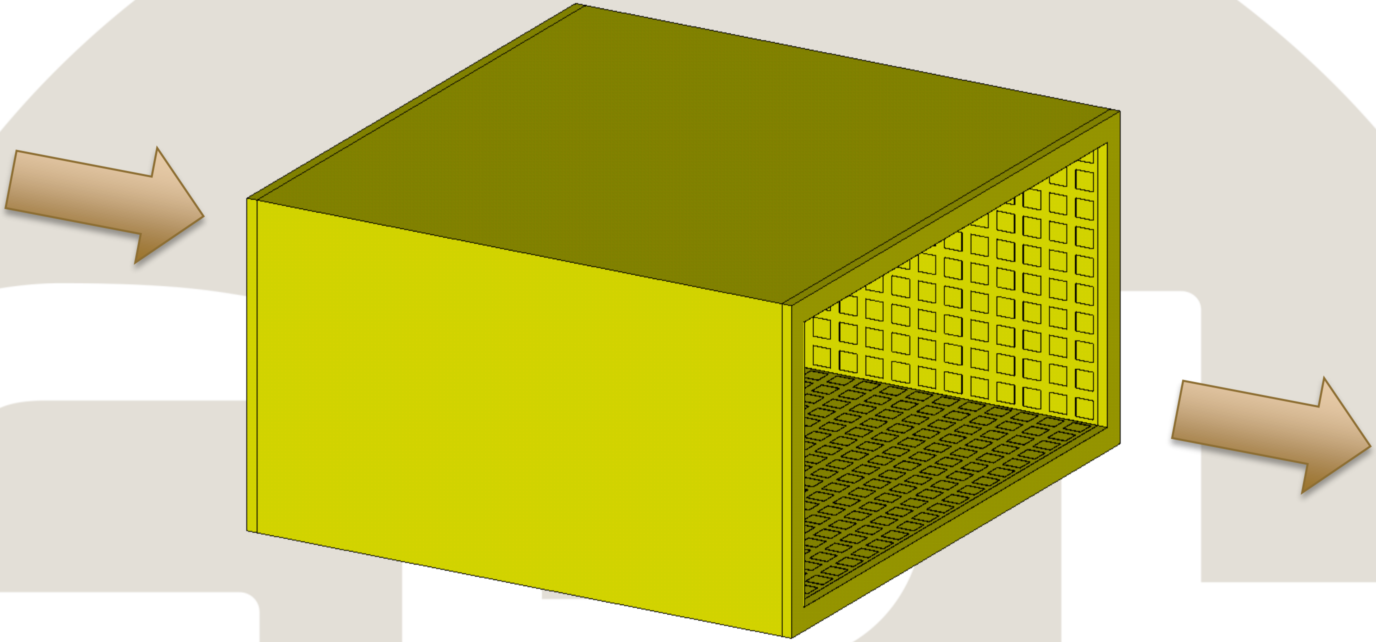

Studies on surface roughness

for rectangular waveguide structures

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Contents

Activity 1 : Losses in waveguides – Simulation Difficulties

- **Modeling and numerical problems**
  - Problems with the propagation constant in FD.
  - Propagation constant from Time Domain.
  - All other results best from FD.
  - But hexahedral mesh necessary (large memory resource needed).
  - Modeling the roughness has to account for very large ratios between smallest and largest cell size.
    - Difficulties in convergence.
    - Problems with eigenmode solvers (bad matrix condition).
  - Common similar discretization scheme for all roughness shapes.
  - Delay in project.
  - Presently first results with promising outcome.

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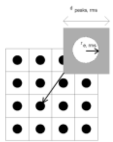
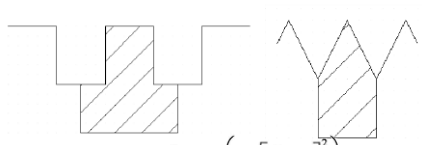
Activity 1 : Losses in waveguides – Analytical approaches

Power Loss Method
- Basic Maxwell
- Phase constant β is not influenced by the decay α



$$K_S = \frac{\left|Re\left[\eta^{3\pi}/_{4k^2}(\alpha(1)+\beta(1))\right]\right| + \frac{\mu_0\omega\delta}{4}(A_{Tile}-A_{base})}{\frac{\mu_0\omega\delta}{4}A_{Tile}}$$

Hall, Heck: *Advanced Signal Integrity for High-Speed Digital Designs*



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

E. Hammerstad and O. Jensen: *Accurate models of computer aided microstrip design*

Fitting Parameters for α
- 1D periodic structures (Hammerstad & Jensen)
- 2D periodic structures (Hall & Heck)

$$\alpha_{\text{cond, rough}} = \alpha_{\text{cond, smooth}} \cdot K_{SR}$$

Conductivity Profile
- Calibrate profile parameters with measurements

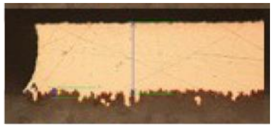


Figure 1. Lateral cut through a PCB trace.

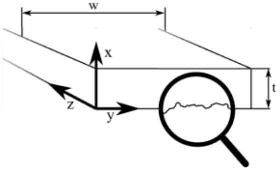
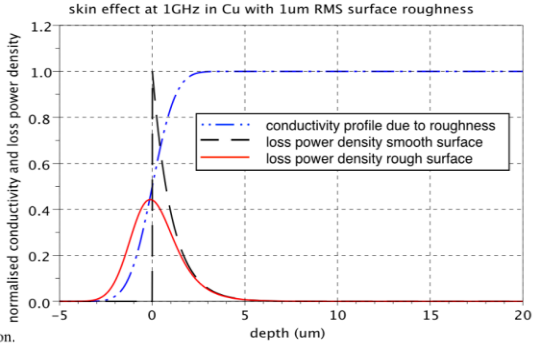


Figure 2. Coordinate system for the following discussion.



G. Gold, K. Helmreich 2012: *A Physical Model for Skin Effect in Rough Surfaces*

† taken from J. Phillips and G. Edwards (2010): *Transmission Line Modelling for Multi-Gigabit Serial Interfaces*

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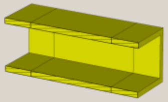
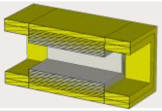
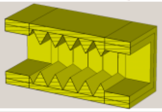
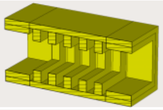
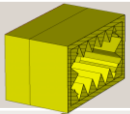
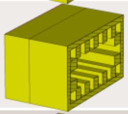
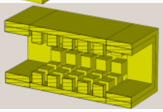
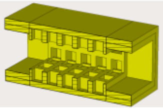
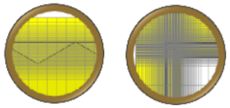
Activity 1 : Losses in waveguides – Simulated Surfaces

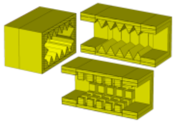
roughnessmodel	not-to-scaleplot	$\frac{a}{r_{RMS}}$	hex. meshcells (FD)
0=none		0	31k
1=layer		?	44k
2=rampT		$\sqrt{3}$	250k
3=stepT		$\sqrt{2}$	238k
4=rampL		$\sqrt{3}$	236k
5=stepL		$\sqrt{2}$	231k
6=tower		1.4186 …*	1.3M
7=tower_inv		1.4186 …*	1.3M

* with a filling rate of $\alpha_1 = \alpha_2 = {}^2/_3$

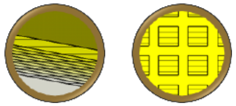


Meshing
- cell resolution in different directions and on the surface

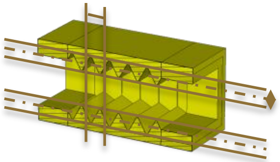
Model type (WL-86)
- flat, ramp, step, layered
- repeating in longitudinal/transversal direction or both



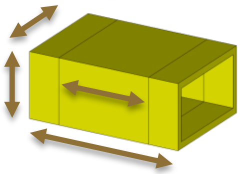
Model dependent parameters
- filling rate (steps/towers)
- conductivity profile (layer)



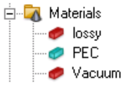
Surface parameters
- period length
- roughness
- border thickness



Dimensions
- waveguide width-height
- border thickness



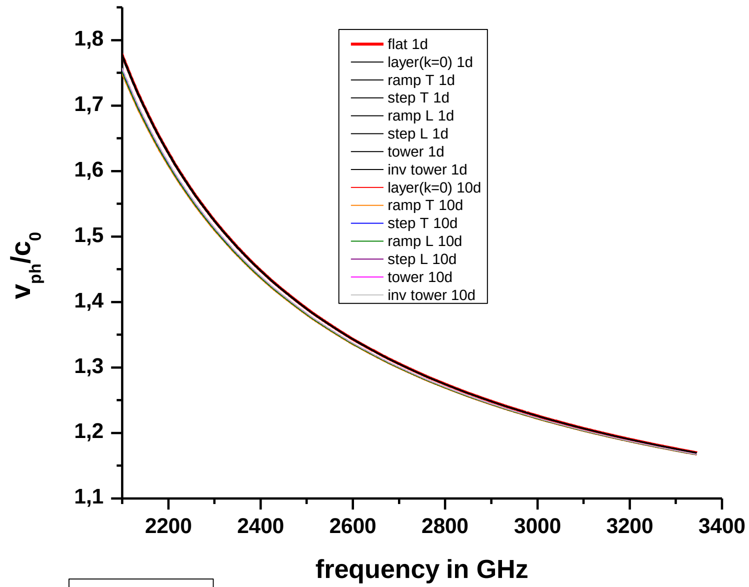
Material and models
- H&J model or regular Maxwell
- conductivity
- solver (freq/time)

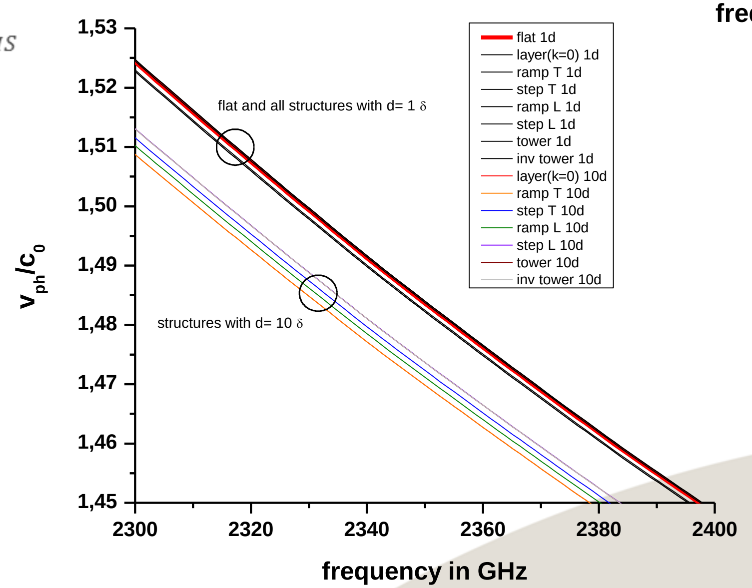


Activity 1 : Losses in waveguides – Results

Propagation constant

- Time domain simulation
- Comparison between r_{RMS} = 1 δ and r_{RMS} = 10 δ
- For low r_{RMS} = 1 δ the phase constant is nearly model independent.
- Influence detectable only for higher r_{RMS}
- Separation between models even difficult for higher r_{RMS}
  - Roughly depending only on r_{RMS}

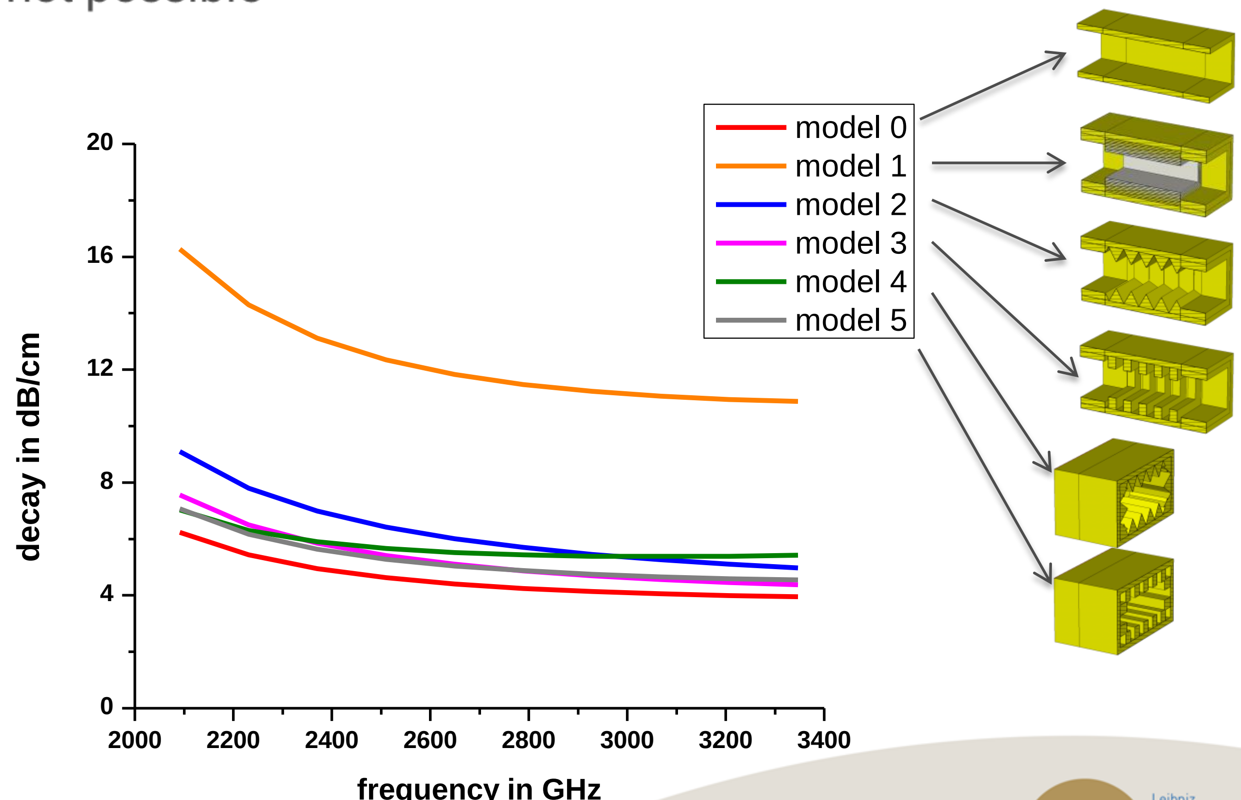




Activity 1 : Losses in waveguides – Results

Roughness effects 1

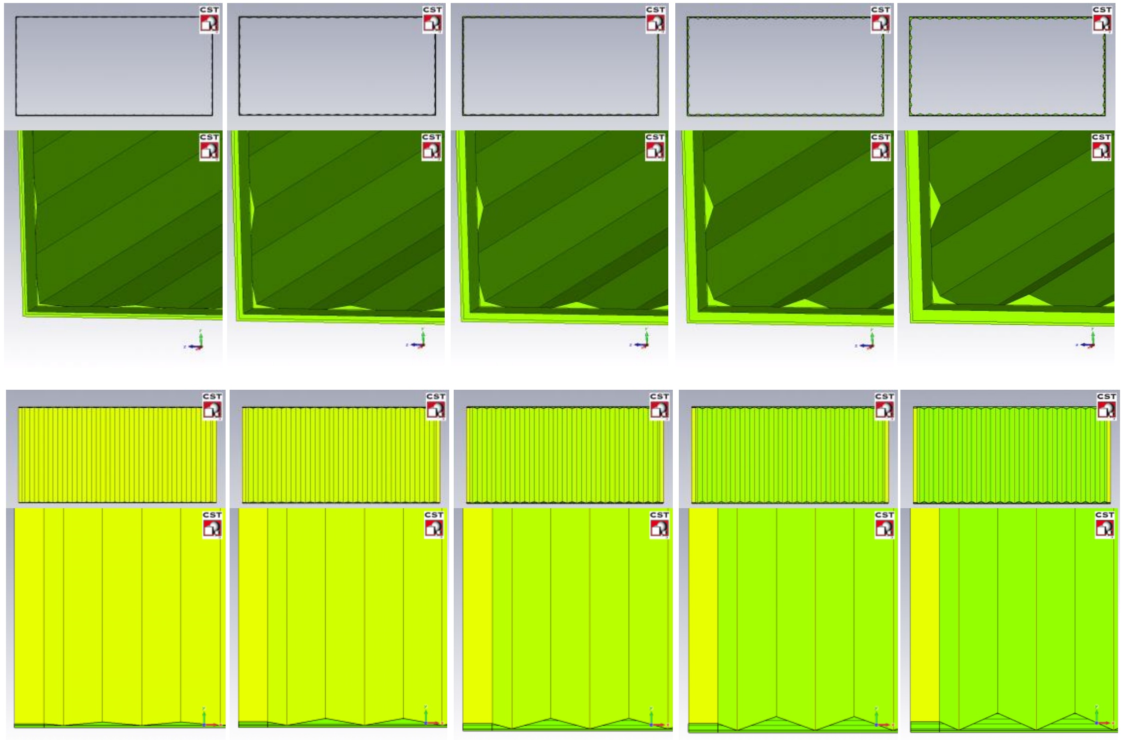
- Frequency domain simulation
- Different frequency behaviour for different profile structures
- Roughness r_{RMS} < 3 δ not possible
  - here 360 nm.

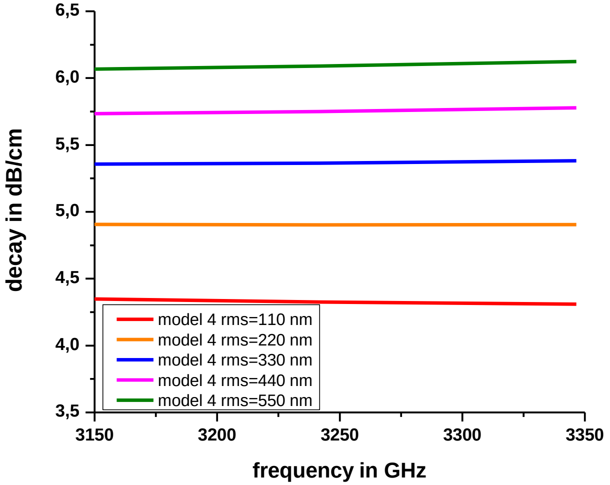


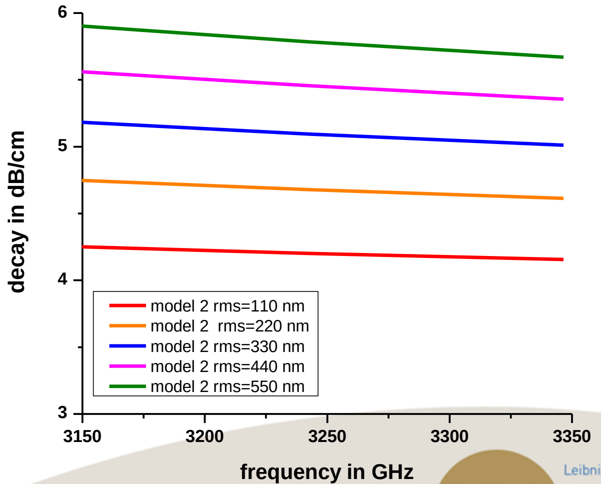
Activity 1 : Losses in waveguides – Results

Roughness effects 2

- Frequency domain simulation
- Different profile structures
  yield different frequency behaviour.



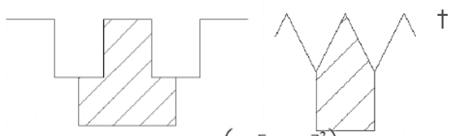




Activity 1 : Losses in waveguides – Results

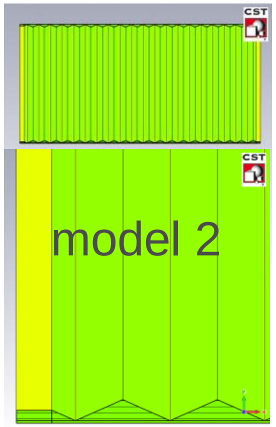
Roughness effects 3

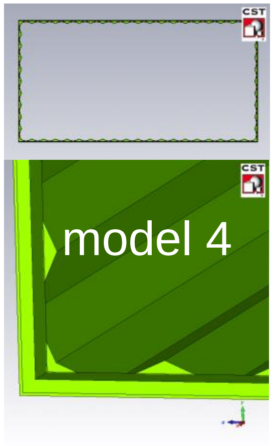
- @3240 GHz
- Comparison to Hammerstad & Jensen (model 2) under research

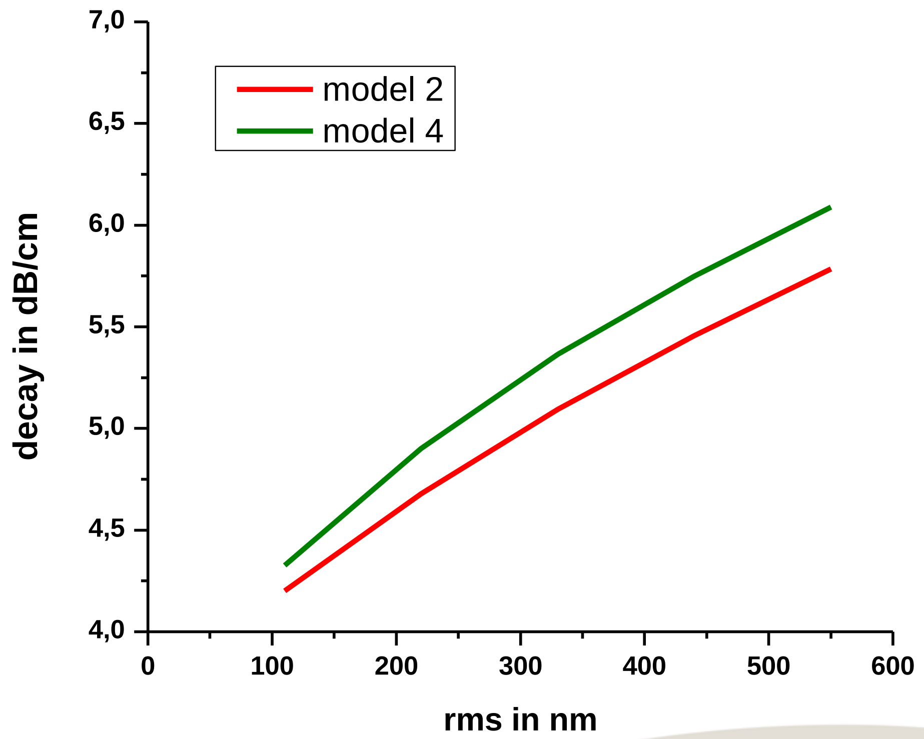


$$K_{SR} = 1 + \frac{2}{\pi}\tan^{-1}\left(1.4\left[\frac{R_{RMS}}{\delta}\right]^2\right)$$

E. Hammerstad and O. Jensen: *Accurate models of computer aided microstrip design*





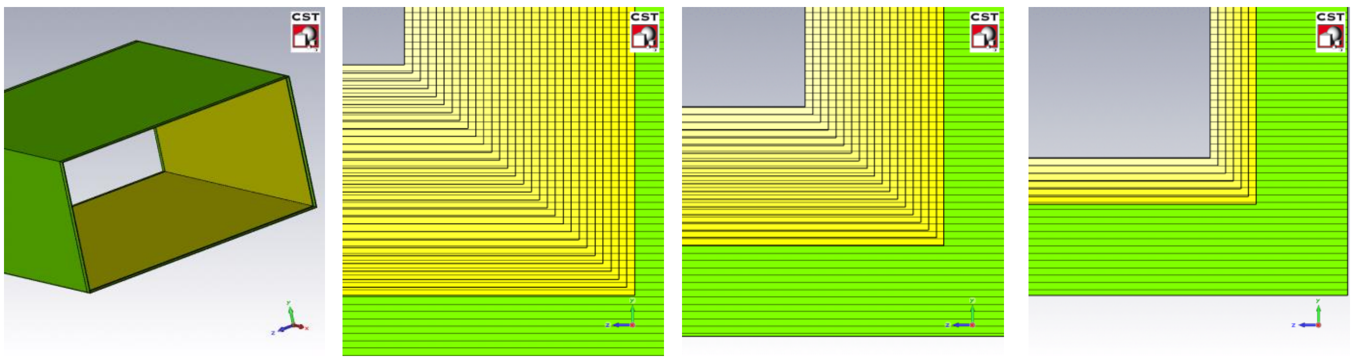


Activity 1 : Losses in waveguides – Results

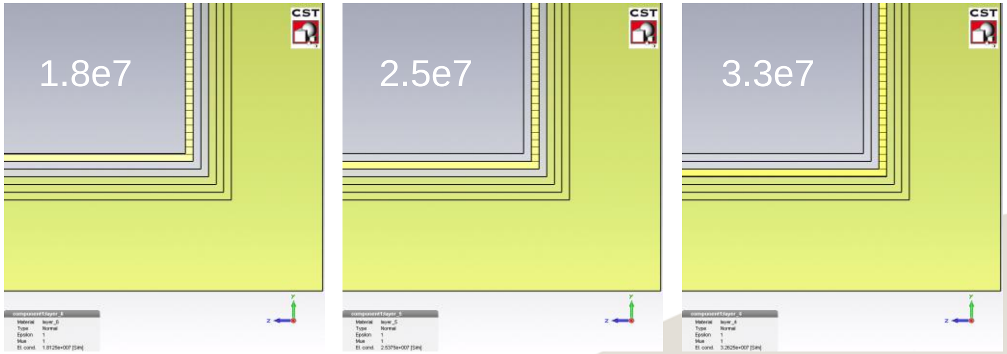
Roughness replacement by layers

- Frequency domain simulation
- Different layer thickness
- Number of layers depending on r_{RMS} =

200 nm 110 nm 40 nm



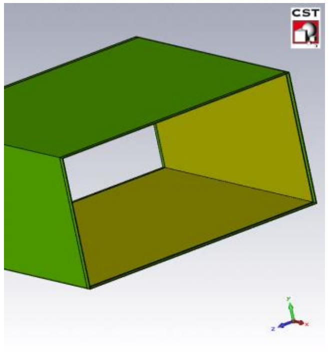
- Layer conductivity depending on several parameters, here as example

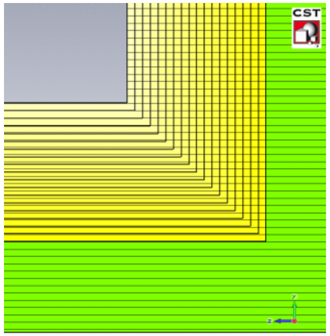


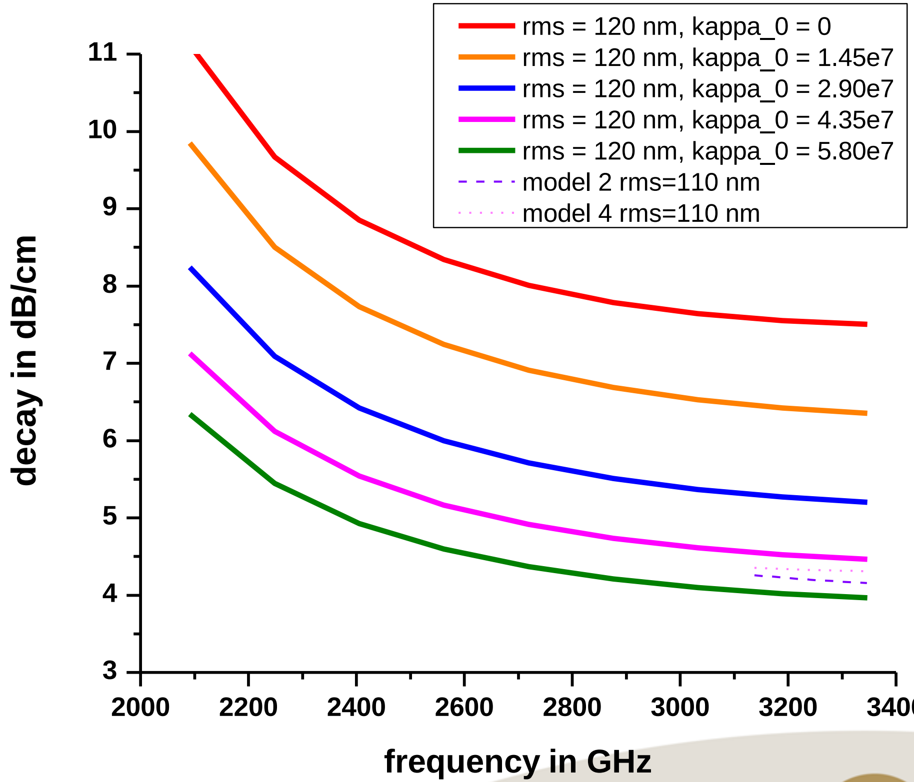
Activity 1 : Losses in waveguides – Results

Roughness replacement by layers

- Frequency domain simulation
- Example for r_{RMS} = 120 nm
- Comparison to profile structures not yet finished







Activity 1 : Conclusion

- Difficult simulation conditions in solver
  - Dense discretization and shape independent distribution.
- Time domain only for propagation constant.
- Frequency best for 3D structures.
- Present results promising
  - Some more results can verify the analytical models
  - Layer model by Gold & Helmreich with best chances