Impact of 3D EM Model Configuration on the Direct Optimization of Microstrip Structures

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Introduction

- Accurate simulation of planar structures at high frequencies requires EM solvers
- Low-resolution discretization in 3D solvers is necessary for direct EM optimization
- Coarsely discretized EM models are vulnerable to the selection of 3D EM model configuration
- We propose a procedure to find an appropriate 3D EM model configuration
Structure Under Study

$\delta_{\min}, \delta_{\max}$: minimum and maximum element size for each region
Selecting a 3D EM Model Configuration

\[ H_{\text{air}} = 20H, \ y_{\text{gap}} = 20H, \ x_{\text{gap}} = 20H \]

\[ C_g = [1 \ 10]^T, \ C_m = [4 \ 10]^T, \ C_p = 3 \text{ and } C_{\text{gap}} = 3 \]
Validating the 3D EM Model Configuration

\[ \tau = 0.2, x_{\text{gap}} = 20H, y_{\text{gap}} = 20H, H_{\text{air}} = 20H, L_p = 5W \]
Validating the 3D EM Model Configuration (cont)

\[ \tau = 0.2, \ x_{\text{gap}} = 20H, \ y_{\text{gap}} = 20H, \ H_{\text{air}} = 20H, \ L_p = 5W_p \]

\[
|S_{21}| = \frac{y_{\text{gap}}(1-\tau) \cdot x_{\text{gap}}(1+\tau) \cdot H_{\text{air}}(1-\tau) \cdot H_{\text{air}}(1+\tau)}{1}
\]
Formulation of the Optimization Problem

\[ x^* = \arg \min_{x \in X} U(R(x)) \]

where \( U \) is the objective function

\[ U(R(x)) = \max \left\{ \ldots e_k(x) \ldots \right\} \]

where \( e_k(x) \) is the \( k \)-th error function

Design specifications:

\[ |S_{21}| > 0.8 \text{ for } 4.9 \text{ GHz} \leq f \leq 5.1 \text{ GHz} \]

\[ |S_{21}| < 0.1 \text{ for } 5.5 \text{ GHz} \leq f \leq 4.5 \text{ GHz} \]

\[ |S_{11}| < 0.2 \text{ for } 4.92 \text{ GHz} \leq f \leq 5.08 \text{ GHz} \]
Band-pass Filter Dimensions

\[ x = [L_1 \ L_2 \ L_3 \ L_4 \ S_g]^T \]

\[ z = [H \ \varepsilon_r \ W_p \ L_p]^T \]

\[ R = [|S_{11}| \ |S_{21}|]^T \]
Optimization Results

\[ \mathbf{x}^{(0)} = [6.275 \ 4.75 \ 5.9 \ 5 \ 0.15]^T \text{ (mm)} \]

Using Nelder-Mead optimization method
Scaled Optimization Variables

\[ x^{(0)} = [6.275 \ 4.75 \ 5.9 \ 5 \ 0.15]^T \text{ (mm)} \]
Reflection at Initial and Optimal Designs

\[ x^{(0)} = [6.275 \ 4.75 \ 5.9 \ 5 \ 0.15]^T \text{ (mm)} \]
Transmission at Initial and Optimal Designs

\[ x^{(0)} = [6.275\ 4.75\ 5.9\ 5\ 0.15]^T \text{ (mm)} \]
Improving Resolution Mesh and Bounding Box

We repeat the same optimization procedure

\[ H_{\text{air}} = 25H, \; y_{\text{gap}} = 25H, \; x_{\text{gap}} = 25H \]

\[ C_g = [1 \; 10]^T, \; C_m = [8 \; 10]^T, \; C_p = 4 \text{ and } C_{\text{gap}} = 4 \]
Optimization Results

\[ x^{(0)} = [6.275 \ 4.75 \ 5.9 \ 5 \ 0.15]^T \text{ (mm)} \]
$x^* = [6.4123 \ 4.4192 \ 6.1825 \ 4.4776 \ 0.15101]^T \text{ (mm)}$
Reflection at Initial and Optimal Designs

$x^* = [6.4123 \ 4.4192 \ 6.1825 \ 4.4776 \ 0.15101]^T \text{ (mm)}$
Transmission at Initial and Optimal Designs

\[ x^* = [6.4123 \; 4.4192 \; 6.1825 \; 4.4776 \; 0.15101]^T \text{ (mm)} \]
The Proposed Methodology

- Select a reasonably small length for the lumped port, using a low-resolution mesh with a large simulation box size
- Validate simulation box by perturbations
- Optimize the structure
- If the optimization process fails, it is necessary to change the model configuration
- Launch the same optimization procedure
- Repeat steps until the objective function becomes negative
Conclusions

- The EM optimization of a coarsely discretized model was realized using two different model configurations.
- It was confirmed that the direct EM optimization of coarse models in COMSOL could be enhanced by an appropriate bounding box size as well as by a suitable meshing scheme.
- We presented a systematic methodology to find an appropriate 3D model configuration on a direct EM optimization.
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