Reliable Full-Wave EM Simulation of a Single-Layer SIW Interconnect with Transitions to Microstrip Lines

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Outline

- Introduction
- SIW design and implementation in COMSOL
- Configuration settings: meshing scheme and simulation bounding box
- Final results
- Conclusions
Introduction

- Procedure to obtain reliable EM responses
- Procedure focuses on meshing scheme and simulation bounding box
- SIW interconnect with transitions to microstrip lines
SIW Design

- Single-layer substrate integrated waveguide (SIW) interconnect with transitions to microstrip lines

\[
\begin{align*}
H &= 16\text{mil} \\
W &= 341.91\text{mil} \\
W_p &= 34.14\text{mil} \\
W_{\text{tap}} &= 211.36\text{mil} \\
d &= 18.9\text{mil} \\
s &= 2d \\
L_p &= 1.5W \\
L_{\text{tap}} &= 3W \\
L_{\SIW} &= 4W \\
\varepsilon_r &= 3.6
\end{align*}
\]

(Rayas-Sanchez et. al. 2009)
SIW COMSOL Configuration

Horizontal lumped ports \( (l_{\text{port}} = 1H) \)
PEC for the trace metals and the bottom box layer
Dielectric losses \( \tan \delta = 0 \)
Scattering boundary condition for the rest of the box
AWE using 100 freq. points, from 0.1-40 GHz
COMSOL Configuration

- Reliable EM responses:
  Meshing scheme
  Simulation bounding box dimensions

\( \delta_{\text{min-glob}} = \min\{\lambda_{\text{air}}/C_{g1} \ H/C_{g2}\} \)
\( \delta_{\text{max-glob}} = 5\delta_{\text{min-glob}} \)
\( \delta_{\text{min-port}} = \min\{\lambda_{\text{mcsl}}/C_{p1} \ l_{\text{port}}/C_{p2}\} \)
\( \delta_{\text{max-port}} = 5\delta_{\text{min-port}} \)
\( \delta_{\text{min-mcsl}} = \min\{\lambda_{\text{mcsl}}/C_{m1} \ \sqrt{W_{\text{avg}}H}/C_{m2}\} \)
\( \delta_{\text{max-mcsl}} = 5\delta_{\text{min-mcsl}} \)
\( \delta_{\text{min-SIW}} = \min\{\lambda_{g}/C_{s1} \ \sqrt{WH}/C_{s2}\} \)
\( \delta_{\text{max-SIW}} = 5\delta_{\text{min-SIW}} \)

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\[ \delta_{\text{min-SIW}} = \min\{\lambda_{g}/C_{s1} \ \sqrt{WH}/C_{s2}\} \]
\[ \delta_{\text{max-SIW}} = 5\delta_{\text{min-SIW}} \]

(Brito-Brito et. al. 2013)
Meshing Scheme

- Minimum element size, $\delta_{\text{min}} = \text{Minimum between a fraction of the wavelength and a fraction of the minimum geometrical size in the region}$

\[
\begin{align*}
\delta_{\text{min-glob}} &= \min\{\frac{\lambda_{\text{air}}}{C_{g1}}, \frac{H}{C_{g2}}\} \\
\delta_{\text{max-glob}} &= 5\delta_{\text{min-glob}} \\
\delta_{\text{min-port}} &= \min\{\frac{\lambda_{\text{mcsl}}}{C_{p1}}, \frac{l_{\text{port}}}{C_{p2}}\} \\
\delta_{\text{max-port}} &= 5\delta_{\text{min-port}} \\
\delta_{\text{min-mcsl}} &= \min\{\frac{\lambda_{\text{mcsl}}}{C_{m1}}, \sqrt{\frac{W_{\text{avg}}H}{C_{m2}}}\} \\
\delta_{\text{max-mcsl}} &= 5\delta_{\text{min-mcsl}} \\
\delta_{\text{min-SIW}} &= \min\{\frac{\lambda_{g}}{C_{s1}}, \sqrt{\frac{WH}{C_{s2}}}\} \\
\delta_{\text{max-SIW}} &= 5\delta_{\text{min-SIW}}
\end{align*}
\]
Meshing Scheme

Resol 0 = \[ C_{g2} = 1, \ C_{p2} = 1, \ C_{m2} = 1, \ C_{t2} = 1, \ C_{s2} = 1 \]
Resol 1 = \[ C_{g2} = 1, \ C_{p2} = 1, \ C_{m2} = 3, \ C_{t2} = 7, \ C_{s2} = 10 \]
Resol 2 = \[ C_{g2} = 1, \ C_{p2} = 1, \ C_{m2} = 7, \ C_{t2} = 14, \ C_{s2} = 20 \]
For all = \[ C_{g1} = 20, \ C_{p1} = 20, \ C_{m1} = 20, \ C_{t1} = 20, \ C_{s1} = 20 \]
Simulation Bounding Box

- Initial dimensions: $H_{\text{air}} = y_{\text{gap}} = x_{\text{gap}} = 5H$
- Procedure: Gradually increase each side until EM convergence is achieved
Simulation Bounding Box – $x_{\text{gap}}$ Sweep

$H_{\text{air}} = 5H$, $y_{\text{gap}} = 5H$
Simulation Bounding Box – $y_{\text{gap}}$ Sweep

$H_{\text{air}} = 5H$, $x_{\text{gap}} = 10H$

$|S_{11}|$

0 0.2 0.4 0.6 0.8 1

0 5 10 15 20 25 30 35 40

frequency (GHz)

0 0.2 0.4 0.6 0.8 1

0 5 10 15 20 25 30 35 40

frequency (GHz)
Simulation Bounding Box – $H_{\text{air}}$ Sweep
Simulation Bounding Box – $H_{\text{air}}$ Sweep (cont.)

$y_{\text{gap}}=10H$, $x_{\text{gap}}=10H$

- $H_{\text{air}}=9H$
- $H_{\text{air}}=10H$
- $H_{\text{air}}=11H$
- $H_{\text{air}}=12H$
- $H_{\text{air}}=13H$

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<th>$S_{21}$</th>
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Box Perturbation Test

- \( H_{\text{air}} = 12H, y_{\text{gap}} = x_{\text{gap}} = 10H \)
- Final box ± 5%
Final EM responses

- $H_{\text{air}} = 12H, y_{\text{gap}} = x_{\text{gap}} = 10H$ with 1000 freq. points

**Resol 0**

**Resol 1**

**Resol 2**

2h 23m  
3h 40m  
5h 22m
Conclusions

- We presented a procedure to configure COMSOL to achieve reliable EM responses for a SIW interconnect.
- We focused on the meshing scheme and the simulation bounding box.
- For the meshing scheme we divided the structure into five regions and we proposed three different resolution schemes.
- For the simulation bounding box we increased each bounding box dimension until visually achieve EM convergence.
- We perturbed the final simulation box and applied the same box to the three resolution schemes.
Backup Slides
**Perturbation Test**

- $H_{\text{air}} = 12H, \ y_{\text{gap}} = x_{\text{gap}} = 10H$ with 1000 freq. points

**Resol 0**

**Resol 1**

**Resol 2**
Final EM Responses Comparison

$H_{air} = 12H$, $y_{gap} = 10H$, $x_{gap} = 10H$

$|S_{11}|$

$|S_{21}|$

frequency (GHz)