

# Circular Waveguide Filter

# Introduction

A circular waveguide filter is designed using a 2D axisymmetric model. Six annular rings added to the waveguide form circular cavities connected in series, and each cavity cutoff frequency is close to the center frequency of the filter. The computed S-parameters show a bandpass frequency response.



Figure 1: 3D visualization of the circular waveguide with irises from a 2D axisymmetric model.

# Model Definition

The model consists of a C-band circular waveguide and six irises. The waveguide walls and iris parts are modeled as perfect electric conductors (PECs) and the inside of the waveguide is set to vacuum.

One end of the circular waveguide is excited with a predefined  $TE_1$  mode port boundary condition and the other end is terminated with a passive port boundary condition for the same mode. The combination of azimuthal mode index and the circular port mode index in a 2D axisymmetric model is compatible with the predefined circular port mode index of a 3D model. The  $TE_{11}$  mode cutoff frequency of a circular waveguide with radius of 20 mm is approximately 4.4 GHz, which is calculated by

$$f_{c_{ml}} = \frac{c_0 p'_{nm}}{2\pi a}$$

where  $c_0$  is the speed of light,  $p'_{nm}$  are the roots of the derivative of the Bessel functions  $J_n(x)$ , m and n are the mode indices, and a is the radius of a waveguide. The value of  $p'_{11}$  is approximately 1.841. The operating frequency of the filter is necessarily higher than the waveguide cutoff frequency.

The center frequency of the filter is estimated by evaluating the resonance frequency of a hypothetical closed cavity formed by the waveguide and closed irises. that is, a cylindrical cavity, The resonance frequency of the cylindrical cavity is

$$f_{nml} = \frac{c_0}{2\pi \sqrt{\mu_r \varepsilon_r}} \sqrt{\left(\frac{p'_{nm}}{a}\right)^2 + \left(\frac{l\pi}{d}\right)^2}$$

where  $\mu_r$  is relative permeability,  $\varepsilon_r$  is relative permittivity, d is the length of a cavity and l is the longitudinal cavity mode index (along the cylindrical axis). The remaining parameters are identical to those of a circular waveguide cutoff frequency. The resonance frequency at TE<sub>111</sub> mode of the cylindrical cavity is approximately 5.05 GHz. This approximation is obtained assuming that the irises are closed, and so there is only one discrete resonance frequency where the field is nonzero. A more accurate frequency response of the filter is obtained by solving the problem with open irises.

All domains are meshed by a tetrahedral mesh with maximum element size of ten elements per wavelength so that the wave is well resolved.

# Results and Discussion

The default plot shows the norm of the electric field in the waveguide. The standing wave pattern within each partitioned section of the waveguide at 4.98 GHz illustrates that this is a resonance frequency. It also demonstrates qualitatively that each partitioned section of the waveguide functions as a cavity with open ends at the irises.



Figure 2: The E-field norm shows a standing wave pattern near the center frequency of the filter. The plot illustrates that each partitioned section of the waveguide forms an open cavity.





Figure 3: The S-parameter plot shows a bandpass frequency response. The sharp out-of-band rejection below the cutoff frequency is observed.

## Notes About the COMSOL Implementation

The assumed temporal and angular dependence of all field quantities in the 2D axisymmetric formulation is  $e^{j(\omega t - m\phi)}$ , where  $\omega$  is the angular frequency and *m* is the azimuthal mode number.

Application Library path: RF\_Module/Filters/circular\_waveguide\_filter

# Modeling Instructions

From the File menu, choose New.

### NEW

In the New window, click Solution Model Wizard.

#### MODEL WIZARD

- I In the Model Wizard window, click 🚈 2D Axisymmetric.
- 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 I

Step 1: Frequency Domain

- I In the Model Builder window, under Study I click Step I: Frequency Domain.
- 2 In the Settings window for Frequency Domain, locate the Study Settings section.
- 3 In the Frequencies text field, type range(4.8[GHz],10[MHz],5.2[GHz]).

The choices of 4.8 GHz and 5.2 GHz ensured that the parametric sweep will start above the cutoff frequency and contain the resonant frequency.

#### GLOBAL DEFINITIONS

Parameters 1

- I In the Model Builder window, under Global Definitions click Parameters I.
- 2 In the Settings window for Parameters, locate the Parameters section.
- 3 Click **b** Load from File.
- **4** Browse to the model's Application Libraries folder and double-click the file circular\_waveguide\_filter\_parameters.txt.

First load the geometric parameters. Now, we will first calculate the cutoff and resonant frequency of the waveguide to choose appropriate values for the parametric sweep.

**5** In the table, enter the following settings:

Name	Expression	Value	Description
fnml	c_const/pi/2*sqrt((1.841/ r1)^2+(pi/0.06)^2)	5.0528E9 1/s	Cavity resonance frequency
fc	1.841*c_const/2/pi/r1	4.392E9 1/s	Cutoff frequency

Here, c\_const is a predefined COMSOL constant for the speed of light in vacuum.

#### GEOMETRY I

Rectangle 1 (r1)

- I In the **Geometry** toolbar, click **Rectangle**.
- 2 In the Settings window for Rectangle, locate the Size and Shape section.
- 3 In the Width text field, type r1.
- 4 In the **Height** text field, type 0.4.
- 5 Locate the Position section. In the z text field, type -0.2.

Rectangle 2 (r2)

- I In the Geometry toolbar, click 📃 Rectangle.
- 2 In the Settings window for Rectangle, locate the Size and Shape section.
- 3 In the Width text field, type ir1.
- 4 In the **Height** text field, type irth.
- **5** Locate the **Position** section. In the **r** text field, type r1-ir1.
- 6 In the z text field, type -c13/2-c12-c11-irth/2.

Rectangle 3 (r3)

- I In the Geometry toolbar, click 📃 Rectangle.
- 2 In the Settings window for Rectangle, locate the Size and Shape section.
- 3 In the Width text field, type ir2.
- 4 In the **Height** text field, type irth.
- **5** Locate the **Position** section. In the **r** text field, type r1-ir2.
- 6 In the z text field, type -cl3/2-cl2-irth/2.

Rectangle 4 (r4)

- I In the Geometry toolbar, click 📃 Rectangle.
- 2 In the Settings window for Rectangle, locate the Size and Shape section.
- 3 In the Width text field, type ir3.
- 4 In the **Height** text field, type irth.
- 5 Locate the **Position** section. In the **r** text field, type r1-ir3.
- 6 In the z text field, type -cl3/2-irth/2.

Mirror I (mir I)

- I In the Geometry toolbar, click 💭 Transforms and choose Mirror.
- 2 Select the objects r2, r3, and r4 only.

- 3 In the Settings window for Mirror, locate the Input section.
- 4 Select the Keep input objects check box.
- **5** Locate the Normal Vector to Line of Reflection section. In the **r** text field, type **0**.
- 6 In the z text field, type 1.

Difference I (dif1)

- I In the Geometry toolbar, click i Booleans and Partitions and choose Difference.
- 2 Select the object rI only.
- 3 In the Settings window for Difference, locate the Difference section.
- **4** Find the **Objects to subtract** subsection. Click to select the **Comparison Activate Selection** toggle button.
- 5 Select the objects mir1(1), mir1(2), mir1(3), r2, r3, and r4 only.



#### 6 Click **H** Build All Objects.

ELECTROMAGNETIC WAVES, FREQUENCY DOMAIN (EMW)

- I In the Model Builder window, under Component I (compl) click Electromagnetic Waves, Frequency Domain (emw).
- 2 In the Settings window for Electromagnetic Waves, Frequency Domain, locate the Out-of-Plane Wave Number section.

**3** In the *m* text field, type 1.

This defines the azimuthal dependency of the fields that the model is solving for.

Port I

- I In the Physics toolbar, click Boundaries and choose Port.
- **2** Select Boundary 2 only.
- 3 In the Settings window for Port, locate the Port Properties section.
- **4** From the **Type of port** list, choose **Circular**.

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

Port 2

- I In the Physics toolbar, click Boundaries and choose Port.
- **2** Select Boundary **3** only.
- 3 In the Settings window for Port, locate the Port Properties section.
- **4** From the **Type of port** list, choose **Circular**.

## MATERIALS

Material I (mat1)

- I In the Model Builder window, under Component I (compl) right-click Materials and choose Blank Material.
- 2 In the Settings window for Material, locate the Material Contents section.
- **3** In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Relative permittivity	epsilonr_iso; epsilonrii = epsilonr_iso, epsilonrij = 0	1	I	Basic
Relative permeability	mur_iso ; murii = mur_iso, murij = 0	1	I	Basic
Electrical conductivity	sigma_iso ; sigmaii = sigma_iso, sigmaij = 0	0	S/m	Basic

#### MESH I

In the Model Builder window, under Component I (compl) right-click Mesh I and choose Build All.



## STUDY I

In the **Home** toolbar, click **= Compute**.

## RESULTS

Electric Field (emw)

- I In the Settings window for 2D Plot Group, locate the Data section.
- 2 From the Parameter value (freq (GHz)) list, choose 4.98.



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

S-parameter (emw) This reproduces Figure 3.

## 12 | CIRCULAR WAVEGUIDE FILTER