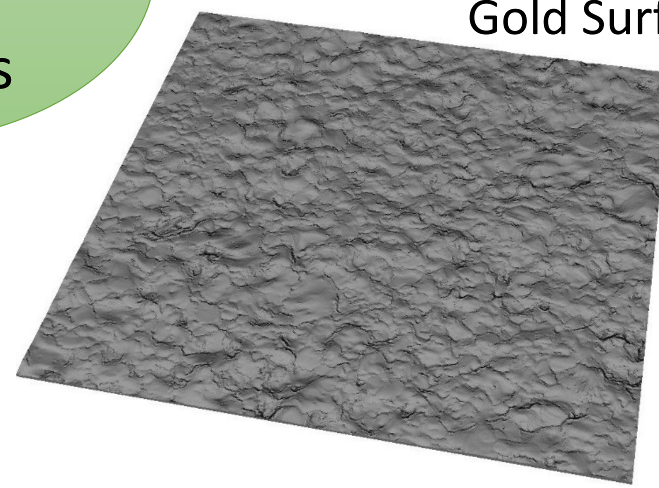
Metallization

Structures

Porosified
Substrate



Gold Surface



Identify influences on high-frequency characteristics

Rebuilding Measured Surfaces

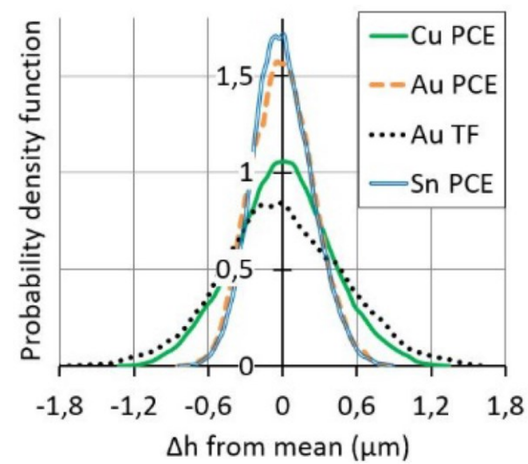
Evaluation and meshing of pointwise surface data for CST

1) Measured data (CSV-type):

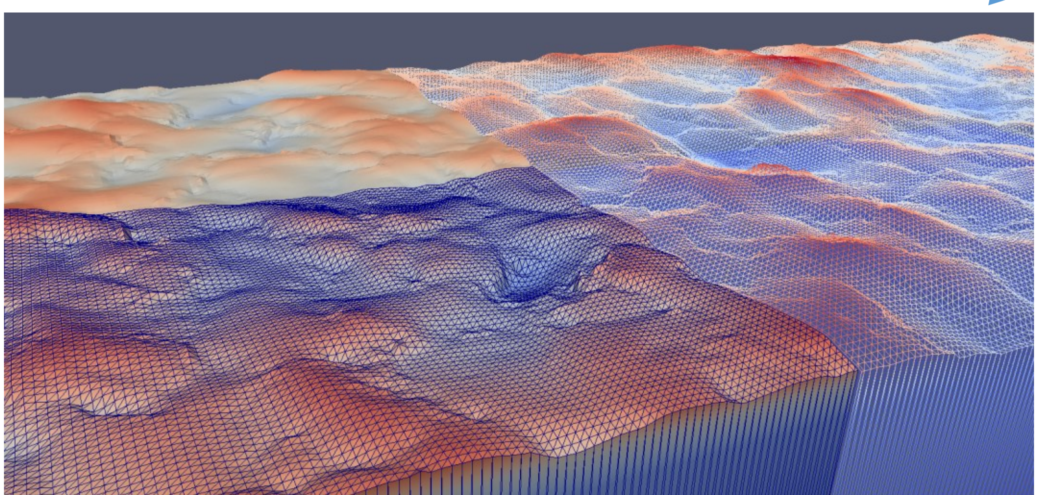
```
62.067, 62.069, 62.070, 62.072, 62.074, 62.076
62.079, 62.082, 62.085, 62.088, 62.092, 62.094
62.097, 62.100, 62.104, 62.107, 62.111, 62.114
62.118, 62.121, 62.124, 62.133, 62.143, 62.152
62.161, 62.170, 62.178, 62.186, 62.193, 62.200
62.207, 62.216, 62.224, 62.232, 62.240, 62.246
```

2) Extract roughness parameters:
(by a python script)

Measured Roughness Parameters after [2]	Sn PCE	Au PCE	Cu PCE	Au TF
Root mean squared R_q (µm)	0.24	0.25	0.39	0.50
Skewness R_{sk}	0.20	0.14	0.03	0.06
Kurtosis R_{ku}	-0.02	-0.14	-0.07	0.07
Profile length ratio L_r	1.022	1.005	1.025	1.026
Max. profile height R_t (µm)	1.76	1.80	2.72	3.50
RMS avgerage wavelength λ_q (µm)	7.3	16.4	11.5	13.9



3) Conversion to a surface (STL):



Generation of Random Structures

Modeling porosified structures by a time-dependent PDE

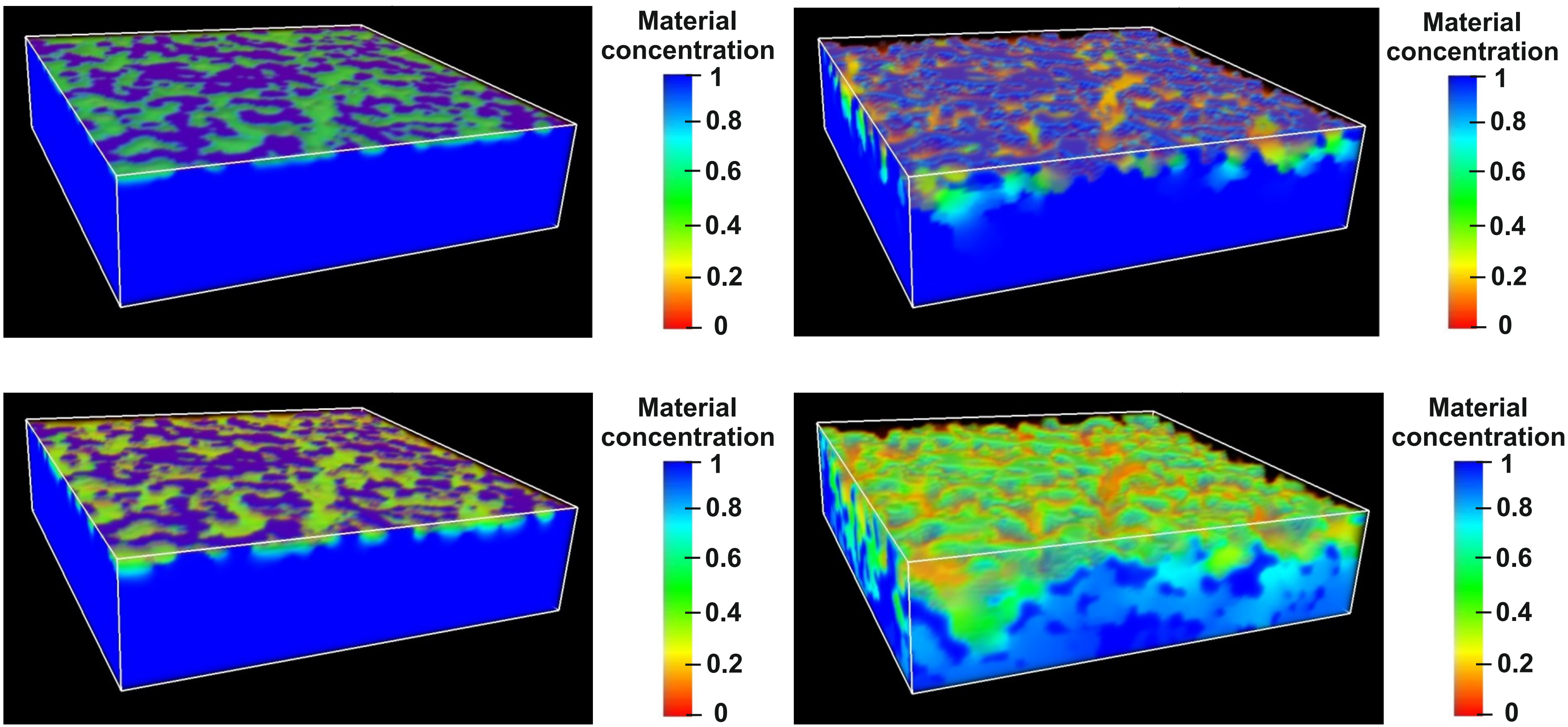
- Diffusion equation:

$$\begin{aligned} \frac{\partial c(x,t)}{\partial t} - \nabla \cdot (D(x)\nabla c(x,t)) &= 0 \text{ in } \Gamma\,, \\ c(x,0) &= 0 \text{ on } \partial\Gamma_D\,, \\ \frac{\partial c(x,t)}{\partial n} &= 0 \text{ on } \partial\Gamma_N\,. \end{aligned}$$

- Approximation by a finite element discretization
- Postprocessing the data for CST using Paraview

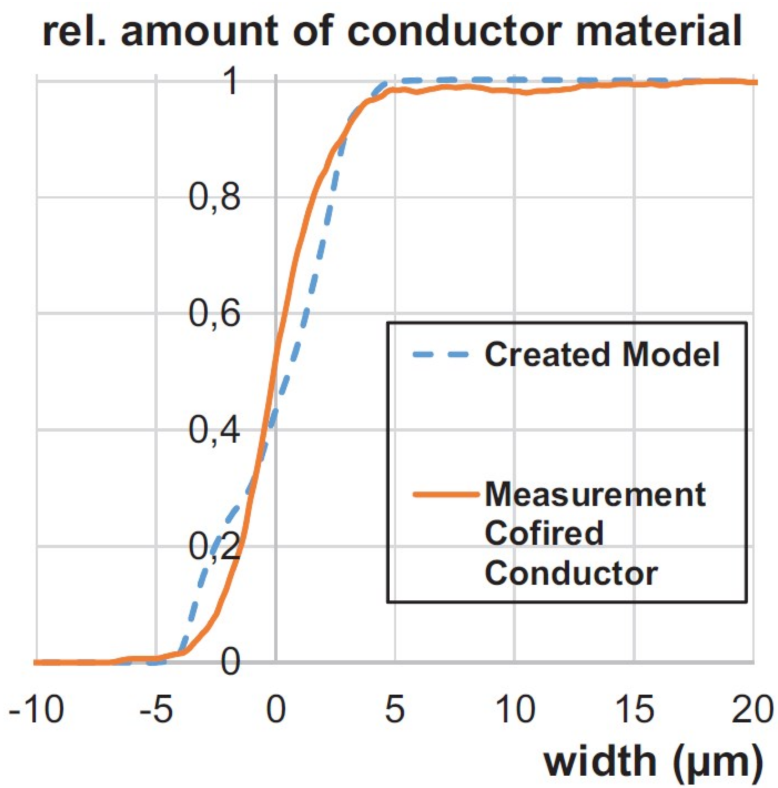
Generation of Random Structures

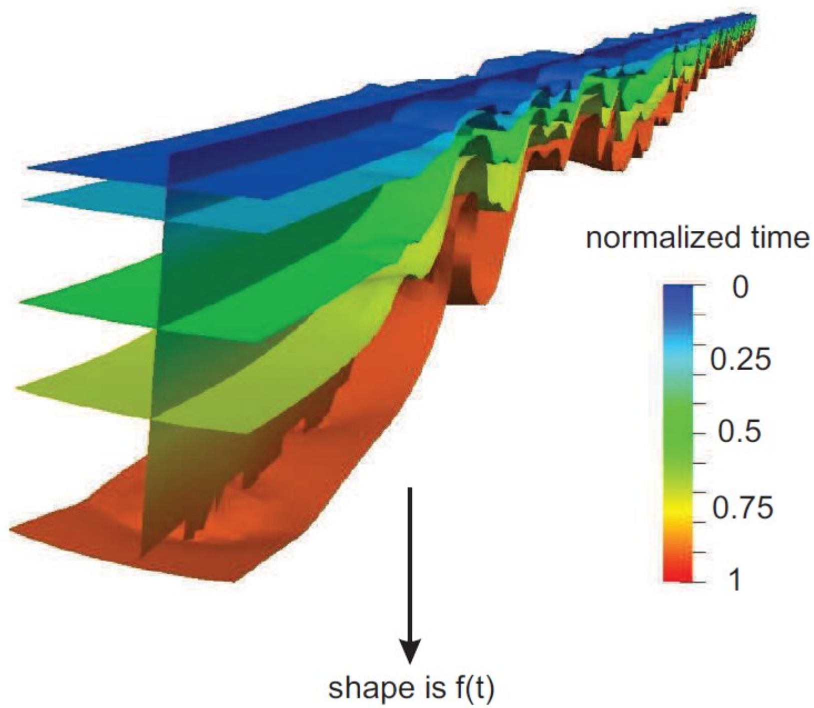
Illustration of different time-steps for a porosified substrate



Generation of Random Structures

Illustration of different time-steps for
a fringed microstrip line

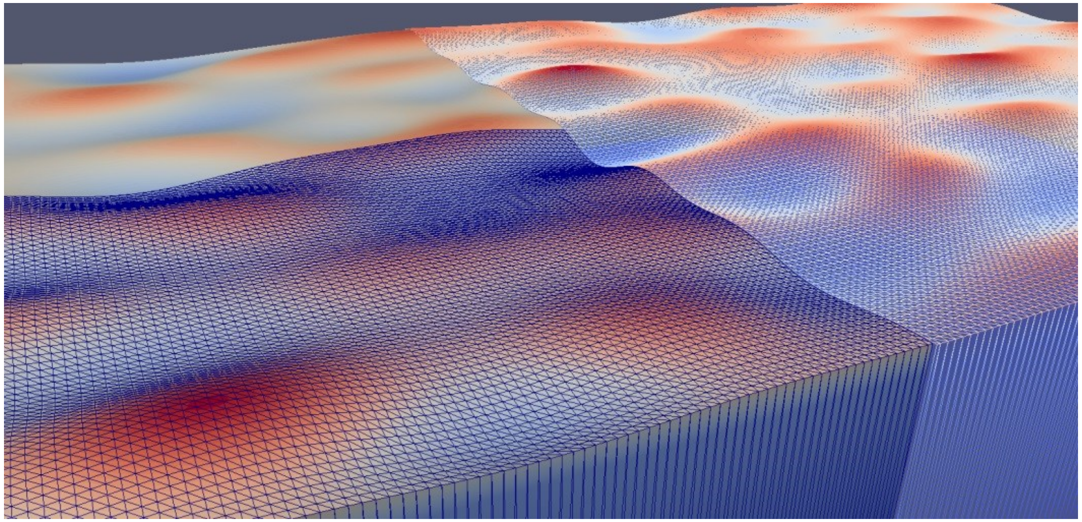




Generation of Random Structures

Modeling surface geometries
by Karhunen-Loève (KL) expansion

- Computation of variations in the surface by a truncated KL expansion:



- Advantage: Specific variation of roughness parameters enabling a correlative study on RF properties

Basic Conditions for subseqent Simulations

- STL coordinate accuracy

→ Closed surface mesh

- Geometry discretization

→ Limited by computational ressources

- Required geometry resolution (e.g. by skin-effect)

→ Essential for accurate simulation

e.g.: ≈ 50 Mio. Hexahedrons on 6 GB Nvidia Tesla

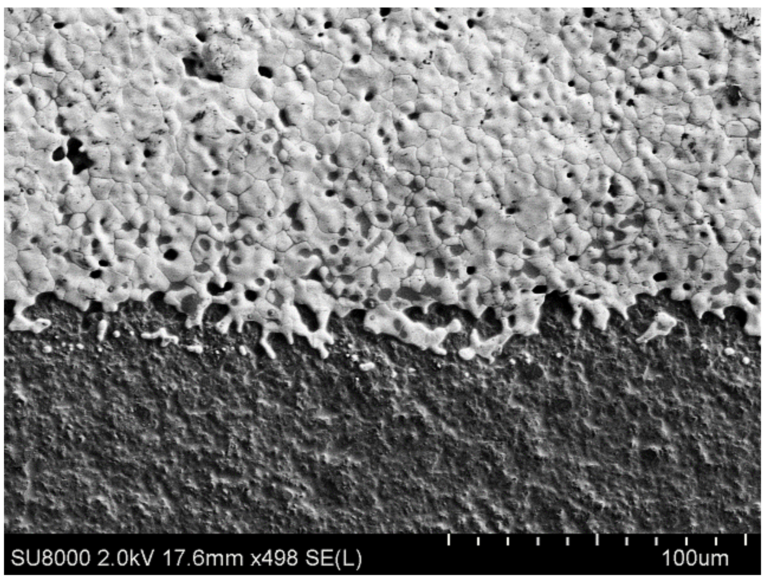
$\delta_{Cu} \approx 200\ nm$
$@77\ GHz$

<u>Trade-off</u>

Required Resolution – Available Hardware

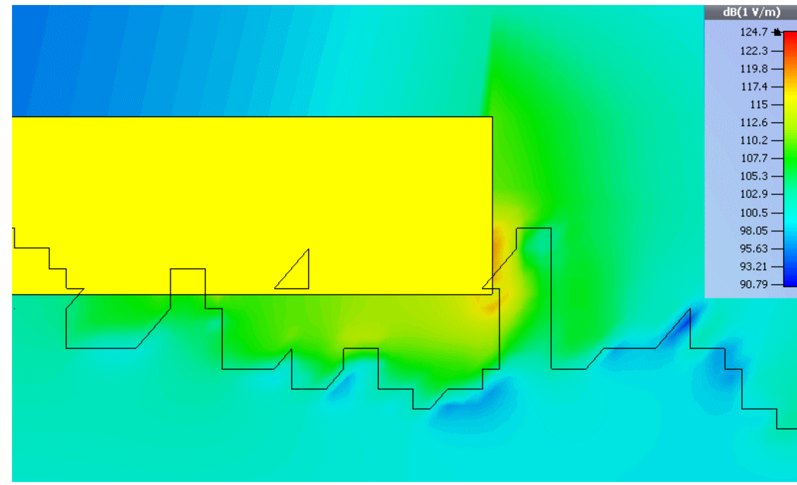
Fringed Microstrip Lines

Printed thick film metallizations on LTCC comprise randomly fringed edges



SEM micrograph of thick film (Au)

Maximum E-Field strength at lower conductor edge



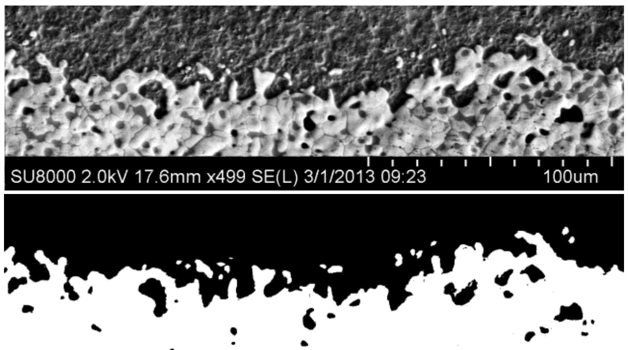
Simulated E-Fields – Rectangular MSL on Porosified LTCC

→ **Gain insights on influence of edge shape on RF properties**

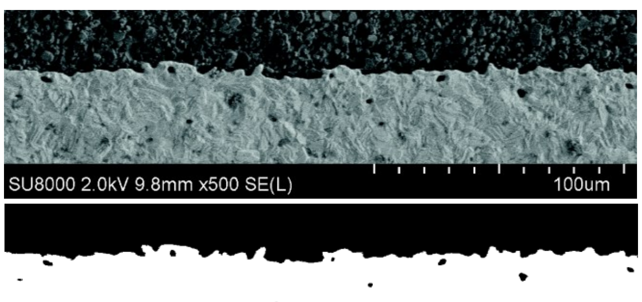
Fringed Microstrip Lines

Measurement of Edge Sharpness

Postfired

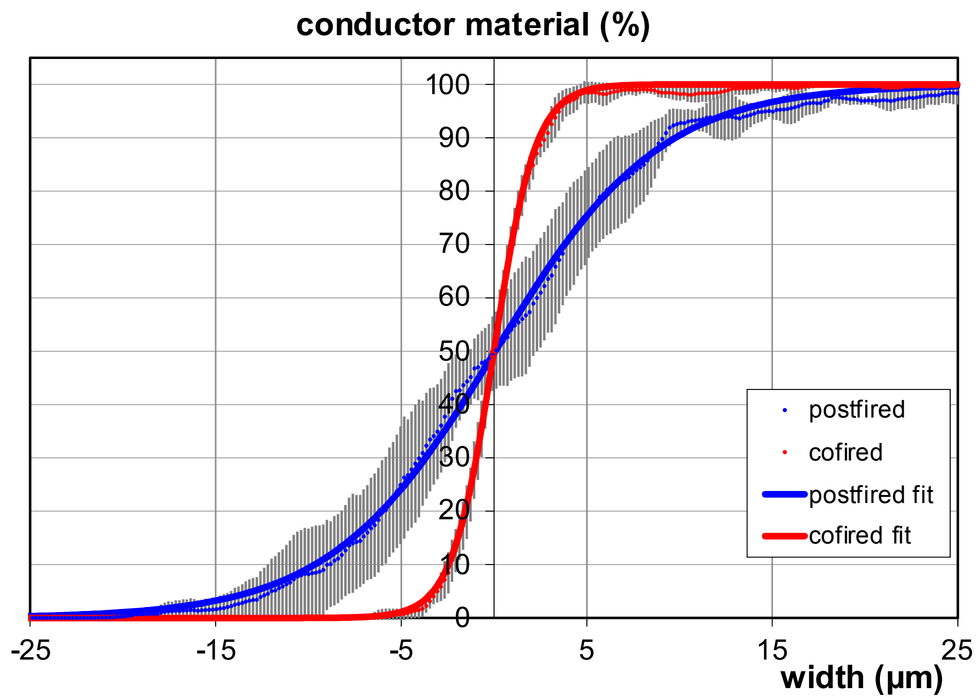


Cofired



SEM pictures of thickfilm edges

Fringing factor of postfired conductors is ≈4 times larger

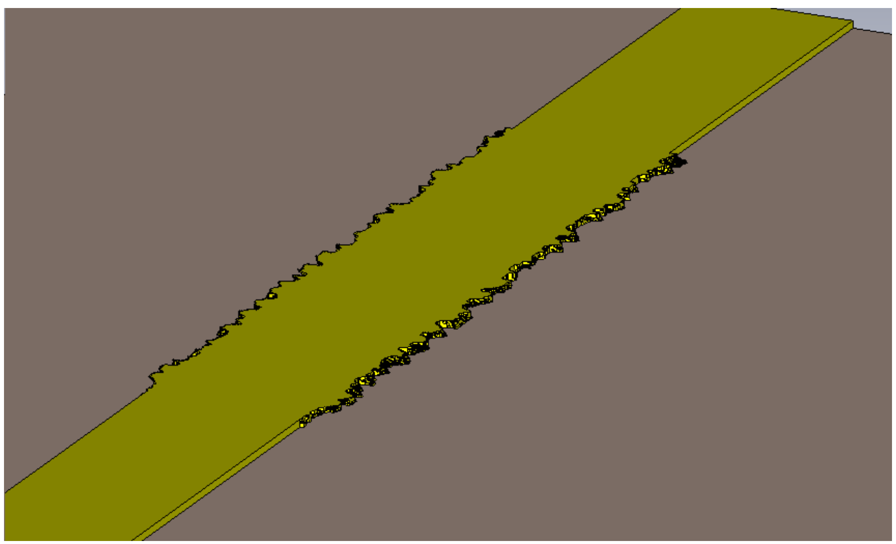


Detected distribution function of edges – standard deviation (grey bars)

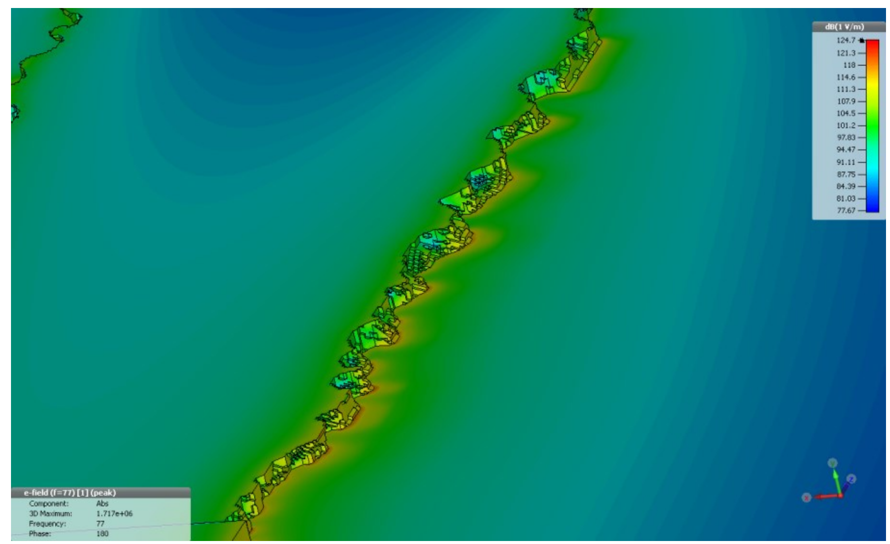
Fringed Microstrip Lines

Simulation Model dense LTCC

- 3D CAD Model in CST Microwave Studio
- Total length 1mm
- Gold track 110µm wide & 5µm high
- Substrate 100µm DuPont 951; ϵ_r=7.8
- Scalable fraying factor χ;   1χ corresponds to cofired tracks



Dense LTCC, frayed conductor (2χ)

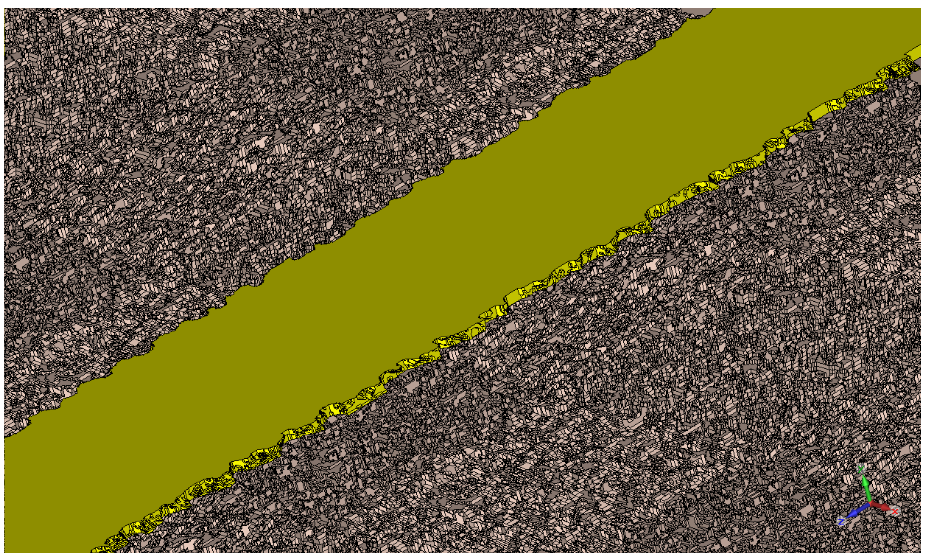


E-Field distribution at 77 GHz (log. scale)

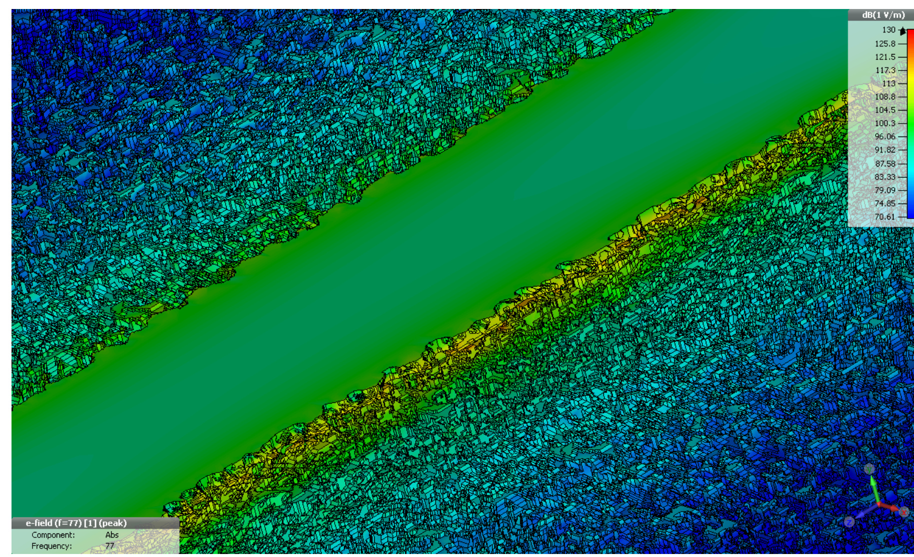
Fringed Microstrip Lines

Simulation Model porous LTCC

- Cofired track on porosified DuPont 951
- Modeled Porosification gradient satisfies measurement
- Model created with diffusion equation



Porosified LTCC, frayed conductor (1χ)

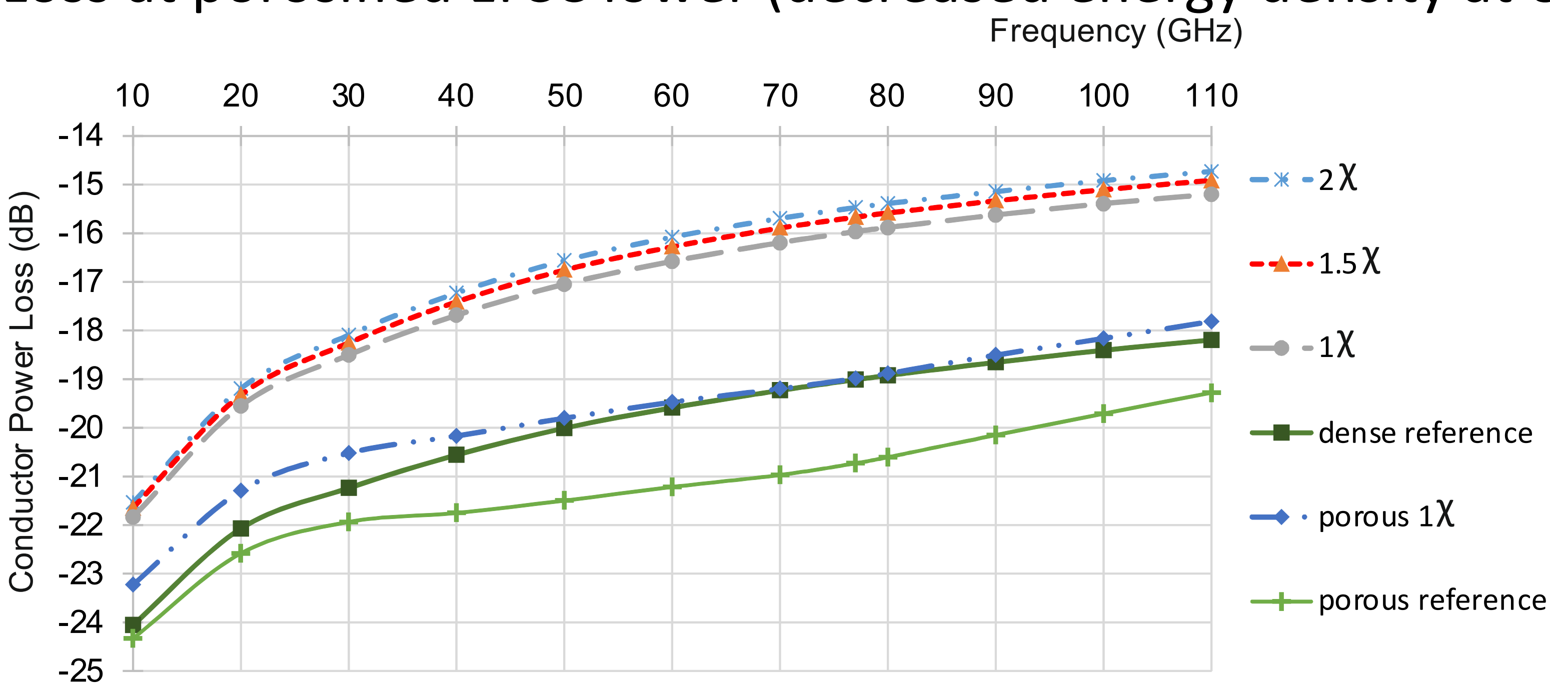


E-Field distribution at 77 GHz (log. scale)

Simulation Results

Conductor Loss (length 1mm)

- Rectangular shaped reference on dense LTCC (-19dB at 77GHz)
- Conductor loss grows with frequency (Skin-Effect)
- Higher χ exhibit increasing losses (effective length grows)
- Loss at porosified LTCC lower (decreased energy density at edges)

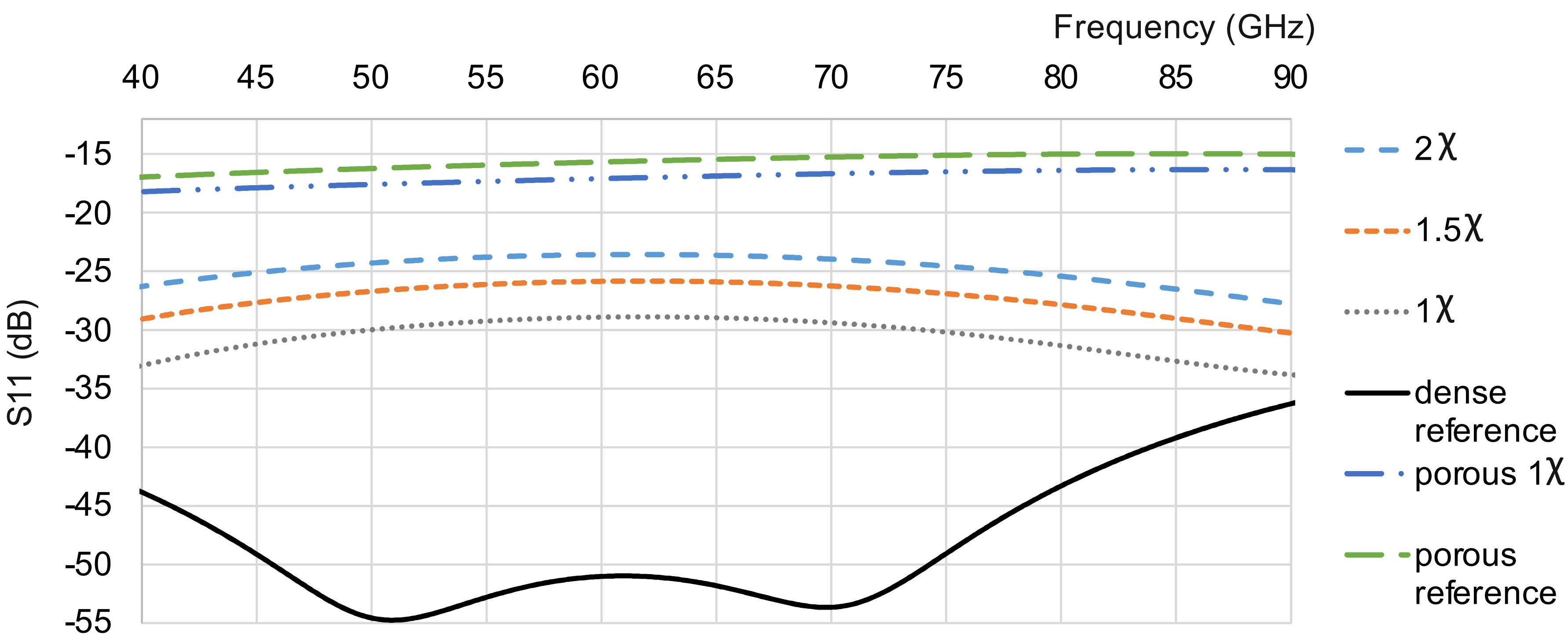


Simulated power loss of frayed gold conductors (10-110GHz)

Simulation Results

Scattering parameter S11

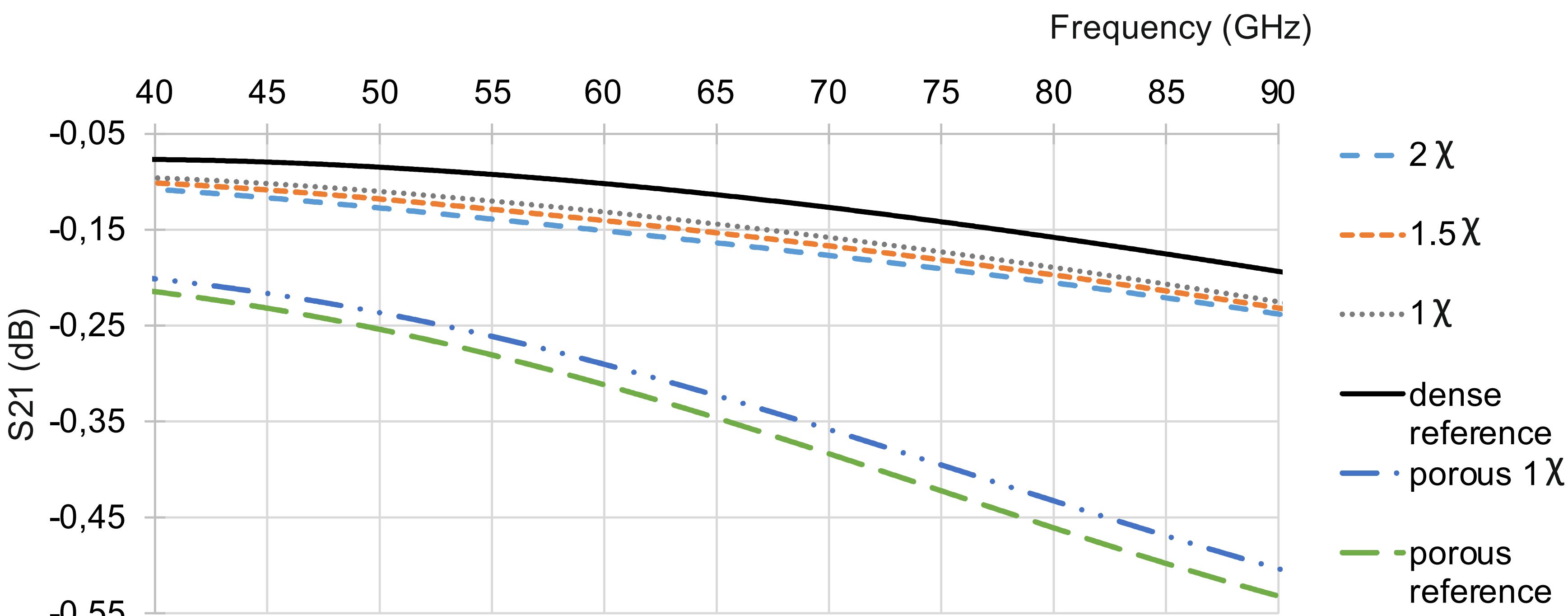
- Rectangular conductor: lowest reflection (homogeneous structure)
- S11 grows with fringing (several dB per χ)
- S11 on porous substrate much higher (local changes of ϵ_r)



Simulation Results

Scattering parameter S21

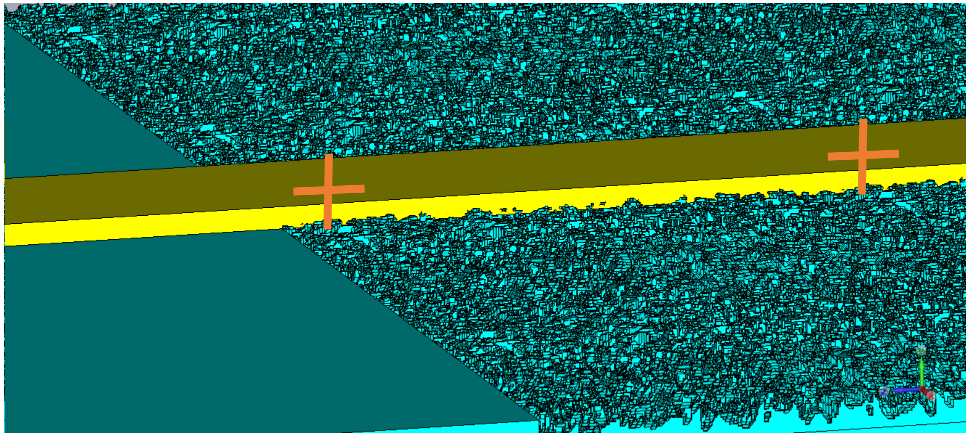
- Inverse behavior to S11
- Stronger Fringing → higher losses and reflections
- Porosified LTCC shows approx. 0.1 dB/mm lower transmission at 77 GHz than the cofired dense case



Simulation Results

Resulting Effective Permittivities

- Extracting effective permittivities of simulated field distributions
- Two E-Field Probes record local phases
- $\epsilon_{r,eff}$ can be calculated by phase difference
- Qualitative comparision of influence by fringed conductor edges possible



Two Field-Probes placed laterally over the conductor track

$\epsilon_{r,eff}$ determination by Probes:

$$\varepsilon_{r,eff} = n^2 = \left(\frac{\lambda_0}{\lambda_{eff}}\right)^2 = \left(\frac{c_0 \cdot \Delta\varphi}{f \cdot 360° \cdot d}\right)^2$$

$\Delta\varphi$: Simulated phase difference

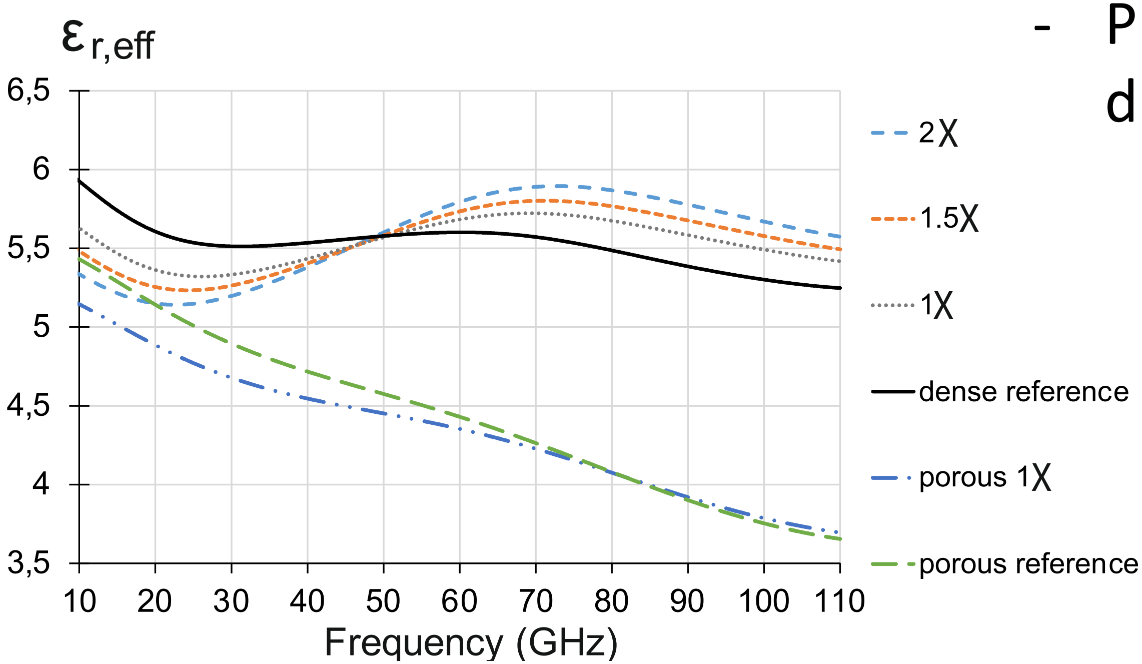
d : Physical length of $\Delta\varphi$ (500µm)

Simulation Results

Frayed conductors: Two different modes of action visible

< 50 GHz:

- Fringing lowers local field strengths
- Increased amount of E-Field in air



> 50 GHz:

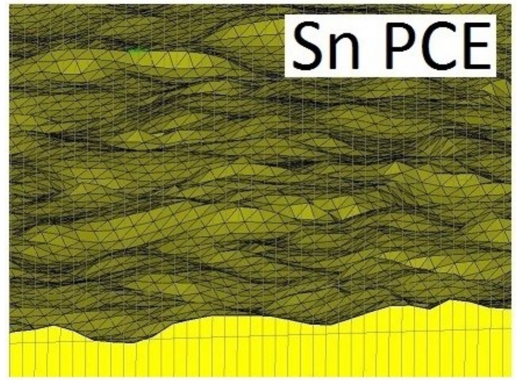
- E-Field concentrates below lower conductor edge
- Physically longer distance due fringing increases $\epsilon_{r,eff}$

Porosified LTCC decreases $\epsilon_{r,eff}$ with an strongly increasing effect at higher frequencies!

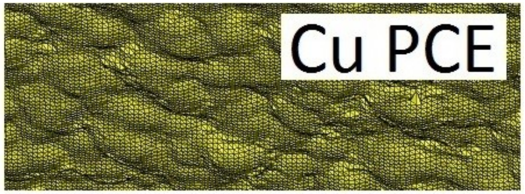
Outlook

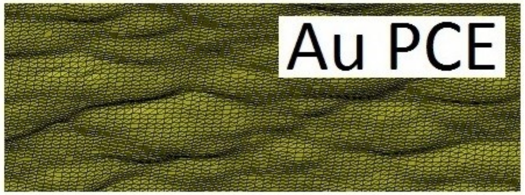
Simulation of rough conductor tracks

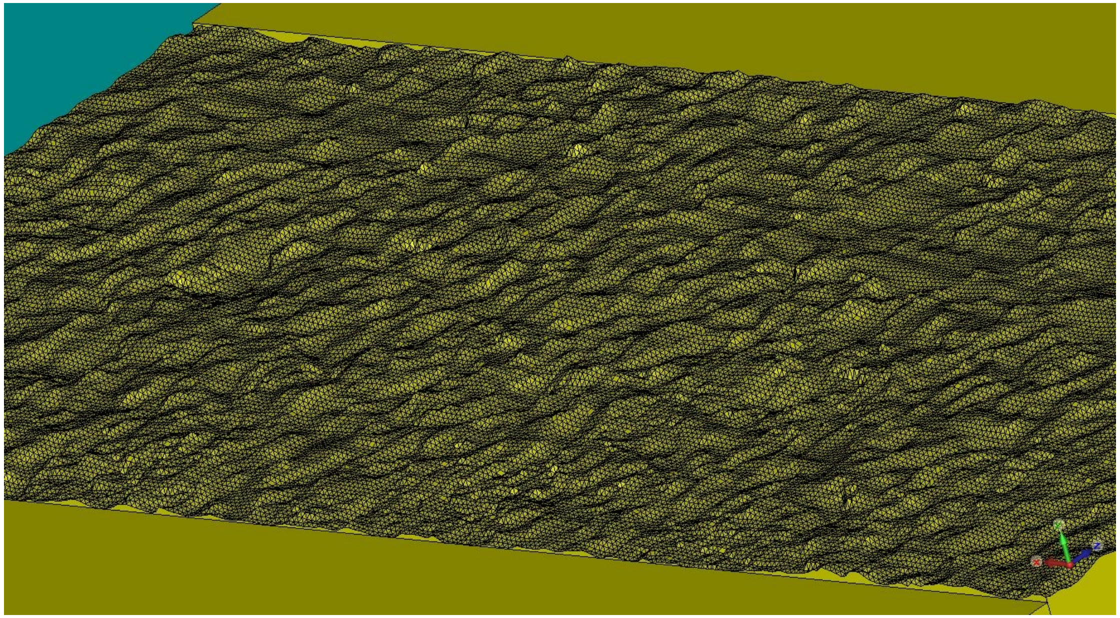
Pointwise surface data



300 nm mesh







Correlation:

Roughness parameter

↕

RF properties

by KL-expansion

Conclusion

- 3D Modeling approaches
  - Diffusion Equation
  - Pointwise surface data
  - KL-expansion
- Rebuilding of porous and rough structures
- Import to CST MWS
- Electromagnetic field simulations of fringed conductors
- New insights between degree of fraying and field-related variables (S-Parameter, losses, $\epsilon_{r,eff}$)

Thank you for your attention - Questions?