Model created in COMSOL Multiphysics 6.4

Efficient Modeling of a Spherical Radome

Introduction

This model demonstrates an efficient approach to simulating a thin, spherical, large radome using a 2D axisymmetric formulation with cubic discretization. The axisymmetric method captures full 3D behavior for azimuthally symmetric geometries at only a fraction of the computational cost. When the simulation domains are predominantly filled with air or dielectric, using higher-order elements such as cubic element on a coarse mesh can significantly reduce computational cost while preserving accuracy.

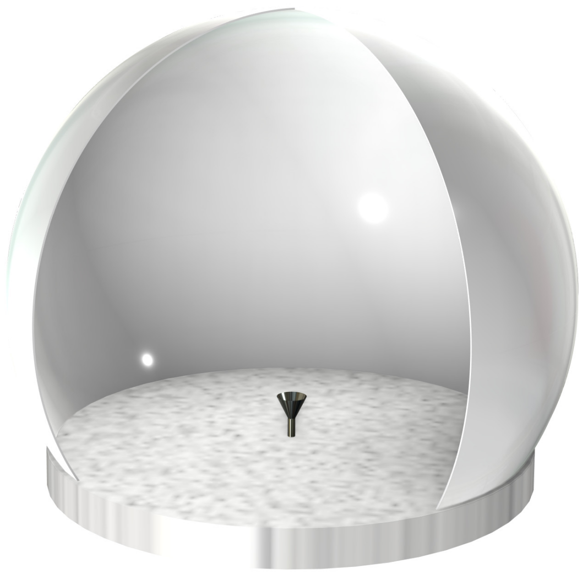


Figure 1: Circular horn antenna mounted inside a spherical radome, where all structures are symmetric about the vertical axis.

Model Definition

The radome geometry is represented by half of its 2D profile, utilizing axisymmetry to enable efficient simulation.

A circular horn operating at 1 GHz with an aperture size exceeding 2.6 wavelengths is mounted on a metallic support that forms the base of the spherical radome. The antenna is excited with the TE_1 circular port mode and further adjusted with azimuthal mode 1 in the 2D axisymmetric formulation. This approach makes the simulation equivalent to the TE_{11} dominant mode of a circular port in a full 3D model.

The radome wall, 5 cm thick, is composed of a low-loss foam material with a relative permittivity of 1.05 and a loss tangent of 0.0005. It is coated with a thin fiber-glass-epoxy skin ($\varepsilon_r = 4$, $\tan\delta = 0.01$) of 2 mm thickness. Since the coating is electrically thin at 1 GHz operating frequency in the L-band, it is modeled using a transition boundary condition.

The entire radome structure is enclosed with a large air domain, whose outer boundary is terminated with a perfectly matched layer (PML) to absorb out going waves and emulate an unbounded space.

The model assumes that the metallic base support is sufficiently large to reflect any spillover from the circular horn, while the actual earth ground is not included in the simulation.

Most of the computational domain is filled with air, which primarily serves as the wave propagation region. In such cases, switching from the default quadratic discretization to cubic elements improves efficiency and accelerates computation.

Results and Discussion

Figure 2 presents the instantaneous norm of the electric field with contour overlays with a Mirror 2D dataset. Unlike the regular norm, the instantaneous representation clearly illustrates the sinusoidal nature of the wave as it propagates radially outward. The view provides additional physical intuition about the field distribution compared to the default norm plot, which only shows the overall field intensity. The results also indicate that the field is not significantly diffracted as it penetrates the radome wall.

Figure 3 shows the realized gain polar plot on the *xy*-plane, where multiple sidelobes are observed.

Figure 4 shows the 3D far-field realized fain pattern. This is not a true 3D result but rather a body-of-revolution of the 2D far-field, and thus the visualization is axisymmetric. In order to obtain a result equivalent to a true 3D presentation, the built-in function `rGaindB3DEfar_TE11(angle)` can be used, provided that the radiation and overall characteristics of the excited port mode remain undistorted. The corresponding results are shown in Figure 5.

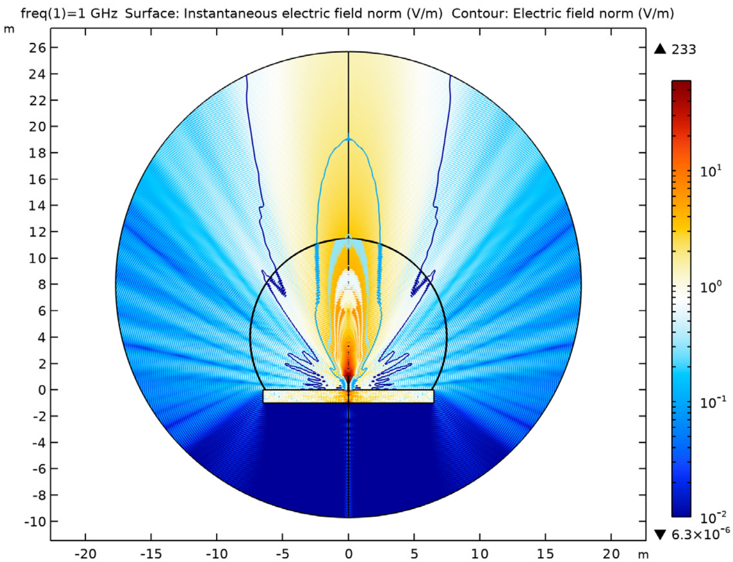


Figure 2: Instantaneous norm of the electric field with contour overlay. The wave propagates in the positive z-direction.

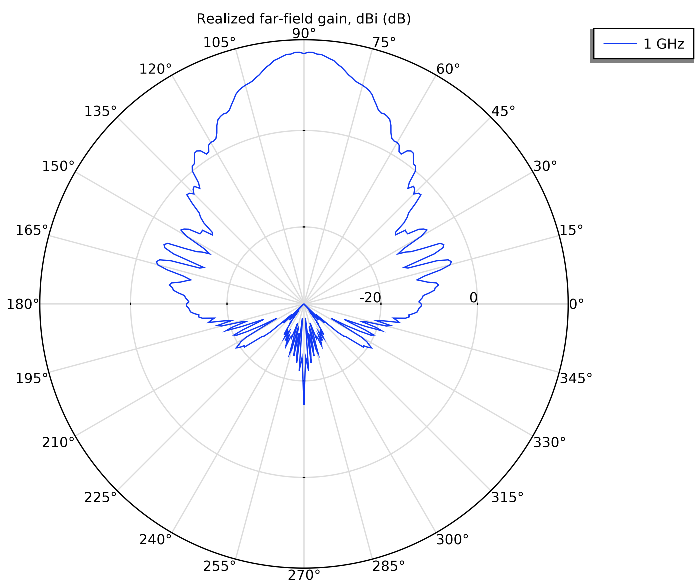


Figure 3: Realized gain on the xz-plane, with the plotting dynamic range of ~55 dB.

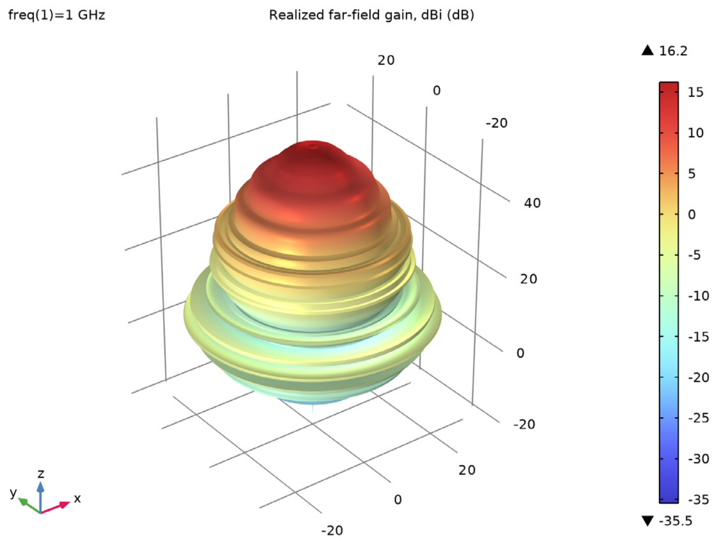


Figure 4: 3D far-field realized gain pattern in dB scale, obtained as a body-of-revolution of the 2D polar plot.

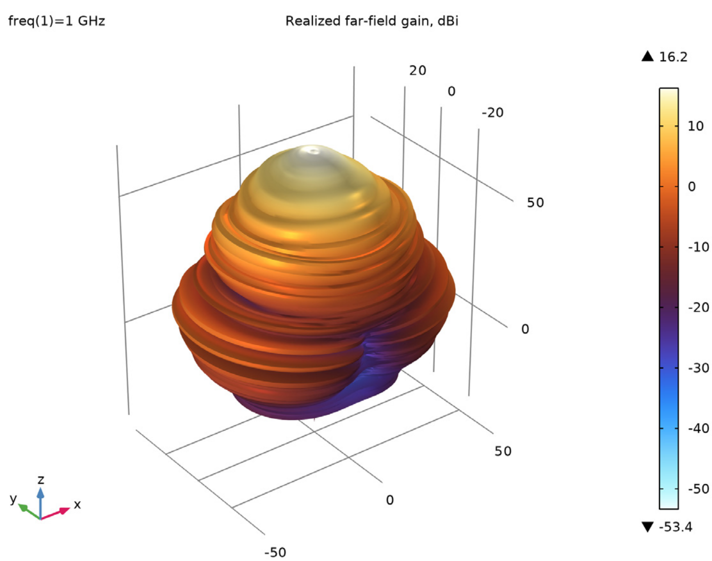


Figure 5: 3D far-field realized gain pattern, corresponding to a 3D model excited with the TE_{11} circular port mode.

Notes About the COMSOL Implementation

When higher-order elements are used, it is important to monitor the reported degrees of freedom (DoFs) in the Message window. With cubic elements, the mesh may become coarser than the default quadratic mesh, thereby reducing the DoFs. However, if the geometry contains many details, the coarse mesh will be overridden by a finer one due to geometric complexity. As a result, the model may require more computational resources than the default quadratic elements, thereby losing the intended advantage.

This model requires at least 25 GB of memory for computation, whereas the default quadratic elements require a minimum of 40 GB.

Application Library path: `RF_Module/Antennas/radome_spherical`

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 **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**.

GEOMETRY 1

Circle 1 (c1)

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

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

3 In the **Radius** text field, type `7.5`.

4 Locate the **Position** section. In the **z** text field, type 4.

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

Layer name	Thickness (m)
Layer 1	5[cm]

Rectangle 1 (r1)

1 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 13.

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

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

6 In the **z** text field, type -2.

7 In the **Model Builder** window, click **Rectangle 1 (r1)**.

8 From the **Base** list, choose **Center**.

Difference 1 (dif1)

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

2 Select the object **c1** 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 object **r1** only.

6 Click **Build Selected**.

Rectangle 2 (r2)

1 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 13.

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

5 In the **z** text field, type -0.5.

Circle 2 (c2)

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

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

3 In the **Radius** text field, type 18.

4 Locate the **Position** section. In the **z** text field, type 8.

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

Layer name	Thickness (m)
`Layer 1`	`0.3`

Rectangle 3 (r3)

1 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 `25`.

4 In the **Height** text field, type `50`.

5 Locate the **Position** section. In the **r** text field, type `-25`.

6 In the **z** text field, type `-15`.

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

8 Click **Build Selected**.

Difference 2 (dif2)

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

2 Click the **Select Box** button in the **Graphics** toolbar.

3 Select the objects **c2**, **dif1**, and **r2** only.

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

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

6 Select the object **r3** only.

7 Click **Build Selected**.

8 Click the **Zoom Extents** button in the **Graphics** toolbar.

Polygon 1 (pol1)

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

2 In the **Settings** window for **Polygon**, locate the **Coordinates** section.

3 In the table, enter the following settings:

r (m)	z (m)
`0.1`	`0.5`
`0.4`	`1.1`
`0`	`1.1`
`0`	`0.5`

Rectangle 4 (r4)

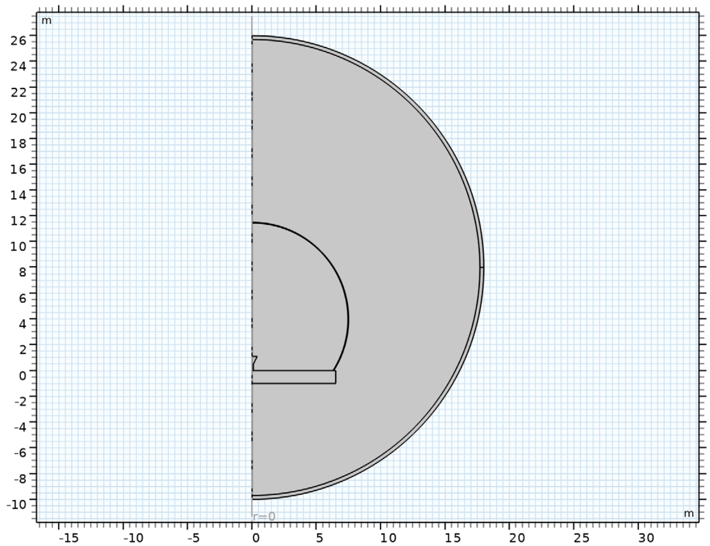
1 In the **Geometry** toolbar, click **Rectangle**.

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

3 In the **Width** text field, type `0.1`.

4 In the **Height** text field, type `0.5`.

5 Click **Build All Objects**.

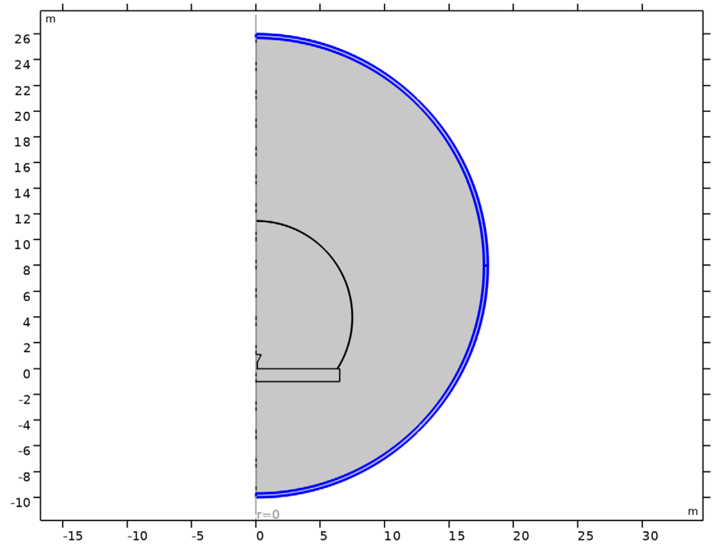


DEFINITIONS

Perfectly Matched Layer 1 (pml1)

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

2 Select Domains 1 and 8 only.



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**, click to expand the **Discretization** section.

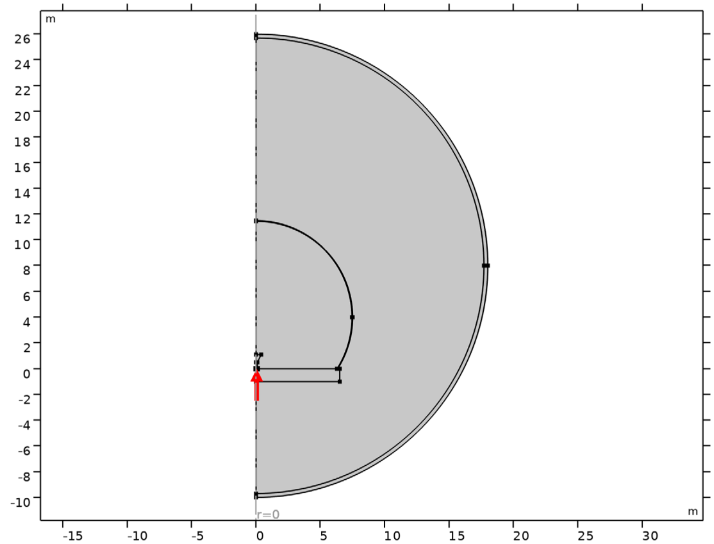
3 Locate the **Out-of-Plane Wave Number** section. In the m text field, type 1.

4 Locate the **Discretization** section. From the **Electric field** list, choose **Cubic**.

Port 1

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

2 Select Boundary 6 only.



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

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

5 Clear the **Enable active port feedback** checkbox.

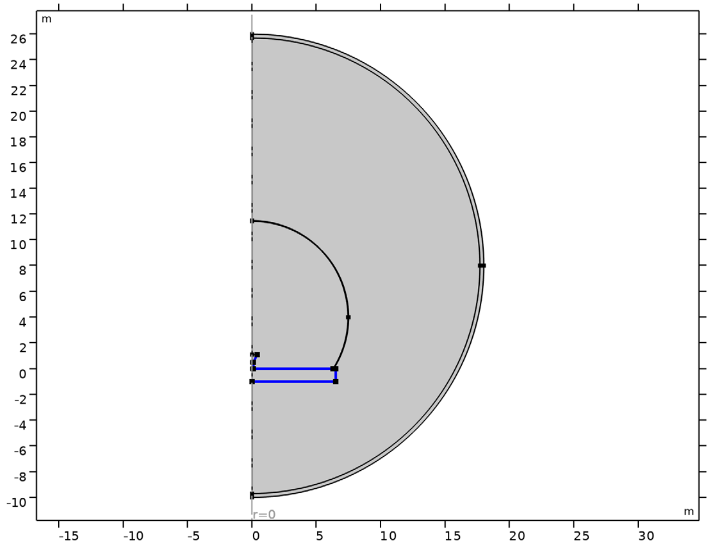
6 Select the **Activate slit condition on interior port** checkbox.

7 Click **Toggle Power Flow Direction**.

Perfect Electric Conductor 2

1 In the **Physics** toolbar, click  **Boundaries** and choose **Perfect Electric Conductor**.

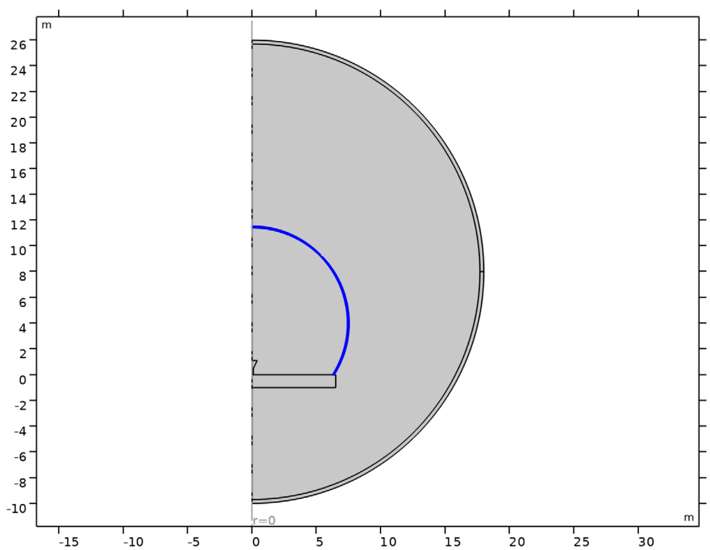
2 Select Boundaries 4 and 14–19 only, including all exterior boundaries of the circular horn and the bottom metallic support.



Wave Equation, Electric 2

1 In the **Physics** toolbar, click **Domains** and choose **Wave Equation, Electric**.

2 Select Domains 7 and 9 only.



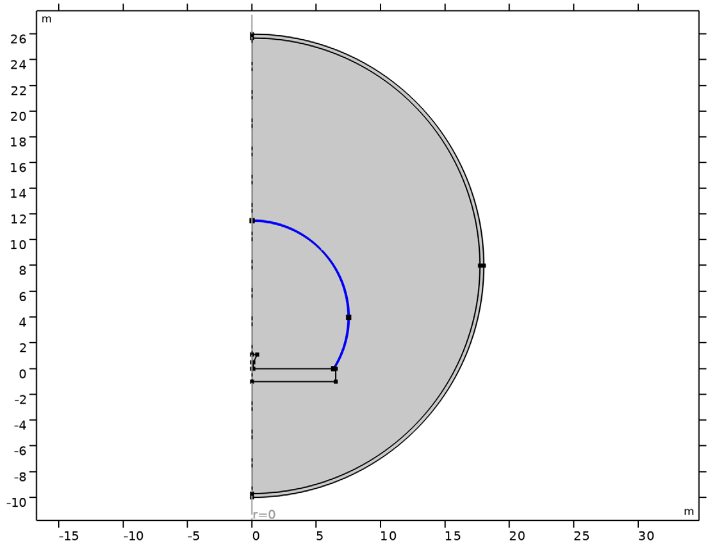
3 In the **Settings** window for **Wave Equation, Electric**, locate the **Electric Displacement Field** section.

4 From the **Electric displacement field model** list, choose **Loss tangent, dissipation factor**.

Transition Boundary Condition 1

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

2 Select Boundaries 25 and 29 only.



3 In the **Settings** window for **Transition Boundary Condition**, locate the **Transition Boundary Condition** section.

4 From the **Electric displacement field model** list, choose **Loss tangent, dissipation factor**.

5 From the ε' list, choose **User defined**. In the associated text field, type `4`.

6 From the $\tan\delta$ list, choose **User defined**. In the associated text field, type `0.01`.

7 From the μ_r list, choose **User defined**. In the *d* text field, type `2[mm]`.

Far-Field Domain 1

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

MATERIALS

Add Material

From the **Home** menu, choose **Add Material**.

ADD MATERIAL

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

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

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

4 From the **Home** menu, choose **Add Material**.

MATERIALS

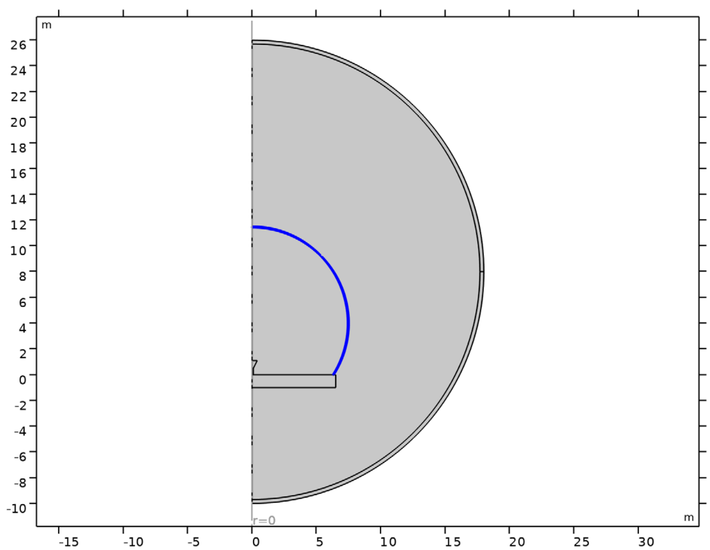
Foam

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

2 Right-click **Component 1 (comp1)** > **Materials** and choose **Blank Material**.

3 In the **Settings** window for **Material**, type `Foam` in the **Label** text field.

4 Select Domains 7 and 9 only.



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

Property	**Variable**	**Value**	**Unit**	**Property group**
Relative permittivity (real part)	epsilonPrim_iso ; epsilonPrimii = epsilonPrim_iso, epsilonPrimij = 0	1.05	1	Loss tangent, dissipation factor

Property	Variable	Value	Unit	Property group
Loss tangent, dissipation factor	tanDelta	0.0005	1	Loss tangent, dissipation factor
Relative permeability	mur_iso ; murii = mur_iso, murij = 0	1	1	Basic

STUDY 1

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

If not already added, the physics-controlled mesh is automatically generated before computation.

RESULTS

Mirror 2D 1

In the **Results** toolbar, click **More Datasets** and choose **Mirror 2D**.

Electric Field (emw)

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

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

3 From the **Dataset** list, choose **Mirror 2D 1**.

Surface 1

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

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

3 In the **Expression** text field, type `emw.normEi`.

4 Click to expand the **Range** section. Select the **Manual color range** checkbox.

5 In the **Minimum** text field, type `1e-2`.

6 In the **Maximum** text field, type `60`.

7 Click to expand the **Range** section. Locate the **Coloring and Style** section. From the **Color table** list, choose **Ranitomeya**.

8 From the **Scale** list, choose **Logarithmic**.

Contour 1

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

2 In the **Settings** window for **Contour**, locate the **Levels** section.

3 In the **Total levels** text field, type `30`.

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

5 Clear the **Color legend** checkbox.

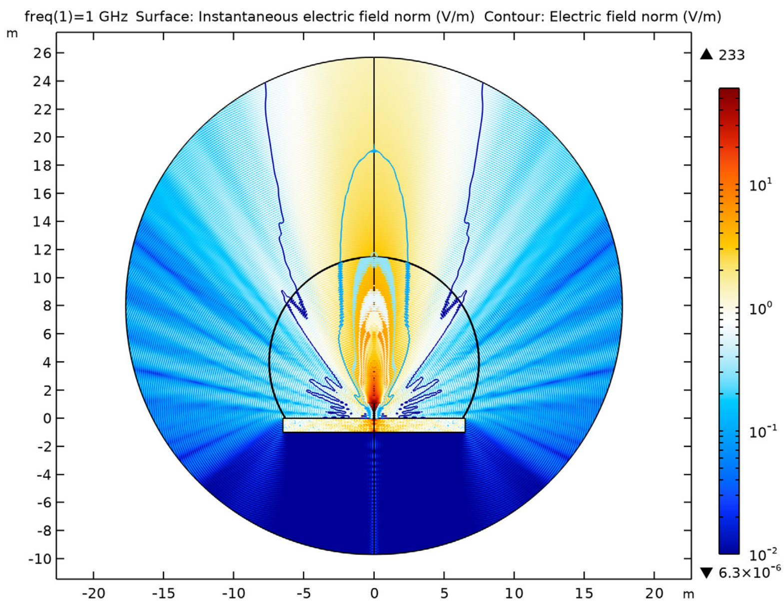
6 From the **Scale** list, choose **Logarithmic**.

Selection 1

1 Right-click **Contour 1** and choose **Selection**.

2 Select Domains 2 and 6 only.

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



Radiation Pattern 1

1 In the **Model Builder** window, expand the **Results** > **2D Far Field (emw)** node, then click **Radiation Pattern 1**.

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

3 In the **Expression** text field, type `emw.rGaindBEfar`.

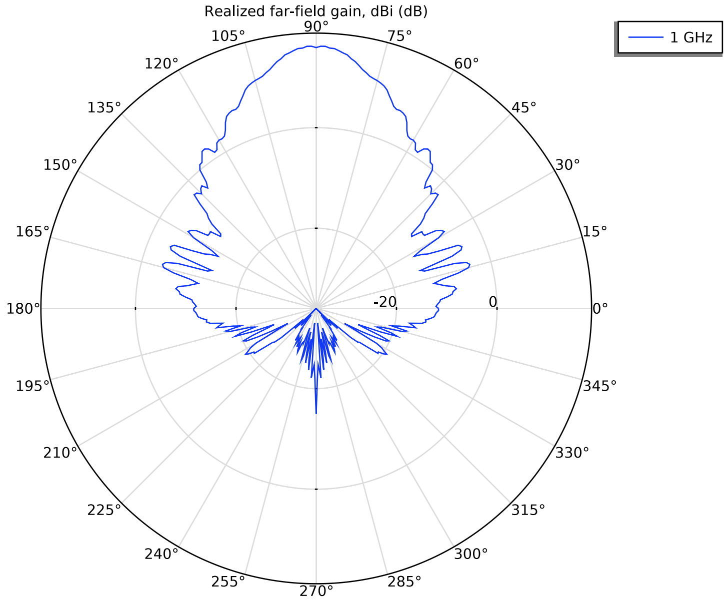
4 Locate the **Evaluation** section. Find the **Angles** subsection. In the **Number of angles** text field, type `360`.

5 Find the **Normal vector** subsection. In the **y** text field, type `-1`.

6 Find the **Reference direction** subsection. In the **x** text field, type `1`.

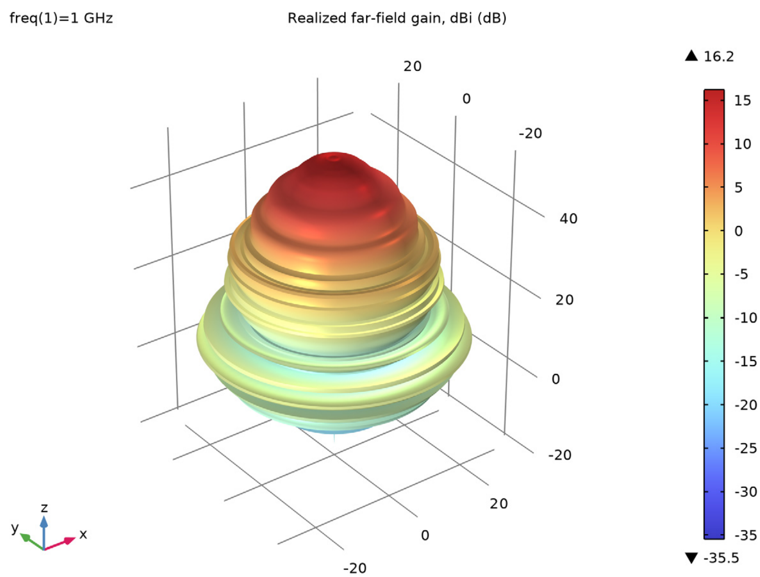
7 In the **z** text field, type `0`.

8 In the **2D Far Field (emw)** toolbar, click **Plot**.



3D Far Field, Gain (emw)

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



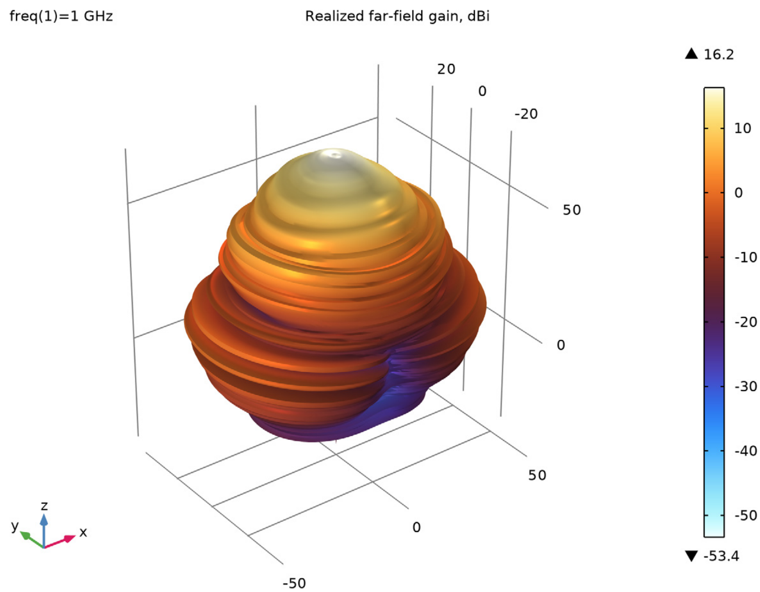
3D Far Field, Gain (emw), TE11

1. Right-click **3D Far Field, Gain (emw)** and choose **Duplicate**.
2. In the **Settings** window for **3D Plot Group**, type `3D Far Field, Gain (emw), TE11` in the **Label** text field.

Radiation Pattern 1

1. In the **Model Builder** window, expand the **3D Far Field, Gain (emw), TE11** node, then click **Radiation Pattern 1**.
2. In the **Settings** window for **Radiation Pattern**, locate the **Expression** section.
3. In the **Expression** text field, type `emw.rGaindB3DEfar_TE11(angle)`.
4. Locate the **Evaluation** section. Find the **Angles** subsection. In the **Azimuthal angle variable** text field, type `angle`.

5 Locate the **Coloring and Style** section. From the **Color table** list, choose **ThermalWave**.



Revolution 2D, Horn

1 In the **Results** toolbar, click **More Datasets** and choose **Revolution 2D**.

2 In the **Settings** window for **Revolution 2D**, type `Revolution 2D, Horn` in the **Label** text field.

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 **Boundary**.

4 Select Boundaries 14 and 16 only.

Revolution 2D, Bottom

1 In the **Model Builder** window, right-click **Revolution 2D, Horn** and choose **Duplicate**.

2 In the **Settings** window for **Revolution 2D**, type `Revolution 2D, Bottom` in the **Label** text field.

Selection

1 In the **Model Builder** window, expand the **Revolution 2D, Bottom** node, then click **Selection**.

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

3 Click **Clear Selection**.

4 Select Boundaries 4, 15, and 17–19 only.

Revolution 2D, Radome

1 In the **Results** toolbar, click **More Datasets** and choose **Revolution 2D**.

2 In the **Settings** window for **Revolution 2D**, type `Revolution 2D, Radome` in the **Label** text field.

3 Click to expand the **Revolution Layers** section. In the **Start angle** text field, type `-90`.

4 In the **Revolution angle** text field, type `270`.

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 Select Domains 7 and 9 only.

3D Plot Group 6

In the **Results** toolbar, click **3D Plot Group**.

Volume 1

1 Right-click **3D Plot Group 6** and choose **Volume**.

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

3 From the **Dataset** list, choose **Revolution 2D, Radome**.

4 Locate the **Expression** section. In the **Expression** text field, type `emw.normE`.

5 Locate the **Coloring and Style** section. From the **Color table** list, choose **Xylethrus**.

Material Appearance 1

1 Right-click **Volume 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 Locate the **Color** section. Select the **Use the plot's color** checkbox.

5 In the **3D Plot Group 6** toolbar, click **Plot**.

Surface 1

1 In the **Model Builder** window, right-click **3D Plot Group 6** and choose **Surface**.

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

3 From the **Dataset** list, choose **Revolution 2D, Horn**.

4 Locate the **Expression** section. In the **Expression** text field, type 1.

Material Appearance 1

1 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 **Gold**.

Surface 2

1 In the **Model Builder** window, right-click **3D Plot Group 6** and choose **Surface**.

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

3 From the **Dataset** list, choose **Revolution 2D, Bottom**.

4 Locate the **Expression** section. In the **Expression** text field, type 1.

Material Appearance 1

1 Right-click **Surface 2** 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 **Chrome**.

3D Plot Group 6

1 In the **Model Builder** window, under **Results** click **3D Plot Group 6**.

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

3 Clear the **Plot dataset edges** checkbox.

4 In the **3D Plot Group 6** toolbar, click **Plot**.

5 Click the  **Zoom Extents** button in the **Graphics** toolbar.