Studies on surface roughness for rectangular waveguide structures

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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.
Activity 1: Losses in waveguides – Analytical approaches

Power Loss Method
- Basic Maxwell
- Phase constant $\beta$ is not influenced by the decay $\alpha$

$$K_s = \frac{Re\left[\frac{3\pi}{4k^2}(\alpha(1)+\beta(1))\right]}{\frac{\hbar}{4}(\bar{A}_{Str}-\bar{A}_{base})}$$

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

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

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

Conductivity Profile
- Calibrate profile parameters with measurements


G. Gold, K. Helmreich 2012: A Physical Model for Skin Effect in Rough Surfaces
### Activity 1: Losses in waveguides – Simulated Surfaces

<table>
<thead>
<tr>
<th>roughnessmodel</th>
<th>not-to-scaleplot</th>
<th>$\frac{a}{\tau_{RMS}}$</th>
<th>hex. meshcells (FD)</th>
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<tbody>
<tr>
<td>0=none</td>
<td></td>
<td>0</td>
<td>31k</td>
</tr>
<tr>
<td>1=layer</td>
<td></td>
<td>?</td>
<td>44k</td>
</tr>
<tr>
<td>2=rampT</td>
<td></td>
<td>$\sqrt{3}$</td>
<td>250k</td>
</tr>
<tr>
<td>3=stepT</td>
<td></td>
<td>$\sqrt{2}$</td>
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<tr>
<td>4=rampL</td>
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<tr>
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<td>$\sqrt{2}$</td>
<td>231k</td>
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<tr>
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<td>1.4186 ... *</td>
<td>1.3M</td>
</tr>
<tr>
<td>7=tower_inv</td>
<td></td>
<td>1.4186 ... *</td>
<td>1.3M</td>
</tr>
</tbody>
</table>

* with a filling rate of $\alpha_1 = \alpha_2 = \frac{2}{3}$

### 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 $r_{RMS} = 1 \delta$ and $r_{RMS} = 10 \delta$
- For low $r_{RMS} = 1 \delta$ the phase constant is nearly model independent.
- Influence detectable only 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 $r_{RMS} < 3\delta$ not possible
  - here 360 nm.

![Graph showing decay in dB/cm vs frequency in GHz for different models.](image)
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

\[
K_\omega = 1 + \frac{2}{\pi} \tan^{-1} \left( 1,4 \frac{R_{\text{rms}}}{\delta} \right)
\]

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

![Graph showing decay in dB/cm vs. rms in nm for model 2 and model 4](chart.png)
Activity 1: Losses in waveguides – Results

**Roughness replacement by layers**

- Frequency domain simulation
- Different layer thickness
- Number of layers depending on $r_{RMS} = \begin{cases} 200 \text{ nm} \\ 110 \text{ nm} \\ 40 \text{ nm} \end{cases}$

- Layer conductivity depending on several parameters, here as example

\[ \begin{align*}
\text{Layer 1:} & \quad 1.8 \times 10^7 \\
\text{Layer 2:} & \quad 2.5 \times 10^7 \\
\text{Layer 3:} & \quad 3.3 \times 10^7 
\end{align*} \]
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

![Graph showing decay in dB/cm versus frequency in GHz for different roughness and kappa_0 values.](image)
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