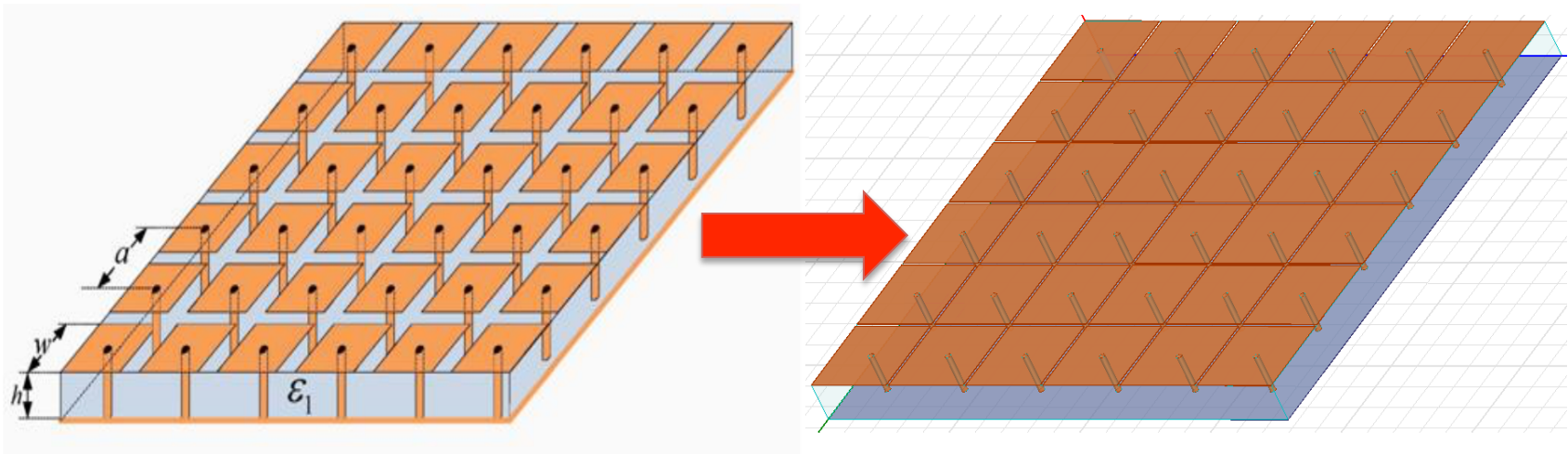


Metamaterial Simulation



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Agenda

- Discuss objectives of the project including design parameters.
- A brief review of image theory for PECs and PMCs.
- Look at metamaterials theory as it applies to Artificial Magnetic Conductors (AMC).
- See how the metamaterial structure was created in HFSS.
- Look at boundary conditions, excitation method, and the generated mesh.
- Compare and discuss initial results (default values).
- Compare and discuss final results after tuning of design parameters.

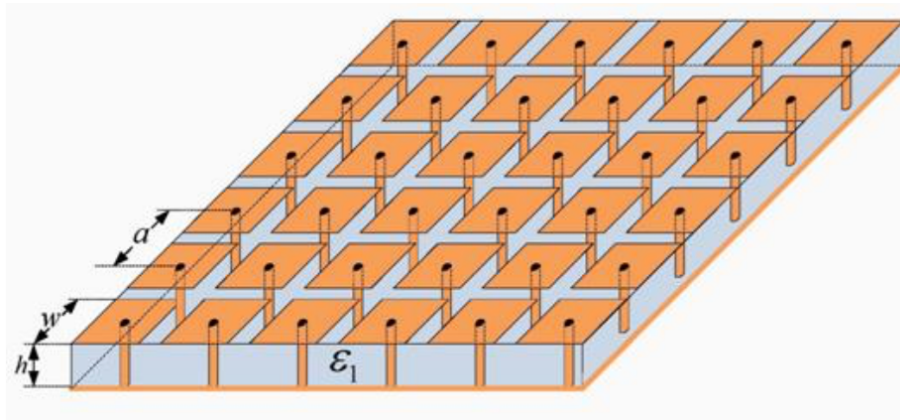


Objectives

- Use HFSS to simulate a mushroom textured metamaterial structure.
- Structure is to exhibit PMC characteristics between 10-14GHz with center frequency of 12GHz.
- Dimensions should be variables in the design environment to tune structure.
- Dielectric is Rogers RT/Duroid, $\epsilon_r = 2.2$.
- Conductive square patches of width w connected to ground plane with posts (vias).
- Excite structure with TEM wave with frequency sweep from 4GHz to 20GHz.
- Examine the angle of the reflection coefficient (S_{11}) to see if it matches Balanis' results.
- Tune structure if required.



Objective: Design Parameters



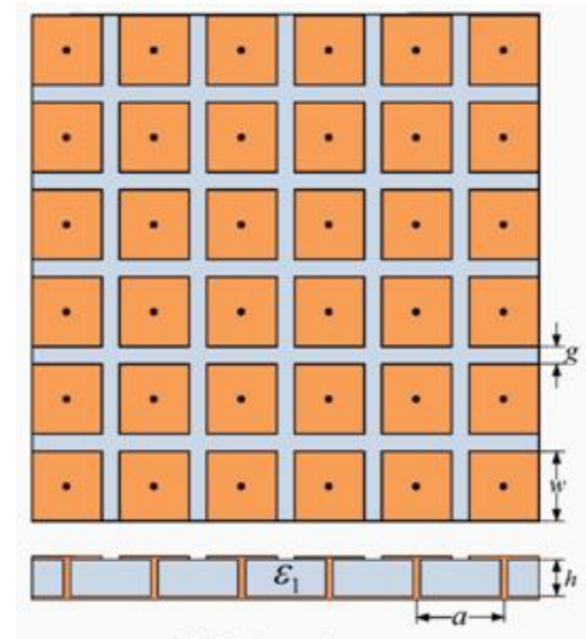
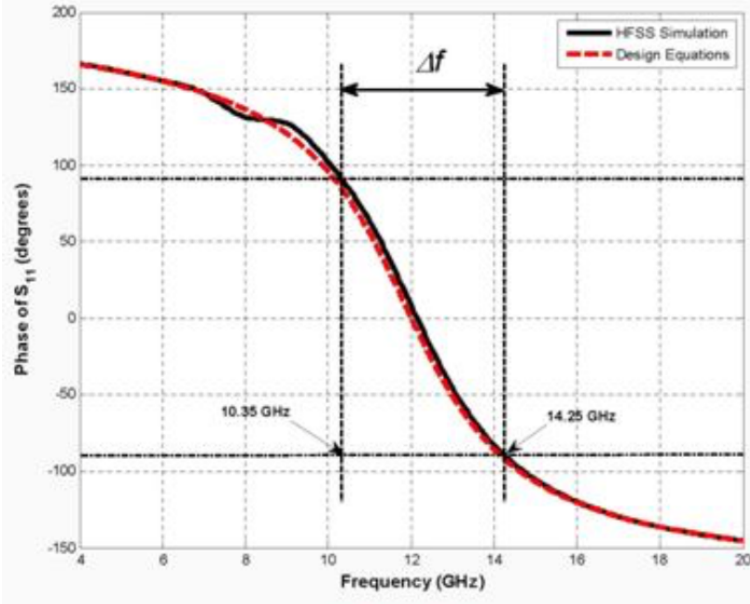
Initial parameters:

$$h = 1.3263\text{mm}$$

$$g = 0.1\text{mm}$$

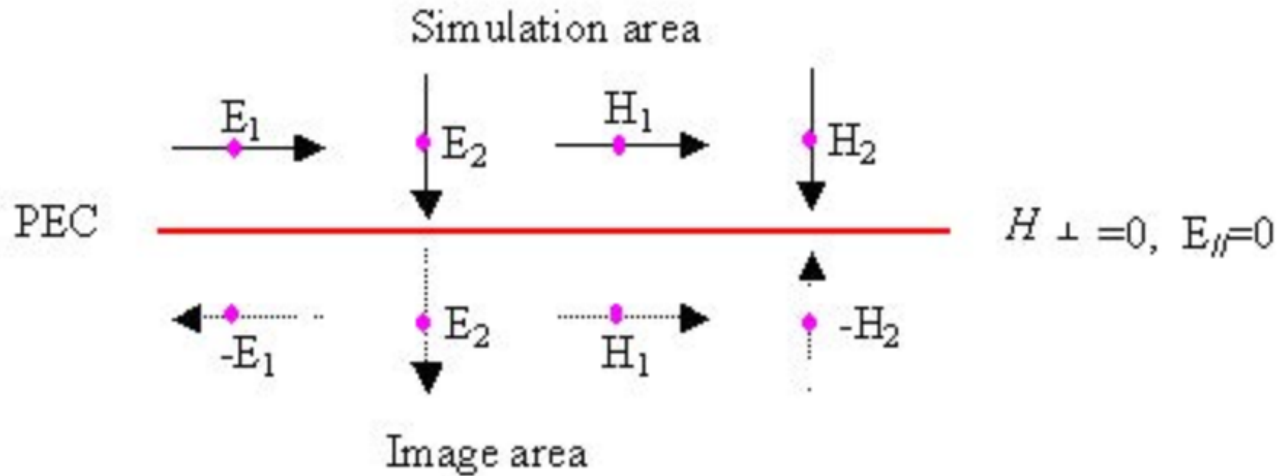
$$w = 2.85\text{mm}$$

$$a = w + g = 2.95\text{mm}$$



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Image Theory (PEC)

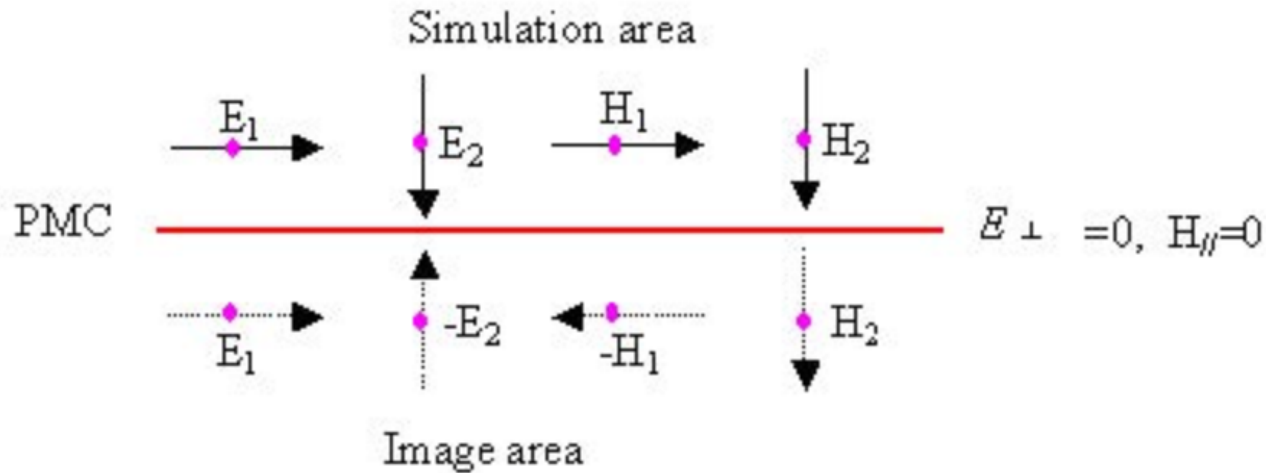


Placing *electric* dipoles above a PEC in a **normal** orientation causes no change in the polarity of the virtual (reflected) image ($S_{11} = +1$). This reflection can enhance the signal.

Placing the *electric* dipole **tangentially** along the PEC gives $S_{11} = -1$ which destructively interferes with the signal.



Image Theory (PMC)



Placing *electric* dipoles above a PMC in a **tangential** orientation causes no change in the polarity of the virtual (reflected) image ($S_{11} = +1$). This reflection can enhance the signal.

This is a desired effect since it is a low profile design and enhances the signal.

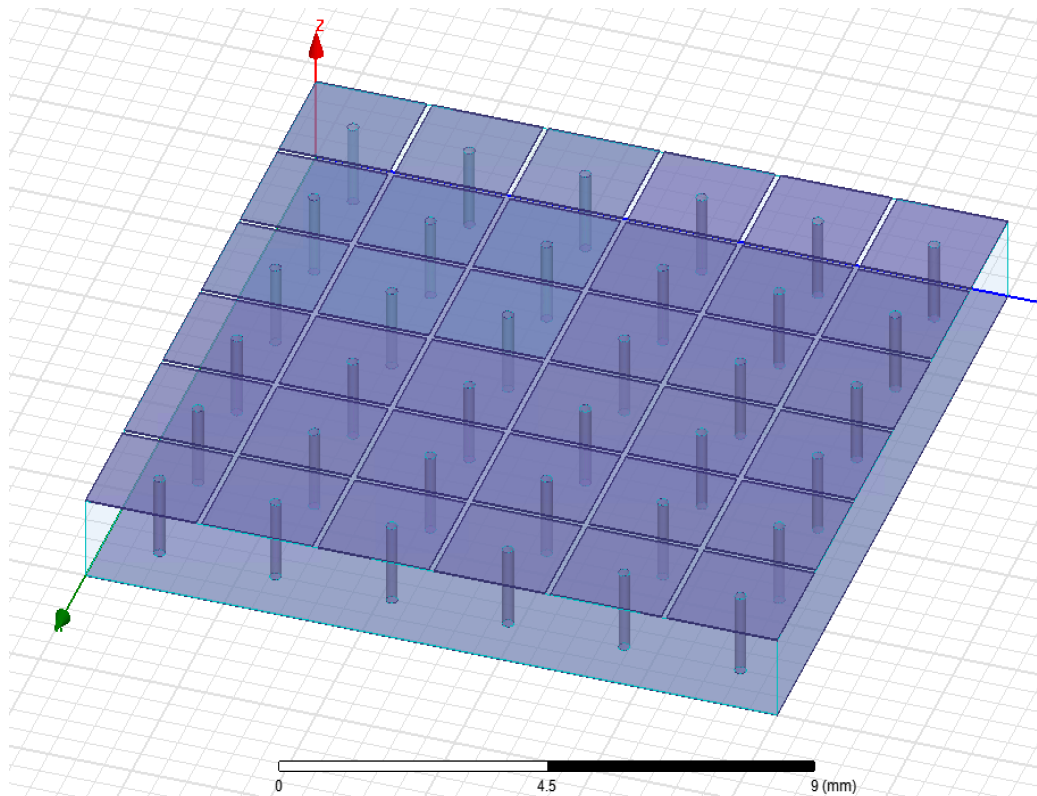


Metamaterial Theory

- PECs exist in some form in nature (Superconductors) as well as very good conductors that approach perfect conduction.
- PMCs do not exist in nature.
- PMCs can be simulated with AMCs (Artificial Magnetic Conductors).
- These periodic structures cancel tangential magnetic fields above them similar to PECs effect on E fields.
- They only operate over a given bandwidth.



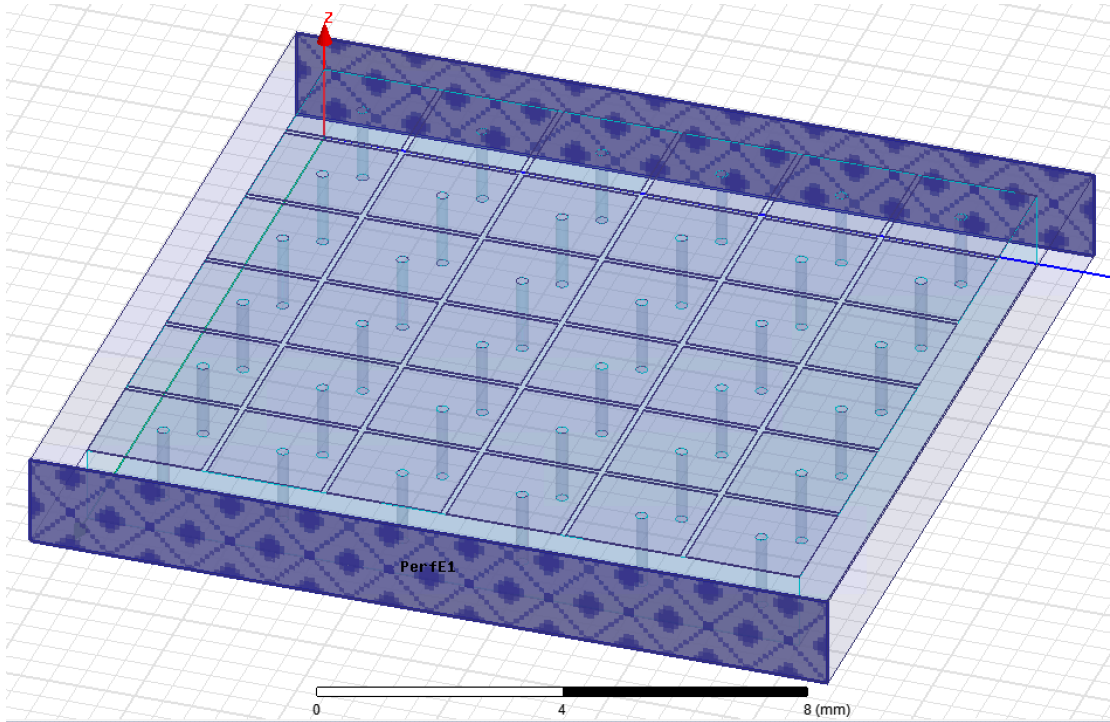
Step 1: Create Structure



- 36 patches connected with vias to ground plane below.
- Superstrate components made from copper.
- Dielectric substrate made of Rogers RT/Duroid, $\epsilon_r = 2.2$.
- Patches and vias combined and replicated with copy + paste.
- Dielectric subtracted from structure to create holes.
- Patch width, gap, and height are variables.



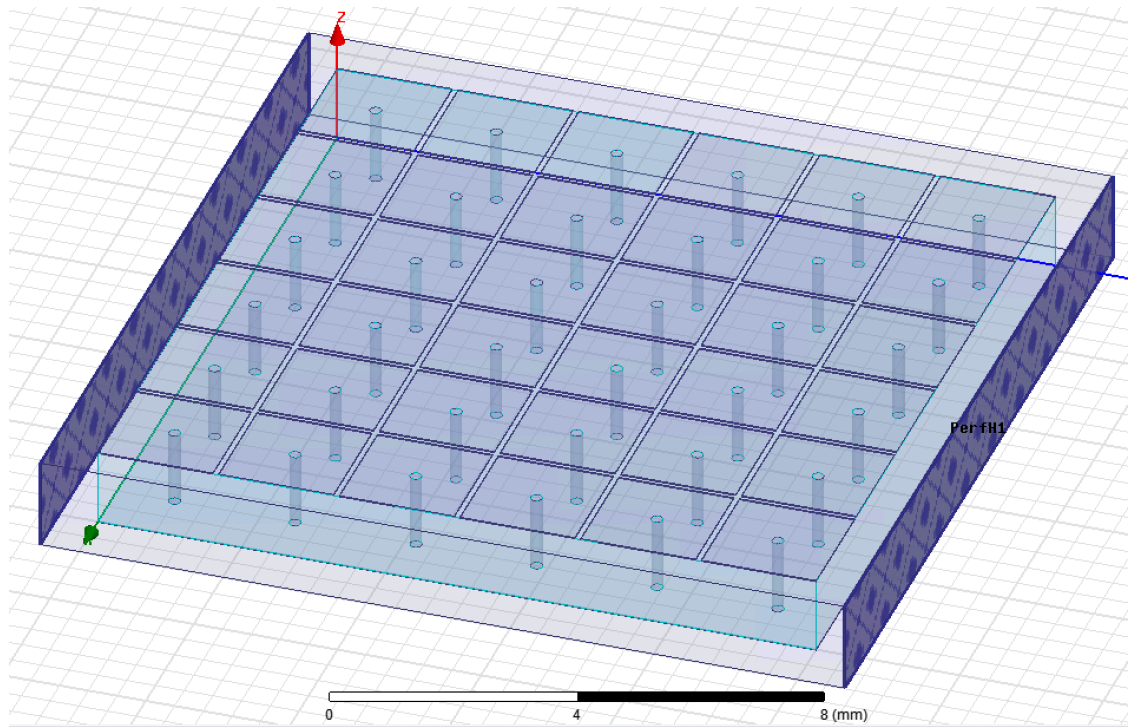
Step 2: Define Boundaries



- Air box surrounds structure.
- Perfect Electrical Conducting walls along y-axis of air box



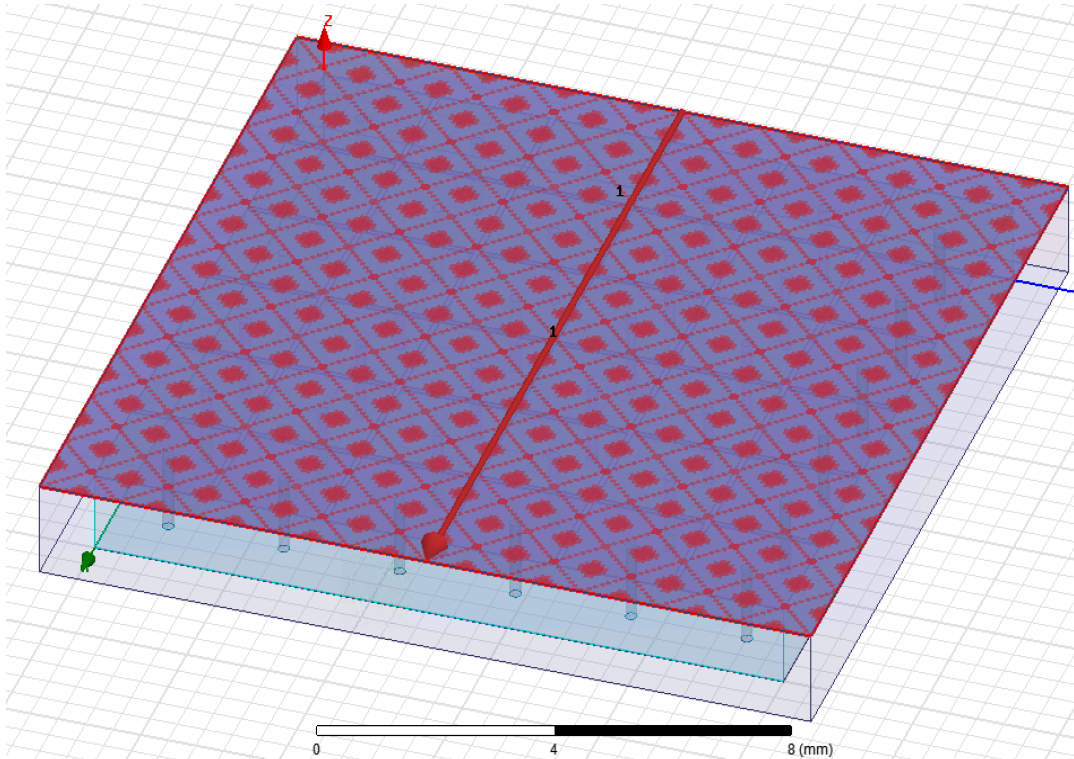
Step 2: Define Boundaries



- Perfect Magnetic Conducting walls along x-axis of air box.
- Radiation boundary on bottom



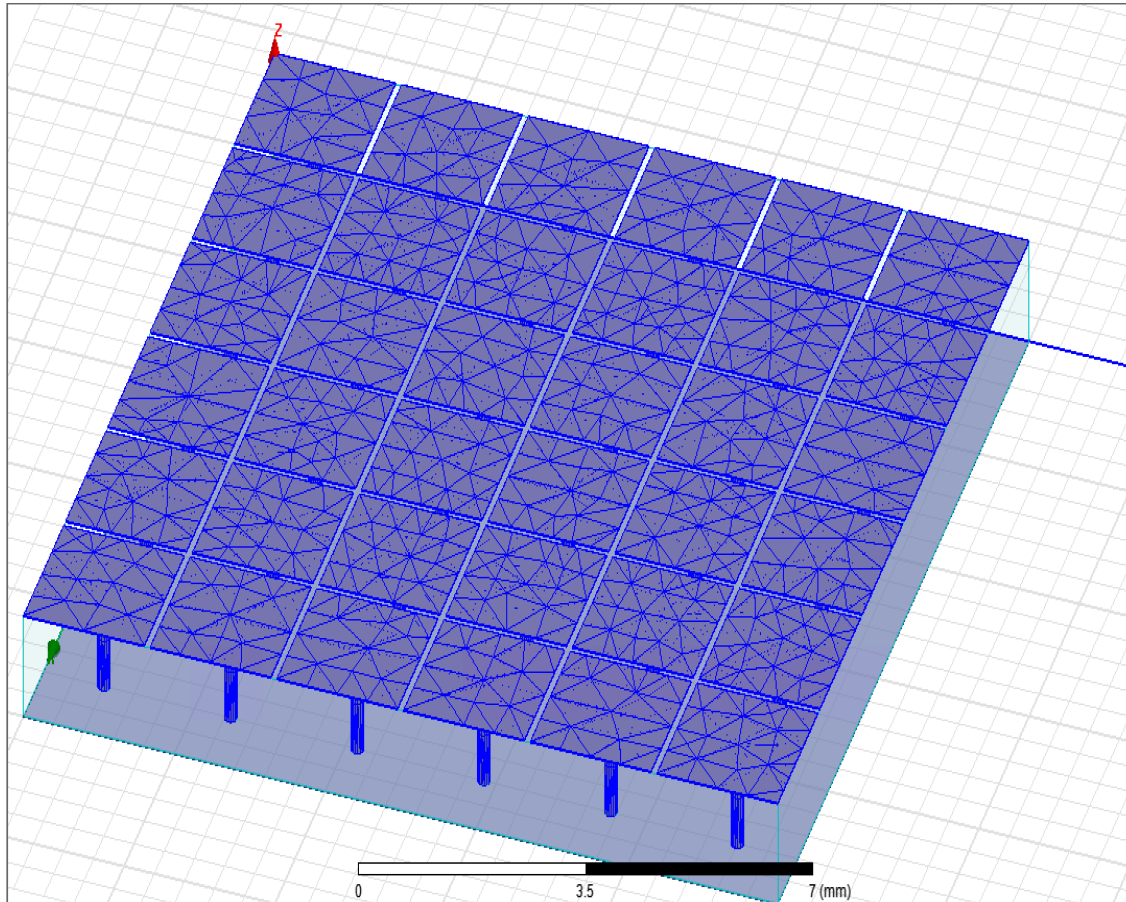
Step 3: Define Excitation



- E field vector defined along excitation plane (top of air box)
- Boundaries and initial conditions create normally-incident TEM plane wave.



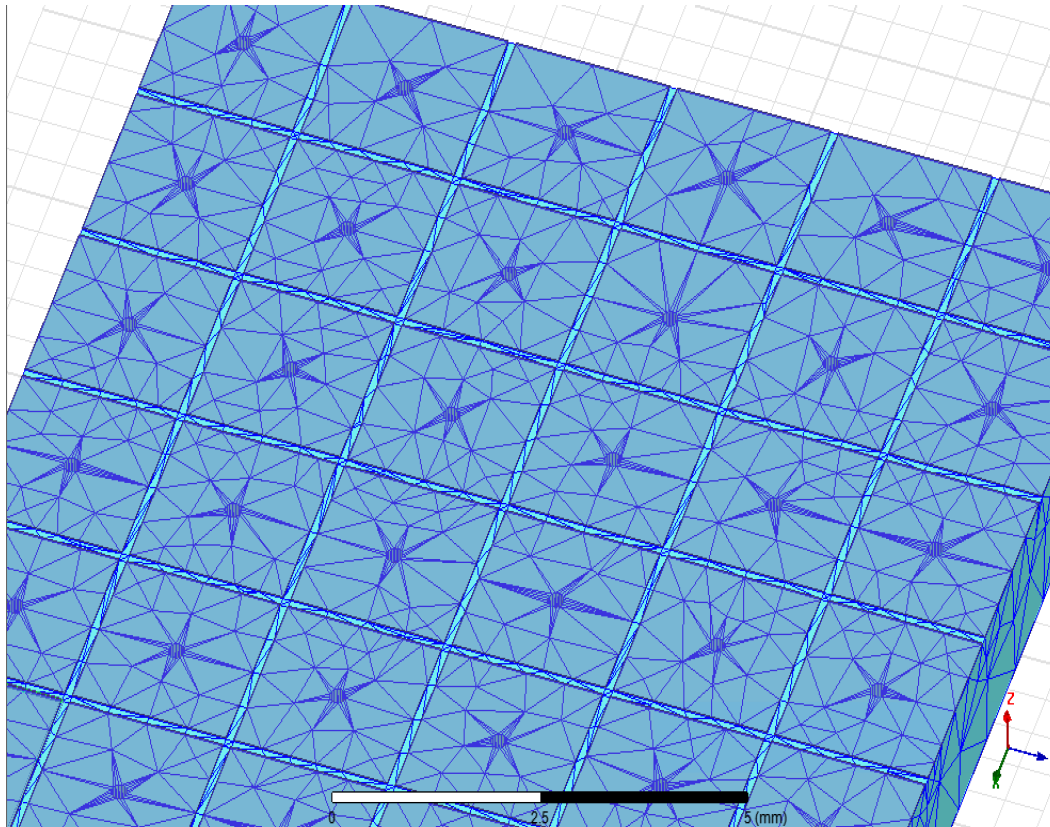
Step 3: Generate Mesh



Tetrahedral mesh
of patches and
vias.



Step 3: Generate Mesh

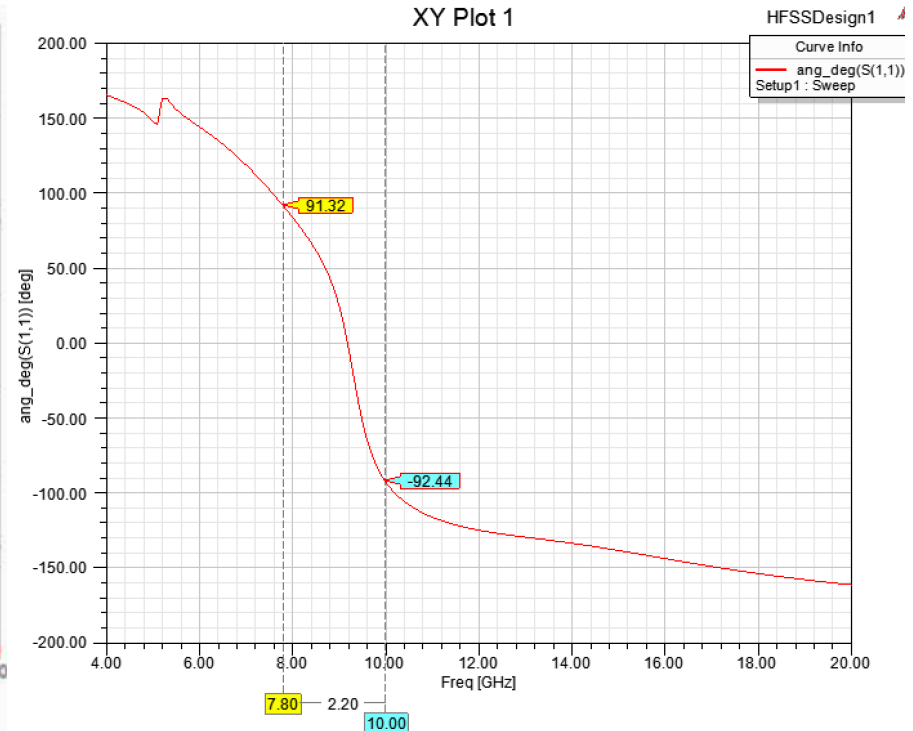
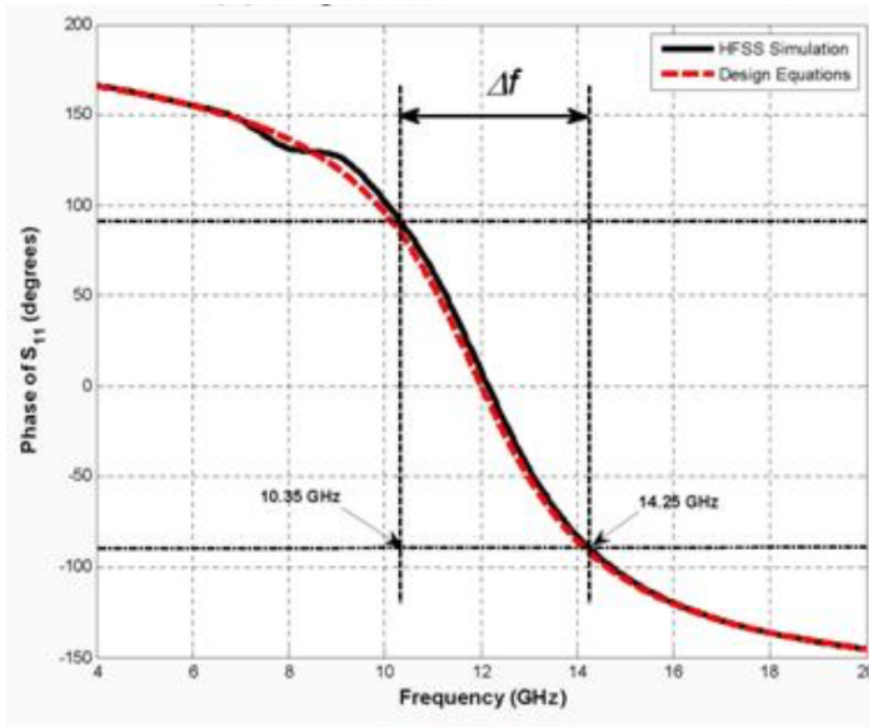


Tetrahedral mesh
of dielectric.



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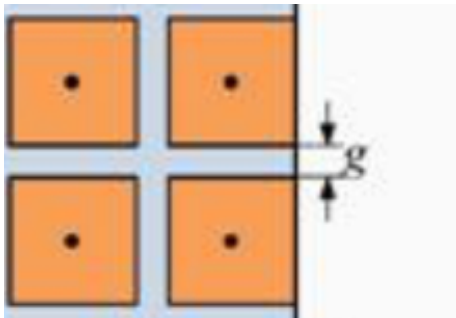
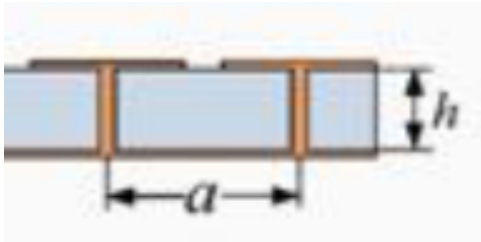
Analysis and Discussion



Balanis' plot on the left shows $\text{ang}(S_{11})=+90$ at 10.35GHz and -90 at 14.25GHz. Using the default values in HFSS results in the plot on the right, where $\text{ang}(S_{11})=+90$ at 7.8GHz and -90 at around 10GHz. The center frequency is 9.2GHz. **While this structure does exhibit AMC behavior, it is not over the correct bandwidth.**



Analysis and Discussion (cont.)



Dimensional values according Balanis:

$$h = 1.3263\text{mm}$$

$$w = 2.85\text{mm}$$

$$g = 0.1\text{mm}$$

$$a = w + g = 2.95\text{mm}$$

Dimensional values after tuning:

$$h = 1.3263\text{mm}$$

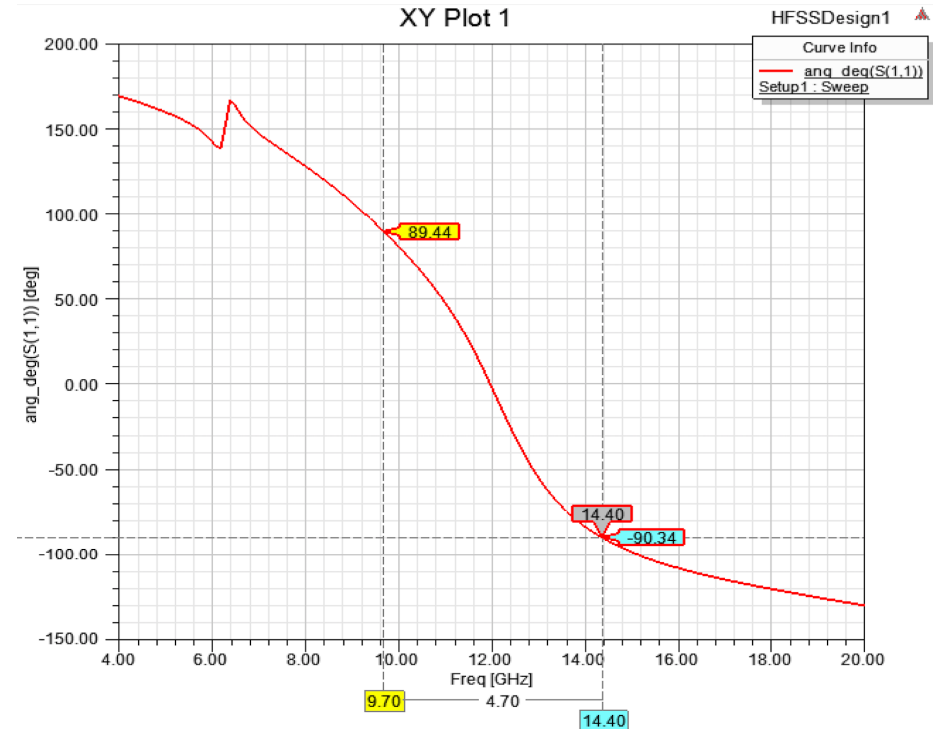
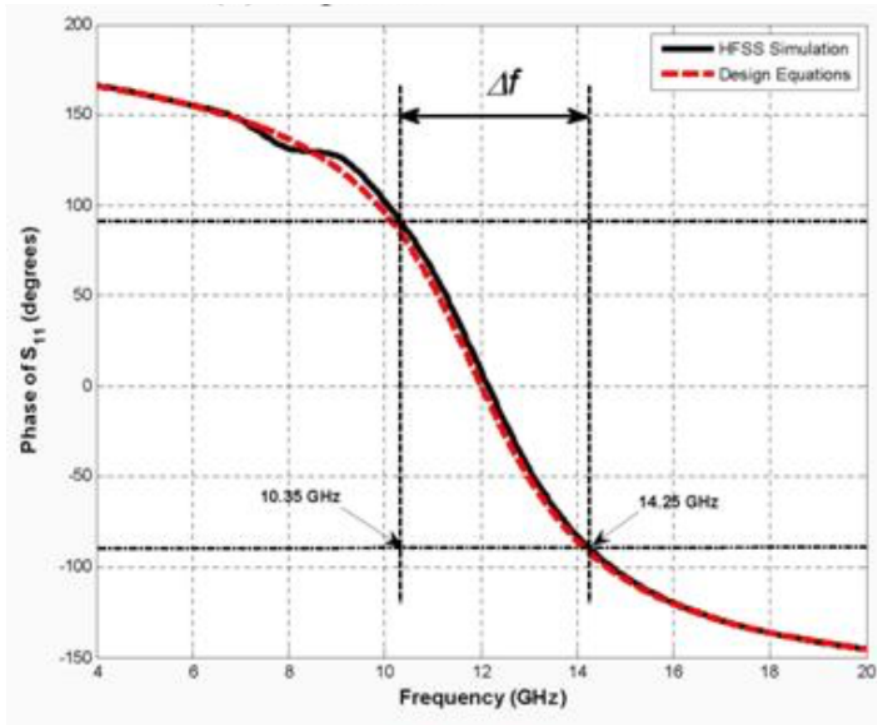
$$w = 2.005\text{mm}$$

$$g = 0.1\text{mm}$$

$$a = w + g = 2.105\text{mm}$$



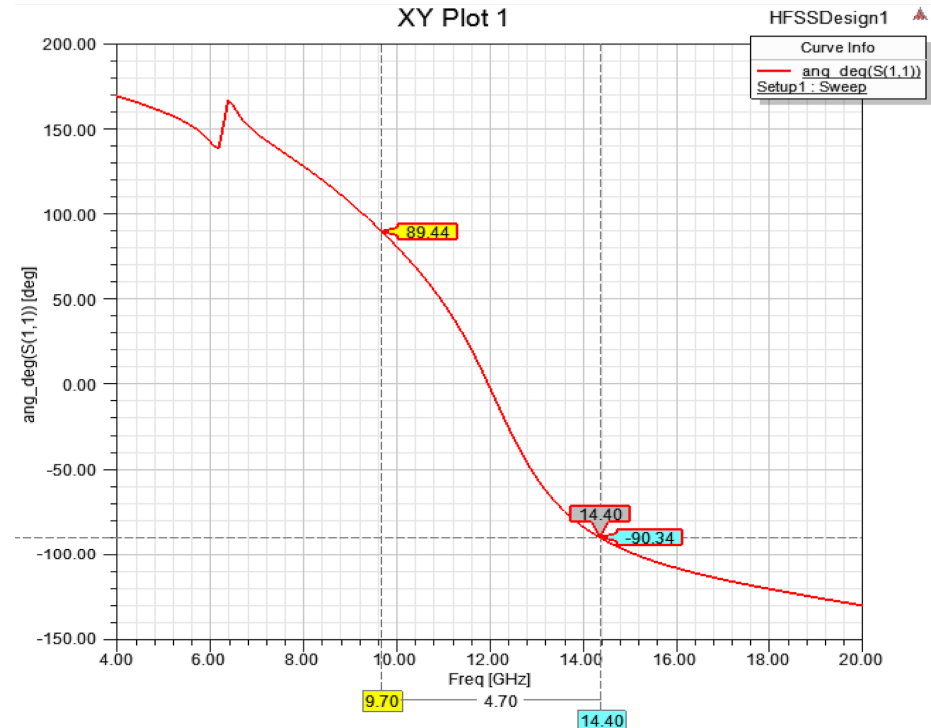
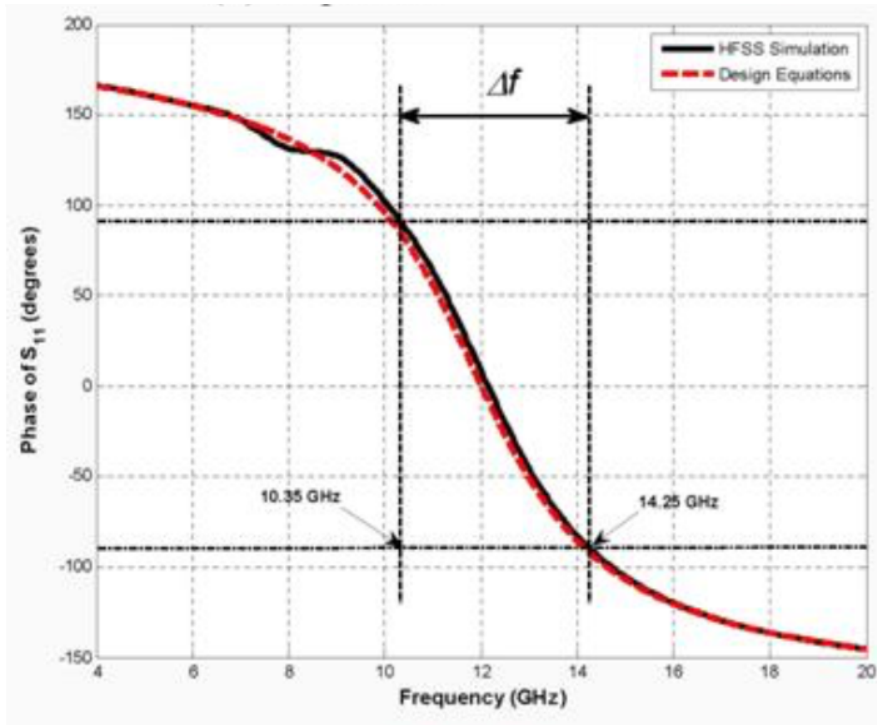
Analysis and Discussion (cont.)



Tuning the values for in HFSS results in the new plot on the right, where $\text{ang}(S_{11}) = +90$ near 9.7GHz and -90 at around 14.4GHz. The center frequency is 12GHz. There is an irregularity in both plots at the lower end of the spectrum. Balanis' is around 8GHz, where the present simulation has it around 6.5GHz and more pronounced.



Analysis and Discussion (cont.)



Although the two bandwidths are close, the exact bandwidth of Balanis' structure could not be matched while also maintaining the center frequency of 12GHz. For this design it was decided that the center frequency of 12GHz was most important so the structure was simulated to achieve that result.



Analysis and Discussion (cont.)

Some possible causes for the differences in results:

- Differences in excitation methods.
- Differences in air box dimensions.
- Differences in boundary conditions.
- Different types of waveports.
- Different diameters of connecting posts, or ratios of patch widths to post diameters.



References

- [1] C. A. Balanis, “Rectangular Cross-Section Waveguides and Cavities,” in *Advanced Engineering Electromagnetics*, Wiley, 2012 ch. 8, sec 8.8.4.

