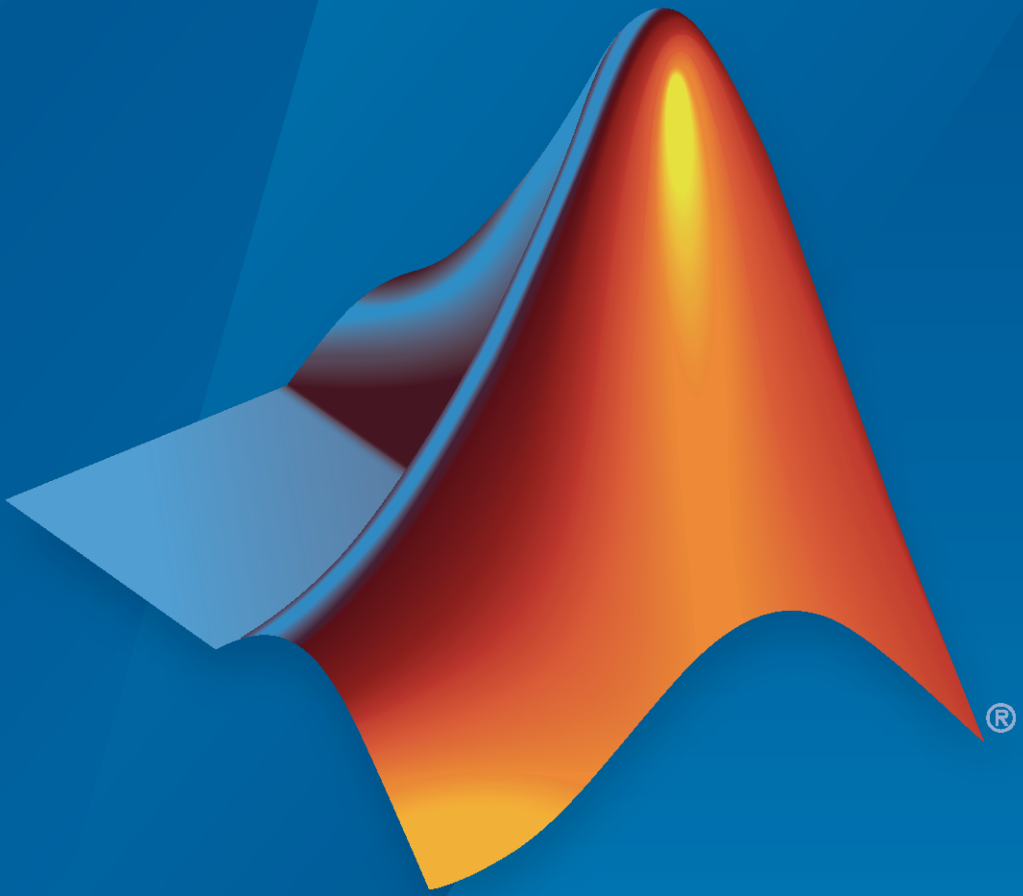
Antenna Toolbox™

Getting Started Guide



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Antenna Toolbox™ Getting Started Guide

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Contents

1 Introduction to Antenna Toolbox

2 Introduction to Arrays

Introduction to Antenna Toolbox

Antenna Toolbox Product Description

Design, analyze, and visualize antenna elements and antenna arrays

Antenna Toolbox provides functions and apps for the design, analysis, and visualization of antenna elements and arrays. You can design standalone antennas and build arrays of antennas using either predefined elements with parameterized geometry or arbitrary planar elements.

Antenna Toolbox uses the method of moments (MoM) to compute port properties such as impedance, surface properties such as current and charge distribution, and field properties such as the near-field and far-field radiation pattern. You can visualize antenna geometry and analysis results in 2D and 3D.

You can integrate antennas and arrays into wireless systems and use impedance analysis to design matching networks. Antenna Toolbox provides radiation patterns for simulating beam forming and beam steering algorithms. Gerber files can be generated from your design for manufacturing printed circuit board (PCB) antennas. You can install the antennas on large platforms such as cars or airplanes and analyze the effects of the structure on antenna performance. A site viewer enables you to visualize antenna coverage on a 3D terrain map using a variety of propagation models.

Antenna Modeling and Analysis

This example shows how to construct, visualize and analyze the antenna elements in the Antenna Toolbox.

Define Antenna Element Using the Antenna Library

Define a helix antenna using the `helix` antenna element in the Antenna Modeling and Analysis library.

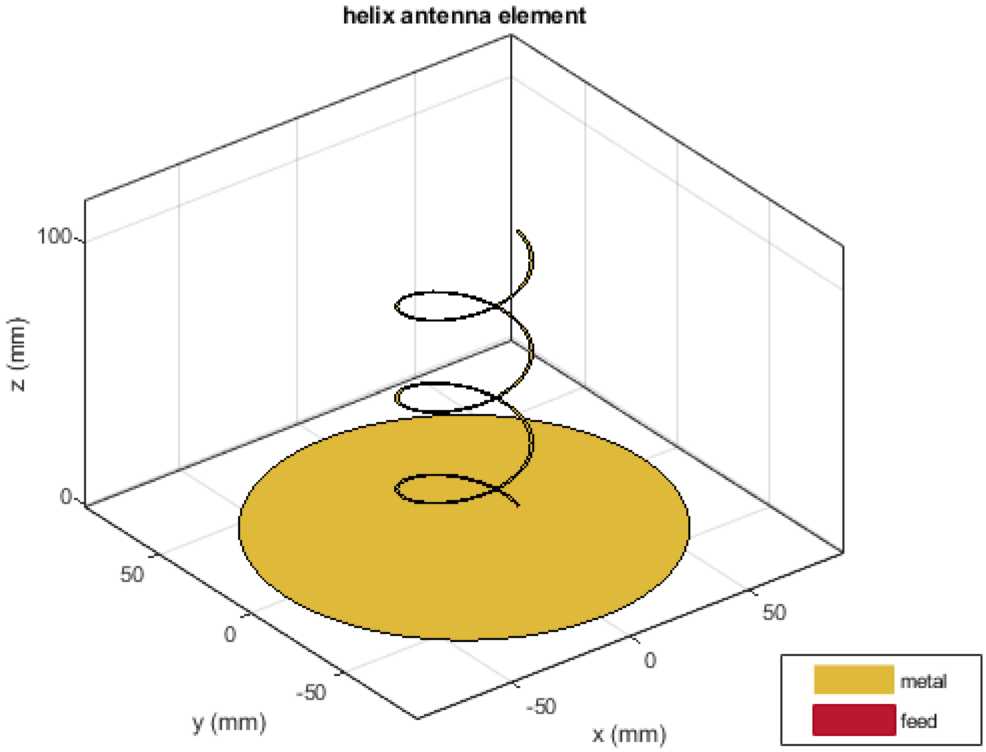
```
hx = helix
```

```
hx = 
  helix with properties:

               Radius: 0.0220
                Width: 1.0000e-03
                Turns: 3
              Spacing: 0.0350
     WindingDirection: 'CCW'
       FeedStubHeight: 1.0000e-03
    GroundPlaneRadius: 0.0750
                 Tilt: 0
             TiltAxis: [1 0 0]
                 Load: [1x1 lumpedElement]
```

Show Structure of Antenna

Use the `show` function to view the structure of the helix antenna. A helical antenna consists of a helical shaped conductor on a ground plane. The ground plane of the antenna is in the X-Y plane.

```
show(hx)
```



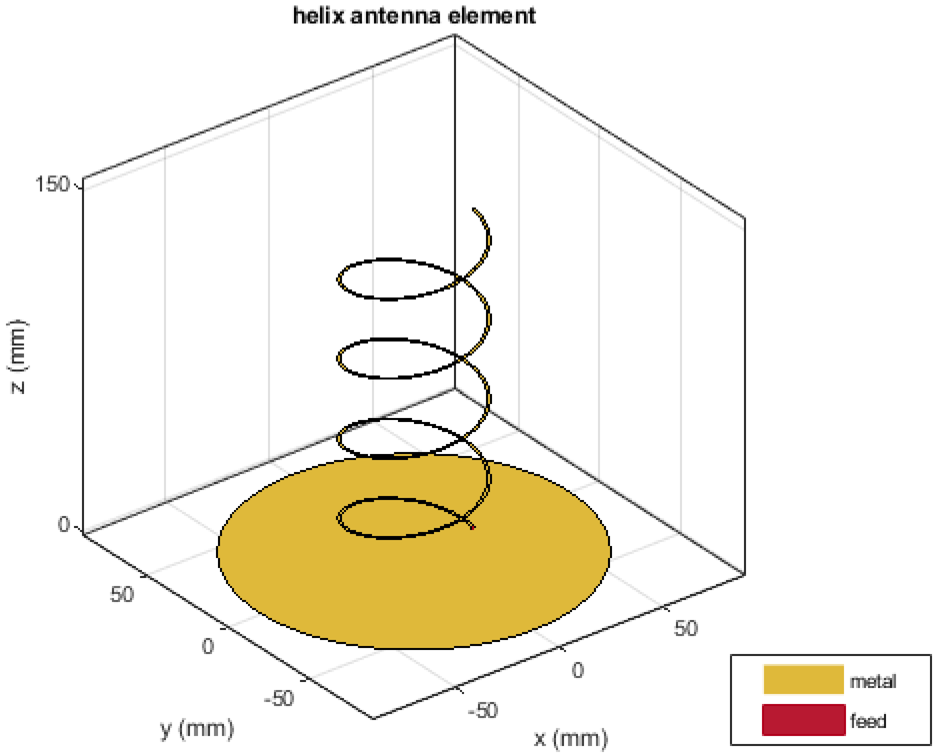
Modify Properties of Antenna

Modify the following properties of the helix antenna: Radius = 28e-3, Width = 1.2e-3, Number of Turns = 4 Display the properties of the antenna. View the antenna to see the change in structure.

```
hx = helix('Radius',28e-3,'Width',1.2e-3,'Turns',4)
```

```
hx = 
  helix with properties:

               Radius: 0.0280
                Width: 0.0012
                Turns: 4
              Spacing: 0.0350
     WindingDirection: 'CCW'
       FeedStubHeight: 1.0000e-03
     GroundPlaneRadius: 0.0750
                 Tilt: 0
             TiltAxis: [1 0 0]
                 Load: [1x1 lumpedElement]
```

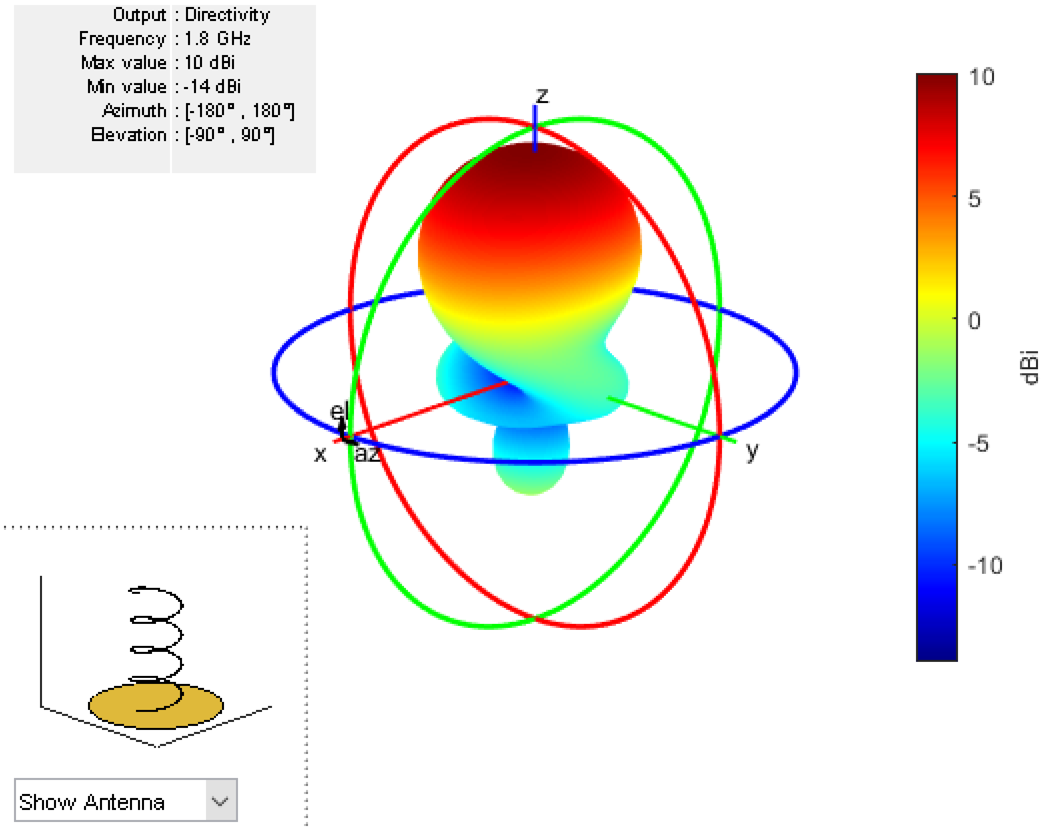
```
show(hx)
```



Plot Radiation Pattern of Antenna

Use `pattern` function to plot the radiation pattern of the helix antenna. The radiation pattern of an antenna is the spatial distribution of power of an antenna. The pattern displays the directivity or gain of the antenna. By default, the pattern function plots the directivity of the antenna.

```
pattern(hx,1.8e9)
```

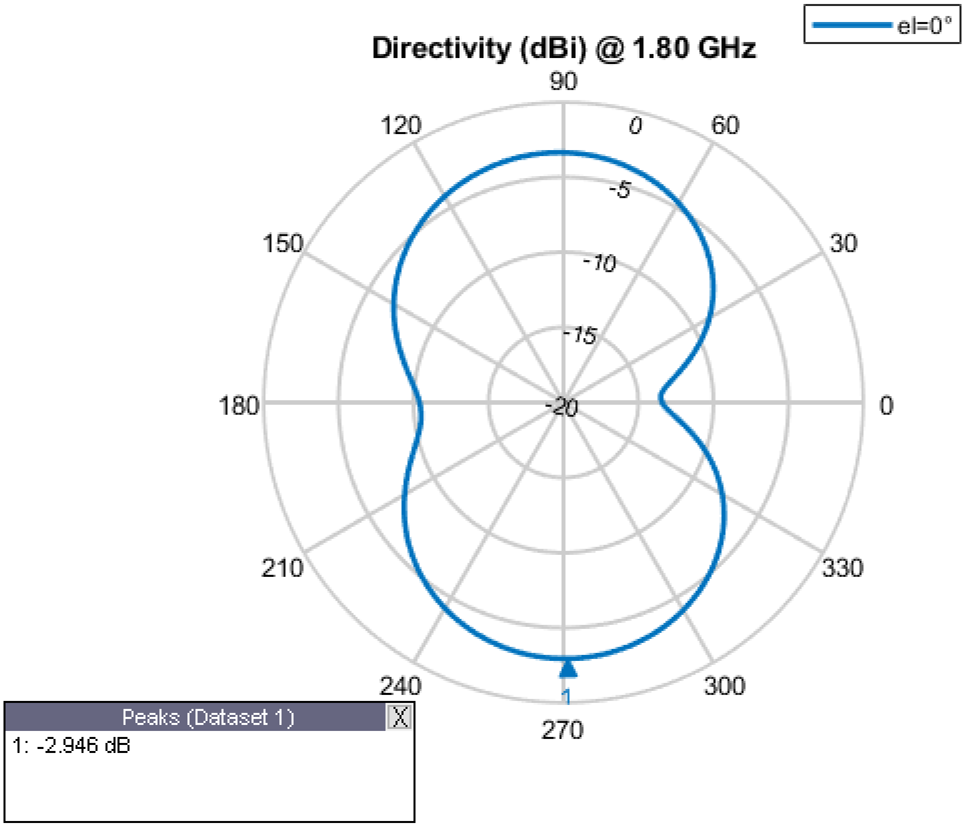


Output : Directivity
Frequency : 1.8 GHz
Max value : 10 dBi
Min value : -14 dBi
Azimuth : [-180° , 180°]
Elevation : [-90° , 90°]

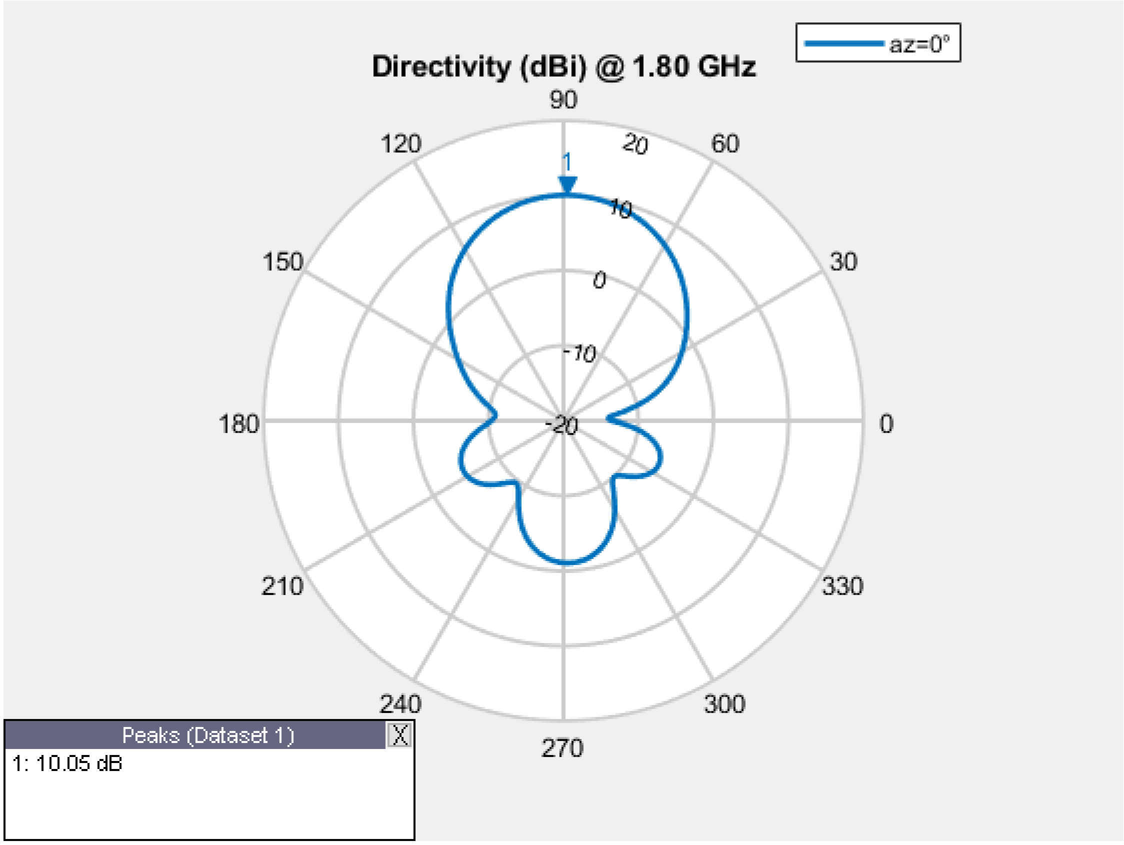
Plot Azimuth and Elevation Pattern of Antenna

Use `patternAzimuth` and `patternElevation` functions to plot the azimuth and elevation pattern of the helix antenna. This is the 2D radiation pattern of the antenna at a specified frequency.

```
patternAzimuth(hx,1.8e9)
```



```
figure
patternElevation(hx,1.8e9)
```



Calculate Directivity of Antenna

Use Directivity name-value pair in the output of the pattern function to calculate the directivity of helix antenna. Directivity is the ability of an antenna to radiate power in a particular direction. It can be defined as ratio of maximum radiation intensity in the desired direction to the average radiation intensity in all other directions.

```
Directivity = pattern(hx,1.8e9,0,90)
```

```
Directivity = 10.0430
```

Calculate EHfields of Antenna

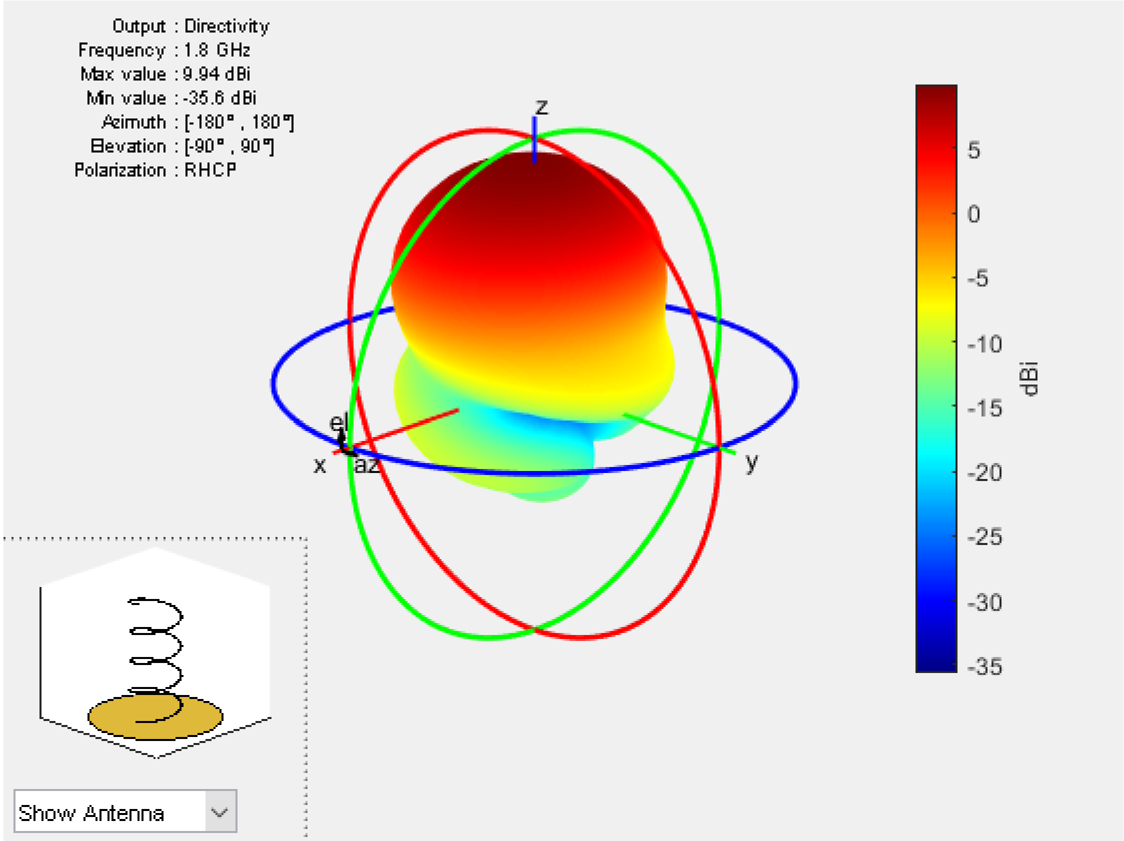
Use the `EHfields` function to calculate the EH fields of the helix antenna. EH fields are the x, y, z components of electric and magnetic fields of an antenna. These components are measured at a specific frequency and at specified points in space.

```
[E,H] = EHfields(hx,1.8e9,[0;0;1]);
```

Plot Different Polarizations of Antenna

Use the Polarization name-value pair in the pattern function to plot the different polarization patterns of the helix antenna. Polarization is the orientation of the electric field, or E-field, of an antenna. Polarization is classified as elliptical, linear, or circular. This example shows the Right-Hand Circularly Polarized(RHCP) radiation pattern of the helix.

```
pattern(hx,1.8e9,'Polarization','RHCP')
```



Calculate Axial Ratio of Antenna

Use the `axialRatio` function to calculate the axial ratio of the helix antenna. Antenna axial ratio (AR) in a given direction quantifies the ratio of two orthogonal field components radiated in a circularly polarized wave. An axial ratio of infinity, implies a linearly polarized wave. The unit of measure is dB.

```
ar = axialRatio(hx,1.8e9,20,30)
```

```
ar = 23.6238
```

Calculate Beamwidth of Antenna

Use the `beamwidth` function to calculate the beamwidth of the antenna. Antenna beamwidth is the angular measure of the antenna pattern coverage. Beamwidth angle is measured in plane containing the direction of main lobe of the antenna.

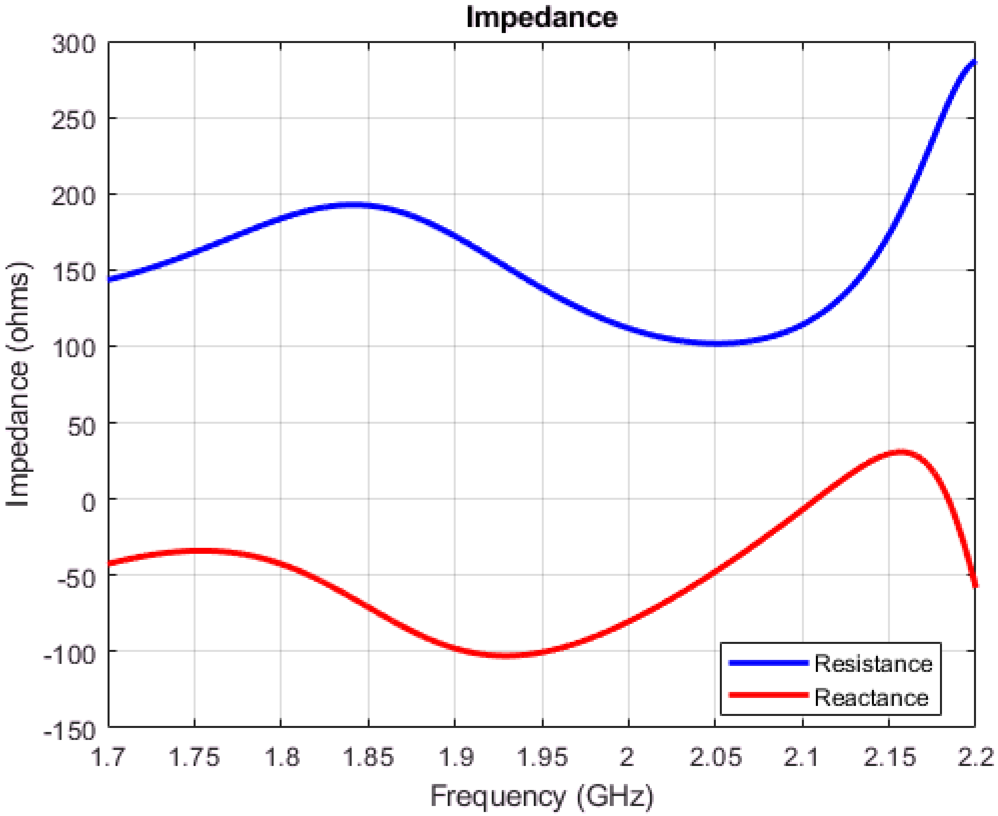
```
[bw, angles] = beamwidth(hx,1.8e9,0,1:1:360)
```

```
bw = 57.0000

angles = 1×2

    60   117
```

Calculate Impedance of Antenna

Use the `impedance` function to calculate and plot the input impedance of helix antenna. Input impedance is a ratio of voltage and current at the port. Antenna impedance is calculated as the ratio of the phasor voltage (which is 1V at a phase angle of 0 deg as mentioned earlier) and the phasor current at the port.

```
impedance(hx,1.7e9:1e6:2.2e9)
```



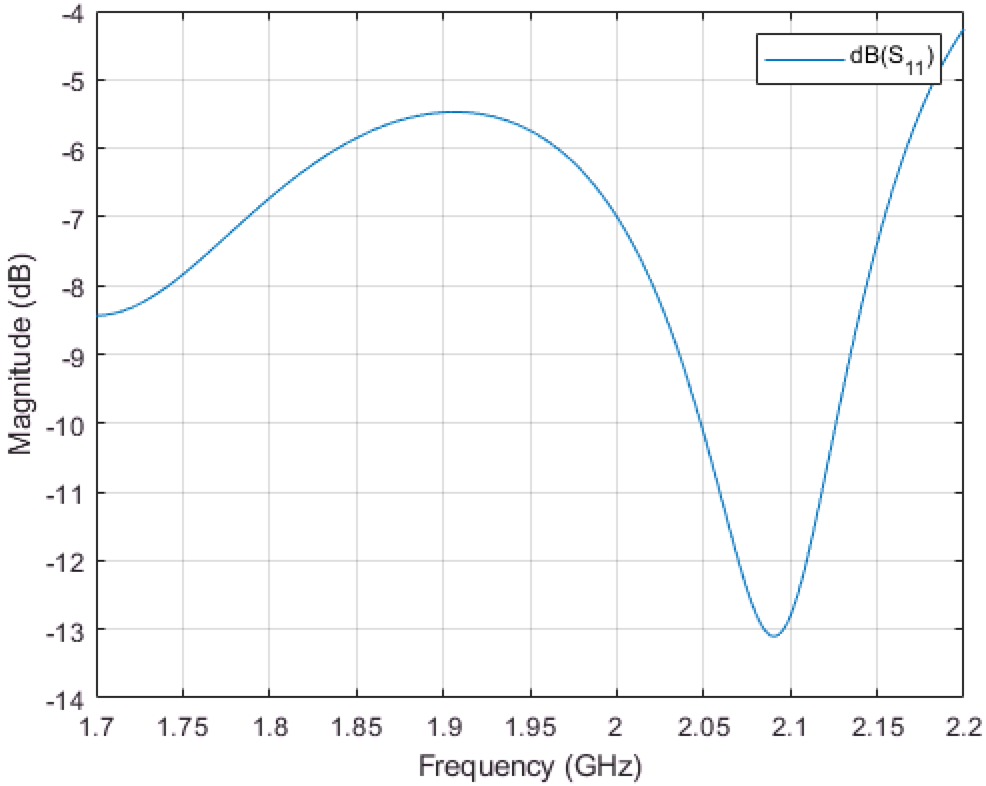
Calculate Reflection Coefficient of Antenna

Use the `sparameters` function to calculate the S11 of the helix antenna. Antenna reflection coefficient, or S_1_1, describes a relative fraction of the incident RF power that is reflected back due to the impedance mismatch.

```
S = sparameters(hx,1.7e9:1e6:2.2e9,72)
```

```
S = 
  sparameters: S-parameters object

       NumPorts: 1
    Frequencies: [501x1 double]
     Parameters: [1x1x501 double]
      Impedance: 72

  rfparam(obj,i,j) returns S-parameter Sij
```

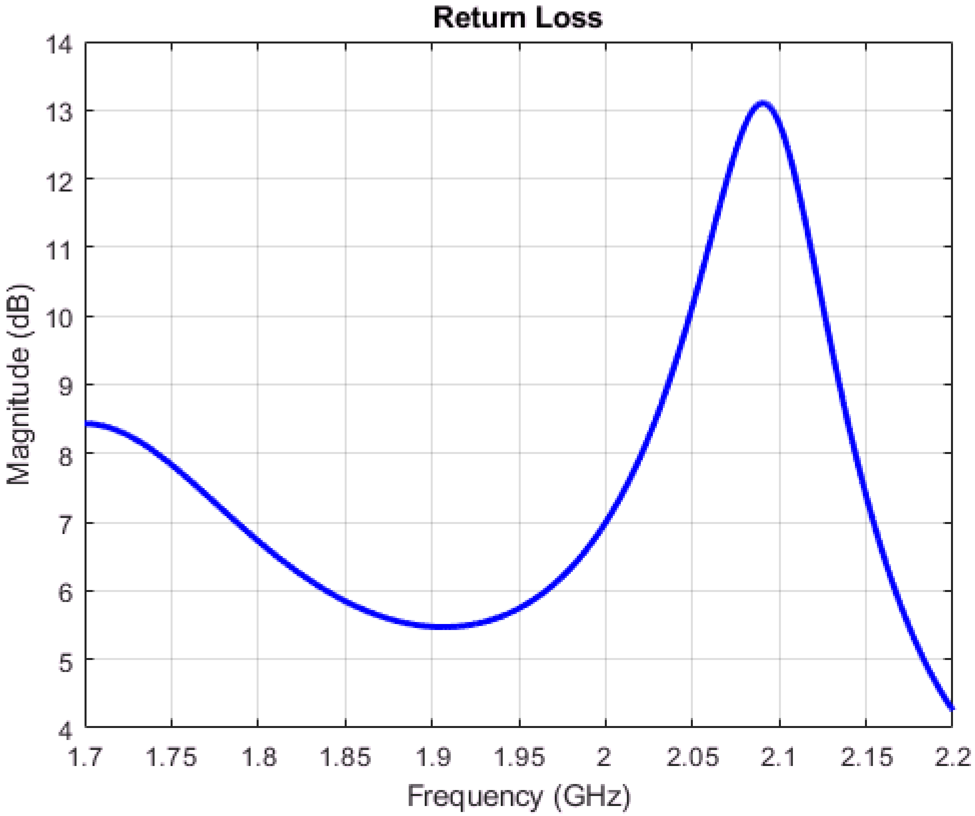
```
rfplot(S)
```



Calculate Return Loss of Antenna

Use the `returnLoss` function to calculate and plot the return loss of the helix antenna. Antenna return loss is a measure of the effectiveness of power delivery from a transmission line to a load such as antenna. The calculations are displayed in logscale.

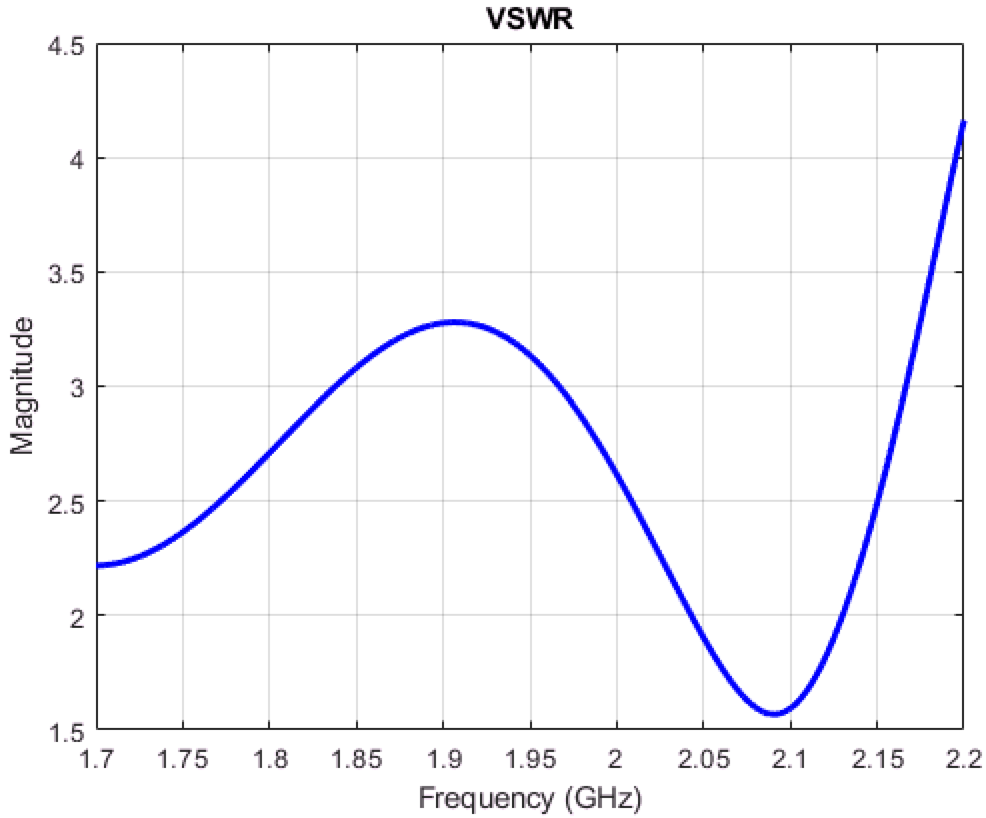
```
returnLoss(hx,1.7e9:1e6:2.2e9,72)
```



Calculate Voltage Standing Wave Ratio (VSWR) of Antenna

Use the `vswr` function to calculate and plot the VSWR of the helix antenna. The antenna VSWR is another measure of impedance matching between transmission line and antenna.

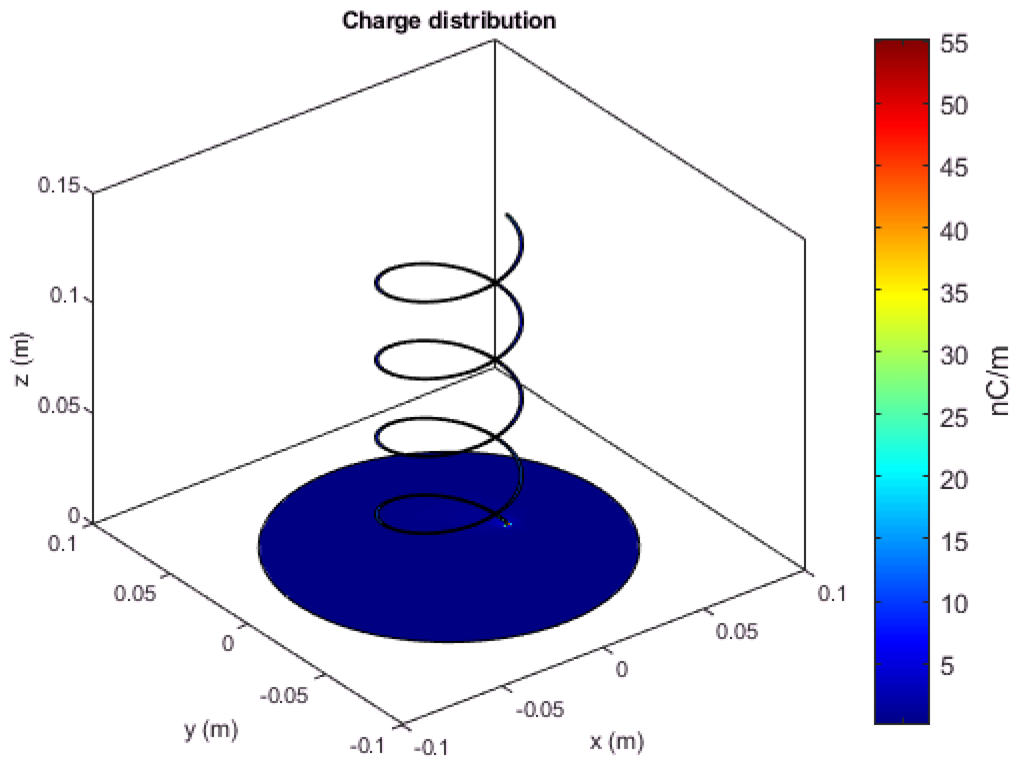
```
vswr(hx,1.7e9:1e6:2.2e9,72)
```



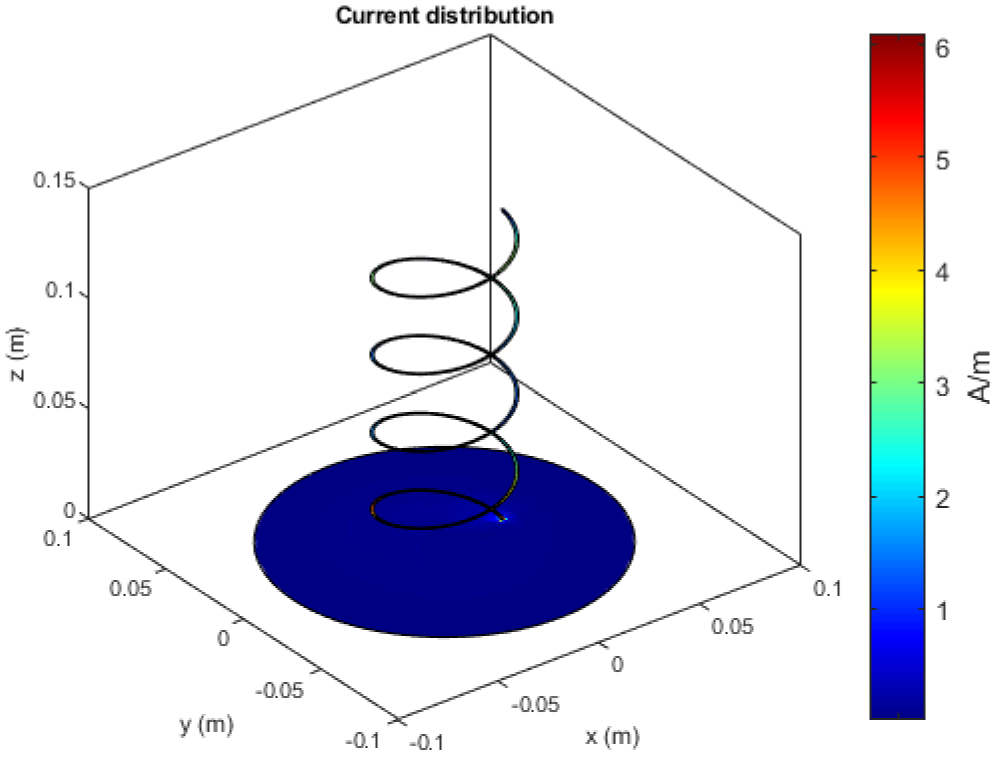
Calculate Current and Charge Distribution of Antenna

Use the `charge` function to calculate the charge distribution of the helix antenna. Charge distribution is the value of charge on the antenna surface at a specified frequency. Use the `current` function to calculate the current distribution of the helix antenna. Current distribution is the value of current on the antenna surface at a specified frequency.

```
charge(hx,2.01e9)
```



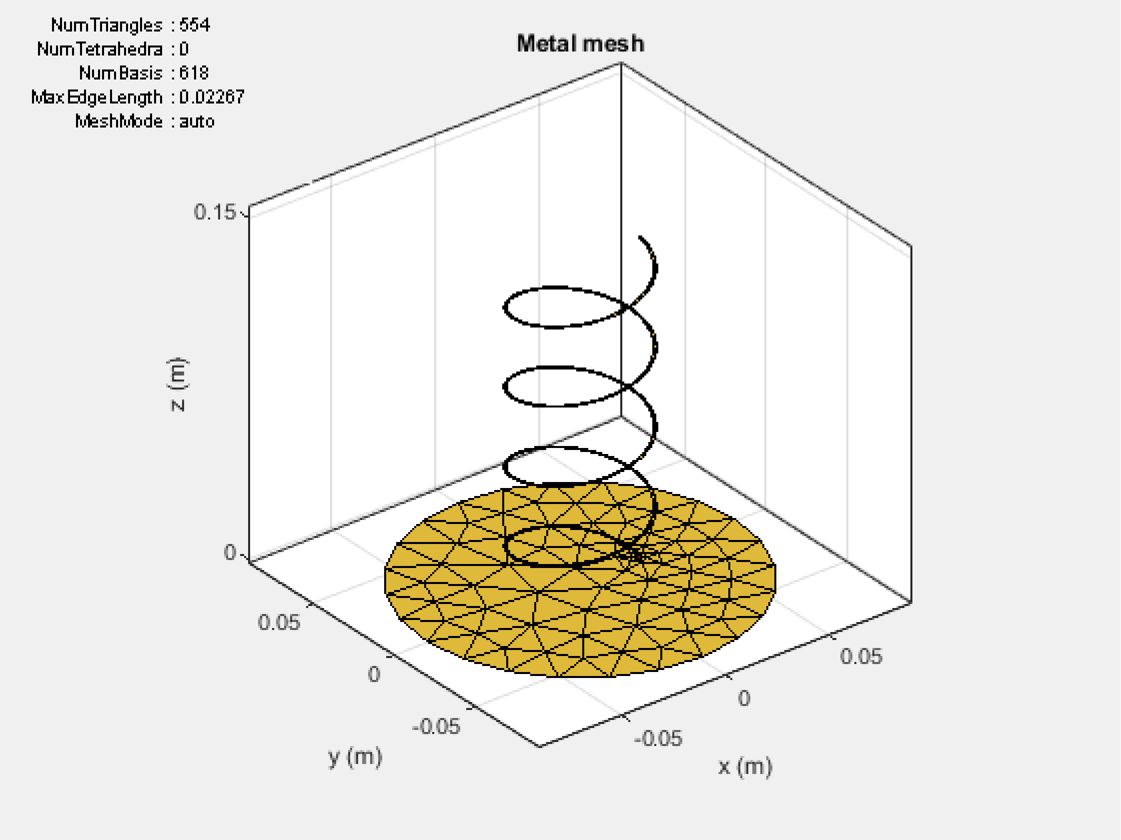
```
figure
current(hx,2.01e9)
```



Show Mesh of Antenna

Use the mesh function to create and show a mesh structure of the helix antenna. mesh is used to discretize antenna surface. In this process, the electromagnetic solver can process the geometry and material of the antenna. The shape of the basis or the discretizing element for subdividing the antenna surface is a triangle.

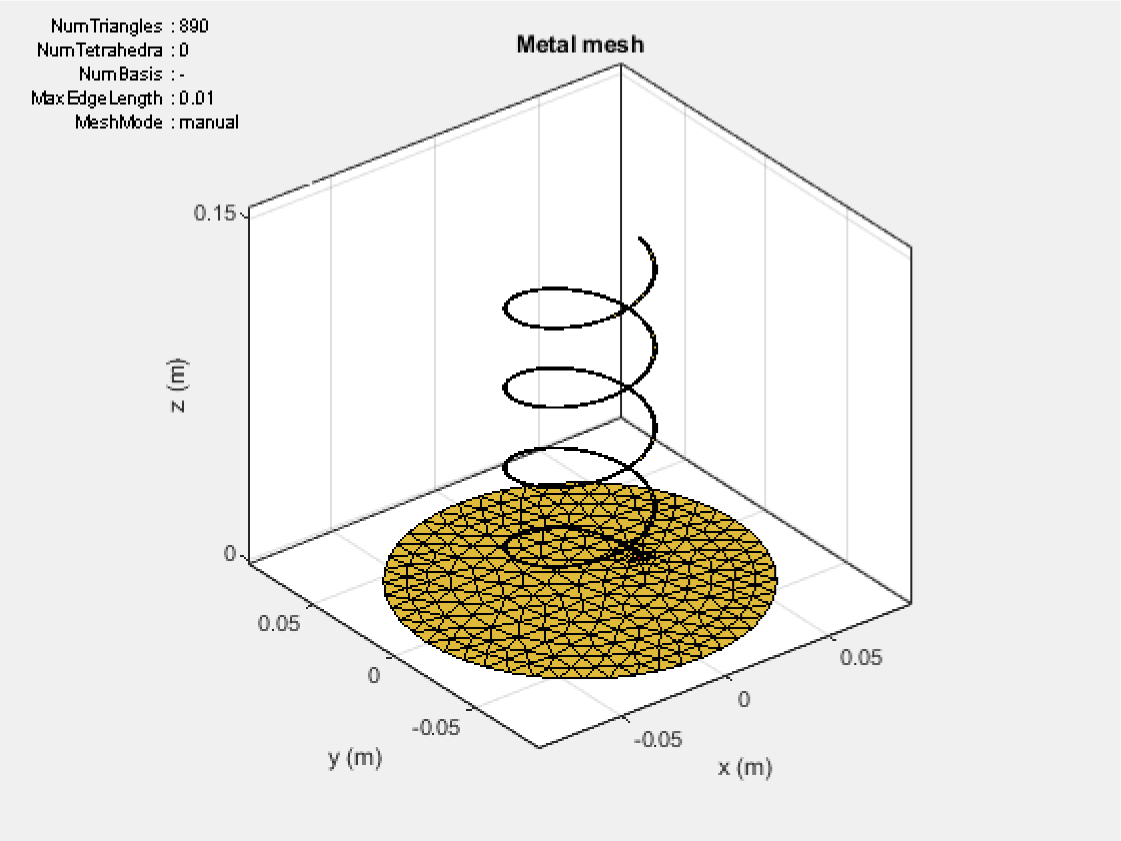
```
figure
mesh(hx)
```



Mesh Antenna Manually

Specify the maximum edge length for the triangles using the 'MaxEdgeLength' name-value pair. This name-value pair meshes the helix structure manually.

```
figure
mesh(hx,'MaxEdgeLength',0.01)
```



Change Meshing to Automatic

```
meshconfig(hx,'auto')
```

```
ans = struct with fields:
     NumTriangles: 890
    NumTetrahedra: 0
         NumBasis: []
    MaxEdgeLength: 0.0100
         MeshMode: 'auto'
```

See Also:

“Antenna Near-Field Visualization”

References

[1] Balanis, C.A. "Antenna Theory. Analysis and Design", p. 514, Wiley, New York, 3rd Edition, 2005.

Antenna Classification

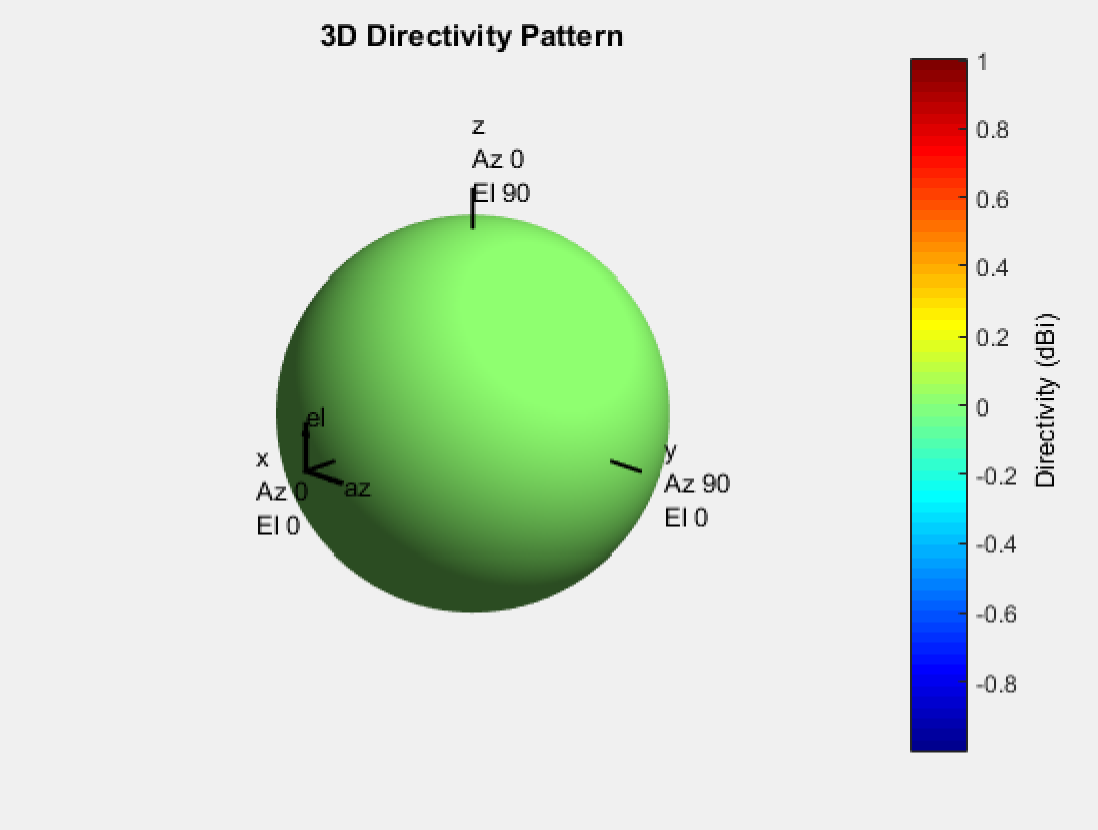
In this section...
"Radiation Pattern" on page 1-18
"Antenna Feeding Mechanism" on page 1-19

Antennas are classified based on the radiation pattern or the feeding mechanism. Antenna radiation pattern is the angular variation of signal strength around the antenna. Feeding mechanism defines how the signal is fed into the antenna and the location of the feed point on the antenna.

Radiation Pattern

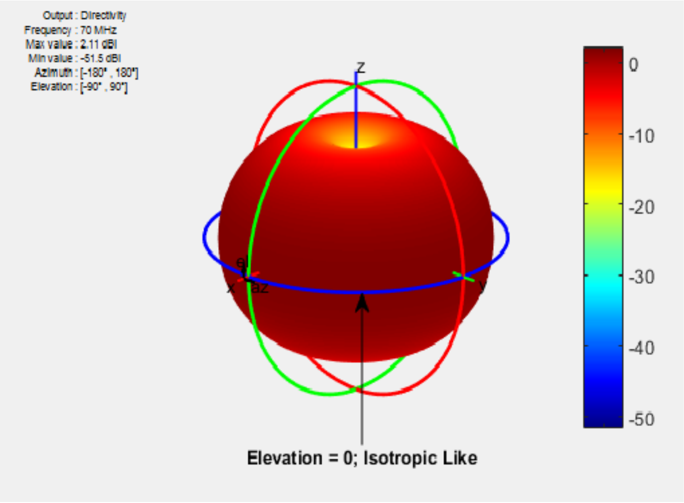
Isotropic Antenna

An *isotropic* antenna is an ideal lossless antenna that radiates uniformly in all directions. The antenna has no spatial selectivity or nulls. Practical antennas are compared against the isotropic antenna, but they rarely behaves like one.



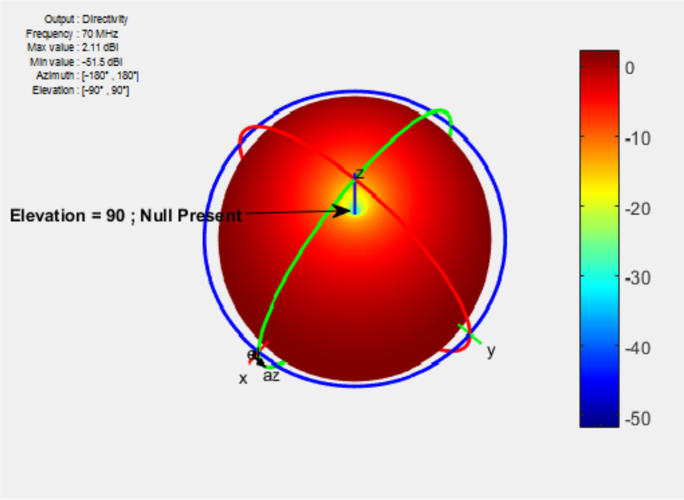
Omnidirectional Antenna

Omnidirectional antennas behave like isotropic antennas in one plane. These antennas have nulls in the orthogonal plane. A common example of an omnidirectional antenna is the `dipole` antenna.



Output : Directivity
Frequency : 70 MHz
Max value : 2.11 dBI
Min value : -51.5 dBI
Azimuth : [-180° , 180°]
Elevation : [-90° , 90°]

Elevation = 0; Isotropic Like



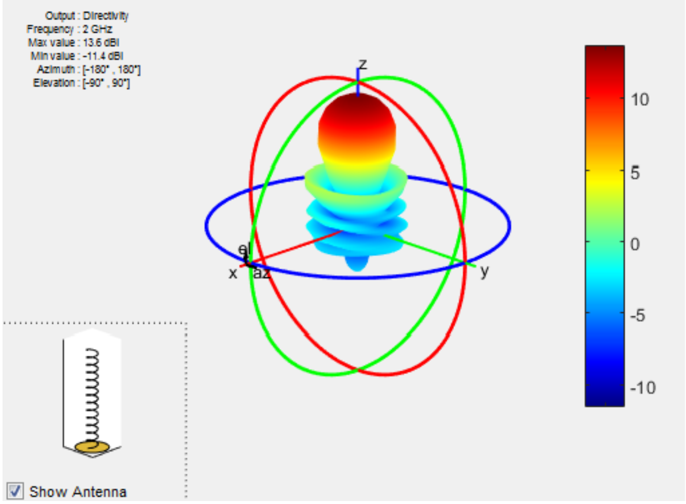
Output : Directivity
Frequency : 70 MHz
Max value : 2.11 dBI
Min value : -51.5 dBI
Azimuth : [-180° , 180°]
Elevation : [-90° , 90°]

Elevation = 90 ; Null Present

The dipole is omnidirectional around the E-plane, or elevation angle. The null is present in the H-plane, or azimuth angle.

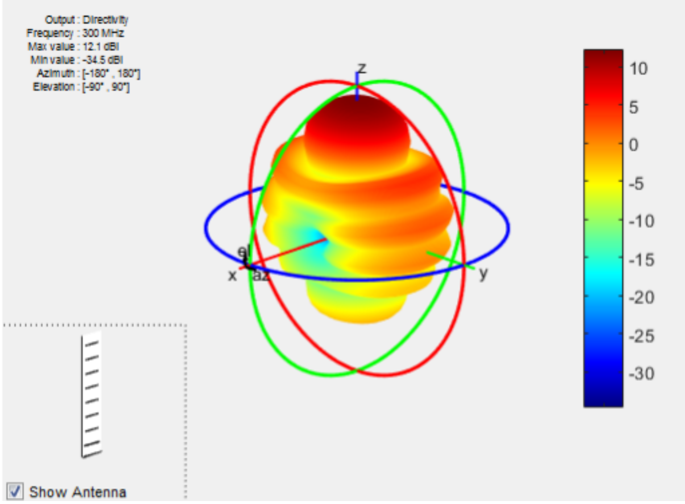
Directional Antennas

Directional antennas are highly directive in a given direction. These antennas show high spatial selectivity, narrow bandwidth. They also have well defined major, or main, beam in the desired directions. Common examples of directional antennas are `helix` and `yagiUda`.



Output : Directivity
Frequency : 2 GHz
Max value : 13.6 dBI
Min value : -11.4 dBI
Azimuth : [-180° , 180°]
Elevation : [-90° , 90°]

☑ Show Antenna



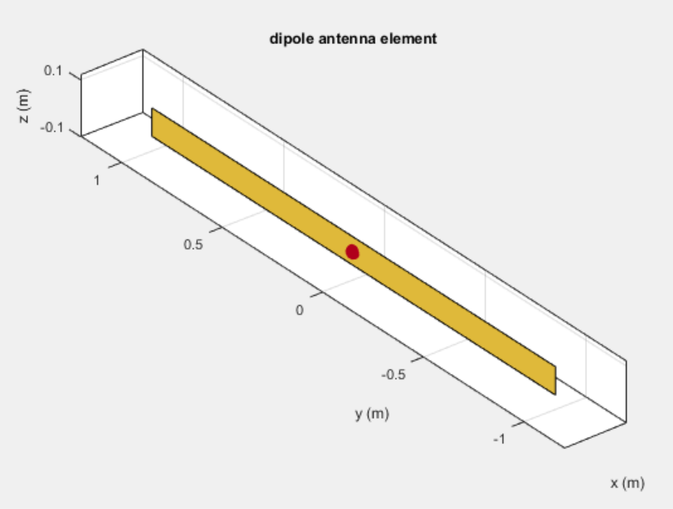
Output : Directivity
Frequency : 300 MHz
Max value : 12.1 dBI
Min value : -34.5 dBI
Azimuth : [-180° , 180°]
Elevation : [-90° , 90°]

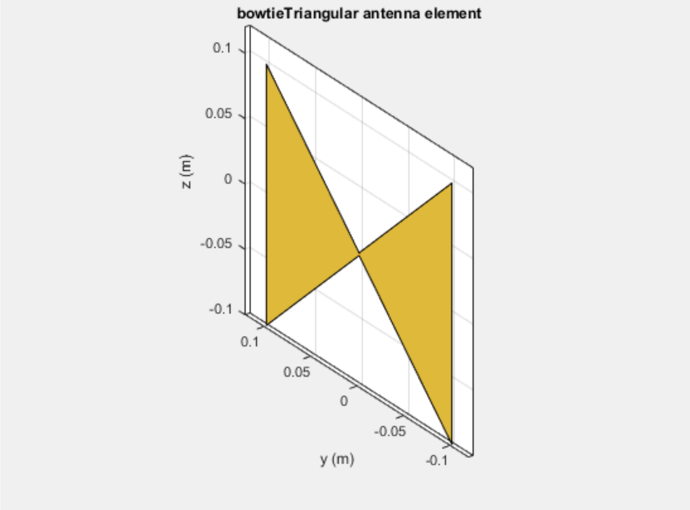
☑ Show Antenna

Antenna Feeding Mechanism

Balanced Antennas

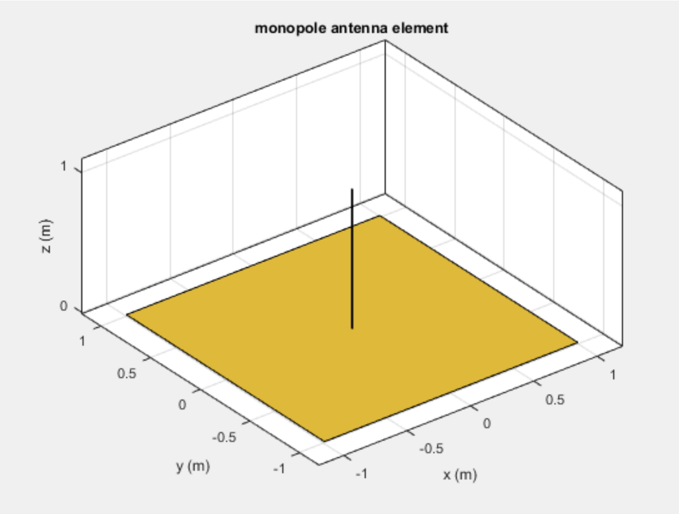
In *balanced* antennas, one side of the antenna is a mirror image of the other. These antennas require a balun to feed it, using a coaxial line. Common examples are: dipoles, bowties, spirals, and loops.

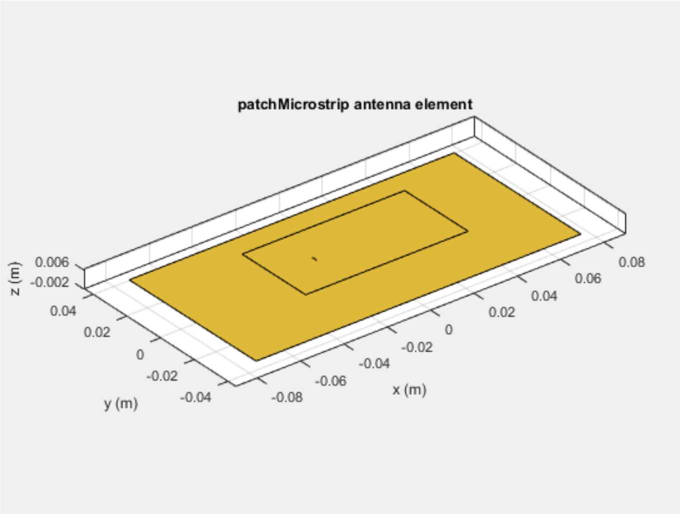




Unbalanced Antennas

Unbalanced antennas are end fed and mounted on top of a ground plane. The coaxial shield is connected to the ground, and the center conductor is connected to the antenna element. Common examples are monopoles and patches.





References

[1] Balanis, C.A. *Antenna Theory: Analysis and Design*. 3rd Ed. New York: Wiley, 2005.

Antenna Toolbox Coordinate System

In this section...

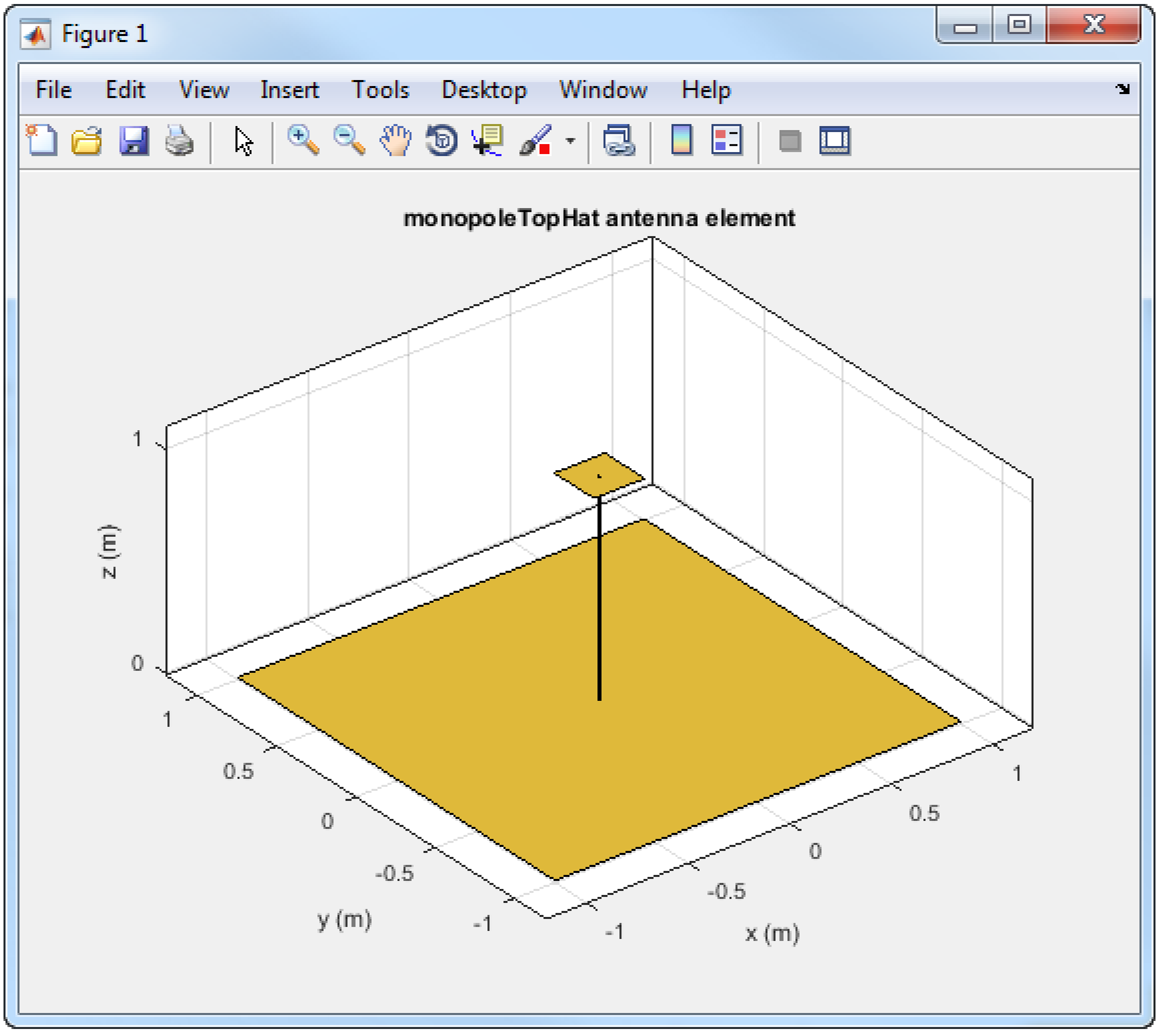
Antenna Toolbox uses two types of coordinate system: *rectangular coordinate system* and *spherical coordinate system* .

Antenna Toolbox uses the *rectangular coordinate system* to visualize antenna or array geometry. The toolbox uses the *spherical coordinate system* to visualize antenna radiation patterns.

Rectangular Coordinate System

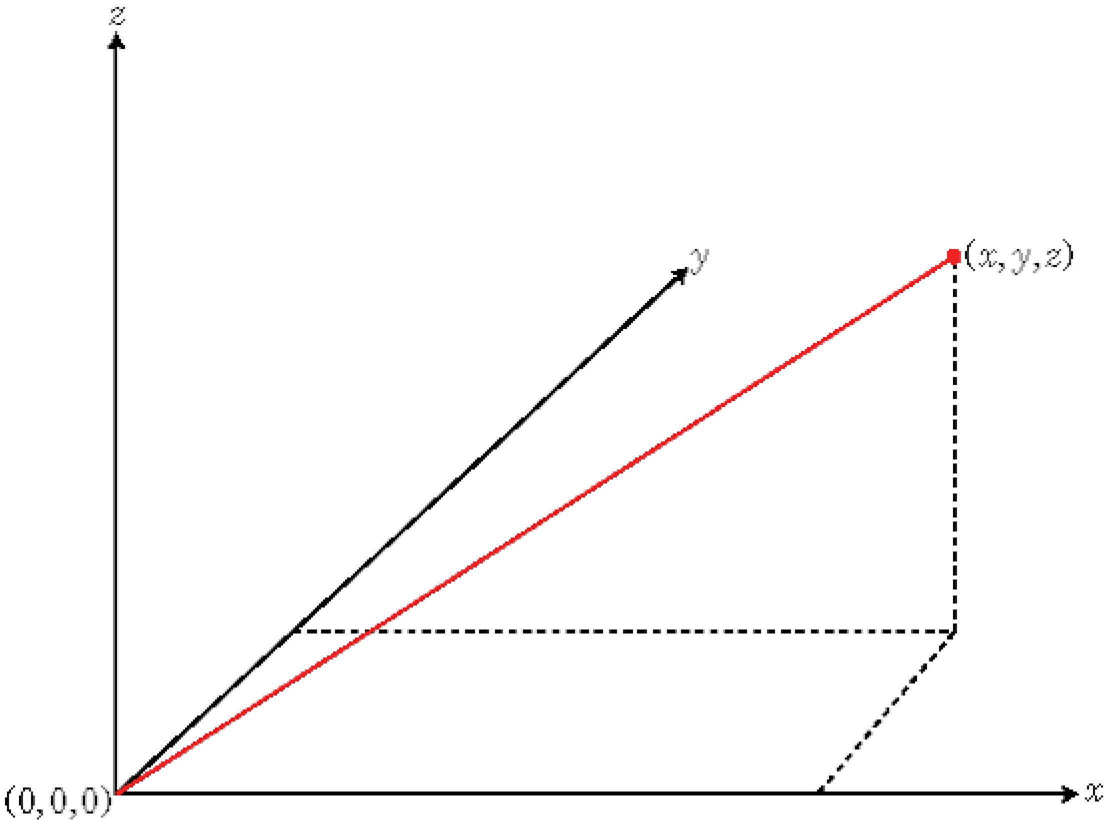
Visualize the geometry of a default `monopoleTopHat` antenna from the antenna library.

```
m = monopoleTopHat;
show(m);
```



The toolbox displays the top-hat monopole antenna in the *rectangular* or *Cartesian* coordinate system.

The *rectangular* coordinate system also called *Cartesian* coordinate system specifies a position in space as an ordered 3-tuple of real numbers, `(x,y,z)`, with respect to the origin `(0,0,0)`.



You can view the 3-tuple as a point in space, or equivalently as a vector in three-dimensional Euclidean space. When viewed as a vector in space, the coordinate axes are basis vectors and the vector gives the direction to a point in space from the origin. Every vector in space is uniquely determined by a linear combination of the basis vectors. The most common set of basis vectors for three-dimensional Euclidean space are the standard unit basis vectors:

$$\{[1\ 0\ 0], [0\ 1\ 0], [0\ 0\ 1]\}$$

.

Orthogonal Basis and Euclidean Norm

Any three linearly independent vectors define a basis for three-dimensional space. However, the Antenna Toolbox assumes that the basis vectors you use are orthogonal.

The standard distance measure in space is the l^2 norm, or Euclidean norm. The Euclidean norm of a vector [*x y z*] is defined by:

$$\sqrt{x^2 + y^2 + z^2}$$

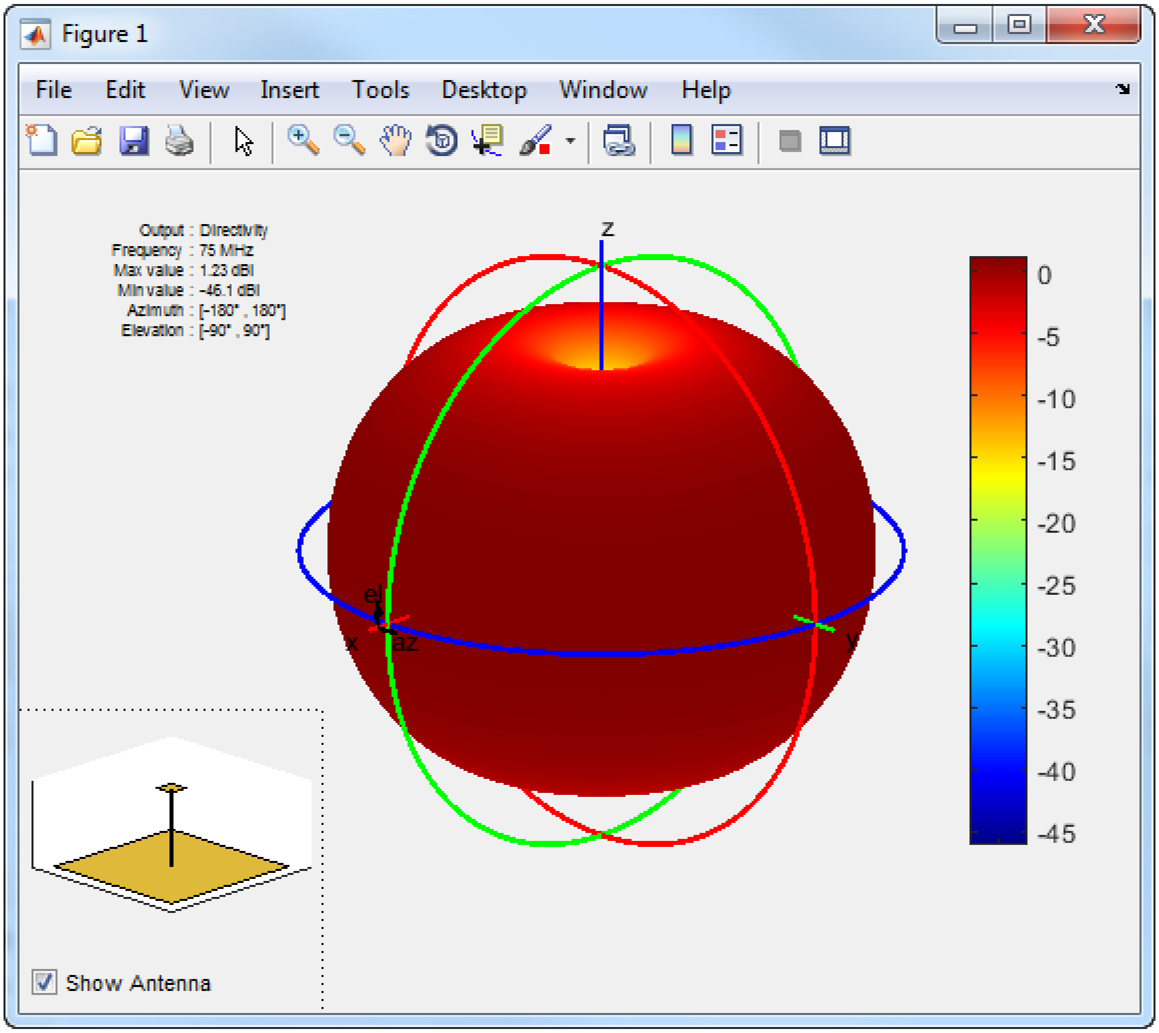
The Euclidean norm gives the length of the vector measured from the origin as the hypotenuse of a right triangle. The distance between two vectors [*x0 y0 z0*] and [*x1 y1 z1*] is:

$$\sqrt{(x_0 - x_1)^2 + (y_0 - y_1)^2 + (z_0 - z_1)^2}$$

Spherical Coordinate System

Visualize the radiation pattern of the default `monopoleTopHat` antenna.

```
m = monopoleTopHat;
pattern(m,75e6);
```



Output : Directivity
Frequency : 75 MHz
Max value : 1.23 dBi
Min value : -46.1 dBi
Azimuth : [-180° , 180°]
Elevation : [-90° , 90°]

☑ Show Antenna

The toolbox displays the radiation pattern of the top-hat monopole using *spherical* coordinate system represented by azimuth and elevation angles.

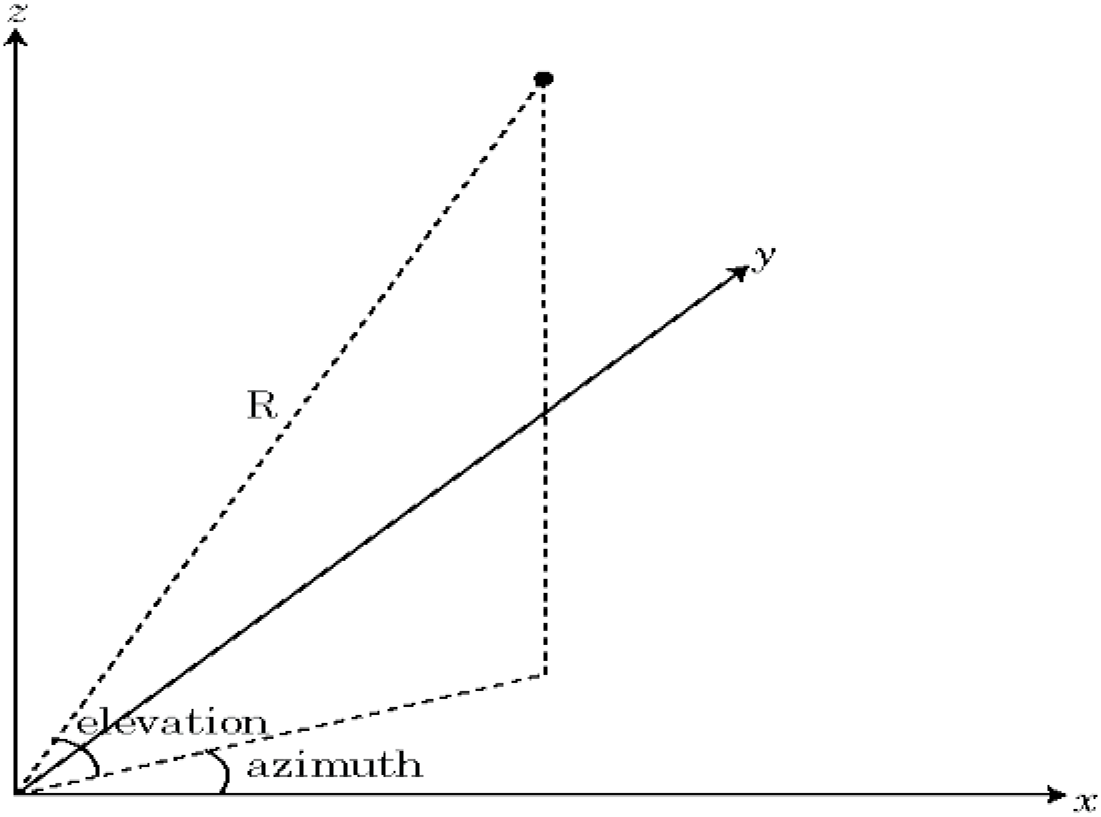
The *spherical* coordinate system defines a vector or point in space with a distance *R* and two angles. You can represent the angles in this coordinate system:

- Azimuth and elevation angles
- Phi (Φ) and theta (θ) angles
- *u* and *v* coordinates

Azimuth and Elevation Angles

The *azimuth angle* is the angle from the positive *x*-axis to the vector's orthogonal projection onto the *xy* plane, moving in the direction towards the y-axis. The azimuth angle is in the range –180 and 180 degrees.

The *elevation angle* is the angle from the vector's orthogonal projection on the *xy* plane toward the positive *z*-axis, to the vector. The elevation angle is in the –90 and 90 degrees.

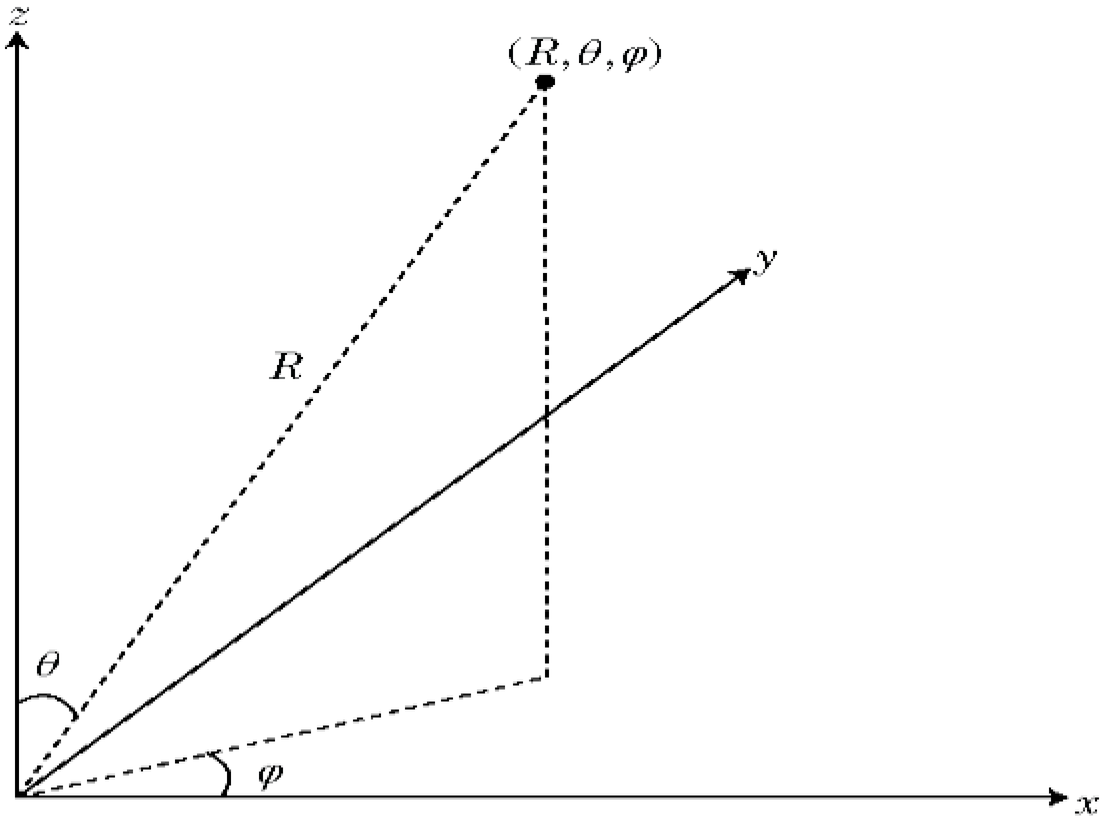


Phi (Φ) and Theta (θ) Angles

The φ angle is the angle from the positive *x*-axis to the vector's orthogonal projection onto the *xy* plane, moving in the direction towards the y-axis. The azimuth angle is between –180 and 180 degrees.

The θ angle is the angle from the positive *z*-axis to the vector itself. The θ angle is in the range 0 degrees and 180 degrees.

These angles are an alternative to using azimuth and elevation angles to express the location of point in a unit sphere.



u and v Coordinates

You can define *u* and *v* in terms of φ and θ:

$$u = \sin\theta\cos\phi$$
$$v = \sin\theta\sin\phi$$

In terms of azimuth and elevation angles, the *u* and *v* coordinates are:

$$u = \cos el \sin az$$
$$v = \sin el$$

The values of *u* and *v* satisfy the inequalities:

$$-1 \leq u \leq 1$$
$$-1 \leq v \leq 1$$
$$u^2 + v^2 \leq 1$$

The φ and θ angles in terms of *u* and *v* are:

$$\tan\phi = u/v$$
$$\sin\theta = \sqrt{u^2 + v^2}$$

The azimuth and elevation angles in terms of *u* and *v* are:

$$\sin el = v$$

$$\tan az = \frac{u}{\sqrt{1 - u^2 - v^2}}$$

Conversion Between Rectangular and Spherical Coordinates

Convert rectangular coordinates to spherical coordinates (*az*, *el*, *R*) using:

$$R = \sqrt{x^2 + y^2 + z^2}$$

$$az = \tan^{-1}\left(\frac{y}{x}\right)$$

$$el = \tan^{-1}\left(\frac{z}{\sqrt{x^2 + y^2}}\right)$$

Convert spherical coordinates (*az*, *el*, *R*) to rectangular coordinates using:

$$x = R\cos(el)\cos(az)$$
$$y = R\cos(el)\sin(az)$$
$$z = R\sin(el)$$

where:

- *R* is the distance from the antenna
- *el* and *az* are the azimuth and elevation angles

References

[1] Balanis, C.A. *Antenna Theory: Analysis and Design*. 3rd Ed. New York: Wiley, 2005.

Antenna Toolbox Limitations

The Antenna Toolbox does not support the following features.

Antenna Library

Antenna Toolbox characterizes the antenna metal as a perfect electrical conductor.

These antenna library objects do not support:

- PIFA and inverted–F antennas with the infinite ground plane.
- Antenna analysis at frequencies less than 1 kHz or greater than 200 GHz.
- pcbStack cannot be used with any arrays, or planeWaveExcitation elements in the library
- `gerberWrite` works only with one feed location or port.

Array Library

These array library objects do not support:

- Arrays using slot, and cavity antennas.
- Reflector-based arrays using helix, slot, Vivaldi, cavity, PIFA antennas as exciters.
- Building arrays using antennas with tilted ground planes.
- Conformal arrays created using unbalanced antennas with infinite ground plane.
- Infinite arrays using dielectric materials.

Interact with Polar Plot

This example shows how to interact with a polar plot created using `polarpattern` class.

Create Polar Plot of Helix Antenna

Create a helix antenna that has a 28 mm radius, a 1.2 mm width and 4 turns.

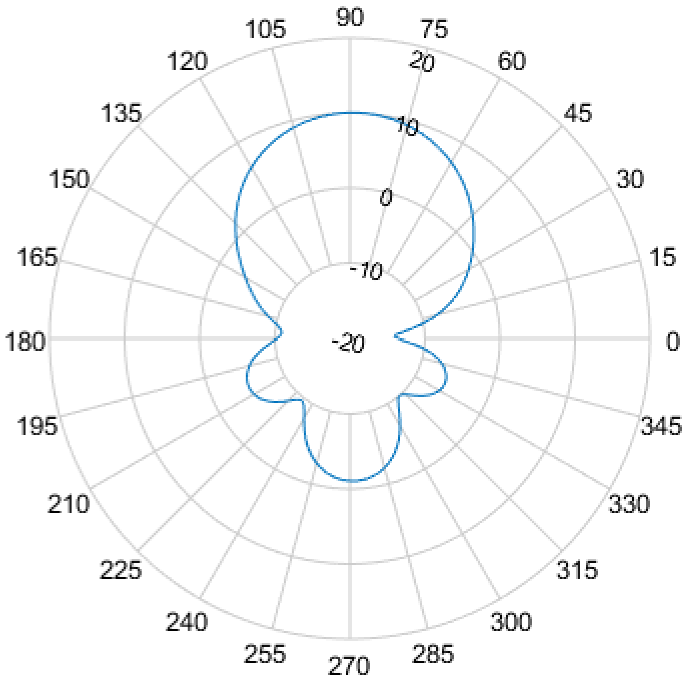
```
hx = helix('Radius',28e-3,'Width',1.2e-3,'Turns',4);
```

Calculate the directivity of the antenna at 1.8 GHz.

```
H = pattern(hx,1.8e9,0,0:1:360);
```

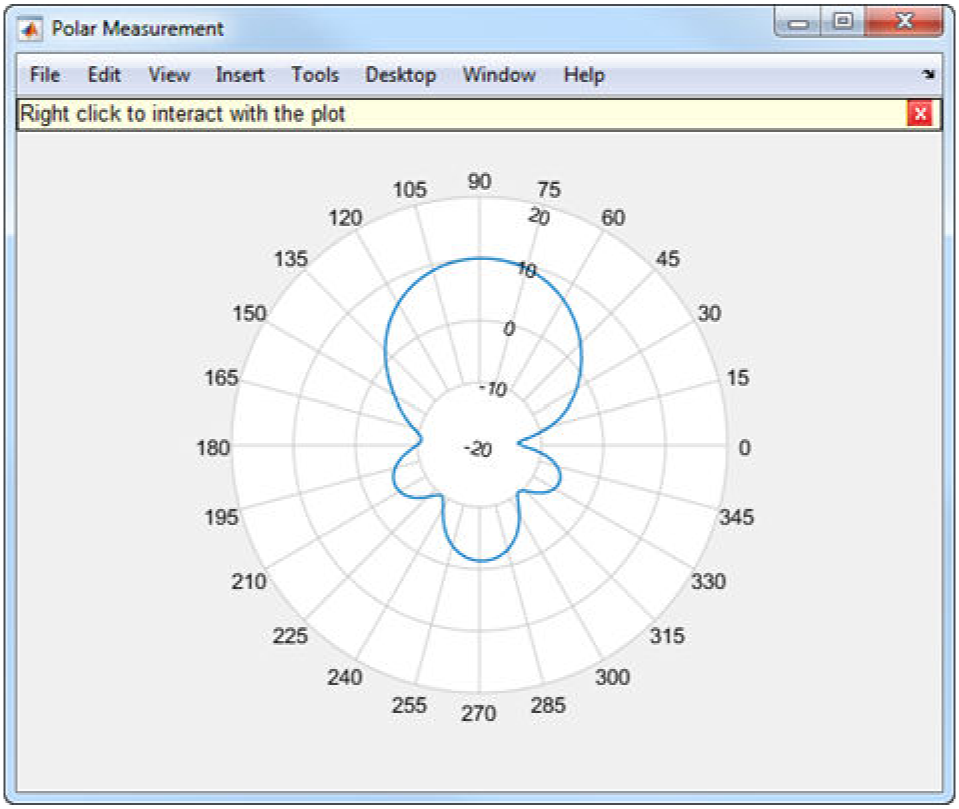
Display the polar plot of the antenna.

```
P = polarpattern(H);
```



Interact with Polar Plot

Hover over the plot. You see a message on top of the plot: **Right click to interact with the plot**. Right-click anywhere in the Polar Measurement window to display a context menu for interacting with the plot. For example, right-click outside the plot to show the **Main** context menu. Right-click inside the plot to show the **Display** context menu.

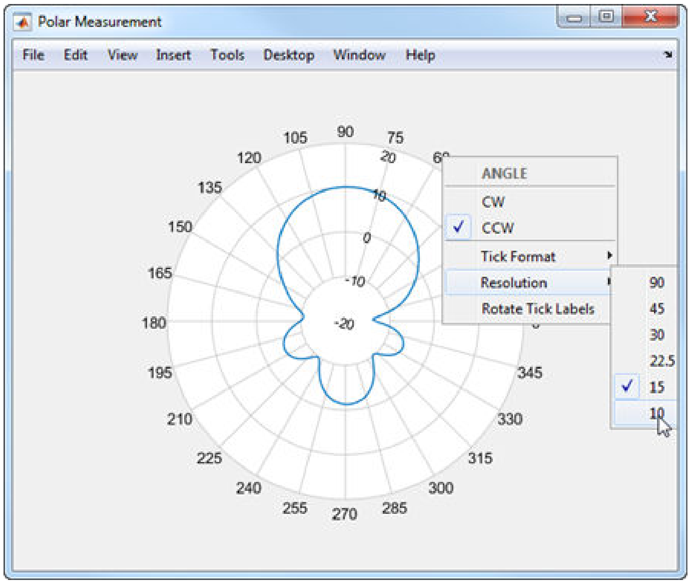


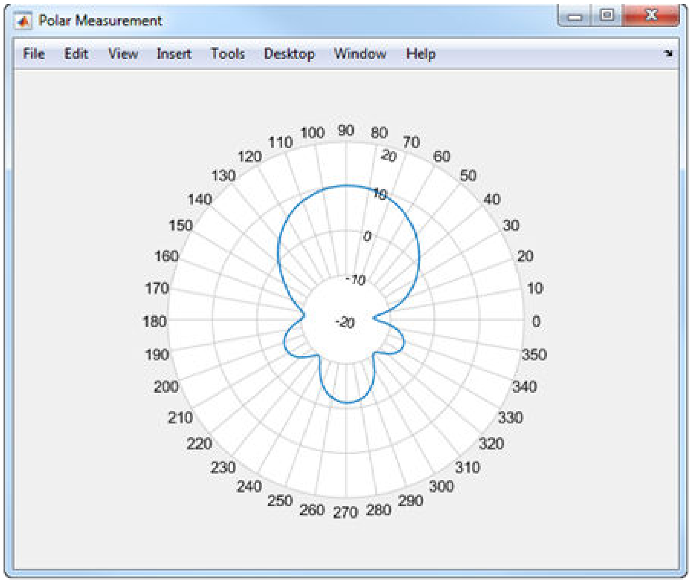
Right click to interact with the plot

Update Angle and Magnitude Values

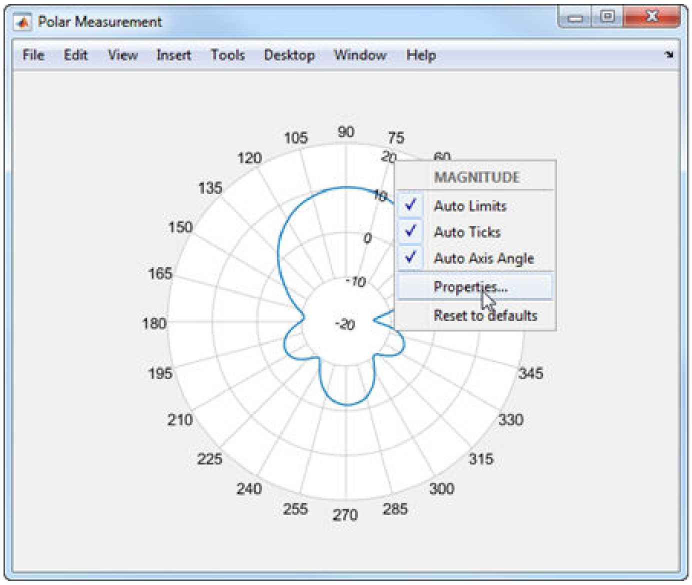
The angular values are around the circumference of the polar plot. Right-click any of the angle values to open **ANGLE** context menu. By default, the angles are displayed `CCW` (counterclockwise).

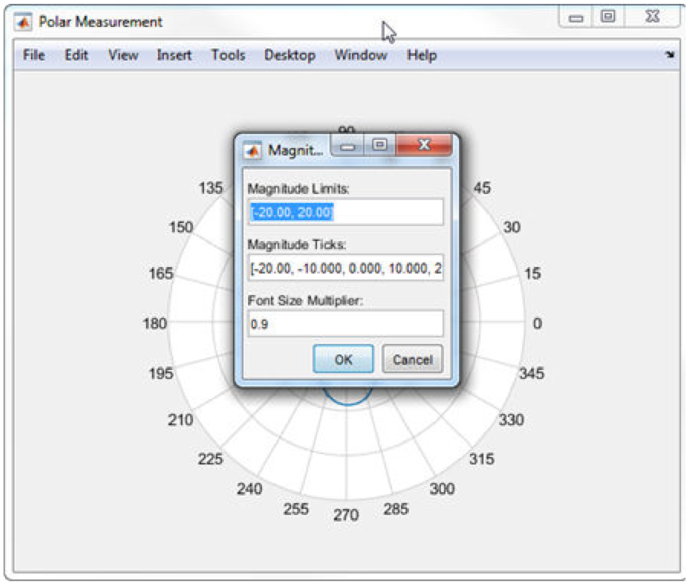
Change the resolution from 15 degrees to 10 degrees.





The magnitude values are on the radial lines of the plot. Right-click any of the magnitude values to open the **MAGNITUDE** context menu. Choose properties from the context menu to change the magnitude limits, magnitude ticks, or font size.





Magnitude Limits: [-20.00, 20.00]

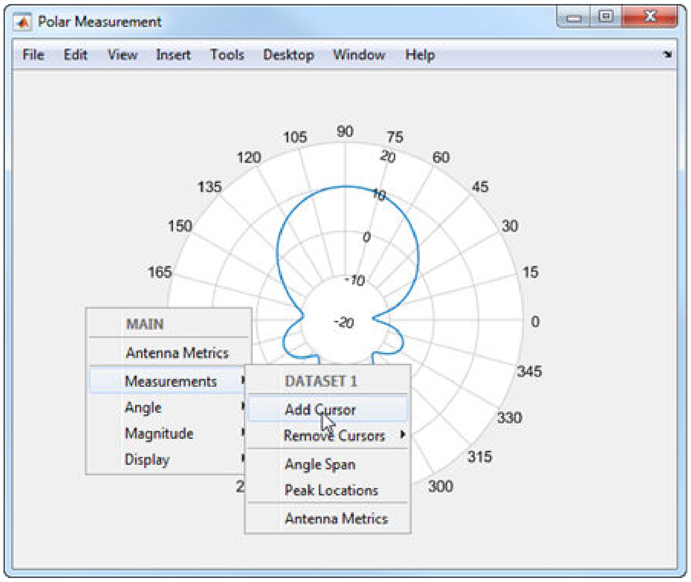
Magnitude Ticks: [-20.00, -10.000, 0.000, 10.000, 2

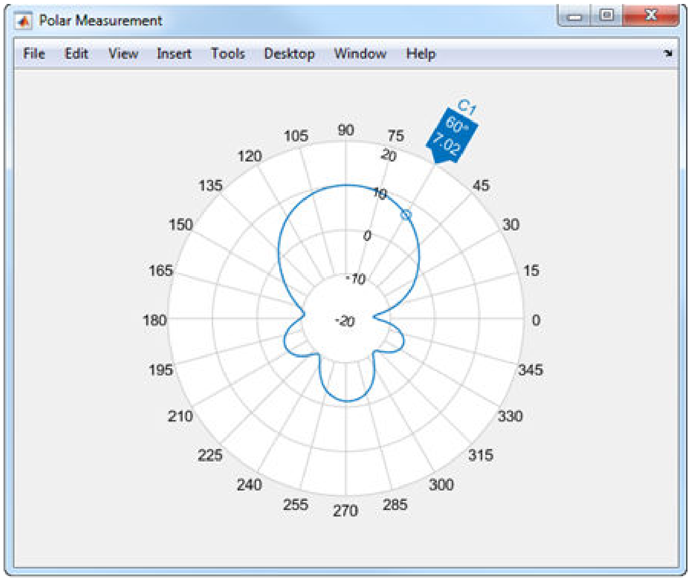
Font Size Multiplier: 0.9

Add Cursors and Calculate Angle Span

Add cursors at 60 degrees and 105 degrees.

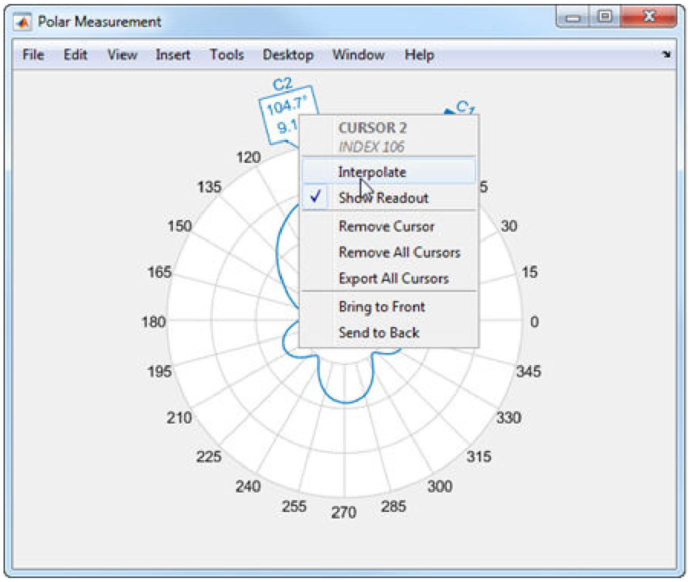
To add a cursor from the **MAIN** or **DISPLAY** context menus, select `Measurements` > **Add Cursor**. After adding the cursor, place the mouse pointer on the cursor and drag it to 60 degrees.

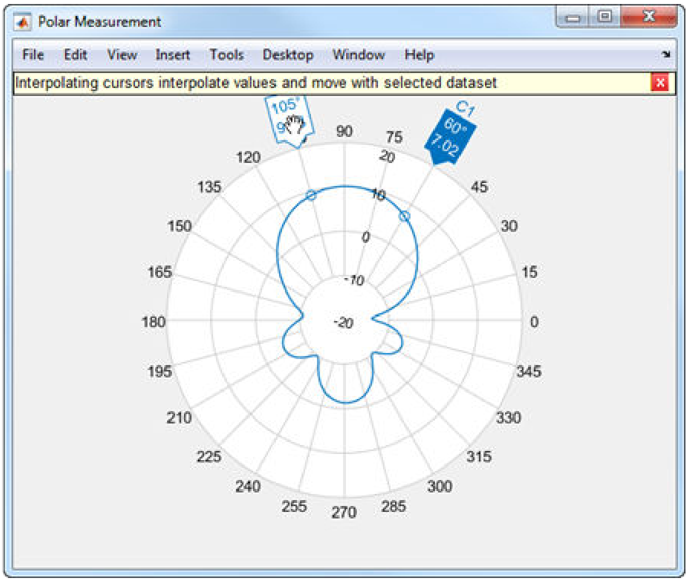




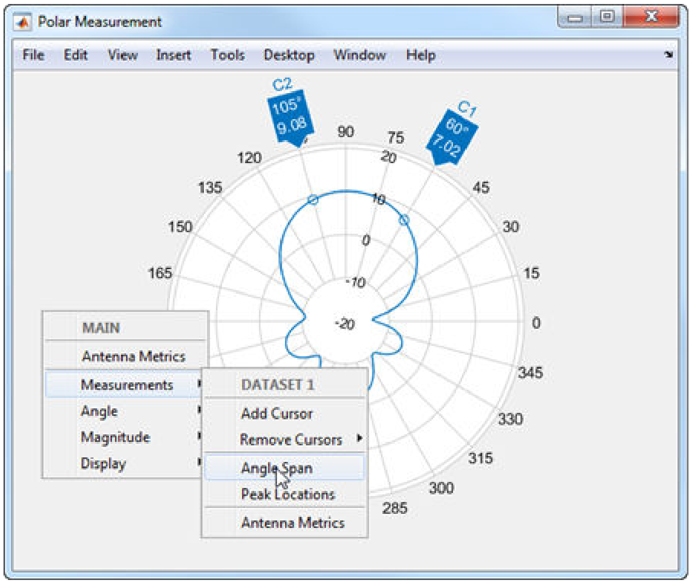
You can also add a cursor by double-clicking on the angle values. Double-click 105 to add a cursor. Right-click the newly added cursor and move the cursor to exact value of 105 degrees.

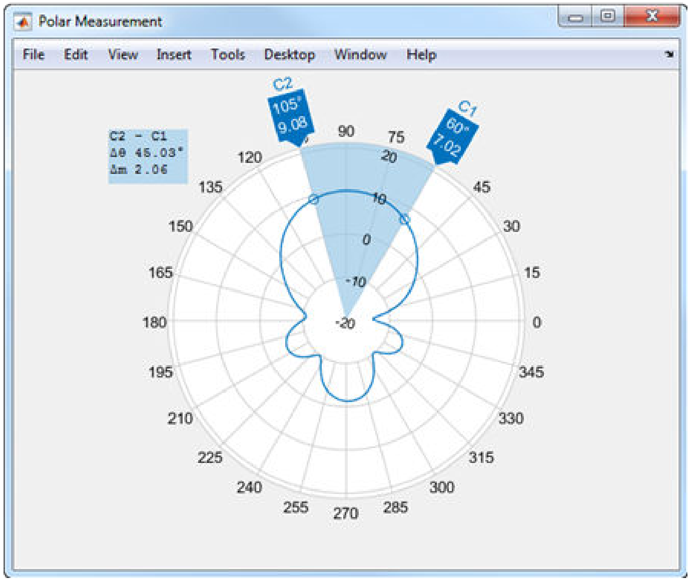
You can also interpolate the two angle values to 60 degrees and 150 degrees. Right-click on each cursor and choose **Interpolate** from the **CURSOR** context menu. To set the angle span, from the **MAIN** or **DISPLAY** context menu, select `Measurements` > **Angle Span**.




Interpolating cursors interpolate values and move with selected dataset

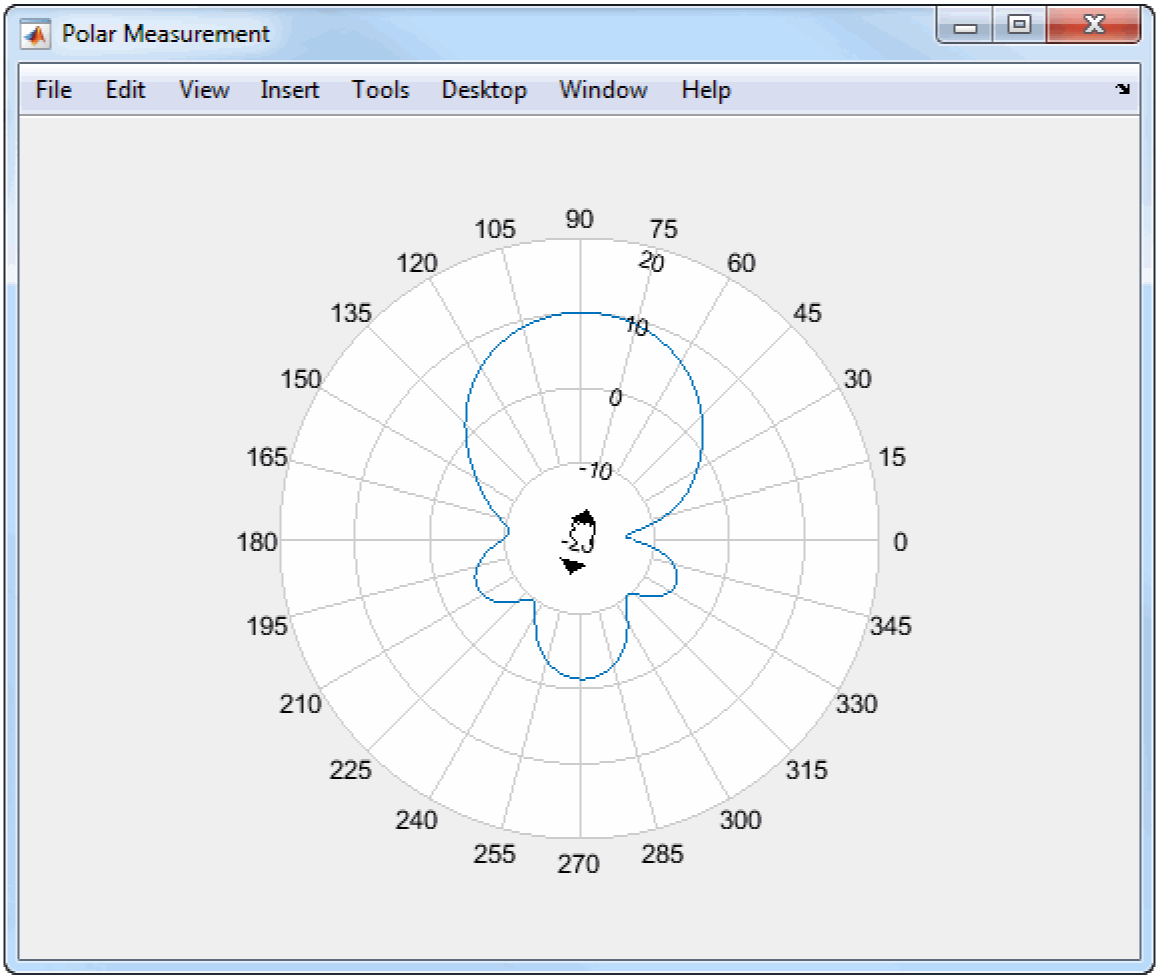
Calculate the counterclockwise angle span between 60 degrees and 105 degrees.




```
C2 - C1
Δθ 45.03°
Δm 2.06
```

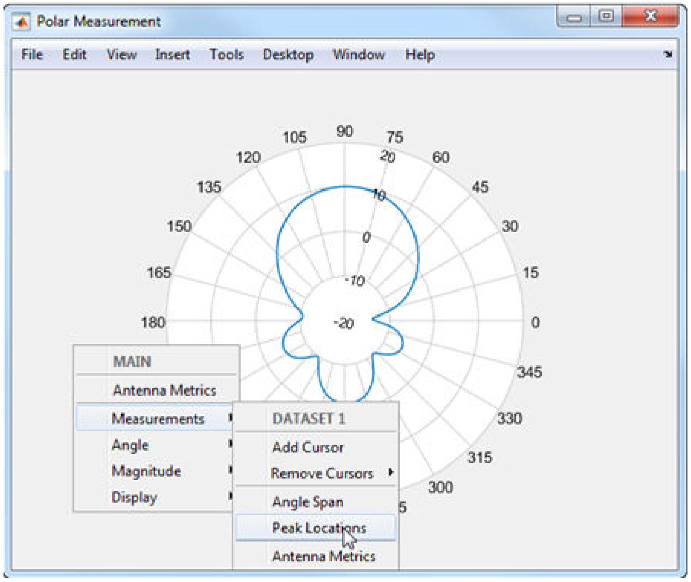
Zoom In and Zoom Out

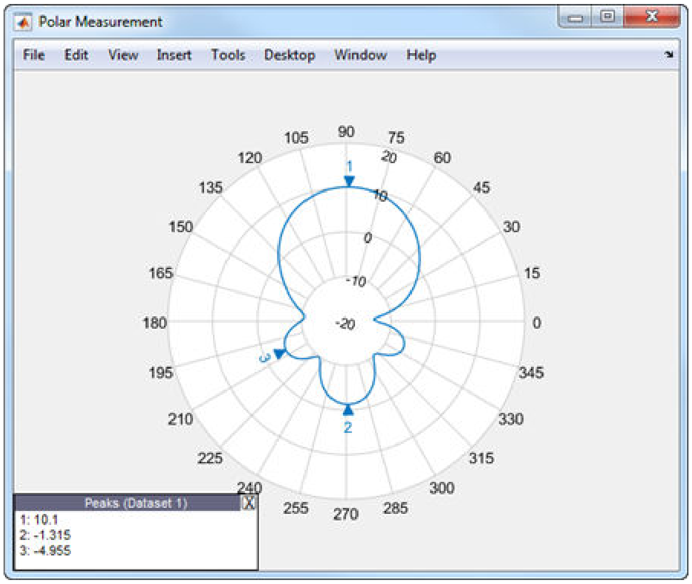
You can use the mouse pointer to zoom in and zoom out of the plot. Place the pointer at the center of the plot and drag radially outward.



Display Peak Locations

To display the peak locations from the **MAIN** or **DISPLAY** context menus, select `Measurements` > **Peak Location**.

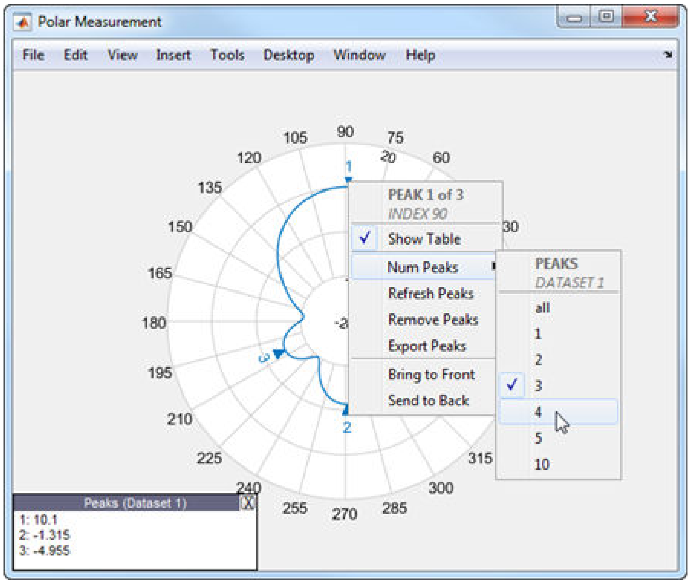




Peaks (Dataset 1)

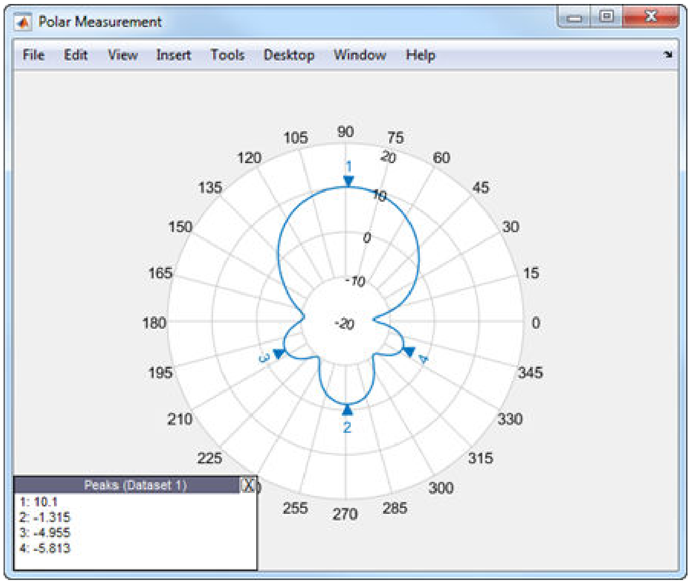
```
1: 10.1
2: -1.315
3: -4.955
```

Right-click any of the peak triangles and choose **NumPeaks**. Increase the number of peaks to 4.



Peaks (Dataset 1)

```
1: 10.1
2: -1.315
3: -4.955
```



Peaks (Dataset 1)

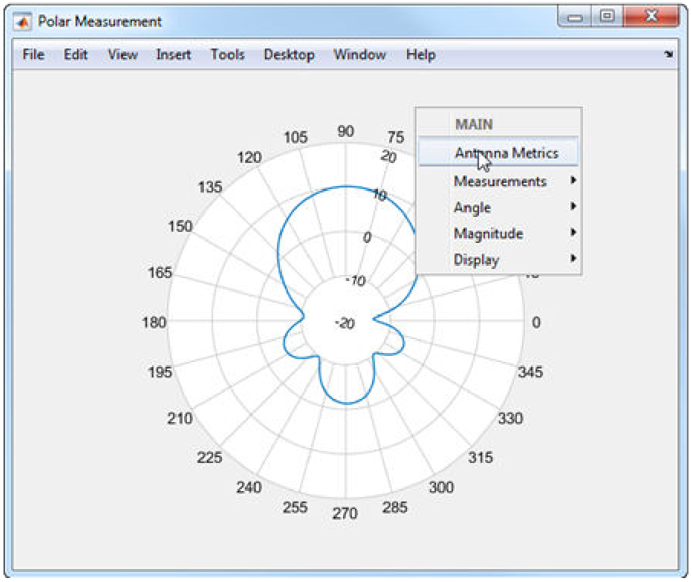
```
1: 10.1
2: -1.315
3: -4.955
4: -5.813
```

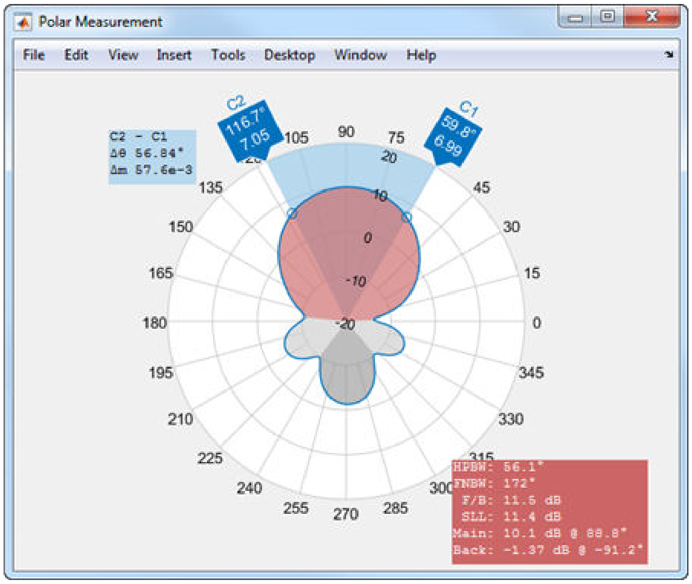
View Antenna Metrics

Antenna metrics in the polar plot display the main, back, and side lobes of the antenna. There are two ways to turn display antenna metrics on the plot:

1. Right-click within the polar figure to open the **Main** context menu. Choose **Antenna Metrics**.

2. Right-click inside the polar plot to open the **Display** context menu. Inside the **Measurement** menu, choose Antenna Metrics.





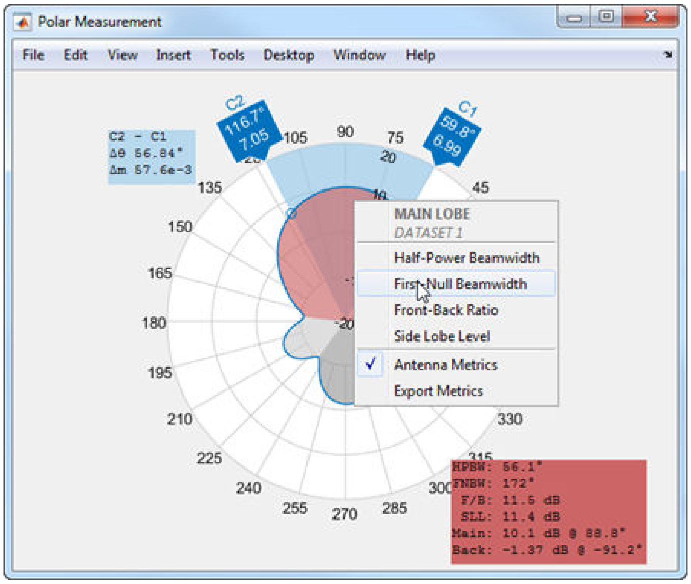
```
C2 - C1
Δθ 56.84°
Δm 57.6e-3
```

```
HPBW: 56.1°
FNBW: 172°
 F/B: 11.5 dB
 SLL: 11.4 dB
Main: 10.1 dB @ 88.8°
Back: -1.37 dB @ -91.2°
```

By default, the plot shows the HPBW (half-power beamwidth) of the antenna. The antenna measurements text box displays:

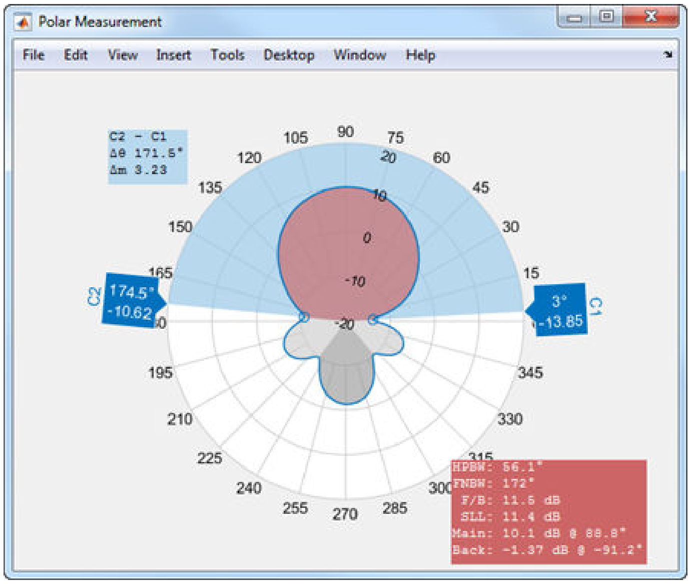
- `HPBW` (half-power beamwidth)
- `FNBW` (first-null beamwidth)
- `F/B` (front-to-back ratio)
- `SLL` (side lobe level)
- `Main` (main lobe peak value and corresponding angle)
- `Back` (back lobe peak value and corresponding angle)

To view the FNBW, right-click inside the red or gray polar plot region to open the **MAIN LOBE** or the **BACK LOBE** context menu and then choose **First-Null Beamwidth**.



```
C2 - C1
Δθ 56.84°
Δm 57.6e-3
```

```
HPBW: 56.1°
FNBW: 172°
 F/B: 11.5 dB
 SLL: 11.4 dB
Main: 10.1 dB @ 88.8°
Back: -1.37 dB @ -91.2°
```



```
C2 - C1
Δθ 171.5°
Δm 3.23
```

```
HPBW: 56.1°
FNBW: 172°
 F/B: 11.5 dB
 SLL: 11.4 dB
Main: 10.1 dB @ 88.8°
Back: -1.37 dB @ -91.2°
```

Design and Analysis Using Antenna Designer App

This example shows how to construct, visualize, and analyze antenna elements using the **Antenna Designer** App.

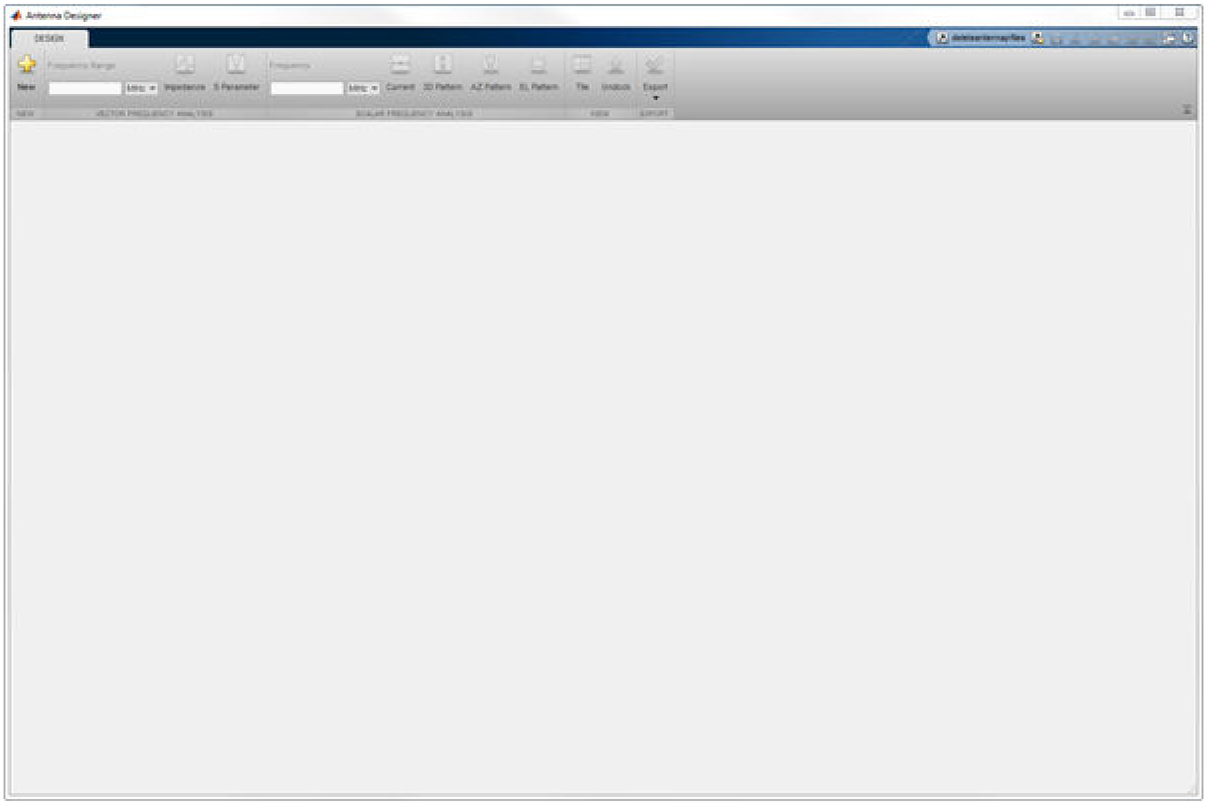
Open Antenna Designer App

To open the app, at the `MATLAB` command prompt, enter:

```
antennaDesigner
```

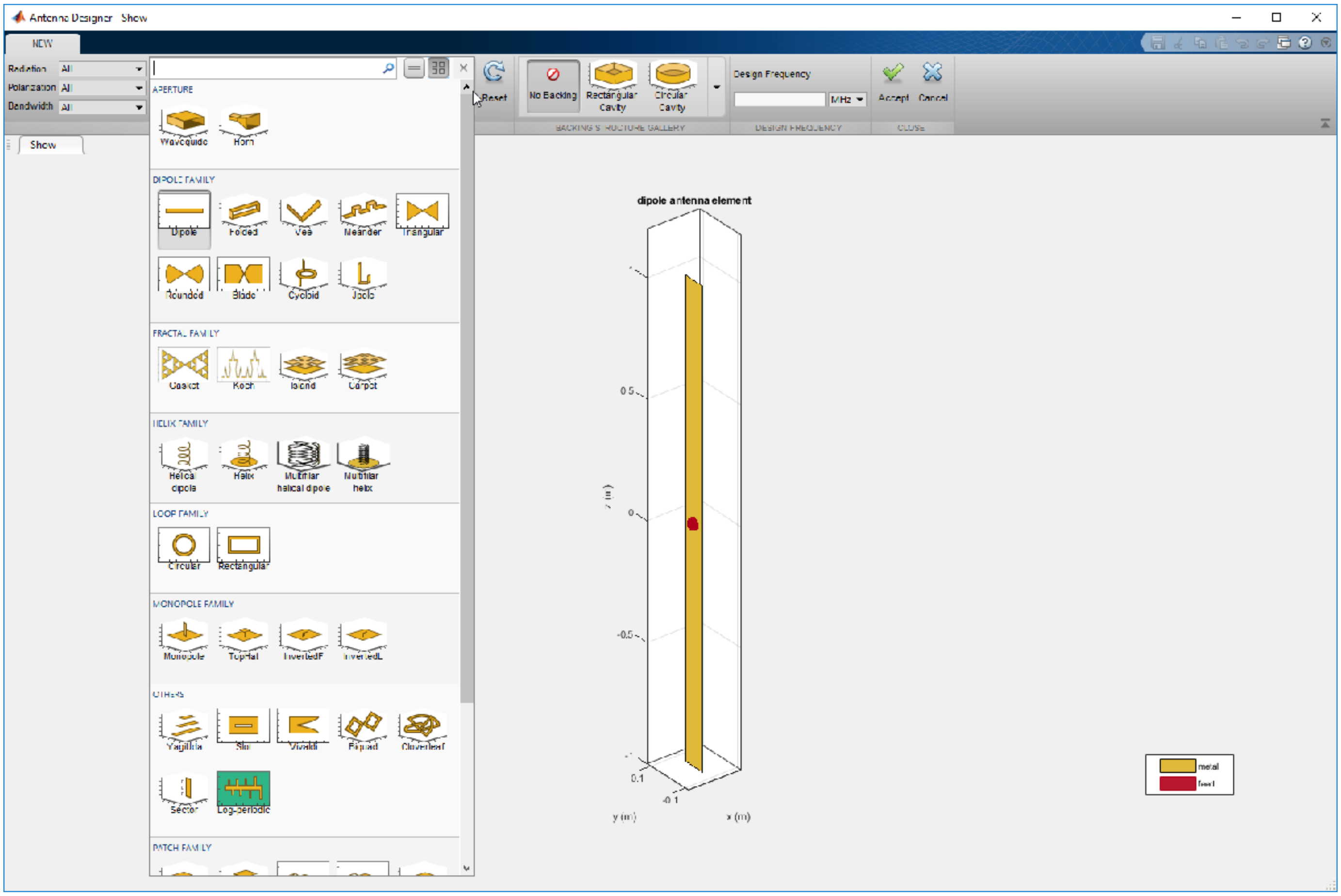
Click on the NEW ('+') button to explore antenna library

This command opens a blank canvas.



Design Helix Antenna

In the blank canvas, click **NEW**. In the **ANTENNA GALLERY**, under **HELIX FAMILY**, select a helix antenna. Set the **Design Frequency** to 1.8 GHz.



To analyze the helix antenna, click **Accept**.

Change Helix Antenna Properties

In the **Antenna Properties** tab, change the following:

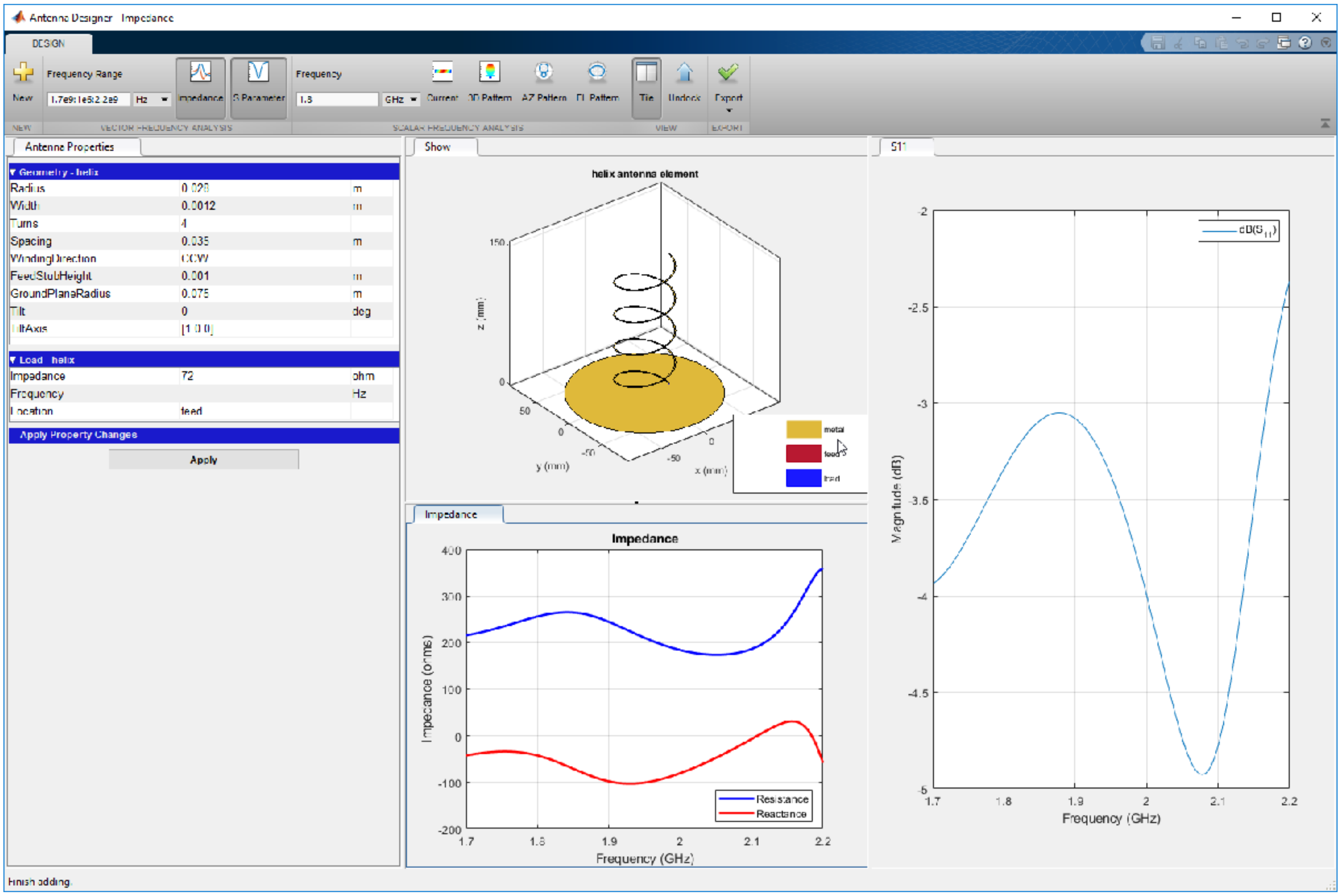
- **Radius** = 0.0280
- **Width** = 0.0012
- **Turns** = 4
- **Spacing** = 0.0350
- **GroundPlaneRadius** = 0.0750

Click **Apply** to see the change in the helix antenna structure.

Plot Impedance and S-Parameters

Open the **Load-helix** section and change the **Impedance** of the antenna to 72 ohms. Click **Apply**. In the toolstrip, under **VECTOR FREQUENCY ANALYSIS** tab, change the **Frequency Range** to `1.7e9:1e6:2.2e9` Hz.

Click **Impedance** to plot the impedance of the helix antenna. Click **S Parameter** to plot the S11 value of the helix antenna. Click **Tile** to view the plots together.



Frequency Range: 1.7e9:1e8:2.2e9 Hz

Frequency: 1.8 GHz

Geometry - helix		
Radius	0.028	m
Width	0.0012	m
Turns	4	
Spacing	0.035	m
WindingDirection	CCW	
FeedStubHeight	0.001	m
GroundPlaneRadius	0.075	m
Tilt	0	deg
TiltAxis	[1 0 0]	

Load - helix		
Impedance	72	ohm
Frequency		Hz
Location	feed	

Apply Property Changes

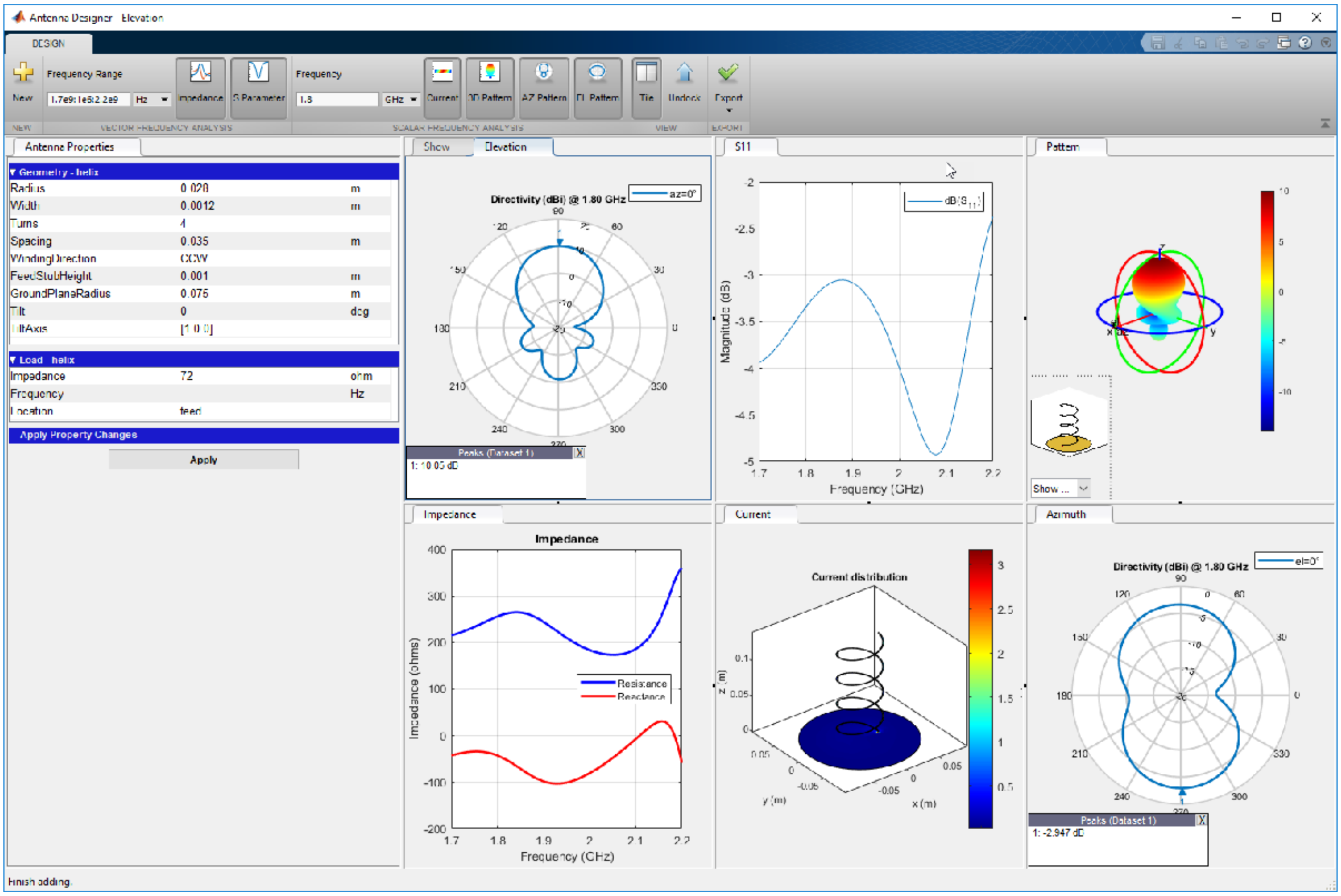
Apply

Finish adding

Plot Current Distribution, 3-D, Azimuth, and Elevation Patterns

In the **SCALAR FREQUENCY ANALYSIS** section of the toolstrip, click **Current** to view the current distribution of the helix at 1.8 GHz.

Click **3D Pattern**, **AZ Pattern**, and **EL Pattern** to view the radiation, azimuth, and elevation patterns of the helix antenna, respectively. Click **Tile** again to view all the plots together.



Frequency Range: 1.7e9:1e8:2.2e9 Hz

Frequency: 1.8 GHz

Antenna Properties

▼ Geometry - helix

Radius	0.028	m
Width	0.0012	m
Turns	4	
Spacing	0.035	m
WindingDirection	CCW	
FeedStubHeight	0.001	m
GroundPlaneRadius	0.075	m
Tilt	0	deg
TiltAxis	[1 0 0]	

▼ Load - helix

Impedance	72	ohm
Frequency		Hz
Location	feed	

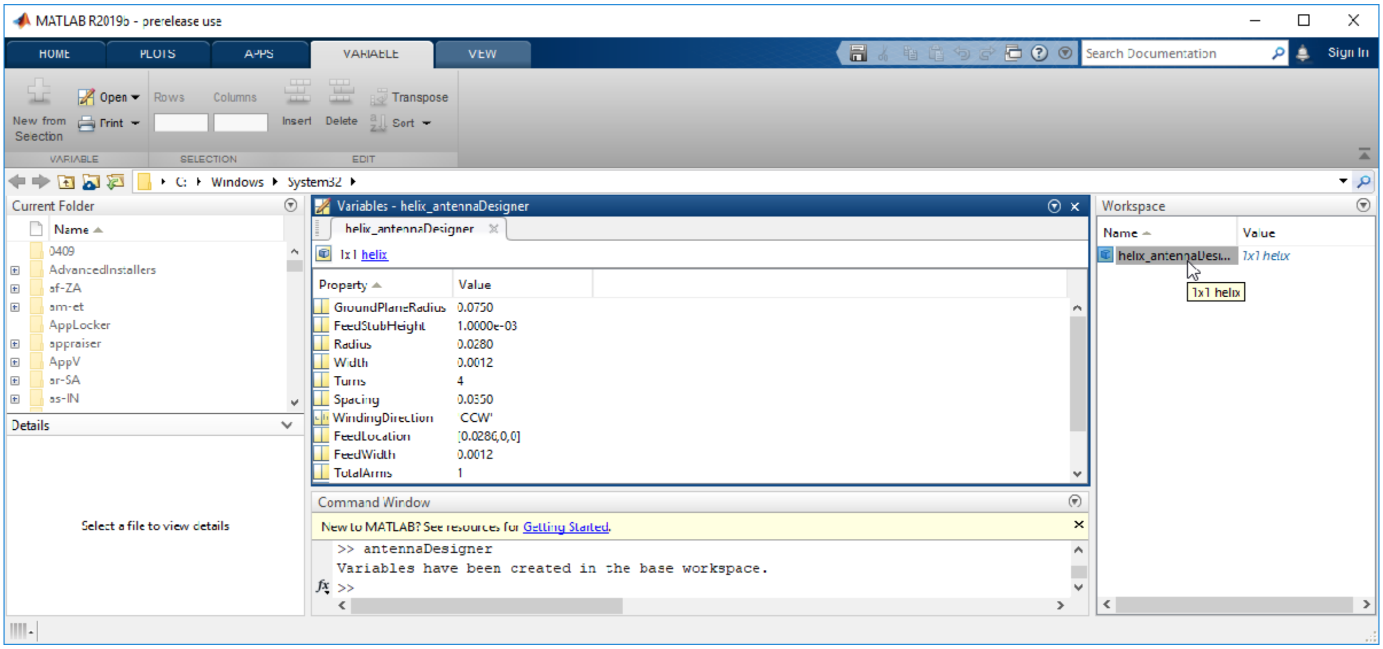
Apply Property Changes

Apply

You can compare the results of this tutorial with the results of `Antenna Modeling and Analysis` tutorial: “Antenna Modeling and Analysis” on page 1-3

Export to MATLAB Workspace

Click the **Export** button arrow and then click **Export tto workspace**. In the **Export to workspace** window, type the name of the antenna file. Click on the variable in the workspace to view the properties of the helix antenna.



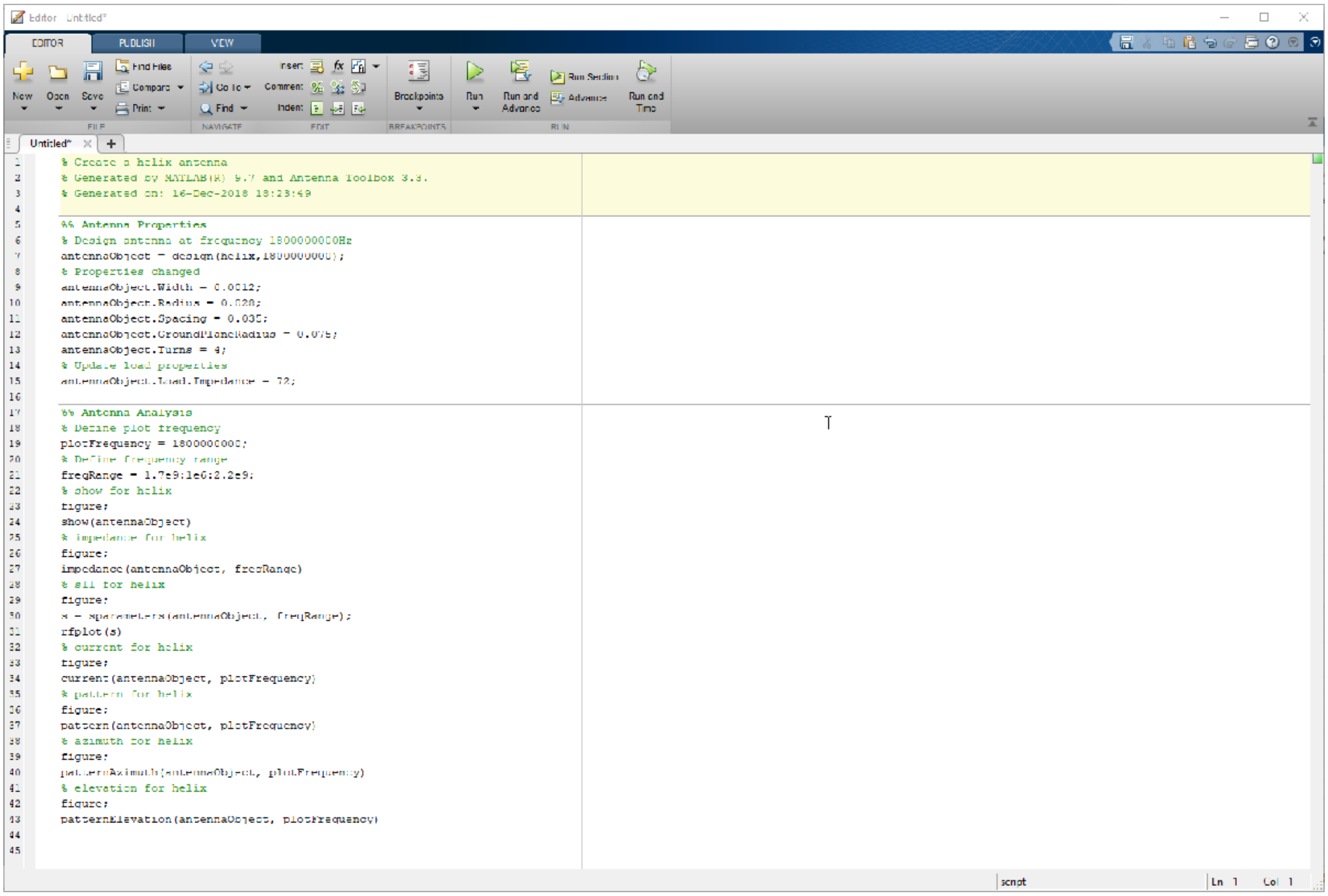
Property	Value
GroundPlaneRadius	0.0750
FeedStubHeight	1.0000e-03
Radius	0.0280
Width	0.0012
Turns	4
Spacing	0.0350
WindingDirection	'CCW'
FeedLocation	[0.0280,0,0]
FeedWidth	0.0012
TotalArms	1

```
>> antennaDesigner
Variables have been created in the base workspace.
>>
```

Name	Value
helix_antennaDesi...	1x1 helix

Export to MATLAB Script

Click the **Export** button arrow again and then click **Export to script** to view the helix antenna and analysis in MATLAB script format. The script has two sections: **Antenna Properties** and **Antenna Analysis.**



```
% Create a helix antenna
% Generated by MATLAB(R) 9.7 and Antenna Toolbox 3.3.
% Generated on: 16-Dec-2018 18:23:49

%% Antenna Properties
% Design antenna at frequency 1800000000Hz
antennaObject = design(helix,1800000000);
% Properties changed
antennaObject.Width = 0.0012;
antennaObject.Radius = 0.028;
antennaObject.Spacing = 0.035;
antennaObject.GroundPlaneRadius = 0.075;
antennaObject.Turns = 4;
% Update load properties
antennaObject.Load.Impedance = 72;

%% Antenna Analysis
% Define plot frequency
plotFrequency = 1800000000;
% Define frequency range
freqRange = 1.7e9:1e6:2.2e9;
% show for helix
figure;
show(antennaObject)
% impedance for helix
figure;
impedance(antennaObject, freqRange)
% s11 for helix
figure;
s = sparameters(antennaObject, freqRange);
rfplot(s)
% current for helix
figure;
current(antennaObject, plotFrequency)
% pattern for helix
figure;
pattern(antennaObject, plotFrequency)
% azimuth for helix
figure;
patternAzimuth(antennaObject, plotFrequency)
% elevation for helix
figure;
patternElevation(antennaObject, plotFrequency)
```

Design Variations On Microstrip Patch Antenna Using PCB Stack

Use the pcbstack to design basic, parasitic, direct-coupled, and CP patch antennas.

Setup parameters.

```
vp  = physconst('lightspeed');
f   = 850e6;
lambda = vp./f;
```

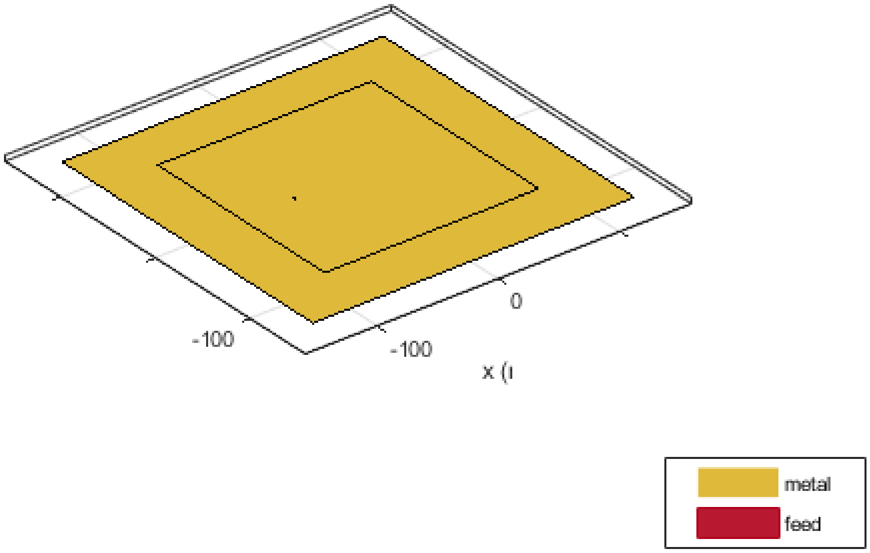
Design Basic Patch Antenna

Set the length and width of the patch and the groundplane.

```
Lp = lambda(1)/2;
Wp = lambda(1)/2;
Lgp = 0.75.*lambda(1);
Wgp = 0.75.*lambda(1);
h = 2.e-3;
p1 = antenna.Rectangle('Length',Lp,'Width',Wp,'NumPoints',30);
p2 = antenna.Rectangle('Length',Lgp,'Width',Wgp);
d1 = dielectric('Air');
```

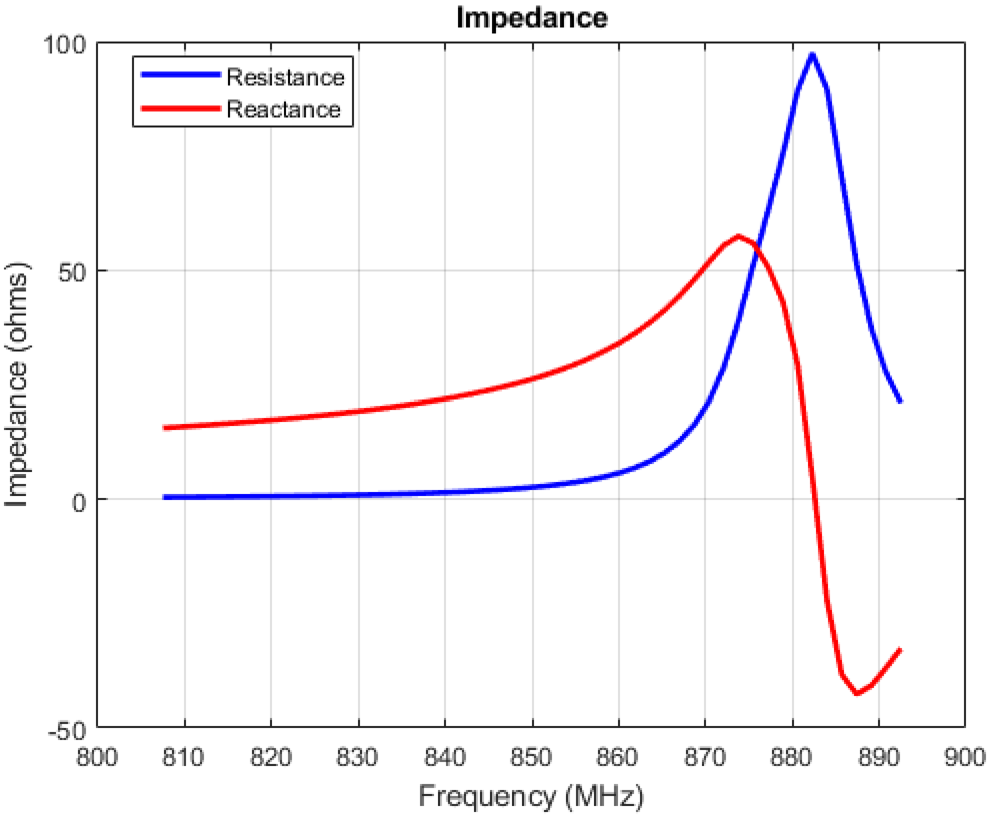
Define the properties of the PCB stack.

```
basicPatch = pcbStack;
basicPatch.Name = 'Basic Patch';
basicPatch.BoardThickness = h;
basicPatch.BoardShape = p2;
basicPatch.Layers = {p1,d1,p2};
basicPatch.FeedLocations = [-lambda(1)/8 0 1 3];
figure
show(basicPatch)
```



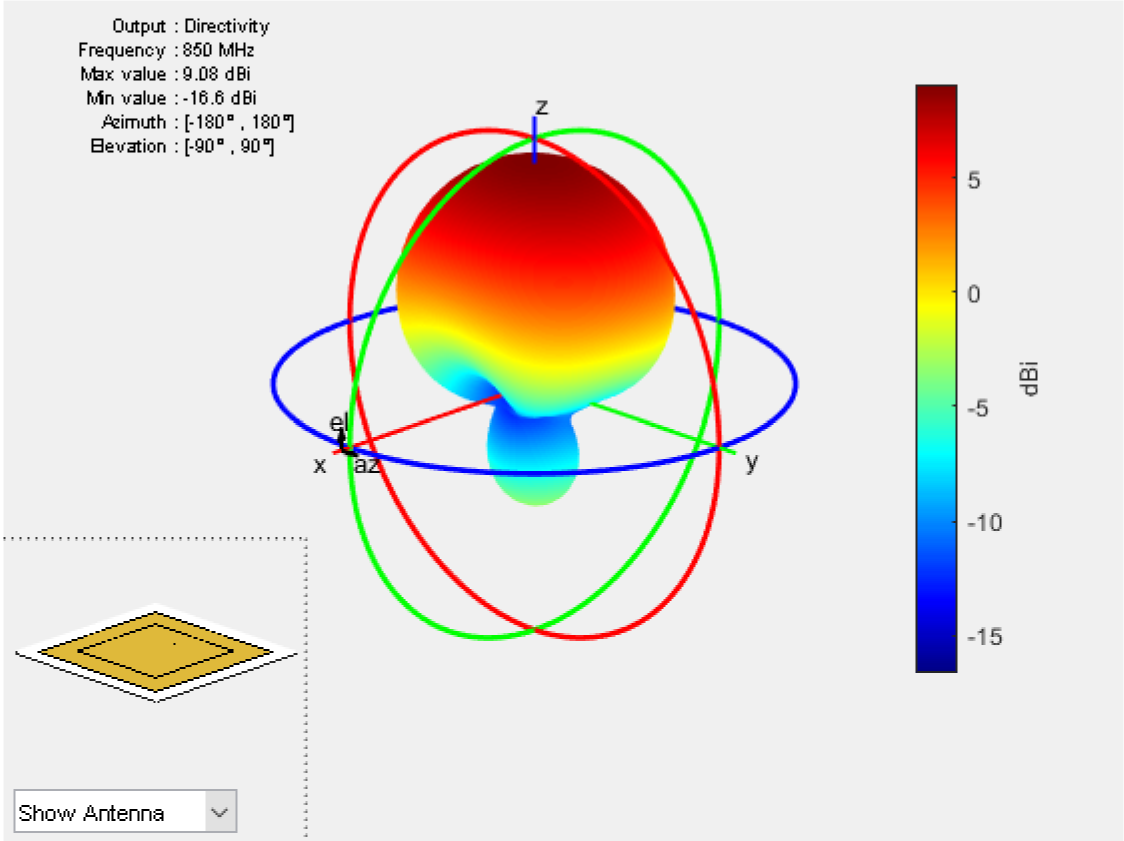
Plot the impedance of the basic patch antenna.

```
freq1 = linspace(f(1)-0.05*f(1),f(1) + 0.05*f(1),51);
figure
impedance(basicPatch,freq1)
```



Plot the radiation pattern of the basic patch antenna.

```
figure
pattern(basicPatch,f(1))
```

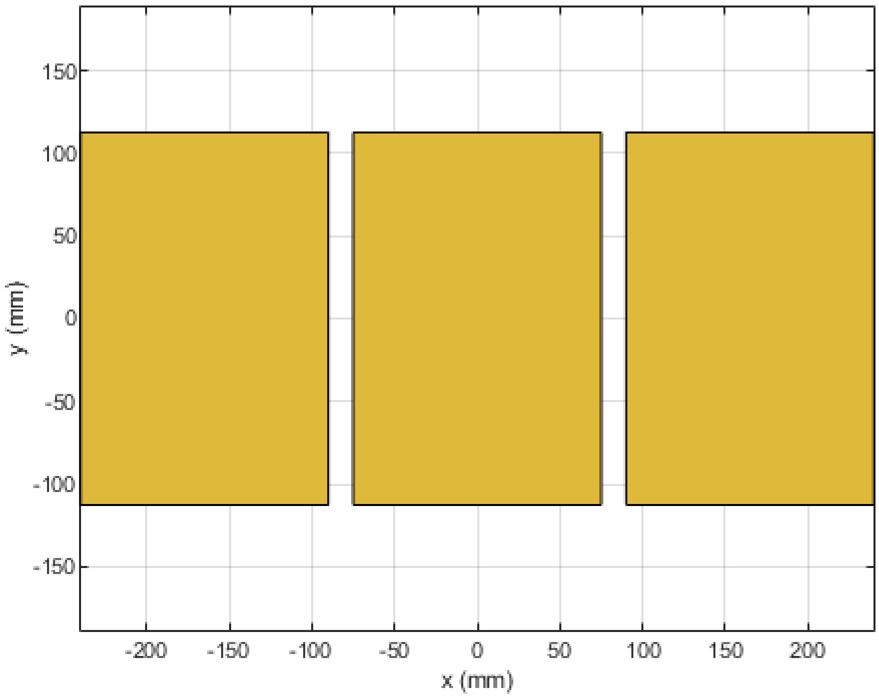


Output : Directivity
Frequency : 850 MHz
Max value : 9.08 dBi
Min value : -16.6 dBi
Azimuth : [-180° , 180°]
Elevation : [-90° , 90°]

Design Parasitic Patch Antenna

Set the dimensions for the patch.

```
L = 0.15;
W = 1.5*L;
stripL = L;
gapx = .015;
gapy = .01;
r1 = antenna.Rectangle('Center',[0,0],'Length',L,'Width',W);
r2 = antenna.Rectangle('Center',[L/2+stripL/2+gapx,0],'Length',stripL,'Width',W,'NumPoints',[2 20
r3 = antenna.Rectangle('Center',[-L/2-stripL/2-gapx,0],'Length',stripL,'Width',W,'NumPoints',[2 2
r = r1+r2+r3;
figure
show(r)
```

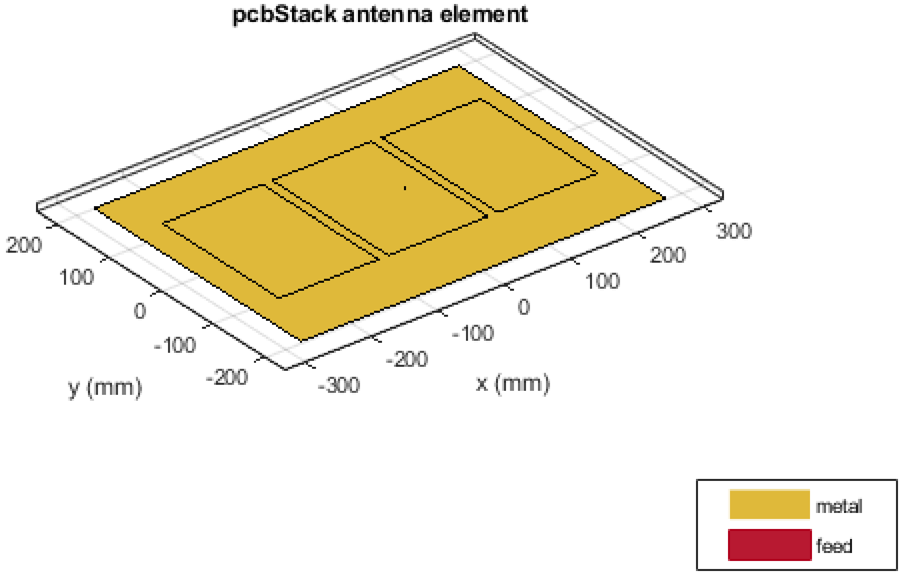


Set the dimensions of the groundplane.

```
Lgp = 0.55;
Wgp = 0.4;
g1  = antenna.Rectangle('Center',[0,0],'Length',Lgp,'Width',Wgp);
```

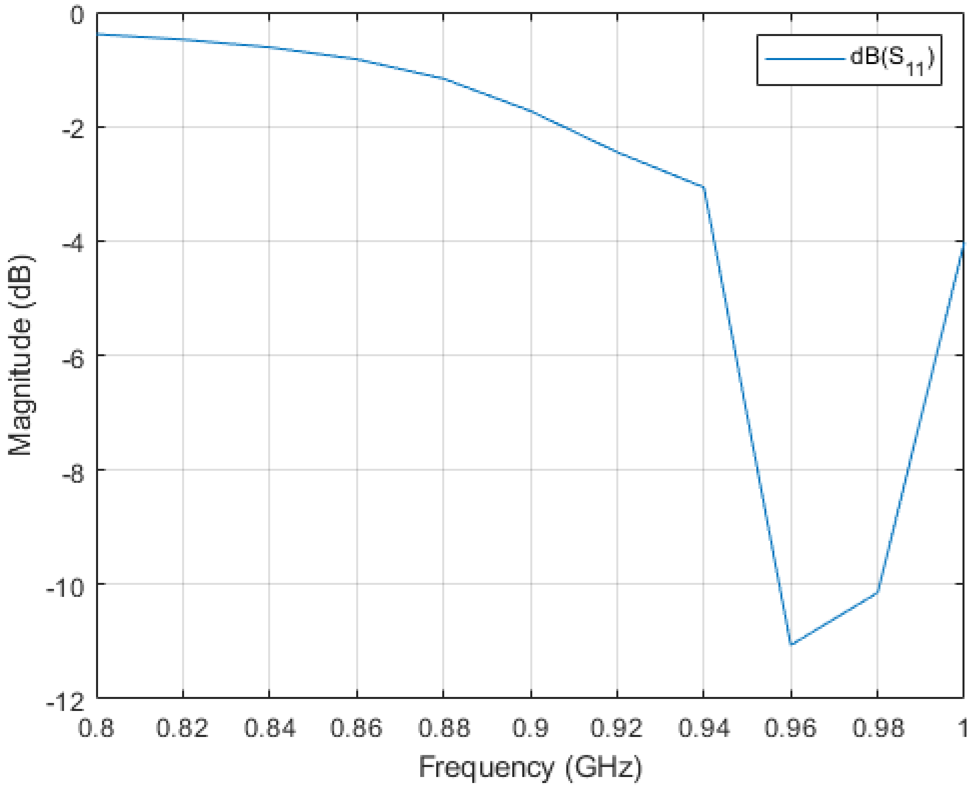
Define the properties of the PCB stack. Create a pcb stack by driving the center radiator.

```
parasitic_patch = pcbStack;
parasitic_patch.BoardShape = g1;
parasitic_patch.BoardThickness = .007;
parasitic_patch.Layers = {r,g1};
parasitic_patch.FeedLocations = [(L)/4 0 1 2];
figure
show(parasitic_patch)
```



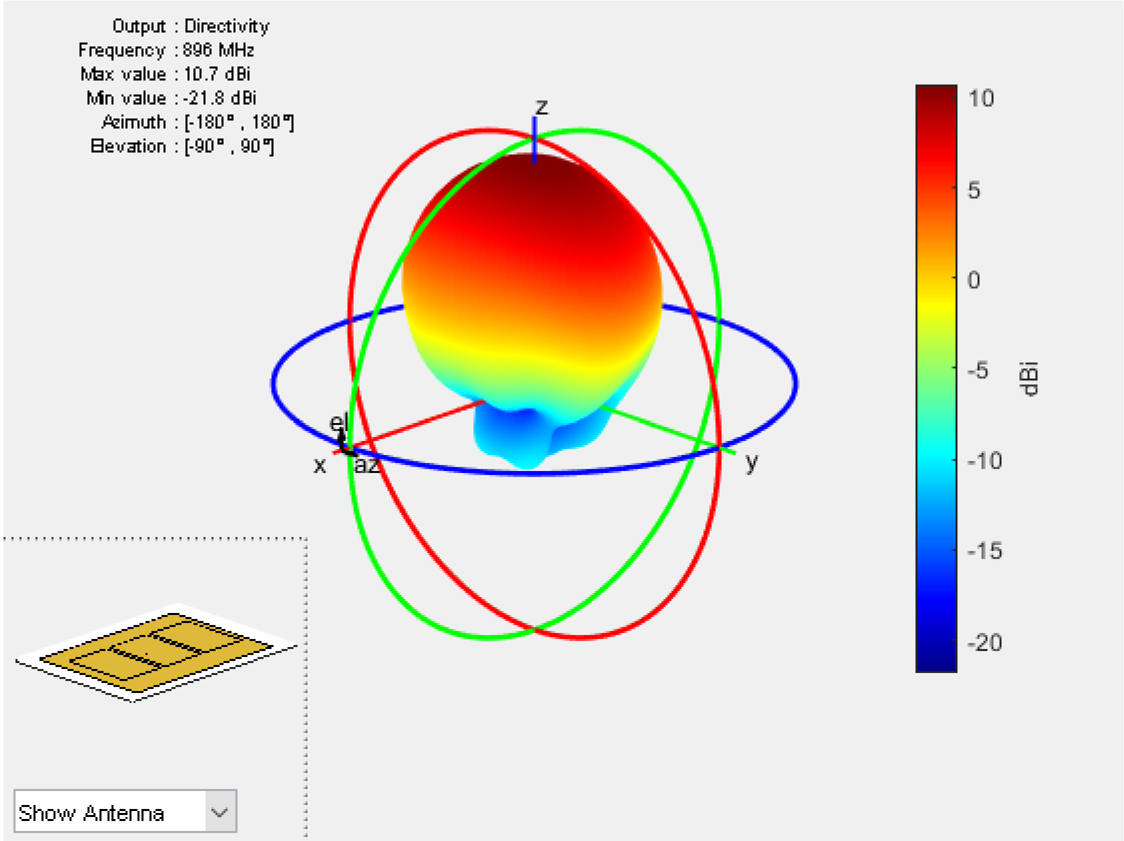
Plot the S-parameters of the parasitic patch antenna.

```
s = sparameters(parasitic_patch,linspace(0.8e9,1e9,11));
figure
rfplot(s)
```



Plot the radiation pattern of the parasitic patch antenna.

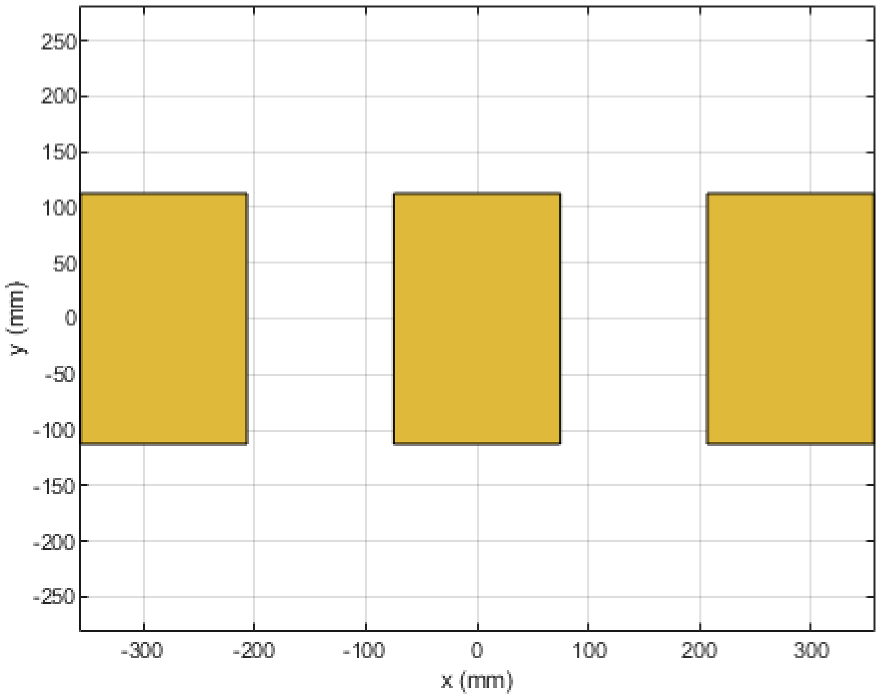
```
figure
pattern(parasitic_patch,0.896e9)
```



```
Output : Directivity
Frequency : 896 MHz
Max value : 10.7 dBi
Min value : -21.8 dBi
Azimuth : [-180° , 180°]
Elevation : [-90° , 90°]
```

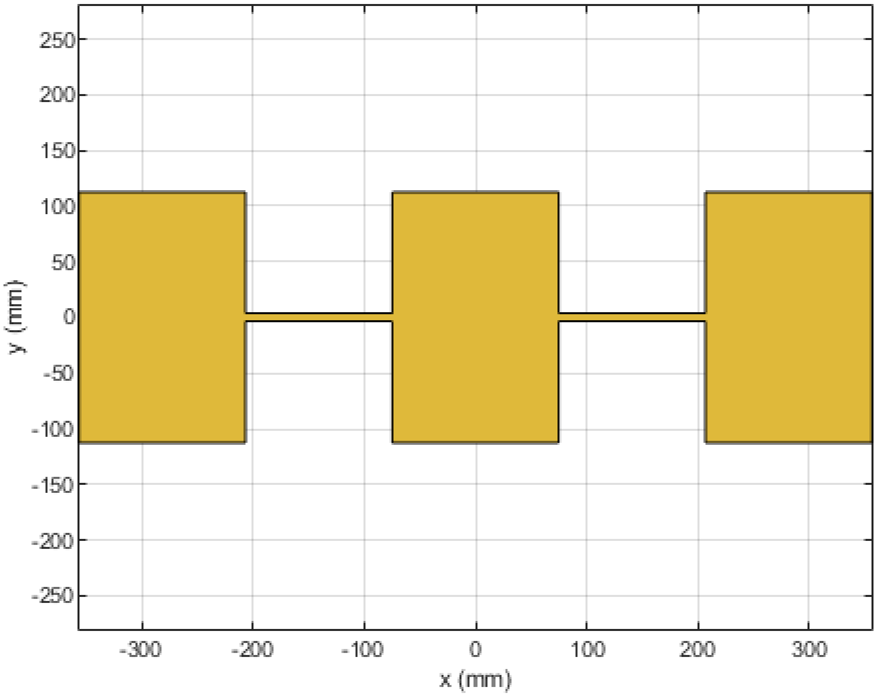
Design Direct-coupled Patch Antenna

```
r2 = copy(r1);
r2.Center = [lambda/1.25,0];
r3 = copy(r1);
r3.Center = [-lambda/1.25,0];
r = r1+r2+r3;
figure
show(r)
```



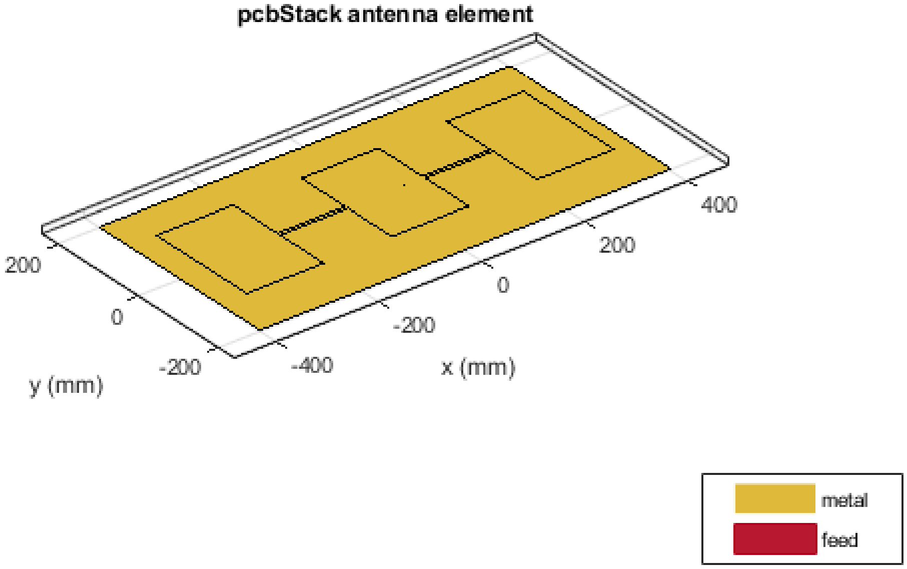
Strip join the sections.

```
r4 = antenna.Rectangle('Length',0.65*lambda,'Width',0.02*lambda,'Center',[lambda/2,0],'NumPoints
r5 = copy(r4);
r5.Center = [-lambda/2,0];
s = r + r4 + r5;
figure
show(s)
```



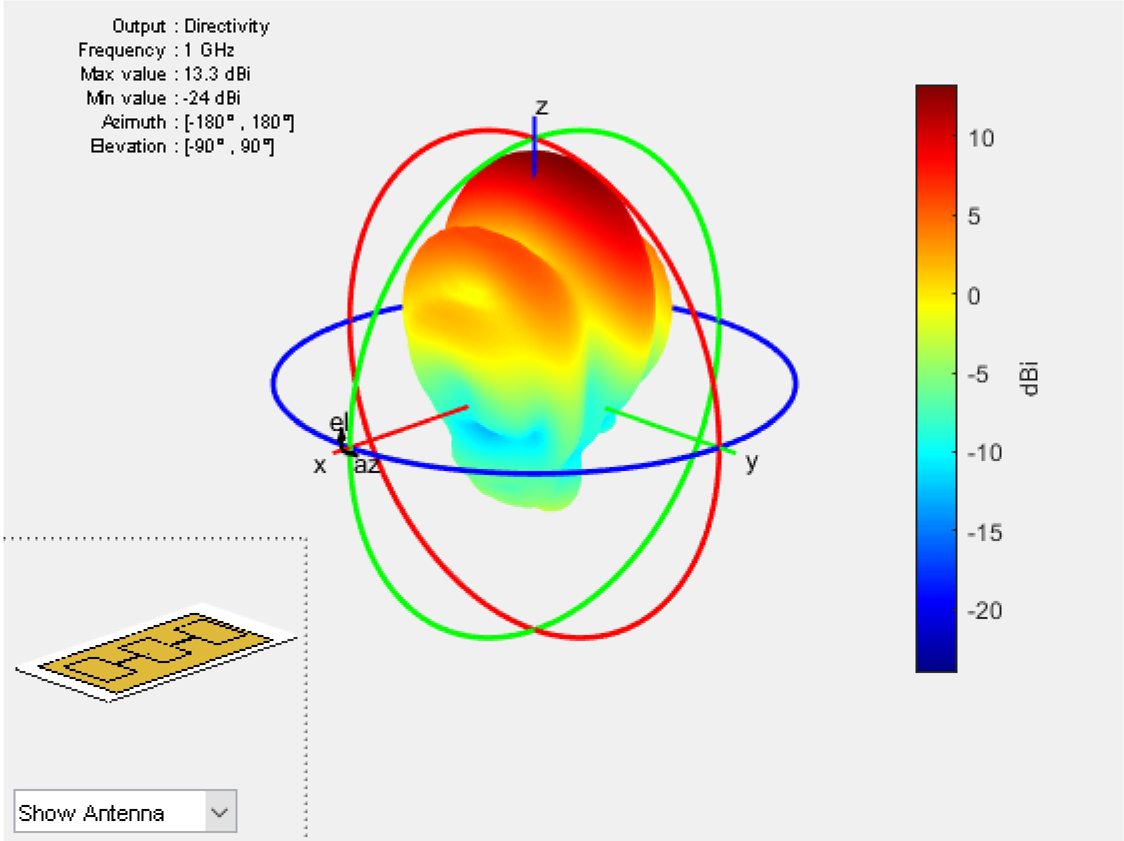
Define the properties of the PCB stack.

```
g1.Length = 0.8;
series_patch = pcbStack;
series_patch.BoardShape = g1;
series_patch.Layers = {s,g1};
series_patch.FeedLocations = [L/4 0 1 2];
figure
show(series_patch)
```



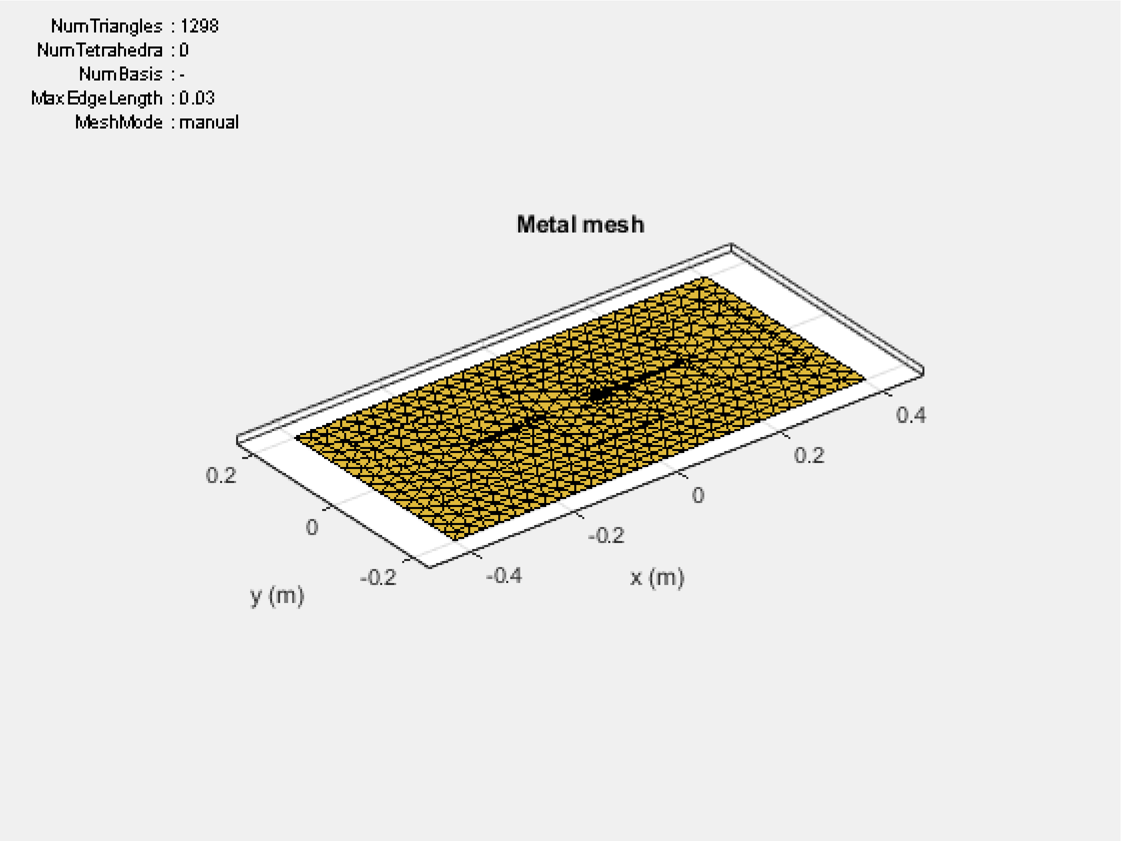
Plot the radiation pattern at 1 GHz for the direct-coupled patch antenna.

```
figure
pattern(series_patch,1e9)
```

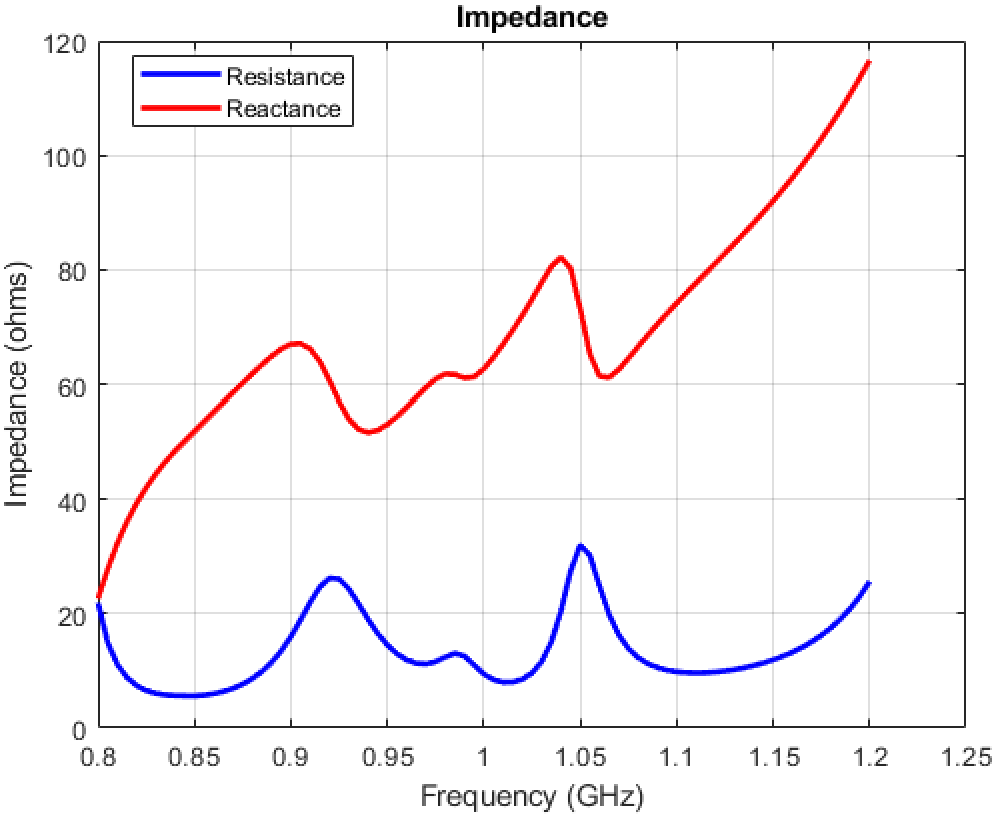


Mesh the antenna using maximum edge length of 0.03 m. Plot the impedance of the direct-coupled patch antenna for the frequency range, 0.8 GHz to 1.2 GHz.

```
figure
mesh(series_patch,'MaxEdgeLength',0.03)
```



```
figure
impedance(series_patch,linspace(0.8e9,1.2e9,81))
```



Design Circularly Polarized Patch - Truncated Corners

Set the length and width of the patch and the groundplane.

```
Lp = lambda(1)/2;
Wp = lambda(1)/2;
Lgp = 0.75.*lambda(1);
Wgp = 0.75.*lambda(1);
h = 2.e-3;
```

Create the base shape for the patch.

```
p1 = antenna.Rectangle('Length',Lp,'Width',Wp,'NumPoints',20);
```

Truncate the corners of the rectangle.

```
Lcorner = 0.25*Lp;
Wcorner = 0.25*Wp;
cornerCenter1 = [-Lp/2,Wp/2,0];
cornerCenter2 = [Lp/2,-Wp/2,0];
pcorner1 = antenna.Rectangle('Length',Lcorner,'Width',Wcorner);
pcorner1 = rotateZ(pcorner1,45);
pcorner1 = translate(pcorner1,cornerCenter1);
pcorner2 = antenna.Rectangle('Length',Lcorner,'Width',Wcorner);
pcorner2 = rotateZ(pcorner2,45);
pcorner2 = translate(pcorner2,cornerCenter2);
pradiator = p1 -pcorner1-pcorner2;
```

Create the groundplane shape.

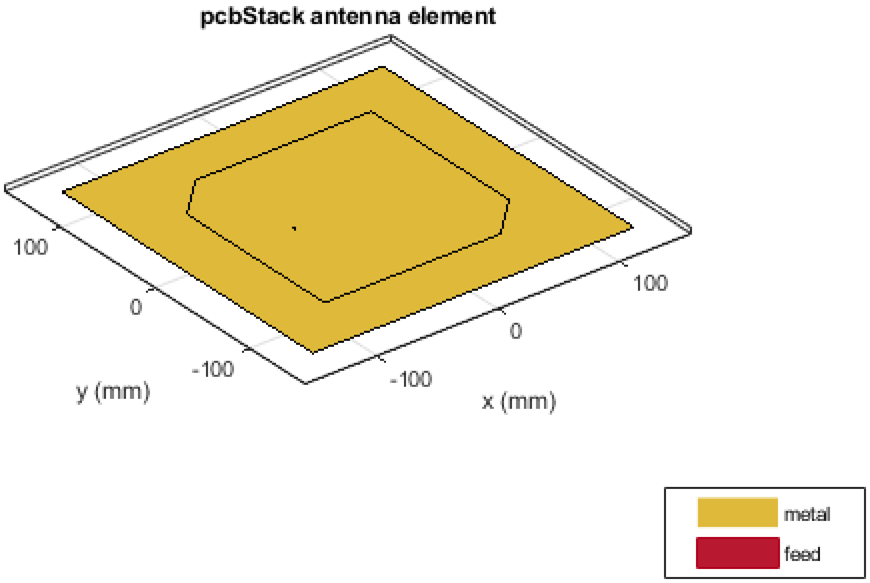
```
p2 = antenna.Rectangle('Length',Lgp,'Width',Wgp);
```

Define the dielectric Layer.

```
d1 = dielectric('Air');
```

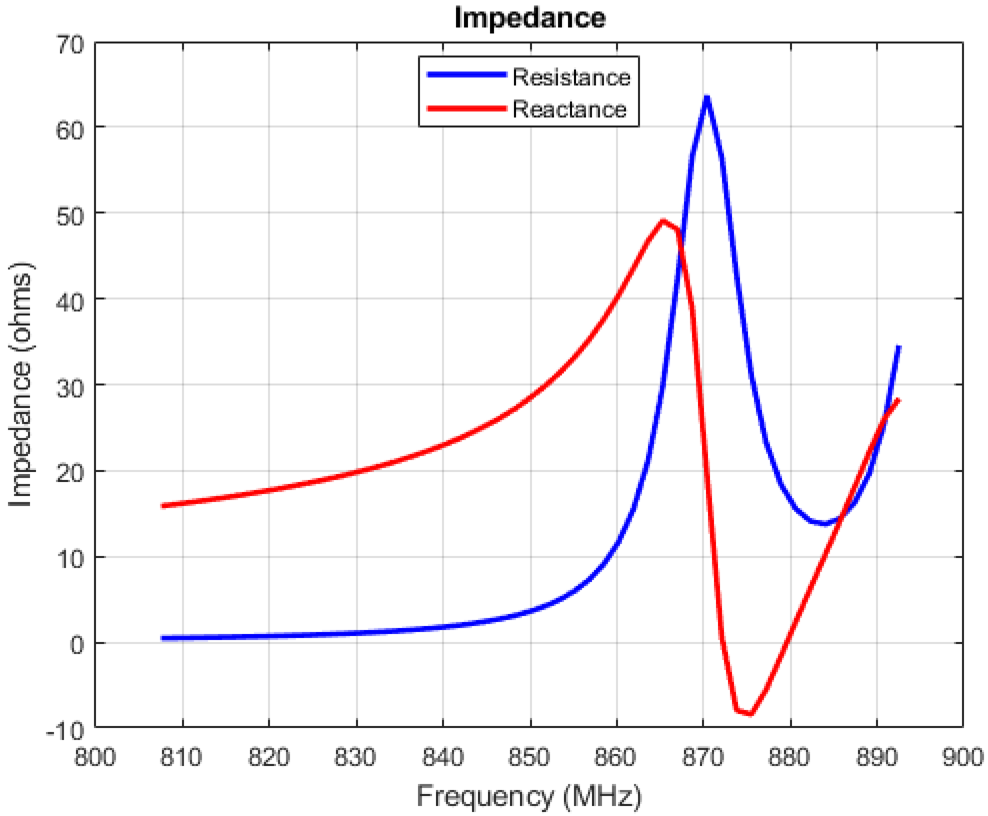
Define the properties of the PCB stack for the circularly polarized patch.

```
truncatedCornerPatch = pcbStack;
truncatedCornerPatch.Name = 'Basic Patch';
truncatedCornerPatch.BoardThickness = h;
truncatedCornerPatch.BoardShape = p2;
truncatedCornerPatch.Layers = {pradiator,d1,p2};
truncatedCornerPatch.FeedLocations = [-lambda(1)/8 0 1 3];
figure
show(truncatedCornerPatch)
```



Plot impedance of the circularly polarized antenna.

```
figure
impedance(truncatedCornerPatch,freq1)
```


Impedance
Resistance
Reactance
Impedance (ohms)
70
60
50
40
30
20
10
0
-10
800
810
820
830
840
850
860
870
880
890
900
Frequency (MHz)

Introduction to Arrays

Array Modeling and Analysis

This example shows how to construct, visualize, and analyze an antenna array from the Antenna Toolbox.

Create Antenna Array Using Antenna Elements

Create a default rectangular antenna array using the `rectangularArray` element in the array library. By default, the array uses the dipole as an antenna element.

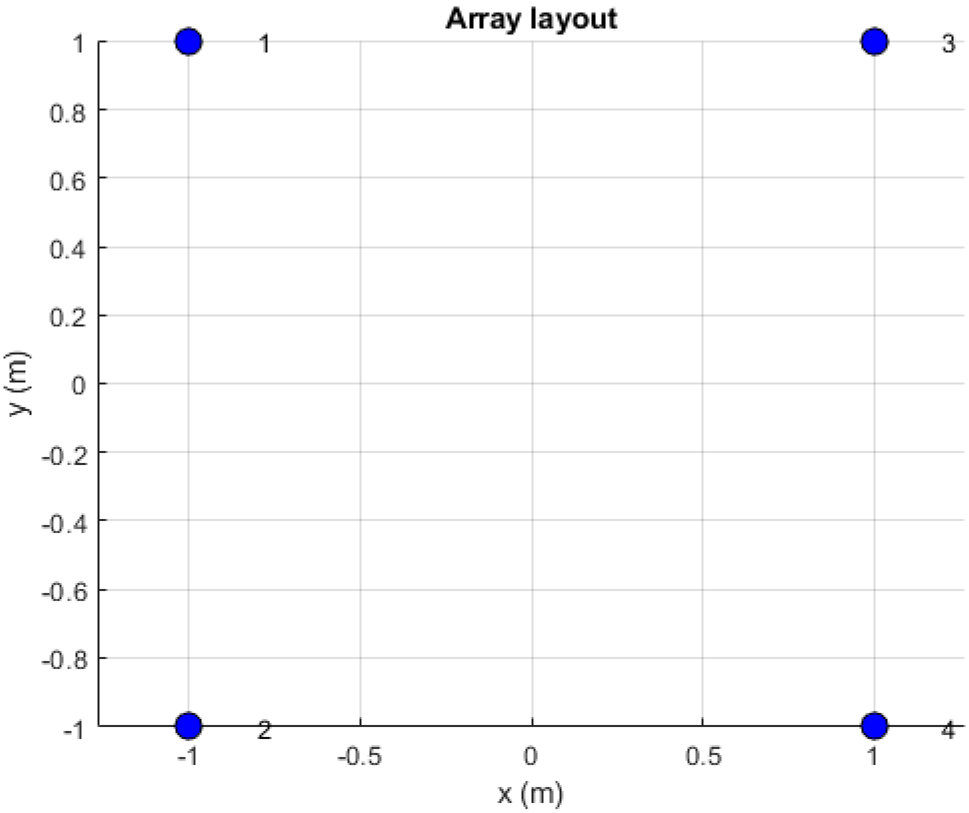
```
ra = rectangularArray
```

```
ra = 
  rectangularArray with properties:

           Element: [1x1 dipole]
              Size: [2 2]
        RowSpacing: 2
     ColumnSpacing: 2
           Lattice: 'Rectangular'
    AmplitudeTaper: 1
        PhaseShift: 0
              Tilt: 0
          TiltAxis: [1 0 0]
```

Visualize Layout of Array

Use the `layout` function to plot the position of array elements in the x-y plane. By default, the rectangular array is a 4-element dipole array in a 2x2 rectangular lattice.

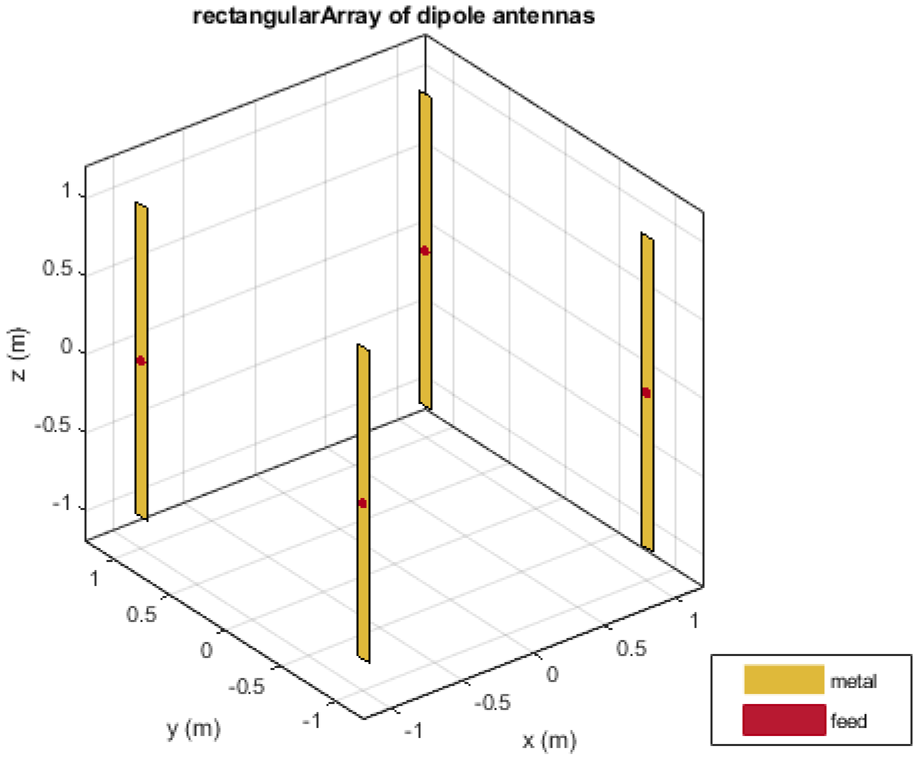
```
layout(ra)
```



Visualize Geometry of Array

Use the `show` function to view the structure of the rectangular antenna array.

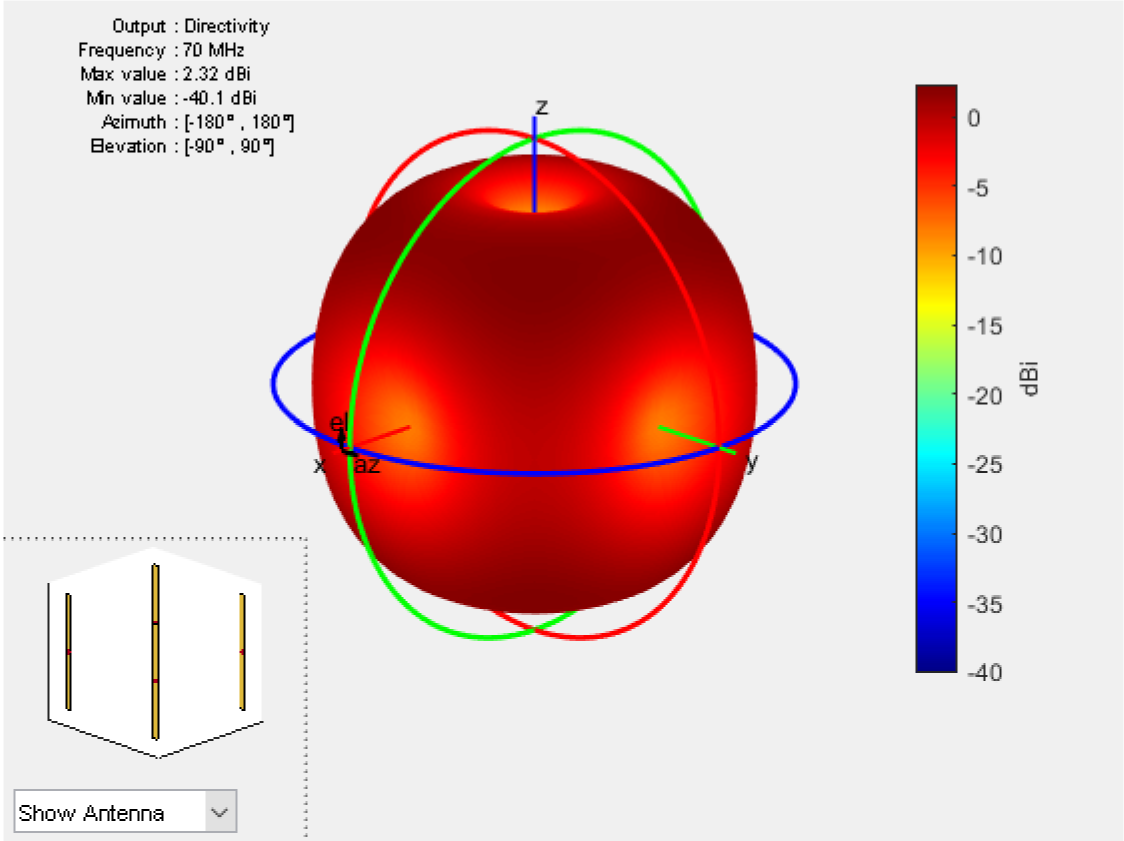
```
show(ra)
```



Plot Radiation Pattern of Array

Use the `pattern` function to plot the radiation pattern of the rectangular array. The radiation pattern is the spatial distribution of the power of an array. The pattern displays the directivity or gain of the array. By default, the pattern function plots the directivity of the array.

```
pattern(ra,70e6)
```

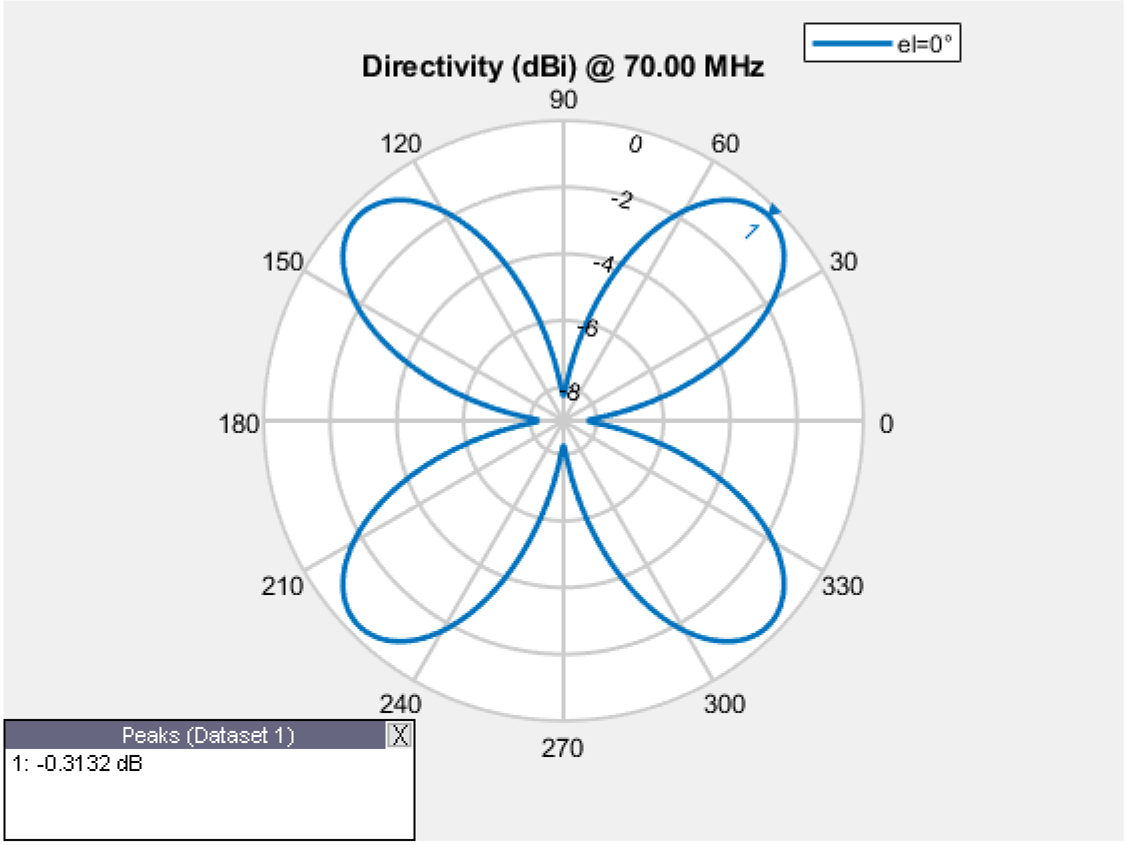


Output : Directivity
Frequency : 70 MHz
Max value : 2.32 dBi
Min value : -40.1 dBi
Azimuth : [-180° , 180°]
Elevation : [-90° , 90°]

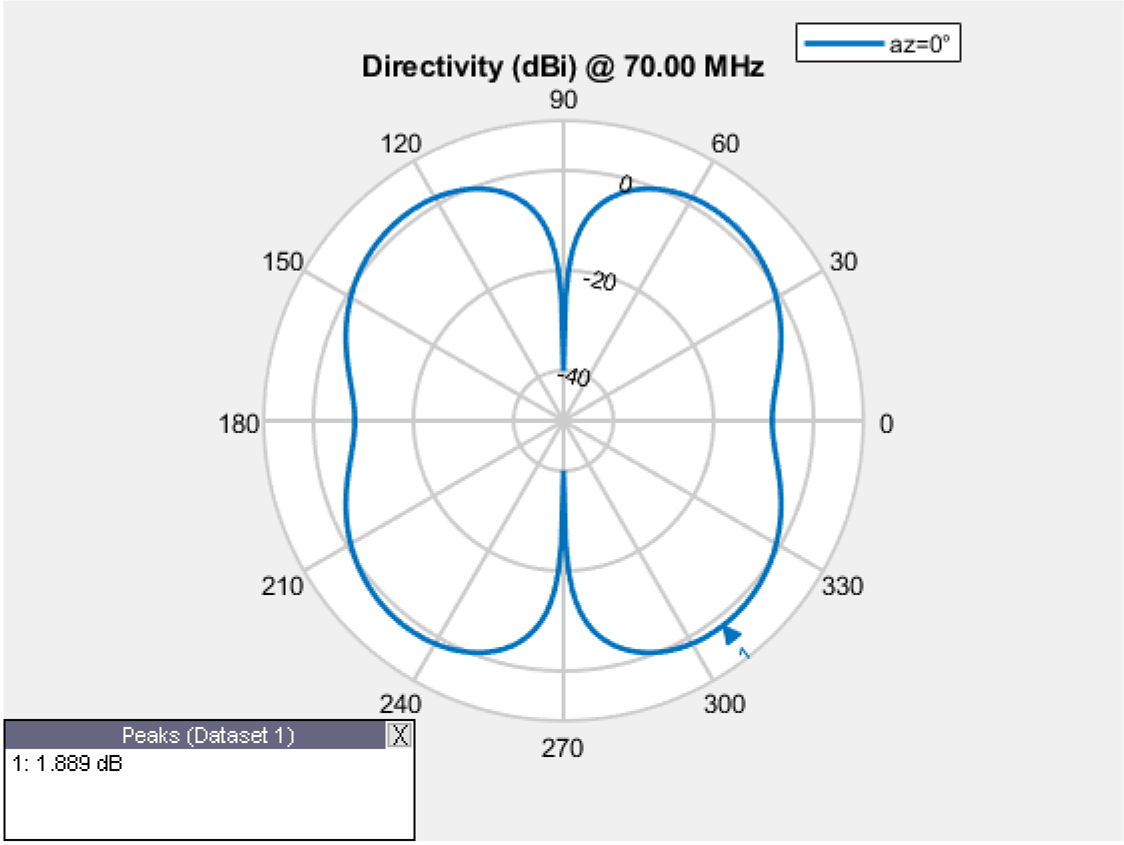
Plot Azimuth and Elevation Pattern of Array

Use `patternAzimuth` and `patternElevation` functions to plot the azimuth and elevation pattern of the rectangular array. These two patterns are the 2D radiation pattern of the array at a specified frequency.

```
patternAzimuth(ra,70e6)
```



```
figure
patternElevation(ra,70e6)
```



Calculate the Directivity of Array

Directivity is the ability of an array to radiate power in a particular direction. It can be defined as the ratio of the maximum radiation intensity in the desired direction to the average radiation intensity in all other directions. Use the `pattern` function to calculate the directivity of the rectangular array.

```
[Directivity] = pattern(ra,70e6,0,90)
```

```
Directivity = -40.1001
```

Calculate EH Fields of Array

Use the `EHfields` function to calculate the EH fields of the rectangular array. EH fields are the x, y, and z components of the electric and magnetic fields of an array. These components are measured at a specific frequency and at specified points in space.

```
[E,H] = EHfields(ra,70e6,[0;0;1])
```

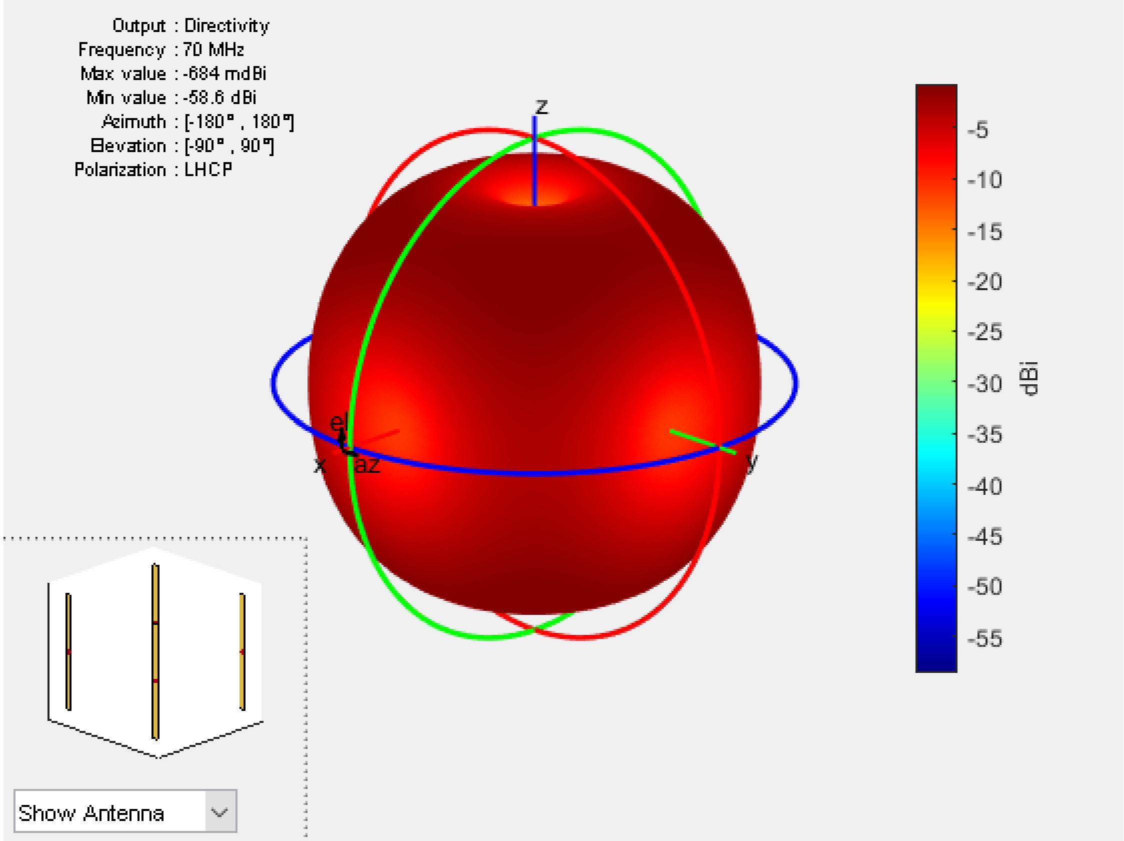
```
E = 3×1 complex

   0.0000 + 0.0000i
  -0.0002 + 0.0002i
  -1.3304 - 0.0758i


H = 3×1 complex
10^-5 ×
```

```
  -0.1274 - 0.1541i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
```

Plot Different Polarizations of Array

Use the Polarization name-value pair in the pattern function to plot the different polarization patterns of the rectangular array. Polarization is the orientation of the electric field, or E-field, of an array. Polarization is classified as elliptical, linear, or circular. This example shows the left-hand circularly polarized (LHCP) radiation pattern of the rectangular array.

```
pattern(ra,70e6,'Polarization','LHCP')
```



```
     Output : Directivity
  Frequency : 70 MHz
  Max value : -684 mdBi
  Min value : -58.6 dBi
    Azimuth : [-180° , 180°]
  Elevation : [-90° , 90°]
Polarization : LHCP
```

Calculate Beamwidth of Array

Use the `beamwidth` function to calculate the beamwidth of the rectangular array. The beamwidth of an array is the angular measure of the array pattern coverage. The beamwidth angle is measured in the plane that contains the direction of main lobe of the array.

```
[bw,angles] = beamwidth(ra,70e6,0,1:1:360)
```

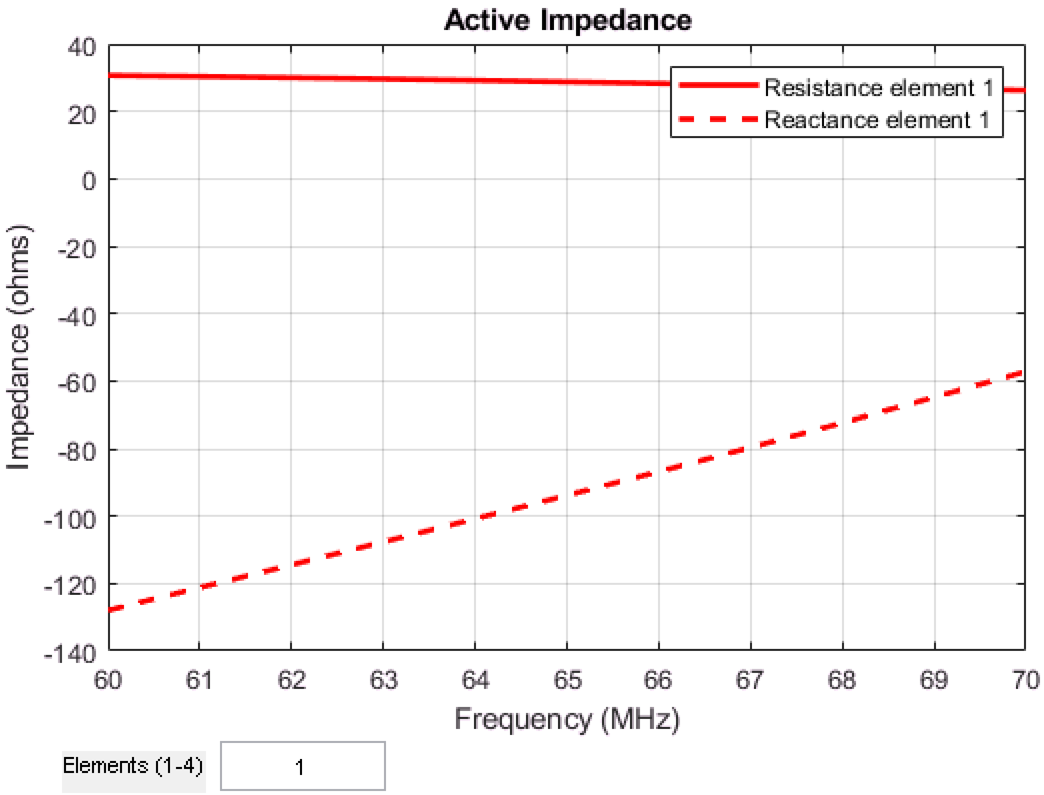
```
bw = 2×1

   44.0000
   44.0000
```

```
angles = 2×2

   208   252
   288   332
```

Calculate Scan Impedance of Array

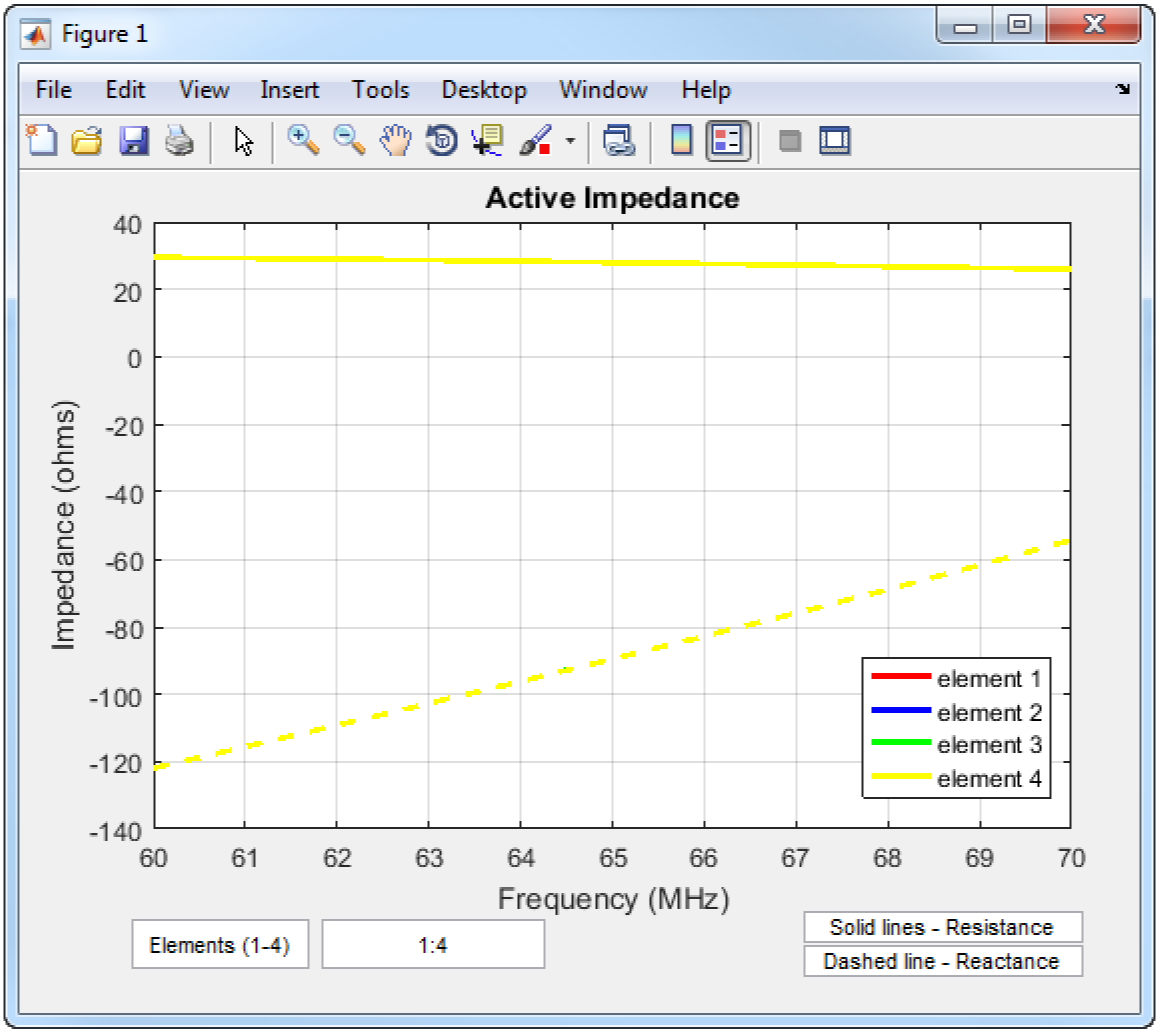
Use the `impedance` function to calculate and plot the input impedance of rectangular array. Active impedance, or scan impedance, is the input impedance of each antenna element in an array, when all elements are excited.

```
impedance(ra,60e6:1e6:70e6)
```



Elements (1-4) 1

You can also view the impedance of all four elements by changing the number of elements on the plot from 1 to 1:4. See figure.



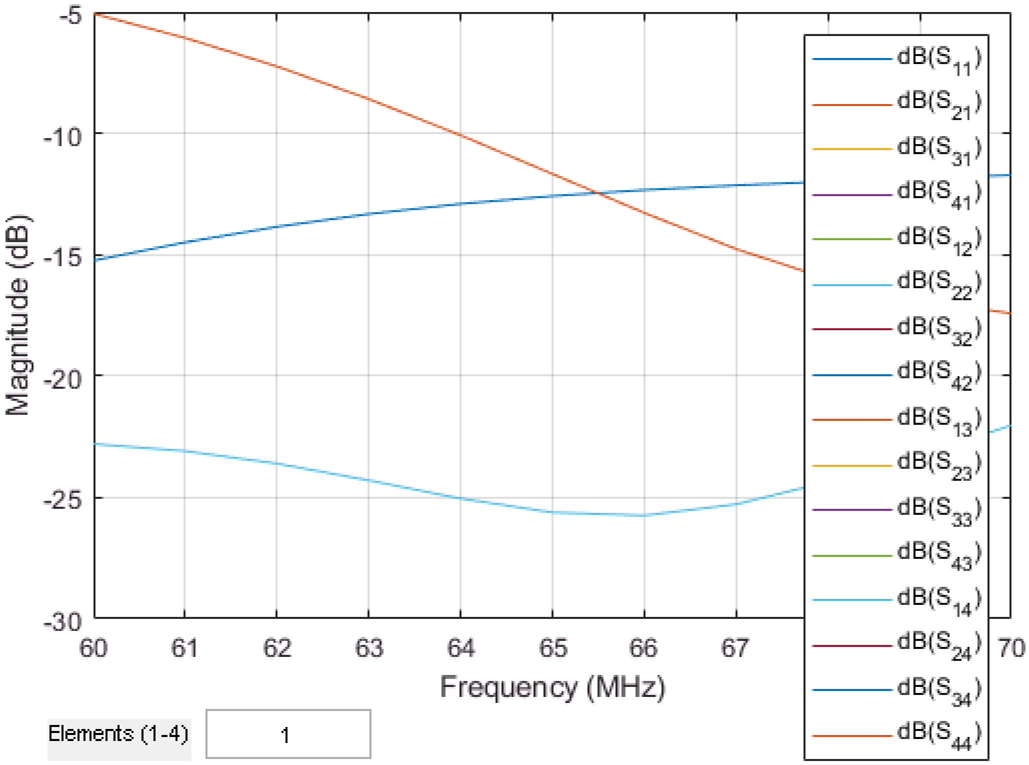
Calculate Reflection Coefficient of Array

Use the `sparameters` function to calculate the S11 value of the rectangular array. S11 value gives the reflection coefficient of the array.

```
S = sparameters(ra,60e6:1e6:70e6,72)
```

```
S = 
  sparameters: S-parameters object

       NumPorts: 4
    Frequencies: [11x1 double]
     Parameters: [4x4x11 double]
      Impedance: 72

  rfparam(obj,i,j) returns S-parameter Sij
```

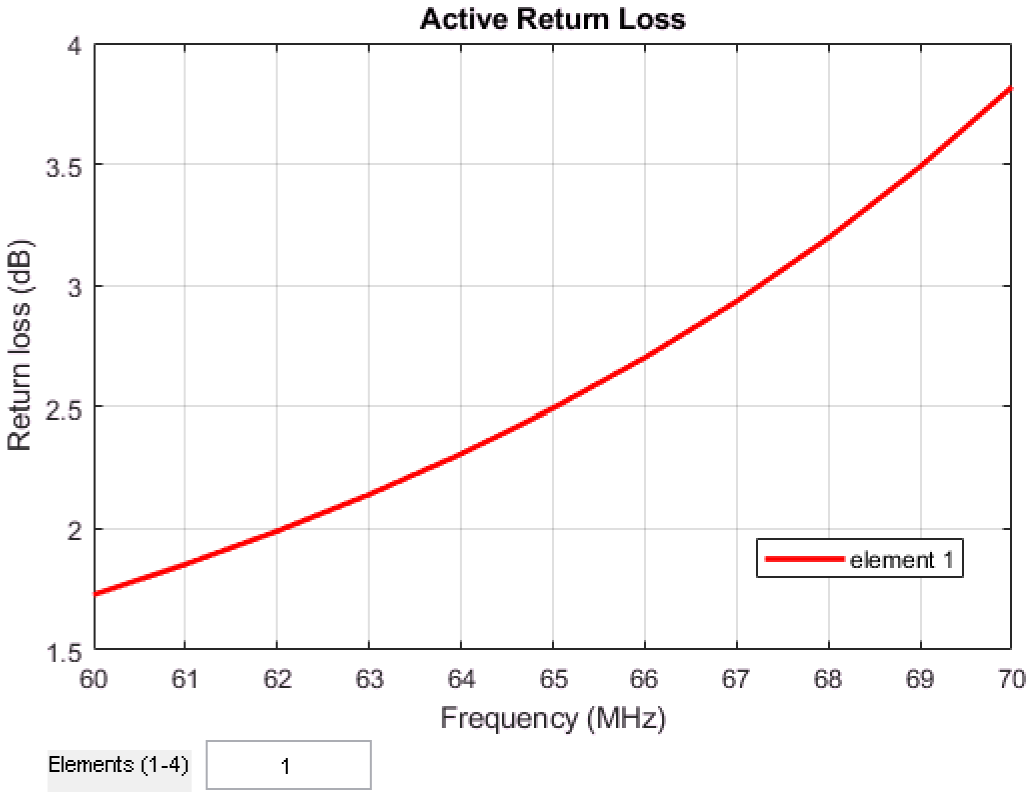
```
rfplot(S)
```



Calculate Return Loss of Array

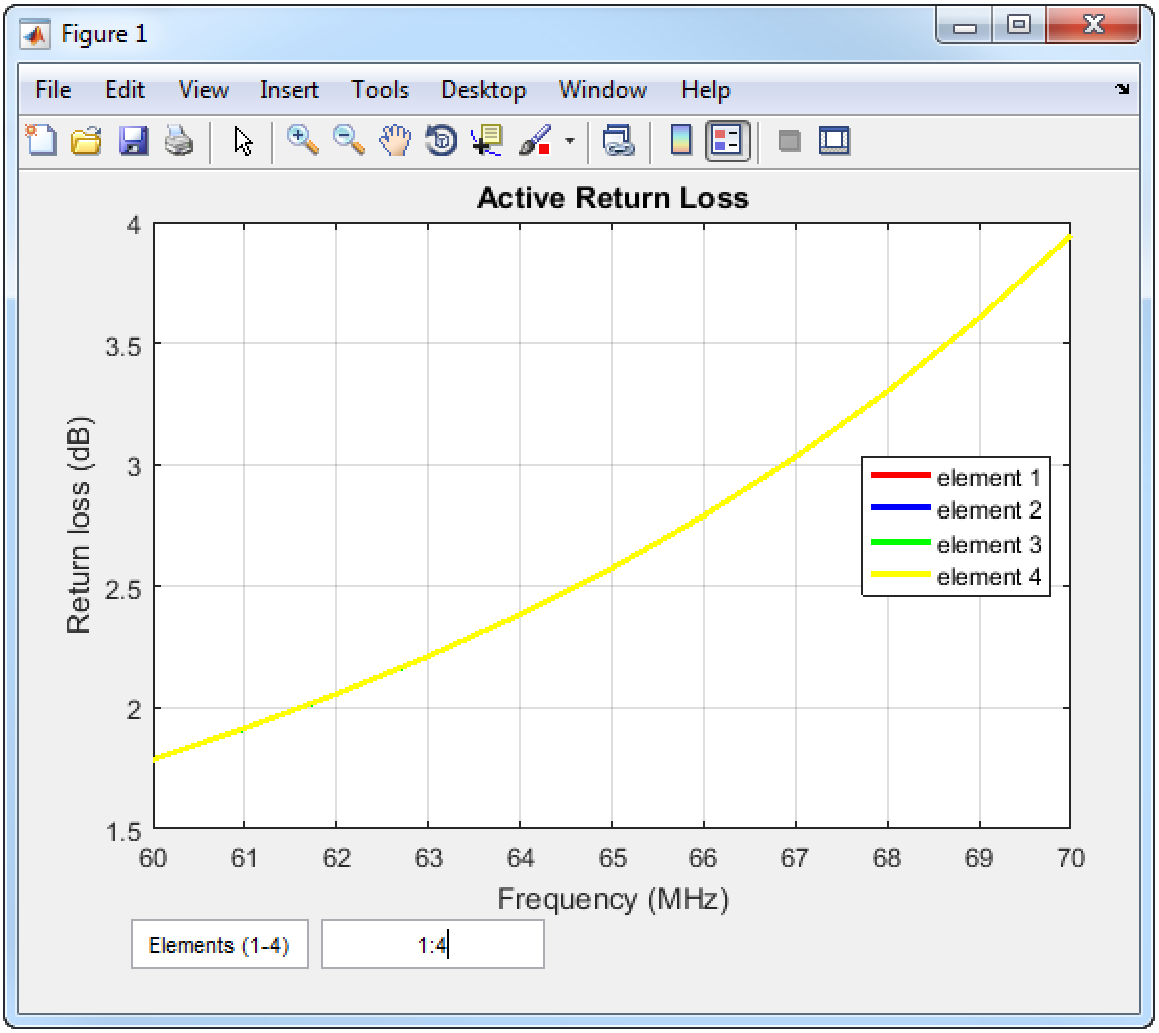
Use the `returnLoss` function to calculate and plot the return loss of the rectangular array.

```
returnLoss(ra,60e6:1e6:70e6,72)
```



Elements (1-4) 1

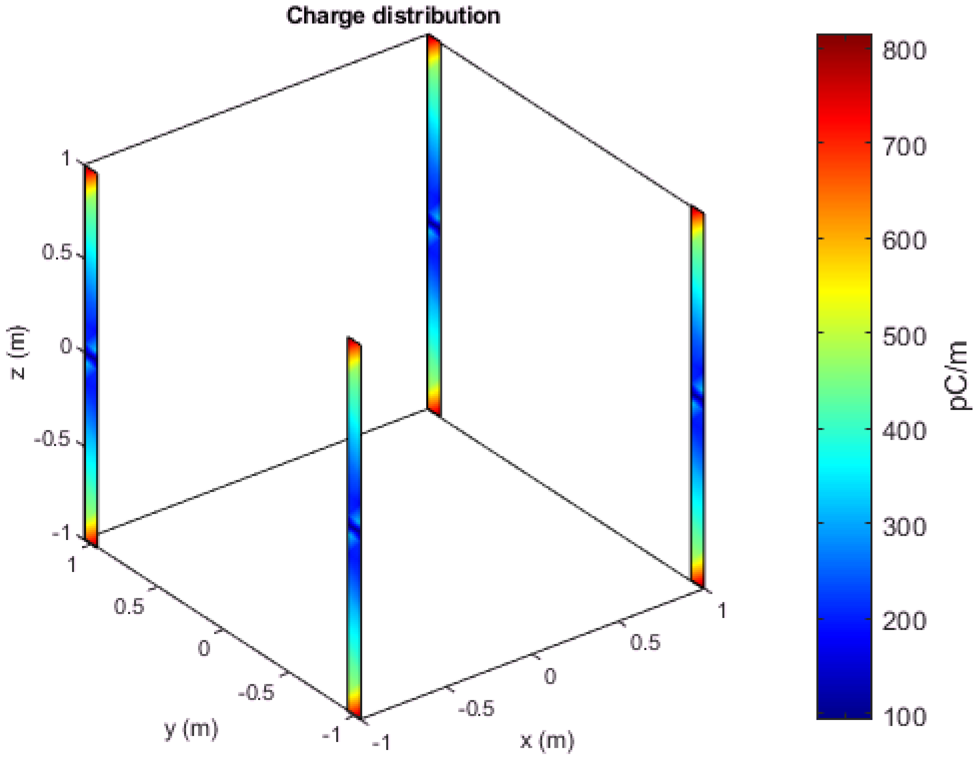
You can also view the return loss of all four elements by changing the number of elements on the plot from 1 to 1:4. See figure.



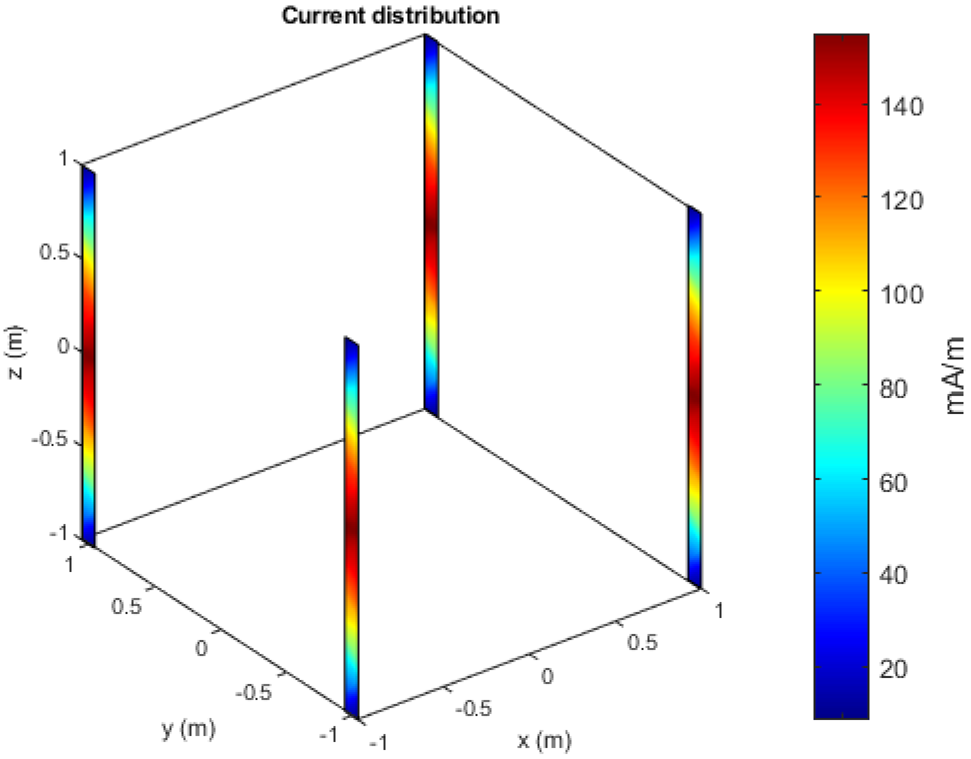
Calculate Charge and Current Distribution Of Array

Use the `charge` and `current` functions to calculate the charge and current distribution on the rectangular array surface.

```
charge(ra,70e6)
```



```
figure
current(ra,70e6)
```



Calculate Correlation Coefficient of Array

Use the `correlation` to calculate the correlation coefficient of the rectangular array. The correlation coefficient is the relationship between the incoming signals at the antenna ports in an array.

```
correlation(ra,60e6:1e6:70e6,1,2)
```

Change Size of Array and Visualize Layout

Use the 'Size' property of the rectangular array to change it to a 16-element dipole array.

```
ra.Size = [4 4];
show(ra)
```

Change Array Elements Spacing To Nonuniform

Use the 'RowSpacing' and 'ColumnSpacing' properties of rectangular array to change the spacing between the antenna elements.

```
ra.RowSpacing = [ 1.1 2 1.2];
ra.ColumnSpacing =[0.5 1.4 2]
```

```
ra =
  rectangularArray with properties:

           Element: [1x1 dipole]
              Size: [4 4]
```

```
          RowSpacing: [1.1000 2 1.2000]
       ColumnSpacing: [0.5000 1.4000 2]
             Lattice: 'Rectangular'
      AmplitudeTaper: 1
          PhaseShift: 0
                Tilt: 0
            TiltAxis: [1 0 0]
```

```
show(ra)
```

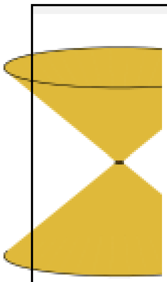
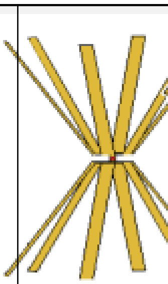
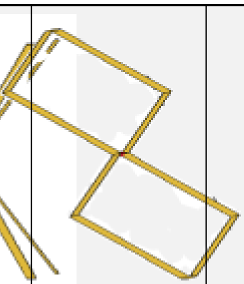
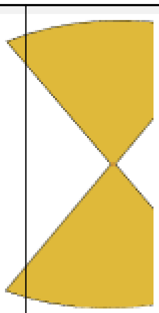
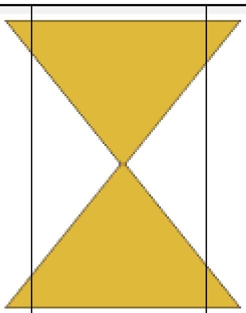
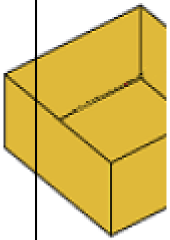
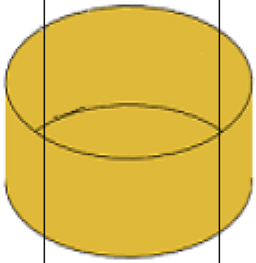
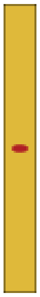
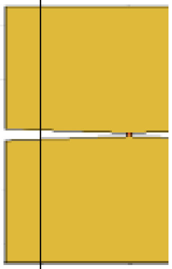
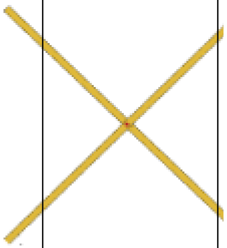
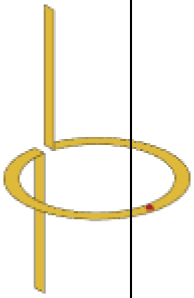
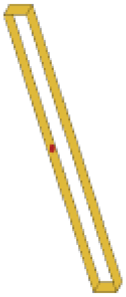
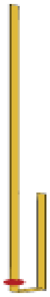
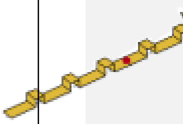
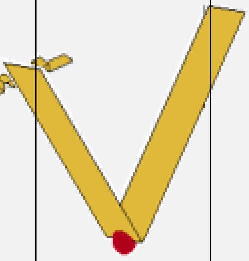
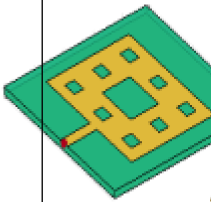
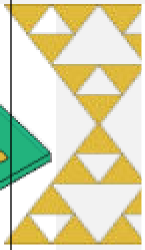
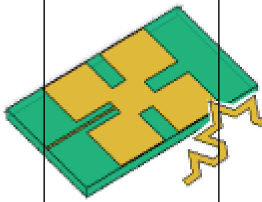
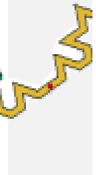
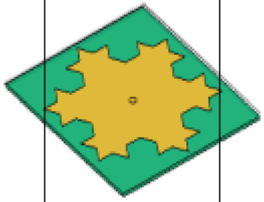
References

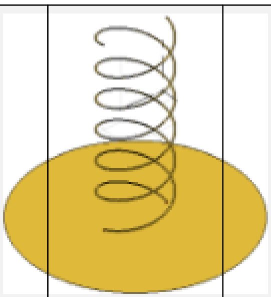
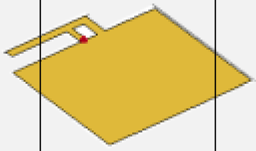
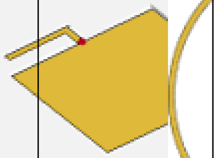
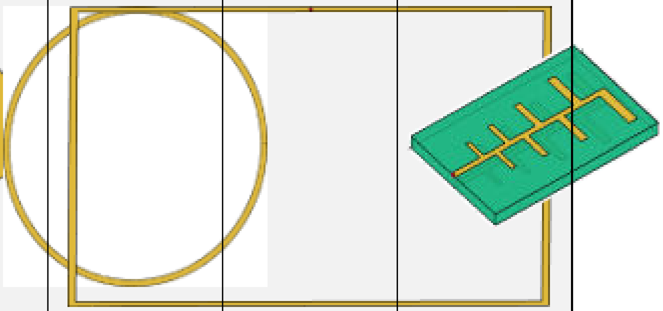
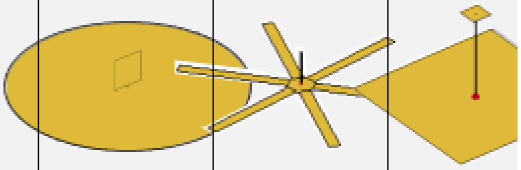
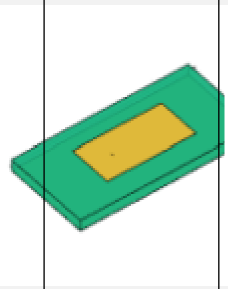
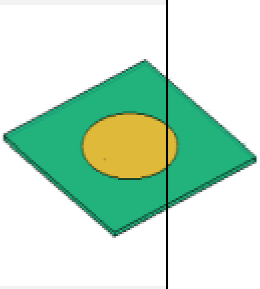
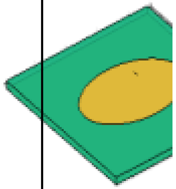
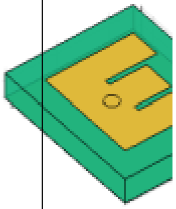
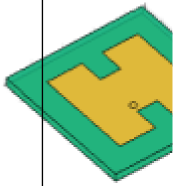
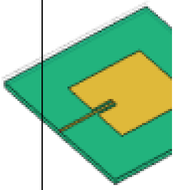
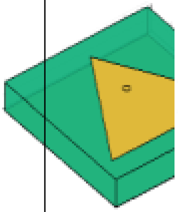
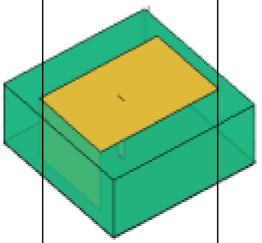
[1] Balanis, C.A. "Antenna Theory. Analysis and Design", p. 514, Wiley, New York, 3rd Edition, 2005.

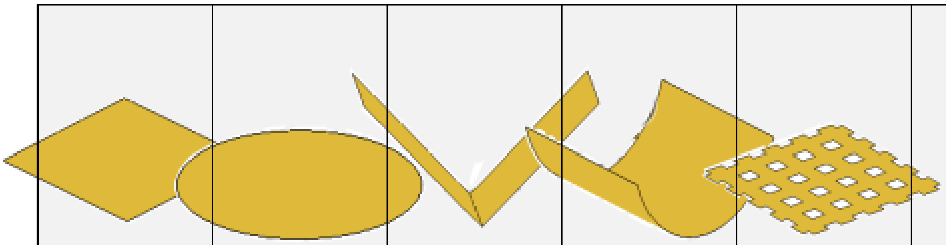
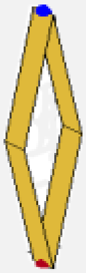
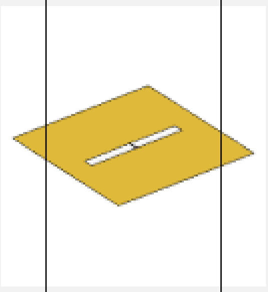
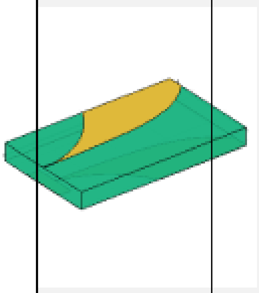
Antenna Element Catalog

The Antenna Toolbox consists of two catalogs: Antenna and Array.

Catalog Elements

						
bicone	biconeStrip	biquad	birdcage	bowtieRounded	bowtieTriangular	cassegrain
						
cavity	cavityCircular	cloverleaf	dipole	dipoleBlade	dipoleCrossed	dipoleCycloid
						
dipoleFolded	dipoleHelix	dipoleHelixMultifilar	dipoleJ	dipoleMeander	dipoleVee	discone
						
disconeStrip	fractalCarpet	fractalGasket	fractalIsland	fractalKoch	fractalSnowflake	gregorian

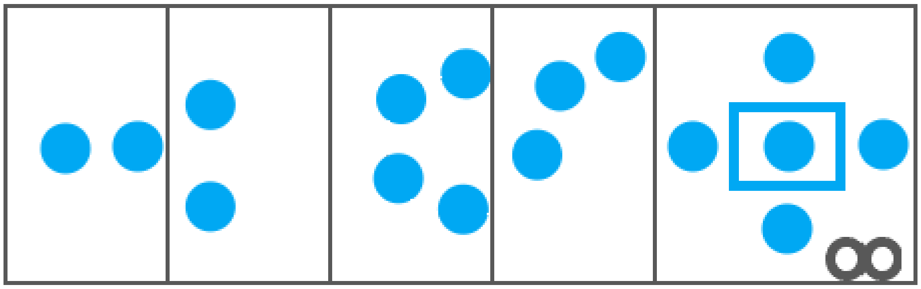
						
helix	helixMultifilar	horn	hornConical	hornConicalCorrugated	hornCorrugated	hornRidge
						
invertedF	invertedFcoplanar	invertedL	invertedLcoplanar	loopCircular	loopRectangular	lpda
						
monocone	monopole	monopoleCustom	monopoleRadial	monopoleTopHat	patchMicrostrip	patchMicrostripCircular
						
patchMicrostripElliptical	patchMicrostripEnotch	patchMicrostripHnotch	patchMicrostripInsetfed	patchMicrostripTriangular	pifa	quadCustom

						
reflector	**reflectorCircular**	**reflectorCorner**	**reflectorCylindrical**	**reflectorGrid**	**reflectorParabolic**	**reflectorSpherical**
						
rhombic	**sectorInvertedAmos**	**slot**	**spiralArchimedean**	**spiralEquiangular**	**spiralRectangular**	**vivaldi**
						
vivaldiAntipodal	**waveguide**	**waveguideCircular**	**waveguideRidge**	**waveguideSlotted**	**yagiUda**	

See Also

"Array Catalog Elements" on page 2-21

Array Catalog Elements

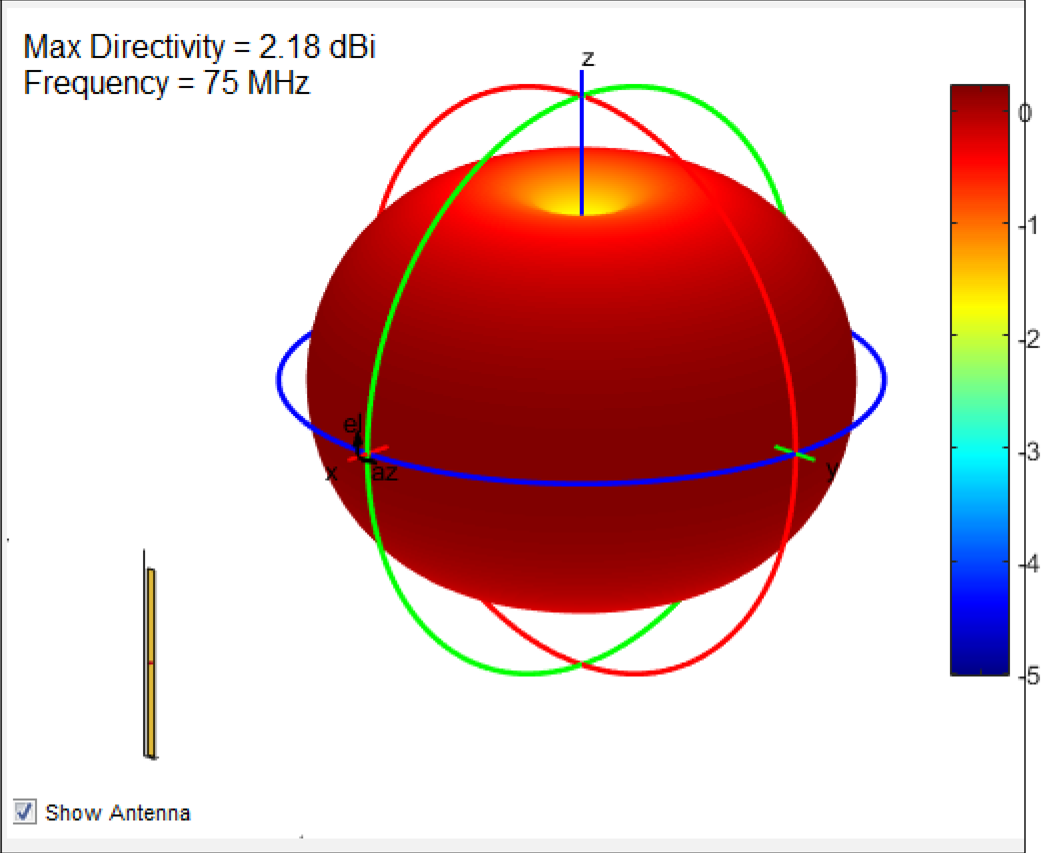


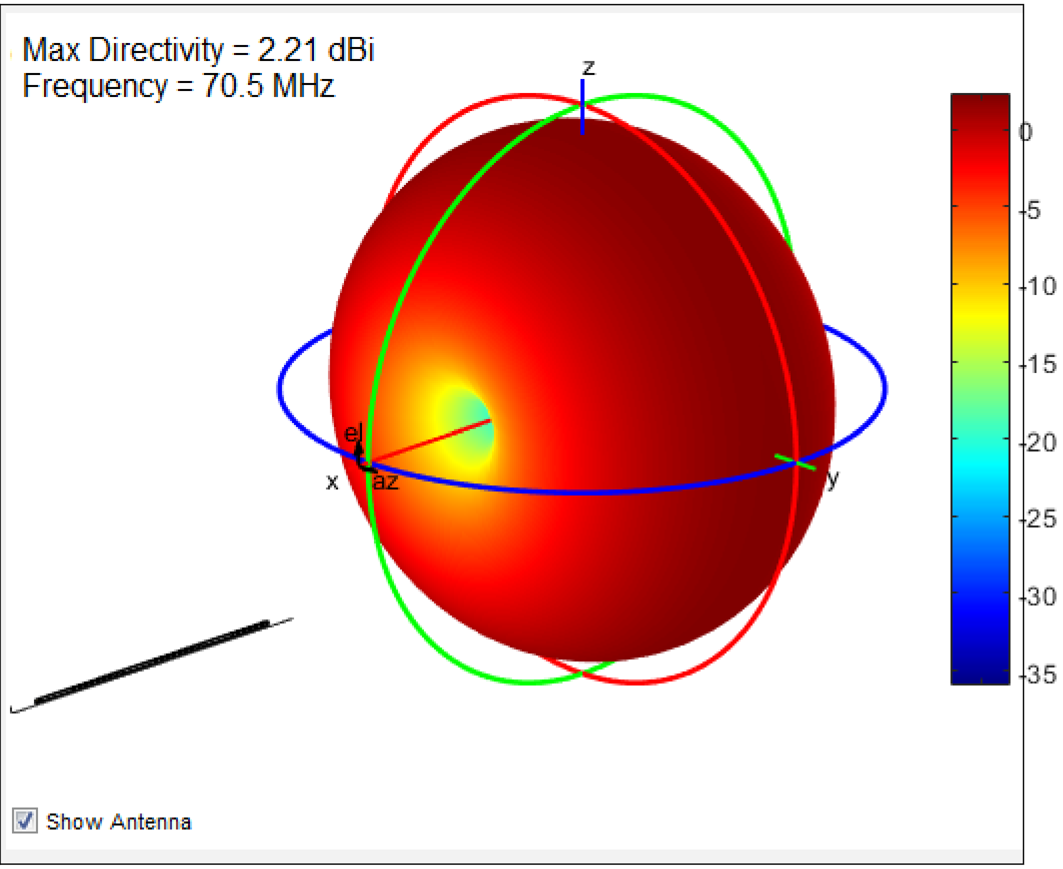
linearArray **rectangularArray** **circularArray** **conformalArray** **infiniteArray**

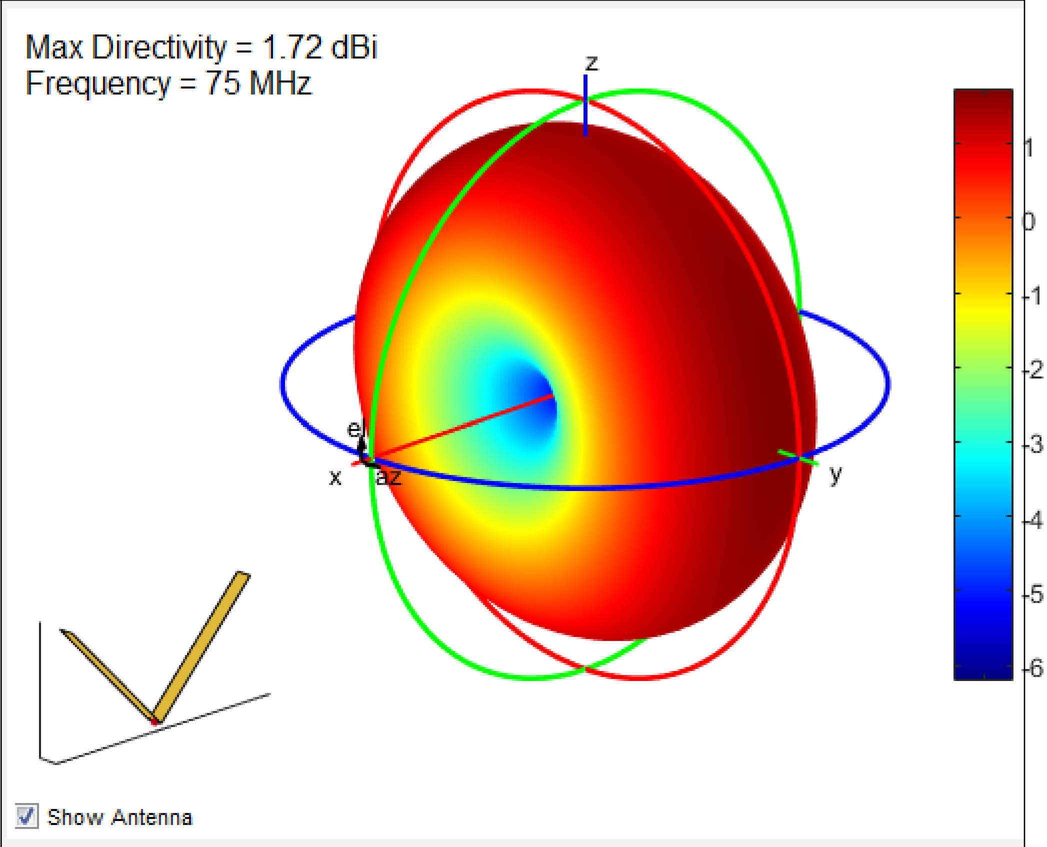
See Also

"Antenna Element Catalog" on page 2-17

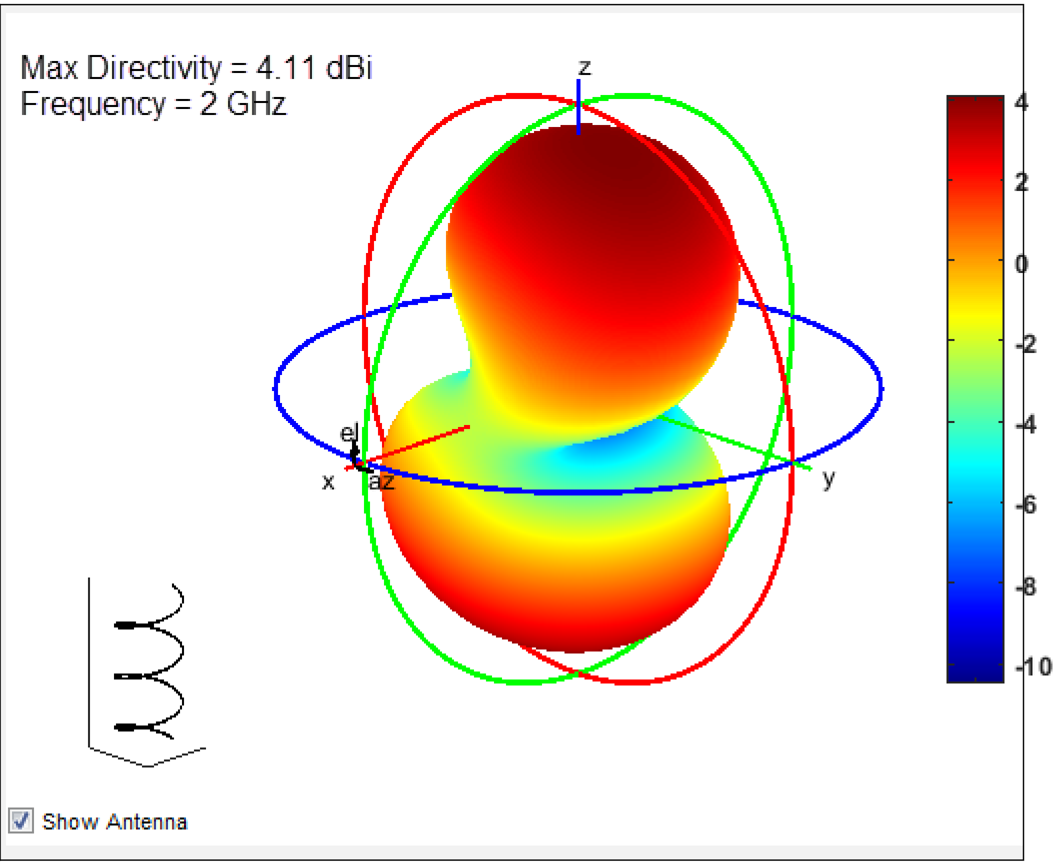
Antenna Radiation Patterns

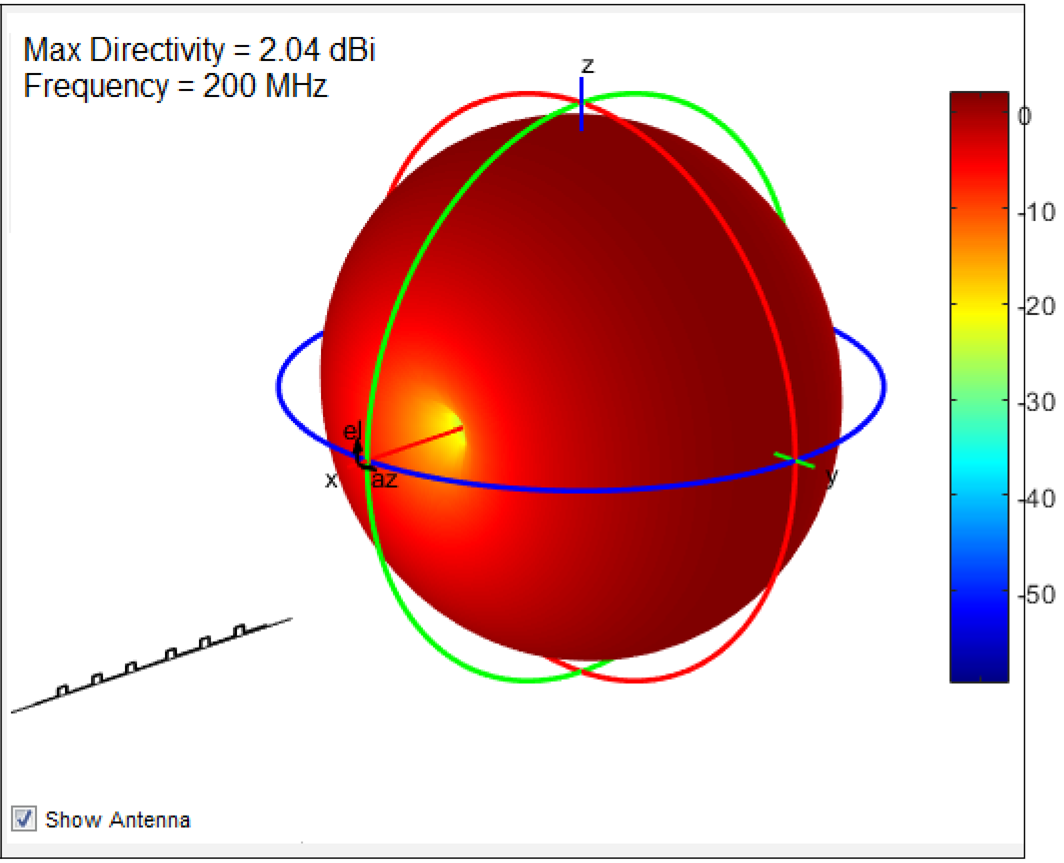
`dipole`	

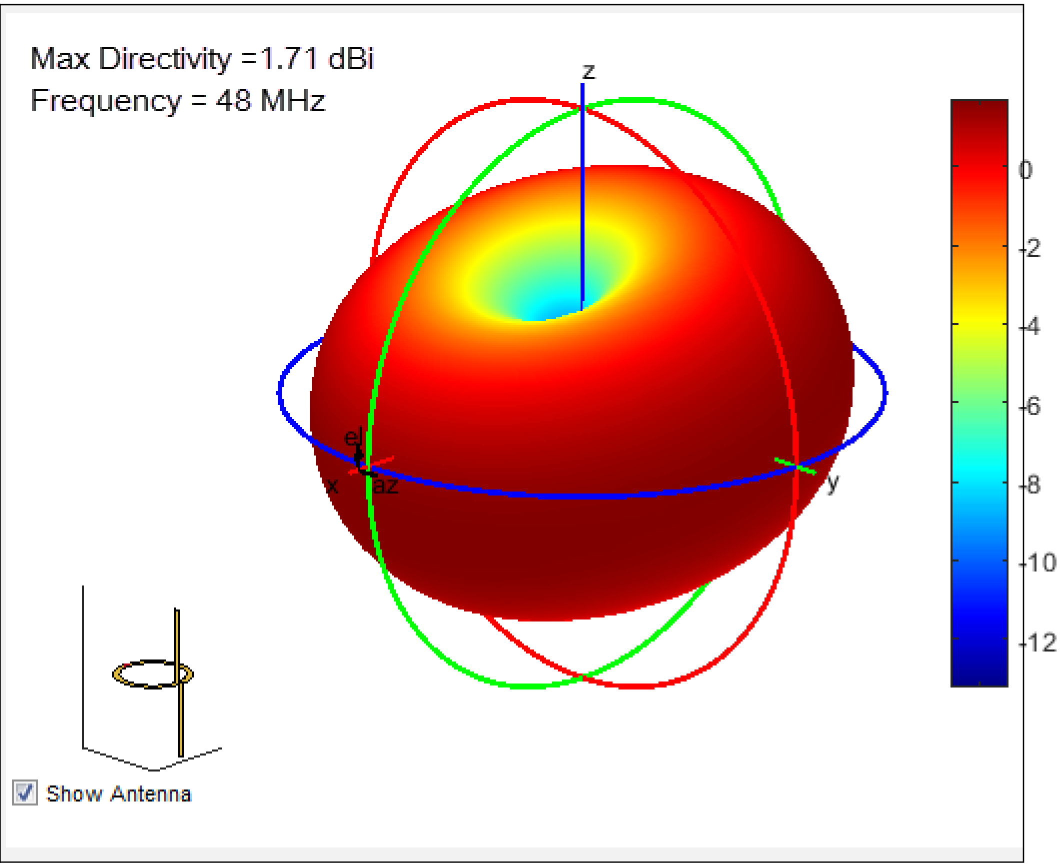
`dipoleFolded`	 Max Directivity = 2.21 dBi Frequency = 70.5 MHz z x y az el 0 -5 -10 -15 -20 -25 -30 -35 ☑ Show Antenna

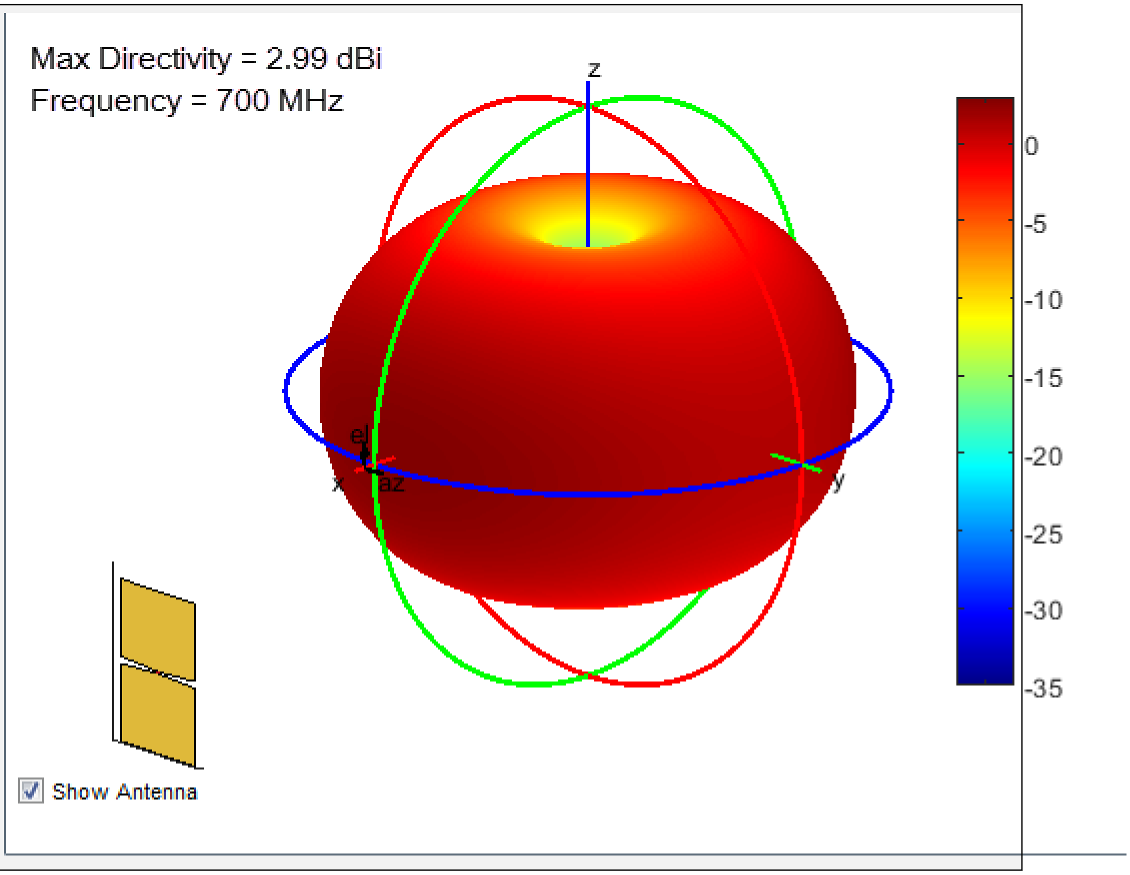
`dipoleVee`	

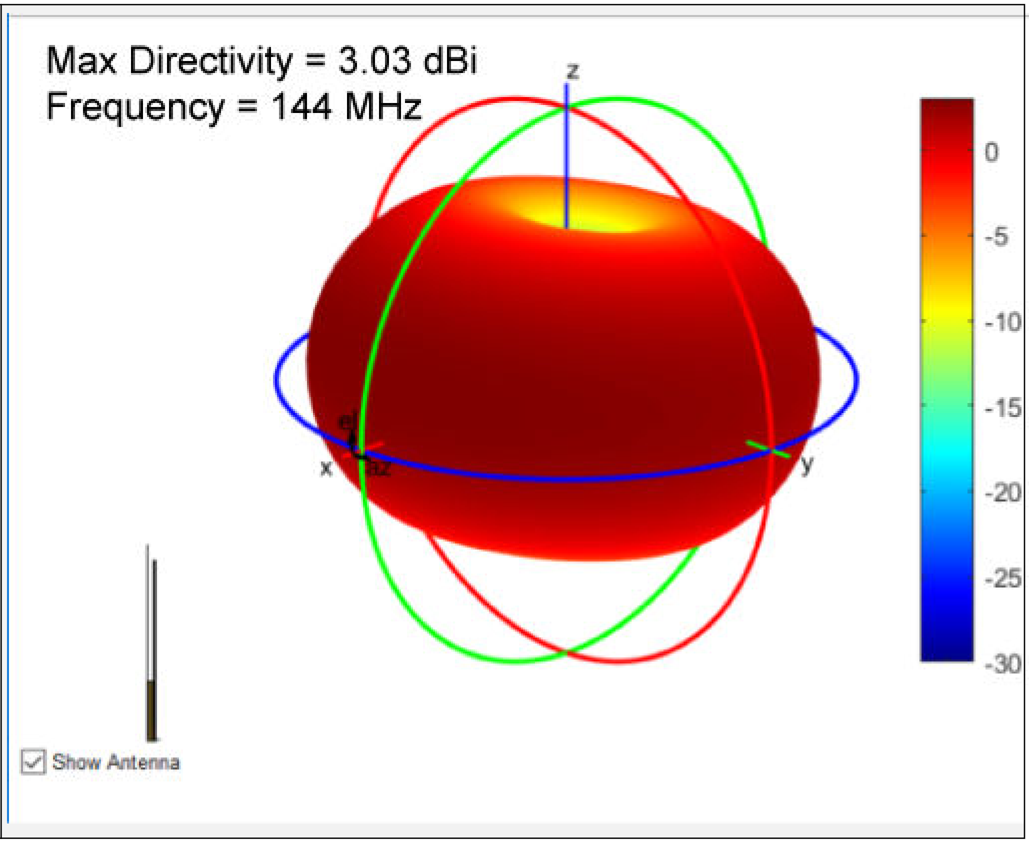
Max Directivity = 1.72 dBi
Frequency = 75 MHz
z
x
y
el
az
1
0
-1
-2
-3
-4
-5
-6
☑ Show Antenna

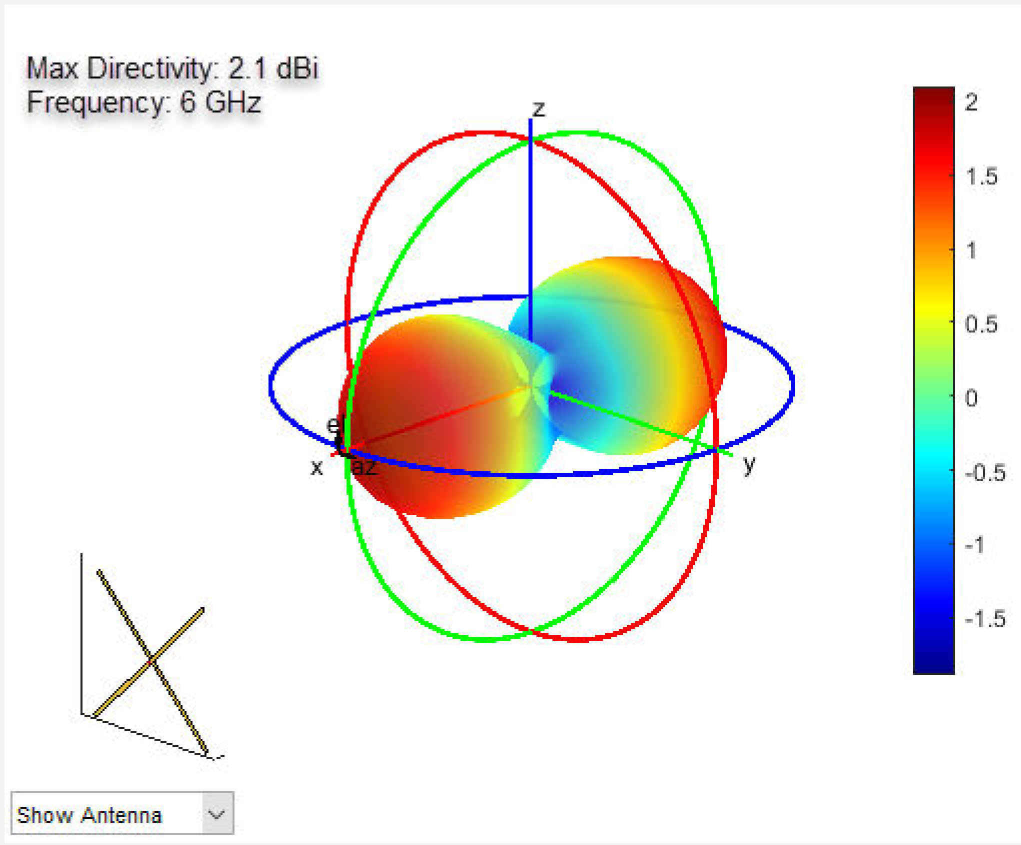
`dipoleHelix`	 Max Directivity = 4.11 dBi Frequency = 2 GHz z el x az y 4 2 0 -2 -4 -6 -8 -10 ☑ Show Antenna

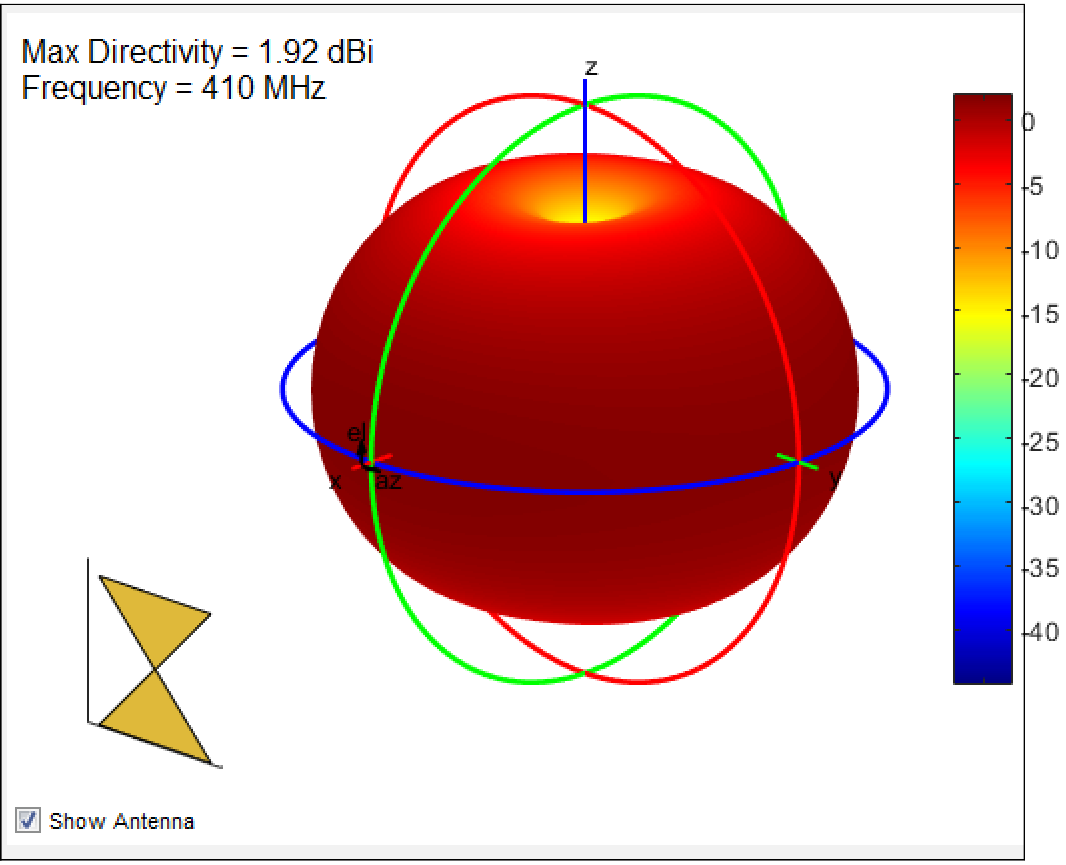
`dipoleMeander`	 Max Directivity = 2.04 dBi Frequency = 200 MHz z el x az y 0 -10 -20 -30 -40 -50 ☑ Show Antenna

`dipoleCycloid`	 Max Directivity =1.71 dBi Frequency = 48 MHz ☑ Show Antenna

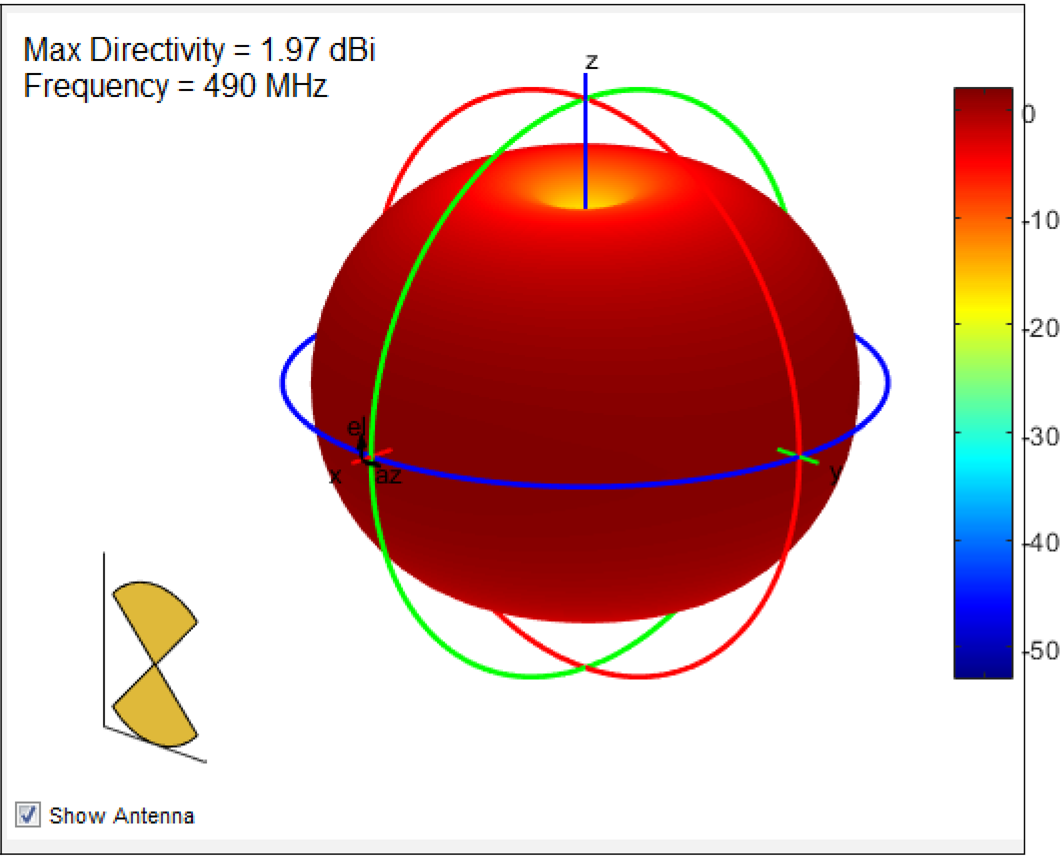
`dipoleBlade`	 Max Directivity = 2.99 dBi Frequency = 700 MHz z x y el az 0 -5 -10 -15 -20 -25 -30 -35 ☑ Show Antenna

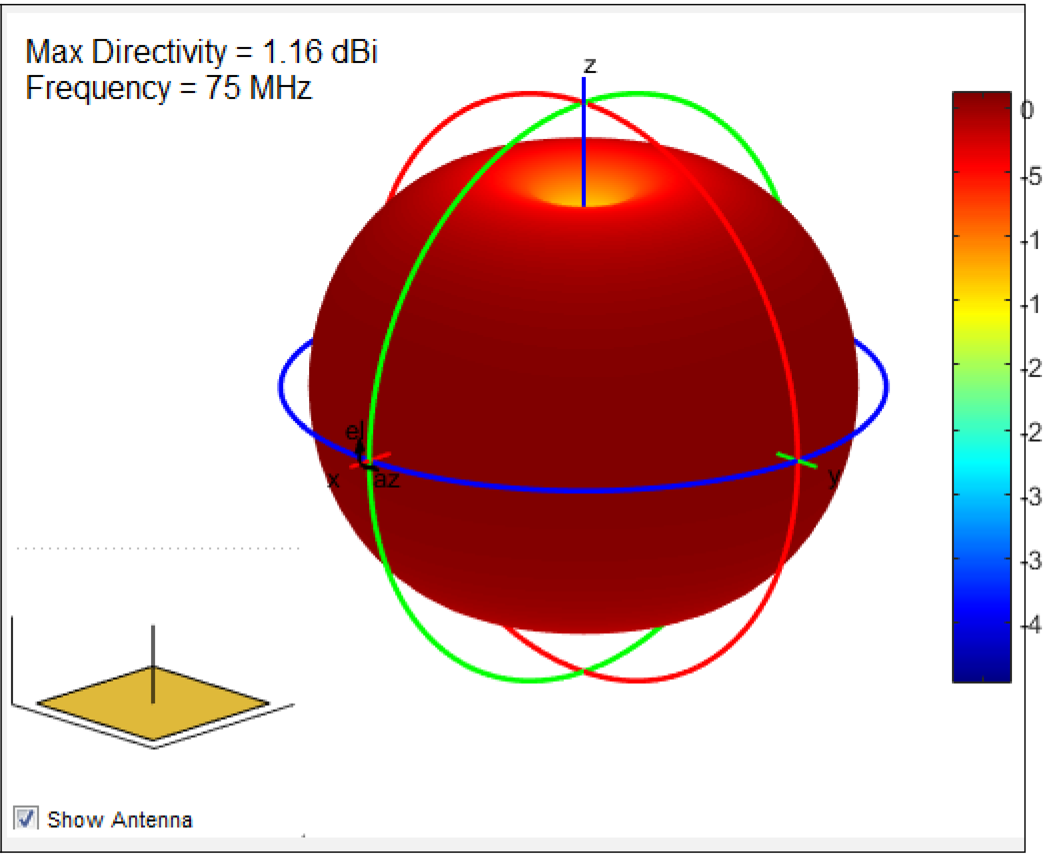
`dipoleJ`	 Max Directivity = 3.03 dBi Frequency = 144 MHz ☑ Show Antenna

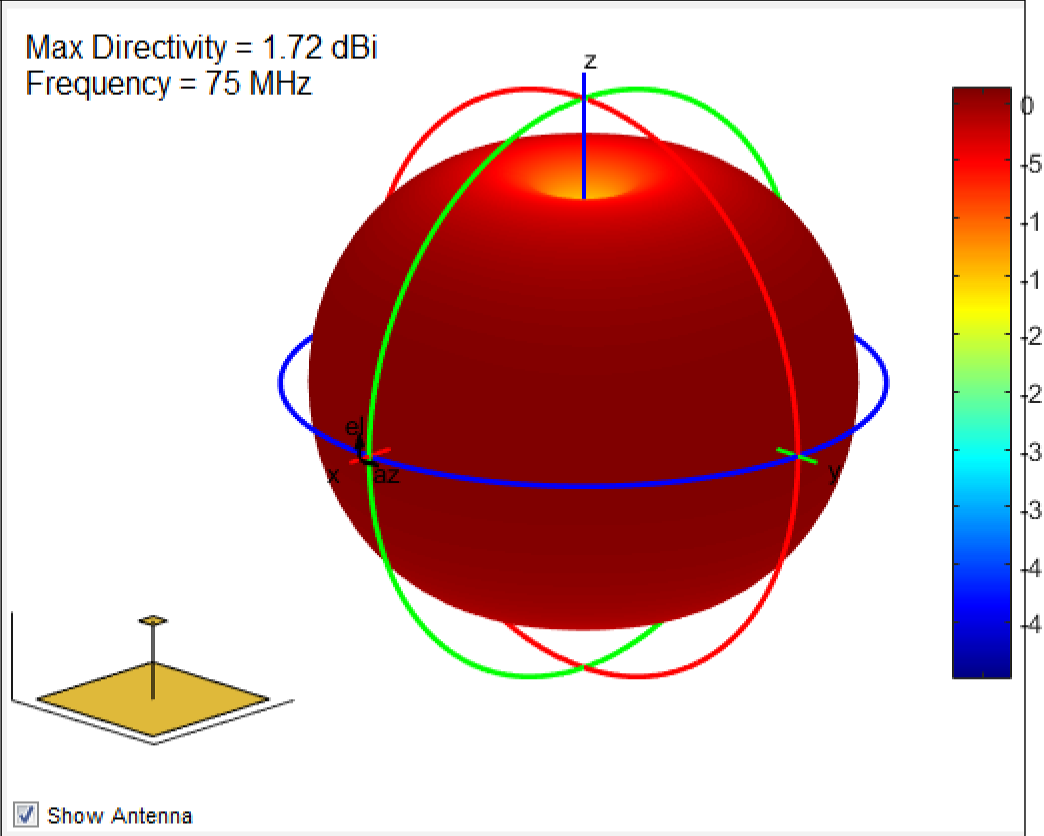
`dipoleCrossed`	 Max Directivity: 2.1 dBi Frequency: 6 GHz z x y el az 2 1.5 1 0.5 0 -0.5 -1 -1.5 Show Antenna

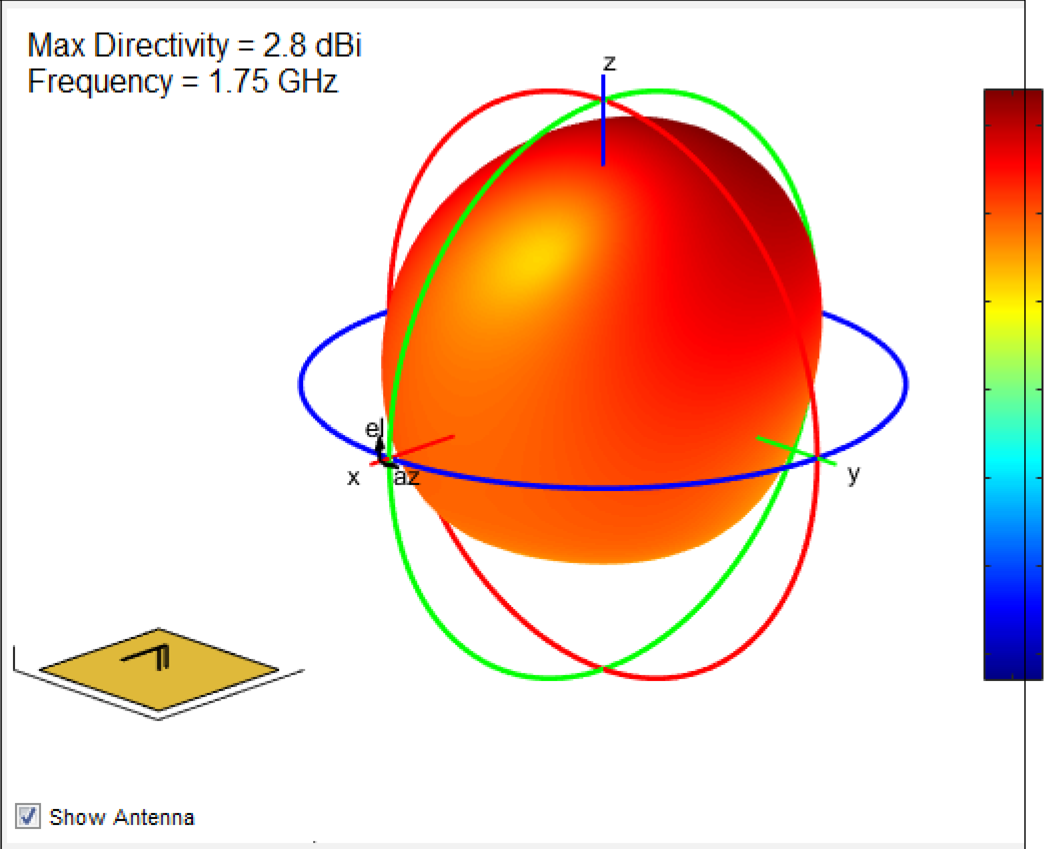
`bowtieTriangular`	

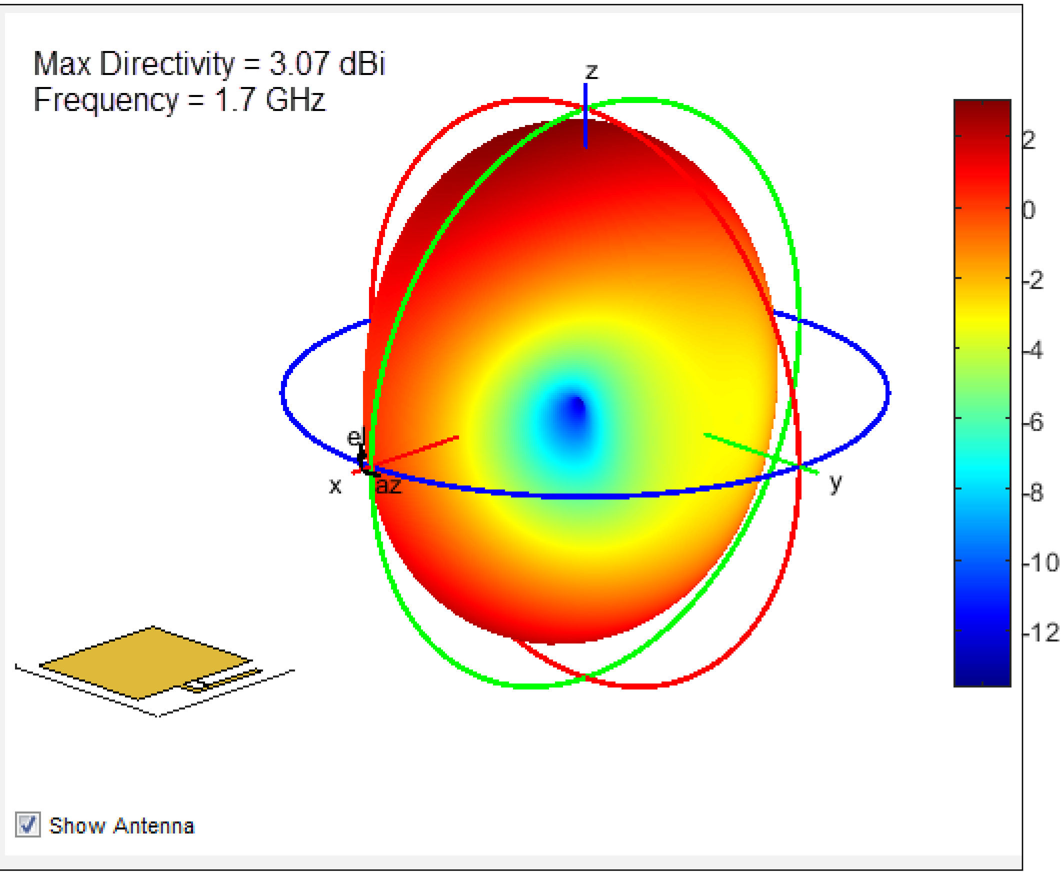
Max Directivity = 1.92 dBi
Frequency = 410 MHz

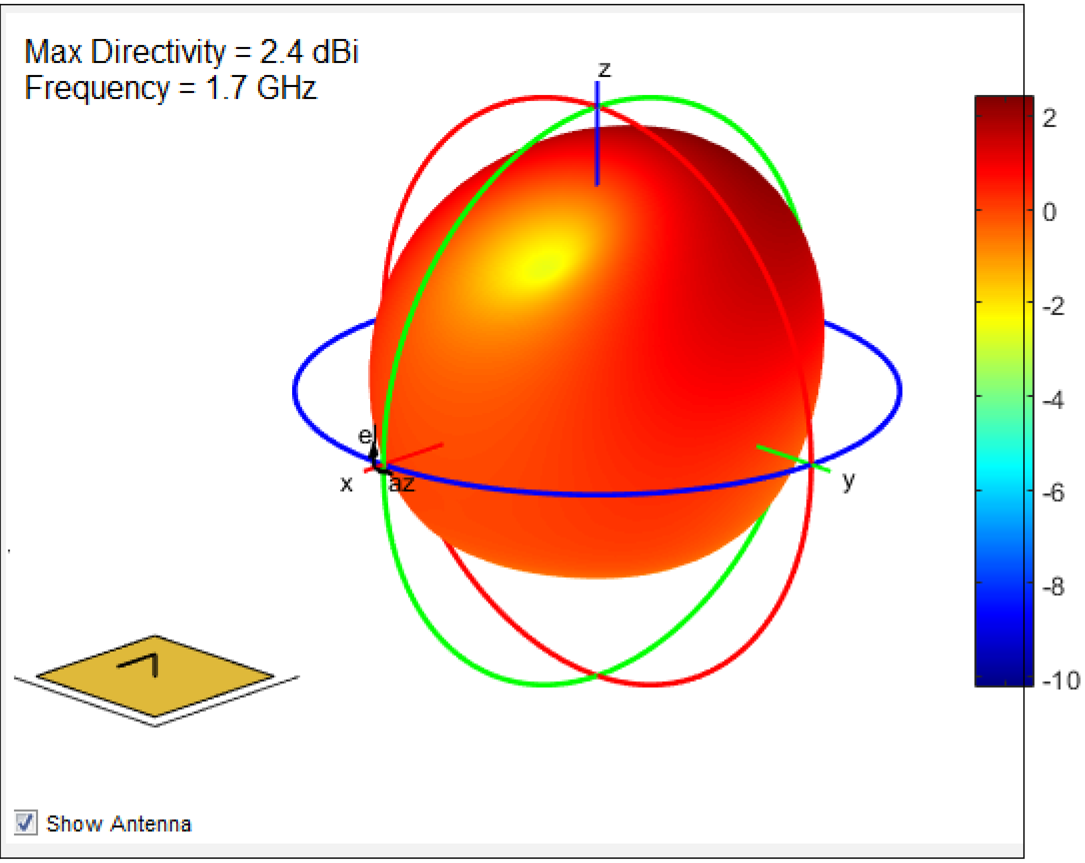
`bowtieRounded`	 Max Directivity = 1.97 dBi Frequency = 490 MHz

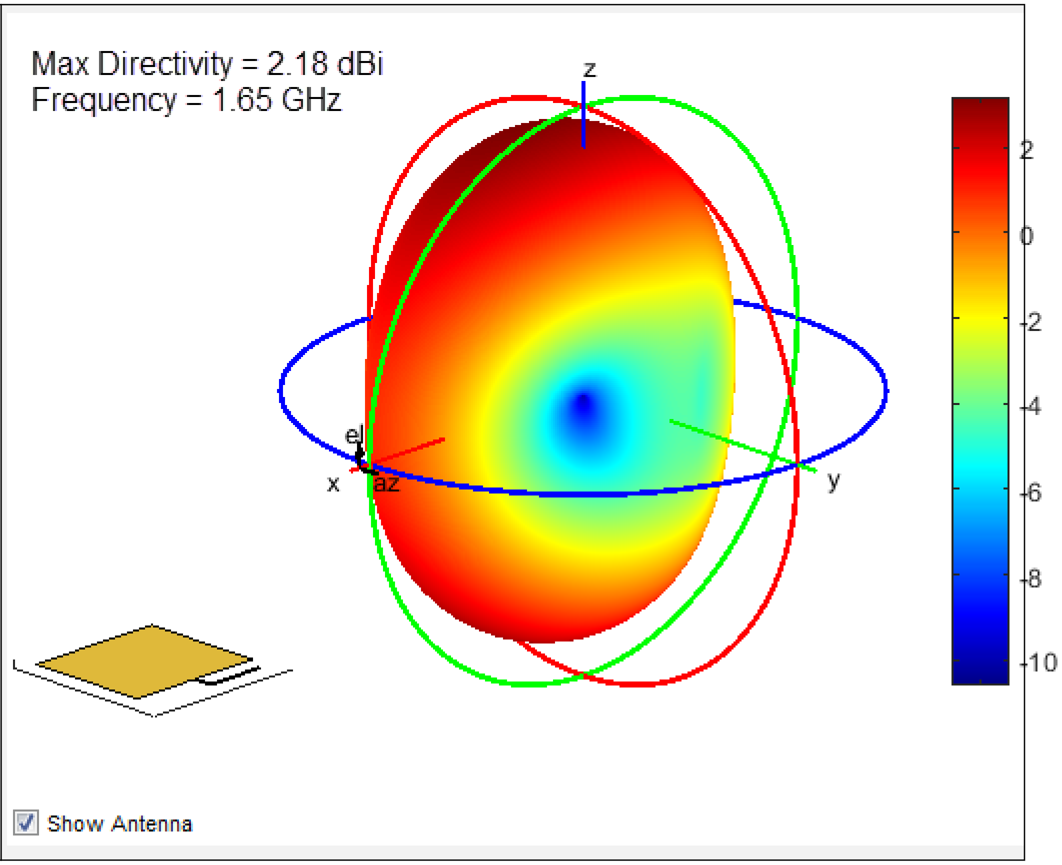
`monopole`	Max Directivity = 1.16 dBi Frequency = 75 MHz z el x az y 0 -5 -10 -15 -20 -25 -30 -35 -40 ☑ Show Antenna

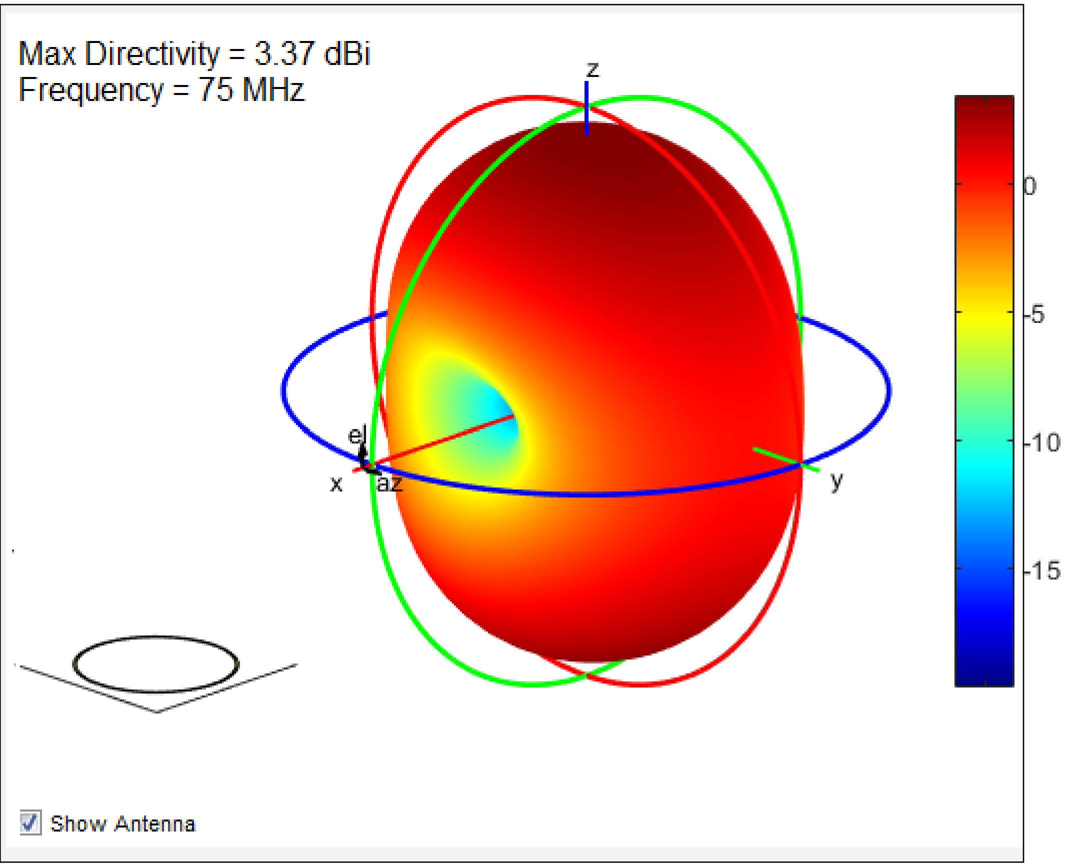
`monopoleTopHat`	 Max Directivity = 1.72 dBi Frequency = 75 MHz z x y el az 0 -5 -10 -15 -20 -25 -30 -35 -40 -45 ☑ Show Antenna

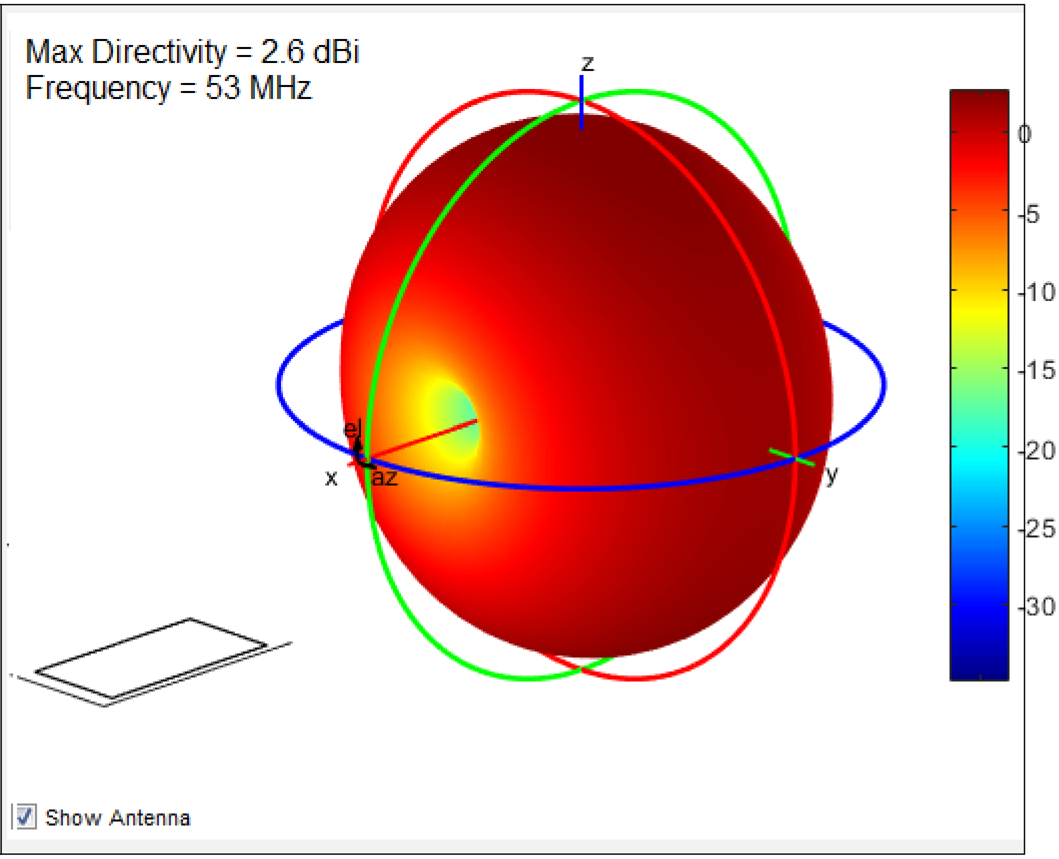
`invertedF`	Max Directivity = 2.8 dBi Frequency = 1.75 GHz z el x az y 2 0 -2 -4 -6 -8 -10 ☑ Show Antenna

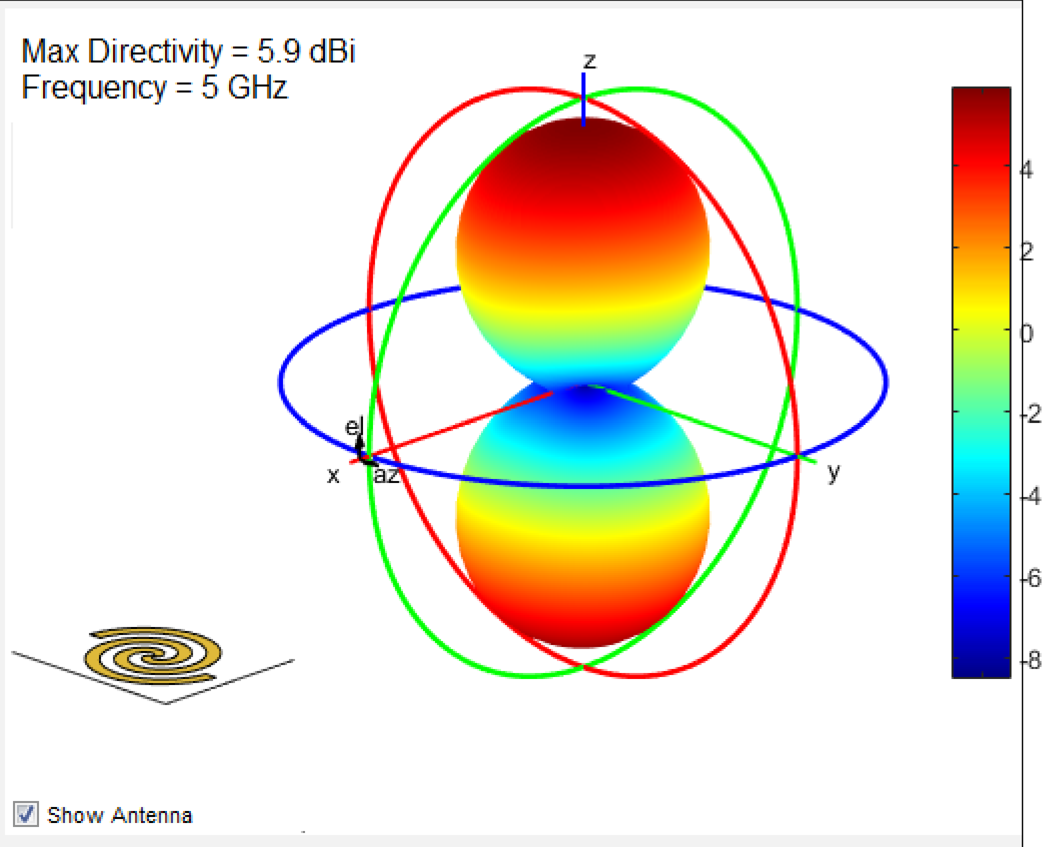
`invertedFcoplanar`	 Max Directivity = 3.07 dBi Frequency = 1.7 GHz ☑ Show Antenna z x y el az 2 0 -2 -4 -6 -8 -10 -12

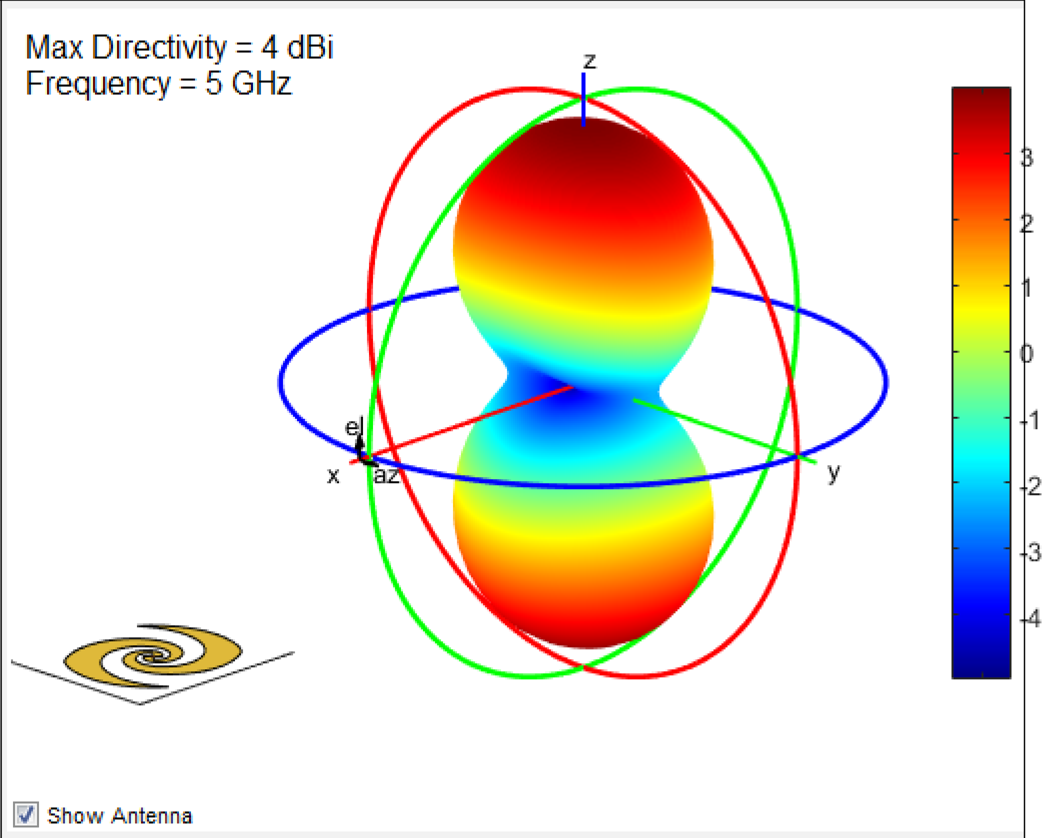
`invertedL`	 Max Directivity = 2.4 dBi Frequency = 1.7 GHz z x y el az 2 0 -2 -4 -6 -8 -10 ☑ Show Antenna

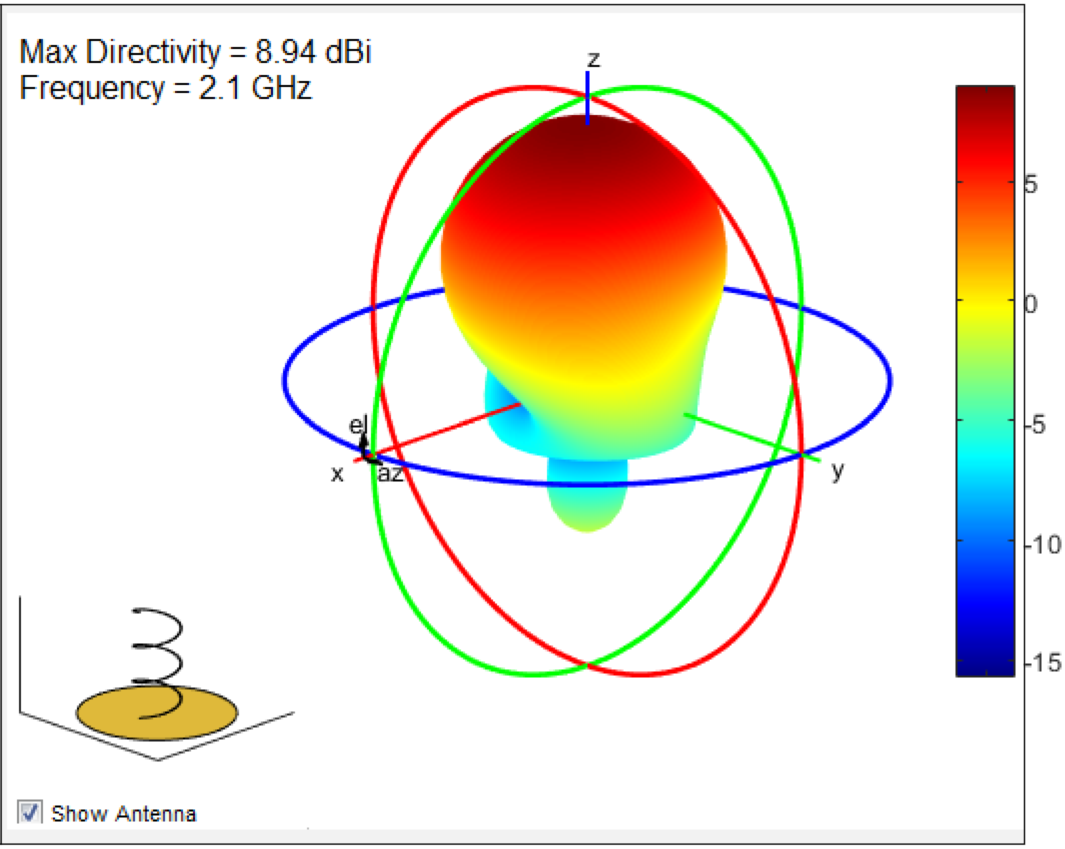
`invertedLcoplanar`	

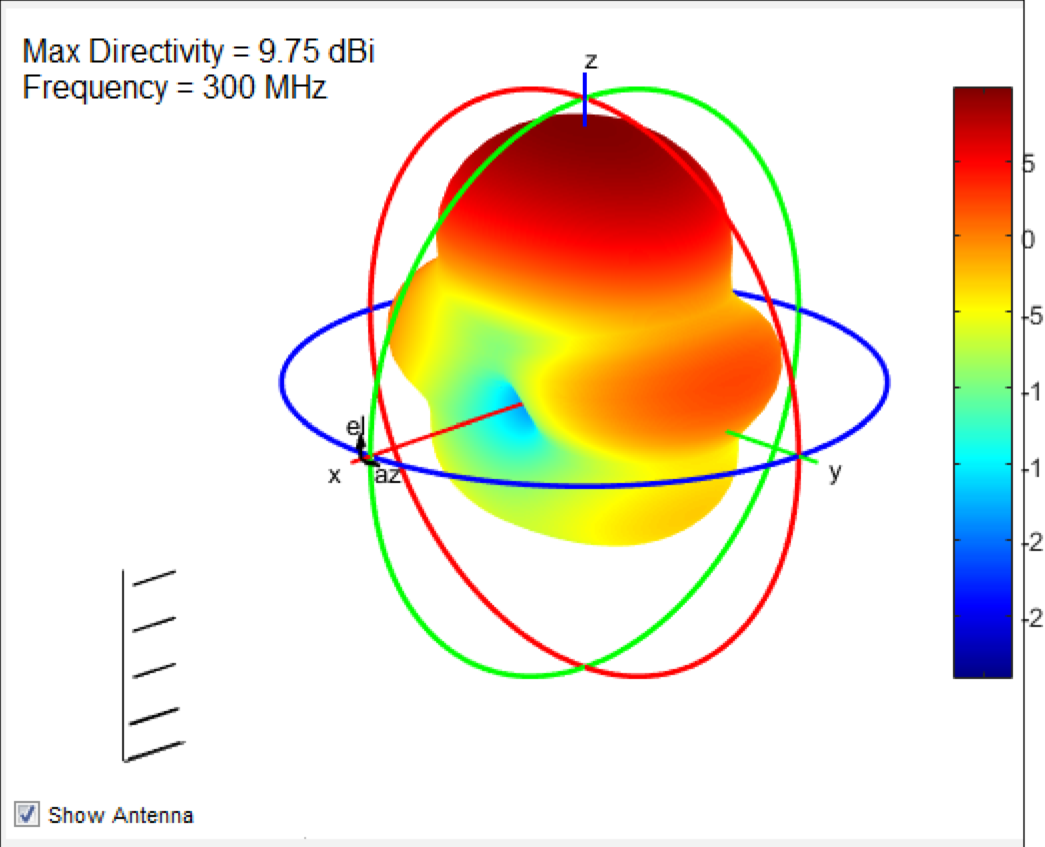
`loopCircular`	 Max Directivity = 3.37 dBi Frequency = 75 MHz z el x az y 0 -5 -10 -15 ☑ Show Antenna

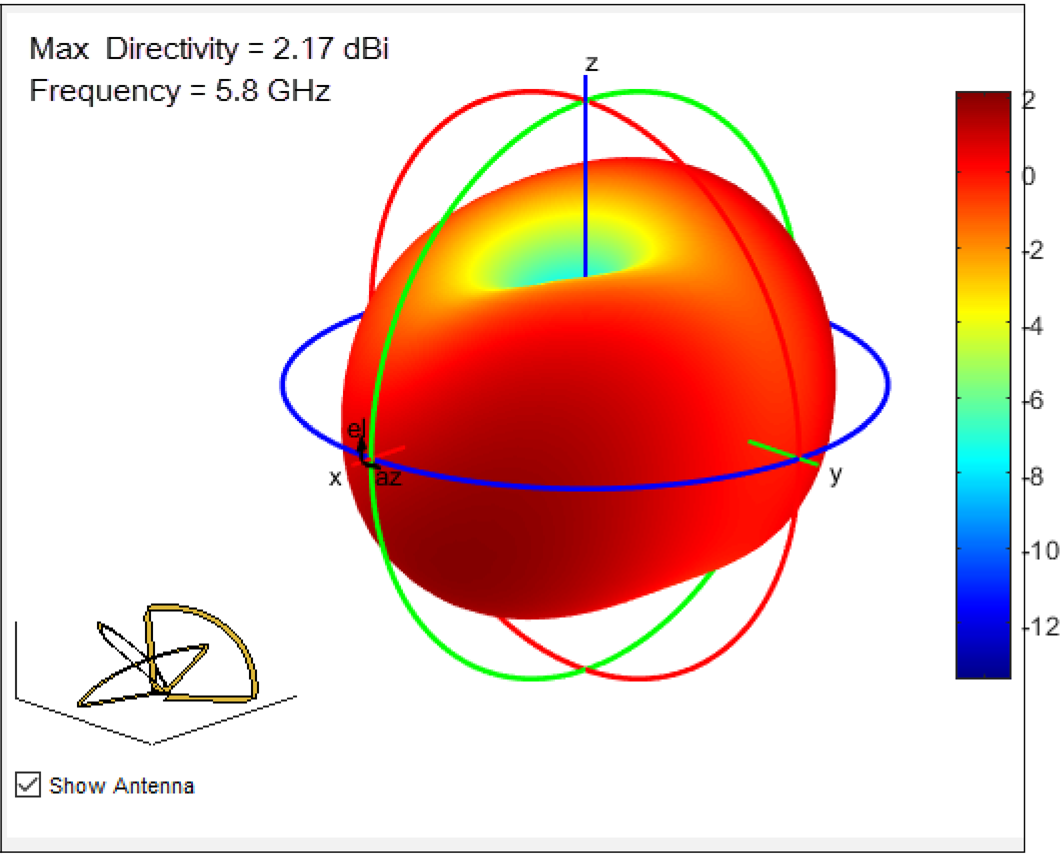
`loopRectangular`	 Max Directivity = 2.6 dBi Frequency = 53 MHz ☑ Show Antenna z x y el az 0 -5 -10 -15 -20 -25 -30

`spiralArchimedean`	 Max Directivity = 5.9 dBi Frequency = 5 GHz ☑ Show Antenna z x y el az 4 2 0 -2 -4 -6 -8

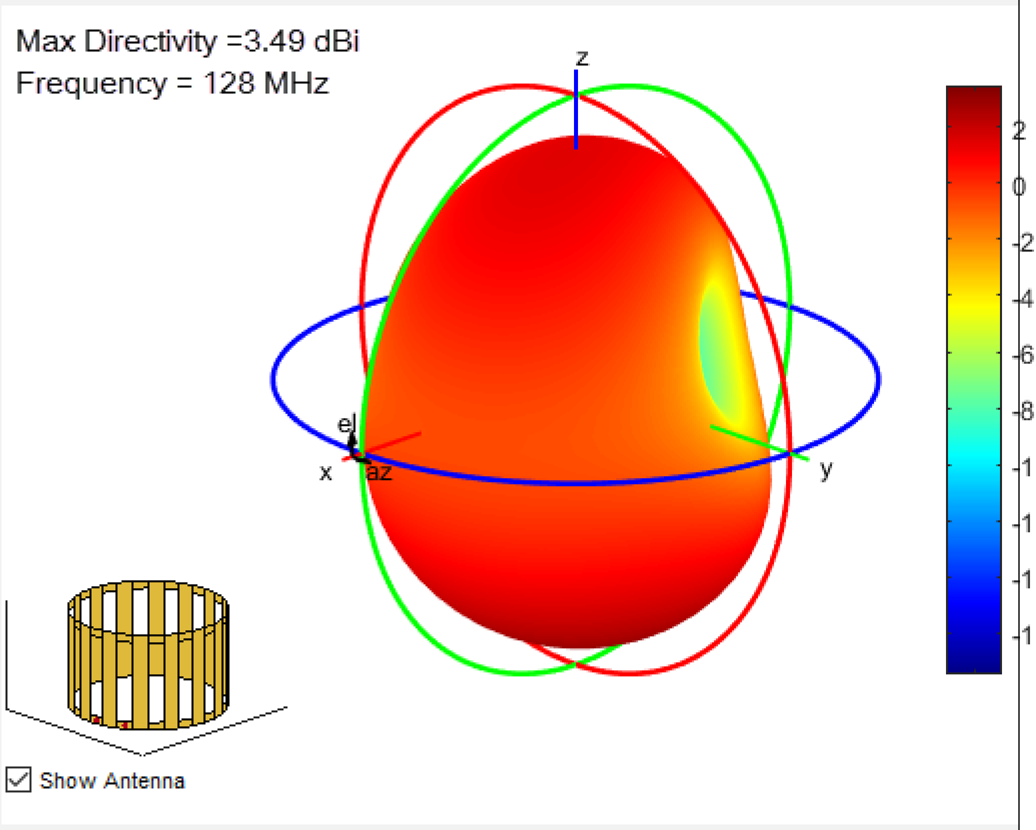
`spiralEquiangular`	

`helix`	Max Directivity = 8.94 dBi Frequency = 2.1 GHz z el x az y 5 0 -5 -10 -15 ☑ Show Antenna

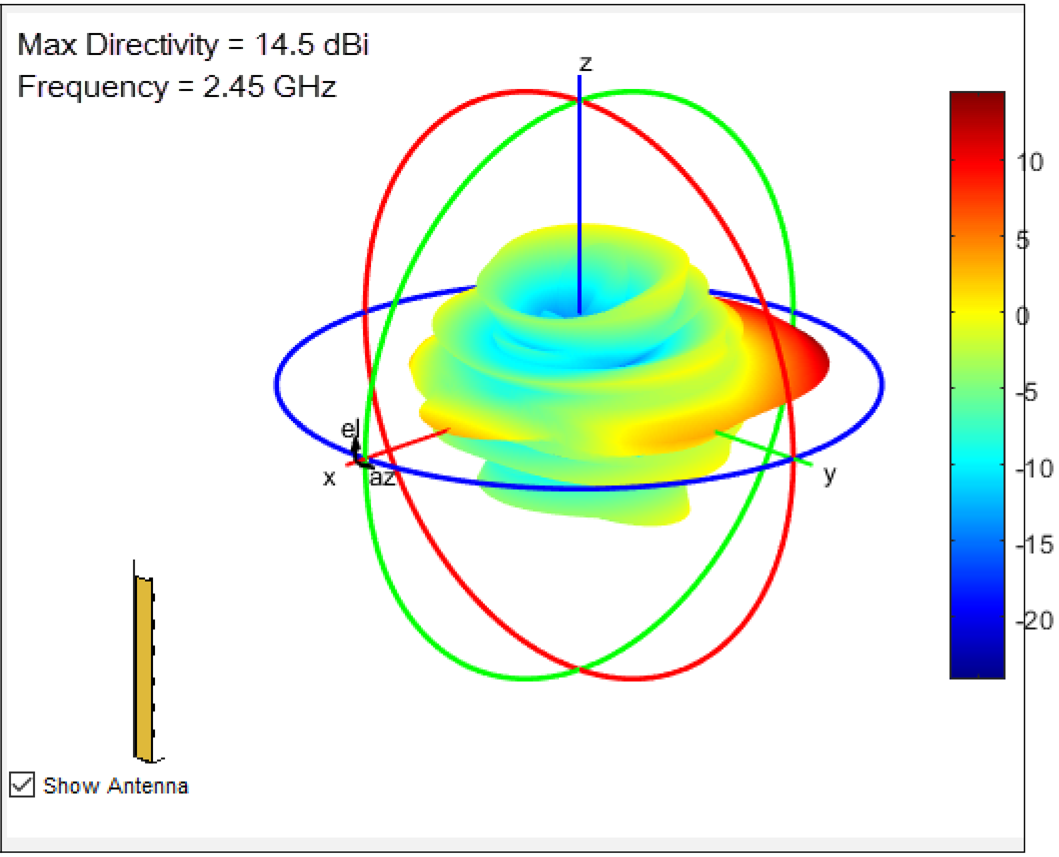
`yagiUda`	 Max Directivity = 9.75 dBi Frequency = 300 MHz z x y el az 5 0 -5 -10 -15 -20 -25 ☑ Show Antenna

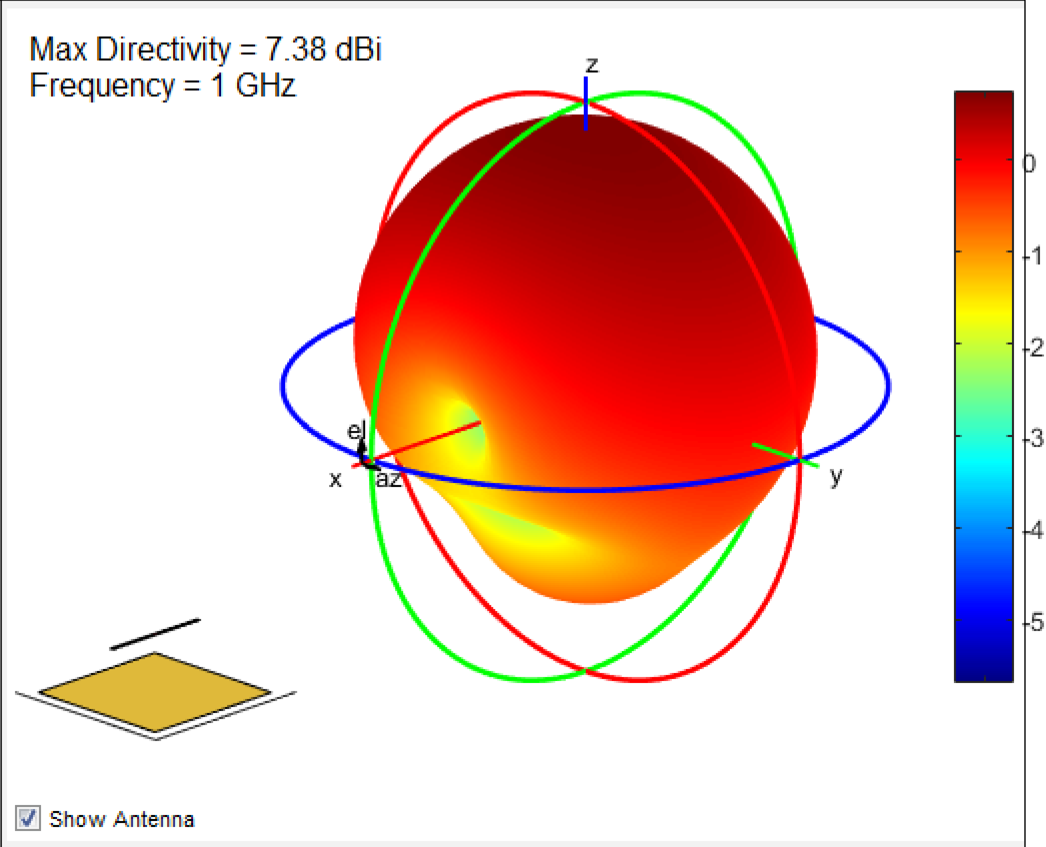
`cloverleaf`	

Max Directivity = 2.17 dBi
Frequency = 5.8 GHz
z
x
y
el
az
2
0
-2
-4
-6
-8
-10
-12
☑ Show Antenna

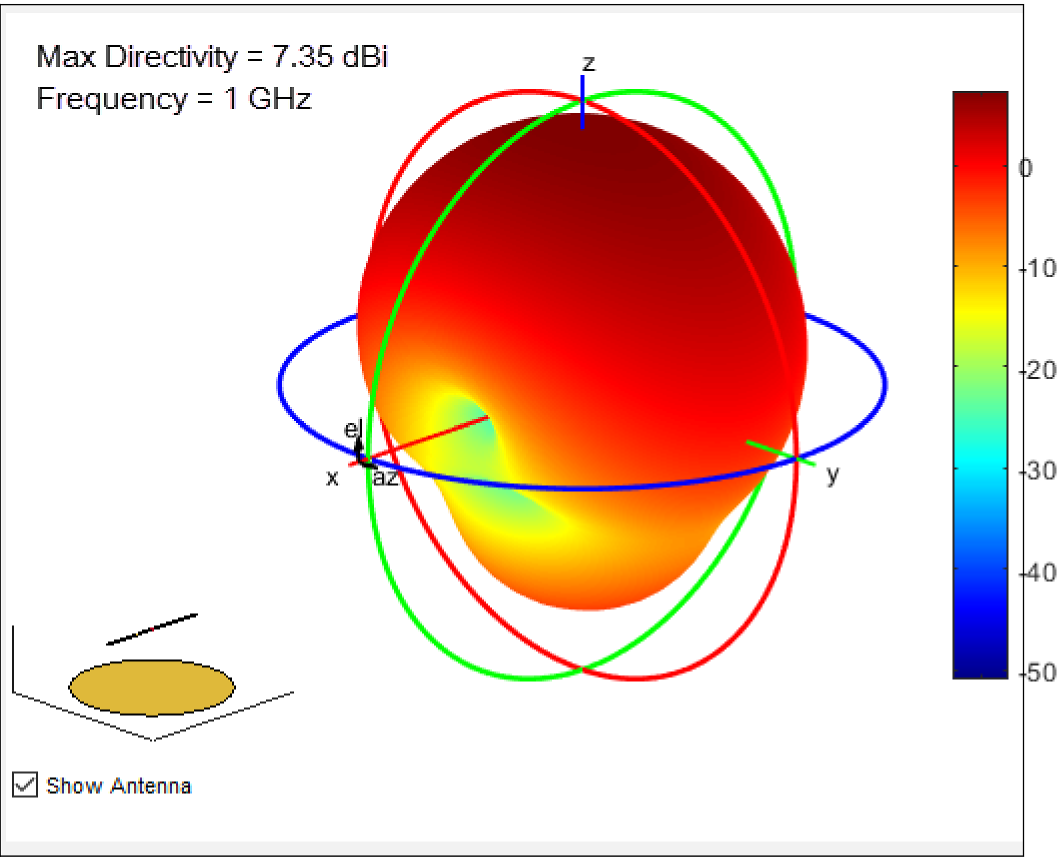
`birdcage`	

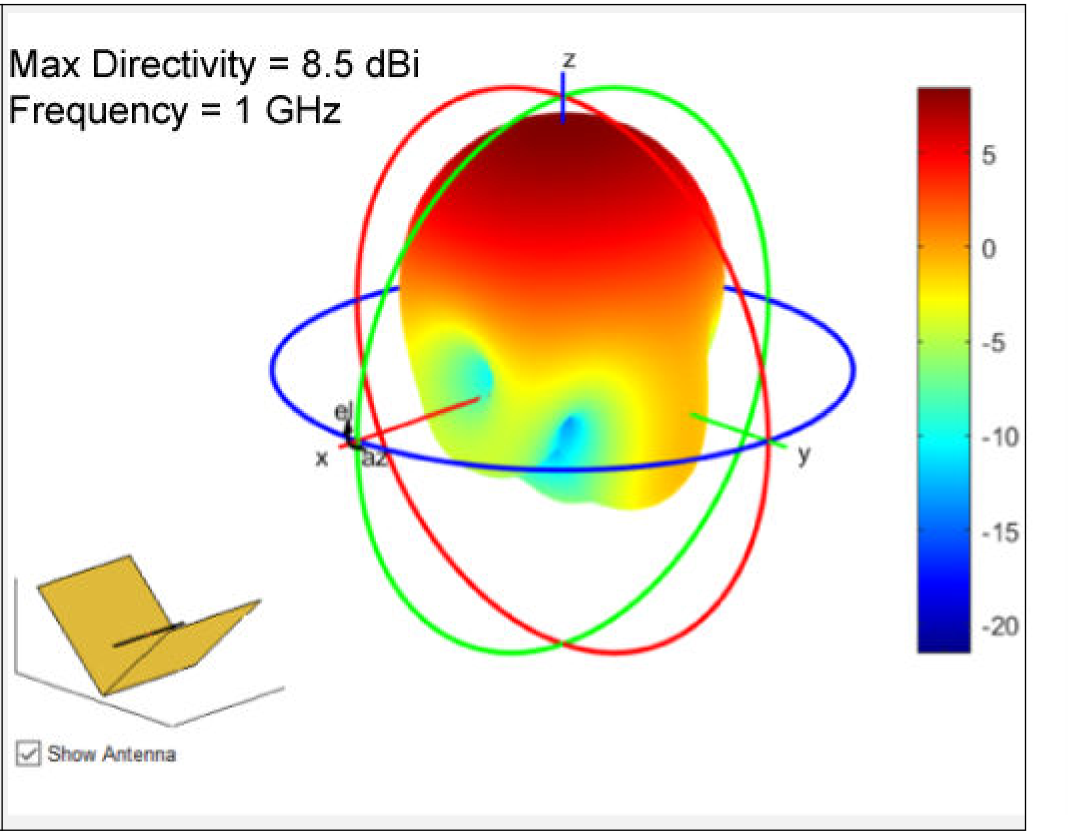
Max Directivity =3.49 dBi
Frequency = 128 MHz
z
x
y
el
az
2
0
-2
-4
-6
-8
-10
-12
-14
-16
☑ Show Antenna

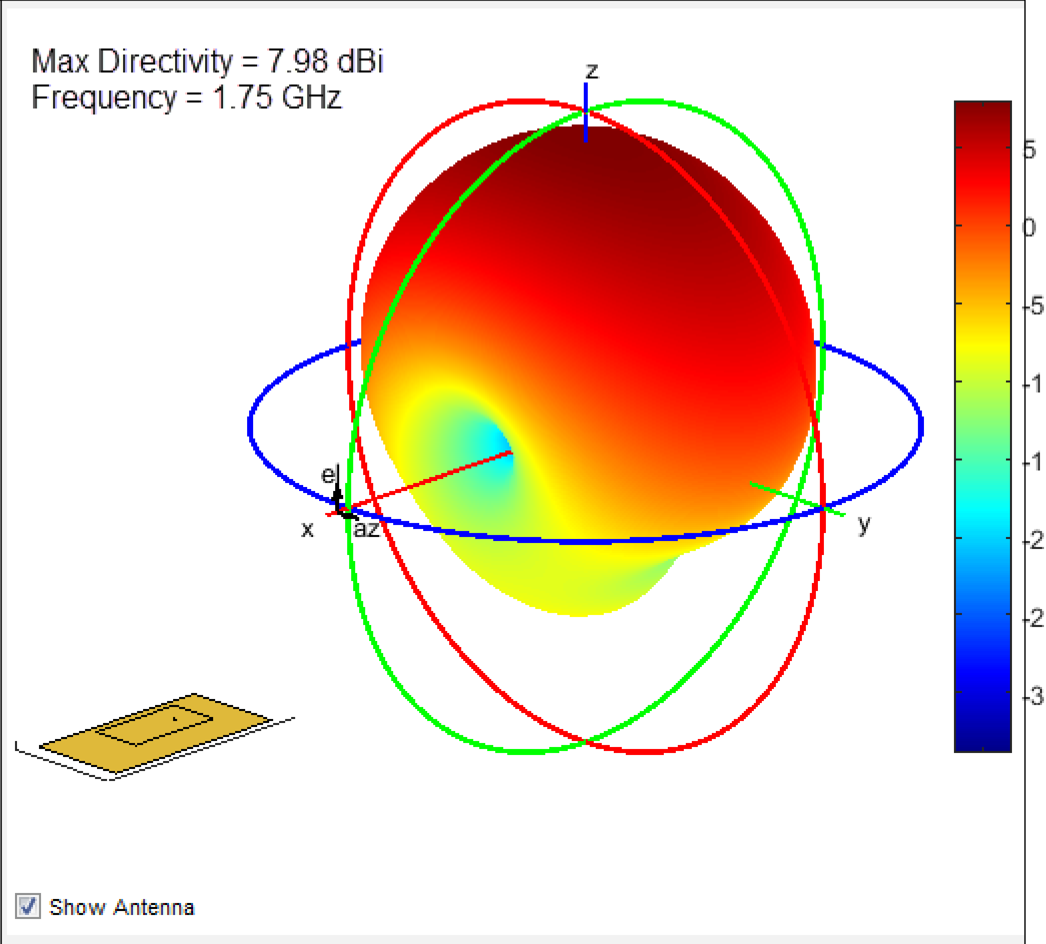
`sectorInvertedAmos`	

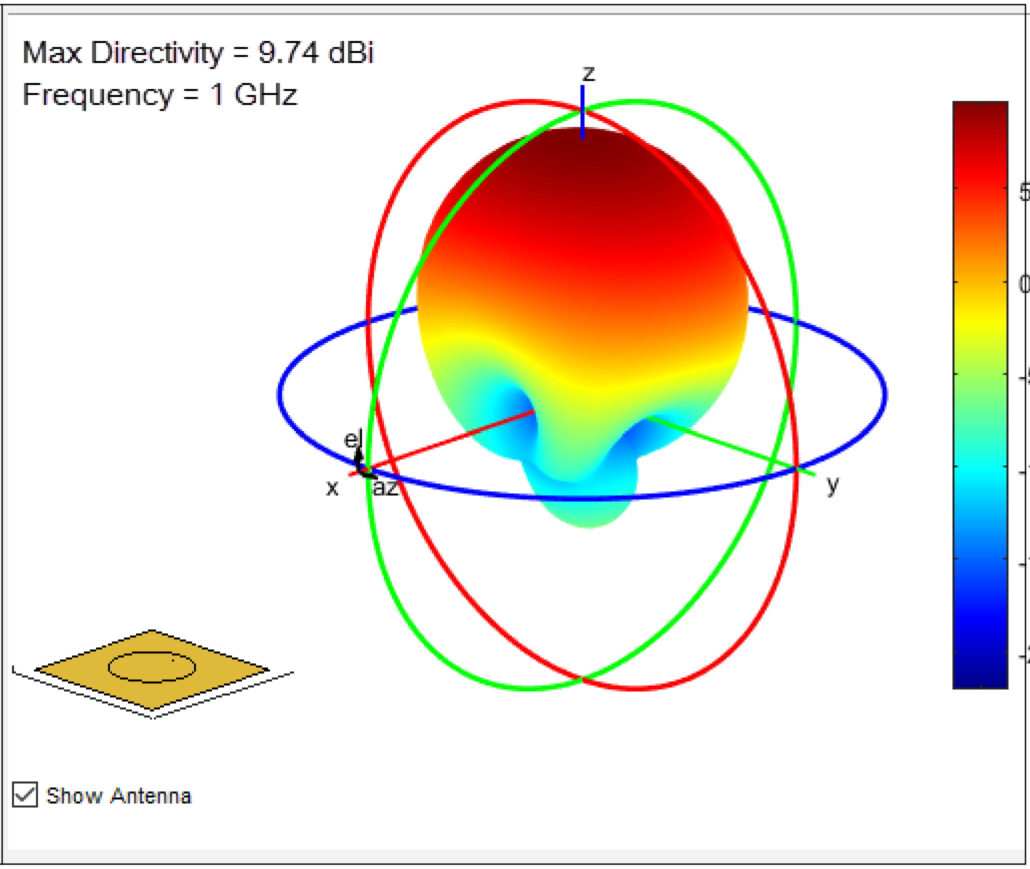
`reflector`	

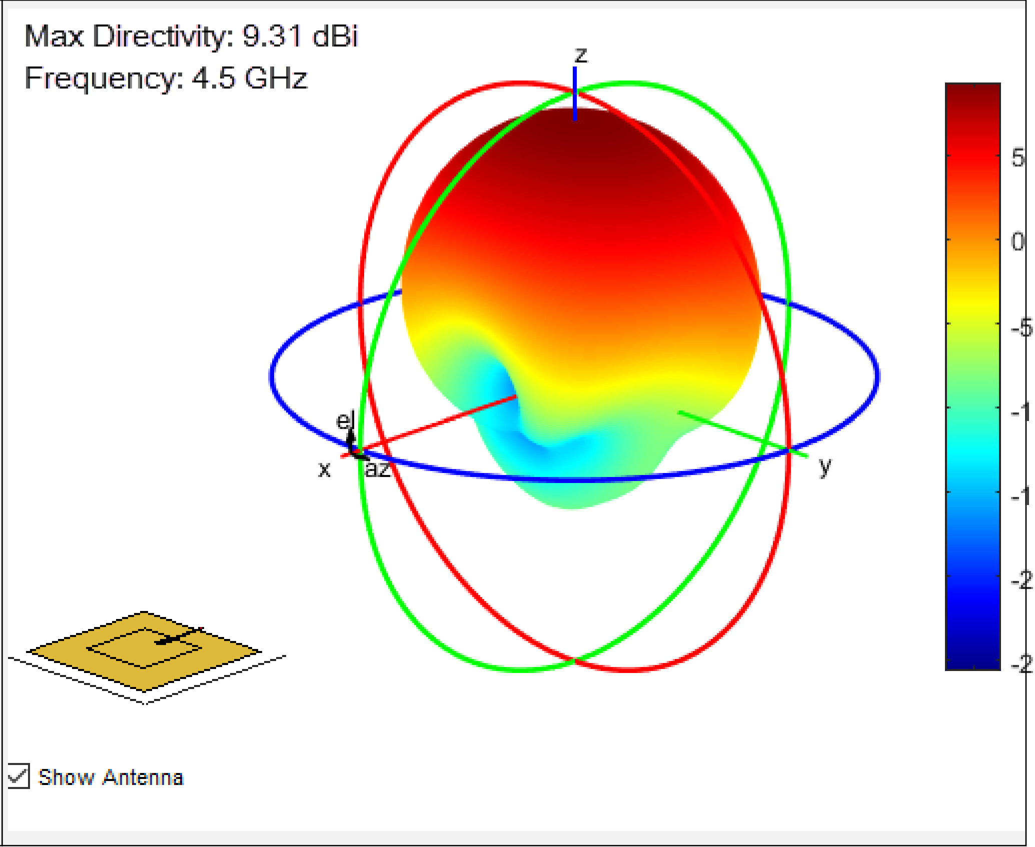
Max Directivity = 7.38 dBi
Frequency = 1 GHz
z
el
x
az
y
0
-10
-20
-30
-40
-50
☑ Show Antenna

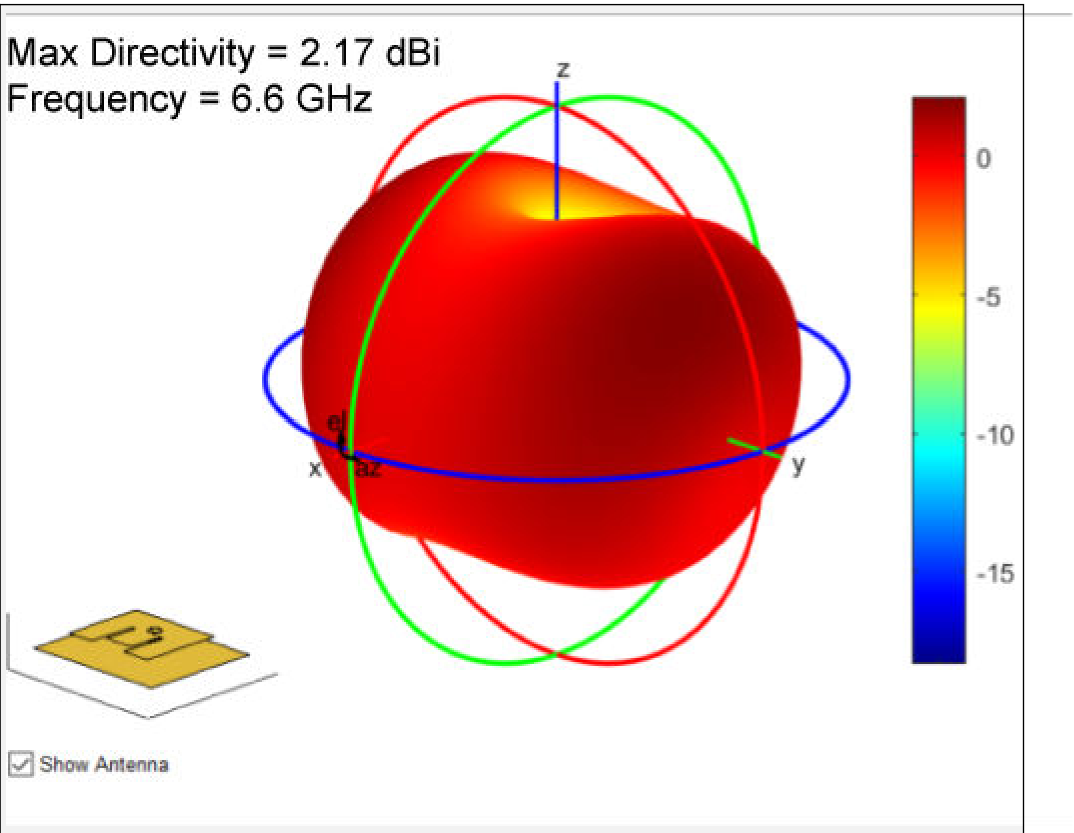
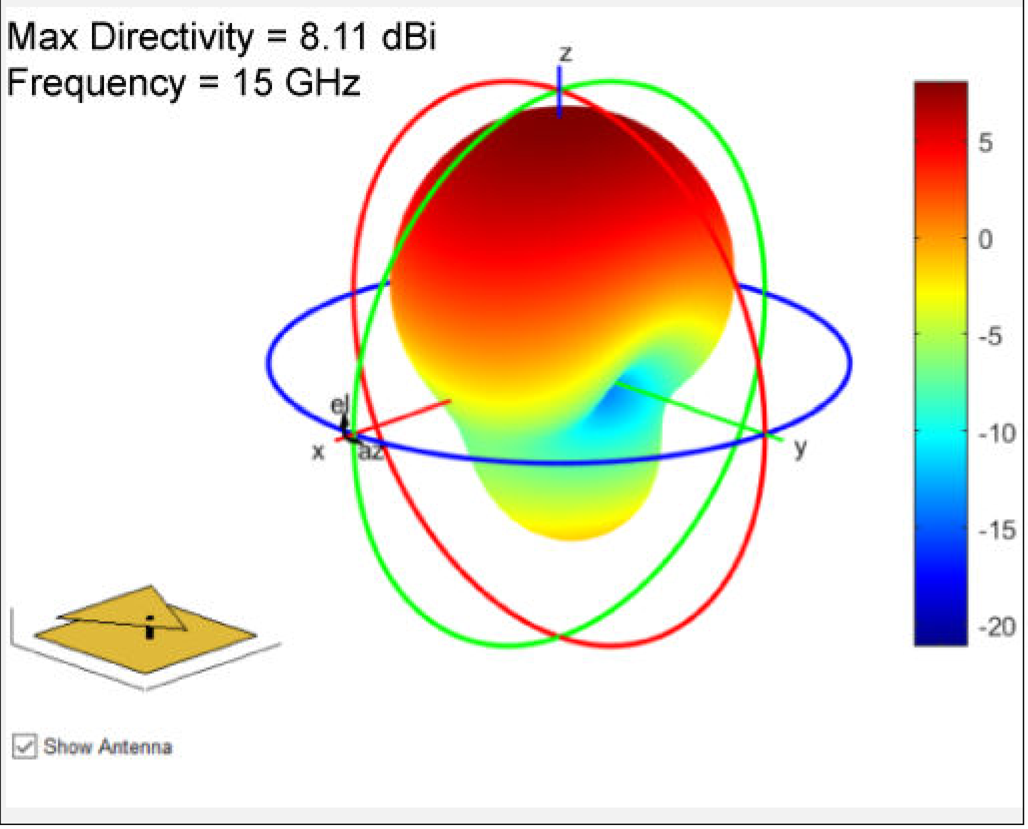
`reflectorCircular`	

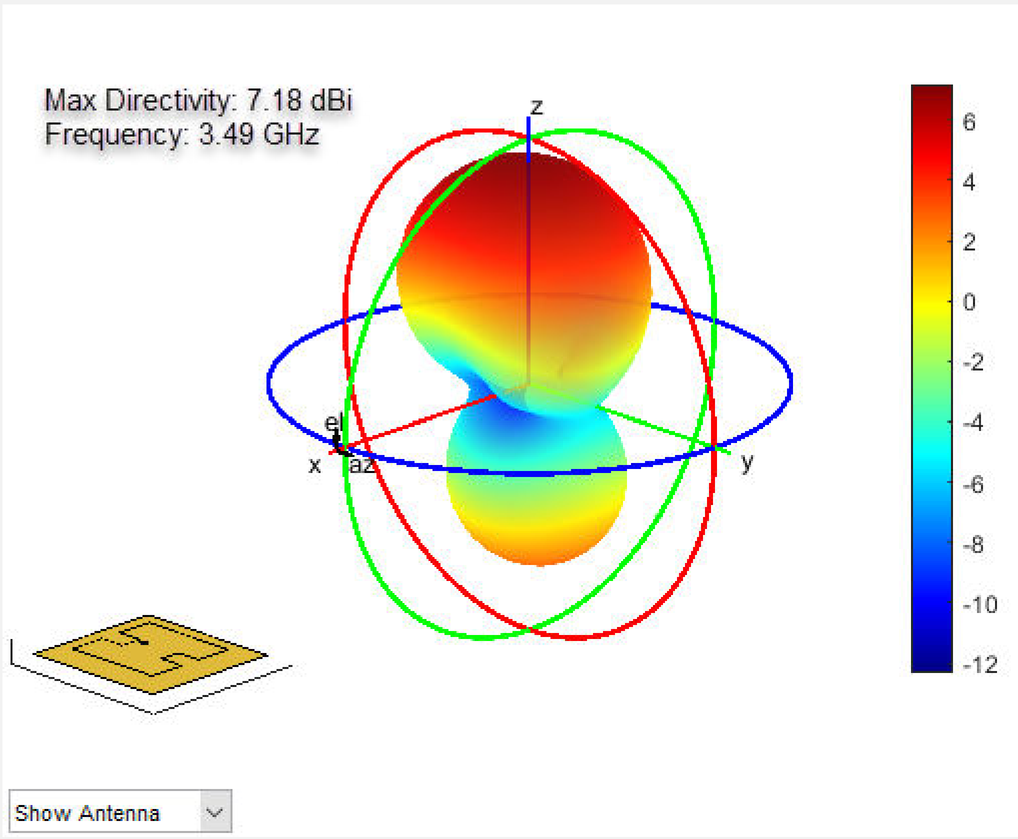
`reflectorCorner`	

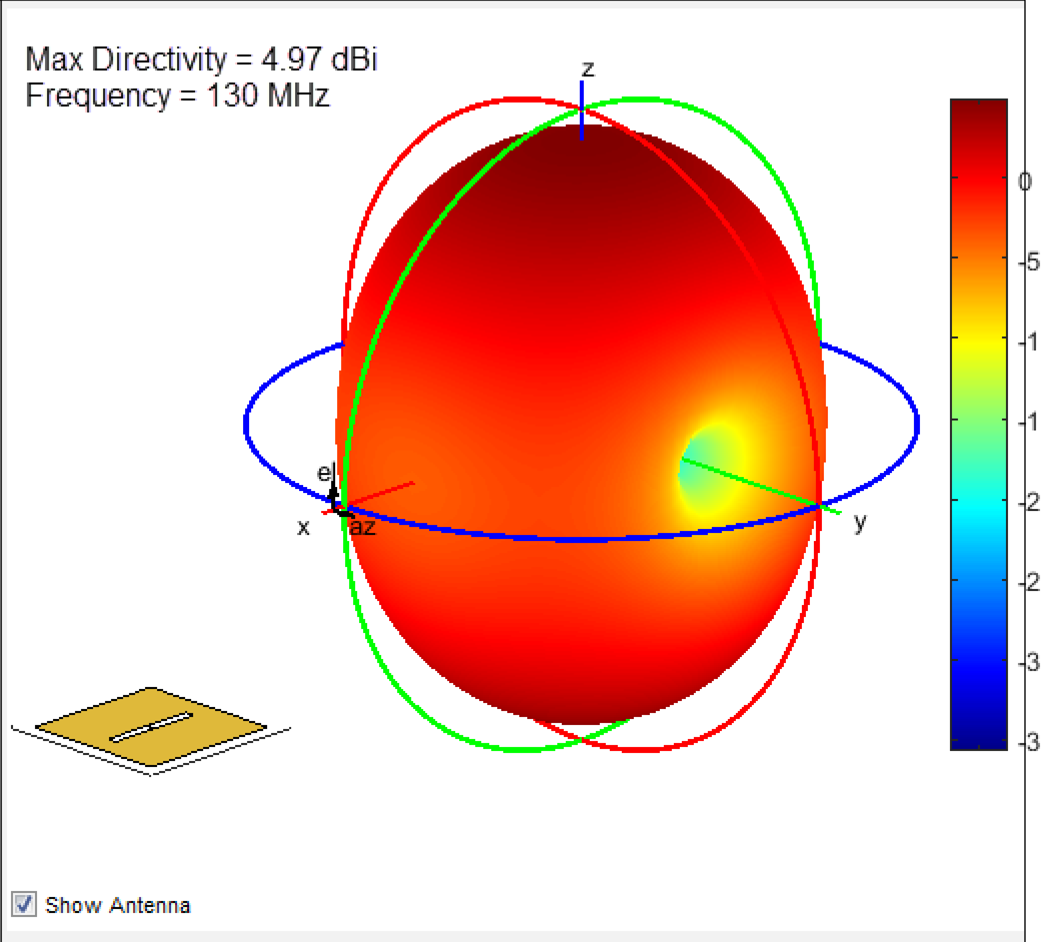
`patchMicrostrip`	

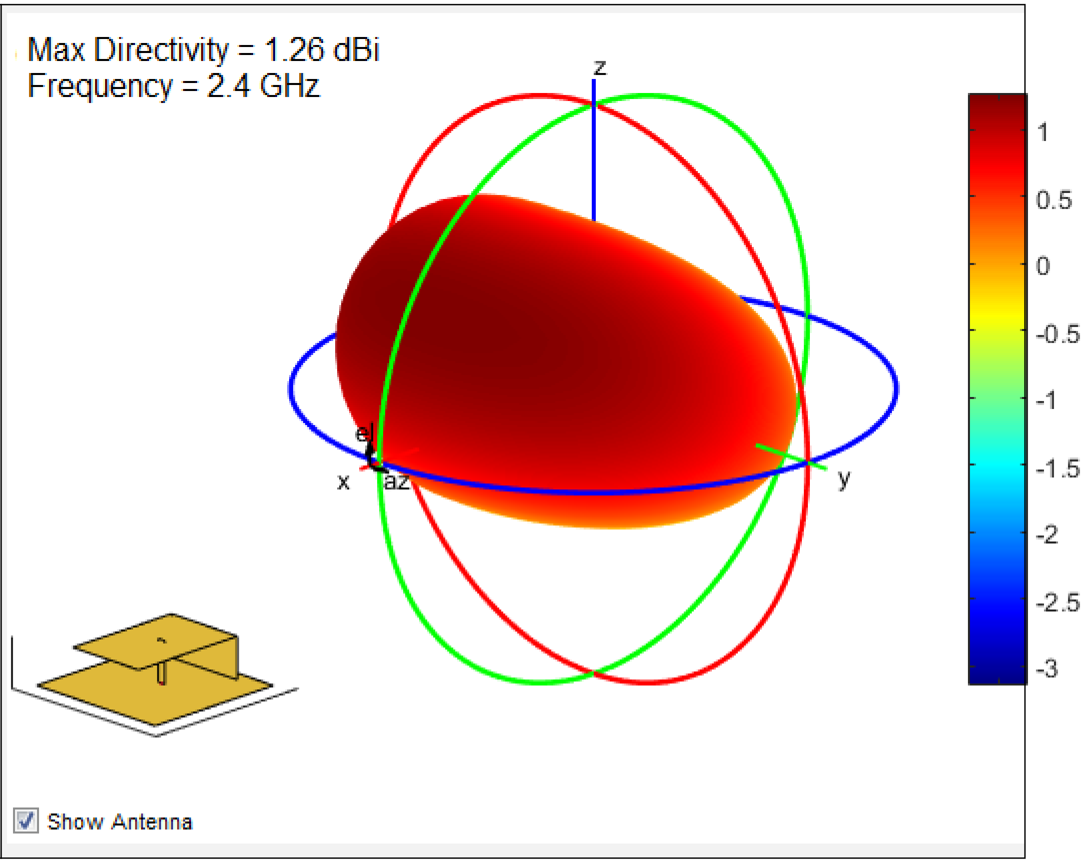
`patchMicrostripCircular`	 Max Directivity = 9.74 dBi Frequency = 1 GHz z x y el az 5 0 -5 -10 -15 -20 ☑ Show Antenna

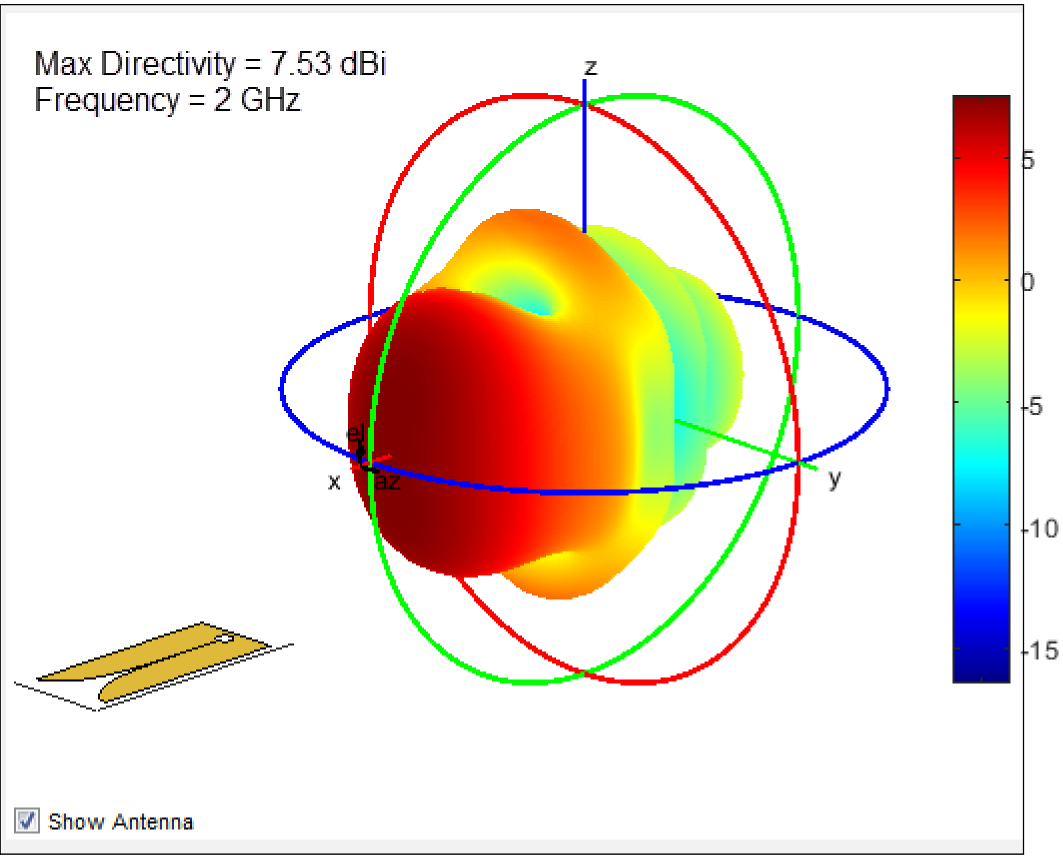
`patchMicrostripInsetfed`	 Max Directivity: 9.31 dBi Frequency: 4.5 GHz ☑ Show Antenna z el x az y 5 0 -5 -10 -15 -20 -25

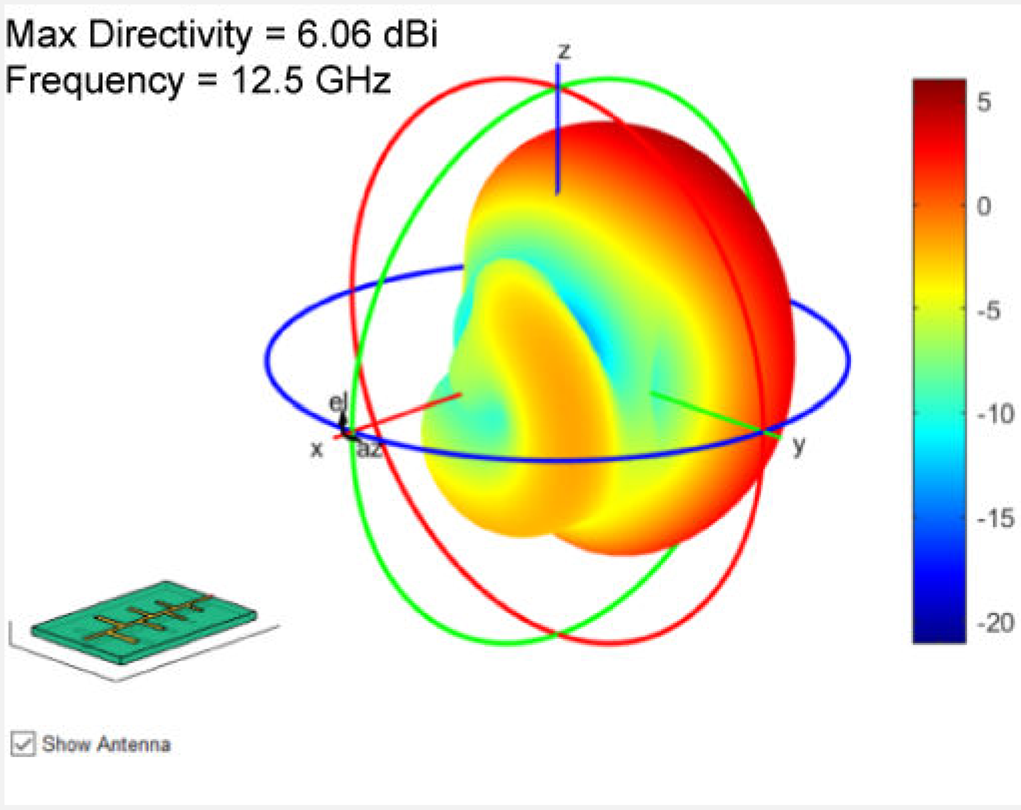
`patchMicrostripEnotch`	 Max Directivity = 2.17 dBi Frequency = 6.6 GHz z el x az y 0 -5 -10 -15 ☑ Show Antenna
`patchMicrostripTriangular`	 Max Directivity = 8.11 dBi Frequency = 15 GHz z el x az y 5 0 -5 -10 -15 -20 ☑ Show Antenna

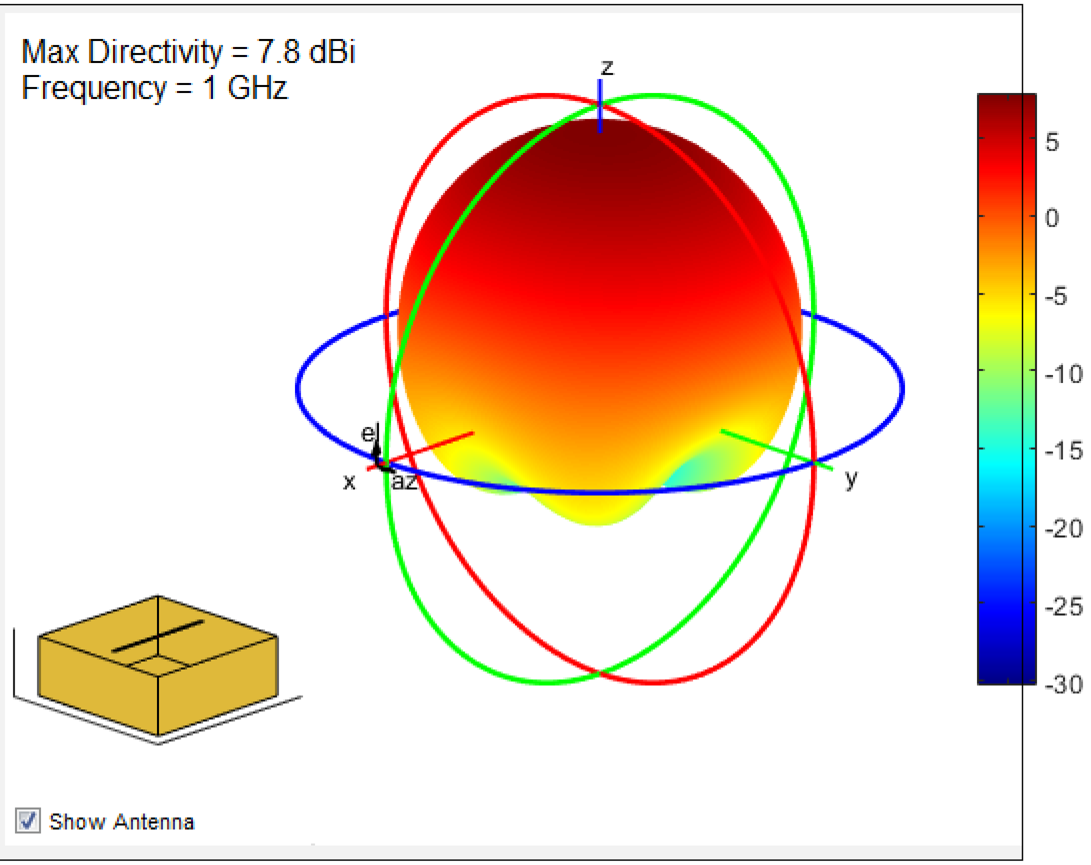
`patchMicrostripHnotch`	

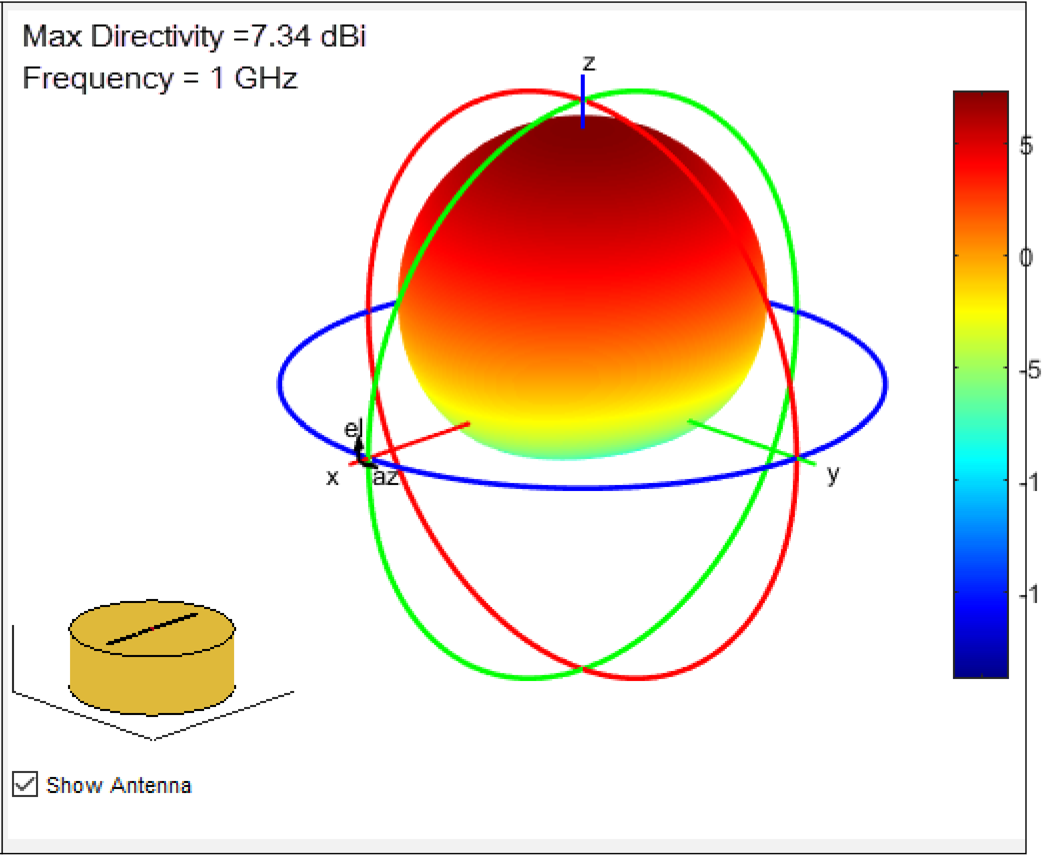
`slot`	 Max Directivity = 4.97 dBi Frequency = 130 MHz z x y el az 0 -5 -10 -15 -20 -25 -30 -35 ☑ Show Antenna

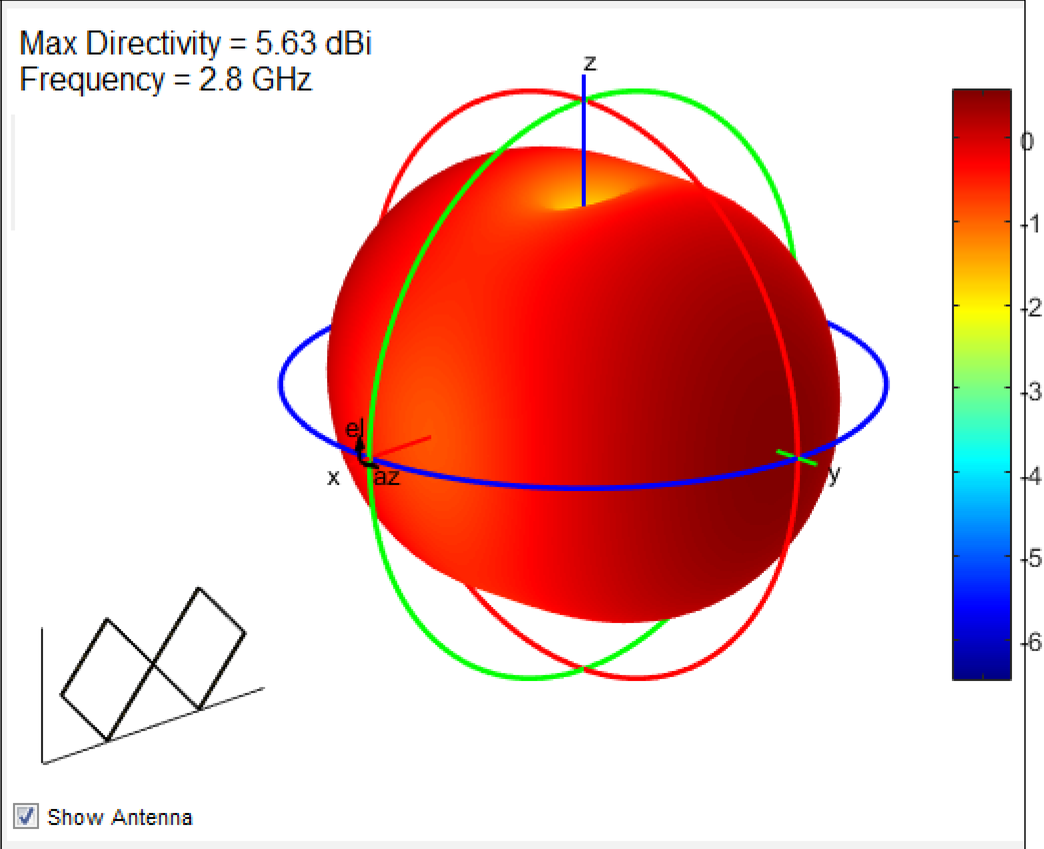
`pifa`	 Max Directivity = 1.26 dBi Frequency = 2.4 GHz ☑ Show Antenna

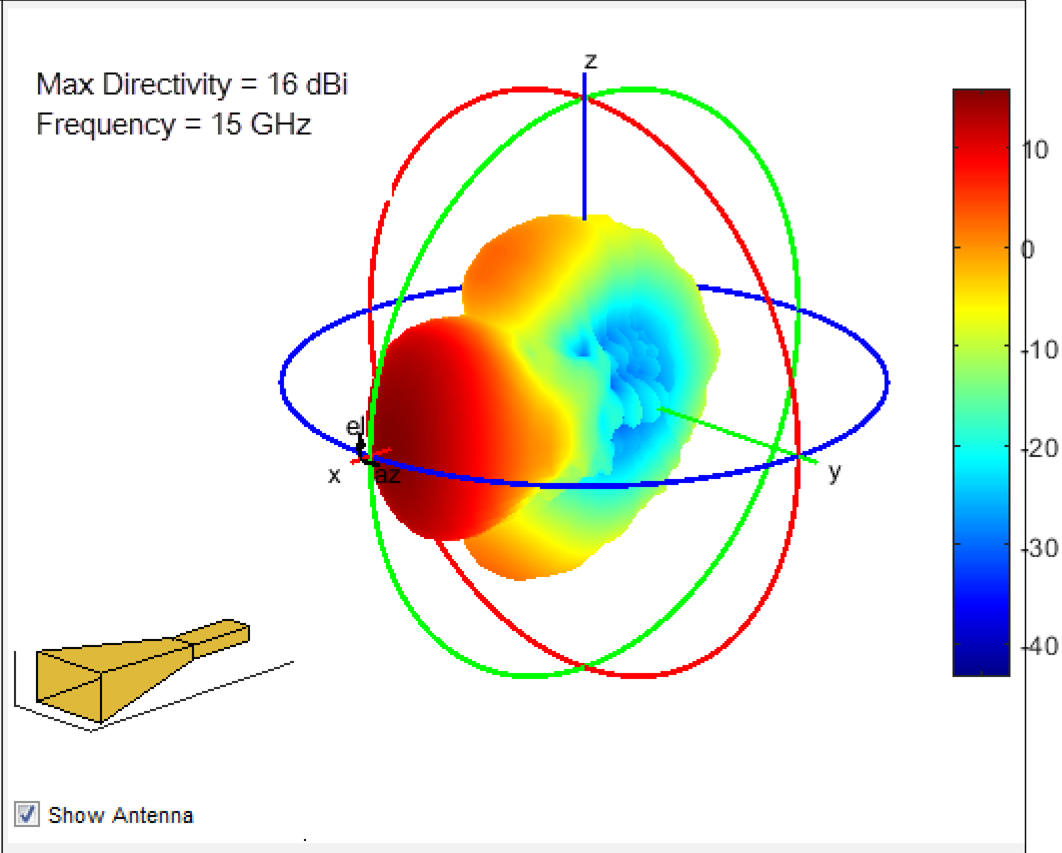
`vivaldi`	Max Directivity = 7.53 dBi Frequency = 2 GHz z x y el az 5 0 -5 -10 -15 ☑ Show Antenna

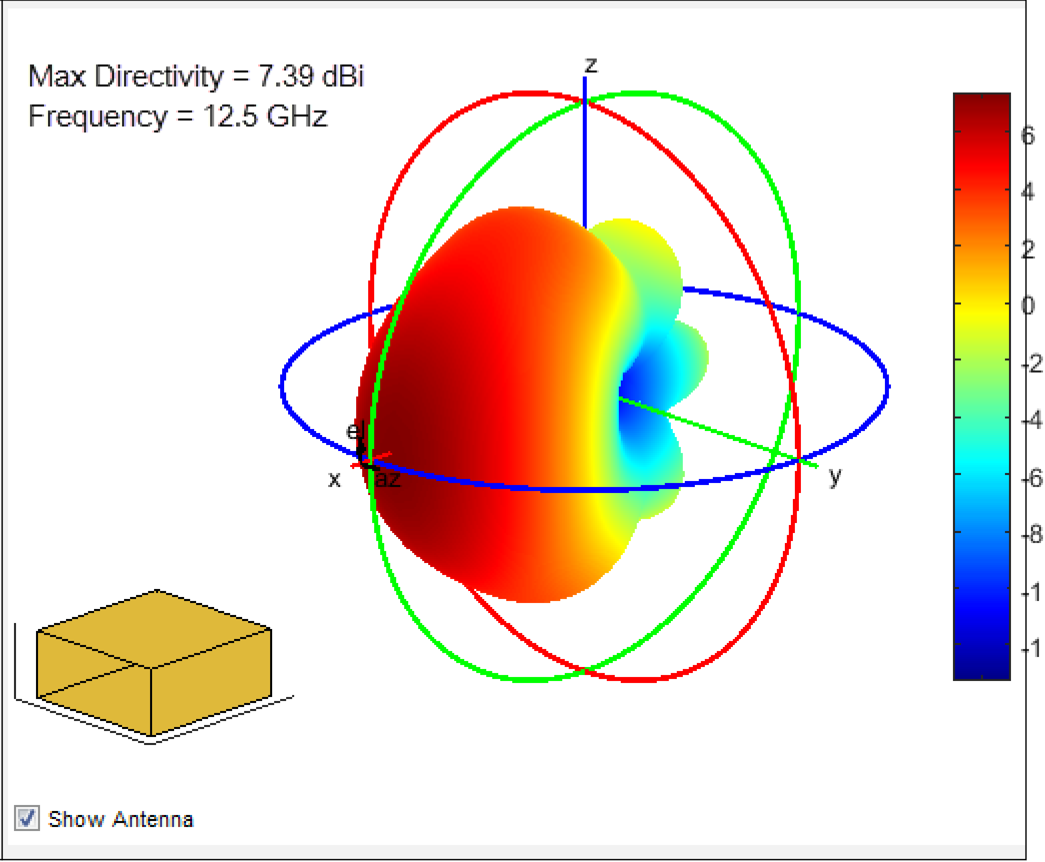
`lpda`	 Max Directivity = 6.06 dBi Frequency = 12.5 GHz ☑ Show Antenna

`cavity`	Max Directivity = 7.8 dBi Frequency = 1 GHz z x y el az 5 0 -5 -10 -15 -20 -25 -30 ☑ Show Antenna

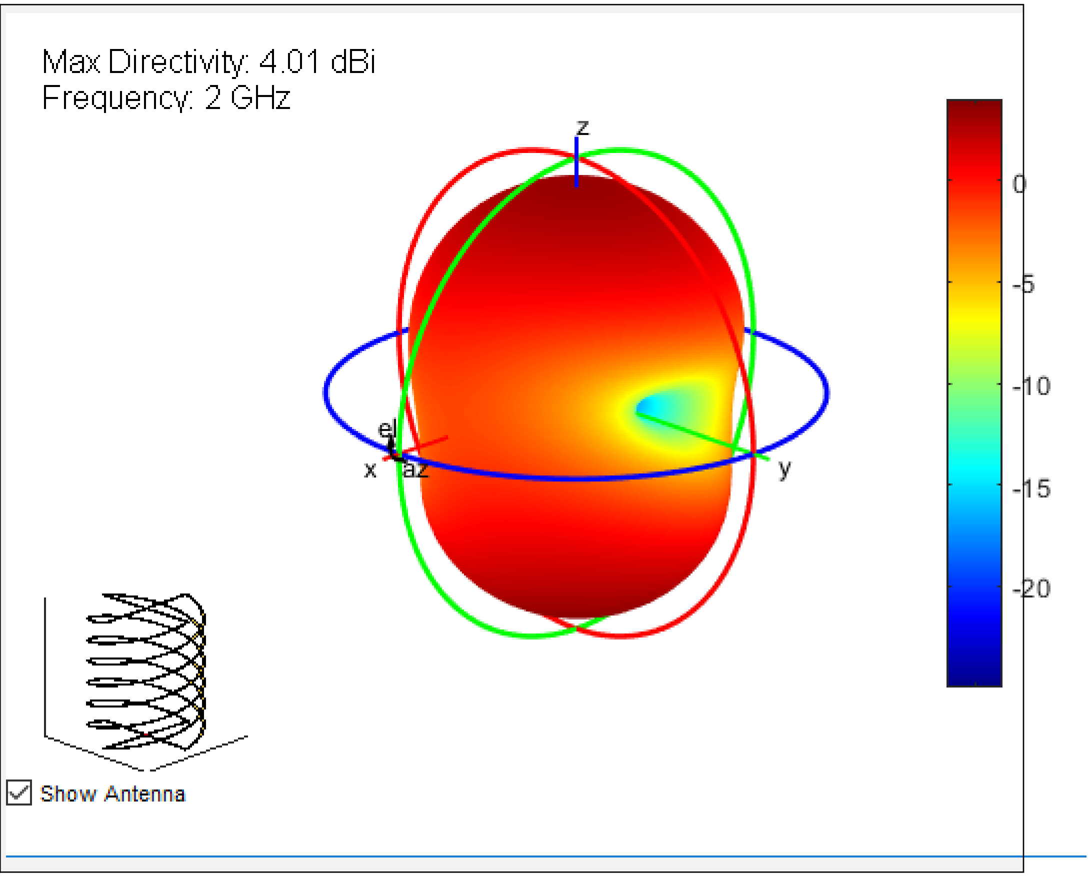
`cavityCircular`	 Max Directivity =7.34 dBi Frequency = 1 GHz z x y el az 5 0 -5 -10 -15 ☑ Show Antenna

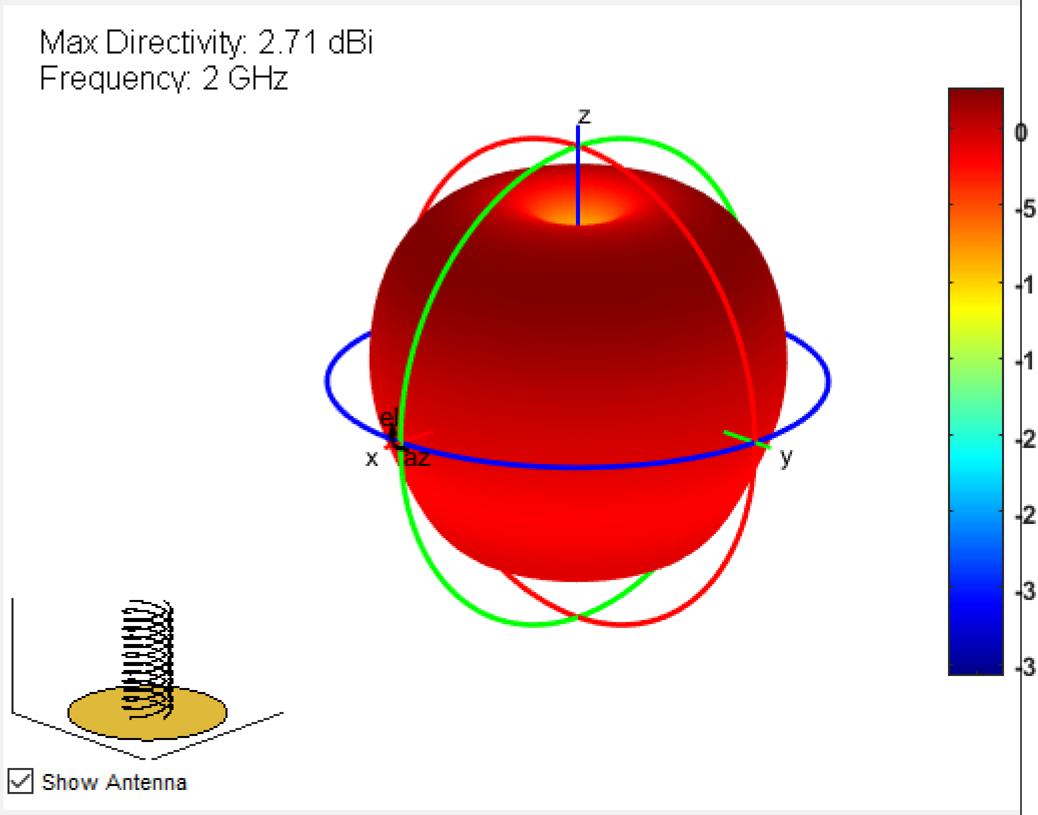
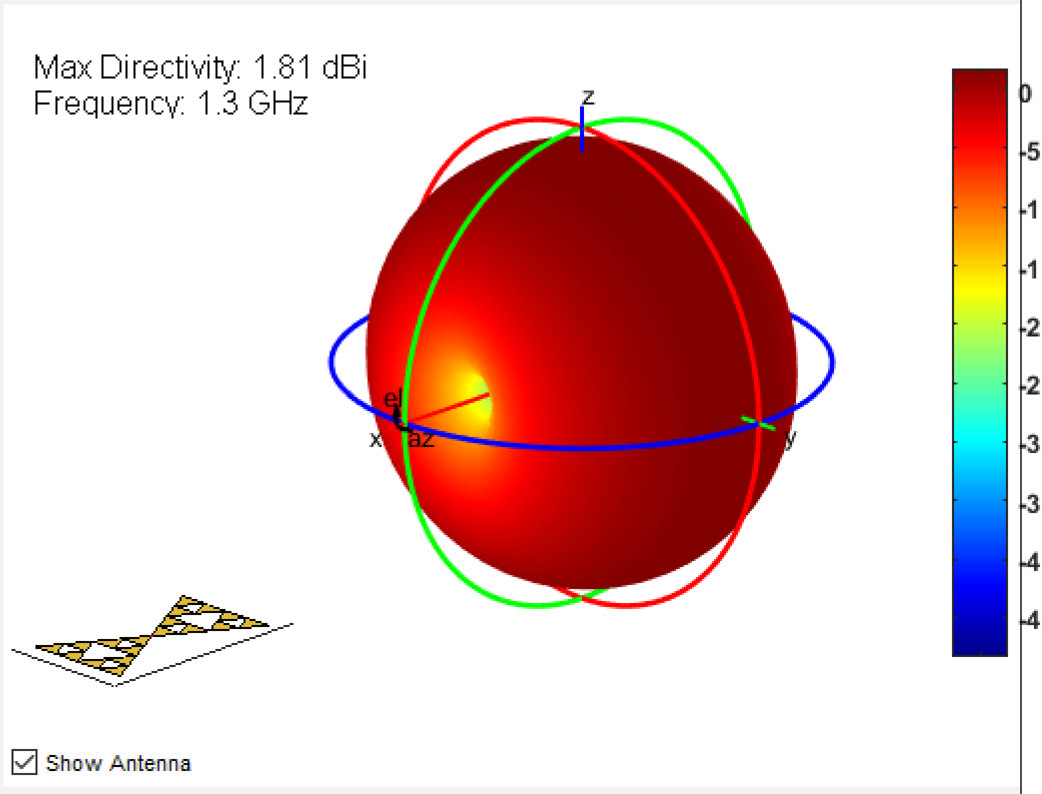
`biquad`	 Max Directivity = 5.63 dBi Frequency = 2.8 GHz ☑ Show Antenna z x y el az 0 -10 -20 -30 -40 -50 -60

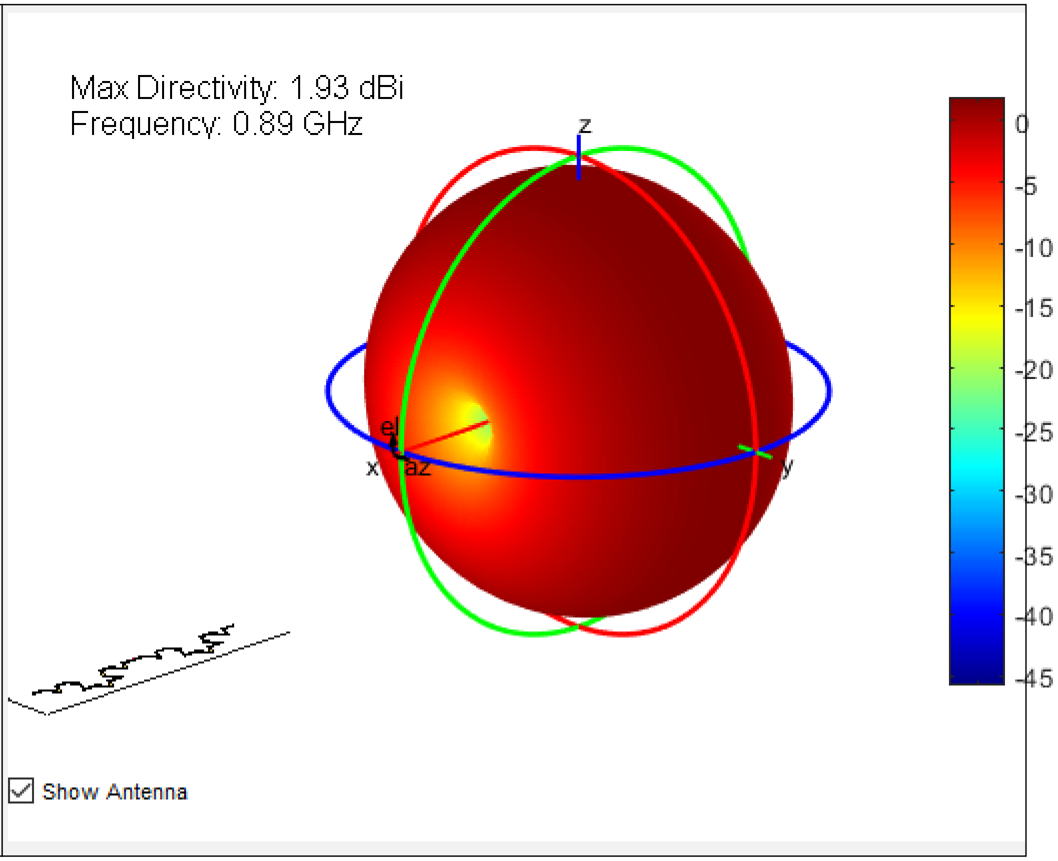
horn	 Max Directivity = 16 dBi Frequency = 15 GHz ☑ Show Antenna

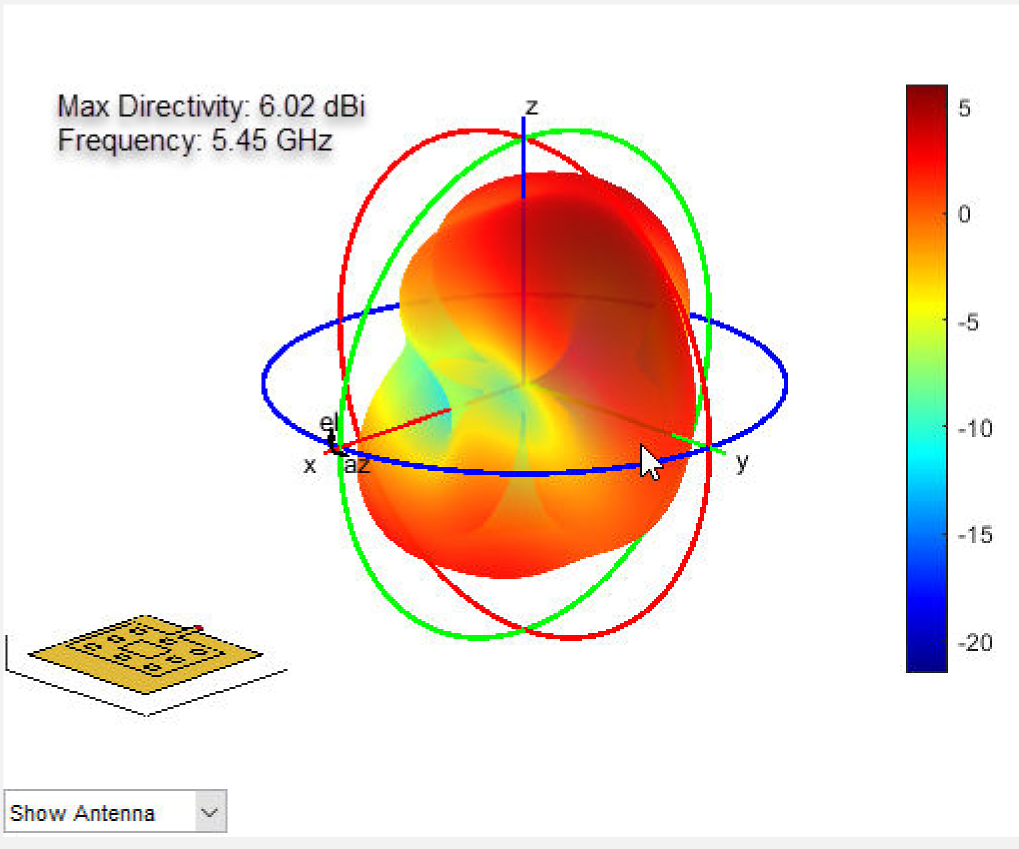
`waveguide`	

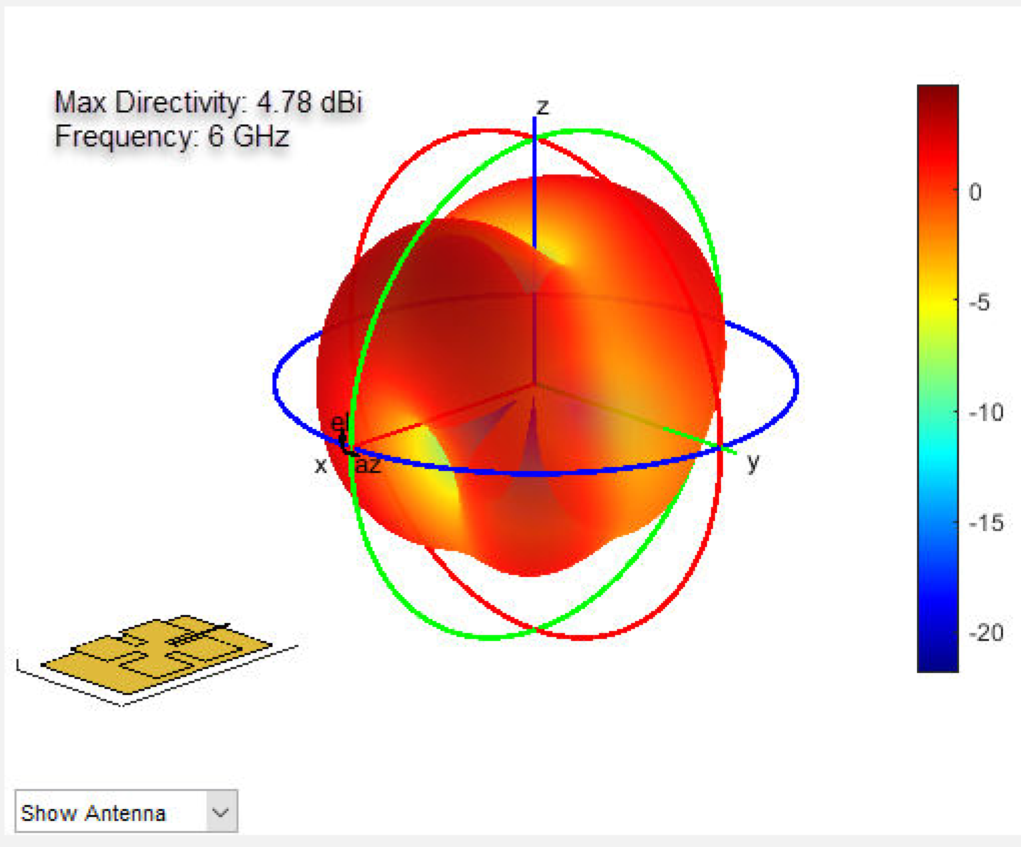
Max Directivity = 7.39 dBi
Frequency = 12.5 GHz
z
x
y
el
az
6
4
2
0
-2
-4
-6
-8
-10
-12
☑ Show Antenna

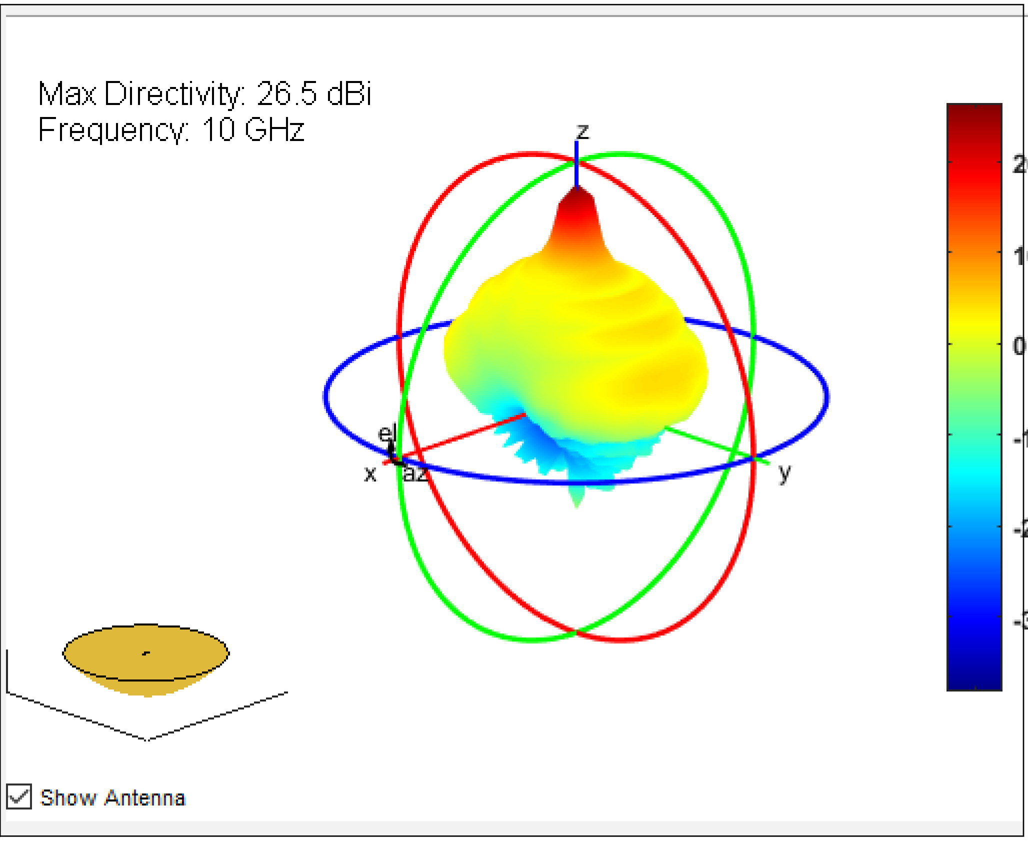
`dipoleHelixMultifilar`	 Max Directivity: 4.01 dBi Frequency: 2 GHz ☑ Show Antenna

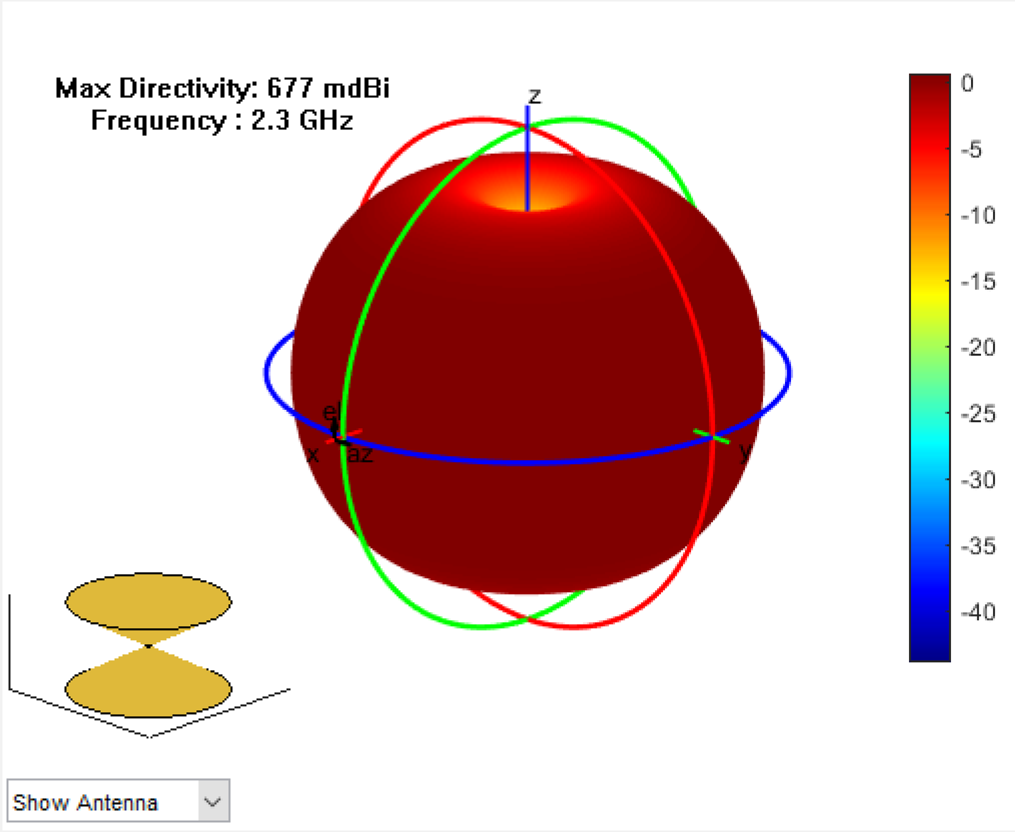
`helixMultifilar`	 Max Directivity: 2.71 dBi Frequency: 2 GHz ☑ Show Antenna z x y el az 0 -5 -10 -15 -20 -25 -30 -35
`fractalGasket`	 Max Directivity: 1.81 dBi Frequency: 1.3 GHz ☑ Show Antenna z x y el az 0 -5 -10 -15 -20 -25 -30 -35 -40 -45

`fractalKoch`	 Max Directivity: 1.93 dBi Frequency: 0.89 GHz z el x az y 0 -5 -10 -15 -20 -25 -30 -35 -40 -45 ☑ Show Antenna

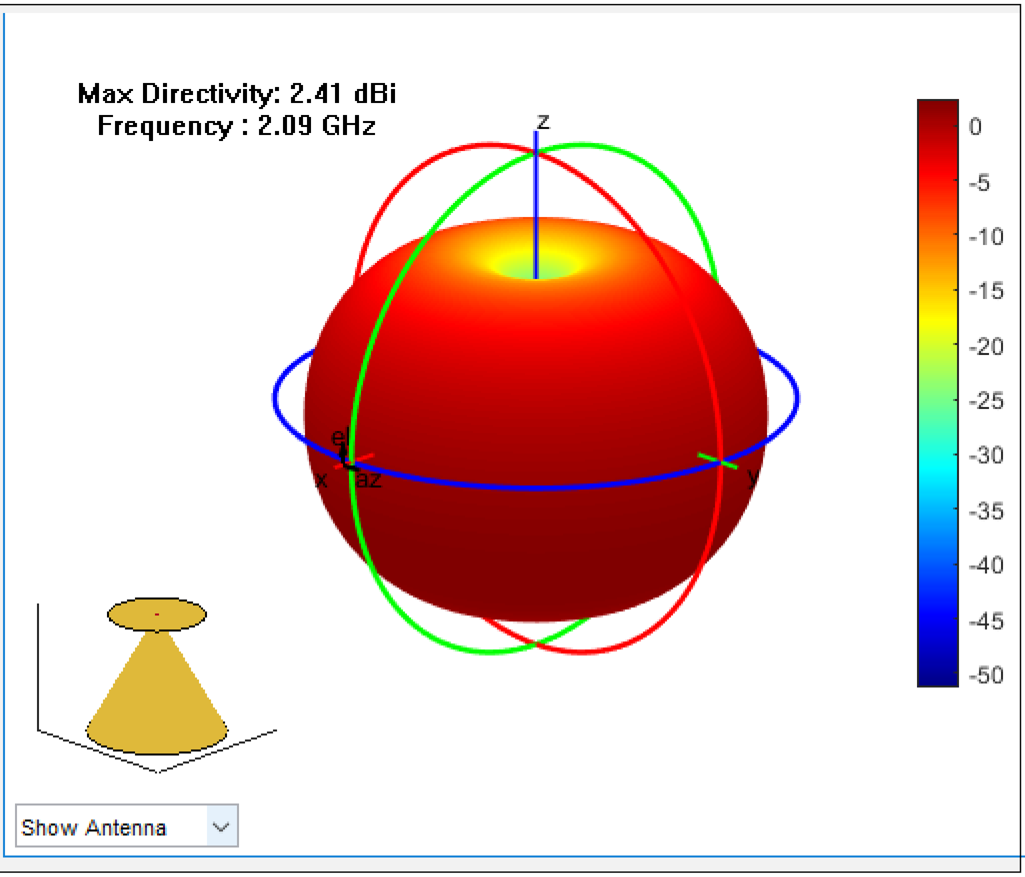
`fractalCarpet`	 Max Directivity: 6.02 dBi Frequency: 5.45 GHz z x y el az 5 0 -5 -10 -15 -20 Show Antenna

`fractalIsland`	

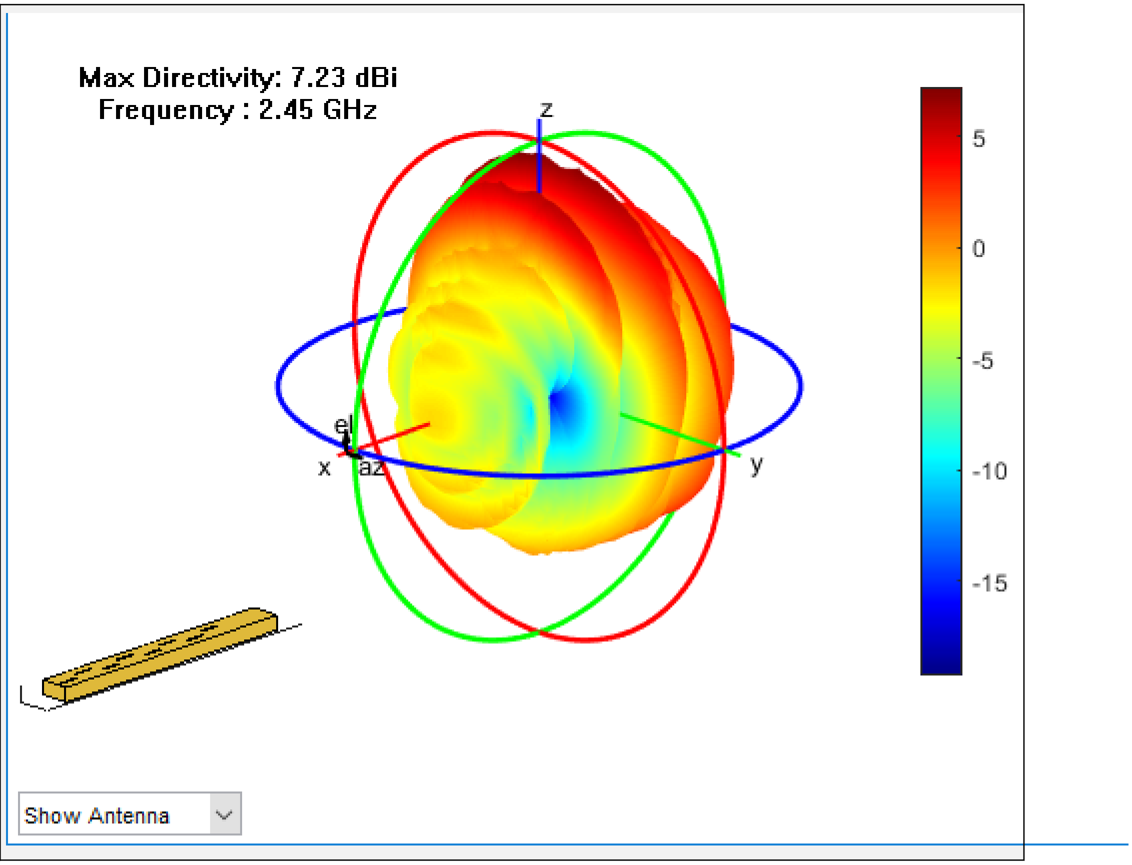
reflectorParabolic	 Max Directivity: 26.5 dBi Frequency: 10 GHz z el x az y 20 10 0 -10 -20 -30 ☑ Show Antenna

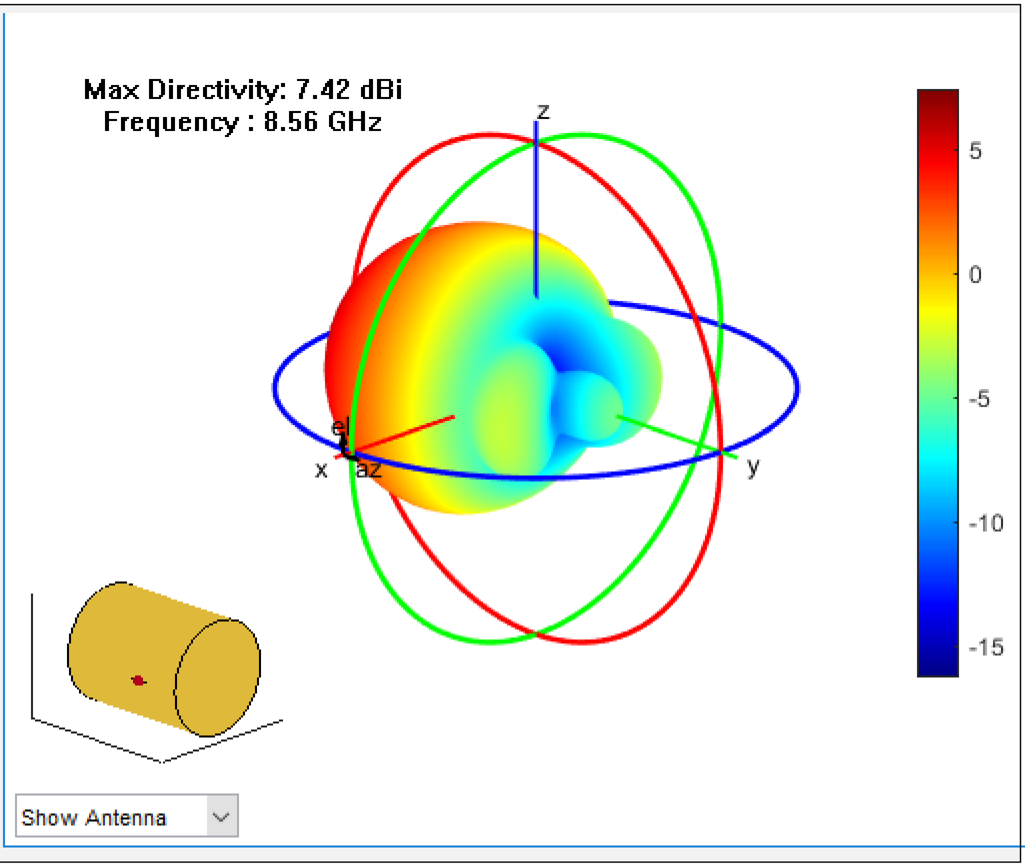
`bicone`	

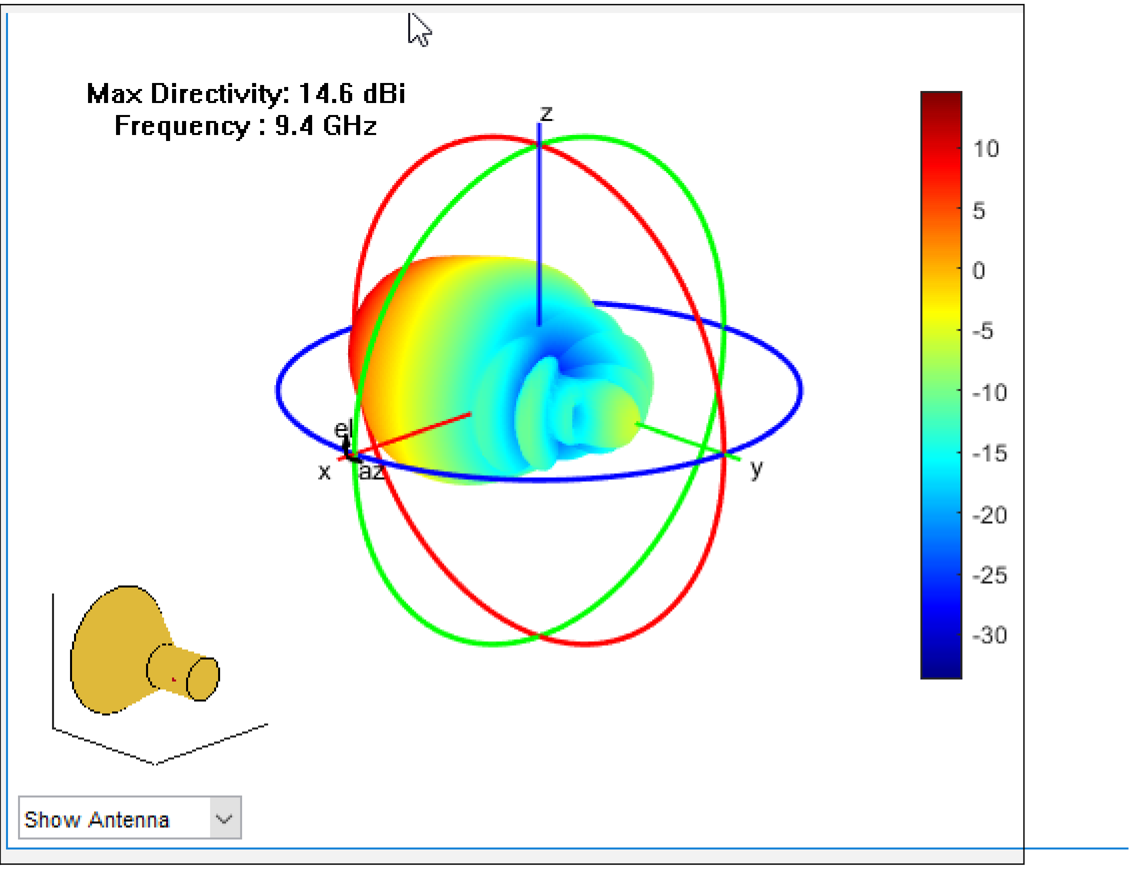
Max Directivity: 677 mdBi
Frequency : 2.3 GHz
z
el
x
az
y
0
-5
-10
-15
-20
-25
-30
-35
-40
Show Antenna

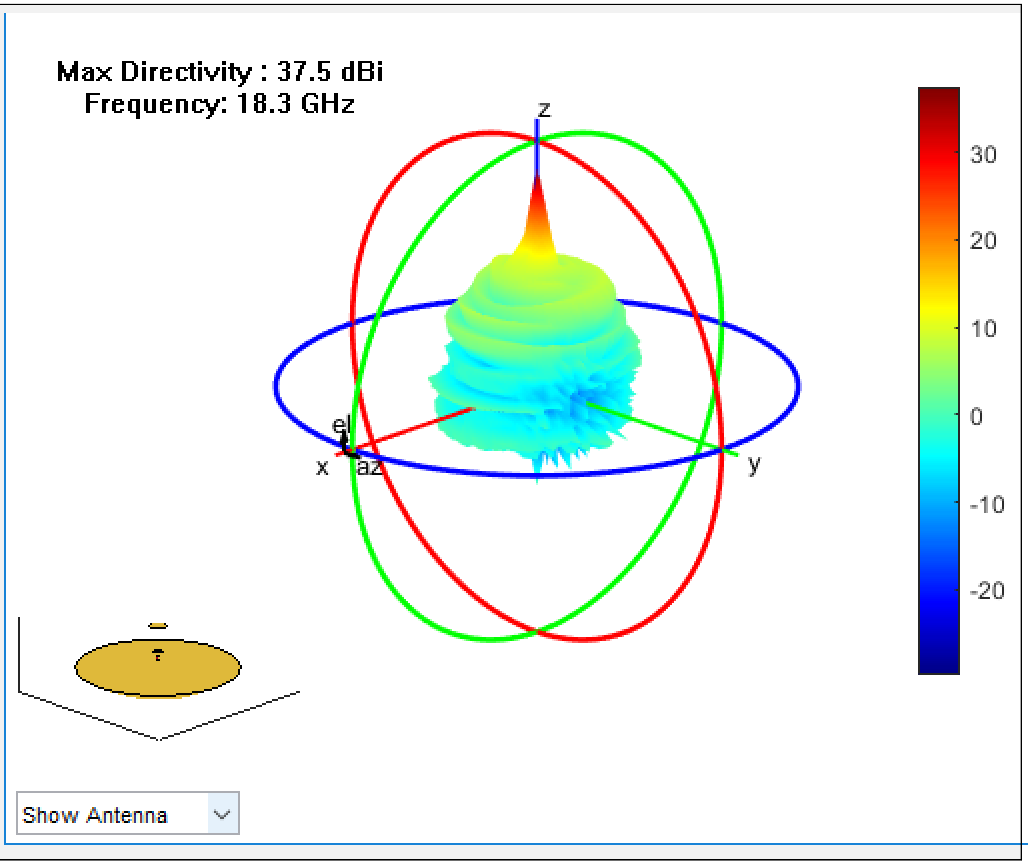
discone	

Max Directivity: 2.41 dBi
Frequency : 2.09 GHz
z
el
x
az
y
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
Show Antenna

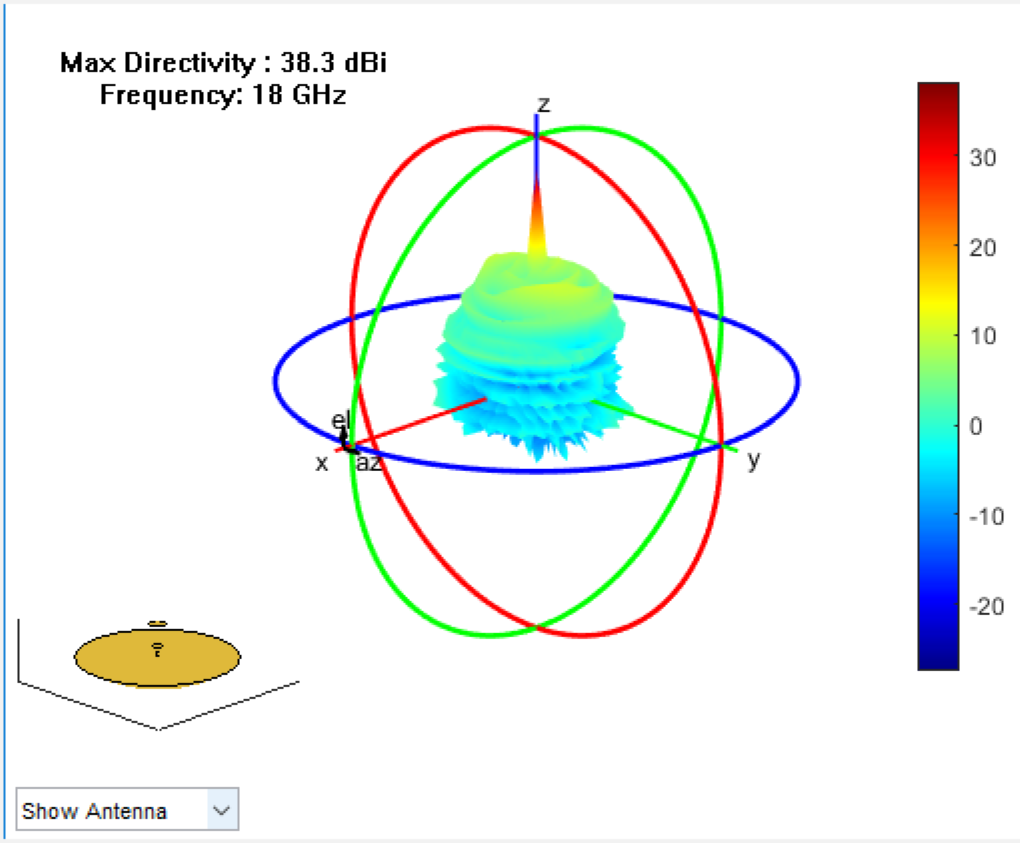
waveguideSlotted	 Max Directivity: 7.23 dBi Frequency : 2.45 GHz z el x az y 5 0 -5 -10 -15 Show Antenna

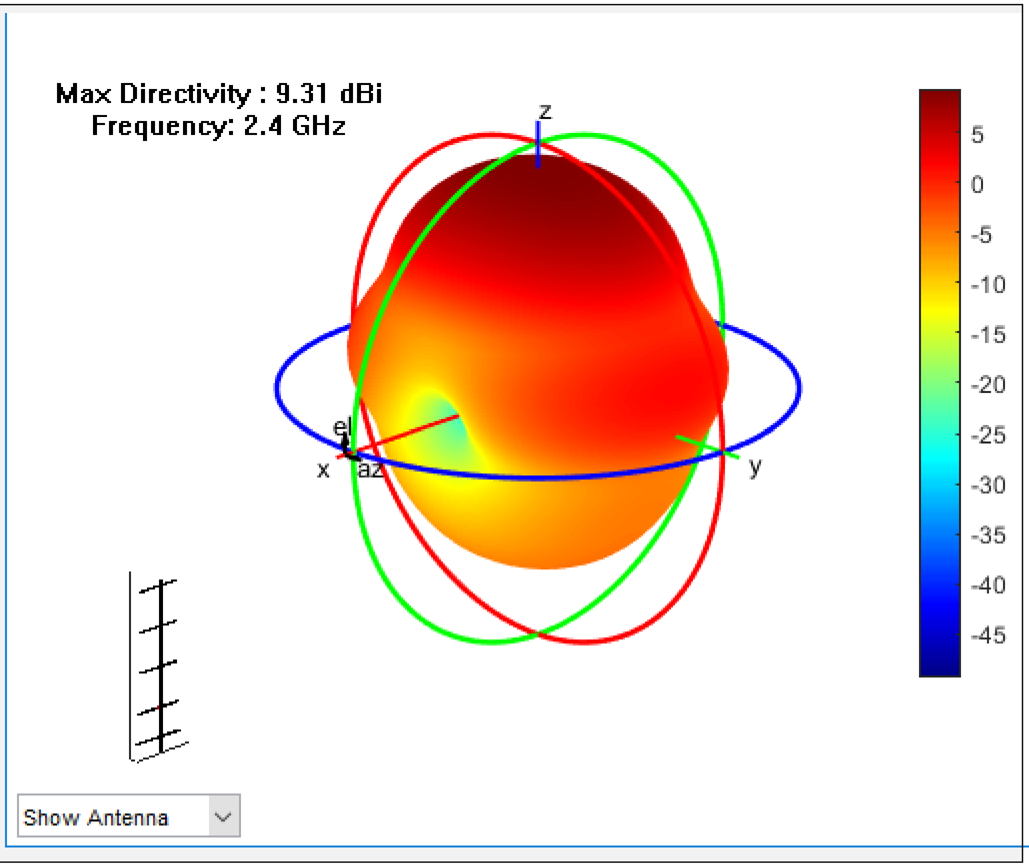
`waveguideCircular`	

hornConical	 Max Directivity: 14.6 dBi Frequency : 9.4 GHz z x y el az 10 5 0 -5 -10 -15 -20 -25 -30 Show Antenna

`gregorian`	

Max Directivity : 37.5 dBi
Frequency: 18.3 GHz
z
el
x
az
y
30
20
10
0
-10
-20
Show Antenna

cassegrain	 Max Directivity : 38.3 dBi Frequency: 18 GHz z el x az y 30 20 10 0 -10 -20 Show Antenna

`quadCustom`	

See Also

Design and Analysis Using Antenna Array Designer App

This example demonstrates how to create and analyze a 6-element linear array of half-wavelength dipoles using Antenna Array Designer app in Antenna Toolbox (TM). The design and analysis are performed at 2.1GHz

Open Antenna Array Designer App

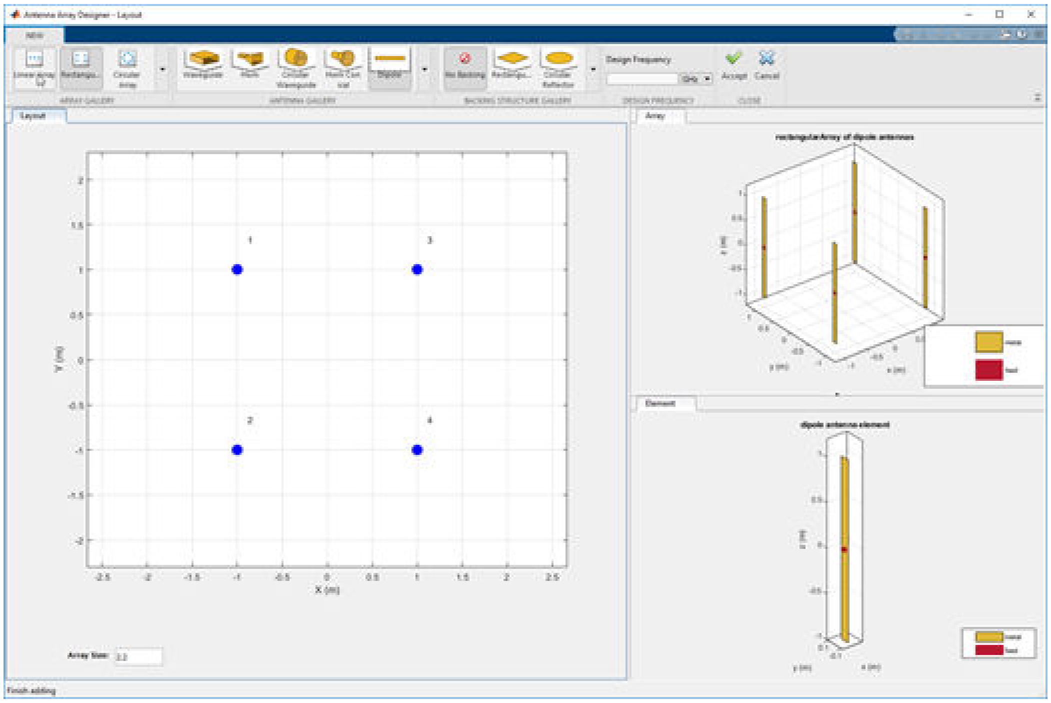
To open the app, at the MATLAB command prompt enter: The command opens a blank canvas.

```
antennaArrayDesigner
```

Click on the NEW ('+') button to explore and make an antenna array

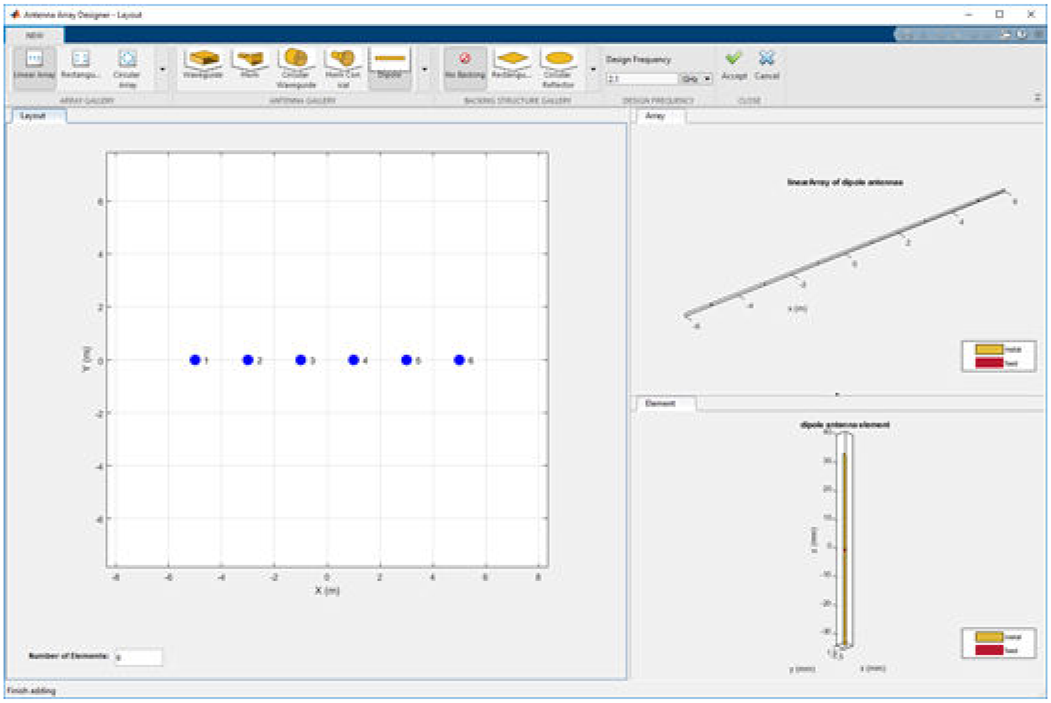
Design Antenna Array

In the blank canvas, click New. In the **ARRAY GALLERY**, select **Linear Array**.



Array Size: 2,2

Set the **Design Frequency** value to **2.1GHz**. Set the **Number of Elements** to **6**.



Design Frequency 2.1 GHz

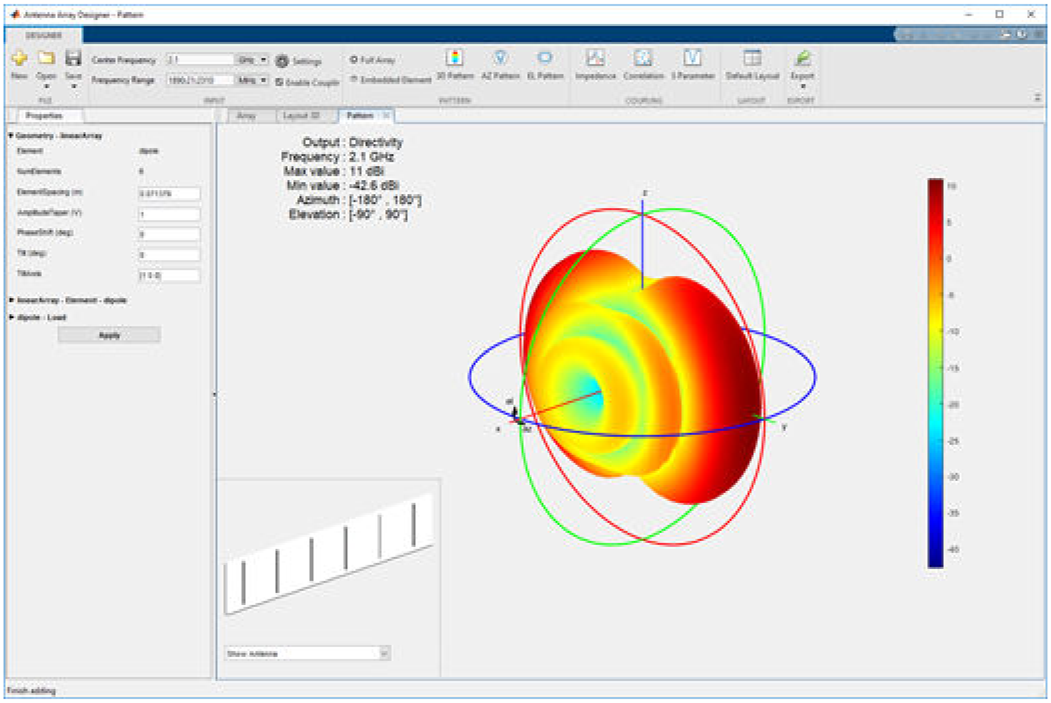
Number of Elements: 6

To analyze this antenna array, click **Accept.**

Plot 3-D Pattern

Observe the array geometry and the dipole's geometry at 2.1GHz in the **Array** and **Layout** figure tabs.

In the toolstrip under the **PATTERN** section, click **3D Pattern** to visualize the pattern for the linear array at the design frequency.

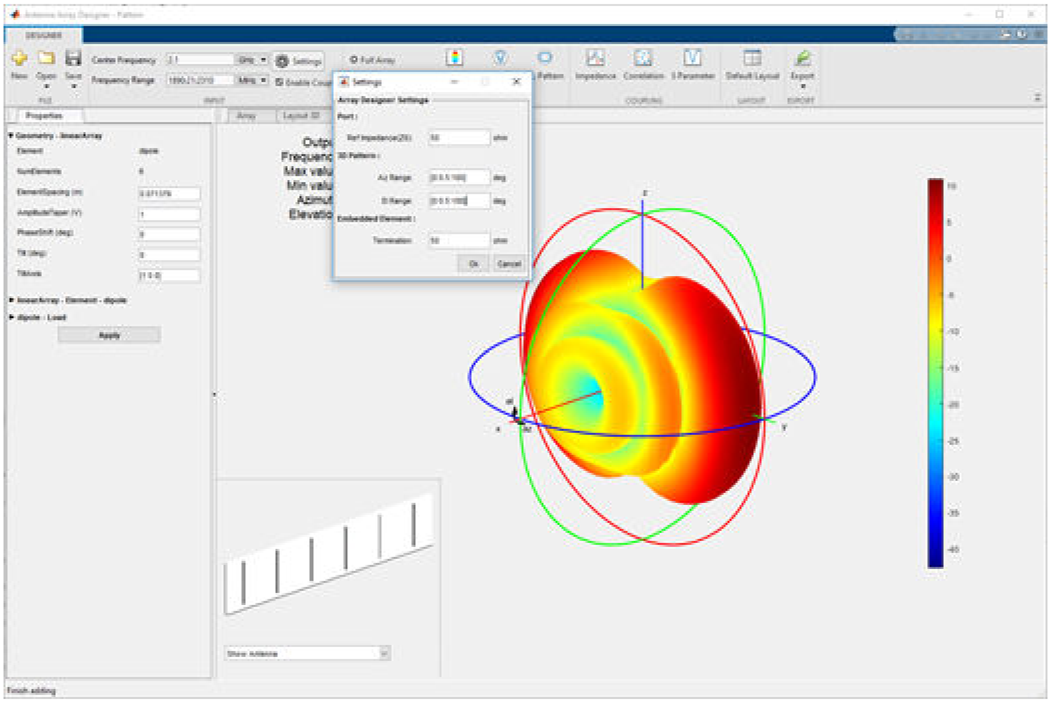


Output : Directivity
Frequency : 2.1 GHz
Max value : 11 dBi
Min value : -42.6 dBi
Azimuth : [-180° , 180°]
Elevation : [-90° , 90°]

The array has a peak directivity of **11 dBi** with maximum beam directed at 90 degree azimuth.

Plot Azimuth and Elevation Pattern

In the toolstrip, under the **INPUT** section click on the **Settings** (⚙ icon) to change the azimuth and elevation range values. Change the **Az Range** and **El Range** to **0:0.5:180**. Click **Ok**.



Settings

Array Designer Settings

Port :

Ref Impedance(Z0): 50 ohm

3D Pattern :

Az Range: [0:0.5:180] deg

El Range: [0:0.5:180] deg

Embedded Element :

Termination: 50 ohm

Ok Cancel

Geometry - linearArray

Element: dipole

NumElements: 6

ElementSpacing (m): 0.071376

AmplitudeTaper (V): 1

PhaseShift (deg): 0

Tilt (deg): 0

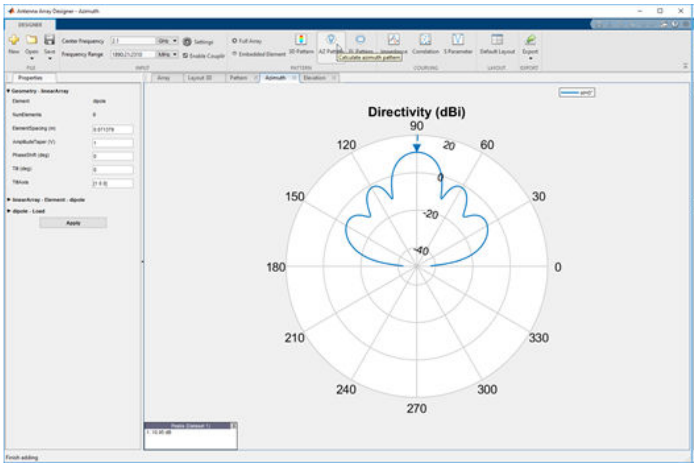
TiltAxis: [1 0 0]

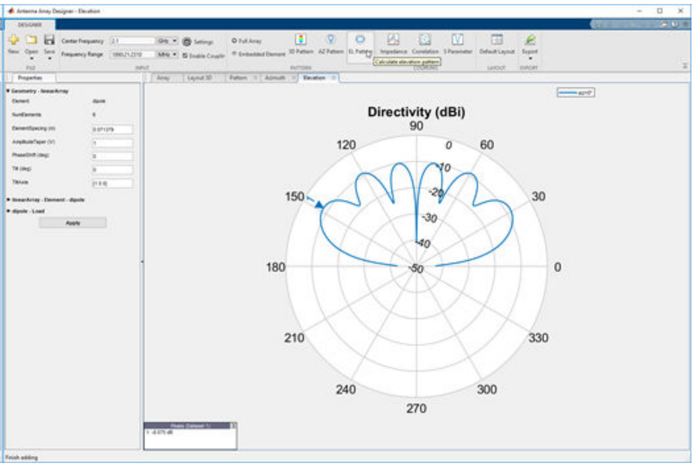
linearArray - Element - dipole

dipole - Load

Apply

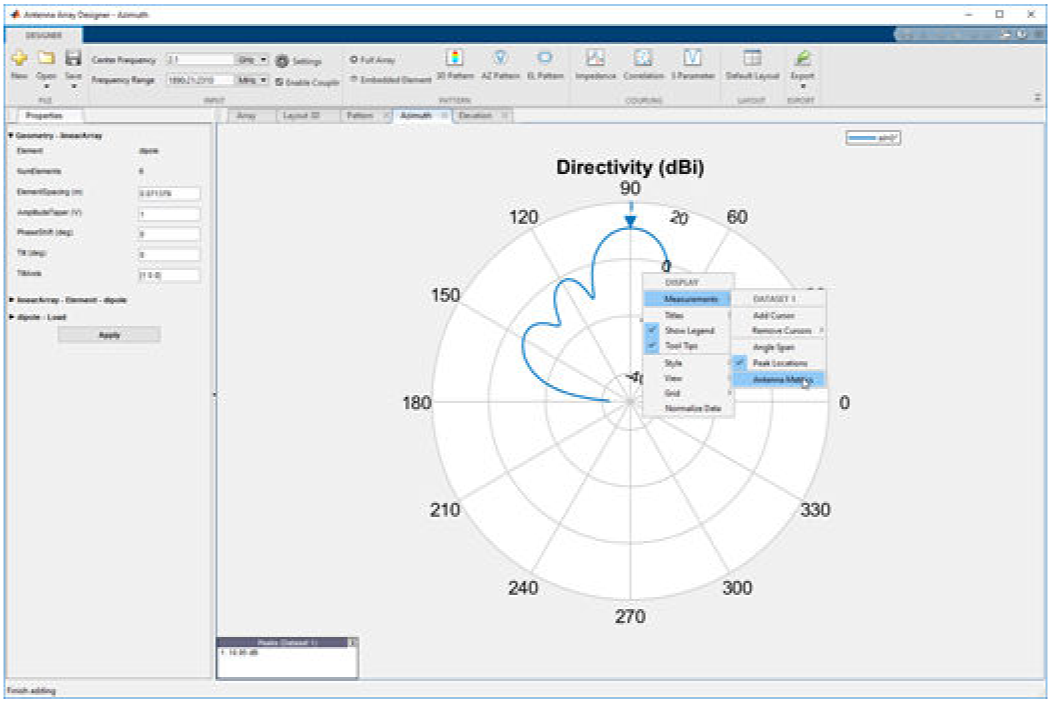
Under **PATTERN** section, click on the **AZ Pattern** and **EL Pattern** to view azimuth and elevation patterns of the linear array. Observe the azimuth and elevation range.



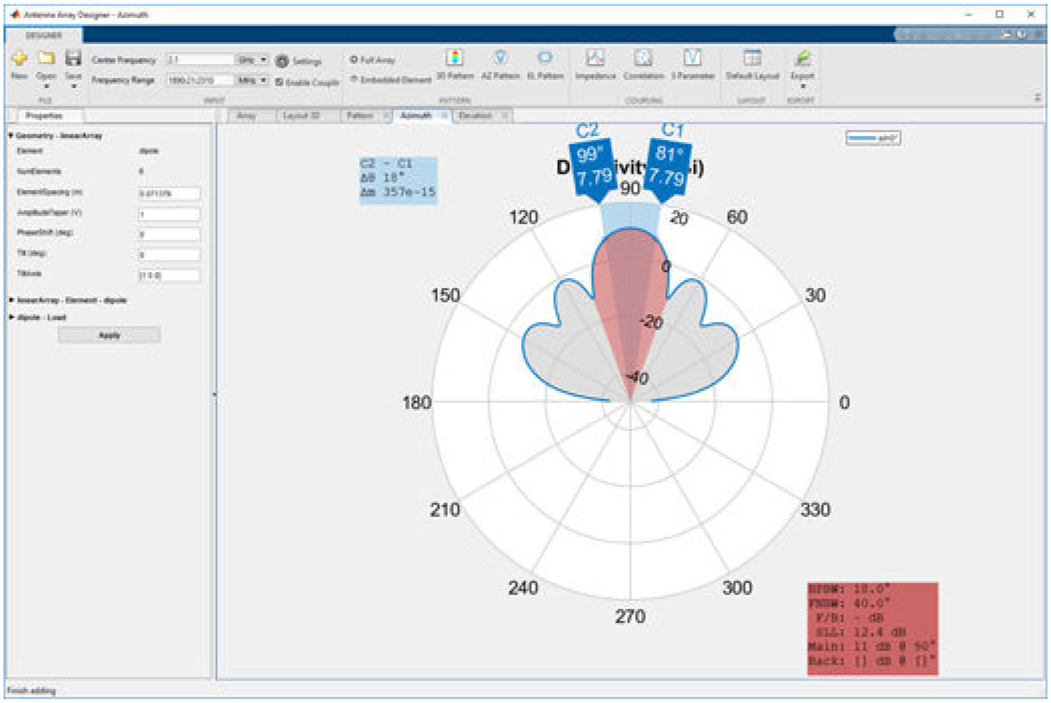


Half-power beamwidth (HPBW) and Sidelobe level (SLL)

Click on the AZ Pattern tab in the designer. Right click on the polar plot. Select **Antenna Metrics** from the **Measurements** tab of the context menu.



The half-power beamwidth is **18**degree and the sidelobe level is **12.4dB**.



```
C2 - C1
Δθ 18°
Δm 357e-15
```

```
HPBW: 18.0°
FNBW: 40.0°
 F/B: - dB
 SLL: 12.4 dB
Main: 11 dB @ 90°
Back: [] dB @ []°
```

Change Maximum Beam Angle

Phase shift property of the array allows to direct the maximum beam to a specific angle. Steer the beam direction to azimuth 80 degree.

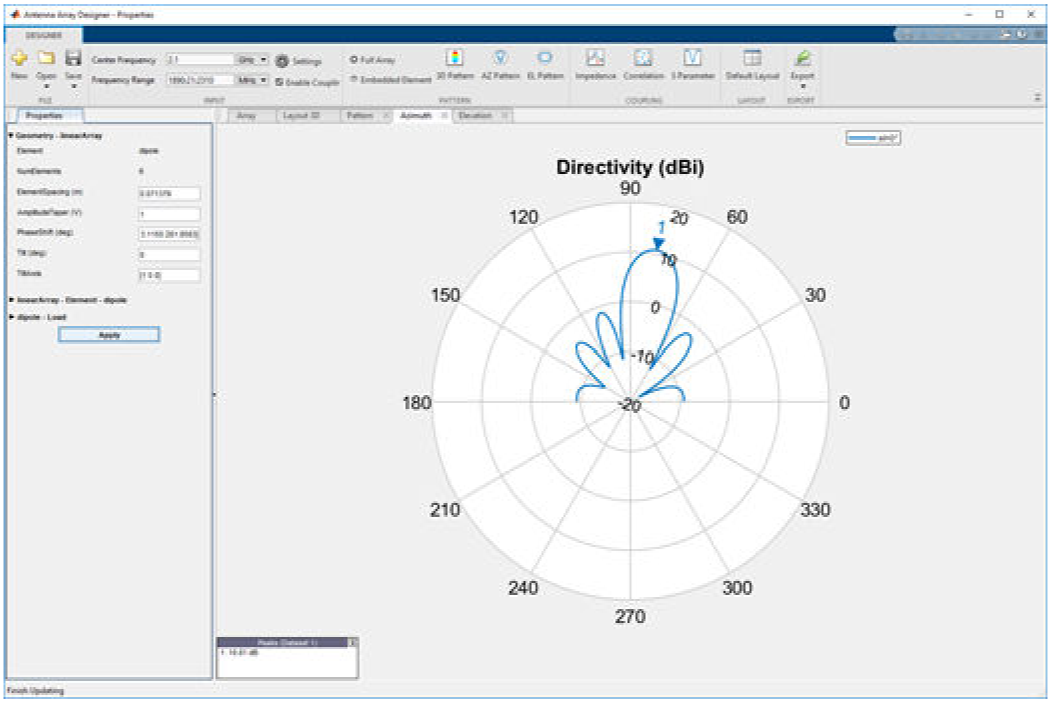
Antenna Toolbox's **phaseShift** method can be used to compute the progressive phase shift required to steer the beam to 80 degrees azimuth.

The values for phase shift are obtained as below

```
linArray = design(linearArray('NumElements',6),2.1e9);
ps = phaseShift(linArray,2.1e9,[80 0])';
```

In the **Property Panel**, under **Geometry - linearArray** change the **PhaseShift** property to **[78.1417 46.8850 15.6283 344.3717 313.1150 281.8583].**

Click **Apply**. All the analysis gets updated to account for the changes to array configuration. Click on **AZ Pattern plot** tab to see the maximum beam which is now at 80 degree azimuth.

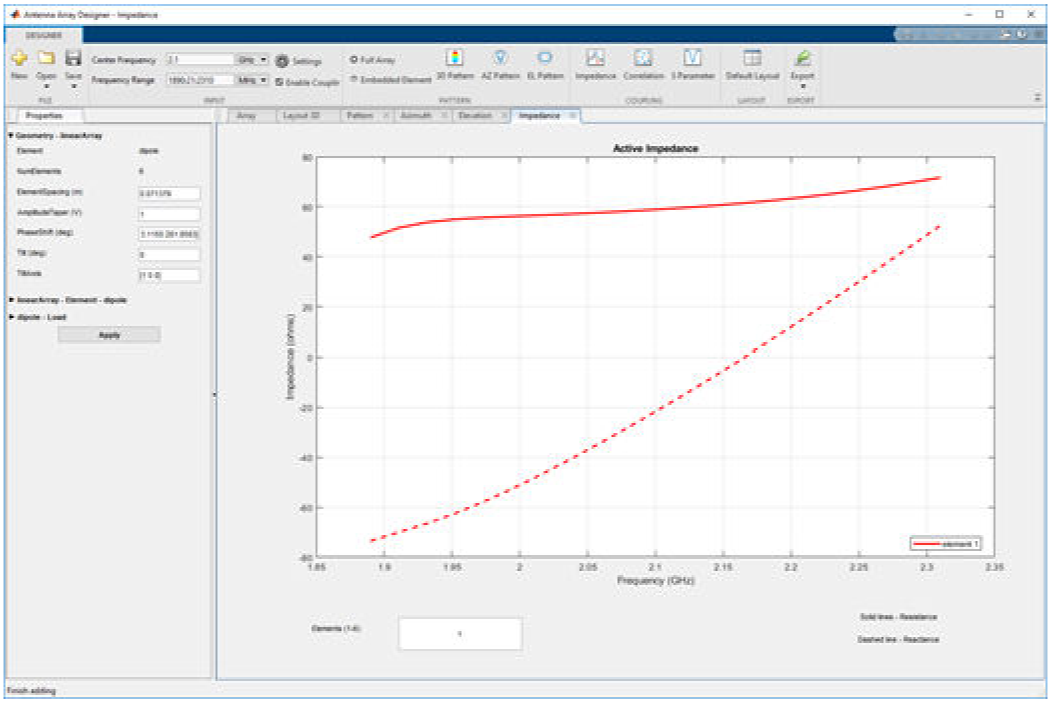


Coupling Analysis

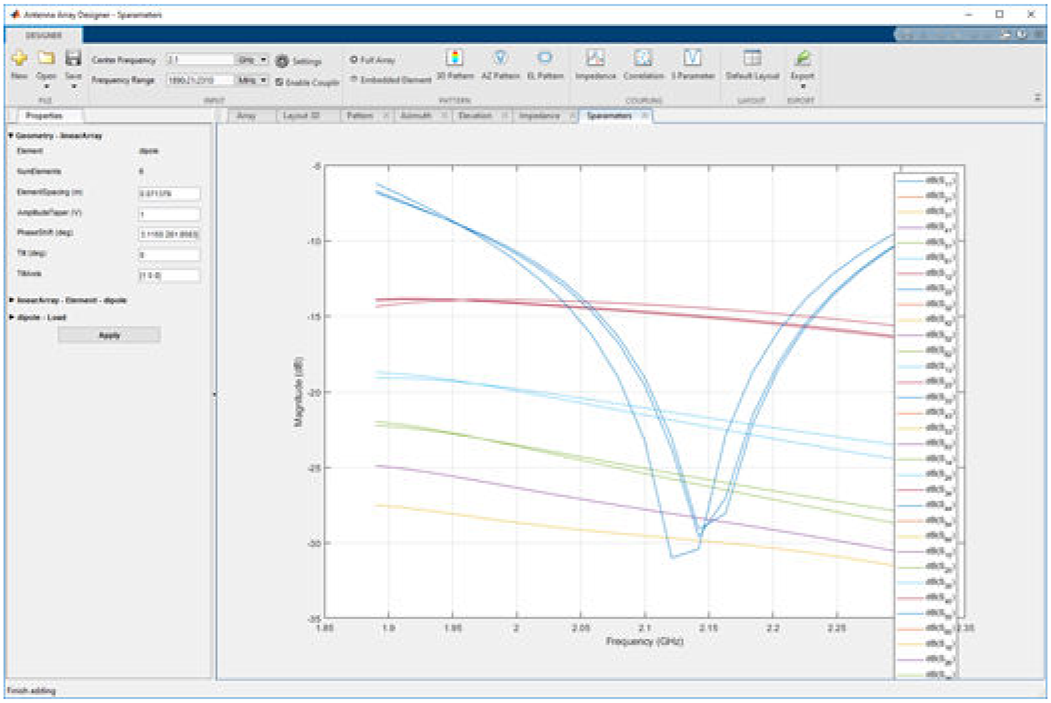
Plot Impedance and S-Parameter

In the toolstrip under **COUPLING** section, click **Impedance** to plot the impedance of each element. Change the edit field **Element** to plot the impedance of a different element.

The default reference impedance for S-Parameters plot is 50 Ohms. To change this value, click on **Settings** under the **INPUT** section of toolstrip. Change the **Ref Impedance(Z0)**value to **75** Ohms and click **Ok**.

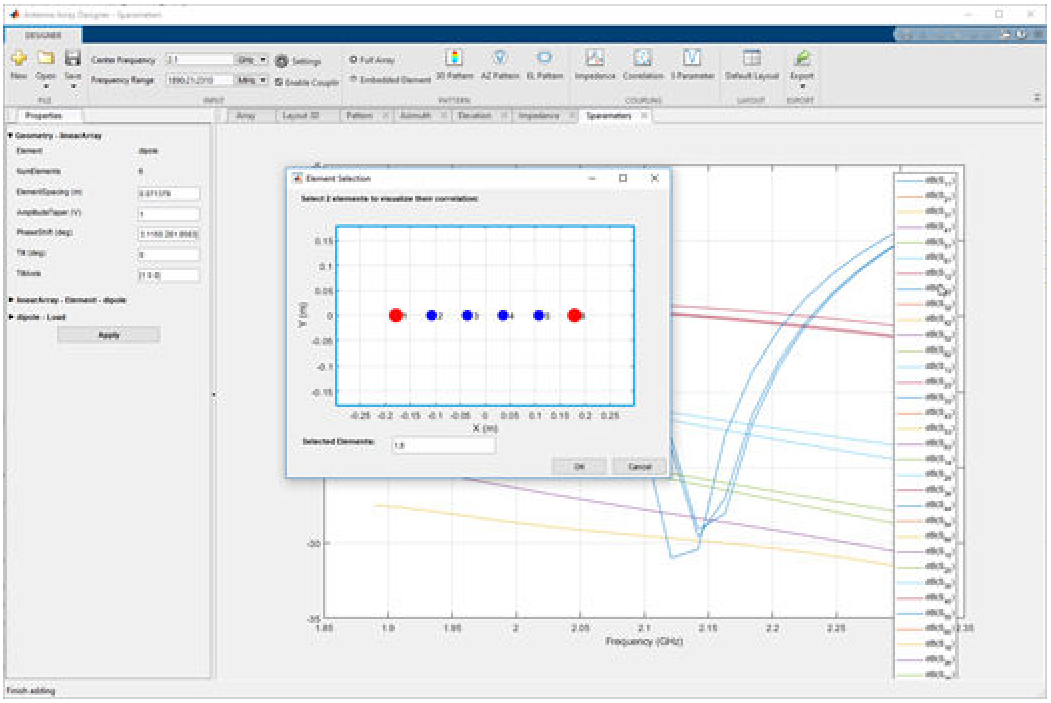


Click **S-Parameter**, under **COUPLING** section to plot the 6 port S-parameters of the array.



Correlation Analysis

In the toolstrip, under **COUPLING** section click on **Correlation.** In the **Element Selection** window pop-up, click on 1 and 6 to select element **1** and element of the array.



Element: dipole

NumElements: 6

AmplitudeTaper (V): 1

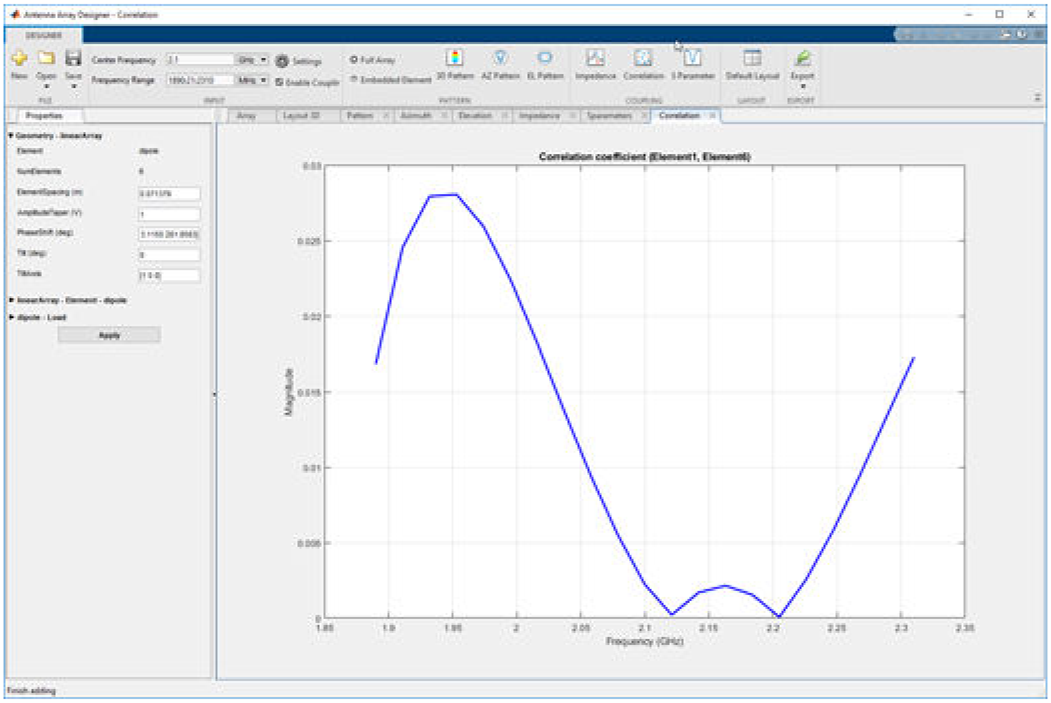
Tilt (deg): 0

TiltAxis: [1 0 0]

Select 2 elements to visualize their correlation:

Selected Elements: 1,6

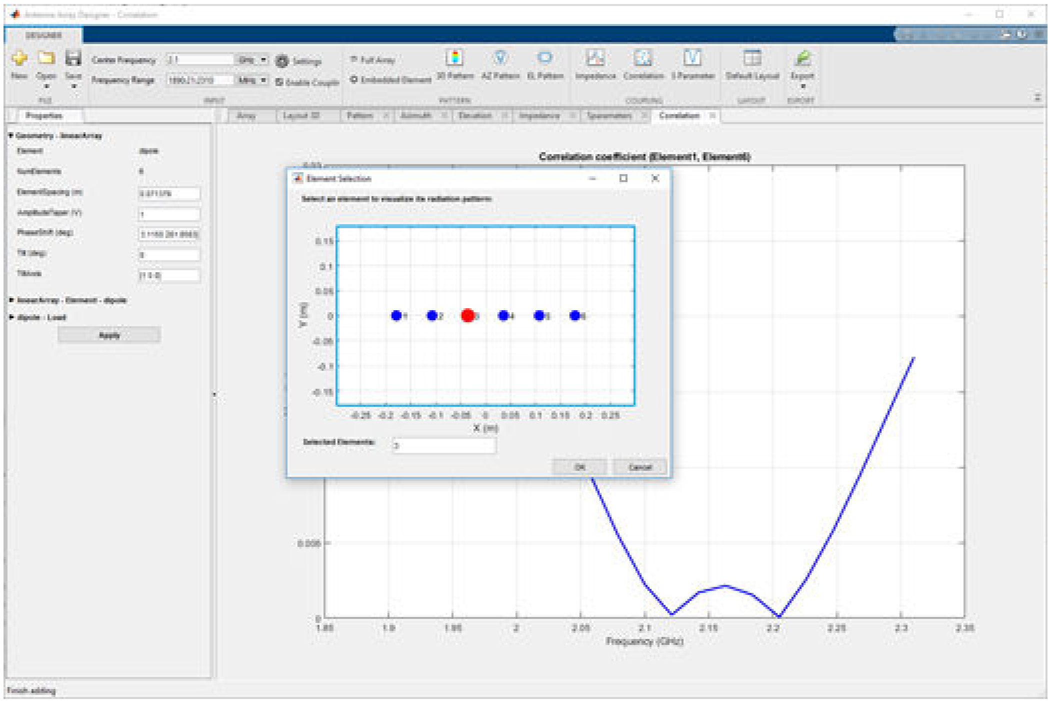
Click **OK.**



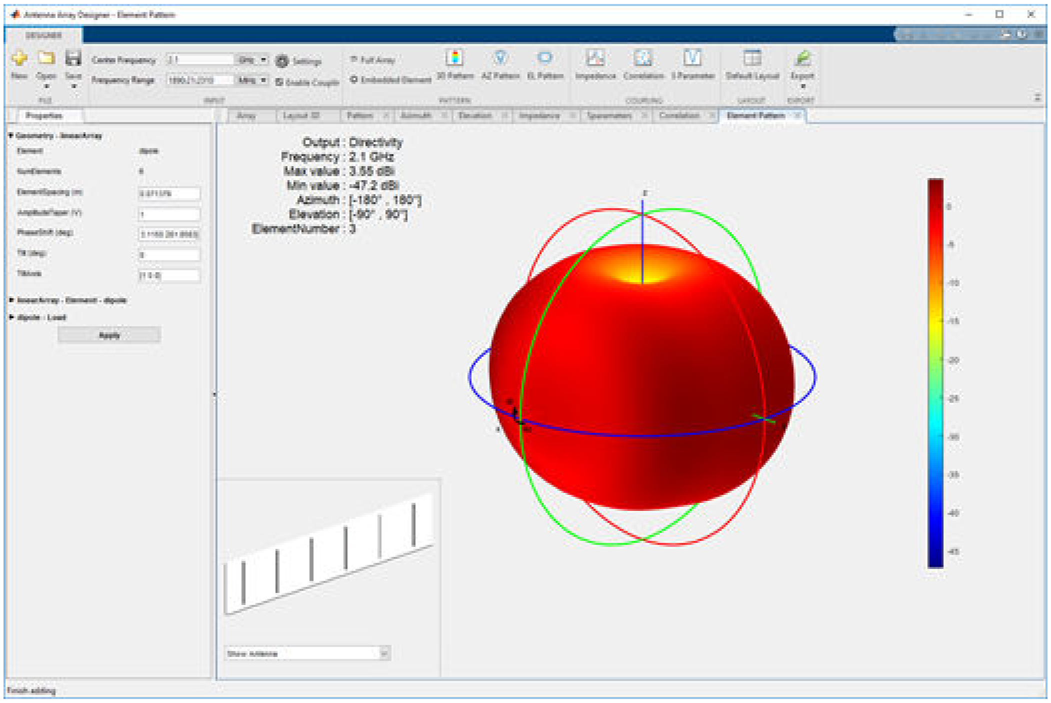
Embedded Element Analysis

Plot 3D, Azimuth and Elevation Pattern

To visualize the radiation properties of an individual element in the array, click on **Embedded Element** under **PATTERN** section of the toolstrip. Click on **3D Pattern**. An **Element Selection** window opens which allows to choose an element from the array.

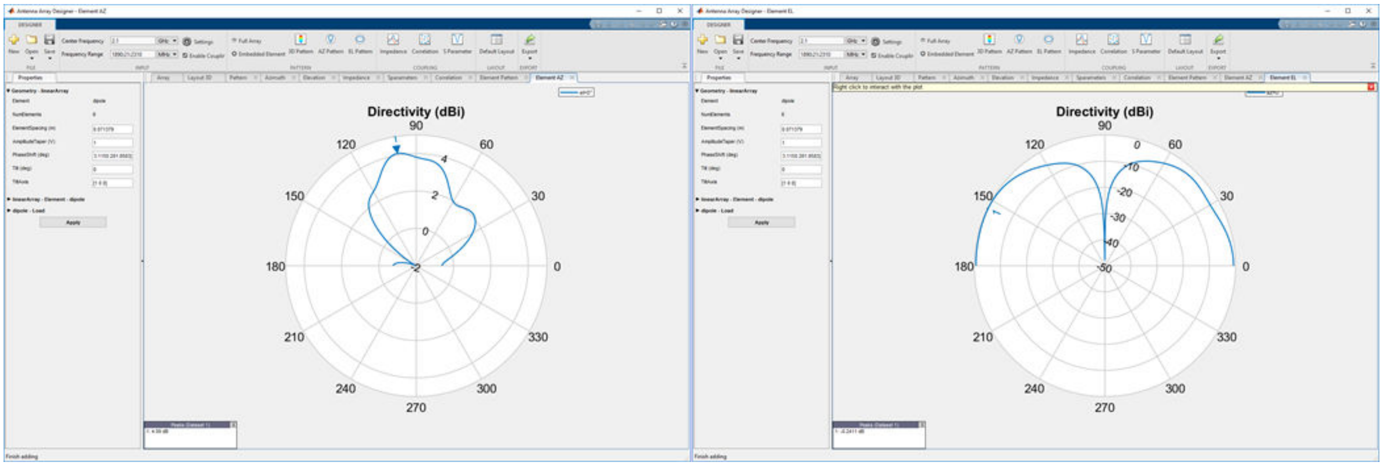


Select element 3 to visualize its 3D radiation pattern. Click **OK**. A new figure named **Element Pattern** is displayed



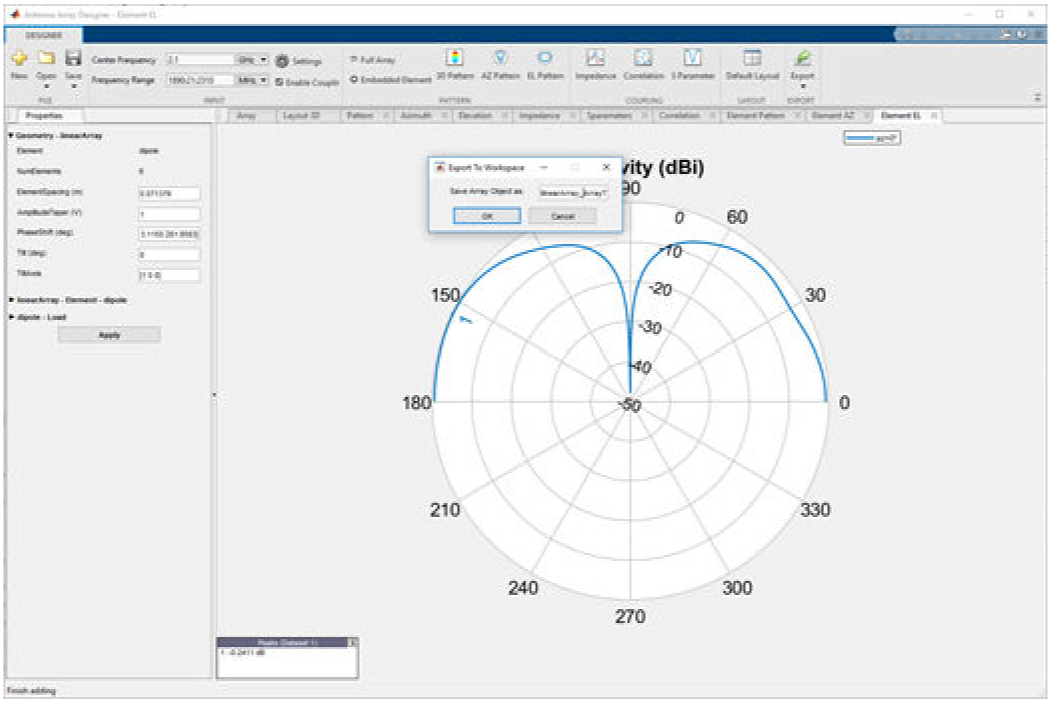
```
Output : Directivity
Frequency : 2.1 GHz
Max value : 3.55 dBi
Min value : -47.2 dBi
Azimuth : [-180° , 180°]
Elevation : [-90° , 90°]
ElementNumber : 3
```

Click on **AZ Pattern**, and select the element **5**. Similarly, click on **EL Pattern** and select element **2**.



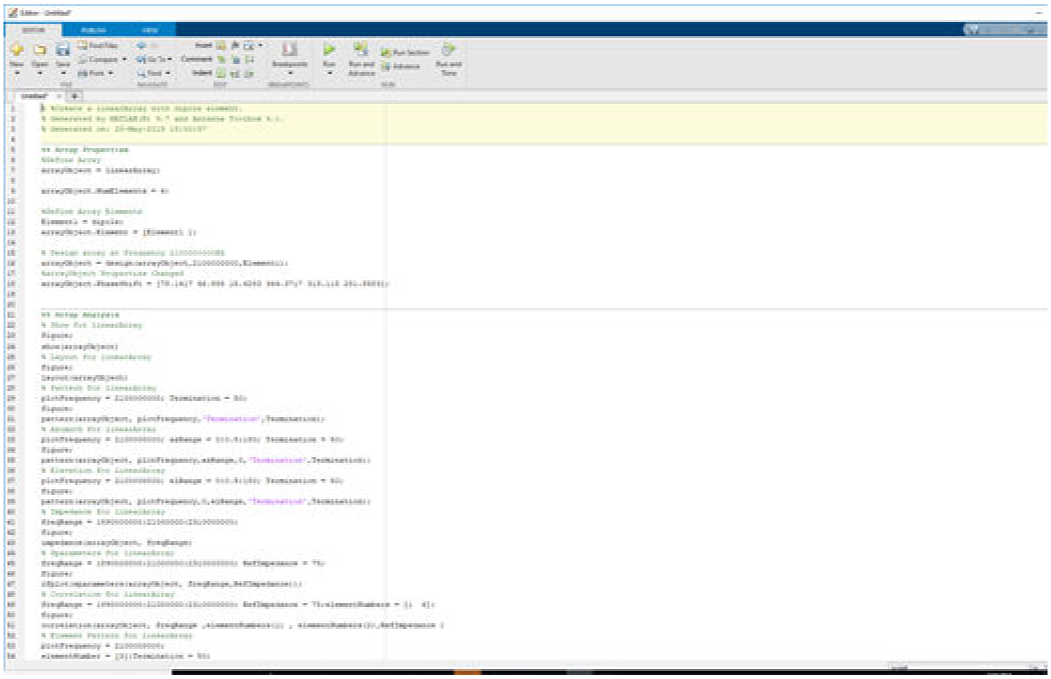
Export to MATLAB Workspace

Click the **Export** button arrow and then click **Export to workspace**. In the **Export to workspace** window, give a name to the array that you've designed. Click on the variable in the workspace to view the properties of the antenna array.



Export to MATLAB Script

Click the **Export** button arrow again and then click **Export to script** to view the linear array and analysis in MATLAB script format. The script has two sections: **Array Properties** and **Array Analysis.**



```
%Create a linearArray with dipole element.
% Generated by MATLAB(R) 9.7 and Antenna Toolbox 4.1.
% Generated on: 29-May-2019 15:53:37

%% Array Properties
%Define Array
arrayObject = linearArray;

arrayObject.NumElements = 6;

%Define Array Elements
Element1 = dipole;
arrayObject.Element = [Element1 ];

% Design array at frequency 2100000000Hz
arrayObject = design(arrayObject,2100000000,Element1);
%arrayObject Properties Changed
arrayObject.PhaseShift = [illegible];


%% Array Analysis
% Show for linearArray
figure;
show(arrayObject)
% Layout for linearArray
figure;
layout(arrayObject)
% Pattern for linearArray
plotFrequency = 2100000000; Termination = 50;
figure;
pattern(arrayObject, plotFrequency,'Termination',Termination);
% Azimuth for linearArray
plotFrequency = 2100000000; azRange = 0:5:360; Termination = 50;
figure;
pattern(arrayObject, plotFrequency,azRange,0,'Termination',Termination);
% Elevation for linearArray
plotFrequency = 2100000000; elRange = 0:5:360; Termination = 50;
figure;
pattern(arrayObject, plotFrequency,0,elRange,'Termination',Termination);
% Impedance for linearArray
freqRange = 1890000000:21000000:2310000000;
figure;
impedance(arrayObject, freqRange);
% Sparameters for linearArray
freqRange = 1890000000:21000000:2310000000; RefImpedance = 50;
figure;
rfplot(sparameters(arrayObject, freqRange,RefImpedance));
% Correlation for linearArray
freqRange = 1890000000:21000000:2310000000; RefImpedance = 50;elementNumbers = [1  6];
figure;
correlation(arrayObject, freqRange ,elementNumbers(1) , elementNumbers(2),RefImpedance );
% Element Pattern for linearArray
plotFrequency = 2100000000;
elementNumber = [3];Termination = 50;
```

3

Introduction to RF Propagation

RF Propagation and Visualization

This example shows how to compute and visualize outdoor wireless coverage between a transmitter and receiver. This includes:

- Transmitter and receiver site creation using Antenna Toolbox antenna library.
- Distance and angle calculation between the transmitter and the receiver.
- Signal strength computation using free space propagation or other propagation models.
- Communication link visualization.
- Transmitter coverage area calculation.
- Signal-to-interference plus noise ratio (SINR) calculation at the receiver.

Close `Site Viewer` if open before running the example.

Transmitter Site

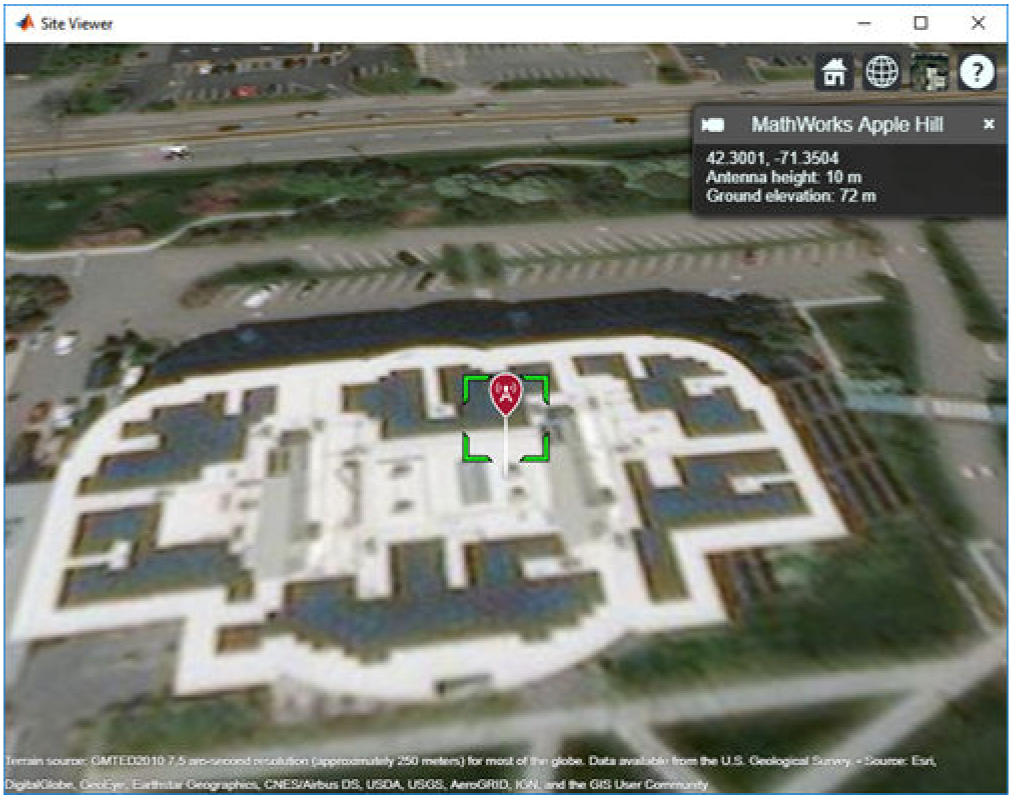
A transmitter consists of an RF circuit and an antenna, where the RF circuit excites the antenna with a signal and power. Key characteristics of a transmitter include its output power, operating frequency, and its antenna radiation pattern.

Use the `txsite` object to create a transmitter site at MathWorks Apple Hill campus. The latitude of the campus is 42.3001 degrees and the longitude is -71.3504 degrees.

```
tx = txsite('Name','MathWorks Apple Hill',...
       'Latitude',42.3001, ...
       'Longitude',-71.3504)
```

```
tx = 
  txsite with properties:

                     Name: 'MathWorks Apple Hill'
                 Latitude: 42.3001
                Longitude: -71.3504
                  Antenna: 'isotropic'
             AntennaAngle: 0
            AntennaHeight: 10
               SystemLoss: 0
    TransmitterFrequency: 1.9000e+09
        TransmitterPower: 10
```

```
show(tx)
```



MathWorks Apple Hill

42.3001, -71.3504
Antenna height: 10 m
Ground elevation: 72 m

Terrain source: GMTED2010 7.5 arc-second resolution (approximately 250 meters) for most of the globe. Data available from the U.S. Geological Survey. • Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Receiver Site

A receiver consists of an RF circuit and an antenna, where the antenna intercepts radio waves and converts them to a current that is decoded by the RF circuit (e.g. demodulated) into a signal. Key characteristics of a receiver include its sensitivity and its antenna radiation pattern.

Use the `rxsite` object to create a receiver site at MathWorks Lakeside campus. The latitude of the campus is 42.3021 degrees and the longitude is -71.3764 degrees.

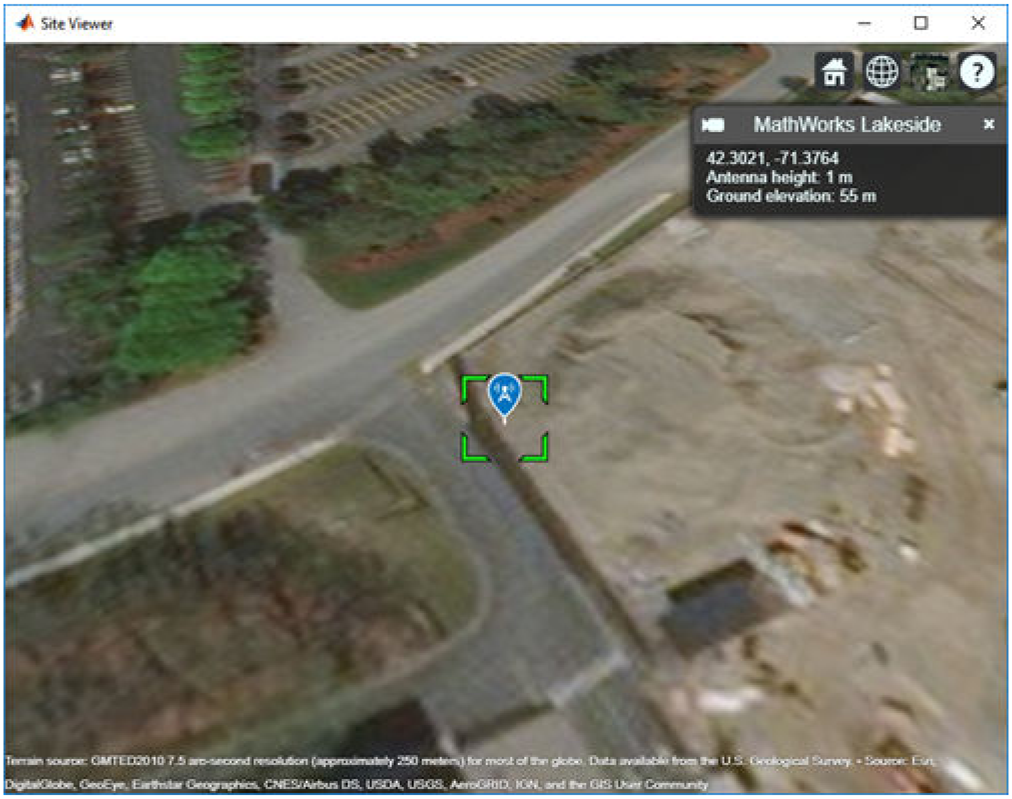
Receiver Sensitivity is the minimum signal power level that is necessary for a receiver to accurately decode a signal. Sensitivity is a power quantity and typically specified in dBm. To determine if a receiver will be in the coverage area of a transmitter, the sensitivity is compared to the received power.

```
rx = rxsite('Name','MathWorks Lakeside', ...
       'Latitude',42.3021, ...
       'Longitude',-71.3764)
```

```
rx = 
  rxsite with properties:

                 Name: 'MathWorks Lakeside'
             Latitude: 42.3021
            Longitude: -71.3764
              Antenna: 'isotropic'
         AntennaAngle: 0
        AntennaHeight: 1
           SystemLoss: 0
```

```
    ReceiverSensitivity: -100
```

```
show(rx)
```



MathWorks Lakeside
42.3021, -71.3764
Antenna height: 1 m
Ground elevation: 55 m

Terrain source: GMTED2010 7.5 arc-second resolution (approximately 250 meters) for most of the globe. Data available from the U.S. Geological Survey. • Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Distance Between Sites

Use the `distance` function to calculate the distance between the transmitter site and the receiver site. By default, this function draws a straight line between the transmitter and the receiver sites to calculate the distance. This path is called the Euclidean path and ignores all obstructions including the earth.

Another path option for the distance function is the Geodesic path, where the distance is calculated considering the curvature of the earth.

```
dm = distance(tx,rx) % Unit: m
```

```
dm = 2.1556e+03
```

```
dkm = dm / 1000
```

```
dkm = 2.1556
```

Angle Between Sites

Use the `angle` function to calculate the angle between the transmitter site and the receiver site.

```
azFromEast = angle(tx,rx) % Unit: degrees counter-clockwise from East
```

```
azFromEast = 174.0753
```

```
azFromNorth = -azFromEast + 90 % Convert angle to clockwise from North
```

```
azFromNorth = -84.0753
```

Received Power and Link Margin

The received power is given by the equation:

$$P_{\mathrm{rx}} = P_{\mathrm{tx}} + G_{\mathrm{tx}} + G_{\mathrm{rx}} - \mathrm{pathloss}$$

where,

- P_{rx} = Power available at the receiver.
- P_{tx} = Transmitter output power.
- G_{tx} = Transmitter gain.
- G_{rx} = Receiver gain.
- pathloss = RF attenuation suffered by the transmitter signal when it arrives at the receiver.

Signal strength is the signal level that is available at the receiver at a particular distance and angle from the transmitter. It is also known as received signal strength. Signal strength can be a power quantity or a voltage quantity.

Use the `sigstrength` function to calculate the signal strength of the transmitter at the receiver site. You can calculate two types of signal strength: Power and Electric field (e-field).

```
ss = sigstrength(rx,tx)
```

```
ss = -67.0767
```

Link margin is a measure of robustness of the communication link, calculated by subtracting the required receiver sensitivity from the signal strength available at the receiver.

```
margin = abs(rx.ReceiverSensitivity - ss)
```

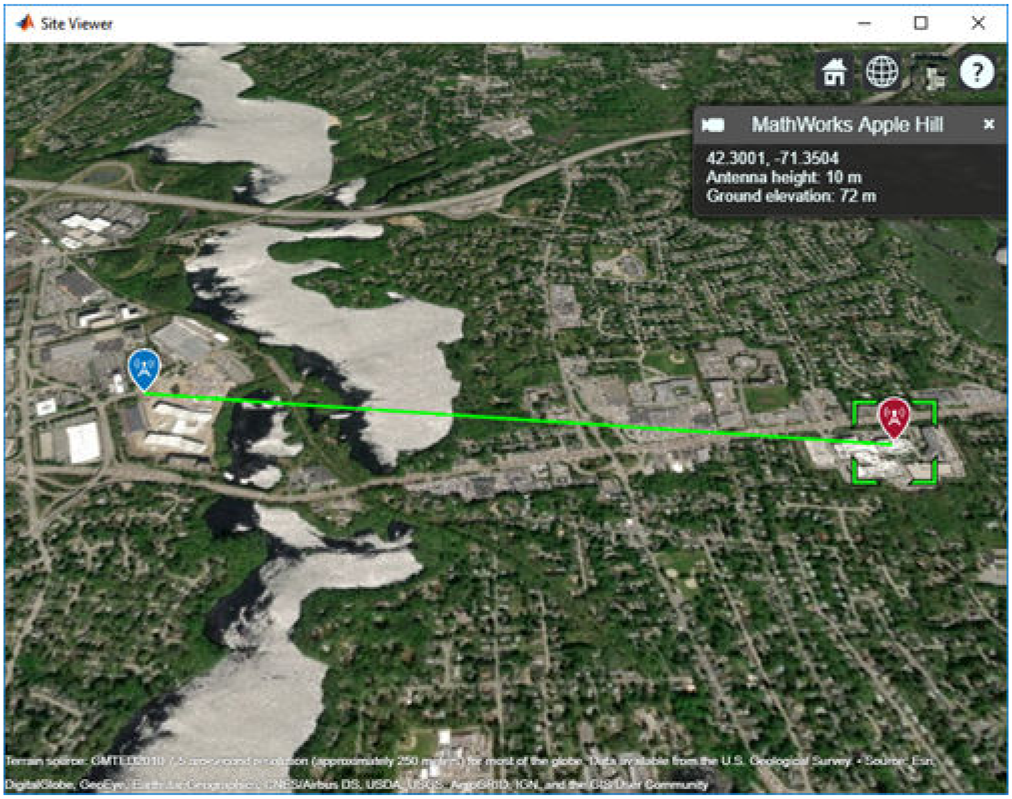
```
margin = 32.9233
```

Communication Link on Map

Use the `link` function to plot the success of the communication between the two sites on a map. The success of the link depends on the power received by the receiver from the transmitter.

By default, a green link shows you that power received meets or exceeds the receiver sensitivity. A red link shows unsuccessful communication between the transmitter and receiver sites.

```
link(rx,tx)
```


Site Viewer
Terrain source: GMTED2010 7.5 arc-second resolution (approximately 250 meters) for most of the globe. Data available from the U.S. Geological Survey. • Sources: Esri,
DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

MathWorks Apple Hill

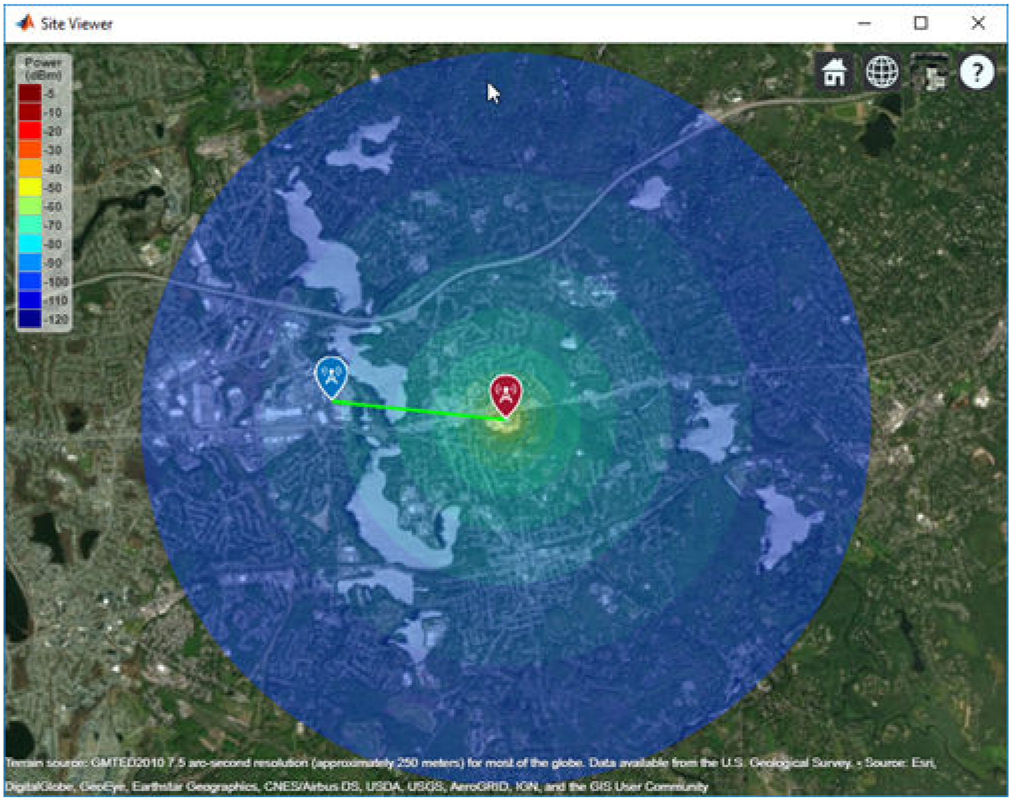
42.3001, -71.3504
Antenna height: 10 m
Ground elevation: 72 m

Coverage Map of Transmitter Site

A coverage map is the visualization of the geographic service area of the transmitter, which is where the received signal strength for a reference receiver meets its sensitivity. A coverage map may depict signal strength as either a power quantity (typically dBm) or a voltage quantity (typically dBμV/m).

Use the `coverage` function to calculate the coverage of the transmitter.

```
coverage(tx,'close-in', ...
       'SignalStrengths',-100:5:-60)
```



Terrain source: GMTED2010 7.5 arc-second resolution (approximately 250 meters) for most of the globe. Data available from the U.S. Geological Survey. • Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Location of New Transmitter

Use the `location` function to calculate the location of a new receiver site or transmitter site from an existing site.

Calculate a new transmitter location 1 km North of the transmitter site.

```
[lat,lon] = location(tx,1000,90)
```

```
lat = 42.3091

lon = -71.3504
```

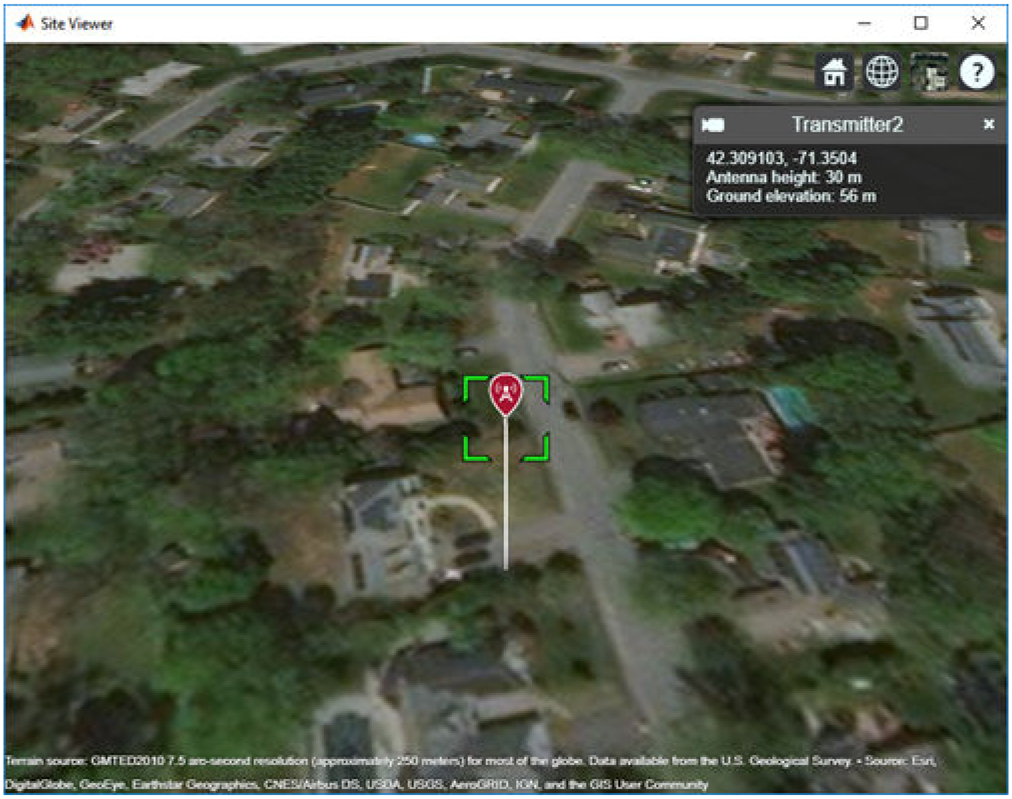
Create a new transmitter site using the latitude and longitude values given by the `location` function. Use an antenna of height 30 m.

```
tx2 = txsite('Name','Transmitter2','Latitude',lat,'Longitude',lon,'AntennaHeight',30)
```

```
tx2 = 
  txsite with properties:

                     Name: 'Transmitter2'
                 Latitude: 42.3091
                Longitude: -71.3504
                  Antenna: 'isotropic'
             AntennaAngle: 0
            AntennaHeight: 30
               SystemLoss: 0
    TransmitterFrequency: 1.9000e+09
```

```
        TransmitterPower: 10
```

```
show(tx2)
```



42.309103, -71.3504
Antenna height: 30 m
Ground elevation: 56 m

Terrain source: GMTED2010 7.5 arc-second resolution (approximately 250 meters) for most of the globe. Data available from the U.S. Geological Survey. • Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

SINR of Receiver

Use the `sinr` function to calculate the SINR of the receiver. The SINR of a receiver is given by the equation:

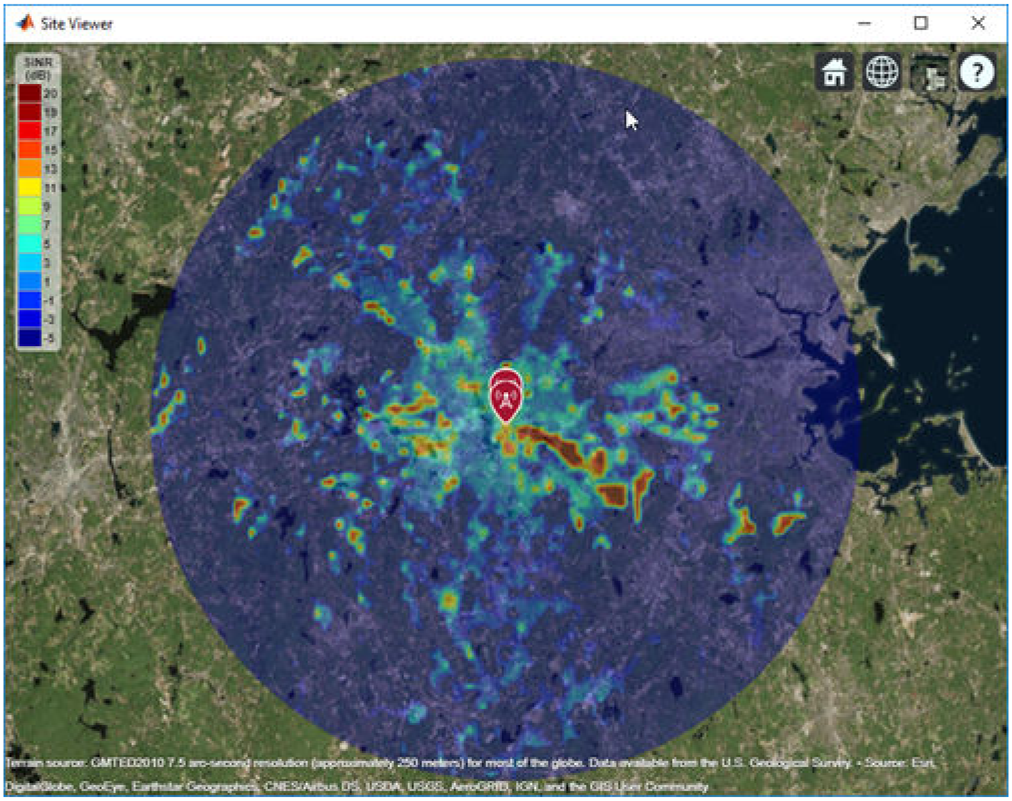
$$\text{SINR} = \frac{S}{I + N}$$

where,

- S = Received power of signal of interest
- I = Received power of interfering signals in the network
- N = Total received noise power

SINR is expressed in decibels.

```
sinr([tx,tx2])
```


Site Viewer
SINR (dB)
20
19
17
15
13
11
9
7
5
3
1
-1
-3
-5
Terrain source: GMTED2010 7.5 arc-second resolution (approximately 250 meters) for most of the globe. Data available from the U.S. Geological Survey. • Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community