

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

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**Abstract:** We present a procedure to obtain reliable EM responses for a substrate integrated waveguide (SIW) interconnect with microstrip line transitions. The procedure focuses on two COMSOL configuration settings: meshing sizes and simulation bounding box. Once both are properly configured, the implemented structure is tested by perturbing the simulation bounding box to assure it has no effect on the EM responses.

**Keywords:** Simulation bounding box, meshing scheme, SIW, microstrip line, interconnect, EM simulation.

## 1. Introduction

In this work, we present a procedure to configure the simulation bounding box dimensions and the meshing scheme for a substrate integrated waveguide (SIW) interconnect with microstrip line transitions implemented in COMSOL. Both simulator settings must be properly configured to obtain reliable EM responses.

We start the configuration by dividing the whole structure into different regions, this allows us to have different meshing sizes for the structure, using smaller meshing sizes in the regions that are more critical for the EM response estimation.

Once the meshing scheme is defined, we set a suitable initial simulation bounding box. Then, we gradually increase each simulation bounding box dimension until EM responses are no longer affected.

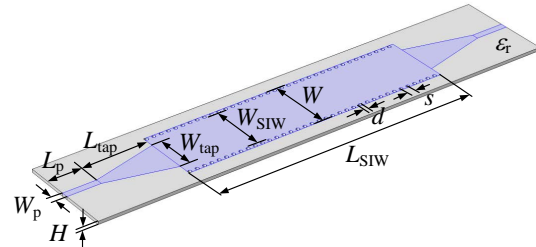
Finally, we test the simulation bounding box robustness by perturbing each dimension and corroborating that the EM responses are not affected.

## 2. Structure under Study

The SIW structure implemented in this work is illustrated in Fig. 1. For our implementation

we use  $\epsilon_r = 3.6$ ,  $H = 16$  mil,  $W = 341.91$  mil,  $d = 18.9$  mil,  $s = 2d$ ,  $W_p = 34.14$  mil,  $L_p = 1.5W$ ,  $L_{\text{tap}} = 3W$ ,  $L_{\text{SIW}} = 4W$ ,  $W_{\text{tap}} = 211.36$  mil and  $W_{\text{SIW}} = W - 2d$ . We neglect dielectric and metallic losses by setting  $\tan \delta = 0$  and by setting metals as perfect electric conductors (PEC). The simulation bounding box is configured as scattering boundary condition excepting the bottom cover which is configured as PEC to act as a ground plane. Design parameters are taken from [1] and correspond to a high pass response with a 10 GHz cutoff frequency.

The SIW model is simulated from 0.1 GHz to 40 GHz using asymptotic waveform evaluation (AWE) with 100 frequency points. We use a CPU Intel Core i7-2600 at 3.4 GHz, with 16 GB RAM and COMSOL 4.4.



**Figure 1.** Design parameters for the SIW interconnect with transitions to microstrip lines.

## 3. Meshing Scheme

A fine meshing size delivers accurate responses but also consumes more computational resources and time. A simulation using a coarse meshing size is faster but the model response is less accurate and it might even lead to non physical responses. In order to have reliable responses for a coarse meshing size, a meshing scheme by zones is proposed in [2], using different meshing sizes for different domains in the model, as required. We follow that approach.

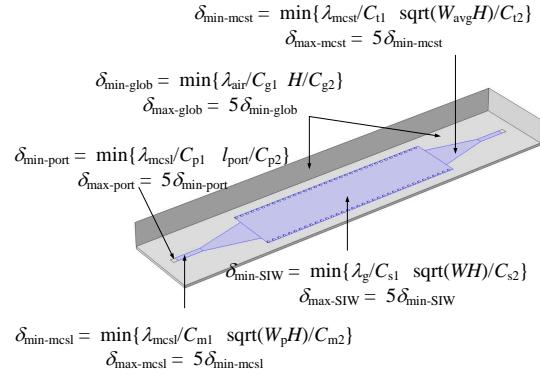
The SIW structure is divided into five meshing regions, as illustrated in Figure 2. We define horizontal lumped ports whose length is  $l_{\text{port}}$  with a 50-ohm characteristic impedance. For

the port region, the minimum element size is defined as the minimum value between  $\lambda_{\text{mcs1}}/C_{p1}$  and  $l_{\text{port}}/C_{p2}$ , where  $\lambda_{\text{mcs1}}$  is the wavelength in the microstrip at the maximum simulated frequency,  $l_{\text{port}}$  is the smallest geometrical dimension inside the port region and  $C_{p1}$  and  $C_{p2}$  are integer dividers used to regulate the mesh resolution in that region. For the microstrip line region, the minimum element size is defined as the minimum value between  $\lambda_{\text{mcs1}}/C_{m1}$  and  $\text{sqrt}(W_p H)/C_{m2}$ , where  $\text{sqrt}(W_p H)$  is the geometrical mean of the smallest geometrical dimensions inside the microstrip region and  $C_{m1}$  and  $C_{m2}$  are integer dividers used to regulate the mesh resolution in that region. For the microstrip tapered line region, the minimum element size is defined as the minimum value between  $\lambda_{\text{mcs1}}/C_{t1}$  and  $\text{sqrt}(W_{\text{avg}} H)/C_{t2}$ , where  $W_{\text{avg}}$  is the average value between  $W_p$  and  $W_{\text{tap}}$ ,  $\lambda_{\text{mcs1}}$  is the wavelength in the microstrip using  $W_{\text{avg}}$  at the maximum simulated frequency, and  $C_{t1}$  and  $C_{t2}$  are integer dividers used to regulate the mesh resolution in that region. For the SIW region, the minimum element size is defined as the minimum value between  $\lambda_{\text{guided}}/C_{s1}$  and  $\text{sqrt}(WH)/C_{s2}$ , where  $\lambda_{\text{guided}}$  is the wavelength in the SIW and  $C_{s1}$  and  $C_{s2}$  are integer dividers used to regulate the mesh resolution in that region. For the global region (remaining regions), the minimum element size is defined as the minimum value between  $\lambda_{\text{air}}/C_{g1}$  and  $H/C_{g2}$ , where  $\lambda_{\text{air}}$  is the wavelength in air at the maximum simulated frequency and  $C_{g1}$  and  $C_{g2}$  are integer dividers used to control the mesh resolution in that region. Maximum element sizes for global region are defined as 20 times the minimum element size. For the remaining regions, maximum element sizes are defined as five times the corresponding minimum element size, since those regions require a finer mesh.

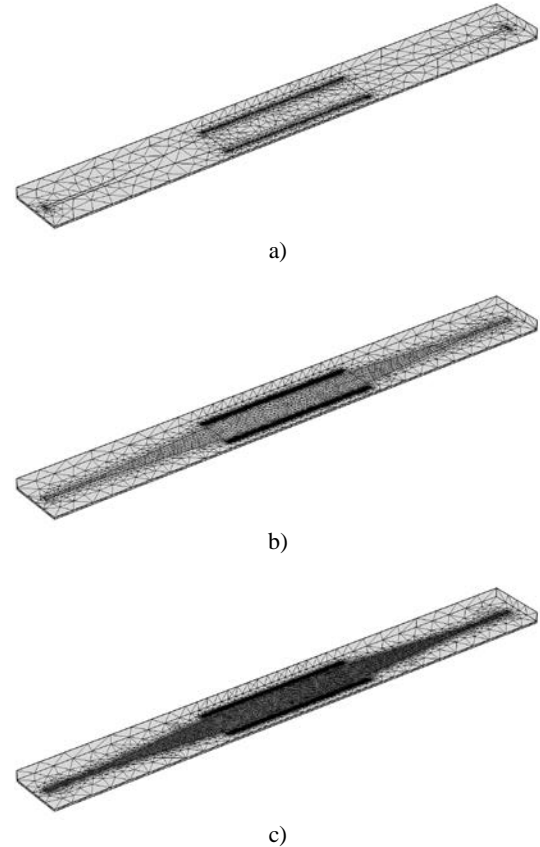
By changing the divider coefficients we defined three resolution schemes for the SIW model simulation: Resol 0 for a coarse resolution, Resol 1 for a medium resolution and Resol 2 for a fine resolution. For the three resolution schemes  $C_{g1} = C_{p1} = C_{m1} = C_{t1} = C_{s1} = 20$ . The remaining coefficients are defined as:

- 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:  $C_{g2}=1, C_{p2}=1, C_{m2}=7, C_{t2}=14, C_{s2}=20$

The meshing schemes for the selected resolutions as seen in COMSOL are illustrated in Fig. 3.



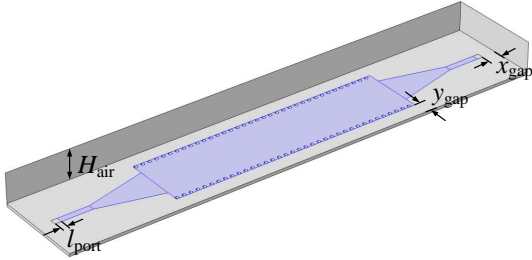
**Figure 2.** Meshing scheme for SIW structure simulation in COMSOL. SIW structure is divided in five meshing regions: global, ports, microstrip lines, microstrip tapered lines and SIW.



**Figure 3.** Meshing schemes as seen in COMSOL for the SIW interconnect with transitions to microstrip lines using: a) Resol 0, b) Resol 1, and c) Resol 2.

## 4. Simulation Bounding Box

A properly configured simulation bounding box should not modify the inherent EM response of the structure under analysis. In our case, the distances from the SIW metals to the lateral, frontal and upper box walls can interfere and modify the EM response of the structure if they are too short. Those distances to the simulation box are illustrated in Fig. 4 as  $x_{\text{gap}}$ ,  $y_{\text{gap}}$  and  $H_{\text{air}}$ .



**Figure 4.** SIW simulation bounding box configuration variables.

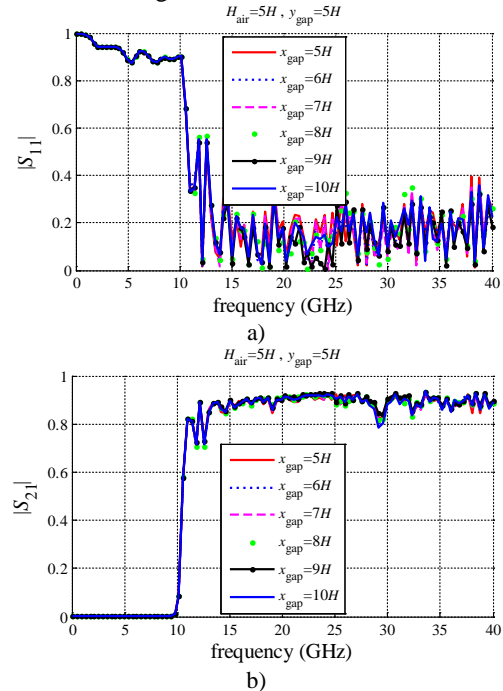
From the technique proposed in [2], we start by defining an arbitrary, but reasonable, initial box configuration by setting  $H_{\text{air}} = y_{\text{gap}} = x_{\text{gap}} = 5H$ . Then, we gradually increase  $x_{\text{gap}}$  using  $1H$  multiples until the EM responses practically do not change. Visually from the corresponding responses we choose  $x_{\text{gap}} = 10H$ . We repeat the procedure for setting  $y_{\text{gap}}$ : using  $H_{\text{air}} = 5H$  and  $x_{\text{gap}} = 10H$ , we gradually increase  $y_{\text{gap}}$  using  $1H$  multiples until EM responses practically do not change. Visually we choose  $y_{\text{gap}} = 10H$ . For setting  $H_{\text{air}}$  we repeat the same procedure: using  $x_{\text{gap}} = 10H$  and  $y_{\text{gap}} = 10H$ , we visually choose  $H_{\text{air}} = 12H$ . EM responses when varying simulation bounding box dimensions are illustrated in Figs. 5-7.

### 4.1 Simulation Bounding Box Perturbation

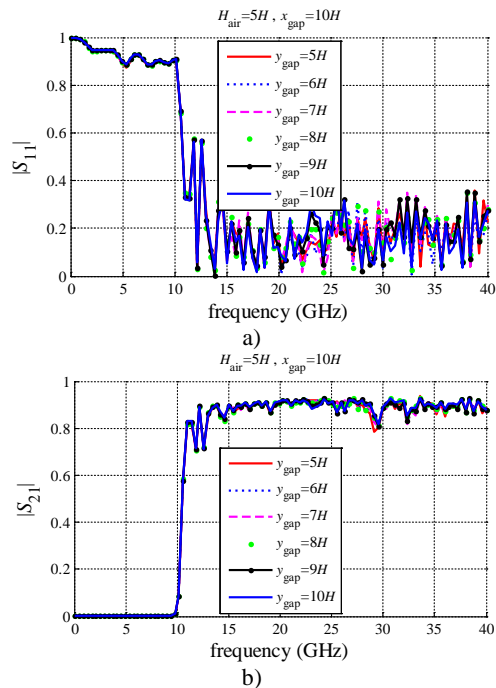
We test the simulation bounding box to verify if it is properly configured is by perturbing the simulation bounding box dimensions. We perturb each side of the box by varying  $\pm 5\%$  around the final values of  $H_{\text{air}}$ ,  $y_{\text{gap}}$  and  $x_{\text{gap}}$ . If simulation bounding box is properly configured, these perturbations should not significantly modify the EM responses of the structure under study.

The simulation bounding box configuration was done using a Resol 0 meshing scheme (to speed up the process). The same procedure can be used for Resol 1 and Resol 2 meshing

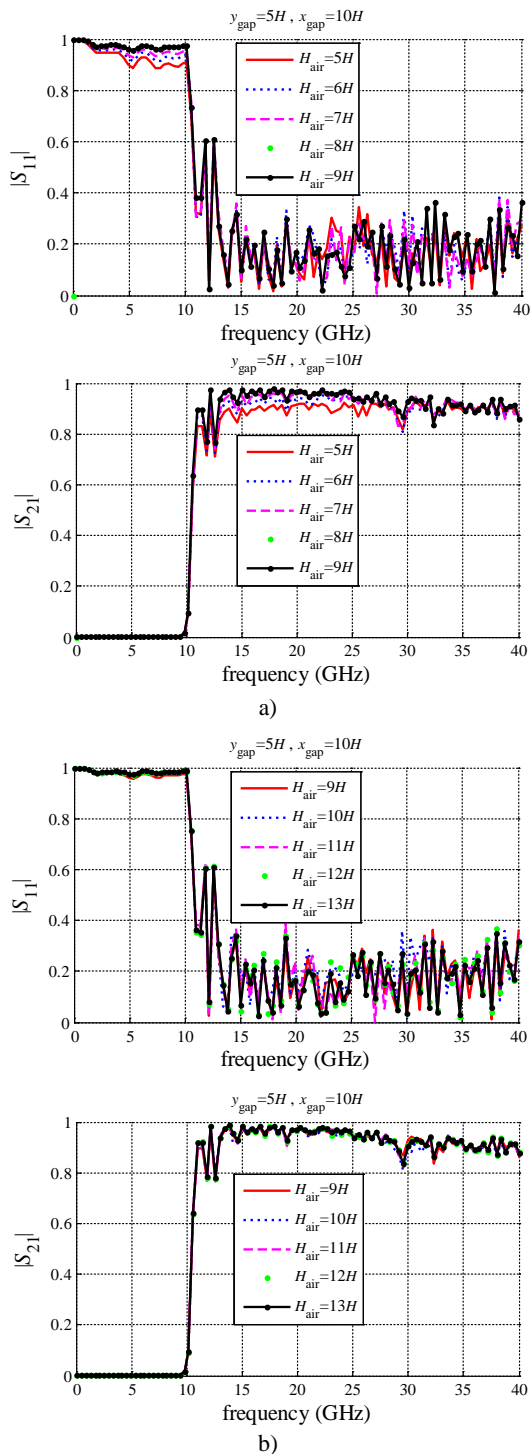
schemes. Perturbation test for Resol 0 is illustrated in Fig. 8.



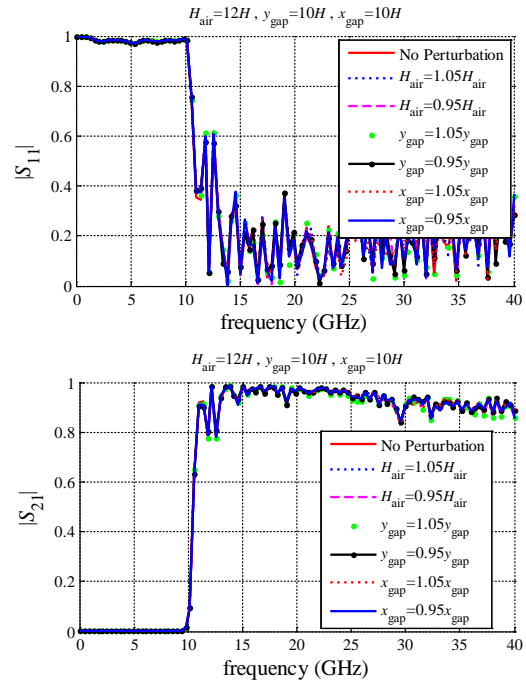
**Figure 5.** Simulation bounding box configuration.  $x_{\text{gap}}$  swept from  $5H$  to  $10H$  using  $H_{\text{air}} = 5H$  and  $y_{\text{gap}} = 5H$ . a)  $|S_{11}|$  and b)  $|S_{21}|$ .



**Figure 6.** Simulation bounding box configuration.  $y_{\text{gap}}$  swept from  $5H$  to  $10H$  using  $H_{\text{air}} = 5H$  and  $x_{\text{gap}} = 10H$ . a)  $|S_{11}|$  and b)  $|S_{21}|$ .



**Figure 7.** Simulation bounding box configuration. a)  $H_{\text{air}}$  swept from  $5H$  to  $9H$  and b)  $H_{\text{air}}$  swept from  $9H$  to  $13H$  using  $x_{\text{gap}} = 10H$  and  $y_{\text{gap}} = 10H$ . Final simulation bounding box dimensions are set to  $H_{\text{air}} = 12H$ ,  $x_{\text{gap}} = 10H$  and  $y_{\text{gap}} = 10H$ .



**Figure 8.** Perturbation box test using Resol 0 to assure final simulation bounding box dimensions do not affect EM responses.

## 5. Final Model Results

Using again Resol 0 and the properly configured simulation bounding box,  $|S_{11}|$  and  $|S_{21}|$  responses for the SIW interconnect with microstrip line transitions are illustrated in Fig. 9.

## 6. Conclusions

In this work we presented a procedure to properly configured COMSOL to achieve reliable EM responses for a SIW interconnect with microstrip line transitions.

Configuration procedure starts by defining a meshing scheme that allow us to use different mesh sizes for different domains in the model, as required. The meshing scheme is done by dividing the whole structure into five regions: ports, microstrip lines, microstrip tapered lines, SIW and global (remaining domains). For each region we define a meshing size considering the minimum value between a fraction of the wavelength and a fraction of the minimal geometric size in the region.

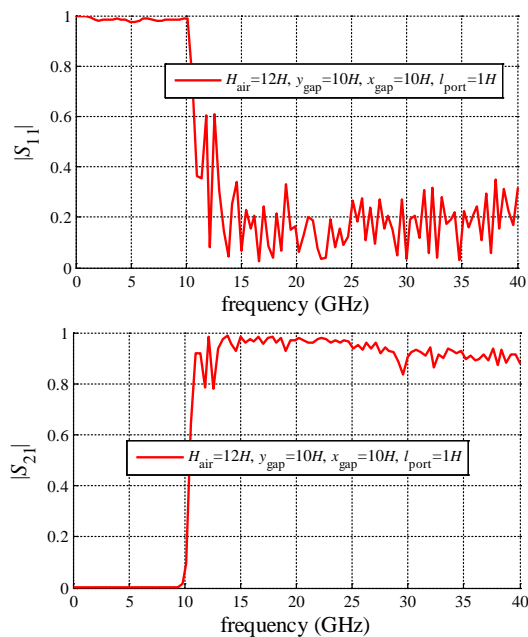
Once the meshing scheme is defined, we properly configure the simulation bounding box

to avoid EM interferences. We start by defining suitable simulation bounding box dimensions and gradually increasing each dimension until visually the EM responses are no longer modified. Initial simulation bounding box dimensions are  $H_{\text{air}} = x_{\text{gap}} = y_{\text{gap}} = 5H$  and final dimensions are  $H_{\text{air}} = 12H$ ,  $x_{\text{gap}} = 10H$  and  $y_{\text{gap}} = 10H$ .

To ensure that we have a reliable simulation bounding box, we perturb each dimension by  $\pm 5\%$  and confirm that the EM responses of the model are not affected, as expected.

By having reliable EM responses, the final SIW structure can be used for further studies.

of 3D EM model configuration on the direct optimization of microstrip structures,” in *COMSOL Conf.*, Boston, MA, Oct. 2013, pp. 1-5.



**Figure 9.** EM responses for the SIW interconnect using microstrip line transitions using Resol 0 and final simulation bounding box dimensions.

## 7. References

- [1] J. E. Rayas-Sánchez and J. A. Jasso-Urzúa, “EM-based optimization of a single layer SIW with microstrip transitions using linear output space mapping,” in *IEEE MTT-S Int. Microwave Symp. Dig.*, Boston, MA, Jun. 2009, pp. 525-528.
- [2] Z. Brito-Brito, J. E. Rayas-Sánchez, J. C. Cervantes-González, and C. A. López, “Impact