Model created in COMSOL Multiphysics 6.4

Detecting the Orientation of a Metallic Cylinder Embedded in a Dielectric Shell

Introduction

A metallic cylindrical rod is hidden inside a spherical dielectric shell and its orientation is unknown. By studying the polarization-dependent scattered field of a cylindrical object and performing a parametric sweep as a function of polarization angle, the rod is detected for the polarization angle where the scattered field is highest. The model uses a linearly polarized plane wave for the background field and computes the far-field radiation patterns.

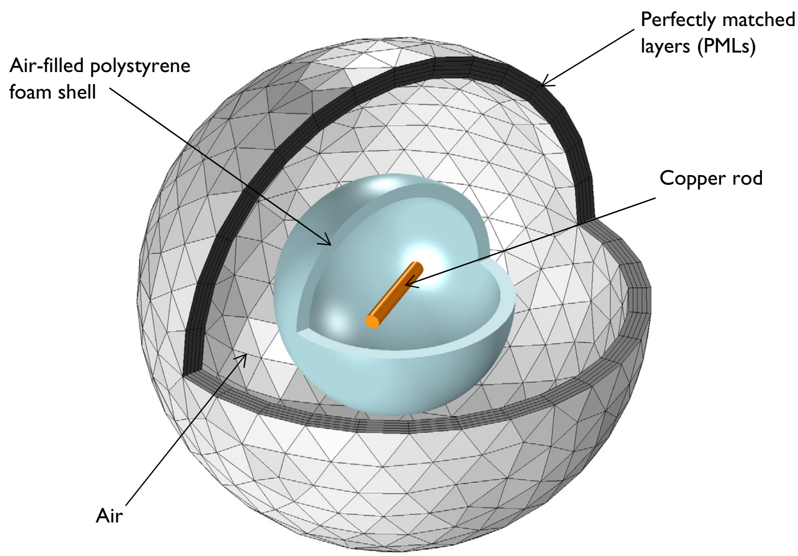


Figure 1: A copper rod inside a spherical polystyrene foam shell. Some parts are removed for visualization purposes.

Model Definition

A cylindrical copper rod is enclosed in a 2 cm thick polystyrene foam ($\varepsilon_r = 1.03$) dielectric shell that is filled with air. The copper rod lies in the *xy*-plane, but its orientation is unknown. The dielectric shell is surrounded by air and the entire model domain is enclosed by perfectly matched layers.

The model is solved using the scattered field formulation, while the built-in linearly polarized plane wave is used for background field. The wave vector of the background field is pointing toward the $-z$ direction after it is transformed from the $+x$-directional initial wave by a 90 degree pitch angle. The polarization is determined by the parameterized value of the yaw angle that varies from 0 to 175 degrees.

The copper rod is modeled using the Impedance boundary condition and its inner volume is removed from the model domain. This is done because the skin depth is much smaller than the size of the rod. The rod's scattered field is computed on the boundaries configured by the Far-Field Domain node and its Far-Field Calculation subfeature by performing a near-field to far-field transformation.

A perfectly matched layer (PML) domain is outside of the surrounding air domain and acts as an absorber of the scattered field. The PML is placed at a half-wavelength away from the dielectric shell.

Results and Discussion

Figure 2 shows the radar cross section (RCS) of the example in dB scale. The maximum occurs when the yaw angle for the polarization is 30 degrees, while the minimum value occurs at 120 degrees. The maximum scattering is known to take a place when the polarization is parallel to the cylinder. This means the cylinder is oriented at 30 degrees, with respect to the *x*-axis.

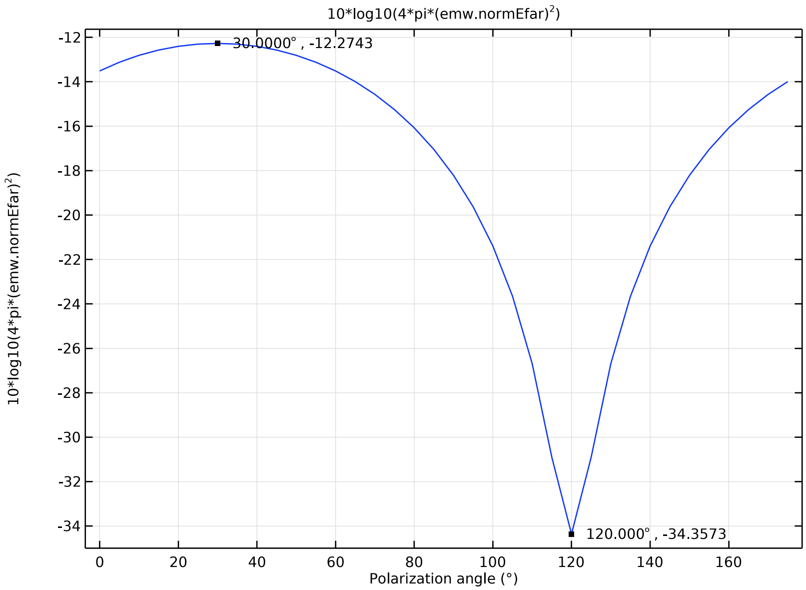


Figure 2: The maximum radar cross section (RCS) is observed at 30 degrees. With respect to the orientation of the cylinder, when the polarization angle of the background field is rotated 45 degrees, the RCS is 3dB lower than the maximum.

[Figure 3](#) shows the electric field norm in the *xy*-plane at the maximum scattering angle. The electric field resembles that of a dipole antenna. The background field induces the oscillating current along the rod which then radiates as a dipole.

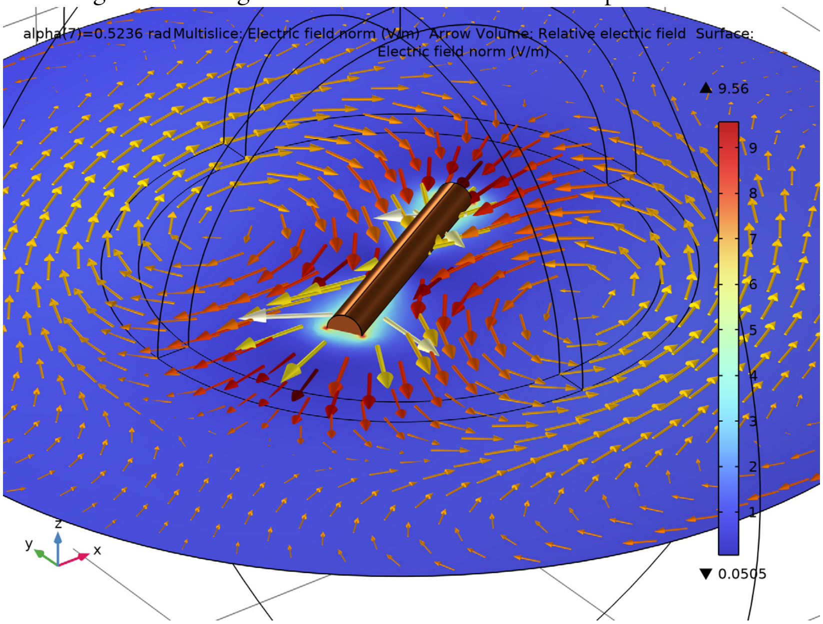


Figure 3: The electric field norm in the xy-plane at the maximum scattering angle.

Application Library path: `RF_Module/Scattering_and_RCS/cylinder_orientation`

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**.

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 In the table, enter the following settings:

Name	Expression	Value	Description
alpha	0[deg]	0 rad	Polarization angle

GEOMETRY 1

Sphere 1 (sph1)

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

2 In the **Settings** window for **Sphere**, locate the **Size** section.

3 In the **Radius** text field, type 0.34.

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

Layer name	Thickness (m)
Layer 1	0.03

5 Click **Build Selected**.

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

Sphere 2 (sph2)

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

2 In the **Settings** window for **Sphere**, locate the **Size** section.

3 In the **Radius** text field, type 0.16.

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

Layer name	Thickness (m)
`Layer 1`	`0.02`

Cylinder 1 (cyl1)

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

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

3 In the **Radius** text field, type `0.01`.

4 In the **Height** text field, type `0.15`.

5 Locate the **Position** section. In the **x** text field, type `-0.075`.

6 Locate the **Axis** section. From the **Axis type** list, choose **x-axis**.

Rotate 1 (rot1)

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

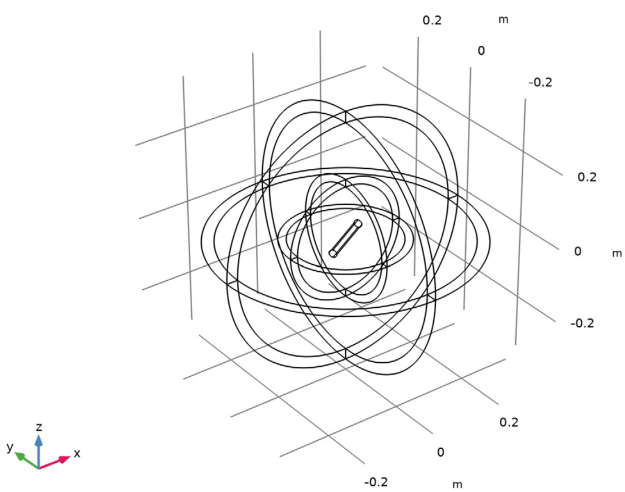
2 Select the object **cyl1** only.

3 In the **Settings** window for **Rotate**, locate the **Rotation** section.

4 In the **Angle** text field, type `30`.

5 Click **Build All Objects**.

6 Click the **Zoom In** button in the **Graphics** toolbar.



The finished geometry should look like this.

DEFINITIONS

Perfectly Matched Layer 1 (pml1)

1 In the **Definitions** toolbar, click **Perfectly Matched Layer**.

2 Select Domains 1–4, 12, 13, 16, and 19 only.

3 In the **Settings** window for **Perfectly Matched Layer**, locate the **Geometry** section.

4 From the **Type** list, choose **Spherical**.

ELECTROMAGNETIC WAVES, FREQUENCY DOMAIN (EMW)

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

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

3 Click **Clear Selection**.

4 Click **Paste Selection**.

5 In the **Paste Selection** dialog, type `1-10, 12-19` in the **Selection** text field.

6 Click **OK**.

7 In the **Settings** window for **Electromagnetic Waves, Frequency Domain**, locate the **Formulation** section.

8 From the list, choose **Scattered field**.

9 From the **Background wave type** list, choose **Linearly polarized plane wave**.

10 In the **Pitch angle** text field, type `90[deg]`.

11 In the **Yaw angle** text field, type `alpha`.

Far-Field Domain 1

In the **Physics** toolbar, click **Domains** and choose **Far-Field Domain**.

Impedance Boundary Condition 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Impedance Boundary Condition**.

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

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog, type `25-29, 62` in the **Selection** text field.

5 Click **OK**.

MATERIALS

Material 1 (mat1)

1 In the **Model Builder** window, under **Component 1 (comp1)** 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	1	Basic
Relative permeability	mur_iso ; murii = mur_iso, murij = 0	1	1	Basic
Electric conductivity	sigma_iso ; sigmaii = sigma_iso, sigmaij = 0	0	S/m	Basic

Material 2 (mat2)

1 Right-click **Materials** and choose **Blank Material**.

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

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog, type `6-9, 14-15, 17-18` in the **Selection** text field.

5 Click **OK**.

6 In the **Settings** window for **Material**, locate the **Material Contents** section.

7 In the table, enter the following settings:

Property	**Variable**	**Value**	**Unit**	**Property group**
Relative permittivity	epsilonr_iso ; epsilonrii = epsilonr_iso, epsilonrij = 0	1.03	1	Basic
Relative permeability	mur_iso ; murii = mur_iso, murij = 0	1	1	Basic
Electric conductivity	sigma_iso ; sigmaii = sigma_iso, sigmaij = 0	0	S/m	Basic

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** > **Copper**.
4. Right-click and choose **Add to Component 1 (comp1)**.
5. In the **Materials** toolbar, click **Add Material** to close the **Add Material** window.

MATERIALS

Copper (mat3)

1. In the **Settings** window for **Material**, locate the **Geometric Entity Selection** section.
2. From the **Geometric entity level** list, choose **Boundary**.
3. Click **Paste Selection**.
4. In the **Paste Selection** dialog, type `25-29, 62` in the **Selection** text field.

   These are same boundaries where you assigned Impedance Boundary Condition.
5. Click **OK**.

DEFINITIONS

Hide for Physics 1

1. In the **Model Builder** window, right-click **View 1** and choose **Hide for Physics**.
2. In the **Settings** window for **Hide for Physics**, locate the **Geometric Entity Selection** section.

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

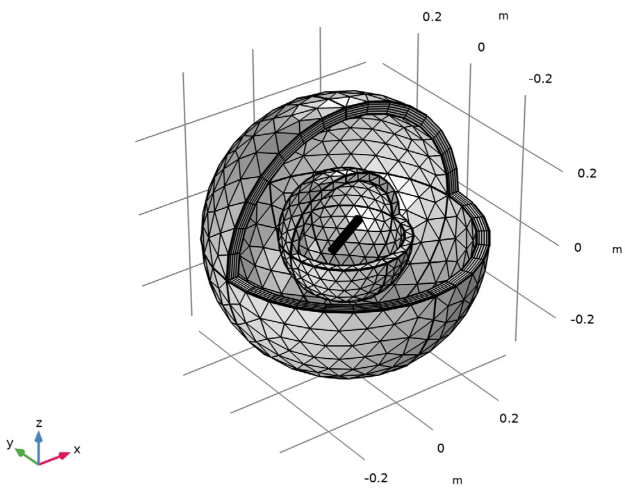
4 Click **Paste Selection**.

5 In the **Paste Selection** dialog, type `6, 10, 18, 22, 31, 34, 36, 38, 41, 43` in the **Selection** text field.

6 Click **OK**.

MESH 1

In the **Model Builder** window, under **Component 1 (comp1)** right-click **Mesh 1** and choose **Build All**.



STUDY 1

Parametric Sweep

1 In the **Study** toolbar, click **Parametric Sweep**.

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

3 Click **Add**.

4 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
alpha (Polarization angle)	`range(0[deg],5[deg],175[deg])`	`rad`

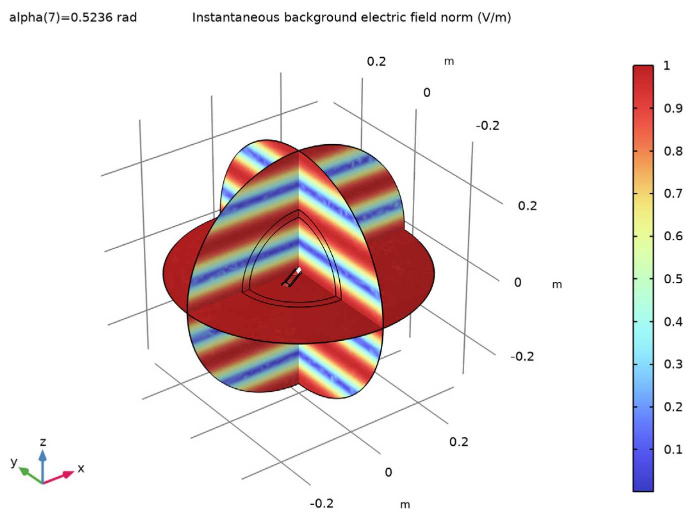
Step 1: Frequency Domain

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

RESULTS

Electric Field, Background (emw)

1 In the **Model Builder** window, under **Results** click **Electric Field, Background (emw)**.
2 In the **Settings** window for **3D Plot Group**, locate the **Data** section.
3 From the **Parameter value (alpha (rad))** list, choose **0.5236**.
4 In the **Electric Field, Background (emw)** toolbar, click **Plot**.



This is the instantaneous norm of the background linearly polarized plane wave.

1D Plot Group 6

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

Point Graph 1

1 Right-click **1D Plot Group 6** and choose **Point Graph**.
2 Select Point 19 only.
3 In the **Settings** window for **Point Graph**, locate the **y-Axis Data** section.
4 In the **Expression** text field, type `10*log10(4*pi*(emw.normEfar)^2)`.
5 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.
6 In the **Expression** text field, type `alpha`.

7 From the **Unit** list, choose **°**.

8 In the **1D Plot Group 6** toolbar, click **Plot**.

Graph Marker 1

1 Right-click **Point Graph 1** and choose **Graph Marker**.

2 In the **Settings** window for **Graph Marker**, locate the **Text Format** section.

3 Select the **Show x-coordinate** checkbox.

4 Select the **Include unit** checkbox.

5 Click to expand the **Coloring and Style** section. From the **Anchor point** list, choose **Middle left**.

This reproduces Figure 2.

Study 1/Solution 1 (sol1)

In the **Model Builder** window, expand the **Results** > **Datasets** node, then click **Study 1/ Solution 1 (sol1)**.

Selection

1 In the **Results** toolbar, click **Attributes** and choose **Selection**.

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

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

4 Click **Paste Selection**.

5 In the **Paste Selection** dialog, type `5-11, 14-15, 17-18` in the **Selection** text field.

6 Click **OK**.

Electric Field (emw)

1 In the **Model Builder** window, under **Results** click **Electric Field (emw)**.

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

3 From the **Parameter value (alpha (rad))** list, choose **0.5236**.

Multislice 1

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

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

3 Find the **X-planes** subsection. In the **Planes** text field, type `0`.

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

Arrow Volume 1

1 In the **Model Builder** window, right-click **Electric Field (emw)** and choose **Arrow Volume**.

2 In the **Settings** window for **Arrow Volume**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1 (comp1)** > **Electromagnetic Waves, Frequency Domain** > **Electric** > **emw.relEx,...,emw.relEz - Relative electric field**.

3 Locate the **Arrow Positioning** section. Find the **X grid points** subsection. In the **Points** text field, type 31.

4 Find the **Y grid points** subsection. In the **Points** text field, type 31.

5 Find the **Z grid points** subsection. In the **Points** text field, type 1.

6 Locate the **Coloring and Style** section. From the **Arrow length** list, choose **Logarithmic**.

Color Expression 1

1 Right-click **Arrow Volume 1** and choose **Color Expression**.

2 In the **Settings** window for **Color Expression**, locate the **Expression** section.

3 In the **Expression** text field, type `20*log10(emw.normE)`.

4 Locate the **Coloring and Style** section. From the **Color table** list, choose **Thermal**.

5 Clear the **Color legend** checkbox.

Surface 1

In the **Model Builder** window, right-click **Electric Field (emw)** and choose **Surface**.

Material Appearance 1

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

2 In the **Settings** window for **Material Appearance**, locate the **Appearance** section.

3 From the **Appearance** list, choose **Custom**.

4 From the **Material type** list, choose **Copper**.

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

Selection 1

1 In the **Model Builder** window, right-click **Surface 1** and choose **Selection**.

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

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

4 Select Domain 11 only.

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

6 Click the **Zoom In** button in the **Graphics** toolbar.

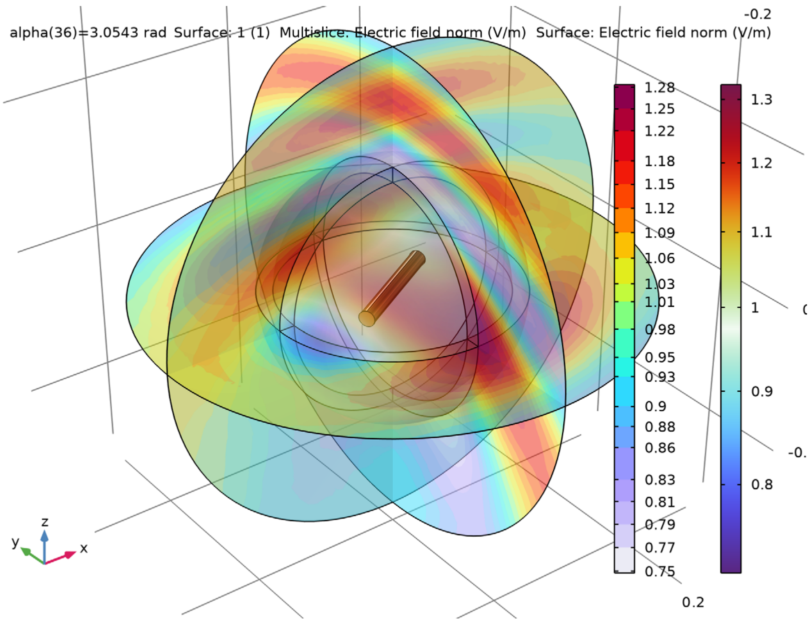
Compare the reproduced plot with Figure 3.

Electric Field, Logarithmic (emw)

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

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

3 From the **Parameter value (alpha (rad))** list, choose **0.5236**.



3D Far Field (emw)

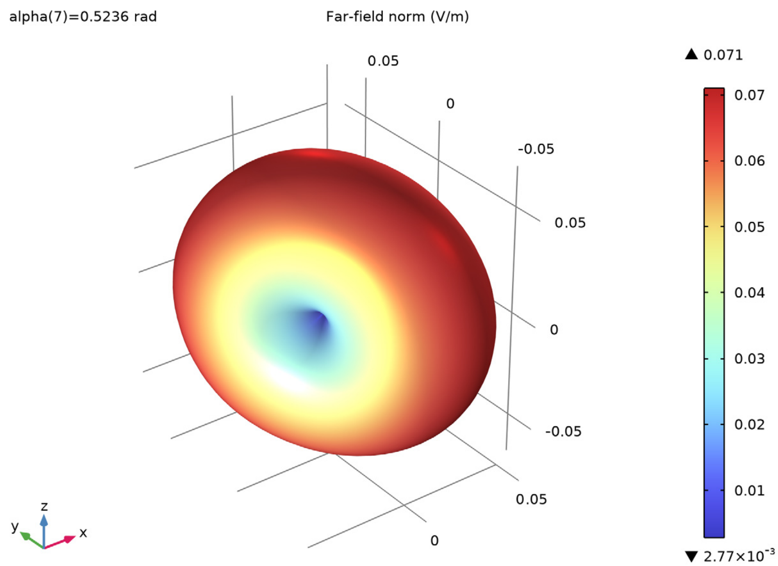
1 In the **Model Builder** window, click **3D Far Field (emw)**.

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

3 From the **Parameter value (alpha (rad))** list, choose **0.5236**.

Radiation Pattern 1

1 In the **Model Builder** window, expand the **3D Far Field (emw)** node, then click **Radiation Pattern 1**.



3D Far-field radiation plot looks like that of a dipole antenna.