Two-Arm Helical Antenna

Introduction

A helical antenna has two major modes. One is normal mode and the other is axial mode. When the helical antenna is operating at the normal mode, its far-field radiation pattern is similar to the torus-shaped pattern of a classic dipole antenna. At the axial mode, the helical antenna is resonant at a much higher frequency band than at the normal mode operation; it works similarly to an end-fire array along the z-axis, generating a directive radiation pattern. This model analyzes a helical antenna at these two different modes. The S-parameters and far-field patterns are calculated at both operating modes, 385 MHz and 4.77 GHz.

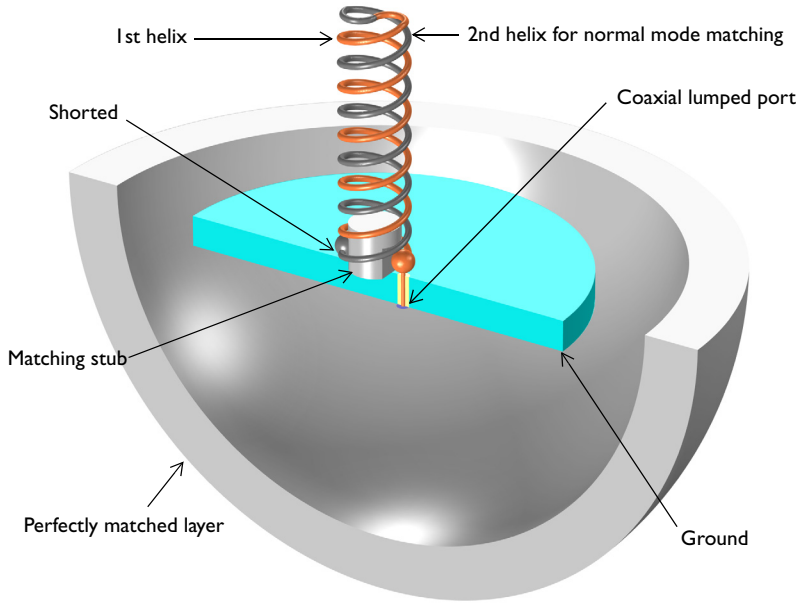

Figure 1: Each end of the two-arm helix is connected to a coaxial cable feed and ground plate. A region of free space bounded by a perfectly matched layer (PML) surrounding the antenna. The ground plate and PML are partially visualized.

Model Definition

The model consists of a two-arm helix radiator, a circular ground plate, a tuning stub, a coaxial cable, and a perfectly matched layer (PML) enclosing an air region. One

bottom end of the helix arm is connected to the inner conductor pin from the coaxial cable and the other end is shorted to the ground plate. Two helix structures are wound along the *z*-axis and meet at the top end. The impedance of a single-helix antenna is much lower than 50 Ω when it is resonant at the normal mode. By adding an additional helix shorted to the ground, the antenna works as a folded antenna which is known for its four times bigger input resistance than that of a same size dipole antenna, and the low impedance can be adjusted close to the reference impedance of the coaxial cable, 50 Ω. An additional impedance matching stub for the axial mode is located at the center of the ground plate.

All metal parts in this example are modeled as perfect electric conductors (PEC) and their interior domains are not included in the analysis. The space between the inner and outer conductor of the coaxial cable is filled with polytetrafluoroethylene (PTFE), a material with relative permittivity $\varepsilon_r = 2.1$. A coaxial type lumped port is used to excite the antenna.

All domains except the PML are meshed by a tetrahedral mesh with approximately five elements per wavelength. The helix and coaxial cable are meshed more finely to provide good resolution of the curved surfaces. The PML is swept with a total of five elements along the radial direction.

The ground plate, the PML sphere shell, and the maximum mesh size are adjusted automatically as a function of wavelength for each helical antenna mode.

Results and Discussion

The antenna is analyzed for two operating modes. Figure 2 and Figure 3 show the log-scaled electric field norm describing the field intensity around the antenna at the axial mode and normal mode, respectively. Figure 4 shows a polar plot of 2D radiation patterns in the *yz*-plane for both modes. A directional radiation pattern is observed at the axial mode while the radiation pattern at the normal mode resembles the E-plane pattern of a classic dipole antenna. The 3D far-field radiation pattern for each mode is also plotted in Figure 5 and Figure 6. The S-parameters for both modes are less than −10 dB.

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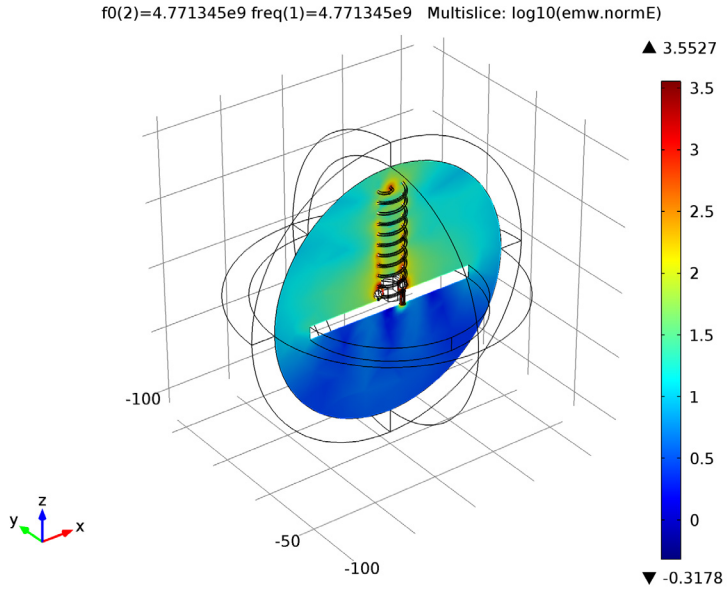

Figure 2: Log-scaled electric field magnitude around the antenna at 4.77 GHz.

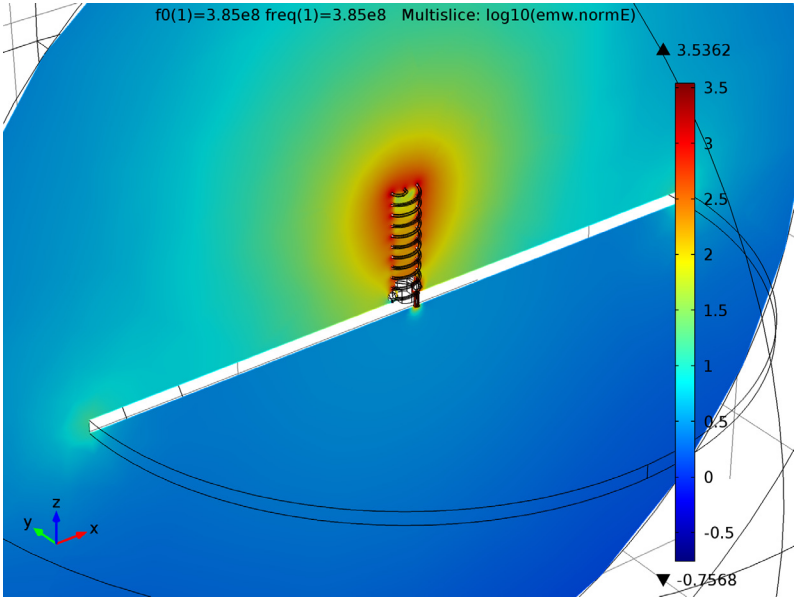

Figure 3: Log-scaled electric field magnitude around the antenna at 385 MHz.

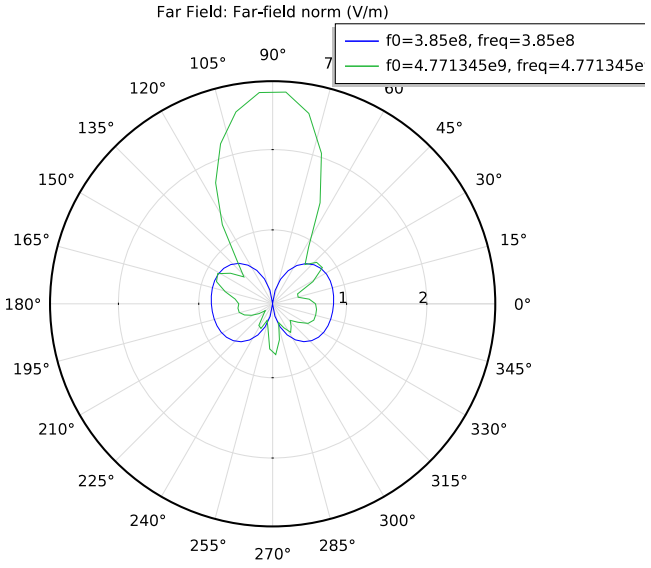

Figure 4: Polar plot of the far-field pattern in the yz-plane

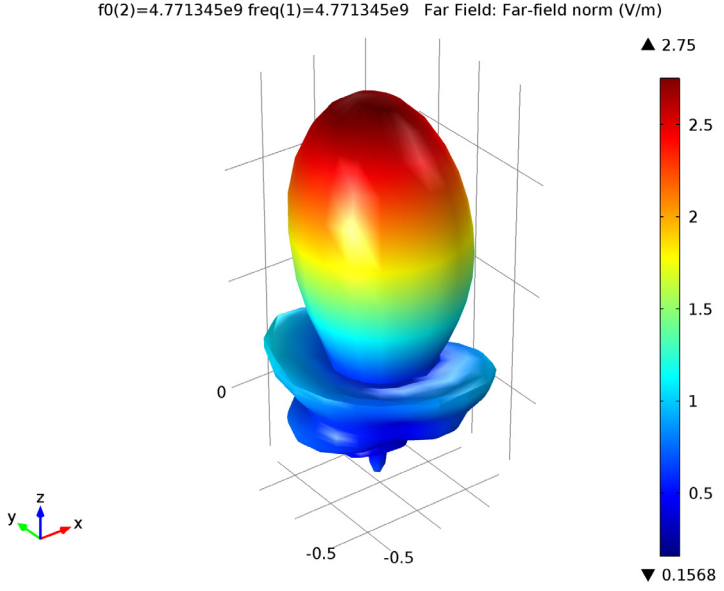

Figure 5: The 3D far-field pattern looks like that of an end-fire array along the z-axis backed by a ground plane.

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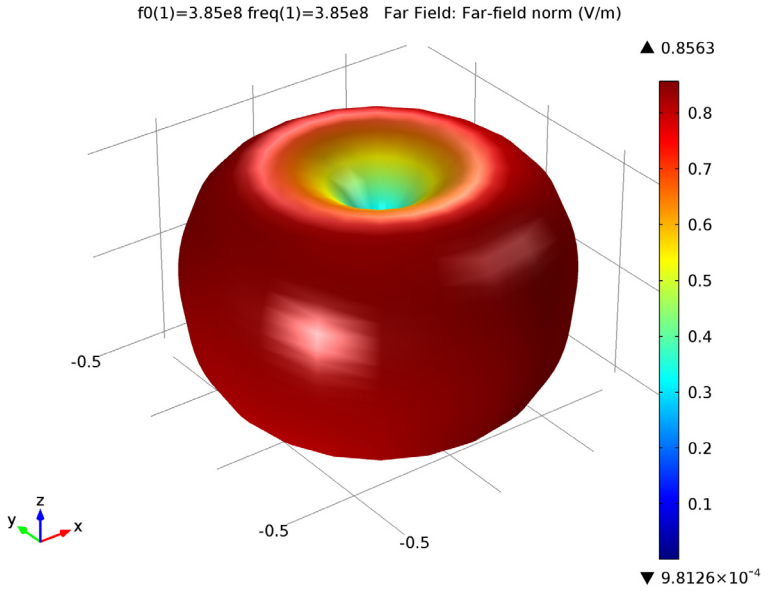

Figure 6: The torus-shaped 3D far-field pattern resembles that of a dipole antenna.

Notes About the COMSOL Implementation

Due to the complexity of the geometry and mesh, more than 7 GB RAM is required to run this model.

Model Library path: `RF_Module/Antennas/helical_antenna`

Modeling Instructions

MODEL WIZARD

1 Go to the **Model Wizard** window.

2 Click **Next**.

3 In the **Add physics** tree, select **Radio Frequency>Electromagnetic Waves, Frequency Domain (emw)**.

4 Click **Add Selected**.

5 Click **Next**.

6 Find the **Studies** subsection. In the tree, select **Preset Studies>Frequency Domain**.

7 Click **Finish**.

GLOBAL DEFINITIONS

Parameters

1 In the **Model Builder** window, right-click **Global Definitions** and choose **Parameters**.

2 In the **Parameters** settings window, locate the **Parameters** section.

3 In the table, enter the following settings:

Name	Expression	Description
r_helix	10[mm]	Helix radius
a_pitch	15.7[mm]	Helix pitch
n_turn	5	Number of turns
h_ground	10[mm]	Ground plane thickness
l_pin	3[mm]	Pin length
f_normal	385[MHz]	Frequency at normal mode
lda_axial	pi*2*r_helix	Wave length at axial mode, air
f_axial	c_const/lda_axial	Frequency at axial mode
f0	f_normal	Frequency in sweep
lda0	c_const/f0	Wave length in sweep, air
h_max	lda0	Maximum mesh size in sweep, air

Here, `c_const` is a predefined COMSOL constant for the speed of light in vacuum.

GEOMETRY 1

1 In the **Model Builder** window, under **Model 1** click **Geometry 1**.

2 In the **Geometry** settings window, locate the **Units** section.

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

Create a helix with the specified parameters.

Helix 1

1 Right-click **Model 1>Geometry 1** and choose **Helix**.

2 In the **Helix** settings window, locate the **Size and Shape** section.

3 In the **Number of turns** edit field, type `n_turn`.

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4 In the **Major radius** edit field, type `r_helix`.

5 In the **Minor radius** edit field, type `1`.

6 In the **Axial pitch** edit field, type `a_pitch`.

Add a torus connected to one end the helix.

Torus 1

1 In the **Model Builder** window, right-click **Geometry 1** and choose **More Primitives>Torus**.

2 In the **Torus** settings window, locate the **Size and Shape** section.

3 In the **Major radius** edit field, type `r_helix/2`.

4 In the **Minor radius** edit field, type `1`.

5 In the **Revolution angle** edit field, type `180`.

6 Locate the **Position** section. In the **x** edit field, type `r_helix/2`.

7 In the **z** edit field, type `a_pitch*n_turn`.

Add a cylinder for the extended part of the coaxial cable inner conductor and ground pin.

Cylinder 1

1 Right-click **Geometry 1** and choose **Cylinder**.

2 In the **Cylinder** settings window, locate the **Size and Shape** section.

3 In the **Radius** edit field, type `0.635`.

4 In the **Height** edit field, type `l_pin`.

5 Locate the **Position** section. In the **x** edit field, type `r_helix`.

6 In the **z** edit field, type `-l_pin`.

Add a sphere for the solder ball.

Sphere 1

1 Right-click **Geometry 1** and choose **Sphere**.

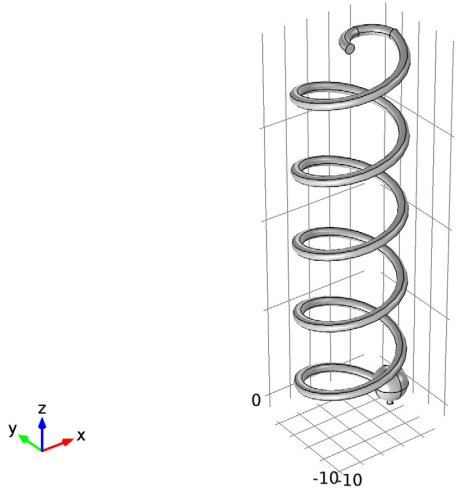
2 In the **Sphere** settings window, locate the **Size and Shape** section.

3 In the **Radius** edit field, type `3.6`.

4 Locate the **Position** section. In the **x** edit field, type `r_helix`.

5 In the **z** edit field, type `1.8`.

6 Click the **Build Selected** button.



Generate the other arm of the helix by rotating the first arm.

Rotate 1

1 Right-click **Geometry 1** and choose **Transforms>Rotate**.

2 Click in the **Graphics** window, press Ctrl+A to highlight all objects, and then right-click to confirm the selection.

3 In the **Rotate** settings window, locate the **Input** section.

4 Select the **Keep input objects** check box.

5 Locate the **Rotation Angle** section. In the **Rotation** edit field, type 180.

Create a union of all geometries to remove unnecessary internal boundaries.

Union 1

1 Right-click **Geometry 1** and choose **Boolean Operations>Union**.

2 Click in the **Graphics** window, press Ctrl+A to highlight all objects, and then right-click to confirm the selection.

3 In the **Union** settings window, locate the **Union** section.

4 Clear the **Keep interior boundaries** check box.

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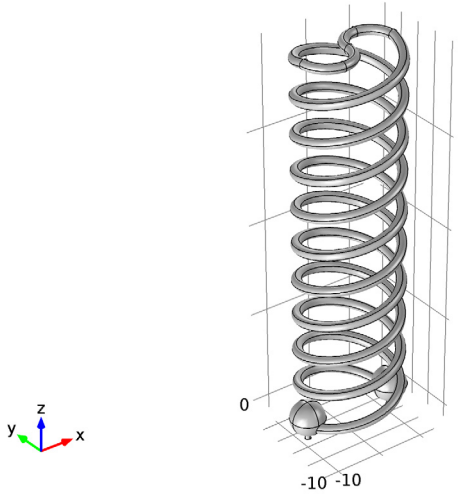
5 Click the **Build Selected** button.



Add a cylinder for the coaxial cable inner conductor.

Cylinder 2

1 Right-click **Geometry 1** and choose **Cylinder**.

2 In the **Cylinder** settings window, locate the **Size and Shape** section.

3 In the **Radius** edit field, type `0.635`.

4 In the **Height** edit field, type `h_ground`.

5 Locate the **Position** section. In the **x** edit field, type `r_helix`.

6 In the **z** edit field, type `-h_ground-l_pin`.

Add a cylinder for the coaxial cable outer conductor.

Cylinder 3

1 Right-click **Geometry 1** and choose **Cylinder**.

2 In the **Cylinder** settings window, locate the **Size and Shape** section.

3 In the **Radius** edit field, type `2.05`.

4 In the **Height** edit field, type `h_ground`.

5 Locate the **Position** section. In the **x** edit field, type `r_helix`.

6 In the **z** edit field, type `-h_ground-l_pin`.

Add a cylinder for the impedance matching stub.

Cylinder 4

1 Right-click **Geometry 1** and choose **Cylinder**.

2 In the **Cylinder** settings window, locate the **Size and Shape** section.

3 In the **Radius** edit field, type `8`.

4 In the **Height** edit field, type `15`.

5 Locate the **Position** section. In the **z** edit field, type `-l_pin`.

Block 1

1 Right-click **Geometry 1** and choose **Block**.

2 In the **Block** settings window, locate the **Size and Shape** section.

3 In the **Width** edit field, type `14`.

4 In the **Depth** edit field, type `14`.

5 In the **Height** edit field, type `10`.

6 Locate the **Position** section. In the **x** edit field, type `6`.

7 In the **y** edit field, type `-7`.

8 In the **z** edit field, type `-l_pin`.

Mirror 1

1 Right-click **Geometry 1** and choose **Transforms>Mirror**.

2 Select the object **blk1** only.

3 In the **Mirror** settings window, locate the **Input** section.

4 Select the **Keep input objects** check box.

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

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

Difference 1

1 Right-click **Geometry 1** and choose **Boolean Operations>Difference**.

2 Select the object **cyl4** only.

3 In the **Difference** settings window, locate the **Difference** section.

4 Under **Objects to subtract**, click **Activate Selection**.

5 Select the objects **mir1** and **blk1** only.

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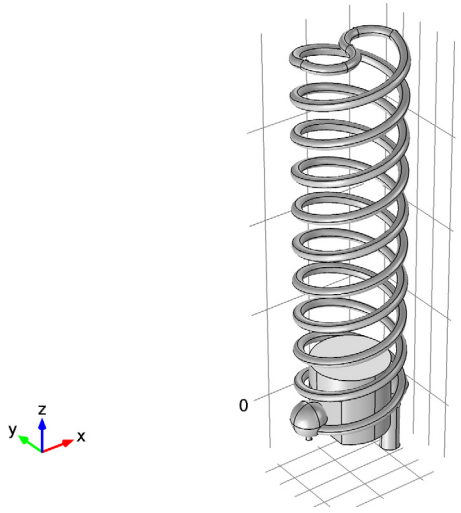
6 Click the **Build Selected** button.



Add a cylinder for the ground plate.

Cylinder 5

1 Right-click **Geometry 1** and choose **Cylinder**.

2 In the **Cylinder** settings window, locate the **Size and Shape** section.

3 In the **Radius** edit field, type `50+lda0/4`.

4 In the **Height** edit field, type `h_ground`.

5 Locate the **Position** section. In the **z** edit field, type `-h_ground-l_pin`.

6 Click the **Build Selected** button.

7 Click the **Zoom Extents** button on the Graphics toolbar.

Choose wireframe rendering to see the interior of the antenna structure.

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

Add a sphere with a layer definition for the PML.

Sphere 2

1 Right-click **Geometry 1** and choose **Sphere**.

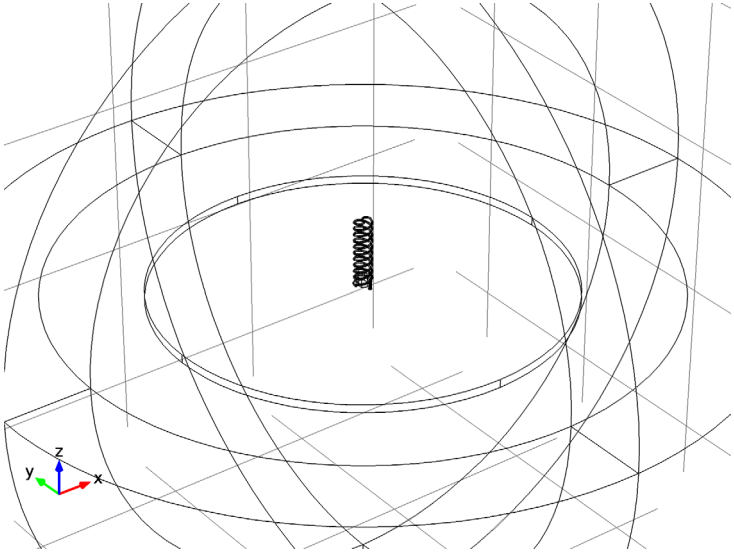
2 In the **Sphere** settings window, locate the **Size and Shape** section.

3 In the **Radius** edit field, type `80+lda0/2`.

4 Click to expand the **Layers** section. In the table, enter the following settings:

Layer name	Thickness (mm)
Layer 1	10+lda0/8

5 Click the **Build All** button.



DEFINITIONS

Create a set of selections to use when setting up the physics. First, create a selection for all metal domains.

Explicit 1

1 In the **Model Builder** window, under **Model 1** right-click **Definitions** and choose **Selections>Explicit**.

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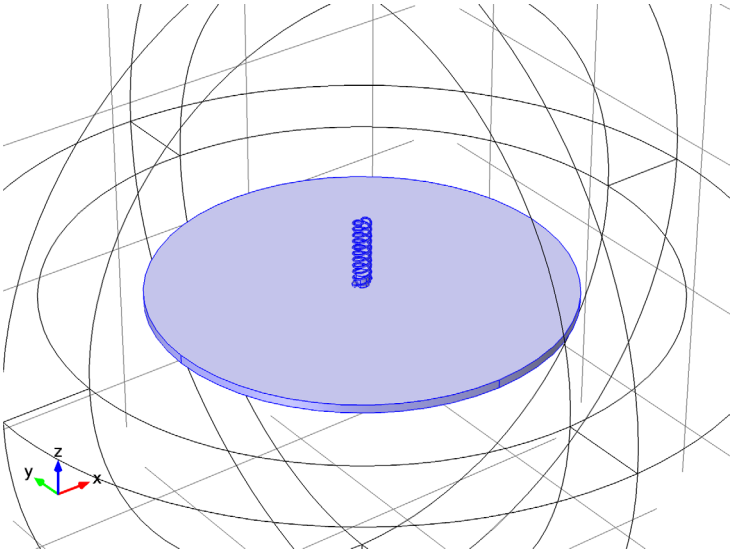
2 Select Domains 6–8 and 14 only.



3 Right-click **Model 1>Definitions>Explicit 1** and choose **Rename**.

4 Go to the **Rename Explicit** dialog box and type `Metal` in the **New name** edit field.

5 Click **OK**.

Add a selection for the lumped port boundary of the coaxial cable.

Explicit 2

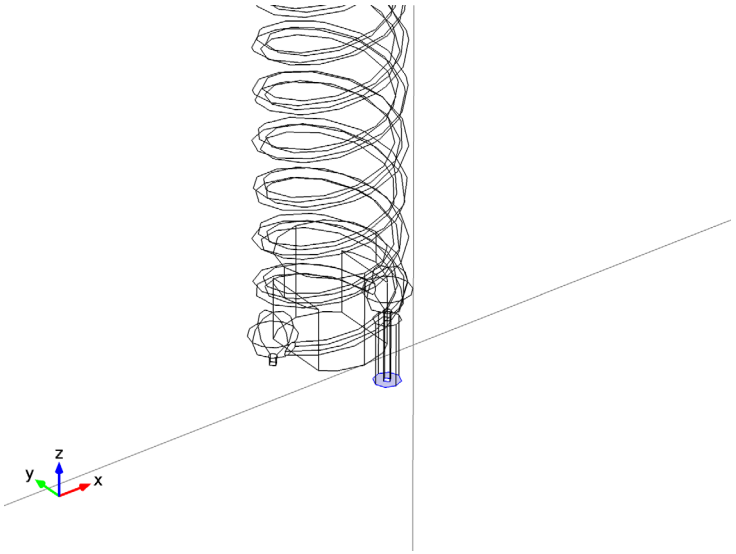
1 Right-click **Definitions** and choose **Selections>Explicit**.

2 In the **Explicit** settings window, locate the **Input Entities** section.

3 From the **Geometric entity level** list, choose **Boundary**.

4 Click the **Zoom In** button on the Graphics toolbar several times until you can see the coaxial feed part clearly.

5 Select Boundary 85 only.



6 Right-click **Model 1>Definitions>Explicit 2** and choose **Rename**.

7 Go to the **Rename Explicit** dialog box and type `Port boundary` in the **New name** edit field.

8 Click **OK**.

Add a selection for the dielectric in the coaxial cable.

Explicit 3

1 Right-click **Definitions** and choose **Selections>Explicit**.

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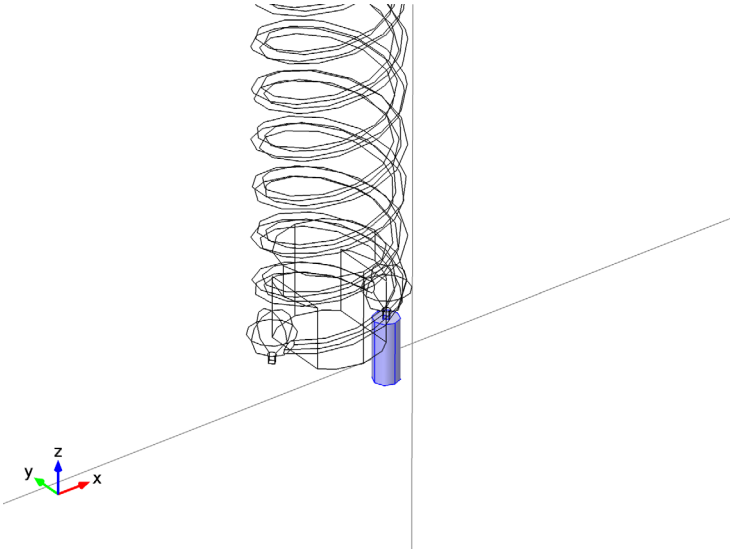
2 Select Domain 13 only.



3 Right-click **Model 1>Definitions>Explicit 3** and choose **Rename**.

4 Go to the **Rename Explicit** dialog box and type `Coax dielectric` in the **New name** edit field.

5 Click **OK**.

Add a selection for the model analysis domain, which is the complement of the Metal selection. So, the inside of the metal structure is not part of the model space.

Complement 1

1 Right-click **Definitions** and choose **Selections>Complement**.

2 In the **Complement** settings window, locate the **Input Entities** section.

3 Under **Selections to invert**, click **Add**.

4 Go to the **Add** dialog box.

5 In the **Selections to invert** list, select **Metal**.

6 Click the **OK** button.

7 Right-click **Model 1>Definitions>Complement 1** and choose **Rename**.

8 Go to the **Rename Complement** dialog box and type `Model domain` in the **New name** edit field.

9 Click **OK**.

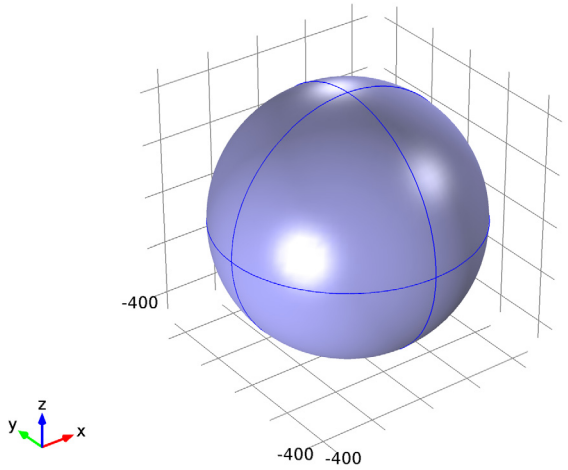
10 Click the **Zoom Extents** button on the Graphics toolbar.

Add a selection for the PML.

Explicit 4

1 Right-click **Definitions** and choose **Selections>Explicit**.

2 Select Domains 1–4 and 9–12 only.



3 Right-click **Model 1>Definitions>Explicit 4** and choose **Rename**.

4 Go to the **Rename Explicit** dialog box and type `PML domain` in the **New name** edit field.

5 Click **OK**.

Add a selection for the far-field domain. This is the complement of the PML.

Complement 2

1 Right-click **Definitions** and choose **Selections>Complement**.

2 In the **Complement** settings window, locate the **Input Entities** section.

3 Under **Selections to invert**, click **Add**.

4 Go to the **Add** dialog box.

5 In the **Selections to invert** list, select **PML domain**.

6 Click the **OK** button.

7 Right-click **Model 1>Definitions>Complement 2** and choose **Rename**.

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8 Go to the **Rename Complement** dialog box and type `Far-field domain` in the **New name** edit field.

9 Click **OK**.

Add a selection for the far-field calculation boundaries which are the outermost surfaces of the far-field domain.

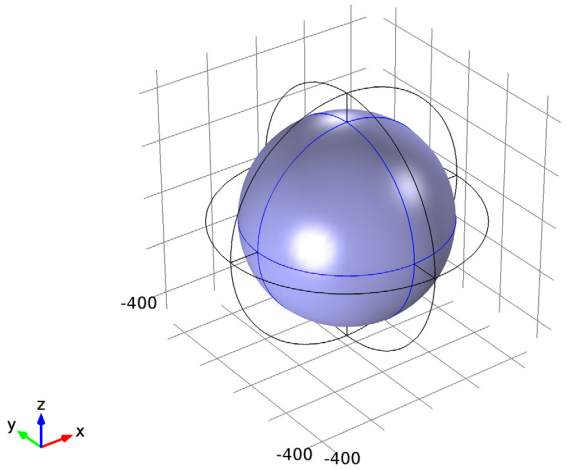
Explicit 5

1 Right-click **Definitions** and choose **Selections>Explicit**.

2 In the **Explicit** settings window, locate the **Input Entities** section.

3 From the **Geometric entity level** list, choose **Boundary**.

4 Select Boundaries 9–12, 56, 57, 63, and 68 only.



5 Right-click **Model 1>Definitions>Explicit 5** and choose **Rename**.

6 Go to the **Rename Explicit** dialog box and type `Far-field calc.` in the **New name** edit field.

7 Click **OK**.

Add a perfectly matched layer. Use the PML selection to specify the domain.

Perfectly Matched Layer 1

1 Right-click **Definitions** and choose **Perfectly Matched Layer**.

2 In the **Perfectly Matched Layer** settings window, locate the **Domain Selection** section.

3 From the **Selection** list, choose **PML domain**.

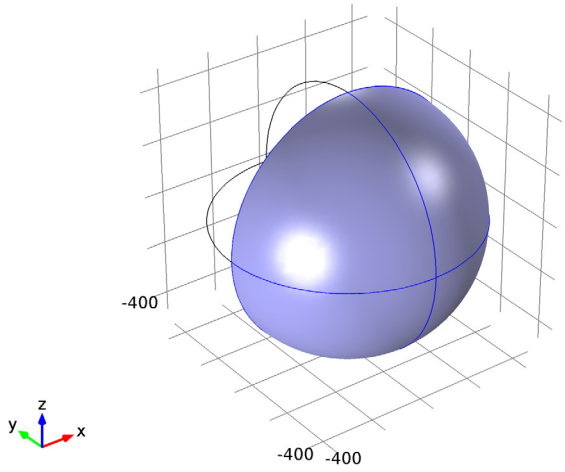
4 Locate the **Geometry** section. From the **Type** list, choose **Spherical**.

View 1

Suppress some domains and boundaries to get a better view of the interior parts when setting up the physics and reviewing the mesh.

1 In the **Model Builder** window, under **Model 1>Definitions** right-click **View 1** and choose **Hide Geometric Entities**.

2 Select Domains 1, 2, 9, and 10 only.



3 In the **Model Builder** window, right-click **View 1** and choose **Hide Geometric Entities**.

4 In the **Hide Geometric Entities** settings window, locate the **Geometric Entity Selection** section.

5 From the **Geometric entity level** list, choose **Boundary**.

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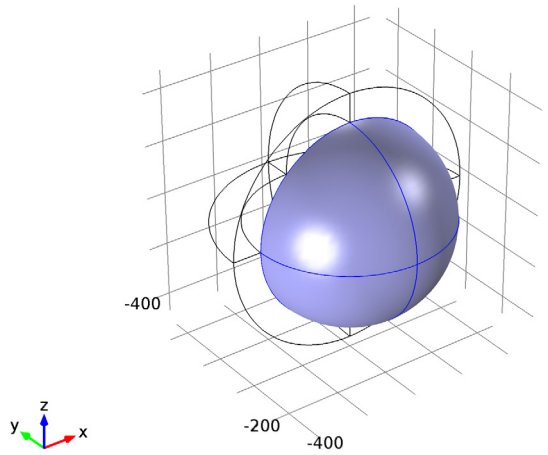
6 Select Boundaries 9, 10, 56, and 57 only.



ELECTROMAGNETIC WAVES, FREQUENCY DOMAIN

Set up the physics. Use the selections already defined when specifying domains and boundaries.

1 In the **Model Builder** window, under **Model 1** click **Electromagnetic Waves, Frequency Domain**.

2 In the **Electromagnetic Waves, Frequency Domain** settings window, locate the **Domain Selection** section.

3 From the **Selection** list, choose **Model domain**.

Far-Field Domain 1

1 Right-click **Model 1>Electromagnetic Waves, Frequency Domain** and choose **Far-Field Domain**.

2 In the **Far-Field Domain** settings window, locate the **Domain Selection** section.

3 From the **Selection** list, choose **Far-field domain**.

Far-Field Calculation 1

1 In the **Model Builder** window, expand the **Far-Field Domain 1** node, then click **Far-Field Calculation 1**.

2 In the **Far-Field Calculation** settings window, locate the **Boundary Selection** section.

3 From the **Selection** list, choose **Far-field calc.**.

Lumped Port 1

1 In the **Model Builder** window, right-click **Electromagnetic Waves, Frequency Domain** and choose **Lumped Port**.

2 In the **Lumped Port** settings window, locate the **Boundary Selection** section.

3 From the **Selection** list, choose **Port boundary**.

4 Locate the **Port Properties** section. From the **Type of port** list, choose **Coaxial**.

5 From the **Wave excitation at this port** list, choose **On**.

MATERIALS

Assign material properties. Use air for all domains. Then, override the dielectric in the coaxial cable with PTFE.

Material Browser

1 In the **Model Builder** window, under **Model 1** right-click **Materials** and choose **Open Material Browser**.

2 In the **Material Browser** window, locate the **Materials** section.

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

4 Right-click and choose **Add Material to Model** from the menu.

Material 2

1 In the **Model Builder** window, right-click **Materials** and choose **Material**.

2 In the **Material** settings window, locate the **Geometric Entity Selection** section.

3 From the **Selection** list, choose **Coax dielectric**.

4 Locate the **Material Contents** section. In the table, enter the following settings:

Property	Name	Value
Relative permittivity	epsilonr	2.1
Relative permeability	mur	1
Electrical conductivity	sigma	0

5 In the **Model Builder** window, right-click **Material 2** and choose **Rename**.

6 Go to the **Rename Material** dialog box and type PTFE in the **New name** edit field.

7 Click **OK**.

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MESH 1

Choose the maximum mesh size in the air domain smaller than 0.2 wavelengths using the parameter `h_max` that you defined earlier.

Size 1

1. In the **Model Builder** window, under **Model 1** right-click **Mesh 1** and choose **Size**.
2. In the **Size** settings window, locate the **Geometric Entity Selection** section.
3. From the **Geometric entity level** list, choose **Domain**.
4. From the **Selection** list, choose **Far-field domain**.
5. Locate the **Element Size** section. Click the **Custom** button.
6. Locate the **Element Size Parameters** section. Select the **Maximum element size** check box.
7. In the associated edit field, type `h_max`.
8. Select the **Minimum element size** check box.
9. In the associated edit field, type `4`.

Size 2

1. In the **Model Builder** window, right-click **Mesh 1** and choose **Size**.
2. In the **Size** settings window, locate the **Geometric Entity Selection** section.
3. From the **Geometric entity level** list, choose **Domain**.
4. From the **Selection** list, choose **Coax dielectric**.
5. Locate the **Element Size** section. Click the **Custom** button.
6. Locate the **Element Size Parameters** section. Select the **Maximum element size** check box.
7. In the associated edit field, type `2`.
8. Select the **Minimum element size** check box.
9. In the associated edit field, type `0.8`.

Size 3

1. Right-click **Mesh 1** and choose **Size**.
2. Click the **Zoom In** button on the Graphics toolbar two or three times to see the helix structure clearly.
3. In the **Size** settings window, locate the **Geometric Entity Selection** section.
4. From the **Geometric entity level** list, choose **Domain**.

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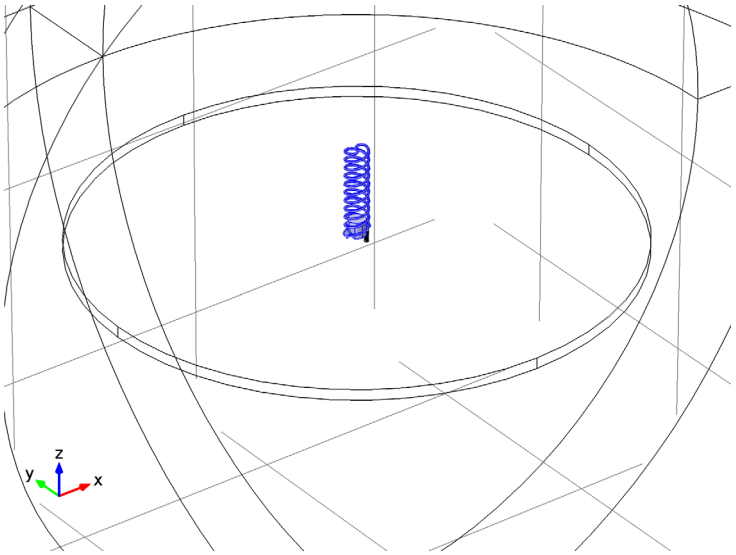
5 Select Domains 7 and 8 only.



6 In the **Size** settings window, locate the **Element Size** section.

7 Click the **Custom** button.

8 Locate the **Element Size Parameters** section. Select the **Maximum element size** check box.

9 In the associated edit field, type `2`.

10 Select the **Minimum element size** check box.

11 In the associated edit field, type `0.8`.

Free Tetrahedral 1

1 Right-click **Mesh 1** and choose **Free Tetrahedral**.

2 In the **Free Tetrahedral** settings window, locate the **Domain Selection** section.

3 From the **Geometric entity level** list, choose **Domain**.

4 From the **Selection** list, choose **Far-field domain**.

Use a swept mesh for the PML.

Swept 1

1 Right-click **Mesh 1** and choose **Swept**.

2 In the **Swept** settings window, locate the **Domain Selection** section.

3 From the **Geometric entity level** list, choose **Domain**.

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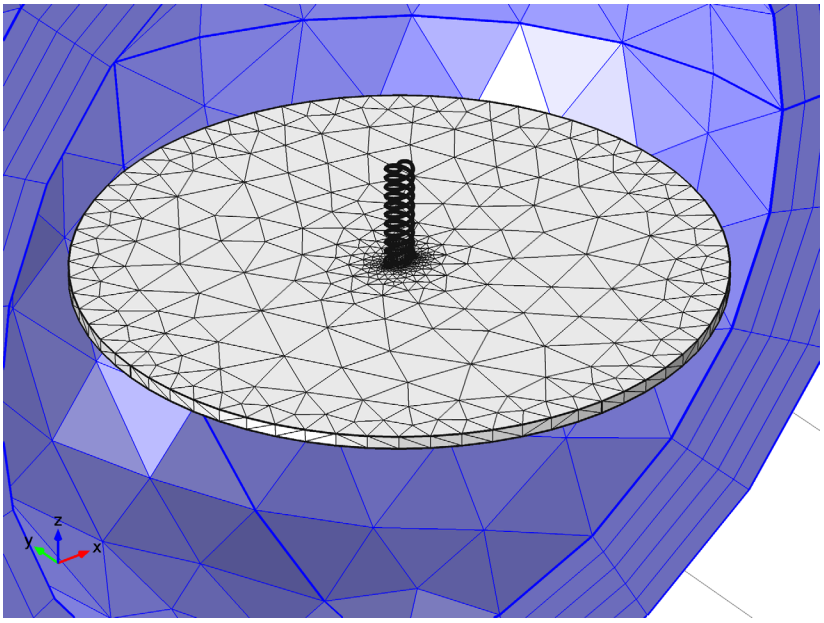
4 From the **Selection** list, choose **PML domain**.

5 Right-click **Model 1>Mesh 1>Swept 1** and choose **Distribution**.

6 Click the **Build All** button.



STUDY 1

Step 1: Frequency Domain

1 In the **Frequency Domain** settings window, locate the **Study Settings** section.

2 In the **Frequencies** edit field, type `f0`.

Parametric Sweep

1 In the **Model Builder** window, right-click **Study 1** and choose **Parametric Sweep**.

2 In the **Parametric Sweep** settings window, locate the **Study Settings** section.

3 Click **Add**.

4 In the table, enter the following settings:

Parameter names	Parameter value list
f0	`f_normal f_axial`

5 Right-click **Study 1** and choose **Compute**.

RESULTS

The default plot shows the *E*-field norm, 2D Far-field polar plot, and 3D Far-field radiation pattern. Suppress the PML domain for the result analysis and adjust the plot settings.

Data Sets

1 In the **Model Builder** window, under **Results>Data Sets** right-click **Solution 2** and choose **Add Selection**.

2 In the **Selection** settings window, locate the **Geometric Entity Selection** section.

3 From the **Geometric entity level** list, choose **Domain**.

4 From the **Selection** list, choose **Far-field domain**.

Electric field

1 In the **Model Builder** window, under **Results>Electric field** click **Multislice**.

2 In the **Multislice** settings window, locate the **Expression** section.

3 In the **Expression** edit field, type `log10(emw.normE)`.

4 Locate the **Multiplane Data** section. Find the **x-planes** subsection. In the **Planes** edit field, type `0`.

5 Find the **z-planes** subsection. In the **Planes** edit field, type `0`.

6 Click the **Plot** button.

7 Click the **Zoom Extents** button on the Graphics toolbar.

This plot shows the log-scaled *E*-field norm in the *zx*-plane around the helical antenna operating at the axial mode; compare with Figure 2.

8 In the **Model Builder** window, click **Electric field**.

9 In the **3D Plot Group** settings window, locate the **Data** section.

10 From the **Parameter value (f0)** list, choose **3.85e8**.

11 Click the **Plot** button.

The log-scaled *E*-field norm at the normal mode is shown in Figure 3.

Polar Plot Group 2

1 In the **Model Builder** window, under **Results>Polar Plot Group 2** click **Far Field 1**.

2 In the **Far Field** settings window, locate the **Evaluation** section.

3 Find the **Normal** subsection. In the **x** edit field, type `1`.

4 In the **z** edit field, type `0`.

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5 Click the **Plot** button.

As shown in Figure 4, the plotted pattern of the axial mode is more directive than that of the normal mode.

3D Plot Group 3

1 Click the **Zoom Extents** button on the Graphics toolbar.

Compare the reproduced axial mode 3D far-field pattern with that shown in Figure 5.

2 In the **Model Builder** window, under **Results** click **3D Plot Group 3**.

3 In the **3D Plot Group** settings window, locate the **Data** section.

4 From the **Parameter value (f0)** list, choose **3.85e8**.

5 Click the **Plot** button.

6 Click the **Zoom Extents** button on the Graphics toolbar.

See Figure 6 for the normal mode 3D far-field pattern.

Derived Values

Evaluate the S-parameters.

1 In the **Model Builder** window, under **Results** right-click **Derived Values** and choose **Global Evaluation**.

2 In the **Global Evaluation** settings window, locate the **Data** section.

3 From the **Data set** list, choose **Solution 2**.

4 Click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Electromagnetic Waves, Frequency Domain>Ports>S-parameter, dB (emw.S11dB)**.

5 Click the **Evaluate** button.

The calculated S-parameters at the input port should be better than –10 dB for both modes.

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