Model created in COMSOL Multiphysics 6.4

Modeling of Dipole Antenna Array Using the Boundary Element Method

Introduction

This example of a dipole antenna array demonstrates a cost-effective analysis using the Boundary Element Method (BEM). When dealing with a large array made of metallic radiators, the Finite Element Method (FEM) would necessitate greater computational resources. The simulation results depict the radiation patterns of a 12-by-1 array, consisting of metallic half-wave dipole antennas resonant at 1 GHz.

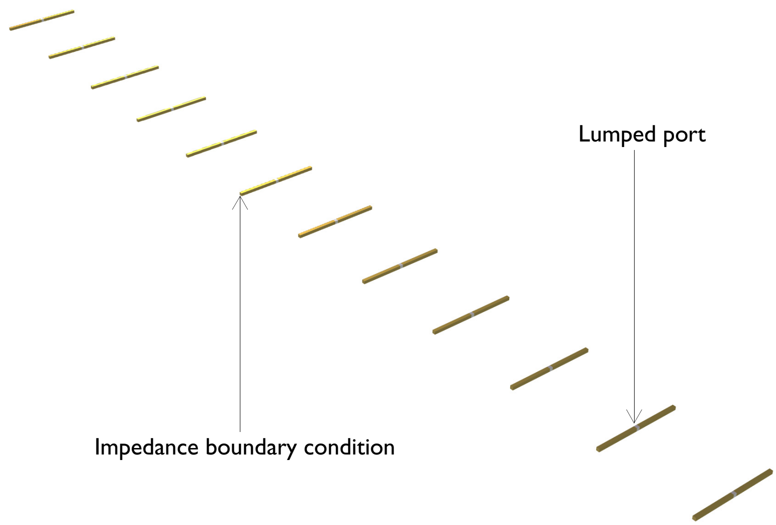


Figure 1: 12-by-1 half-wave dipole antenna array.

Model Definition

The model begins by constructing a single metallic half-wave dipole antenna. The radiator of this antenna has a rectangular rod shape, and an impedance boundary condition is applied to account for losses due to the finite conductivity of copper. Given that the simulation frequency is set at 1 GHz, these losses are negligible. A lumped port is placed at the center of the antenna to excite the radiator and to compute antenna parameters, such as input impedance and S-parameter. The antenna's length is not exactly half the wavelength of the given frequency; instead, it is slightly reduced to achieve better impedance matching with the reference characteristic impedance of 50 ohms. A far-field calculation boundary condition is enforced on the external boundaries for the near-field to far-field transformation.

After analyzing the single antenna, the original geometry is extended to form a 12-by-1 antenna array. Extra lumped ports are integrated to activate all 12 antenna components. The configurations for other boundary conditions are then automatically adjusted based on the updated 12-by-1 antenna array geometry.

Results and Discussion

Figure 2 displays the updated default plot with the modified Grid dataset for visualizing the norm of electric fields outside the antenna radiator. Adjustments have also been made to the manual color range and color table to more clearly depict the resonant near-field surrounding the single dipole antenna.

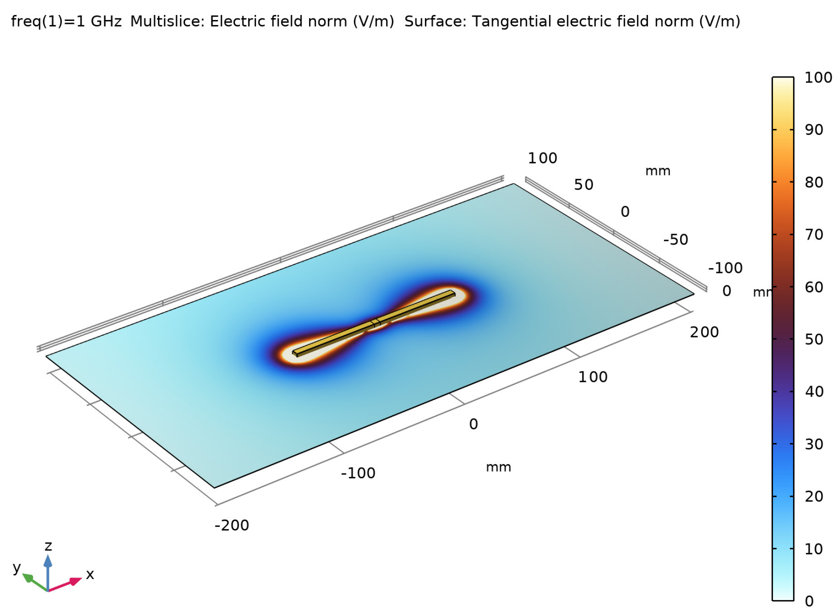


Figure 2: The norm of electric field around the single dipole antenna.

The polar-formatted E- and H-plane patterns are shown in the Figure 3. The E-plane is defined with a plane in which the dominant antenna polarization is included while the H-plane is perpendicular to the antenna polarization.

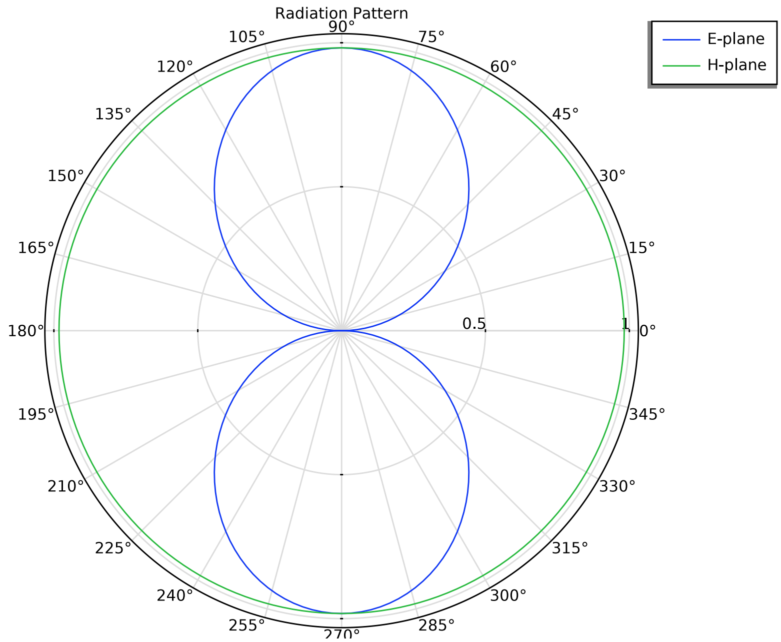


Figure 3: E-plane (blue) and H-plane (green) radiation patterns.

Figure 4 displays the 3D far-field pattern, illustrating a typical dipole antenna radiation pattern: an omnidirectional pattern around the radiator with nulls in the direction of each pole.

For the 12-by-1 dipole antenna array, the analysis of the computed results repeats that of the single dipole antenna, covering aspects such as the norm of the electric field surrounding the antenna structure, the polar-formatted patterns for both the E- and H-planes, and 3D far-field pattern.

Figure 5 depicts the norm of the electric field for the antenna array, and Figure 6 visualizes the radiation patterns in the E- and H-planes, respectively.

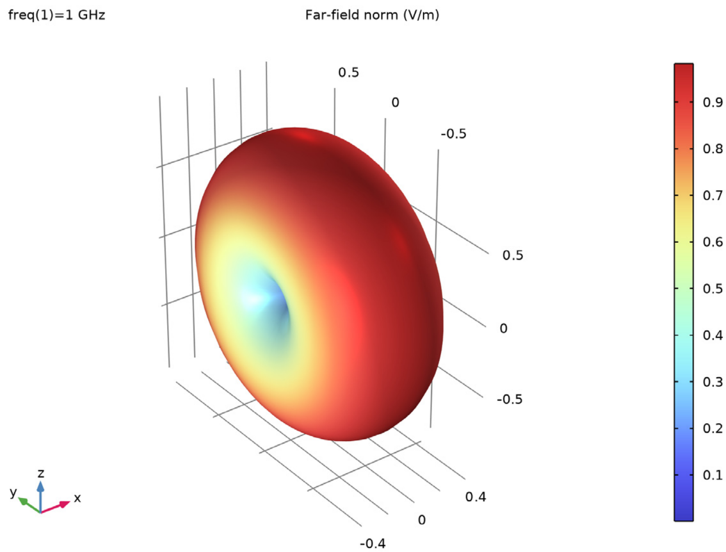


Figure 4: The 3D far-field radiation pattern of the single dipole antenna.

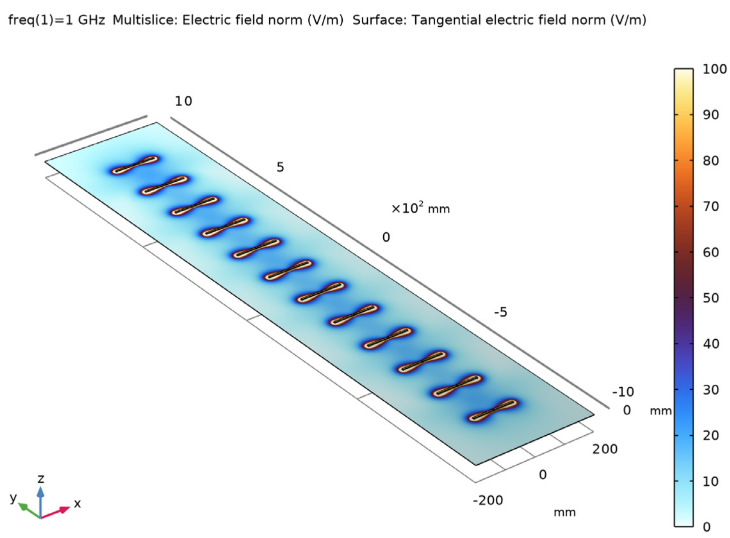


Figure 5: The norm of electric field for 12-by-1 dipole antenna array.

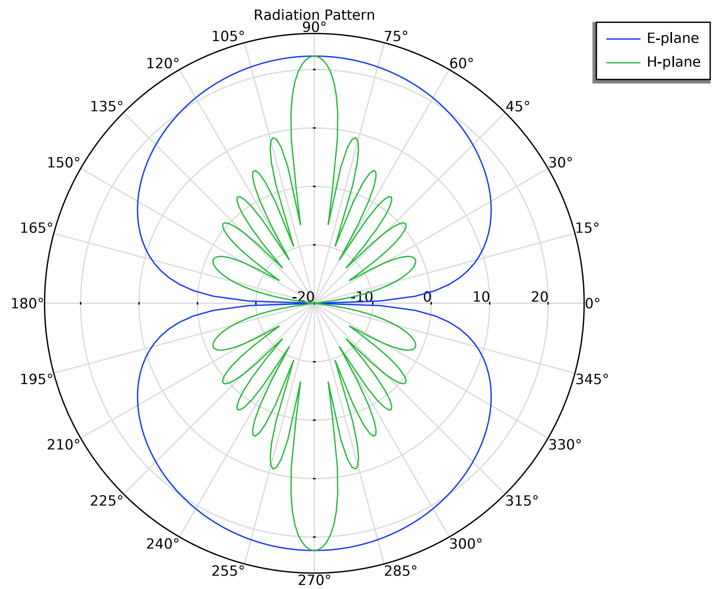


Figure 6: E-plane (blue) and H-plane (green) radiation patterns of the 12-by-1 dipole antenna array.

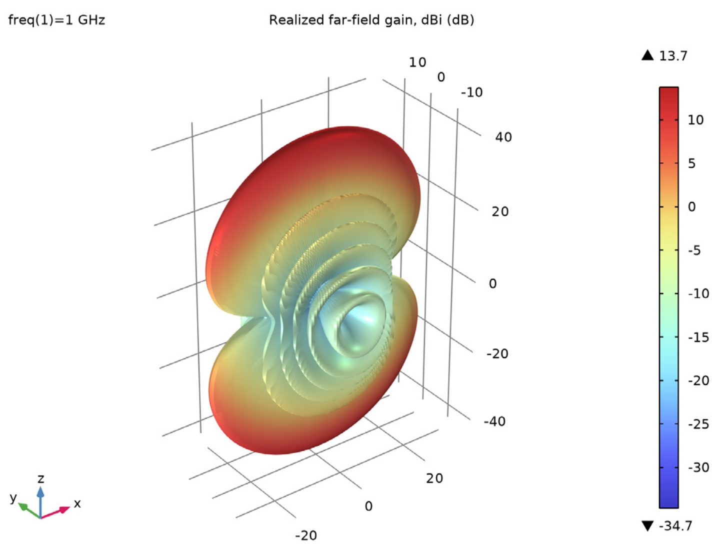


Figure 7: The 3D far-field realized gain pattern of the 12-by-1 dipole antenna array.

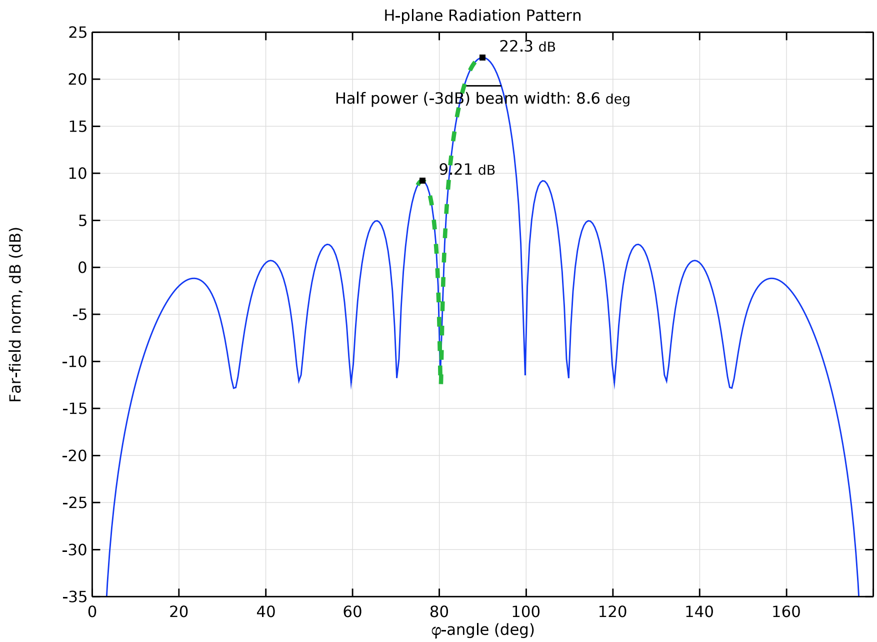


Figure 8: H-plane pattern analysis using graph markers.

Figure 7 displays the realized gain pattern on a dB scale. Owing to the orientation of the array geometry, a directive radiation pattern emerges along the z-axis, with a notably sharp beam width relative to the y-axis.

Radiation patterns can be depicted not only in polar plot groups but also in 1D plot groups. For the latter, graph marker subfeatures are useful for swiftly analyzing maximum, minimum, and bandwidth values. Figure 8 highlights the half-power beam width, as well as the maximum values of the main lobe and the first sidelobe, within the H-plane pattern.

Notes About the COMSOL Implementation

For this type of metallic antenna simulation using the BEM, it is required to set the domain selection for the Electromagnetic Waves, Boundary Elements interface to All voids.

Application Library path: `RF_Module/Antenna_Arrays/dipole_antenna_array`

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, Boundary Elements (embe)**.
3 Click **Add**.
4 Click **Study**.
5 In the **Select Study** tree, select **General Studies** > **Frequency Domain**.
6 Click **Done**.

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 **mm**.

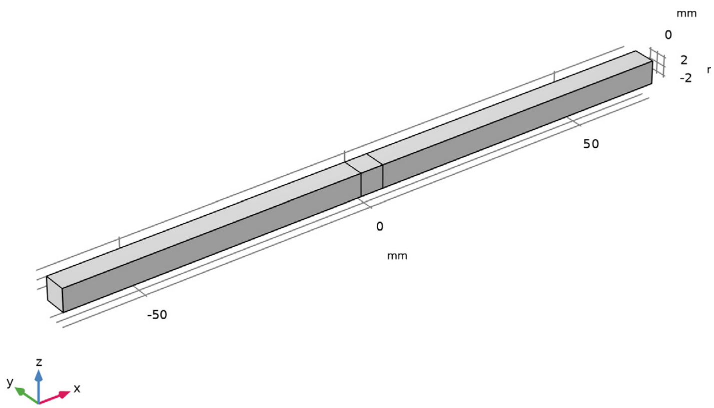
Block 1 (blk1)

1 In the **Geometry** toolbar, click **Block**.
   First, build a single dipole antenna geometry.
2 In the **Settings** window for **Block**, locate the **Size and Shape** section.
3 In the **Width** text field, type 135.
4 In the **Depth** text field, type 5.
5 In the **Height** text field, type 5.
6 Locate the **Position** section. From the **Base** list, choose **Center**.

Block 2 (blk2)

1 Right-click **Block 1 (blk1)** and choose **Duplicate**.
2 In the **Settings** window for **Block**, locate the **Size and Shape** section.
3 In the **Width** text field, type 5.

4 Click **Build All Objects**.



ELECTROMAGNETIC WAVES, BOUNDARY ELEMENTS (EMBE)

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Electromagnetic Waves, Boundary Elements (embe)**.

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

3 From the **Selection** list, choose **All voids**.

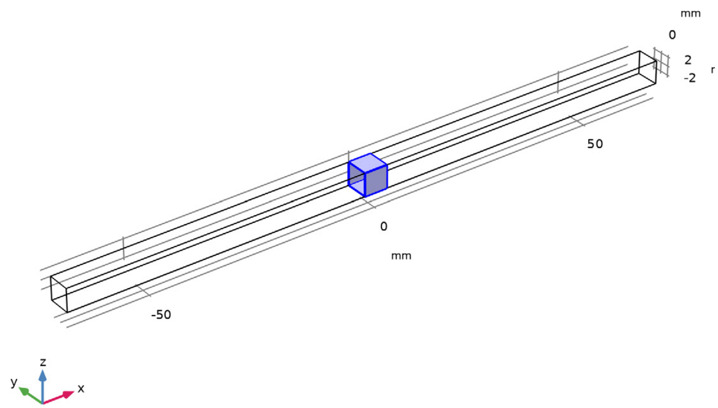
Lumped Port 1

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

Add a **Lumped Port** at the center of the antenna structure.

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

3 Select Boundaries 7–10 only.



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

5 In the h_{port} text field, type `5[mm]`.

6 In the w_{port} text field, type `20[mm]`.

7 Specify the $\mathbf{a}_{\mathrm{h}}$ vector as

1	x
0	y
0	z

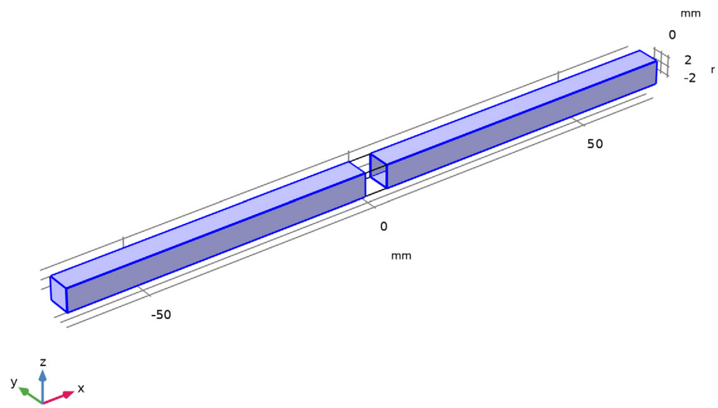
8 From the **Wave excitation at this port** list, choose **On**.

Add a lossy conducting boundary condition.

Impedance Boundary Condition 1

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

2 Select Boundaries 1–5 and 12–16 only.



Define the area where the near-field to far-field transformation should be performed for radiation pattern analyses.

Far-Field Calculation 1

In the **Physics** toolbar, click **Boundaries** and choose **Far-Field Calculation**.

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 **Geometric Entity Selection** section.
3. From the **Selection** list, choose **All voids**.

4 Locate the **Material Contents** section. 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

ADD MATERIAL

1 In the **Home** 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 Click the **Add to Component** button in the window toolbar.

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

MATERIALS

Copper (mat2)

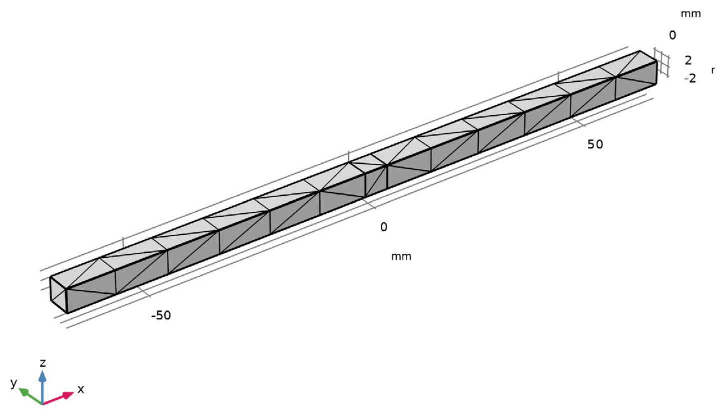
1 In the **Settings** window for **Material**, locate the **Geometric Entity Selection** section.

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

3 Select Boundaries 1–5 and 12–16 only.

MESH 1

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



STUDY 1

Step 1: Frequency Domain

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

RESULTS

Adjust the **Grid 3D** dataset range where the computed solutions can be visualized outside the simulation surfaces.

Grid 3D 1

1 In the **Model Builder** window, expand the **Results > Datasets** node, then click **Grid 3D 1**.
2 In the **Settings** window for **Grid 3D**, locate the **Parameter Bounds** section.
3 Find the **Second parameter** subsection. In the **Minimum** text field, type -100.
4 In the **Maximum** text field, type 100.
5 Find the **Third parameter** subsection. In the **Minimum** text field, type 0.
6 In the **Maximum** text field, type 0.
7 Click to expand the **Grid** section. In the **x resolution** text field, type 100.
8 In the **y resolution** text field, type 100.

9 In the **z resolution** text field, type 2.

Multislice 1

1 In the **Model Builder** window, expand the **Results** > **Electric Field, Domains (embe)** 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.

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

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

7 In the **Minimum** text field, type 0.

8 In the **Maximum** text field, type 100.

Material Appearance 1

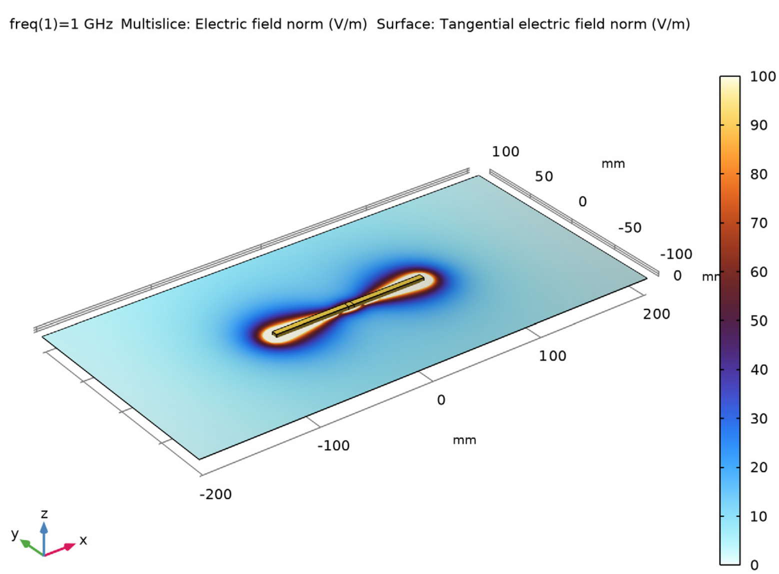
1 In the **Model Builder** window, right-click **Surface 1** and choose **Material Appearance**.

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 **Gold**.

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



Radiation Pattern 1

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

2 In the **Settings** window for **Radiation Pattern**, click to expand the **Legends** section.

3 From the **Legends** list, choose **Manual**.

4 In the table, enter the following settings:

Legends
`E-plane`

Radiation Pattern 2

1 Right-click **Results** > **2D Far Field (embe)** > **Radiation Pattern 1** and choose **Duplicate**.

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

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

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

5 Find the **Reference direction** subsection. In the **x** text field, type `0`.

6 In the **y** text field, type `1`.

7 Locate the **Legends** section. In the table, enter the following settings:

Legends
`H-plane`

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

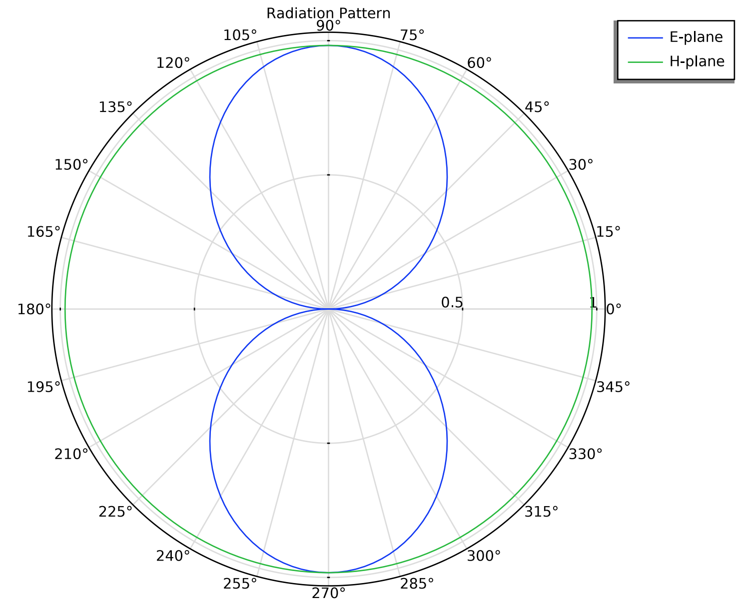
2D Far Field (embe)

1 In the **Model Builder** window, click **2D Far Field (embe)**.

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

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

4 In the **Title** text area, type `Radiation Pattern`.



3D Far-Field, Single Dipole

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

2 In the **Settings** window for **3D Plot Group**, type `3D Far-Field, Single Dipole` in the **Label** text field.

Radiation Pattern 1

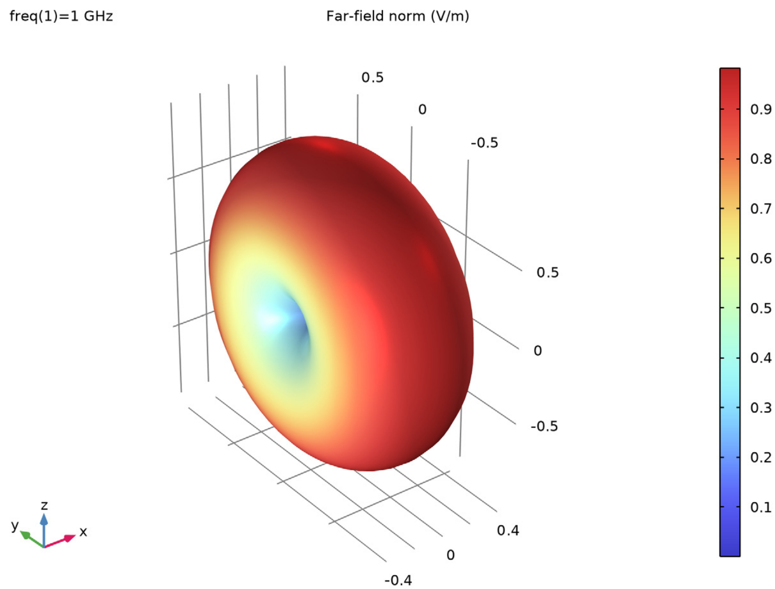
1 In the **3D Far-Field, Single Dipole** toolbar, click **More Plots** and choose **Radiation Pattern**.

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

3 Find the **Angles** subsection. In the **Number of elevation angles** text field, type `45`.

4 In the **Number of azimuth angles** text field, type `45`.

5 In the **3D Far-Field, Single Dipole** toolbar, click **Plot**.



Global Evaluation 1

1 In the **Results** toolbar, click **Global Evaluation**.

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

3 In the table, enter the following settings:

Expression	Unit	Description
embe.Zport_1	Ω	Lumped port impedance
embe.S11dB	1	S11

4 Click **Evaluate**.

GEOMETRY 1

Move 1 (mov1)

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

2 Click in the **Graphics** window and then press Ctrl+A to select both objects.

3 In the **Settings** window for **Move**, locate the **Displacement** section.

4 In the **y** text field, type `-5.5*15[cm]`.

Array 1 (arr1)

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

2 Click in the **Graphics** window and then press Ctrl+A to select both objects.

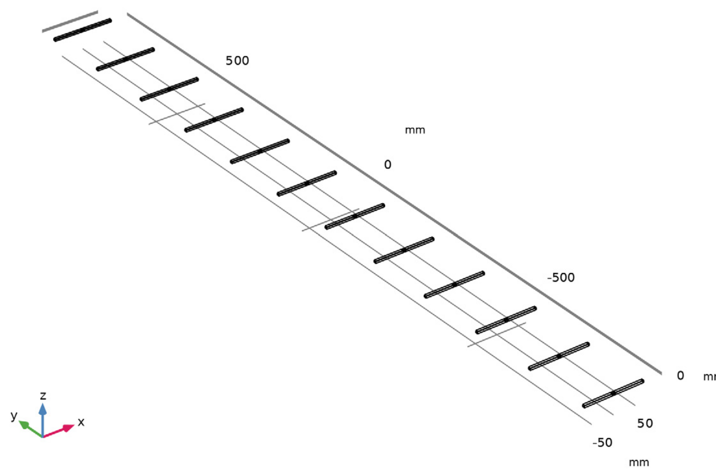
3 In the **Settings** window for **Array**, locate the **Size** section.

4 In the **y size** text field, type `12`.

5 Locate the **Displacement** section. In the **y** text field, type `15[cm]`.

6 Click **Build All Objects**.

7 Click the **Go to Default View** button in the **Graphics** toolbar.



ELECTROMAGNETIC WAVES, BOUNDARY ELEMENTS (EMBE)

Lumped Port 1

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Electromagnetic Waves, Boundary Elements (embe)** click **Lumped Port 1**.

2 In the **Settings** window for **Lumped Port**, click the **Split by Connectivity** button in the window toolbar.

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 **General Studies** > **Frequency Domain**.

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: Frequency Domain

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

RESULTS

Grid 3D 2

1 In the **Settings** window for **Grid 3D**, locate the **Parameter Bounds** section.

2 Find the **First parameter** subsection. In the **Minimum** text field, type -200.

3 In the **Maximum** text field, type 200.

4 Find the **Second parameter** subsection. In the **Minimum** text field, type -1000.

5 In the **Maximum** text field, type 1000.

6 Find the **Third parameter** subsection. In the **Minimum** text field, type 0.

7 In the **Maximum** text field, type 0.

8 Locate the **Grid** section. In the **x resolution** text field, type 400.

9 In the **y resolution** text field, type 800.

10 In the **z resolution** text field, type 2.

Multislice 1

1 In the **Model Builder** window, expand the **Results** > **Electric Field, Domains (embe) 1** 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.

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

6 Locate the **Range** section. Select the **Manual color range** checkbox.

7 In the **Minimum** text field, type 0.

8 In the **Maximum** text field, type 100.

Material Appearance 1

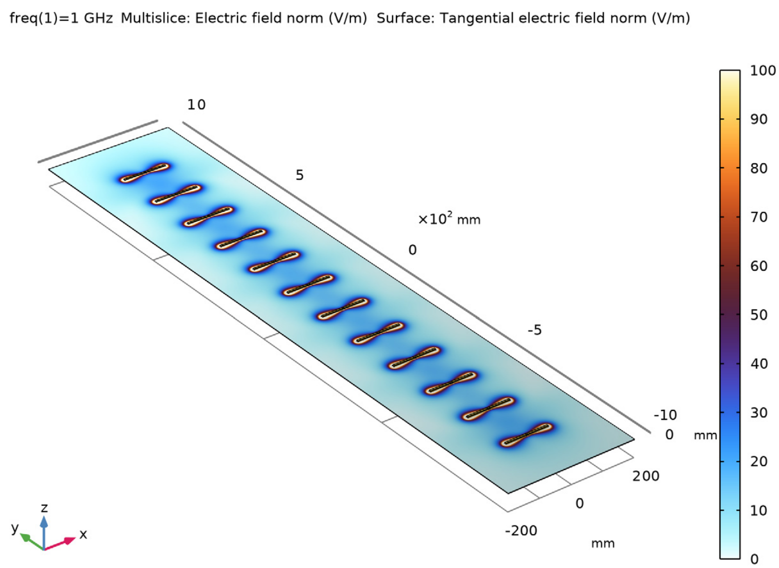
1 In the **Model Builder** window, right-click **Surface 1** and choose **Material Appearance**.

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 **Gold**.

5 In the **Electric Field, Domains (embe) 1** toolbar, click **Plot**.



Radiation Pattern 1

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

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

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

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

5 Locate the **Expression** section. In the **Expression** text field, type `embe.normdBEfar`.

6 Locate the **Legends** section. From the **Legends** list, choose **Manual**.

7 In the table, enter the following settings:

Legends
`E-plane`

8 In the **2D Far Field (embe) 1** toolbar, click **Plot**.

Radiation Pattern 2

1 Right-click **Results** > **2D Far Field (embe) 1** > **Radiation Pattern 1** and choose **Duplicate**.

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

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

4 In the **y** text field, type `0`.

5 Find the **Reference direction** subsection. In the **x** text field, type `0`.

6 In the **y** text field, type `1`.

7 Locate the **Legends** section. In the table, enter the following settings:

Legends
H-plane

8 In the **2D Far Field (embe) 1** toolbar, click **Plot**.

2D Far Field (embe) 1

1 In the **Model Builder** window, click **2D Far Field (embe) 1**.

2 In the **Settings** window for **Polar Plot Group**, locate the **Axis** section.

3 Select the **Manual axis limits** checkbox.

4 In the **r minimum** text field, type `-20`.

5 In the **2D Far Field (embe) 1** toolbar, click **Plot**.

Radiation Pattern 2

1 In the **Model Builder** window, click **Radiation Pattern 2**.

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

3 Find the **Angles** subsection. In the **Number of angles** text field, type `360`.

2D Far Field (embe) 1

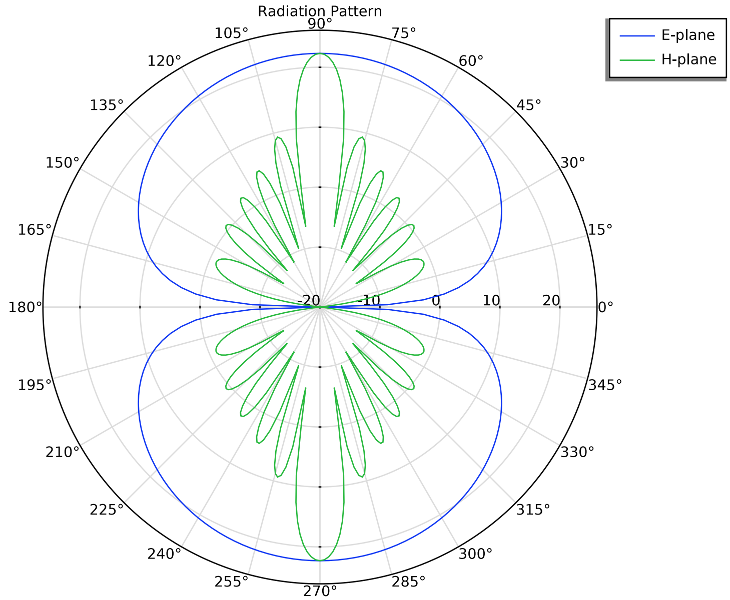
1 In the **Model Builder** window, click **2D Far Field (embe) 1**.

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

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

4 In the **Title** text area, type `Radiation Pattern`.

5 In the **2D Far Field (embe) 1** toolbar, click **Plot**.



3D Far-Field, Dipole Array

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

2 In the **Settings** window for **3D Plot Group**, type `3D Far-Field, Dipole Array` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Study 2/Solution 2 (sol2)**.

4 Locate the **Color Legend** section. Select the **Show maximum and minimum values** checkbox.

Radiation Pattern 1

1 In the **3D Far-Field, Dipole Array** toolbar, click **More Plots** and choose **Radiation Pattern**.

2 In the **Settings** window for **Radiation Pattern**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1 (comp1)** > **Electromagnetic Waves, Boundary Elements** > **Far field** > **embe.rGaindBEfar - Realized far-field gain, dBi - dB**.

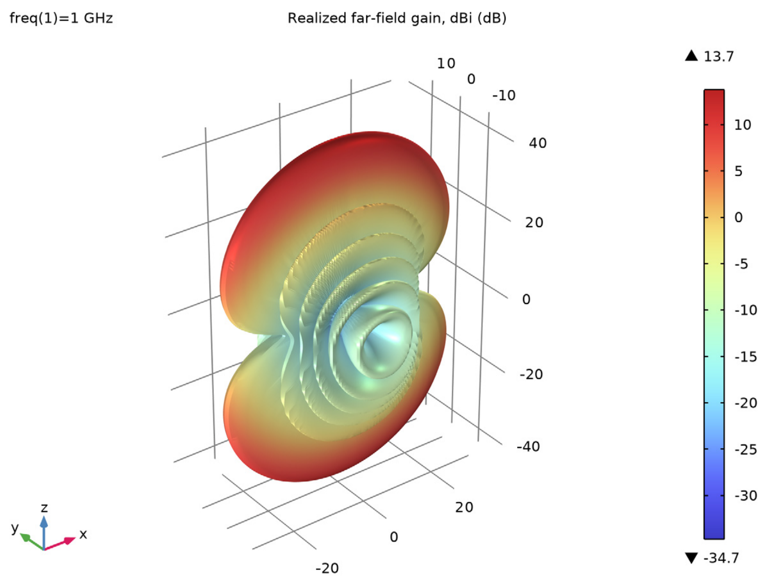
3 Locate the **Expression** section.

4 Select the **Threshold** checkbox. In the associated text field, type `-30`.

5 Locate the **Evaluation** section. Find the **Angles** subsection. In the **Number of elevation angles** text field, type 180.

6 In the **Number of azimuth angles** text field, type 180.

7 In the **3D Far-Field, Dipole Array** toolbar, click **Plot**.



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

2D Far-Field, Dipole Array, H-Plane

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

2 In the **Settings** window for **1D Plot Group**, type `2D Far-Field, Dipole Array, H-Plane` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Study 2/Solution 2 (sol2)**.

4 Locate the **Axis** section. Select the **Manual axis limits** checkbox.

5 In the **x minimum** text field, type 0.

6 In the **x maximum** text field, type 180.

7 In the **y minimum** text field, type -35.

8 In the **y maximum** text field, type 25.

Radiation Pattern 1

1 In the **2D Far-Field, Dipole Array, H-Plane** toolbar, click **More Plots** and choose **Radiation Pattern**.

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

3 In the **Expression** text field, type `embe.normdBEfar`.

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

5 From the **Restriction** list, choose **Manual**.

6 In the ϕ **range** text field, type `180`.

7 Find the **Normal vector** subsection. In the **x** text field, type `1`.

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

9 Find the **Reference direction** subsection. In the **x** text field, type `0`.

10 In the **y** text field, type `1`.

11 In the **2D Far-Field, Dipole Array, H-Plane** toolbar, click **Plot**.

"Use a **Graph Marker** to add additional information to the generated plot.

Graph Marker 1

1 Right-click **Radiation Pattern 1** and choose **Graph Marker**.

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

3 From the **Display mode** list, choose **Width**.

4 From the **Cutoff mode** list, choose **Offset from peak**.

5 Click to expand the **Coloring and Style** section. Locate the **Text Format** section. In the **Precision** text field, type `2`.

6 Select the **Include unit** checkbox.

7 In the **Prefix** text field, type `Half power (-3dB) beam width: `.

8 Locate the **Coloring and Style** section. From the **Background color** list, choose **None**.

9 From the **Anchor point** list, choose **Upper middle**.

10 In the **2D Far-Field, Dipole Array, H-Plane** toolbar, click **Plot**.

Radiation Pattern 2

1 In the **Model Builder** window, under **Results** > **2D Far-Field, Dipole Array, H-Plane** right-click **Radiation Pattern 1** and choose **Duplicate**.

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

3 Find the **Angles** subsection. In the ϕ **start** text field, type `75`.

4 In the ϕ **range** text field, type `15`.

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

6 In the **2D Far-Field, Dipole Array, H-Plane** toolbar, click **Plot**.

7 From the **Width** list, choose **3**.

Graph Marker 1

1 In the **Model Builder** window, expand the **Radiation Pattern 2** node, then click **Graph Marker 1**.

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

3 From the **Display mode** list, choose **Min and max**.

4 From the **Display** list, choose **Max**.

5 From the **Scope** list, choose **Local**.

6 Locate the **Text Format** section. In the **Precision** text field, type `3`.

7 Clear the **Prefix** text field.

8 In the **2D Far-Field, Dipole Array, H-Plane** toolbar, click **Plot**.

2D Far-Field, Dipole Array, H-Plane

1 In the **Model Builder** window, under **Results** click **2D Far-Field, Dipole Array, H-Plane**.

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 `H-plane Radiation Pattern`.

5 In the **2D Far-Field, Dipole Array, H-Plane** toolbar, click **Plot**.