Model created in COMSOL Multiphysics 6.4

Waveguide Iris Bandpass Filter

Introduction

A conductive diaphragm, an iris, placed transverse to a waveguide aperture causes a discontinuity and generates shunt reactance. Bandpass frequency response can be achieved from cascaded cavity resonators combined with such reactive elements, which can be created by inserting a series of iris elements inside the waveguide. This example consists of a WR-90 X-band waveguide and symmetrical inductive diaphragms (irises). The calculated S-parameters show good bandpass response and out-of-band rejection.

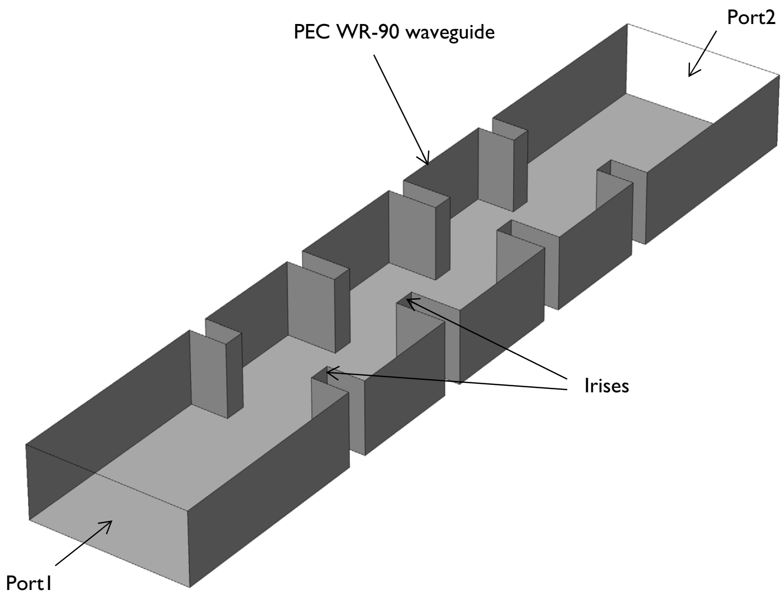


Figure 1: Symmetrical irises inside the waveguide generate shunt inductance. The top surface is removed to show the inside.

Model Definition

This example uses a WR-90 waveguide for X-band applications. The waveguide and iris parts are modeled as perfect electric conductors (PECs) and the inside of the waveguide is filled with air. On each end of the waveguide, a port boundary condition is applied with the predefined rectangular TE_{10} mode. Only one port is excited to observe the S-parameters of the example. The upper cutoff frequency can be approximately estimated using the resonant frequency of the biggest cavity located in the middle of the filter via

$$f_{nml} = \frac{c}{2\pi\sqrt{\varepsilon_r\mu_r}}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 + \left(\frac{l\pi}{d}\right)^2}$$

where a and b are the dimensions of the waveguide's aperture and d is the length of the cavity. For this example, the values $a = 2.286$ cm, $b = 1.016$ cm, and $d = 1.73$ cm give a resonant frequency at the dominant mode, TE_{101}, of 10.87 GHz. Because the cavities are not completely closed but formed with the open irises, this estimation gives only an approximated value.

Results and Discussion

The default plot shows the norm of the electric fields in the waveguide; see Figure 2. At 10 GHz, the shape of the field distribution in each section of cavities looks like that of the dominant mode of a cavity.

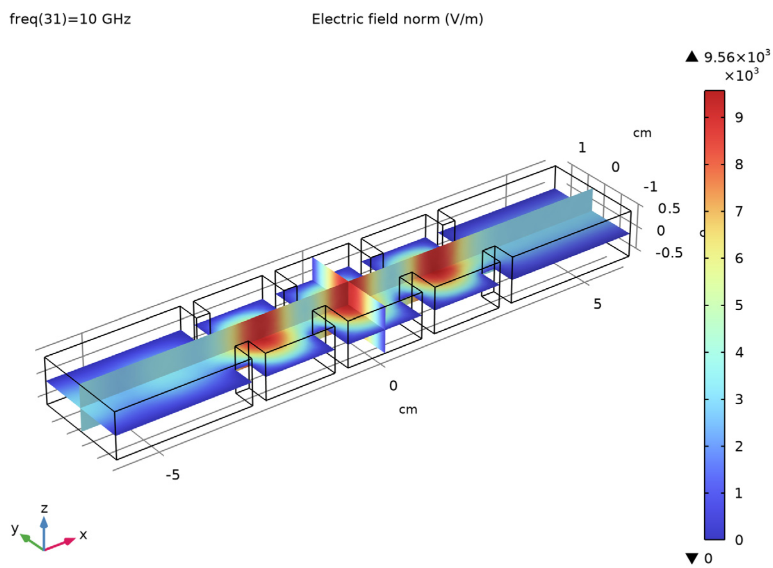


Figure 2: The E-field norm plot at the passband frequency shows the dominant mode resonance in each cavity formed by the irises.

[Figure 3](#) shows the calculated S-parameters. The passband is around 10 GHz and good out-of-band rejection frequency response is observed.

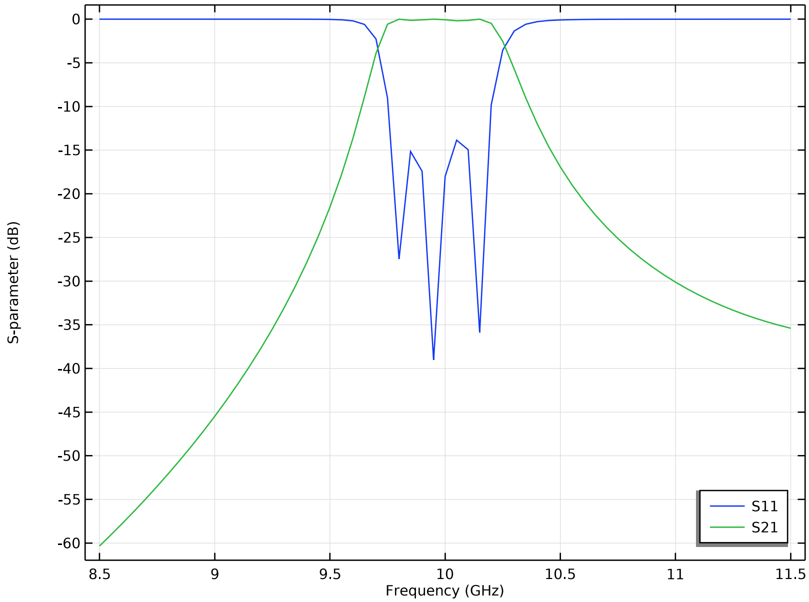


Figure 3: The calculated S-parameters show good matching characteristics as well as out-of-band rejection.

In Figure 4, the calculated S-parameters from the Frequency Domain, Modal method are plotted together with those of the discrete frequency sweep. While the frequency resolution of the Frequency Domain, Modal method is five times finer than that of the discrete frequency sweep, the simulation time is four times faster to analyze the same filter.

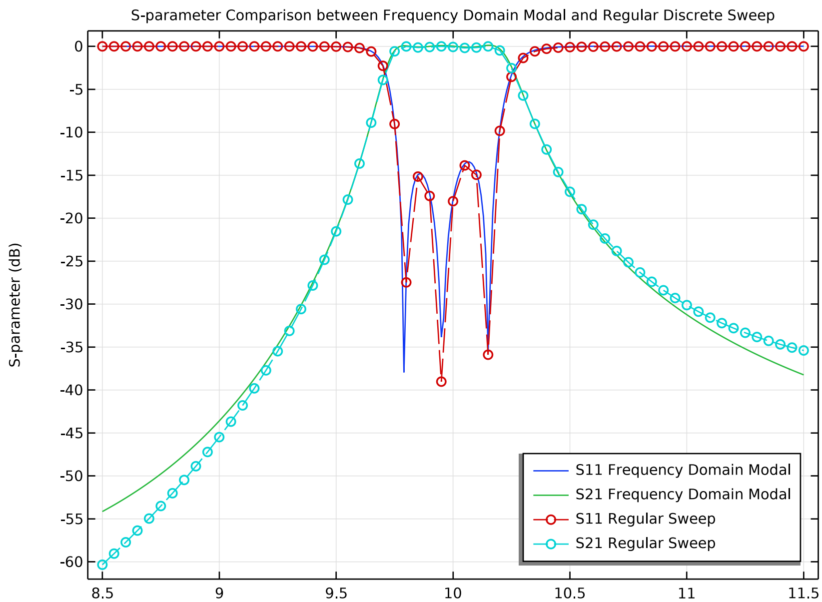


Figure 4: The calculated S-parameters from the Frequency Domain, Modal method are plotted with those of the discrete frequency sweep (dashed lines with circle makers).

References

1. D.M. Pozar, *Microwave Engineering*, John Wiley & Sons, 1998.

2. R.E. Collin, *Foundation of Microwave Engineering*, McGraw Hill, 1992.

Application Library path: `RF_Module/Filters/waveguide_iris_filter`

Modeling Instructions

From the **File** menu, choose **New**.

NEW

In the **New** window, click **Model Wizard**.

MODEL WIZARD

1 In the **Model Wizard** window, click **3D**.

2 In the **Select Physics** tree, select **Radio Frequency** > **Electromagnetic Waves, Frequency Domain (emw)**.

3 Click **Add**.

4 Click **Study**.

5 In the **Select Study** tree, select **General Studies** > **Frequency Domain**.

6 Click **Done**.

STUDY 1

Step 1: Frequency Domain

Define the study frequency ahead of performing any frequency-dependent operation such as building mesh. The physics-controlled mesh uses the highest frequency value in the specified range.

1 In the **Model Builder** window, under **Study 1** click **Step 1: Frequency Domain**.

2 In the **Settings** window for **Frequency Domain**, locate the **Study Settings** section.

3 Click **Range**.

4 In the **Range** dialog, type `8.5[GHz]` in the **Start** text field.

5 In the **Step** text field, type `0.05[GHz]`.

6 In the **Stop** text field, type `11.5[GHz]`.

7 Click **Replace**.

GLOBAL DEFINITIONS

Parameters 1

1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.

2 In the **Settings** window for **Parameters**, locate the **Parameters** section.

3 Click **Load from File**.

4 Browse to the model's Application Libraries folder and double-click the file `waveguide_iris_filter_parameters.txt`.

GEOMETRY 1

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Geometry 1**.

2 In the **Settings** window for **Geometry**, locate the **Units** section.

3 From the **Length unit** list, choose **cm**.

Create a block for the WR-90 waveguide.

WR-90

1 In the **Geometry** toolbar, click **Block**.

2 In the **Settings** window for **Block**, type `WR-90` in the **Label** text field.

3 Locate the **Size and Shape** section. In the **Width** text field, type `12`.

4 In the **Depth** text field, type `w_wg`.

5 In the **Height** text field, type `h_wg`.

6 Locate the **Position** section. From the **Base** list, choose **Center**.

7 Click **Build All Objects**.

Choose wireframe rendering to get a view inside the waveguide when adding the irises.

8 Click the **Wireframe Rendering** button in the **Graphics** toolbar.

Next, add a block for generating the inner irises, which form the center cavity.

Iris1

1 In the **Geometry** toolbar, click **Block**.

2 In the **Settings** window for **Block**, type `Iris1` in the **Label** text field.

3 Locate the **Size and Shape** section. In the **Width** text field, type `d_iris`.

4 In the **Depth** text field, type `l_iris1`.

5 In the **Height** text field, type `h_wg`.

6 Locate the **Position** section. From the **Base** list, choose **Center**.

7 In the **x** text field, type `spacing/2`.

8 In the **y** text field, type `(w_wg-l_iris1)/2`.

Add another block for generating the outer irises, which enclose the first and last cavities.

Iris2

1 In the **Geometry** toolbar, click **Block**.

2 In the **Settings** window for **Block**, type `Iris2` in the **Label** text field.

3 Locate the **Size and Shape** section. In the **Width** text field, type `d_iris`.

4 In the **Depth** text field, type `l_iris2`.

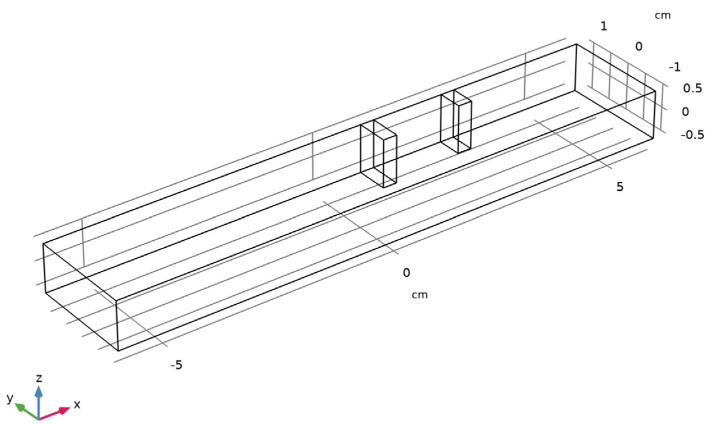
5 In the **Height** text field, type `h_wg`.

6 Locate the **Position** section. From the **Base** list, choose **Center**.

7 In the **x** text field, type `spacing*1.42`.

8 In the **y** text field, type `(w_wg-l_iris2)/2`.

9 Click **Build All Objects**.



Create symmetrical inductive diaphragms by mirroring the iris blocks a couple of times.

Mirror 1 (mir1)

1 In the **Geometry** toolbar, click **Transforms** and choose **Mirror**.

2 Select the objects **blk2** and **blk3** only.

3 In the **Settings** window for **Mirror**, locate the **Input** section.

4 Select the **Keep input objects** checkbox.

5 Locate the **Normal Vector to Plane of Reflection** section. In the **x** text field, type `1`.

6 In the **z** text field, type `0`.

Mirror 2 (mir2)

1 In the **Geometry** toolbar, click **Transforms** and choose **Mirror**.

2 Select the objects **blk2**, **blk3**, **mir1(1)**, and **mir1(2)** only.

3 In the **Settings** window for **Mirror**, locate the **Input** section.

4 Select the **Keep input objects** checkbox.

5 Locate the **Normal Vector to Plane of Reflection** section. In the **y** text field, type `1`.

6 In the **z** text field, type `0`.

Difference 1 (dif1)

1 In the **Geometry** toolbar, click **Booleans and Partitions** and choose **Difference**.

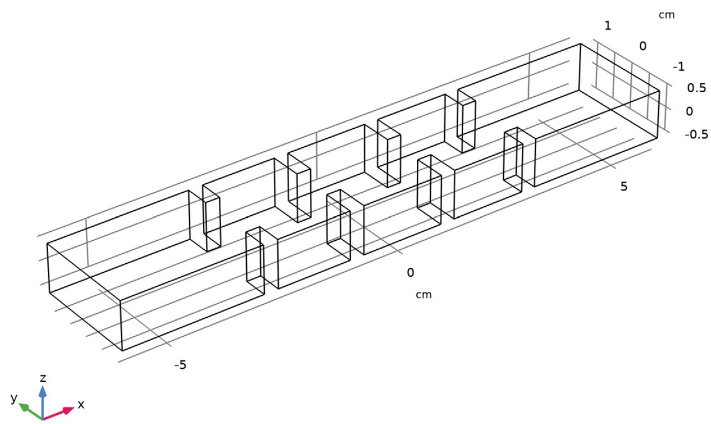
2 Select the object **blk1** only.

3 In the **Settings** window for **Difference**, locate the **Difference** section.

4 Click to select the **Activate Selection** toggle button for **Objects to subtract**.

5 Select the objects **blk2**, **blk3**, **mir1(1)**, **mir1(2)**, **mir2(1)**, **mir2(2)**, **mir2(3)**, and **mir2(4)** only.

6 Click **Build All Objects**.



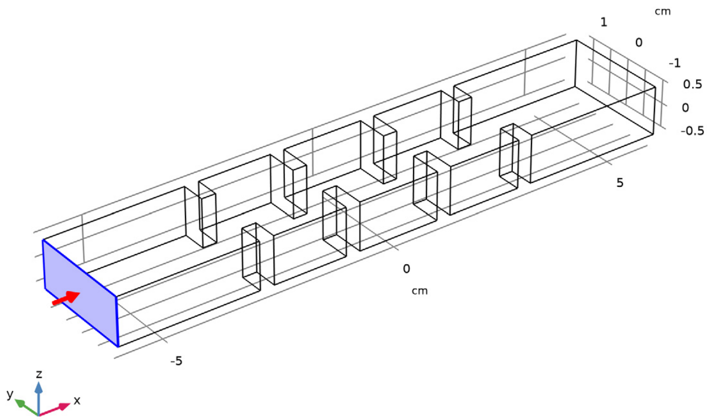
ELECTROMAGNETIC WAVES, FREQUENCY DOMAIN (EMW)

Now, set up the physics. The default boundary condition, Perfect Electric Conductor, applies to all exterior boundaries.

Port 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Port**.

2 Select Boundary 1 only.



The excitation port.

3 In the **Settings** window for **Port**, locate the **Port Properties** section.

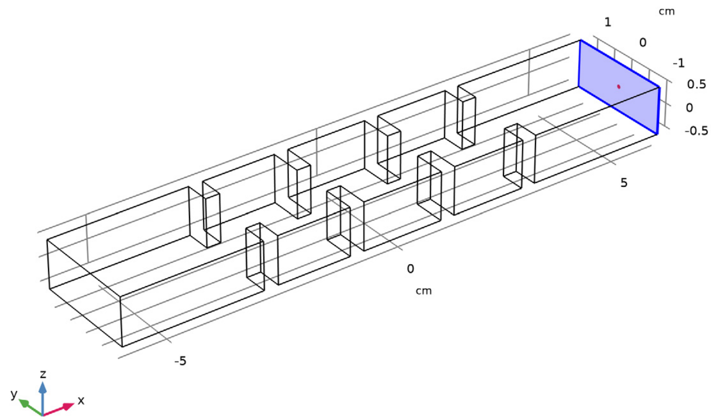
4 From the **Type of port** list, choose **Rectangular**.

For the first port, wave excitation is **on** by default.

Port 2

1 In the **Physics** toolbar, click **Boundaries** and choose **Port**.

2 Select Boundary 38 only.



The observation port.

3 In the **Settings** window for **Port**, locate the **Port Properties** section.

4 From the **Type of port** list, choose **Rectangular**.

MATERIALS

Assign material properties on the model. Use air for all domains.

ADD MATERIAL

1 In the **Materials** toolbar, click **Add Material** to open the **Add Material** window.

2 Go to the **Add Material** window.

3 In the tree, select **Built-in** > **Air**.

4 Click the **Add to Component** button in the window toolbar.

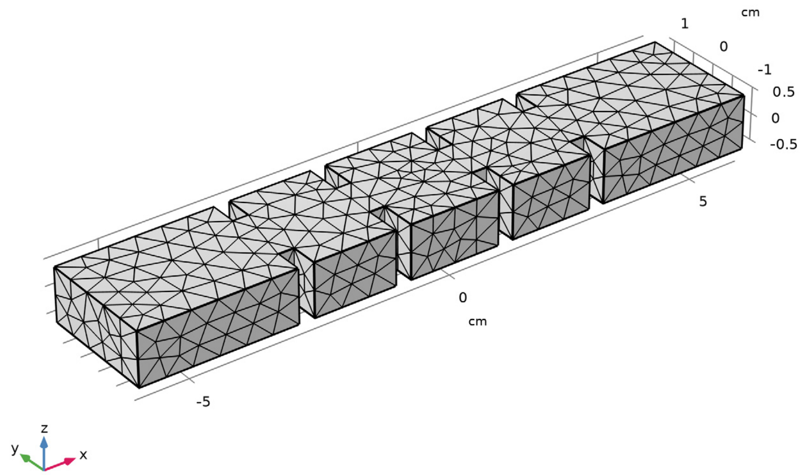
5 In the **Materials** toolbar, click **Add Material** to close the **Add Material** window.

MESH 1

1 In the **Settings** window for **Mesh**, locate the **Physics-Controlled Mesh** section.

2 From the **Element size** list, choose **Coarse**.

3 Click **Build All**.



STUDY 1

In the **Study** toolbar, click **Compute**.

RESULTS

Electric Field (emw)

The default plot shows the distribution of the norm of the electric field. Choose the center frequency of the passband.

1 In the **Settings** window for **3D Plot Group**, locate the **Data** section.

2 From the **Parameter value (freq (GHz))** list, choose **10**.

3 In the **Electric Field (emw)** toolbar, click **Plot**.

The resonant E-field should be observed in the cavities. Compare with Figure 2.

S-Parameter (emw)

1 In the **Model Builder** window, click **S-Parameter (emw)**.

2 In the **Settings** window for **1D Plot Group**, locate the **Legend** section.

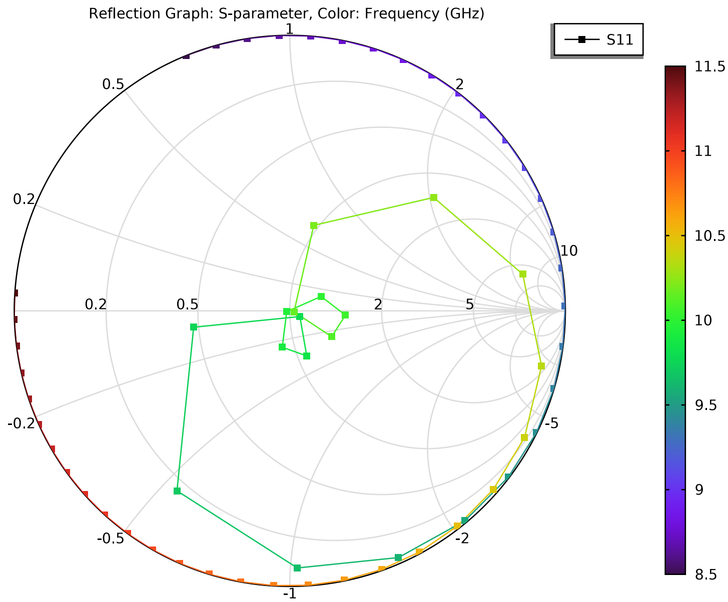
3 From the **Position** list, choose **Lower right**.

4 In the **S-Parameter (emw)** toolbar, click **Plot**.

The resulting plot shows the S-parameters of the filter. Compare the plot with Figure 3.

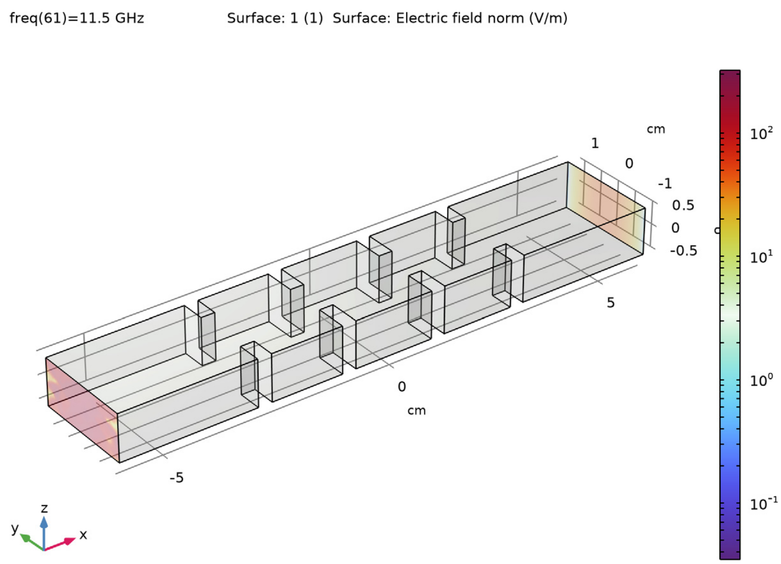
Smith Plot (emw)

In the **Model Builder** window, click **Smith Plot (emw)**.



Electric Field, Logarithmic (emw)

In the **Model Builder** window, click **Electric Field, Logarithmic (emw)**.



Analyze the same model with a Frequency Domain Modal method. When a device presents resonances, the **Frequency Domain Modal** method combined with an **Eigenfrequency** analysis provides a faster solution time.

ADD STUDY

1. In the **Home** toolbar, click **Add Study** to open the **Add Study** window.
2. Go to the **Add Study** window.
3. Find the **Studies** subsection. In the **Select Study** tree, select **Preset Studies for Selected Physics Interfaces** > **Frequency Domain, Modal**.
4. Click the **Add Study** button in the window toolbar.
5. In the **Home** toolbar, click **Add Study** to close the **Add Study** window.

STUDY 2

Step 1: Eigenfrequency

1. In the **Settings** window for **Eigenfrequency**, locate the **Study Settings** section.
2. In the **Search for eigenfrequencies around shift** text field, type `9.5[GHz]`.

3 Select the **Desired number of eigenfrequencies** checkbox. In the associated text field, type `3`, as we expect there to be three dominant modes because of the three cavities.

Step 2: Frequency Domain, Modal

1 In the **Model Builder** window, click **Step 2: Frequency Domain, Modal**.

2 In the **Settings** window for **Frequency Domain, Modal**, locate the **Study Settings** section.

3 In the **Frequencies** text field, type `range(8.5[GHz],0.01[GHz],11.5[GHz])`.

With a very fine frequency step simulation, the solutions contain a lot of data. As a result, the model file size will increase tremendously when it is saved. By selecting the Store in Output checkbox in the Values of Dependent Variables section of the Frequency Domain study step settings, it is possible to define for what part of the model the computed solution should be saved. When only S-parameters are of interest, it is not necessary to store all of the field solutions. Instead, only store the field on the selections for the port boundaries, as those will be used for the S-parameter calculations.

ELECTROMAGNETIC WAVES, FREQUENCY DOMAIN (EMW)

Port 1

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Electromagnetic Waves, Frequency Domain (emw)** click **Port 1**.

2 In the **Settings** window for **Port**, locate the **Boundary Selection** section.

3 Click **Create Selection**.

4 In the **Create Selection** dialog, type `Port 1` in the **Selection name** text field.

5 Click **OK**.

Port 2

1 In the **Model Builder** window, click **Port 2**.

2 In the **Settings** window for **Port**, locate the **Boundary Selection** section.

3 Click **Create Selection**.

4 In the **Create Selection** dialog, type `Port 2` in the **Selection name** text field.

5 Click **OK**.

STUDY 2

Step 2: Frequency Domain, Modal

1 In the **Model Builder** window, under **Study 2** click **Step 2: Frequency Domain, Modal**.

2 In the **Settings** window for **Frequency Domain, Modal**, click to expand the **Store in Output** section.

3 In the table, enter the following settings:

Interface	Output
Electromagnetic Waves, Frequency Domain (emw)	Selection

4 Click to select the first row in the table.

5 Under **Selections**, click **Add**.

6 In the **Add** dialog, in the **Selections** list, choose **Port 1** and **Port 2**.

7 Click **OK**.

It is necessary to include the port boundaries to calculate S-parameters. By choosing only the port boundaries for **Store in Output** settings, it is possible to reduce the size of a model file a lot.

8 In the **Study** toolbar, click **Compute**.

RESULTS

Multislice 1

1 In the **Model Builder** window, expand the **Electric Field (emw) 1** node, then click **Multislice 1**.

2 In the **Settings** window for **Multislice**, locate the **Multiplane Data** section.

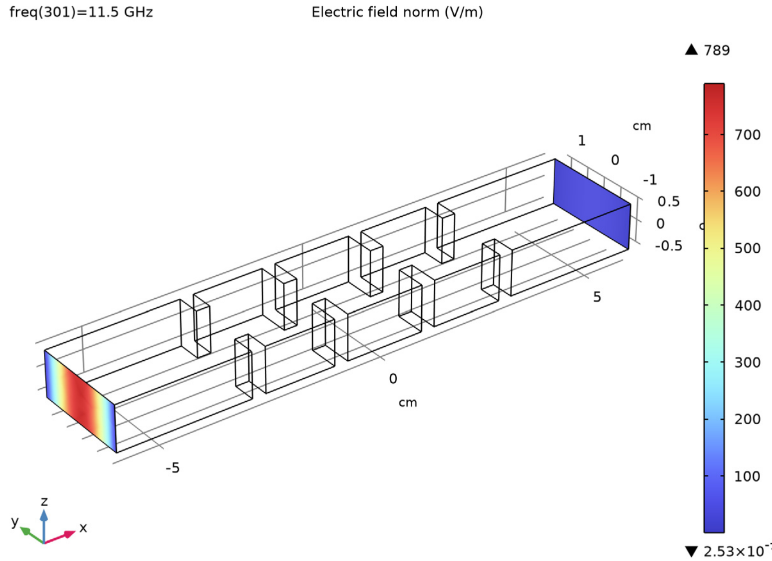
3 Find the **X-planes** subsection. From the **Entry method** list, choose **Coordinates**.

4 In the **Coordinates** text field, type `-6 6`.

5 Find the **Y-planes** subsection. In the **Planes** text field, type `0`.

6 Find the **Z-planes** subsection. In the **Planes** text field, type `0`.

7 In the **Electric Field (emw) 1** toolbar, click **Plot**.

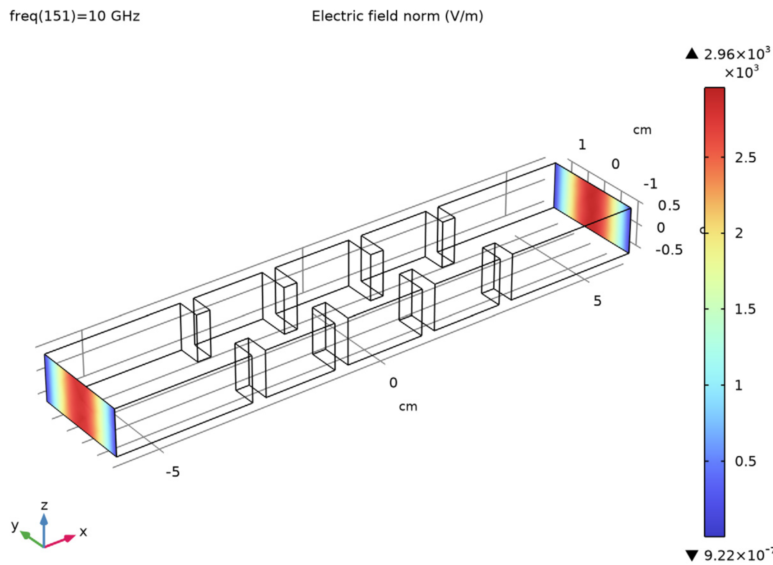


Since 11.5 GHz is not within the passband, the input power at the excitation port is not delivered to the observation port.

Electric Field (emw) 1

1. In the **Model Builder** window, click **Electric Field (emw) 1**.
2. In the **Settings** window for **3D Plot Group**, locate the **Data** section.
3. From the **Parameter value (freq (GHz))** list, choose **10**.

4 In the **Electric Field (emw) 1** toolbar, click **Plot**.



When the frequency of the plot is within the passband, the input power at the excitation port is delivered to the observation port.

Next, plot the calculated S-parameters from the Frequency Domain Modal method together with those of the discrete frequency sweep.

S-Parameter (emw) 1

1 In the **Model Builder** window, click **S-Parameter (emw) 1**.

2 In the **Settings** window for **1D Plot Group**, locate the **Legend** section.

3 From the **Position** list, choose **Lower right**.

Global 1

1 In the **Model Builder** window, expand the **S-Parameter (emw) 1** node, then click **Global 1**.

2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.

3 In the table, enter the following settings:

Expression	Unit	Description
emw.S11dB	dB	S11 Frequency Domain Modal
emw.S21dB	dB	S21 Frequency Domain Modal

Global 2

1 In the **Model Builder** window, right-click **S-Parameter (emw) 1** and choose **Global**.

2 In the **Settings** window for **Global**, locate the **Data** section.

3 From the **Dataset** list, choose **Study 1/Solution 1 (sol1)**.

4 Click **Add Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)** > **Electromagnetic Waves, Frequency Domain** > **Ports** > **S-parameter, dB - dB** > **emw.S11dB - S11**.

5 Click **Add Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)** > **Electromagnetic Waves, Frequency Domain** > **Ports** > **S-parameter, dB - dB** > **emw.S21dB - S21**.

6 Locate the **y-Axis Data** section. In the table, enter the following settings:

Expression	Unit	Description
`emw.S11dB`	`dB`	`S11 Regular Sweep`
`emw.S21dB`	`dB`	`S21 Regular Sweep`

7 Click to expand the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Dashed**.

8 Find the **Line markers** subsection. From the **Marker** list, choose **Circle**.

9 In the **S-Parameter (emw) 1** toolbar, click **Plot**.

S-Parameter (emw) 1

1 In the **Model Builder** window, click **S-Parameter (emw) 1**.

2 In the **Settings** window for **1D Plot Group**, click to expand the **Title** section.

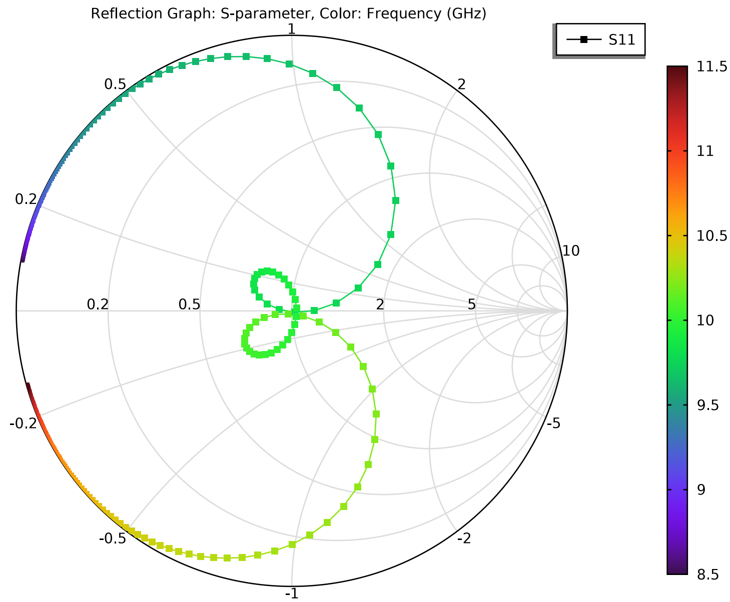
3 From the **Title type** list, choose **Manual**.

4 In the **Title** text area, type `S-parameter Comparison between Frequency Domain Modal and Regular Discrete Sweep`.

Compare the plot with Figure 4.

Smith Plot (emw) 1

In the **Model Builder** window, click **Smith Plot (emw) 1**.



Analyze the same model with a finer frequency resolution using **Adaptive Frequency Sweep** based on asymptotic waveform evaluation (AWE). When a device presents a slowly varying frequency response, the AWE provides a faster solution time when running the simulation on many frequency points. The following example with the AWE can be computed five times faster than regular Frequency Domain sweeps with a same finer frequency resolution.

ADD STUDY

1 In the **Home** toolbar, click **Add Study** to open the **Add Study** window.

2 Go to the **Add Study** window.

3 Find the **Studies** subsection. In the **Select Study** tree, select **Preset Studies for Selected Physics Interfaces** > **Adaptive Frequency Sweep**.

4 Click the **Add Study** button in the window toolbar.

5 In the **Home** toolbar, click **Add Study** to close the **Add Study** window.

STUDY 3

Step 1: Adaptive Frequency Sweep

1. In the **Settings** window for **Adaptive Frequency Sweep**, locate the **Study Settings** section.
2. In the **Frequencies** text field, type `range(8.5[GHz],0.01[GHz],11.5[GHz])`.

   Use a five times finer frequency resolution.

   A slowly varying scalar value curve works well for AWE expressions. When **AWE expression type** is set to **Physics controlled** in the **Adaptive Frequency Sweep** study settings, `abs(comp1.emw.S21)` is used automatically for two-port devices.
3. Click to expand the **Store in Output** section. In the table, enter the following settings:

Interface	Output
Electromagnetic Waves, Frequency Domain (emw)	Selection

4. Click to select the first row in the table.
5. Under **Selections**, click **Add**.
6. In the **Add** dialog, in the **Selections** list, choose **Port 1** and **Port 2**.
7. Click **OK**.
8. In the **Study** toolbar, click **Compute**.

RESULTS

Electric Field (emw) 2

1. In the **Settings** window for **3D Plot Group**, locate the **Data** section.
2. From the **Parameter value (freq (GHz))** list, choose **10**.

Multislice 1

1. In the **Model Builder** window, expand the **Electric Field (emw) 2** node.
2. Right-click **Multislice 1** and choose **Delete**.

Surface 1

Right-click **Electric Field (emw) 2** and choose **Surface**.

Selection 1

1. In the **Model Builder** window, right-click **Surface 1** and choose **Selection**.
2. Select Boundaries 1 and 38 only.
3. In the **Electric Field (emw) 2** toolbar, click **Plot**.

S-Parameter (emw) 2

1 In the **Model Builder** window, under **Results** click **S-Parameter (emw) 2**.

2 In the **Settings** window for **1D Plot Group**, locate the **Title** section.

3 From the **Title type** list, choose **Manual**.

4 In the **Title** text area, type `S-parameter Comparison between Adaptive Frequency Sweep and Regular Discrete Sweep`.

5 Locate the **Legend** section. From the **Position** list, choose **Lower right**.

Global 1

1 In the **Model Builder** window, expand the **S-Parameter (emw) 2** node, then click **Global 1**.

2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.

3 In the table, enter the following settings:

Expression	**Unit**	**Description**
`emw.S11dB`	`dB`	`S11 Adaptive Frequency Sweep`
`emw.S21dB`	`dB`	`S21 Adaptive Frequency Sweep`

Global 2

1 Right-click **Results** > **S-Parameter (emw) 2** > **Global 1** and choose **Duplicate**.

2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.

3 In the table, enter the following settings:

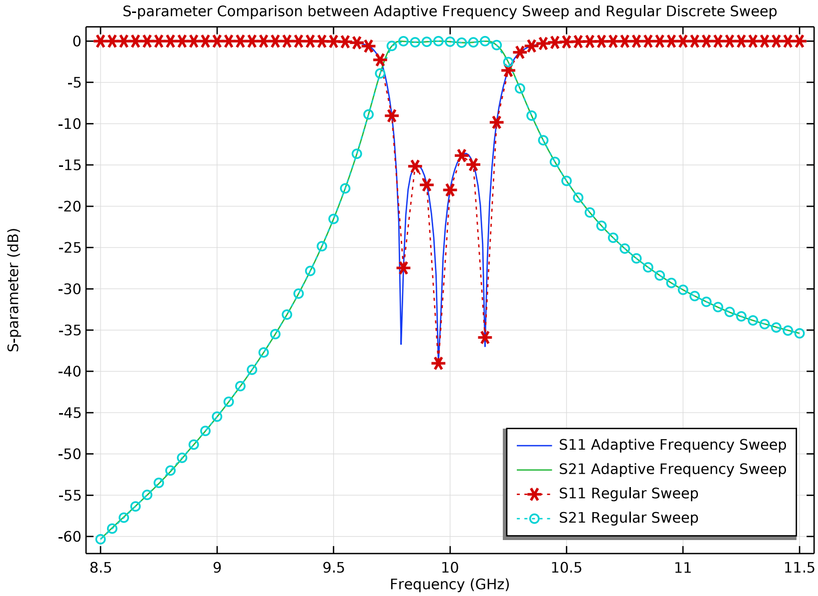
Expression	**Unit**	**Description**
`emw.S11dB`	`dB`	`S11 Regular Sweep`
`emw.S21dB`	`dB`	`S21 Regular Sweep`

4 Locate the **Data** section. From the **Dataset** list, choose **Study 1/Solution 1 (sol1)**.

5 Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Dotted**.

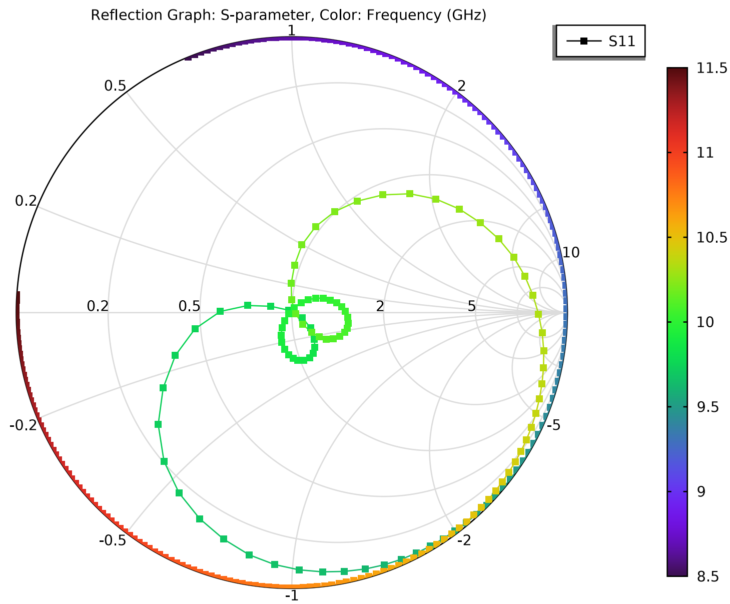
6 Find the **Line markers** subsection. From the **Marker** list, choose **Cycle**.

7 In the **S-Parameter (emw) 2** toolbar, click **Plot**.



Smith Plot (emw) 2

In the **Model Builder** window, under **Results** click **Smith Plot (emw) 2**.



The following instruction shows how to use the **Graph Marker** and **Filter** subfeatures to analyze 1D plots. When plotting S11 of a bandpass filter, poles are of interest and a graph marker captures the local minima. For analyzing the insertion loss such as S21, the -3dB bandwidth of the passband can be computed through an additional graph marker. The filter subfeature helps truncating the less interesting bands and for visualizing only the area of the passband.

S-parameter with Graph Markers

1 In the **Results** toolbar, click **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `S-parameter with Graph Markers` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Study 3/Solution 4 (sol4)**.

Global 1

1 Right-click **S-parameter with Graph Markers** and choose **Global**.

2 In the **Settings** window for **Global**, click **Add Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)** >

Electromagnetic Waves, Frequency Domain > **Ports** > **S-parameter, dB - dB** > **emw.S11dB - S11**.

Graph Marker 1

1 Right-click **Global 1** and choose **Graph Marker**.
2 In the **Settings** window for **Graph Marker**, locate the **Display** section.
3 From the **Display** list, choose **Min**.
4 From the **Scope** list, choose **Local**.
5 Locate the **Text Format** section. In the **Precision** text field, type 3.
6 Select the **Show x-coordinate** checkbox.
7 Select the **Include unit** checkbox.
8 Click to expand the **Coloring and Style** section. From the **Anchor point** list, choose **Lower left**.

Filter 1

1 In the **Model Builder** window, right-click **Global 1** and choose **Filter**.
2 In the **Settings** window for **Filter**, locate the **Point Selection** section.
3 In the **Logical expression for inclusion** text field, type `emw.freq>9.2[GHz] && emw.freq<10.8[GHz]`.

Global 2

1 In the **Model Builder** window, right-click **S-parameter with Graph Markers** and choose **Global**.
2 In the **Settings** window for **Global**, click **Replace Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)** > **Electromagnetic Waves, Frequency Domain** > **Ports** > **S-parameter, dB - dB** > **emw.S21dB - S21**.

Graph Marker 1

1 Right-click **Global 2** and choose **Graph Marker**.
2 In the **Settings** window for **Graph Marker**, locate the **Display** section.
3 From the **Display mode** list, choose **Bandwidth**.
4 Locate the **Text Format** section. In the **Precision** text field, type 3.
5 Select the **Include unit** checkbox.
6 Locate the **Coloring and Style** section. Select the **Show frame** checkbox.

Filter 1

In the **Model Builder** window, under **Results** > **S-parameter with Graph Markers** > **Global 1** right-click **Filter 1** and choose **Copy**.

Filter 1

In the **Model Builder** window, right-click **Global 2** and choose **Paste Filter**.