Longitudinally Slotted Rectangular Waveguide

Introduction

In this tutorial, a longitudinal shunt slot oriented along the broad wall side of a rectangular WR-975 waveguide is analyzed using the HFSS simulation software. The slot will cause the waveguide to radiate and acts as an antenna. Results obtained from HFSS are compared to those obtained from the Finite Difference Time Domain (FDTD) method [1] and the Method of Moments (MoM) [2]. Excellent agreement has been achieved which validates the suitability of HFSS for handling slotted waveguide problems.

A Brief description of the structure used in this tutorial is given below:

All measurements are in centimeters. $\lambda = c/f = 0.32787$ m, where λ is the free space wavelength in m, c is the speed of light (3×10^8 m/s), and $f = 915\times10^6$ is the frequency in Hz . The slot is symmetrically oriented half away along the waveguide and is positioned at an offset of 10 cm from the center line of the broad face. The pertinent dimensions of the problem, which is depicted in Figure 1, are as follows:

- Standard WR-975 waveguide, of length, $L = 3\lambda_g$, where $\lambda_g = 43.74273$ cm is the waveguide wavelength at 915 MHz, width, $W = 24.765$ cm, and height, $H = W/2 = 12.3825$ cm.
- A rounded-end slot with an initial length of $\lambda/2$ is considered first. The slot length will be optimized to achieve resonance, and the width of the slot is fixed at $\lambda/20$.

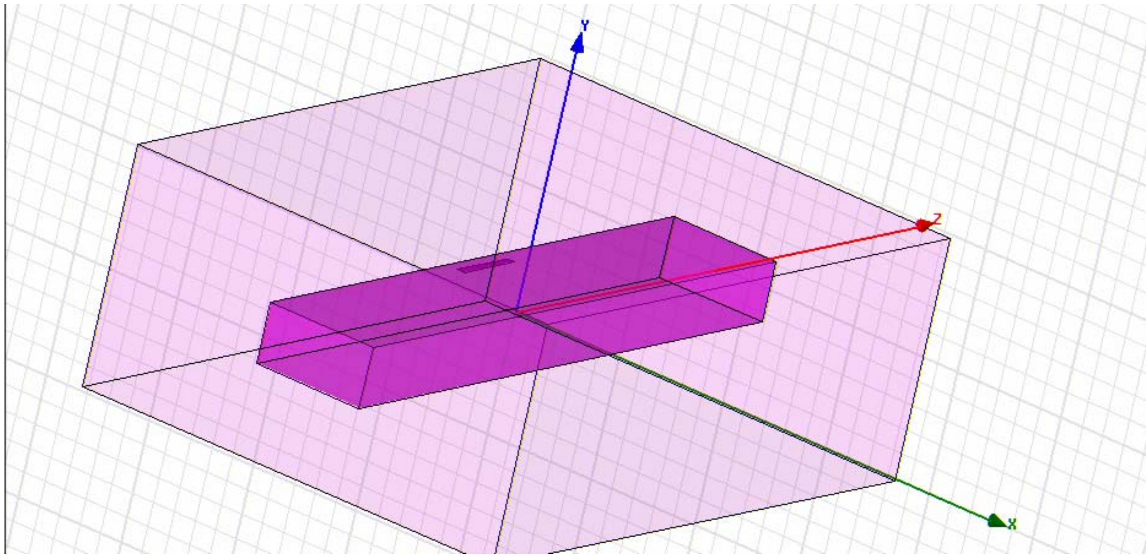


Figure 1: The slotted waveguide geometry

SIMULATION AND PARAMETERIZATION PROCEDURE

Open HFSS and save a New Project

How to start HFSS?

HFSS should be installed on the computer or station you are working on. There should be an HFSS icon on the desktop you can double click on it to launch HFSS, or you can go to "**Start**" button on the lower left corner of your screen, click on it, then go to "**Programs**" button and a list of programs will pop up. Go to "**Ansoft<< HFSS 9<< HFSS 9**".

How to Open a New Project?

As you start HFSS v 9, a project is listed in the project tree in the **Project Manager** window and is named **project1** by default. Project definitions, such as material assignment, boundary conditions, and excitation ports are stored under the project name.

Save the Project

On the **File** menu, click **Save As.** Use the file browser to locate the folder in which you want to save the project, such as **C:\Ansoft\HFSS9\Projects**, and then double-click the folder's name. Type **WG_slot** in the **File Name** text box and click **Save**. Now, the project is saved in the folder you selected by the file name with an extension of hfss, **WG_slot.hfss.**

Insert an HFSS Design

On the **Project** menu, click **Insert HFSS Design**. The new design is listed in the project tree. It is named **Model** by default. The **3D Modeler** window appears to the right of the Project Manager (Figure 2).

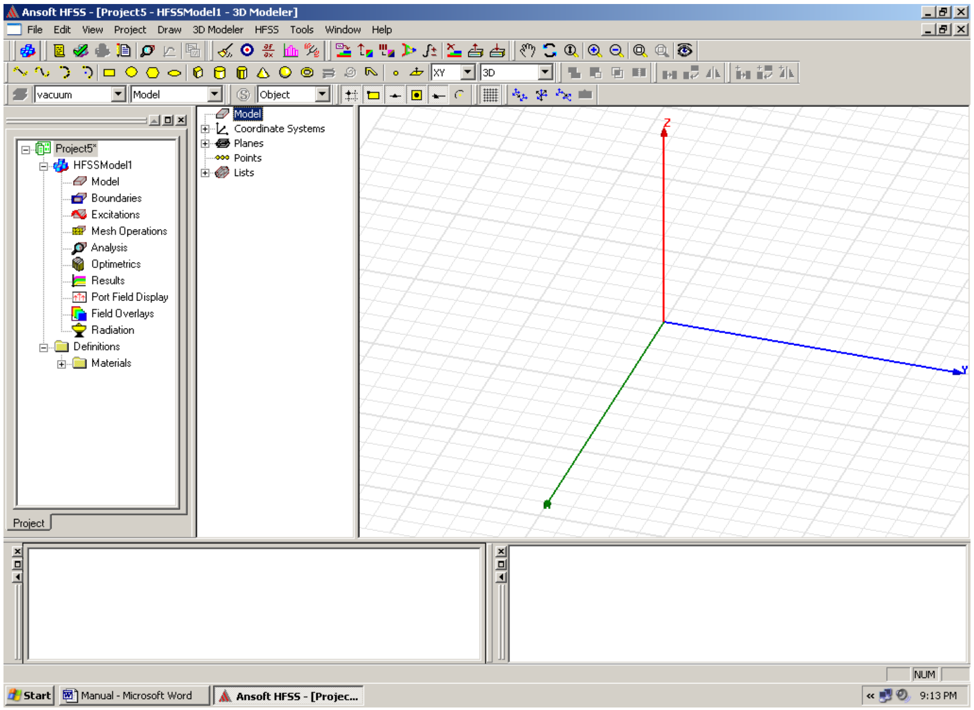


Figure 2: HFSS window

You can rename the model by right-clicking on the Model and then click **Rename**. Type the name then press **Enter**.

Select a Solution type

Now you need to specify the design's solution type. As you set up the design for analysis, available settings will depend upon the solution type. For this design, you will choose **Driven Modal** as the solution type, which is appropriate when calculating mode-based *S*-parameters of passive, high frequency components and antenna problems driven by a source.

On the **HFSS** menu, click **Solution Type**. In the **Solution type** dialog box, select **Driven Modal**, and then click **OK.**

Set the Drawing Units

You will now set the units of measurement for drawing the geometric model.

On the **3D Modeler** menu, click **Units.** In the **Set Model Units** dialog box, click **cm** in the **Select Units** pull-down list, and then click **OK** (Figure 3).

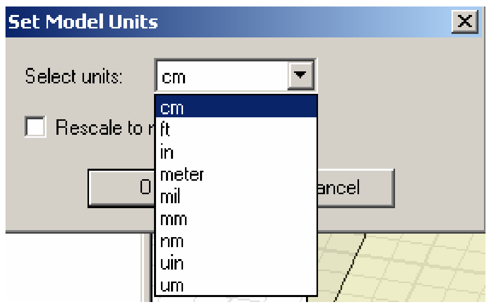


Figure 3: Set model units box

Creating the Model

Due to the symmetry, the origin of the Cartesian coordinate system (0, 0, 0) will be considered as the center of the object. Parameterization will be used to allow for various designs to be modeled in the future.

Drawing the WR-975 Waveguide

To draw the WR-975 waveguide, click  on the toolbar. Then draw a box by filling the following variables as shown in Figure 4.

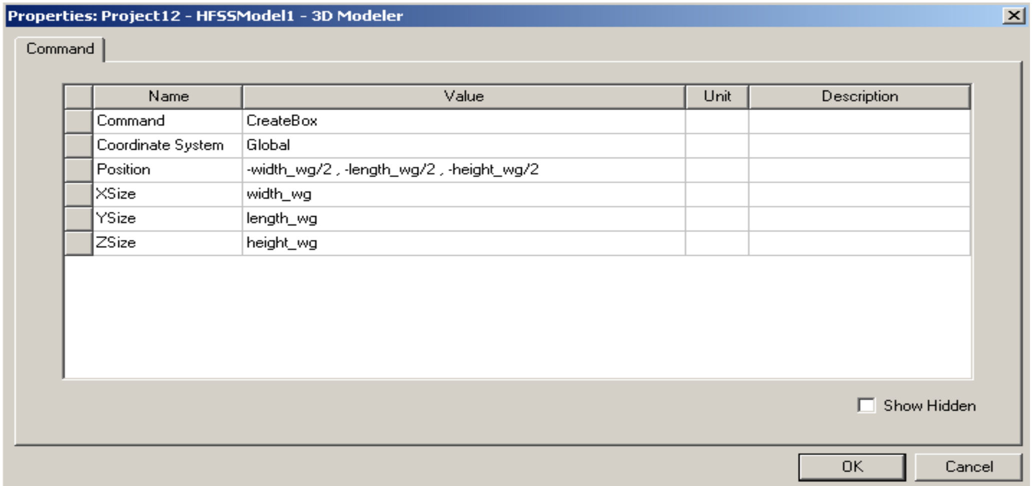


Figure 4: Create box pop up window.

Once you are done, another window will pop up. Fill in the values of the variables, **width_wg, length_wg,** and **height_wg.** Enter their values and then click on the **Attribute** tab and choose **transparency** and **color** of your own and click **Ok** when done**.** You will have the following (Figure 5).

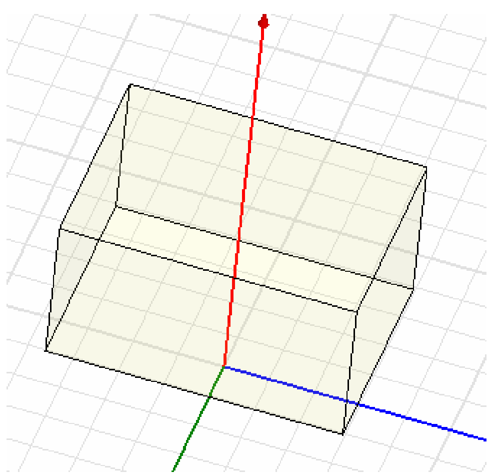


Figure 5: WR-975 waveguide box

Drawing the Slot

The slot consists of a box and two cylinders located one at each side. Let's start by drawing the box by clicking on  on the toolbar and follow the same procedure as before. Fill in the fields as seen in Figure 6.

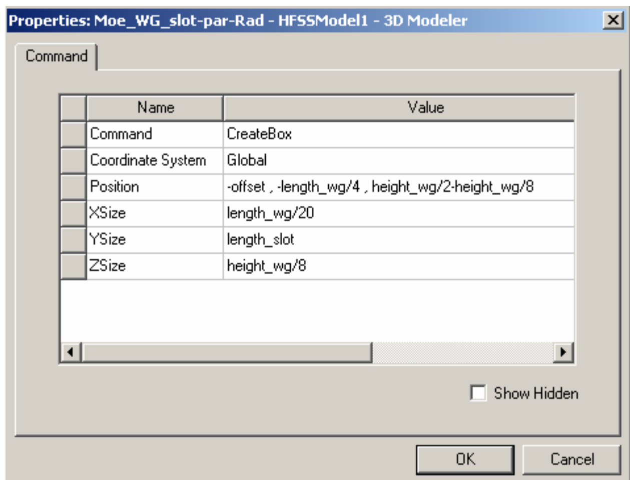


Figure 6: Create box pop up window

Notice that we have defined new variables, **offset** and **length_slot,** in the **position** and **YSize** fields, respectively. Remember to choose a **color** and **transparency** of your own and then click **Ok**. The value of the **offset** is 10 cm and that of **length_slot** is λ/2, which is 16.3935 cm. To check for the design variables, choose **HFSS<Design Properties** (Figure 7)**.**

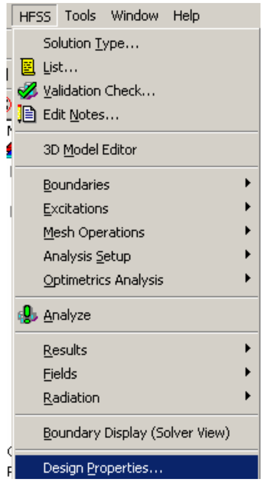


Figure 7: Design properties window

A window will pop up with the whole design variables used so far (Figure 8).

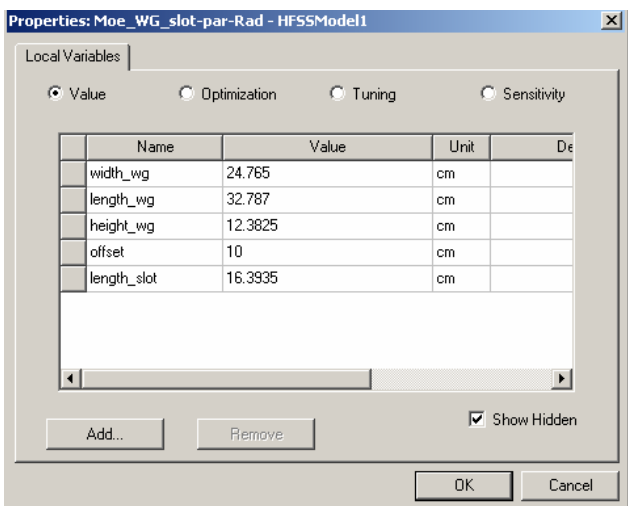


Figure 8: Design variables window

The model should look like the following (Figure 9):

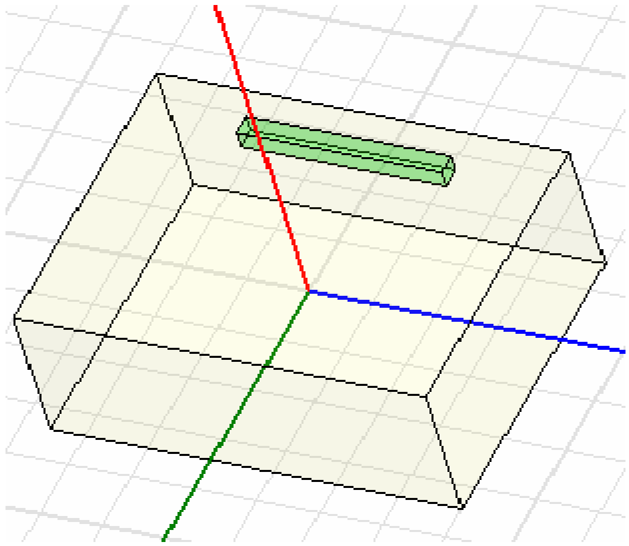


Figure 9: WR-975 and rectangular slot

Now, we have to add two cylinders at the two ends of the slot in order to create rounded-end slot geometry. Click  on the toolbar, fill in the fields as seen in Figure 10.

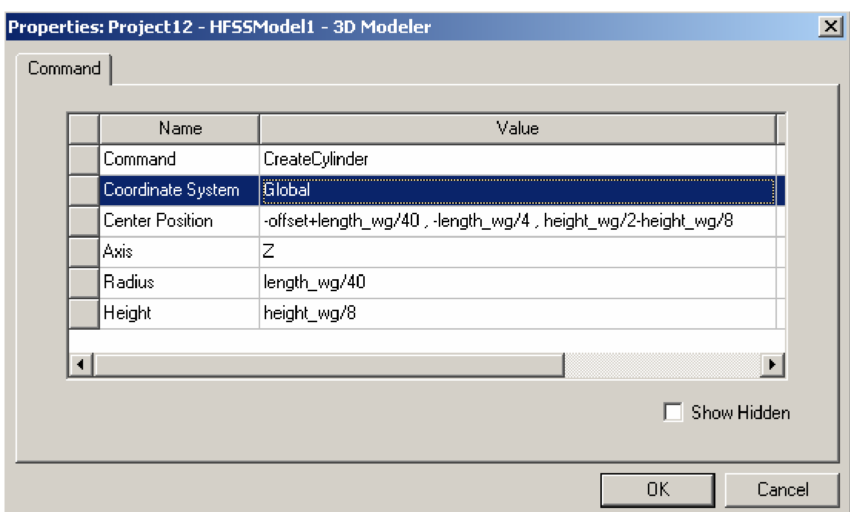


Figure 10: Cylinder coordinates

The model should look like Figure 11.

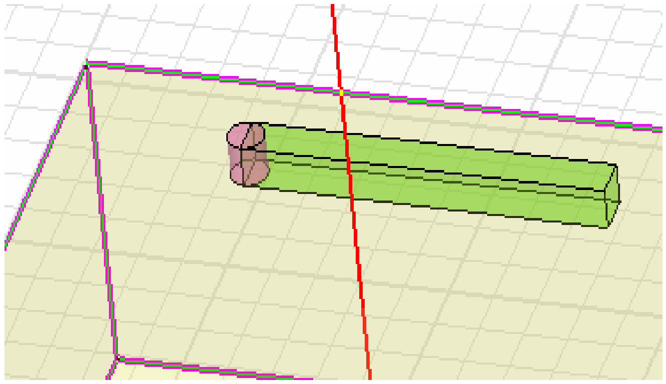


Figure 11: The rectangular slot with one cylinder

The next step is to duplicate the cylinder onto the other side of the rectangular slot. Select the Cylinder then **Edit< Duplicate< Mirror** and take the middle of the slot as the reference as shown in Figures 12 and 13, respectively.

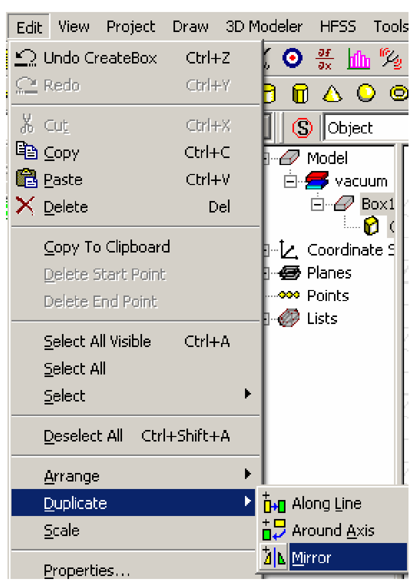


Figure 12: Mirror command

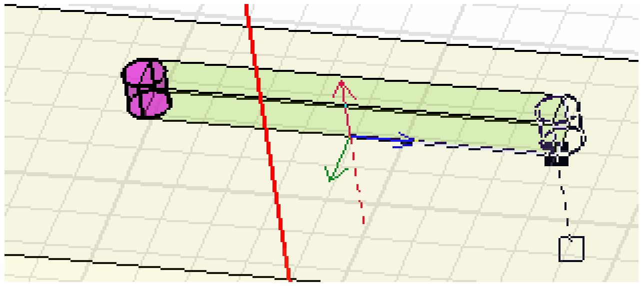


Figure 13: Duplicated cylinder with the mid point of the slot as the reference

We have the two cylinders and the rectangular slot. Unite the three objects together to form one object, the rounded-end slot. Click  on the toolbar and select the two cylinders and the slot. Go to **3D Modeler< Boolean< Unite** as shown in Figure 14.

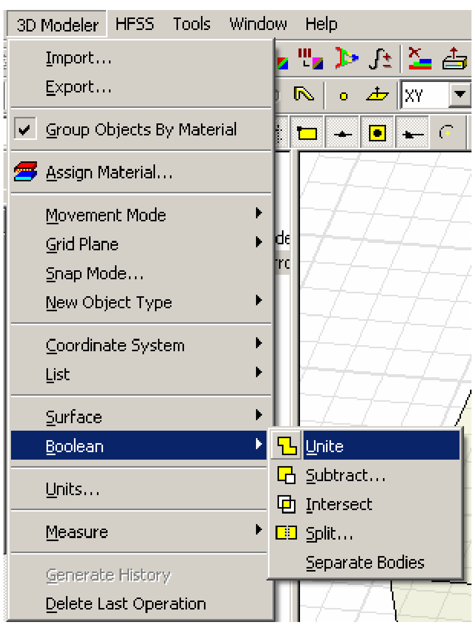


Figure 14: Uniting the two cylinders and the slot

The model should look like the following, Figure 15:

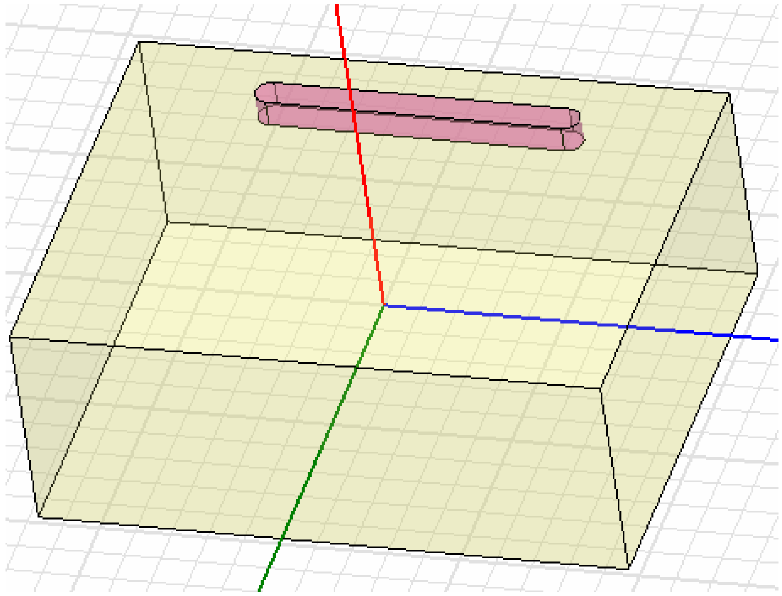


Figure 15: The two cylinders and the slot united

Select the faces of the slot and detach faces. Change mode to faces by clicking **F** on the keyboard and click  on the toolbar and choose the faces as in Figure 16.

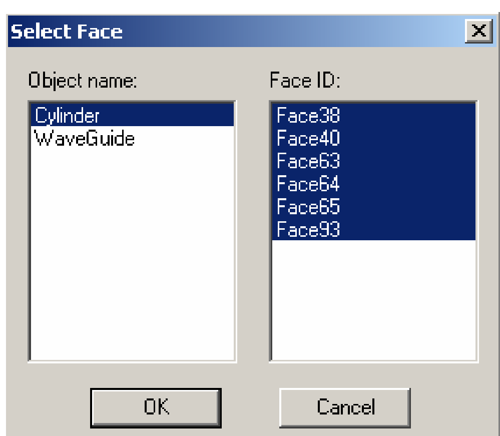


Figure 16: Selection of the slot faces

After the faces has been selected click **Ok,** then right click mouse and follow directions on Figure 17 to detach faces.

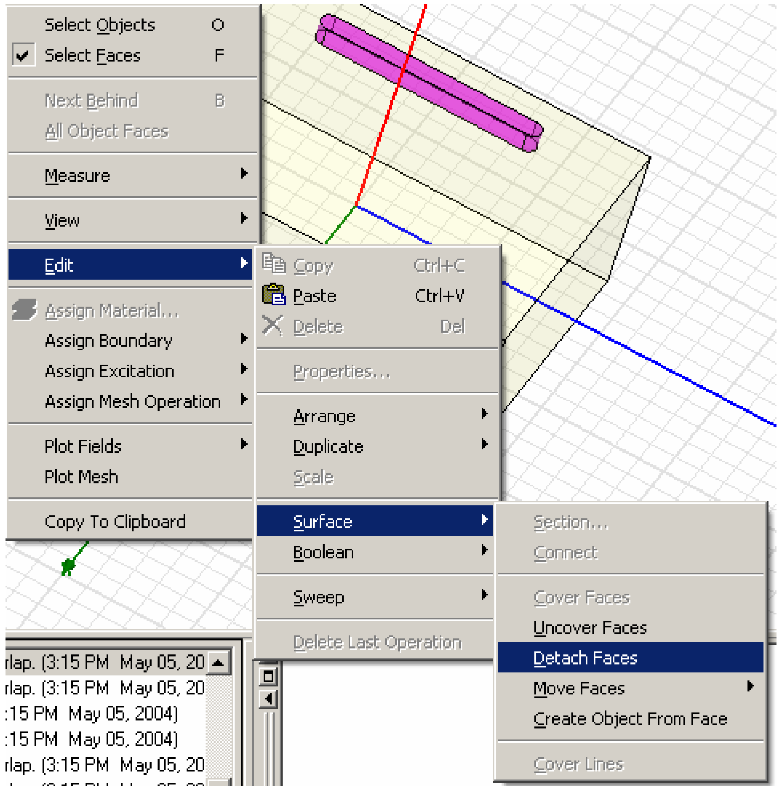


Figure 17: Detaching faces from the slot

From the model tree select **Detach1** (far side)**, Detach2** (closer side)**, Detach3** (left cylinder)**, Detach4** (bottom side)**,** and **Detach6** (right cylinder) then click **Delete** button on the keyboard. The resulting model is shown in Figure 18. Knowing that **Detach1, Detach2, Detach3, Detach4,** and **Detach6** are the names of the detached faces and between parentheses to what side it refers.

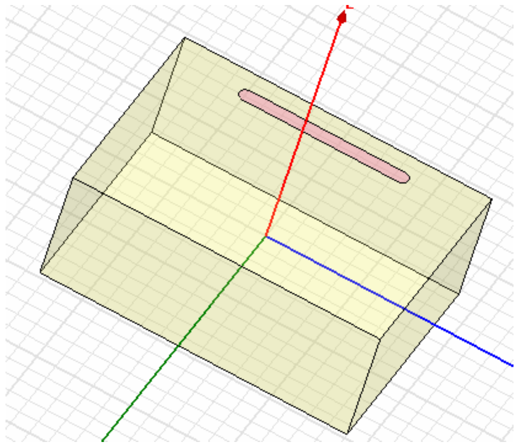


Figure 18: Current model with faces of the slot deleted

Assigning Boundaries

All faces of the waveguide are to be assigned **perfect E**, except for the right and left faces that are to be assigned excitations.

Click "**F"** on the keyboard to switch to **Face** mode, then click  on the toolbar and select the surrounding faces of the waveguide. Right-click and **Assign Boundary<** **Perfect E**. Leave name as default and click **Ok,** Figure 19.

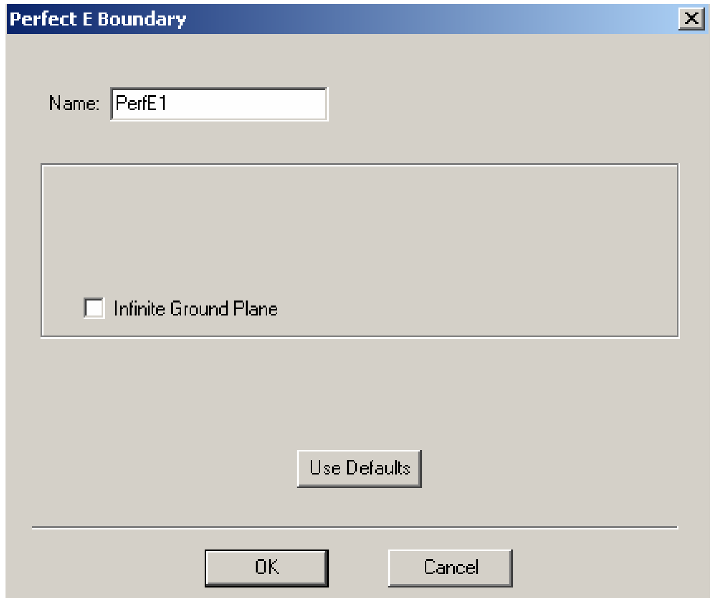


Figure 19: Perfect E assignment window

Now we select the **Detach5** (slot) in the same manner and assign perfect H. Leave the name as default and click **Ok**, Figure 20.

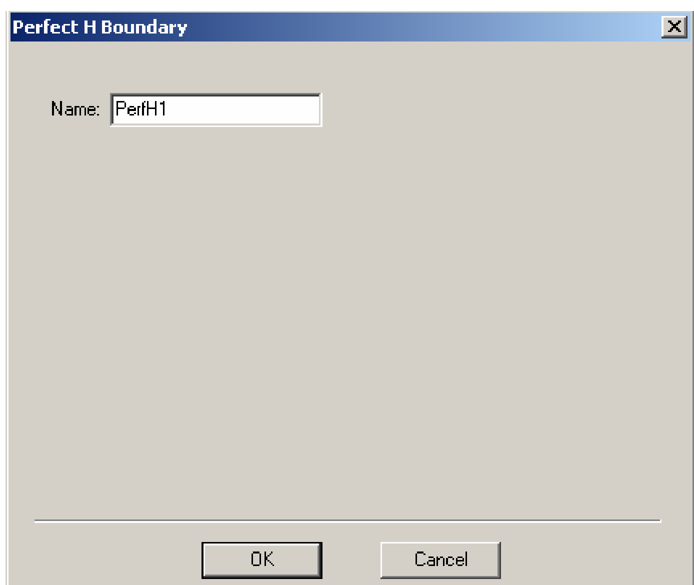


Figure 20: Perfect H assignment window

To make sure you assigned the boundaries, go to **Project Tree** window and double-click on boundaries and single-click on **PerfectE1,** Figure 21**.** Follow the same procedure and click on **PerfectH1,** Figure 22.

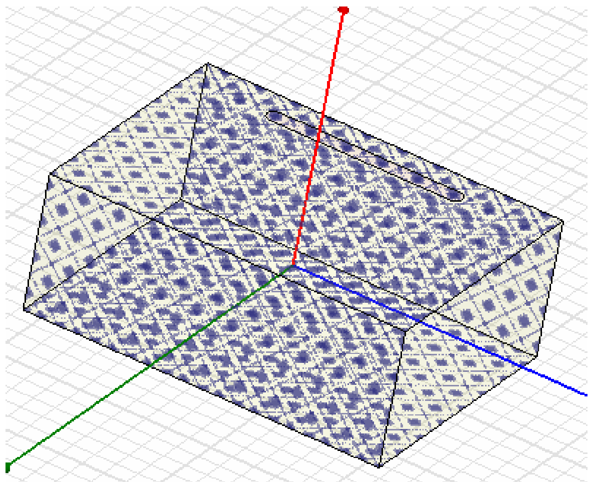


Figure 21: Perfect E1

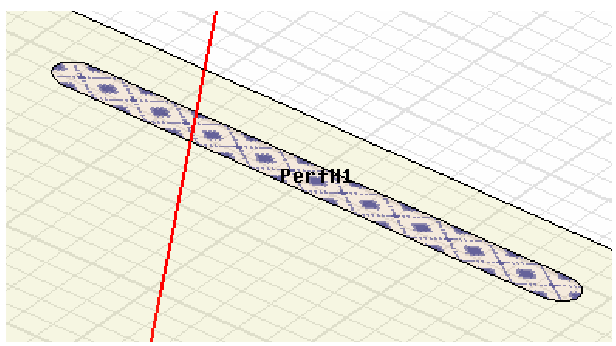


Figure 22: Perfect H1

A radiation boundary should be added to the model. In this case the radiation boundary is a box fixed symmetrically around the slotted waveguide.

Click  on the toolbar and follow same procedure for drawing 3-D object in HFSS, then have the fields filled as in Figure 23.

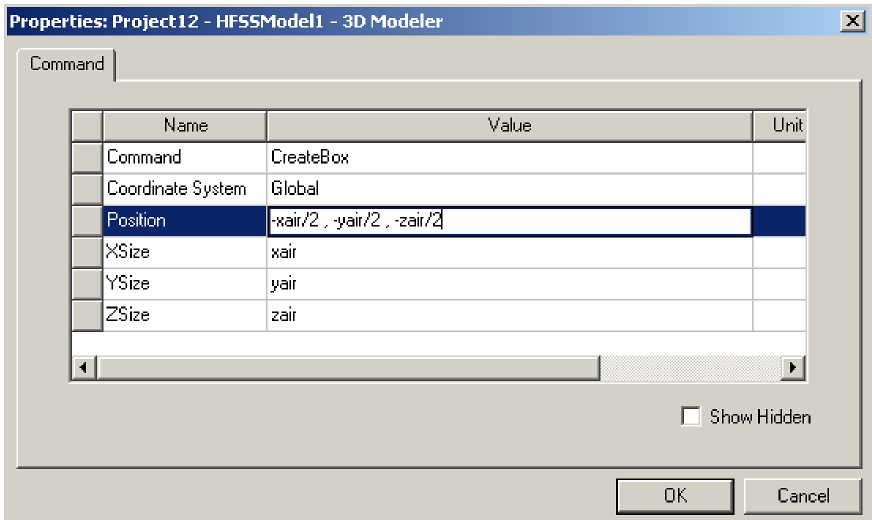


Figure 23: Air radiation box dimensions

xair, yair, and **zair** have the values of 50 cm, length_wg, and 40 cm, respectively.

Now choose the box and assign to it radiation boundary. Make sure you are in **Object** mode, if not click **"O"** on the keyboard to shift to **Object** mode. Select the radiation box and right-click mouse and **Assign Boundary< Radiation.**

The model should look like the following, Figure 24:

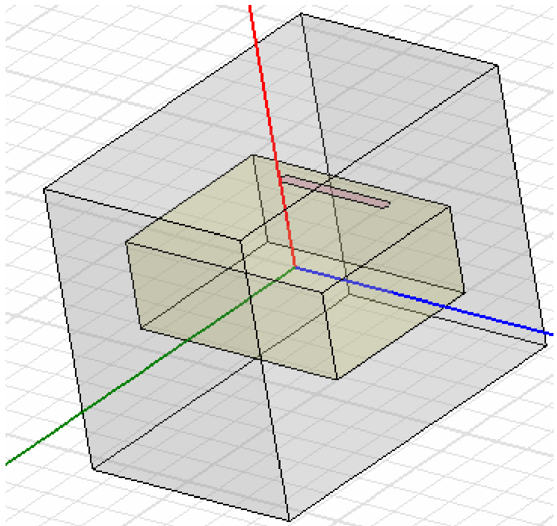


Figure 24: Model after radiation box is added

Assigning Excitation

Click  on the toolbar and select the right face of the slotted waveguide and assign wave port excitation. Go to project tree and right-click **Excitation<Assign<Wave Port**, and accept the default setting by clicking **Next** and **Ok**, Figures 25 and 26, respectively.

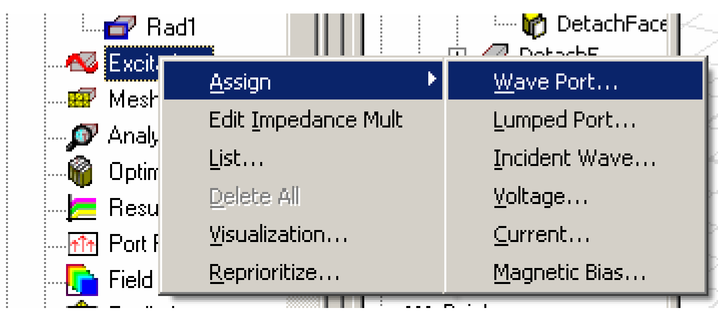


Figure 25: Assigning wave port excitation to the right face

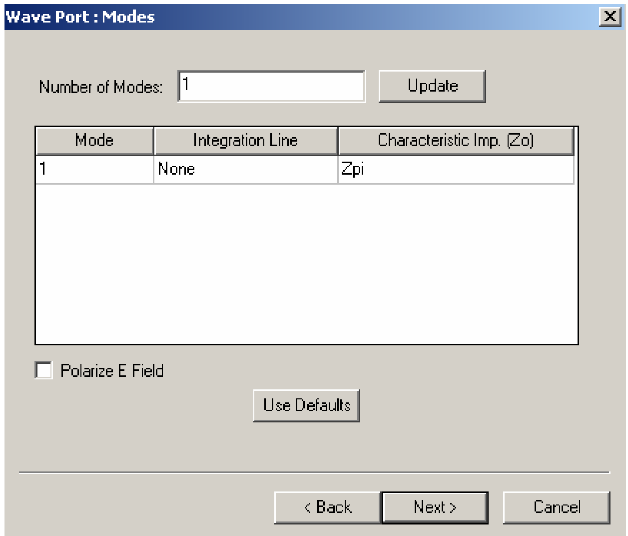


Figure 26: Wave port window

Similarly, assign a wave port to the left face of the slotted waveguide.

Make sure that the excitations are assigned properly by clicking on the content of the **excitation** in the project tree, Figure 27.

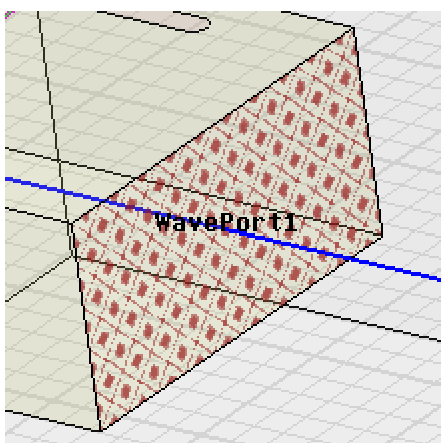


Figure 27: Wave port on the right face of the slotted waveguide

Adding Solution Setup

Now we should define the solution setup for our problem after having the model setup. Right-click on **Analysis** in the project tree and **Add Solution Setup,** Figure 28.

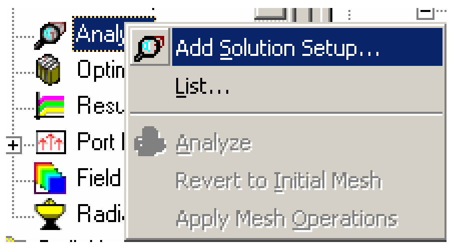


Figure 28: Adding solution setup

A window will pop up, fill in the following fields then click **Ok**, Figure 29.

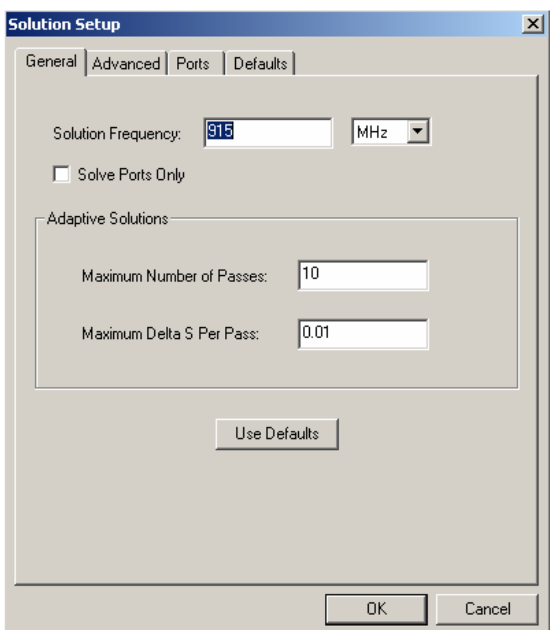


Figure 29: Solution setup window

Adding Sweep

To add a sweep, go to **Analysis** then right-click on **Setup1< Add Sweep.** Fill in the following fields then click **Ok,** Figure 30.

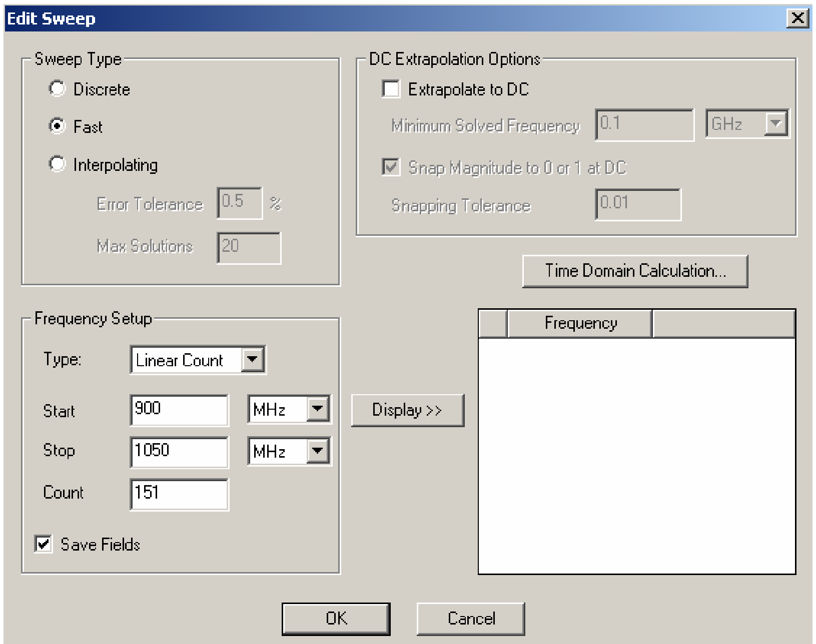


Figure 30: Add sweep window

Running Simulation

The model is ready to be simulated. However, it is preferable to run a validation check before you simulate the model. Click  on the toolbar.

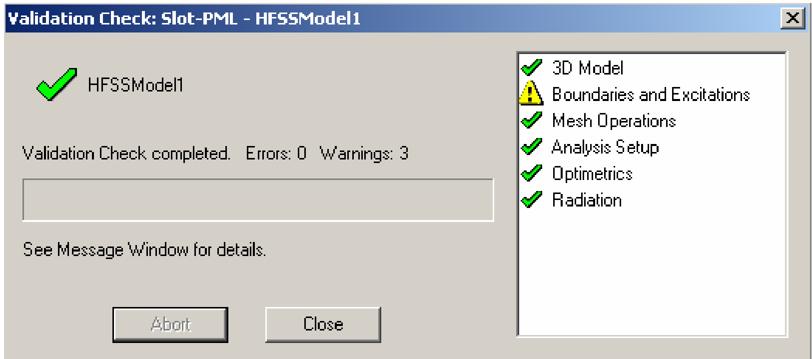


Figure 31: Validation check window

You can check for errors and warnings of your model in the **message window.**

Click  on the toolbar to run simulation. Simulation progress is noticed in the **progress window,** Figure 32.

Figure 32: Simulation progress window

Creating Reports

When simulation is done, you can create reports to view the results. Go to **HFSS<Results<Create Report** on the menu, Figure 33.

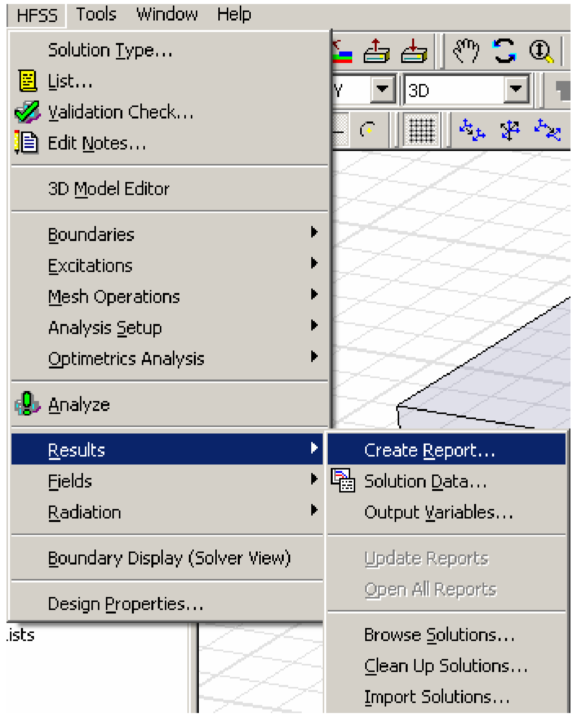


Figure 33: Create report

A window will pop up then click **Ok**, Figure 34.

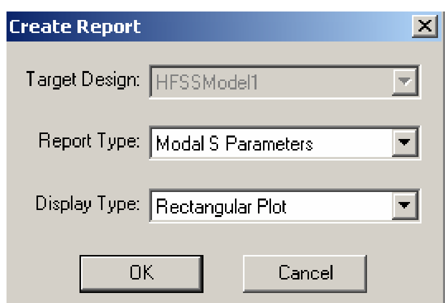


Figure 34: Create report window

Traces window will open up and choose fields as shown in Figure 35, then click **Add Trace** and **Done,** respectively.

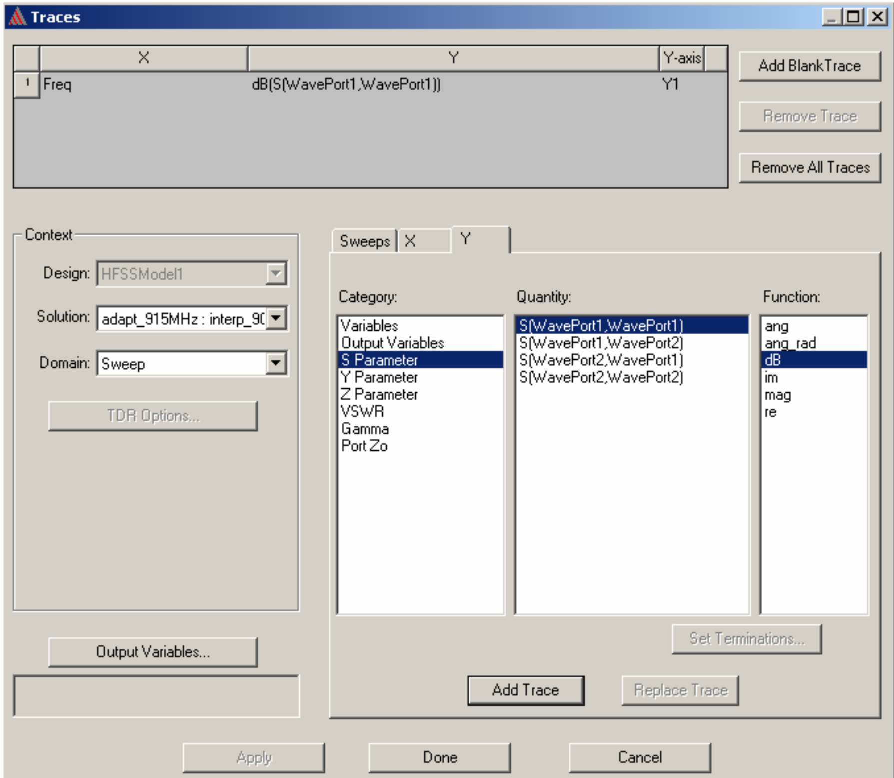


Figure 35: Traces window

A plot will be revealed of S(waveport1, waveport1) dB versus frequency (GHz), Figure 36.

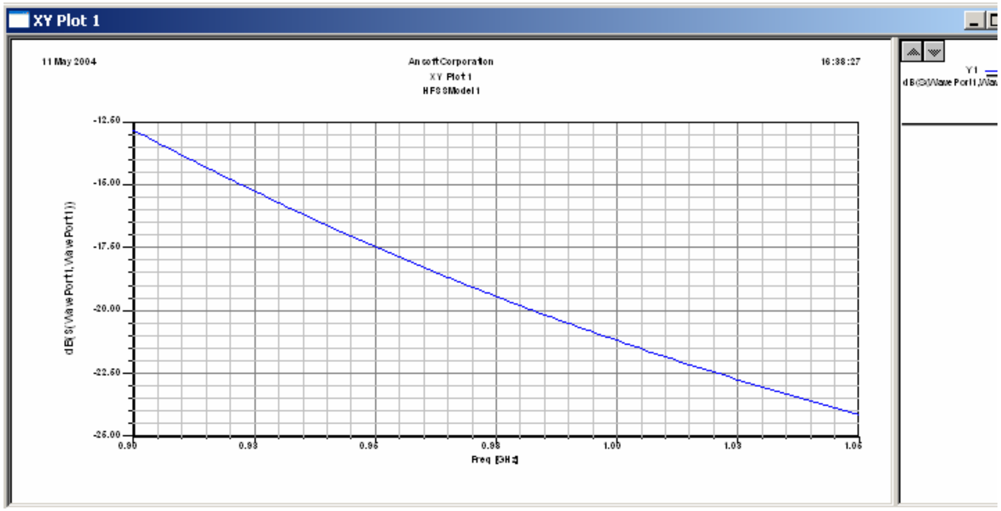


Figure 36: plot of S_{11} versus frequency

Similarly for S(waveport1, wavepor2) versus frequency, Figure 37.

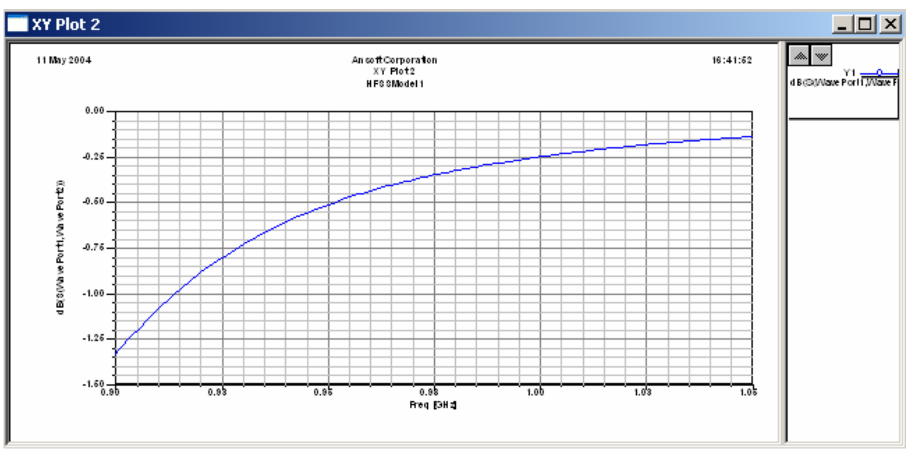


Figure 37: plot S_{12} versus frequency

Finally, follow same procedure but this time choose S(waveport1, waveport1) under quantity and **ang** under function tab, respectively, Figure 38.

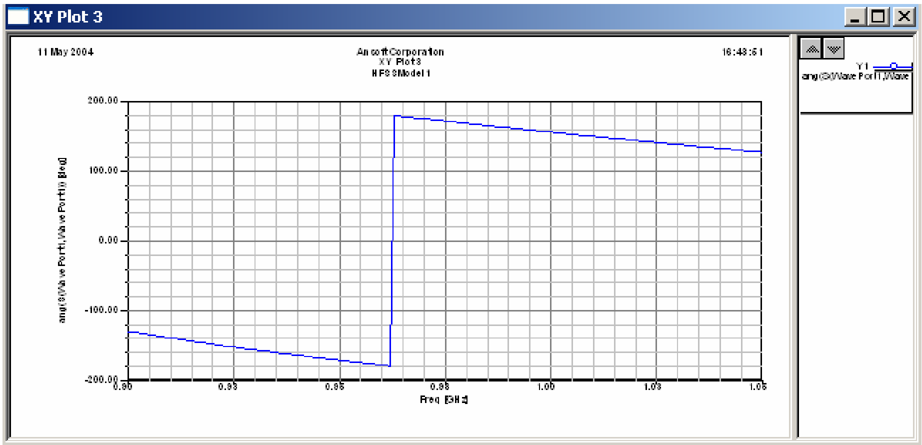


Figure 38: S_{11} in degrees versus frequency

We notice resonance at 962 MHz of the slotted waveguide.

Comparison against the experimental and MoM data provided in [1]

A square ended slot, of length 0.6597 inches, width = 0.0625 inches is considered in an X-band waveguide, broad wall width = 0.9 inches, height = 0.4 inches. The waveguide is 7.659 inches long (4 waveguide wavelengths at 9 GHz). The slot is at an offset of 0.35 inches from the center line of the broad wall. The waveguide wall thickness is 0.005 inches. A parametric code whereby the geometry is defined by variables is provided along with this tutorial. The 3-D model is shown in Figure 39.

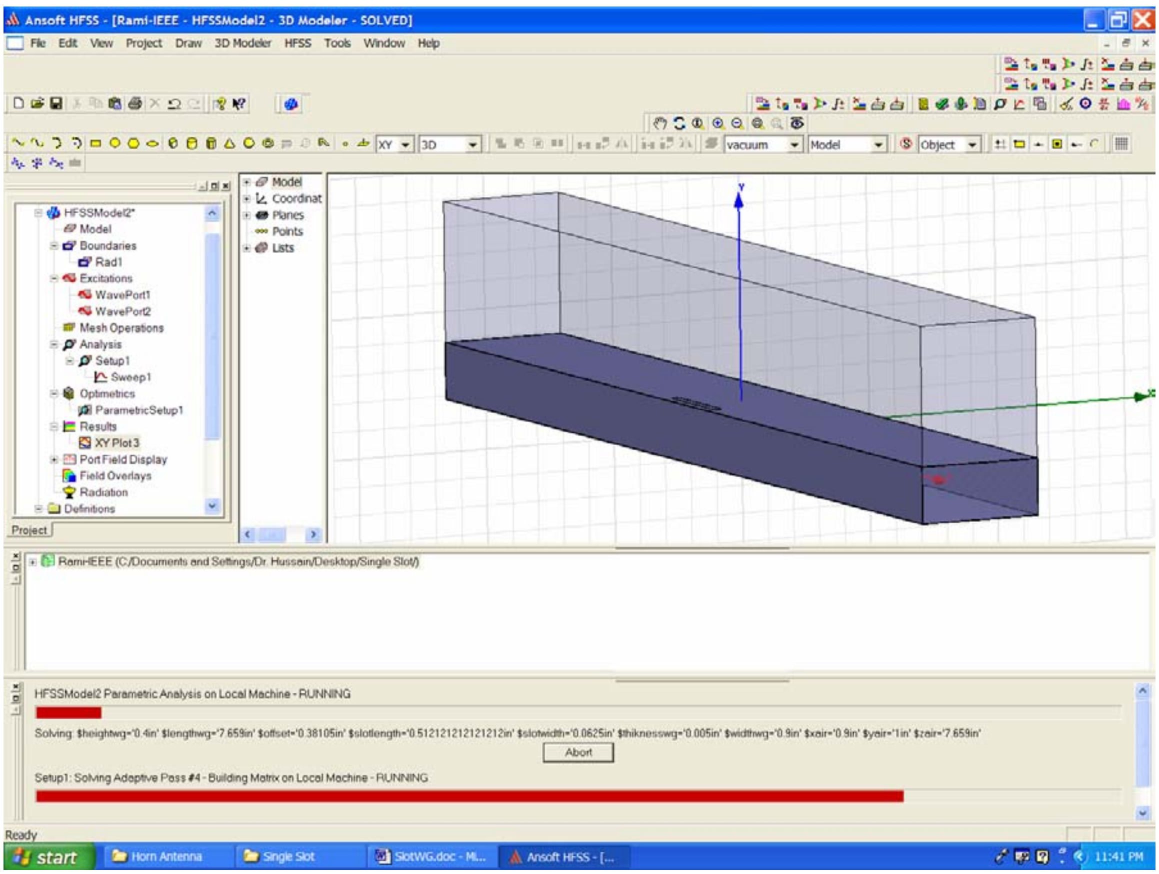


Figure 39 Geometry of the square-ended slot in a rectangular waveguide of a finite thickness

The antenna is terminated by two ports. This allows the evaluation of the reflection and transmission coefficients and to check the validity of the shunt equivalent circuit.

Resonance is determined when the imaginary part of the input admittance is equal to zero. The resonant frequency is 8.985 GHz (Figure 40) while the measured value as reported in [2] is 8.999 GHz.

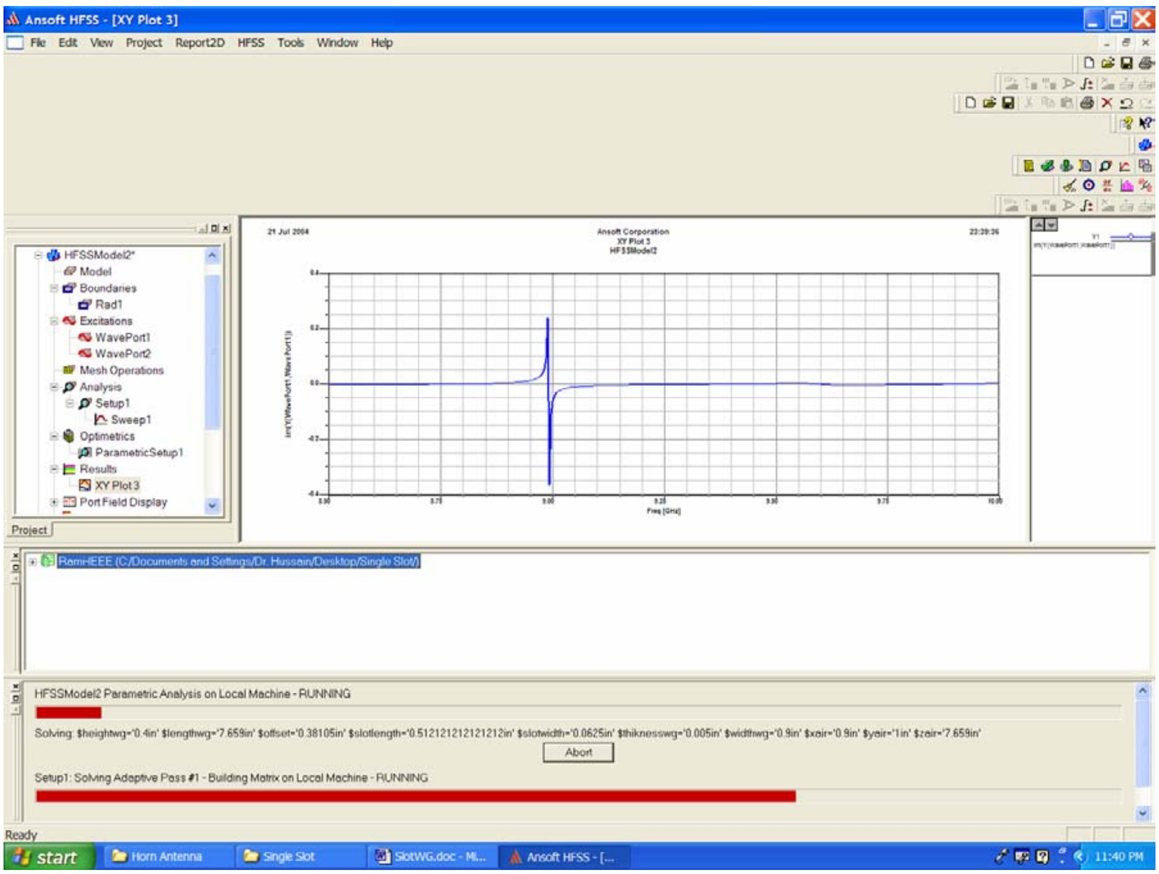


Figure 40 Imaginary part of Y_{11} versus frequency

Comparison against the FDTD results provided in [2]

A square-ended slot is of width $\lambda_0/2$ and length of 16 cm, width $\lambda_0/20$, and offset of 10 cm from the broad wall center is considered in a WR-975 waveguide, σ = 3.816 107 S/m. The waveguide has a cross sectional dimensions of 24.765 cm × 12.3825 cm, the length is 3 λ_g , where λ_g is the waveguide wavelength at 915 MHz. The 3-D model is shown in Figure 41.

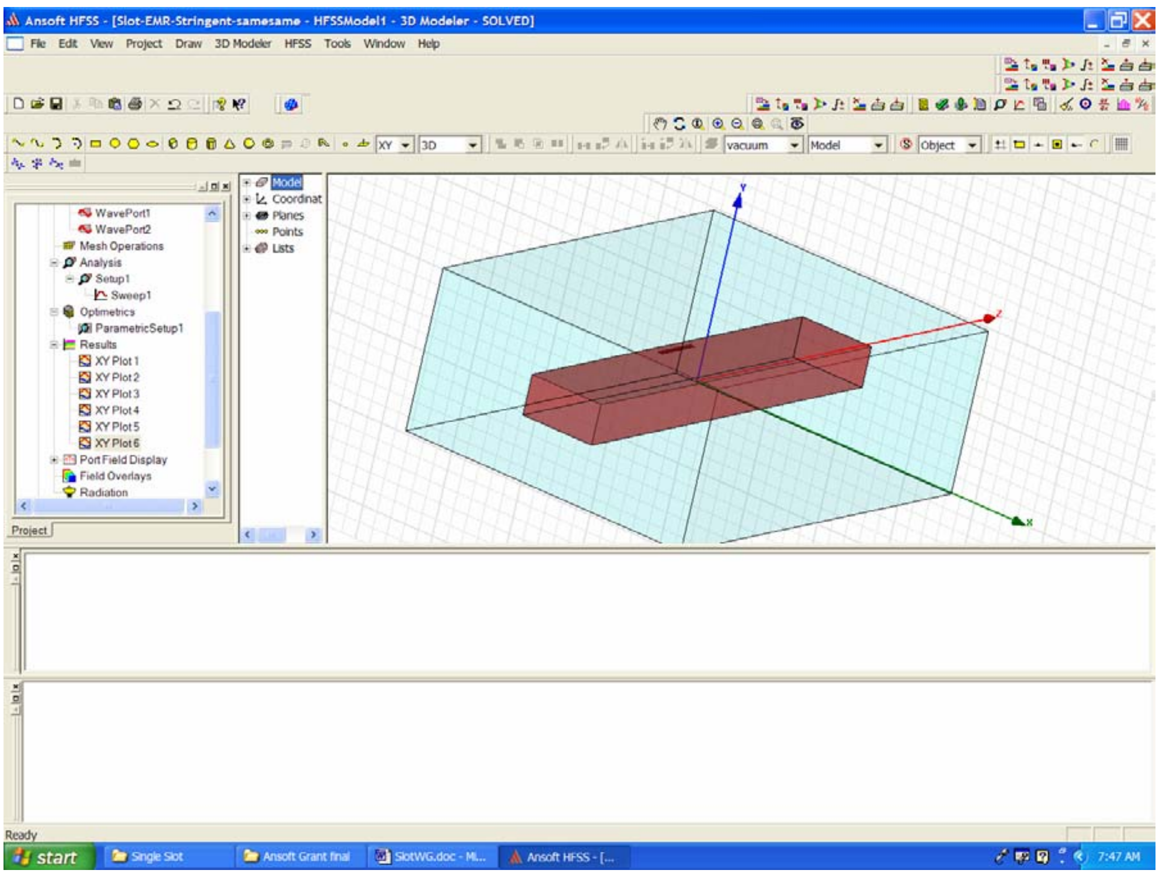
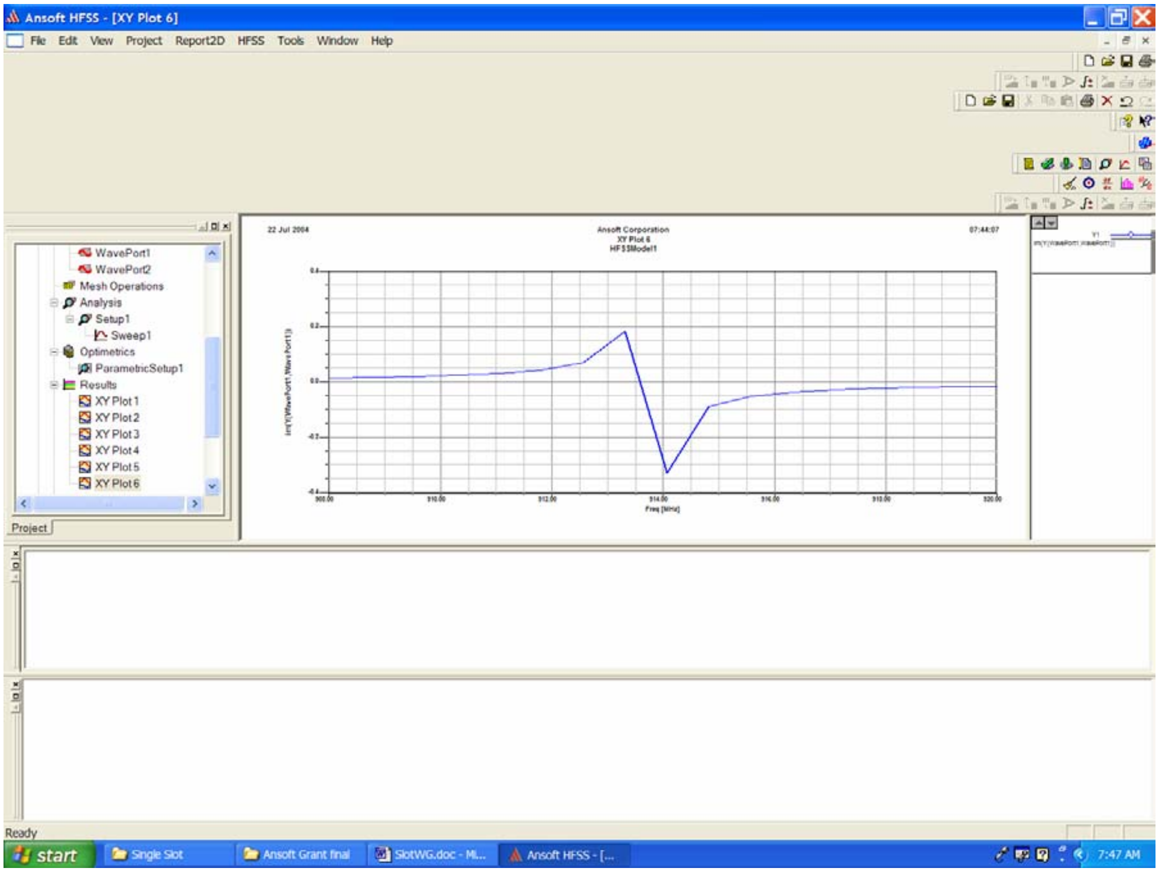


Figure 41 Geometrical model for the problem of [2]

The resonant frequency determined from HFSS is 913.5 MHz compared to 915 MHz as determined from the FDTD algorithm described in [2].



References

[1] Hussain M. Al-Rizzo, Hassan Z. Younies, Ken G. Clark, and Jim Tranquilla, "FDTD analysis of dielectric-loaded longitudinally slotted rectangular waveguides," Journal of Microwave Power and Electromagnetic Energy, vol. 38, no. 3, 2003.

[2] George J. Stern, and Robert S. Elliott, "Resonant length of longitudinal slots and validity of circuit representation: Theory and experiment," IEEE Trans. Antennas and Propagation, vol. AP-33, no. 11, Nov. 1985.