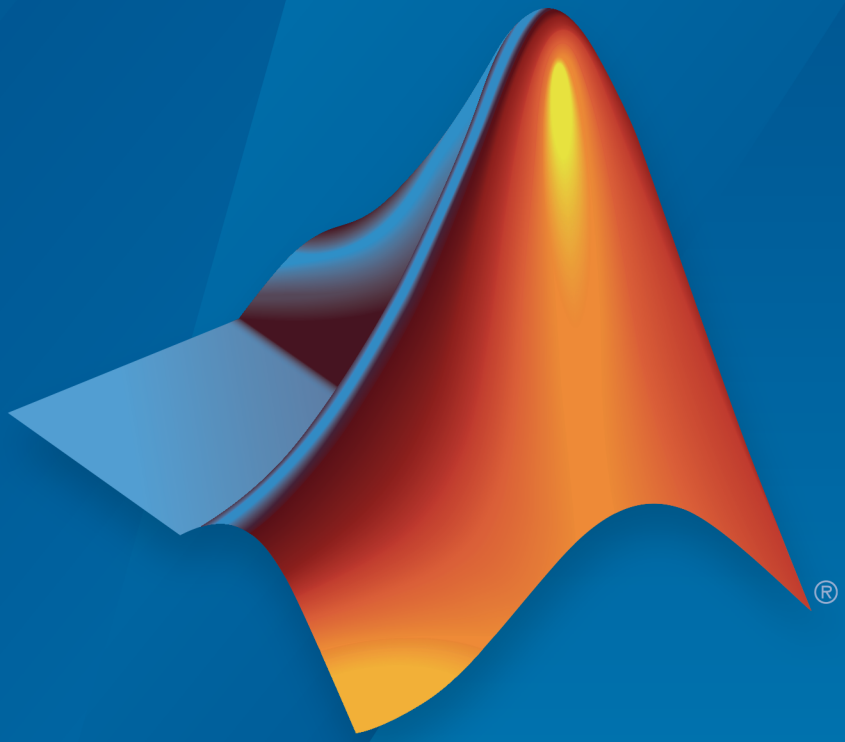
Antenna Toolbox™

Getting Started Guide



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Antenna Toolbox™ Getting Started Guide

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Revision History

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Introduction to Antenna Toolbox

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Antenna Toolbox Product Description

Design, analyze, and visualize antenna elements and antenna arrays

Antenna Toolbox™ provides functions for the design, analysis, and visualization of antenna elements and arrays. You can design standalone antennas and build linear and rectangular arrays of antennas using a library of predefined elements with parameterized geometry.

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 radiation pattern.

The antenna geometry and the analysis results can be visualized with dedicated functions, and used for antenna-to-bits wireless system design. Antenna Toolbox provides impedance analysis that can be used to design matching networks. It also provides radiation patterns for simulating beam forming algorithms.

Key Features

- Antenna library including 22 elements for rapid design and visualization of metal antenna elements using parameterized geometries
- Antenna array design of linear and rectangular arrays using antenna elements
- Port analysis of impedance, return loss, and S-parameters of antennas and antenna arrays
- Field analysis of the pattern, E-H fields, and beam width of antennas and antenna arrays
- Surface analysis of current, charge, and meshing of antennas and antenna arrays
- Antenna array analysis for the embedded element pattern and the correlation coefficient of the elements of the array
- Infinite ground plane specification for analyzing balanced antennas

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 class antenna element in the Antenna Modeling and Analysis library.

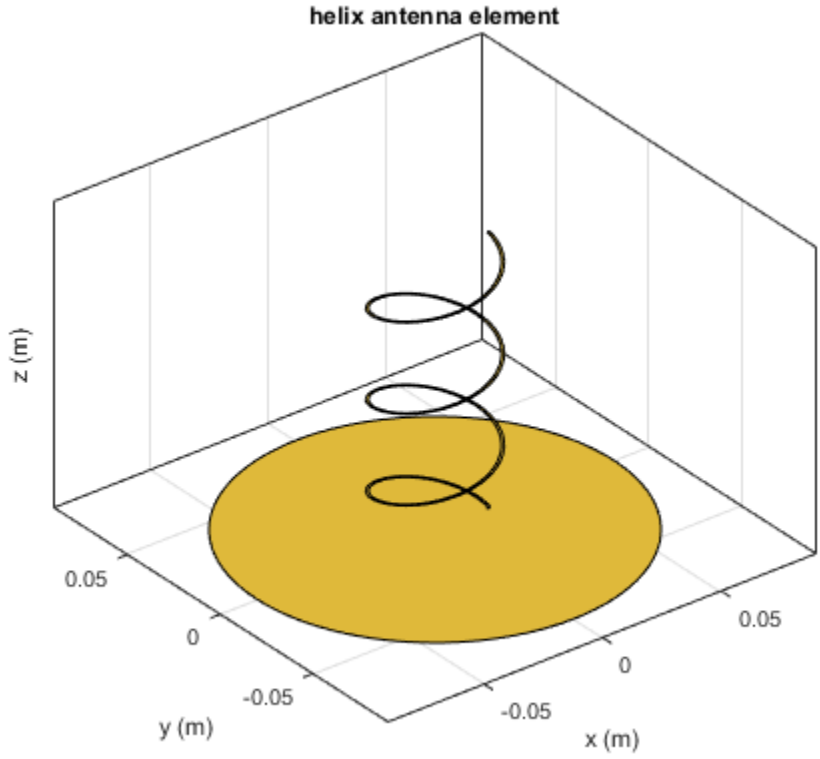
```
hx = helix
```

```
hx =

  helix with properties:

              Radius: 0.0220
               Width: 1.0000e-03
               Turns: 3
             Spacing: 0.0350
    GroundPlaneRadius: 0.0750
                Tilt: 0
            TiltAxis: [1 0 0]
```

Show Structure of Antenna

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

```
show(hx)
```



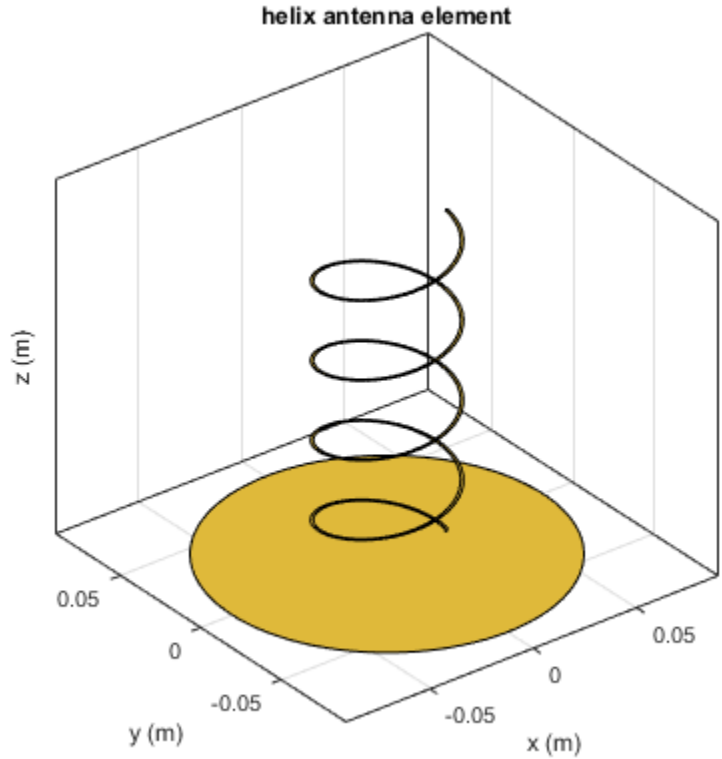
Modify Properties of Antenna

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)
show(hx)
```

```
hx =

  helix with properties:

              Radius: 0.0280
```

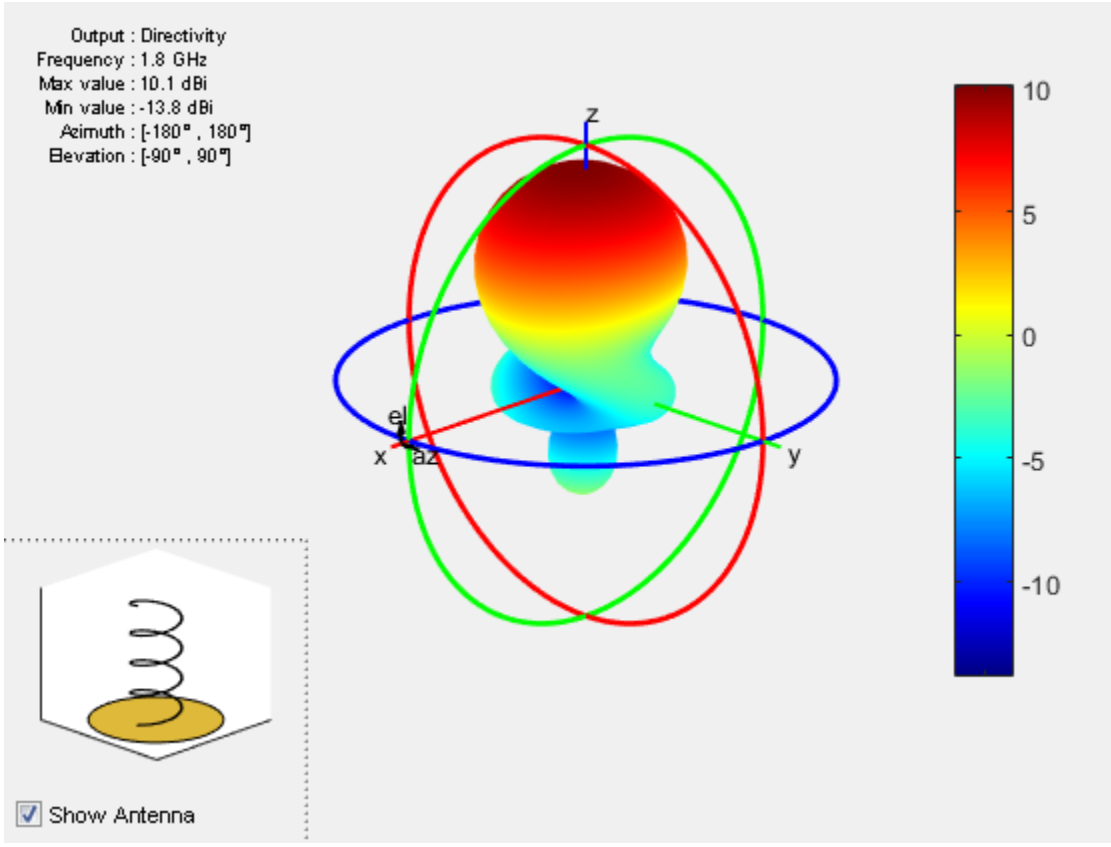
```
            Width: 0.0012
            Turns: 4
          Spacing: 0.0350
GroundPlaneRadius: 0.0750
             Tilt: 0
         TiltAxis: [1 0 0]
```



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.

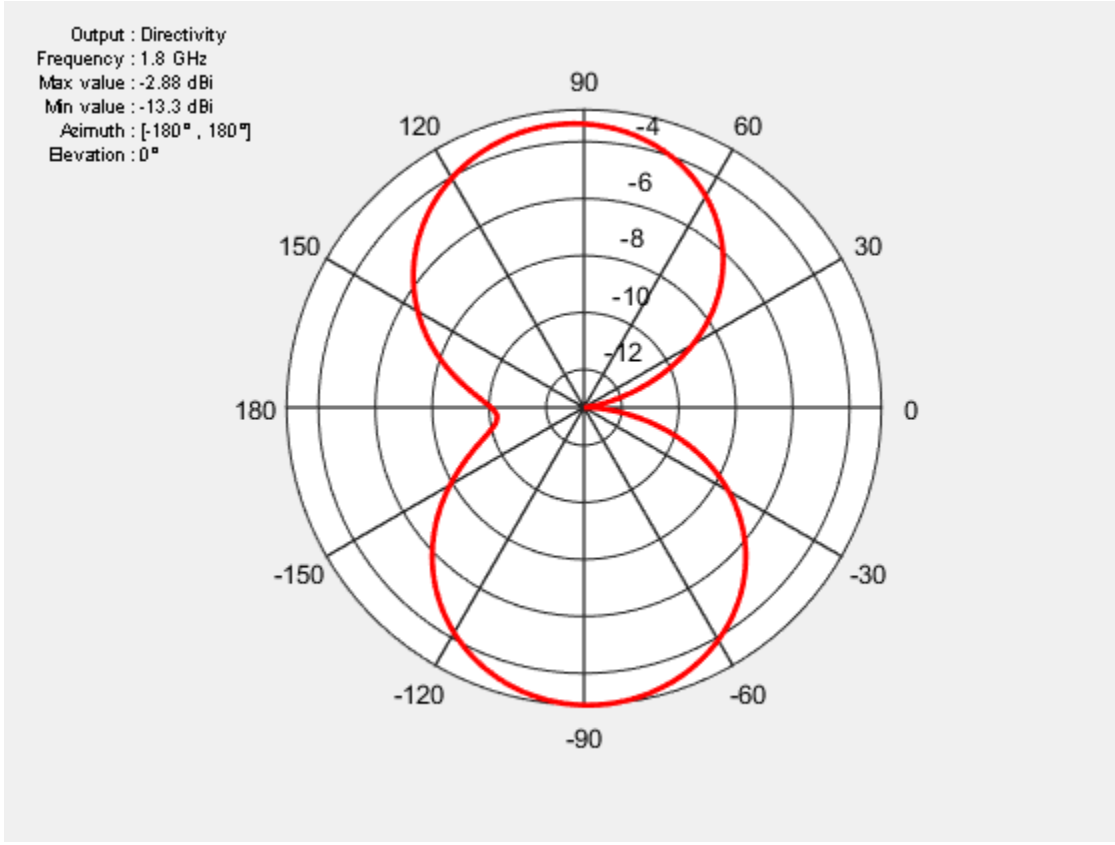
```
pattern(hx,1.8e9)
```

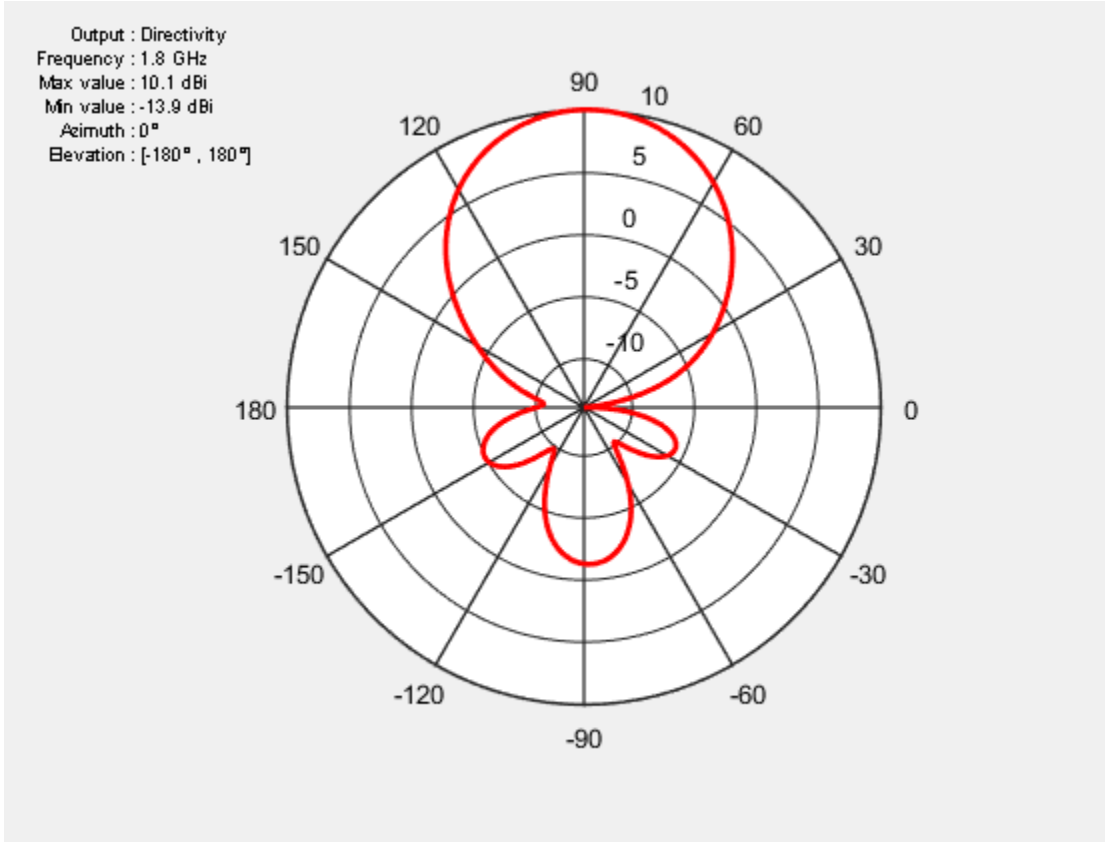


Plot Azimuth and Elevation Pattern of Antenna

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)
```


Output : Directivity
Frequency : 1.8 GHz
Max value : -2.88 dBi
Min value : -13.3 dBi
Azimuth : [-180° , 180°]
Elevation : 0°
90
120
60
150
30
180
0
-150
-30
-120
-60
-90
-4
-6
-8
-10
-12



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 =

   10.0744
```

Calculate EHfields Of Antenna

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

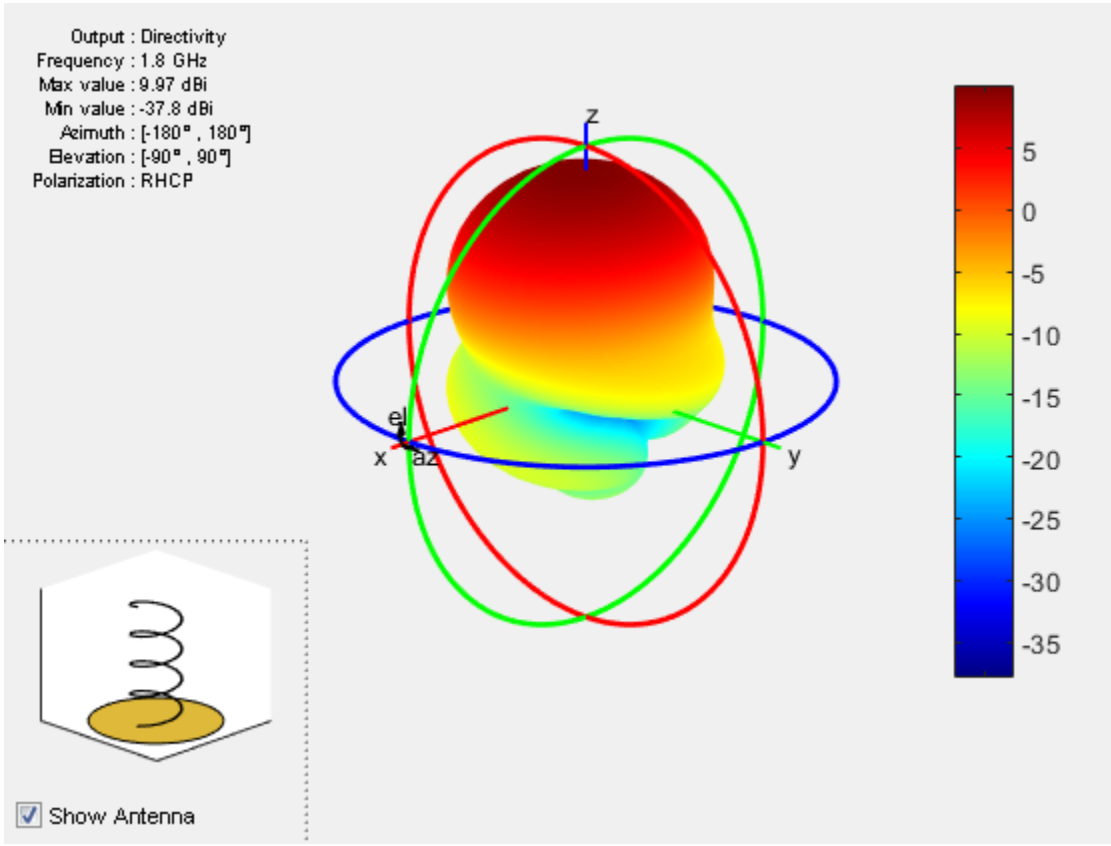
```
[E,H] = EHfields(hx,1.8e9,[0;0;1])
```

```
E =

  -0.5327 - 0.5980i
  -0.9102 + 0.5338i
  -0.0041 + 0.0007i


H =

   0.0024 - 0.0014i
  -0.0014 - 0.0016i
   0.0000 - 0.0000i
```

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 =

   27.7584
```

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.

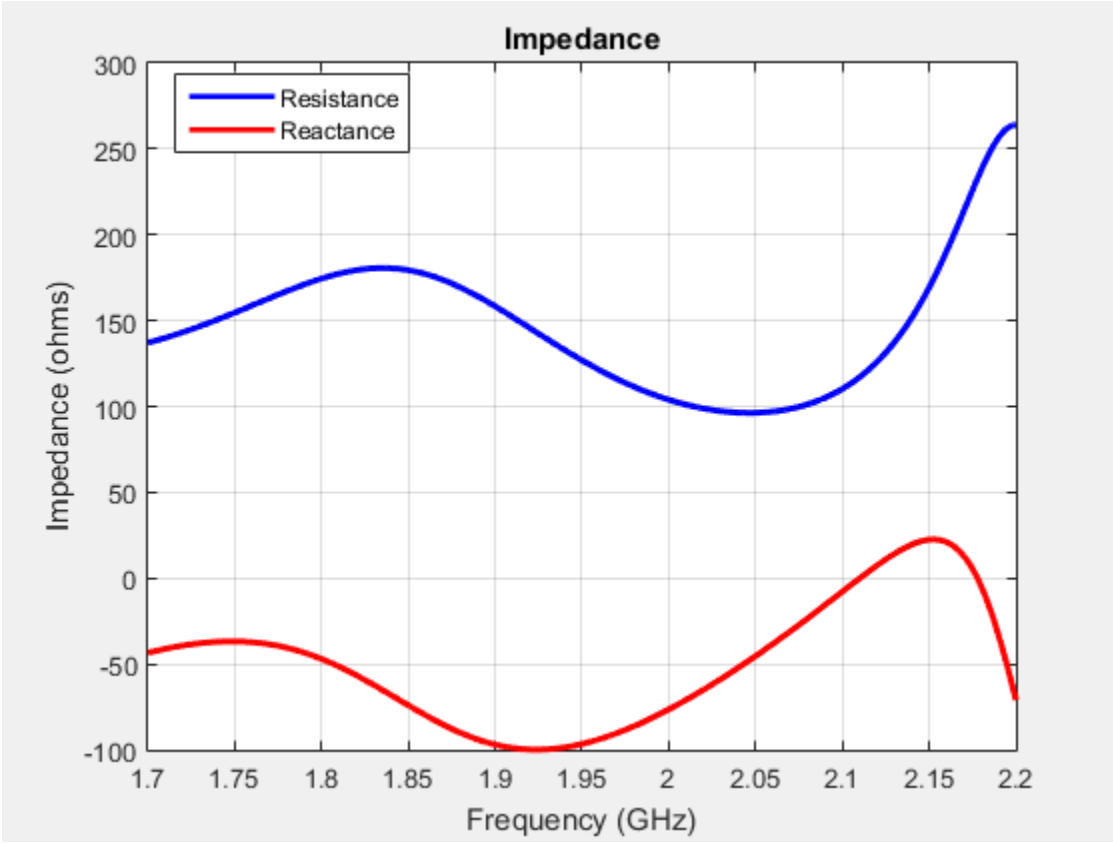
```
[bw, angles] = beamwidth(hx,1.8e9,0,1:1:360)
```

```
bw =

    58


angles =

    60   118
```

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)
```



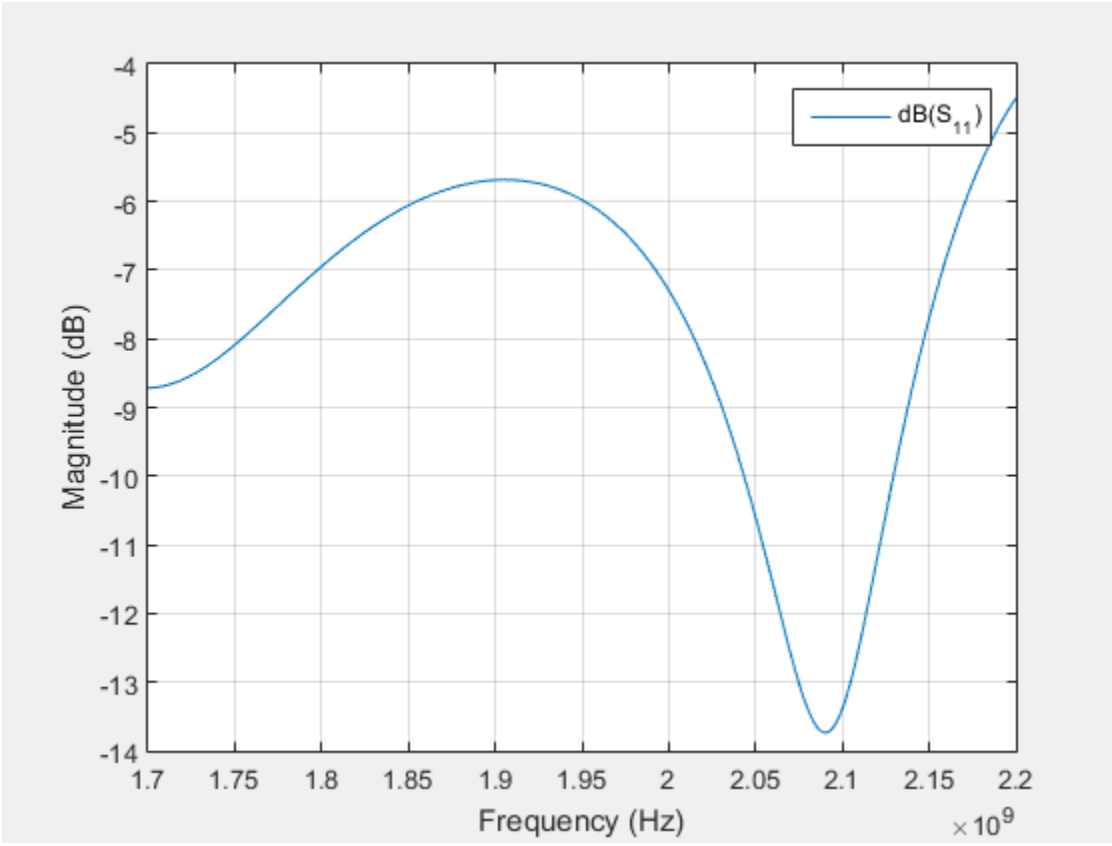
Calculate Reflection Coefficient of Antenna

Use the sparameters function to calculate the S11 value 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)
rfplot(S)
```

```
S =

  sparameters: S-parameters object
```

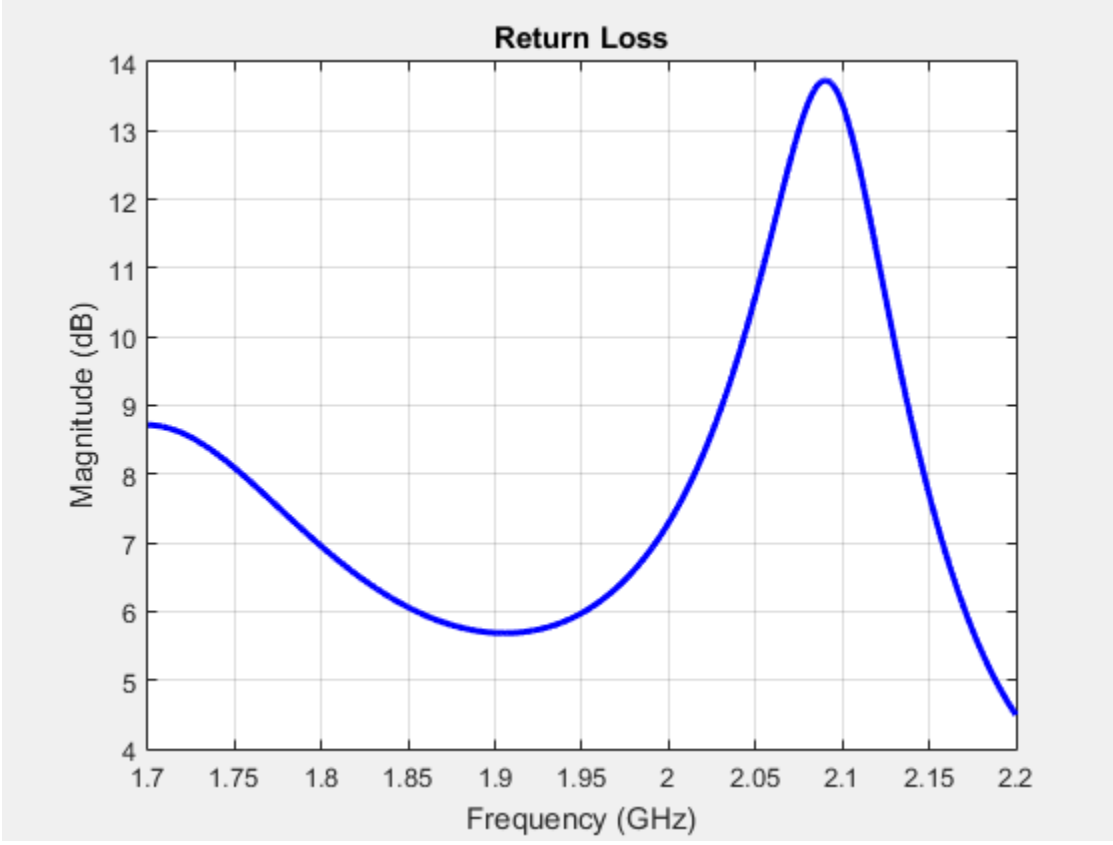
```
      NumPorts: 1
   Frequencies: [501x1 double]
    Parameters: [1x1x501 double]
     Impedance: 72

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



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 or coaxial cable to a load such as antenna. The unit of measure is dB.

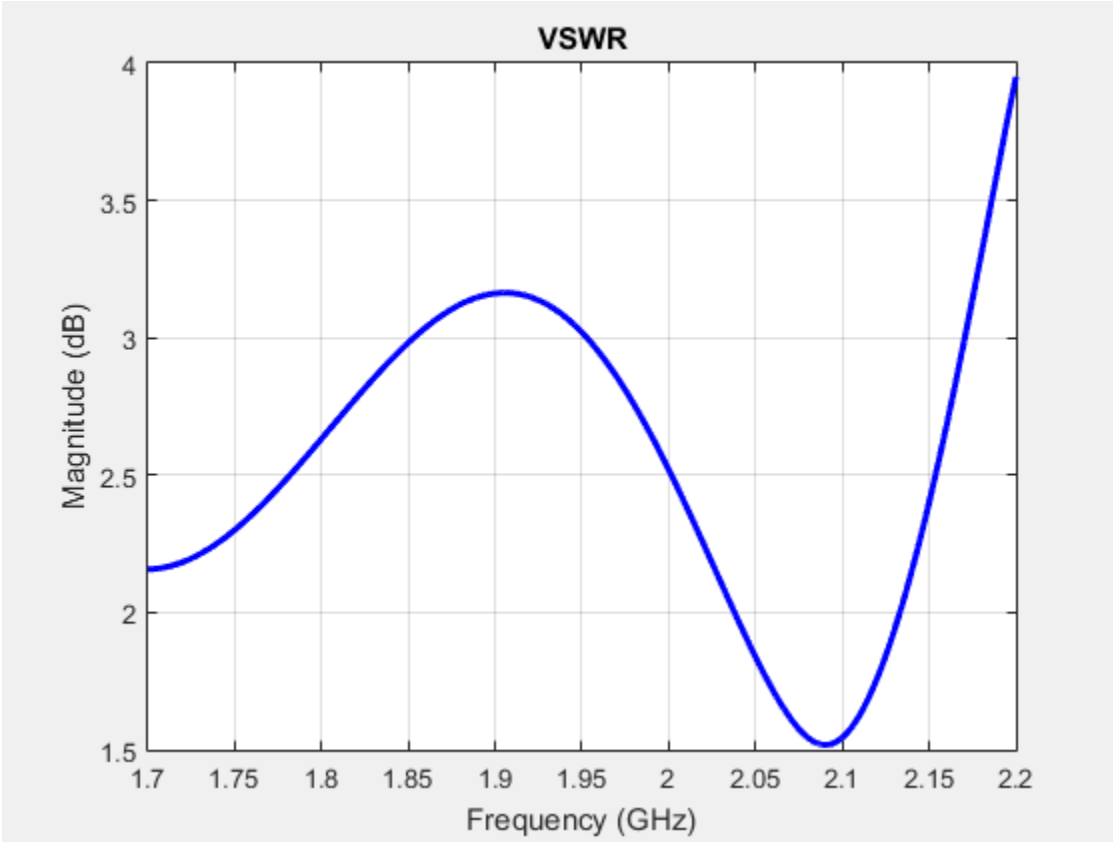
```
returnLoss(hx,1.7e9:1e6:2.2e9,72)
```



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.

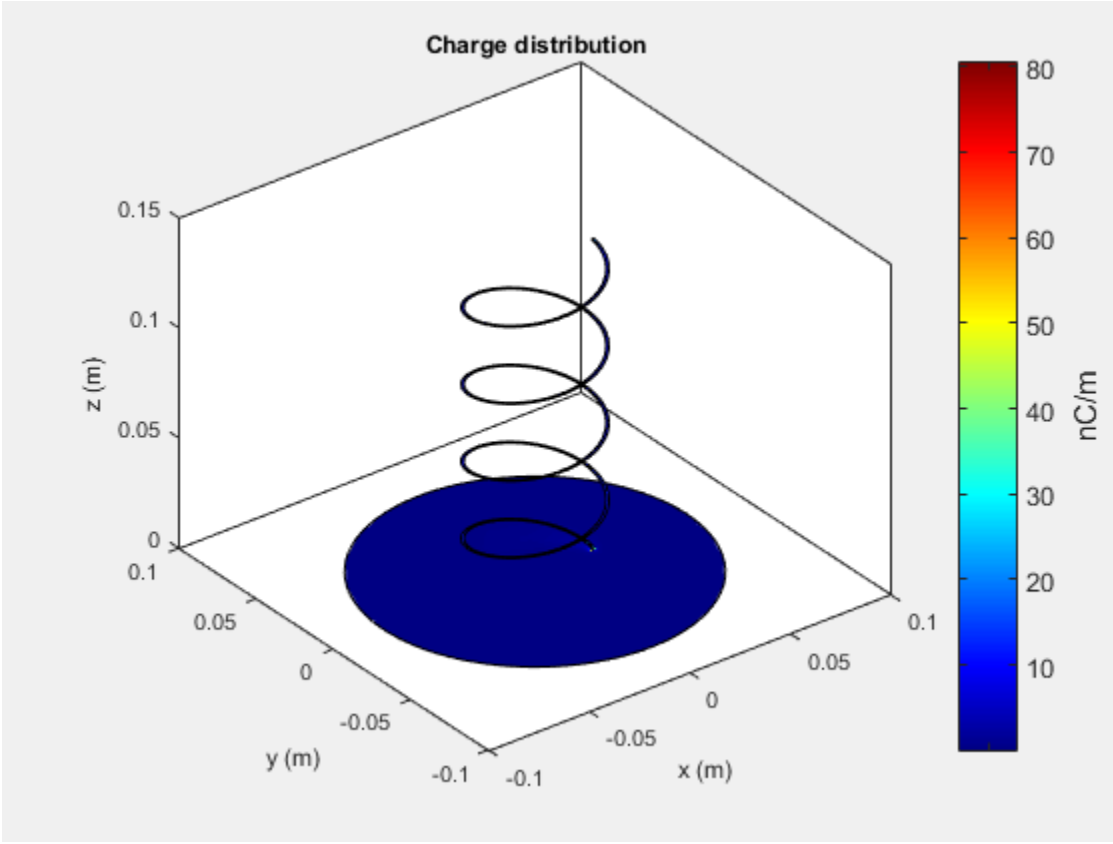
```
vswr(hx,1.7e9:1e6:2.2e9,72)
```

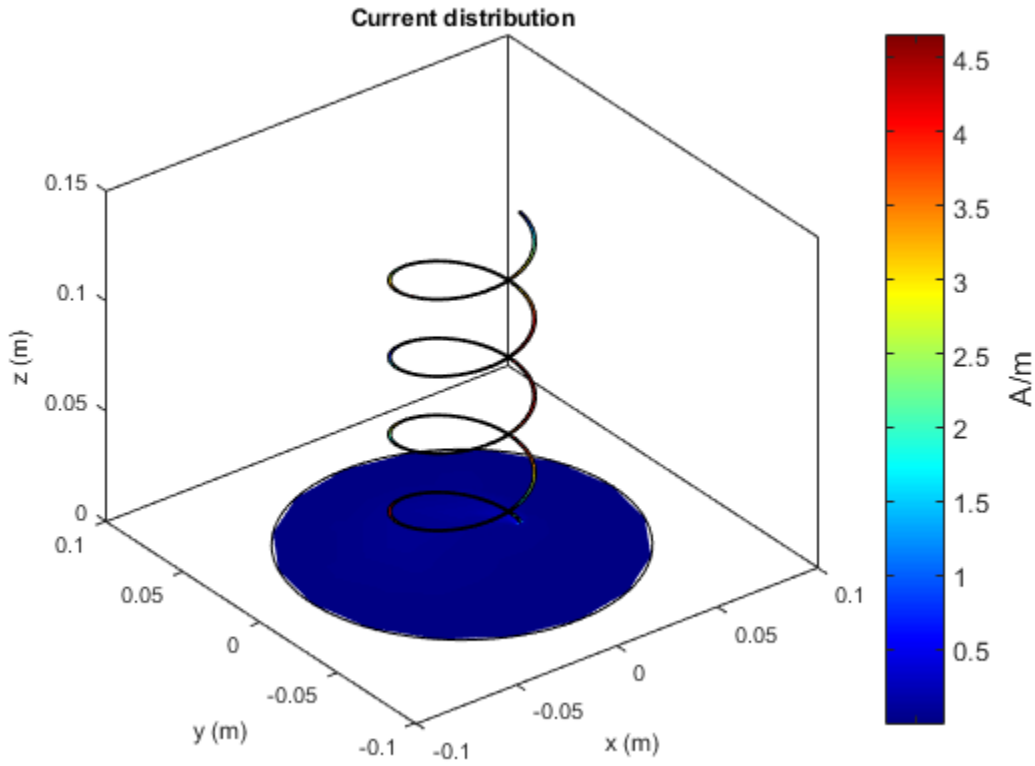


Calculate Current and Charge Distribution Of Antenna

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,1.0e9)
```

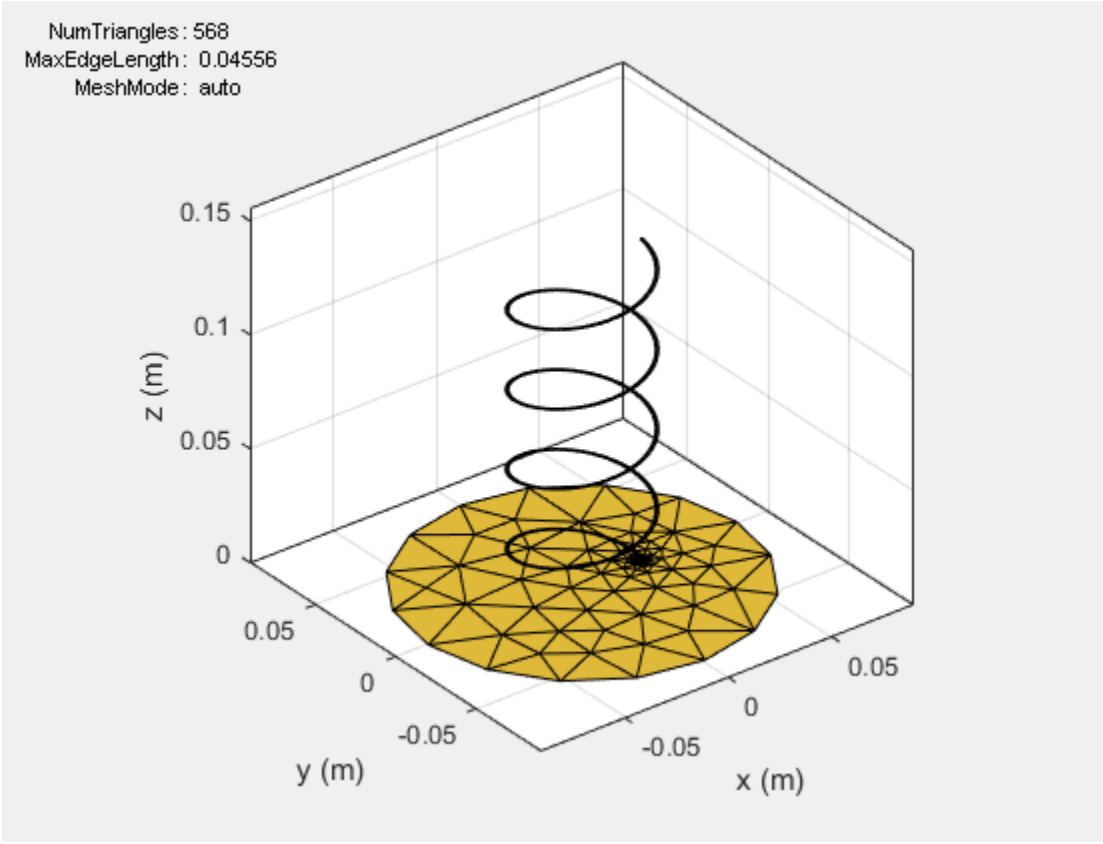

Charge distribution
z (m)
0.15
0.1
0.05
0
0.1
0.05
0
-0.05
-0.1
y (m)
-0.1
-0.05
0
0.05
0.1
x (m)
80
70
60
50
40
30
20
10
nC/m



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.

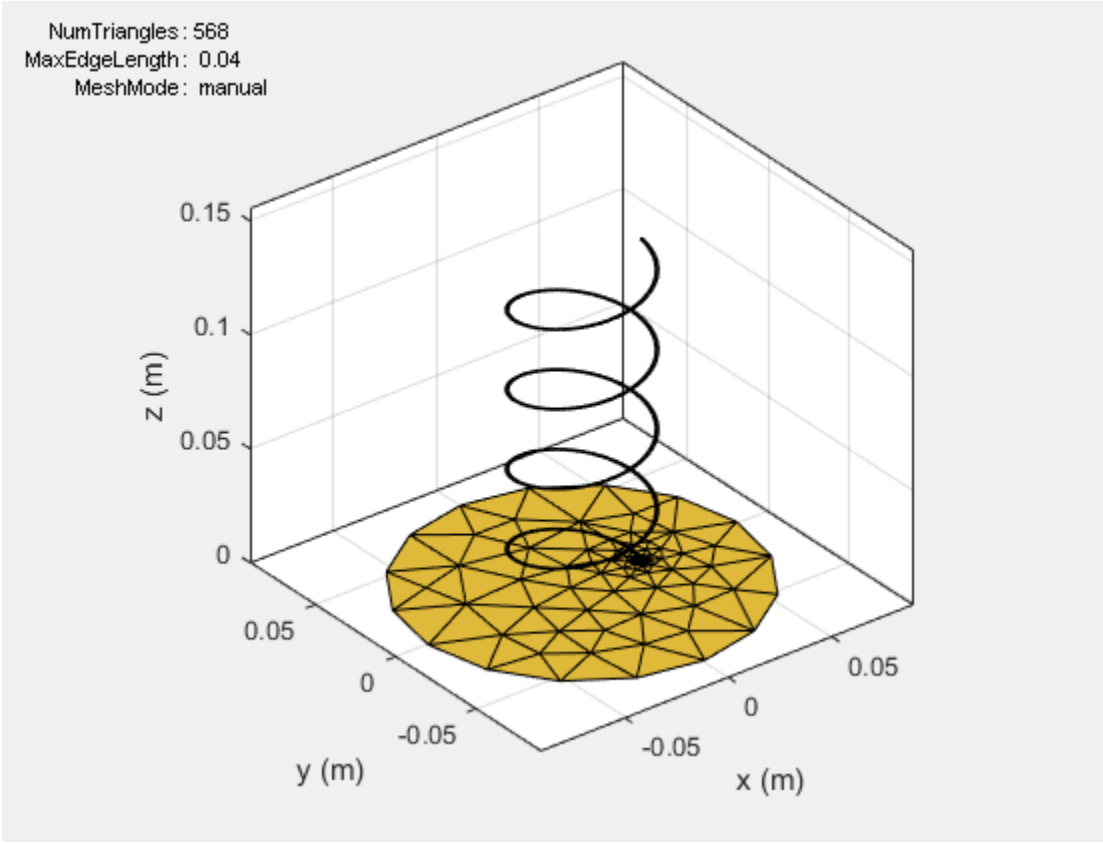
```
mesh(hx)
```



Mesh Antenna Manually

Specify the maximum edge length for the triangles using the 'MasEdgeLength' flag. This flag meshes the helix structure manually.

```
mesh(hx,'MaxEdgeLength',0.04)
```



Change Meshing to Automatic

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

```
ans =

     NumTriangles: 568
    MaxEdgeLength: 0.0400
         MeshMode: 'auto'
```

References

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

Antenna Toolbox Library Elements

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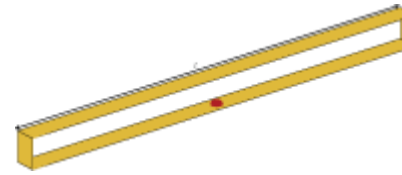
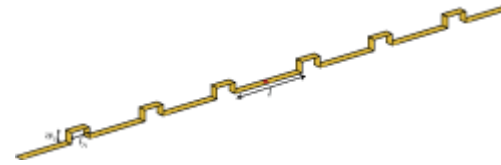
Dipole Antennas

`dipole`

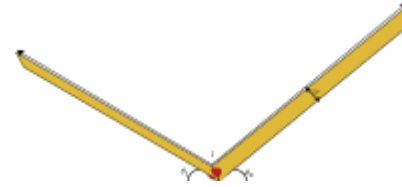
`dipoleFolded`



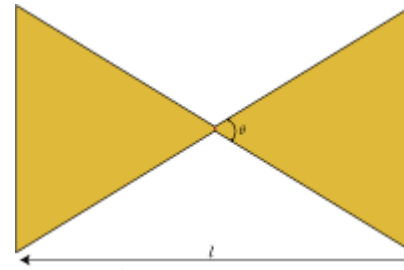
`dipoleMeander`



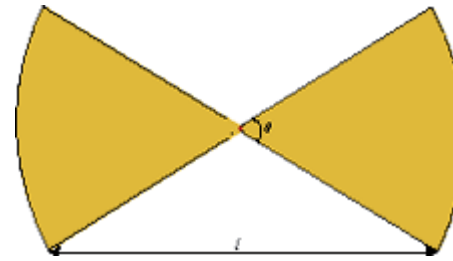
`dipoleVee`



`bowtieTriangular`

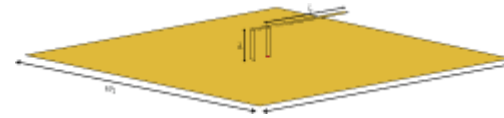


`bowtieRounded`

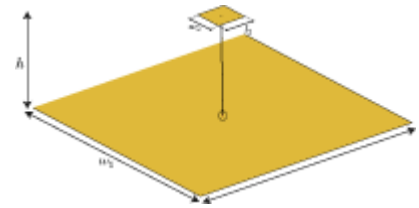


Monopole Antennas

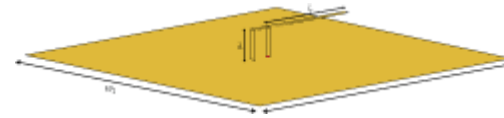
`monopole`



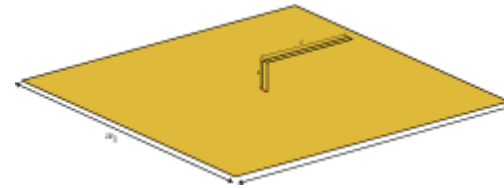
`monopoleTopHat`



`invertedF`

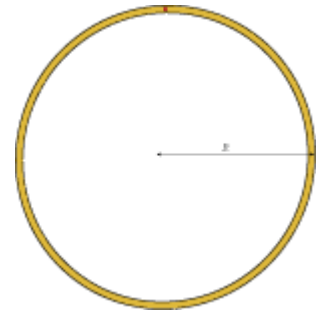


`invertedL`



Loop Antennas

`loopCircular`



`loopRectangular`

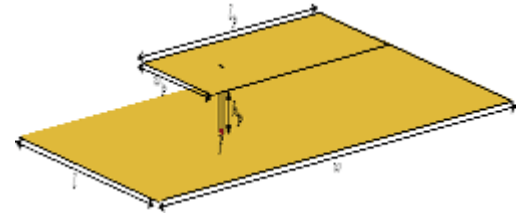
Spiral Antennas

`spiralArchimedean`

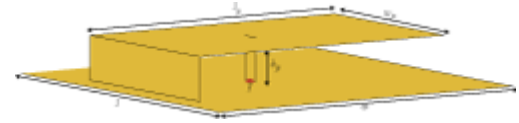
`spiralEquiangular`

Patch Antennas

`patchMicrostrip`

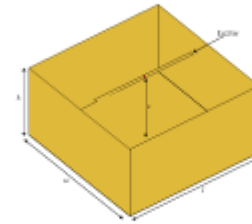


`pifa`

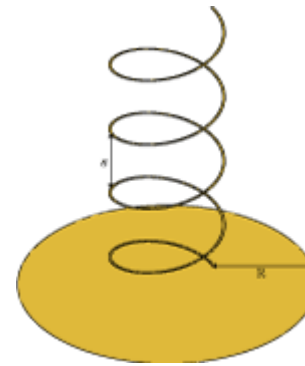


Other Antennas

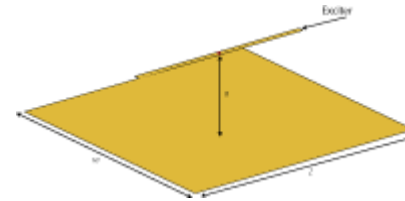
`cavity`



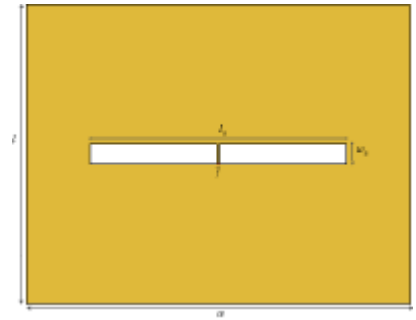
`helix`



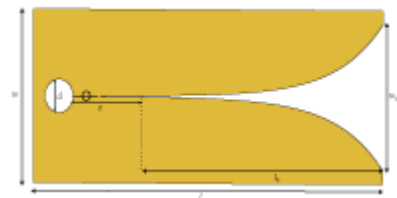
`reflector`



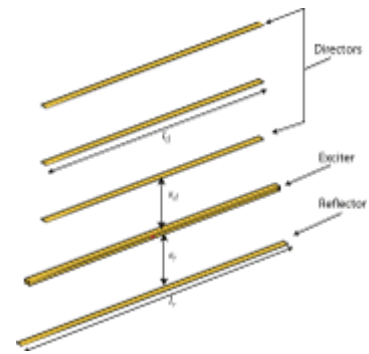
`slot`



`vivaldi`

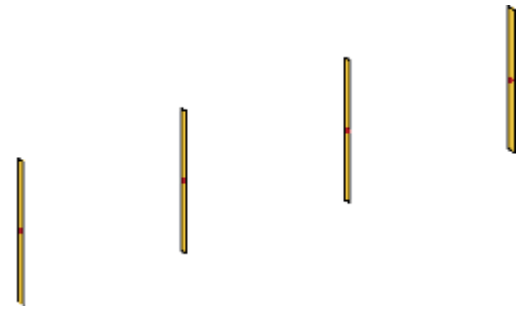


`yagiUda`

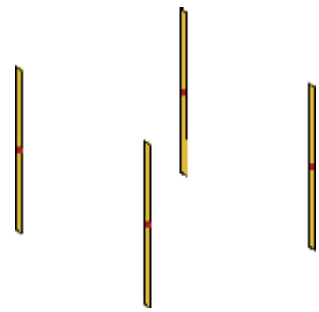


Arrays

`linearArray`



`rectangularArray`



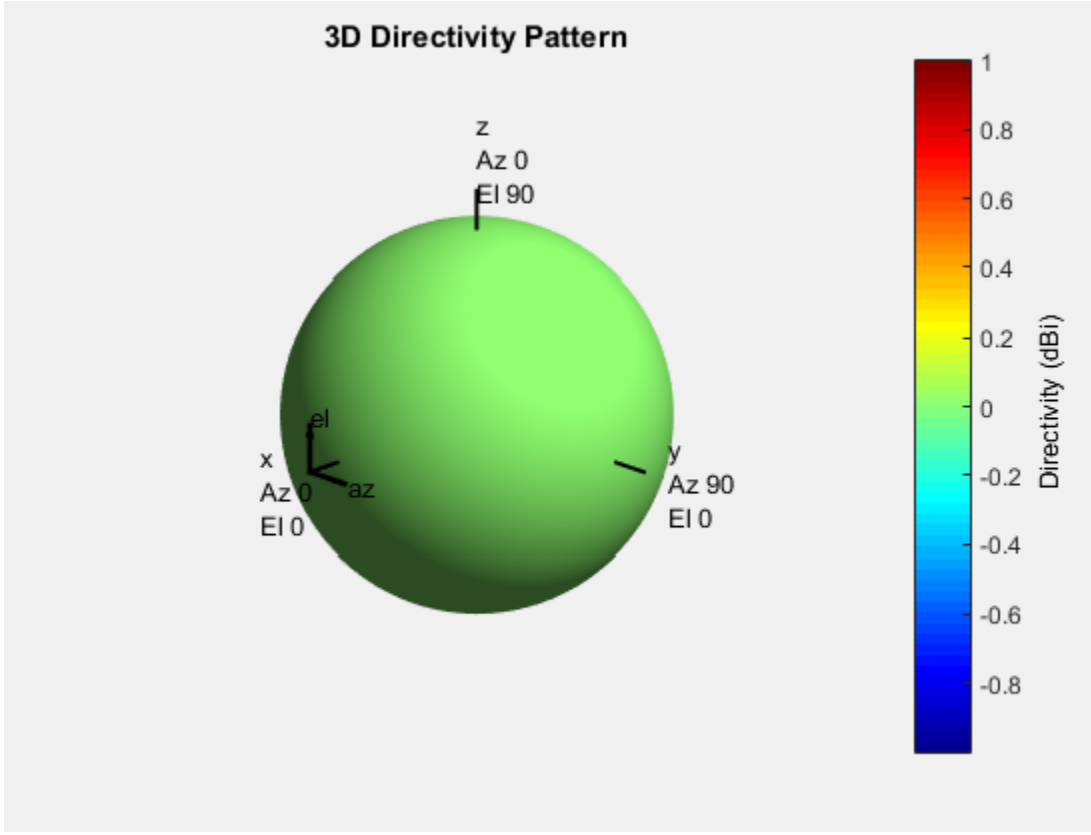
Antenna Classification

In this section...
“Radiation Pattern” on page 1-28
“Antenna Feeding Mechanism” on page 1-31

Radiation Pattern

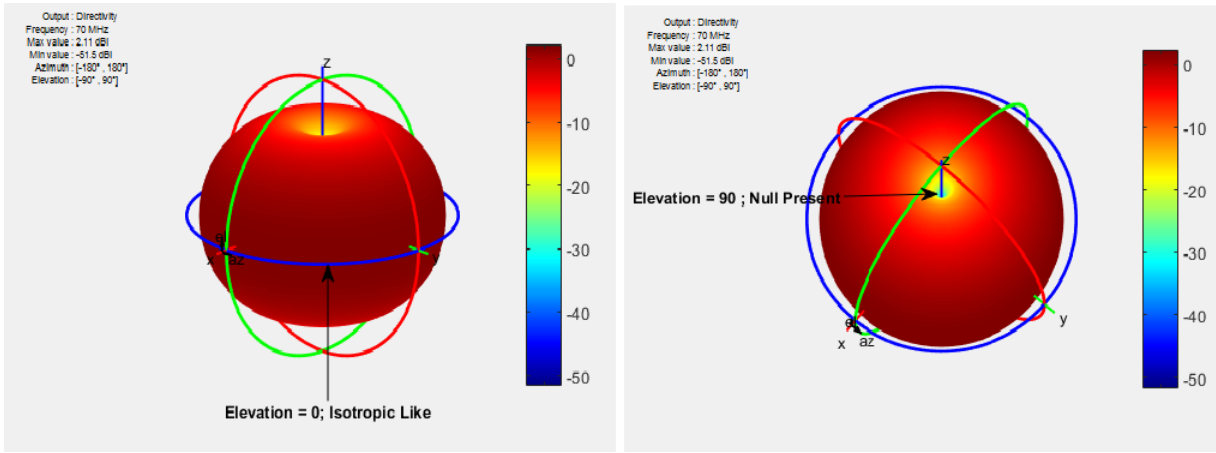
Isotropic Antenna

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

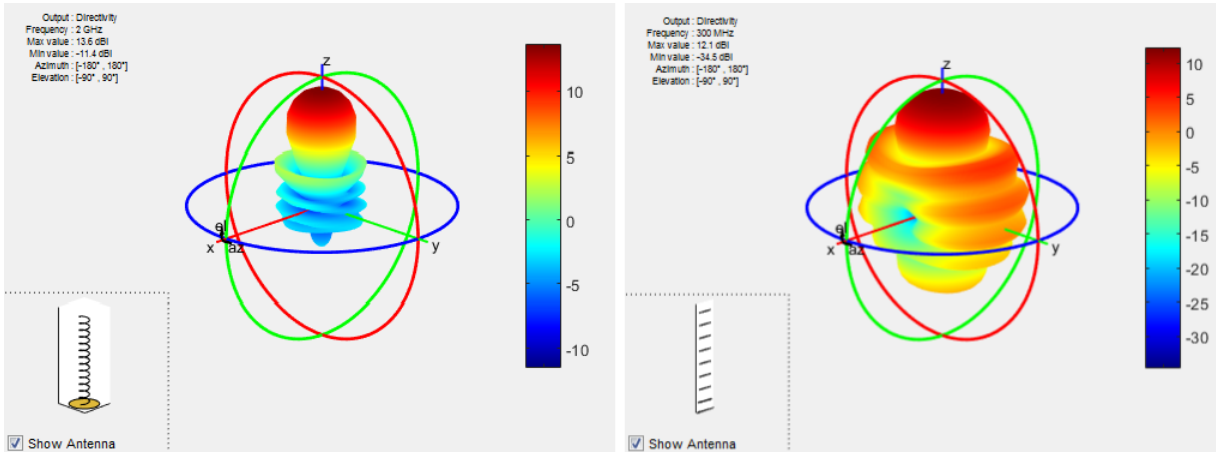
Omnidirectional antennas behave like isotropic antennas in one plane. These antennas have nulls in the orthogonal plane. A common example of an omnidirectional antenna is the `dipole` antenna.



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

Directional Antennas

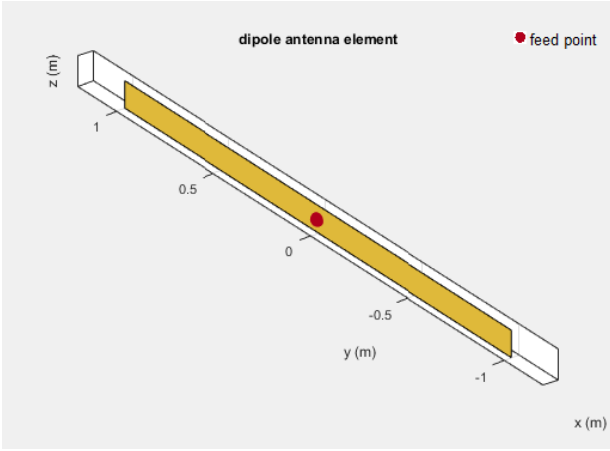
Directional antennas are highly directive in a given direction. These antennas show high spatial selectivity, narrow bandwidth. They also have well defined major, or main, beam in the desired directions. Common examples of directional antennas are `helix` and `yagiUda`.

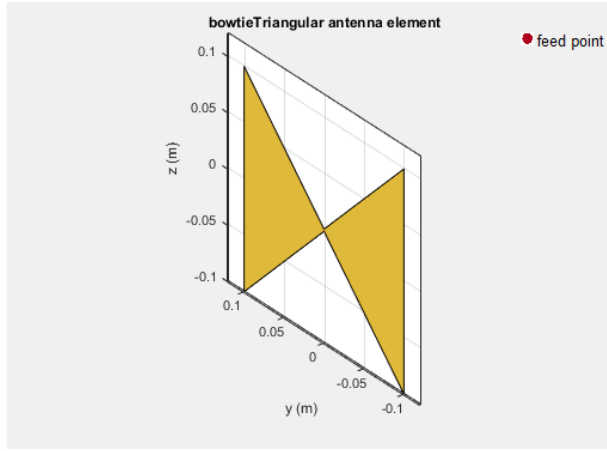


Antenna Feeding Mechanism

Balanced Antennas

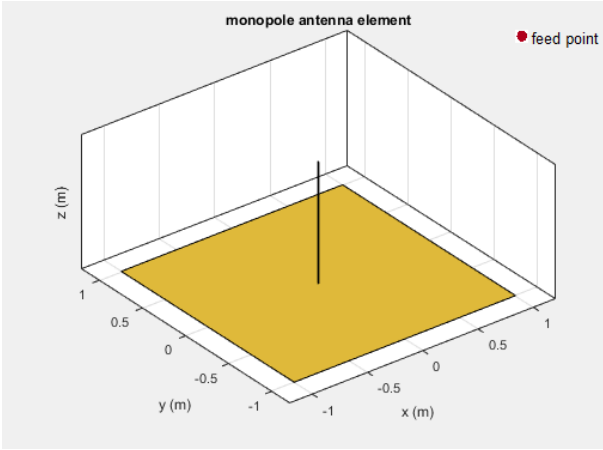
In *balanced* antennas, one side of the antenna is a mirror image of the other. These antennas require a balun to feed it, using a coaxial line. Common examples are: dipoles, bowties, spirals, and loops.

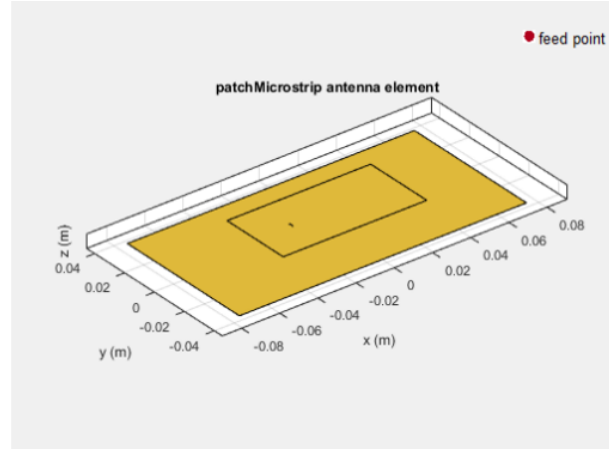




Unbalanced Antennas

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

Antenna Toolbox uses two types of coordinate system. The *rectangular coordinate system* orients the antennas along the X-Y plane. The *spherical coordinate system* is used for antenna radiation patterns.

In this section...

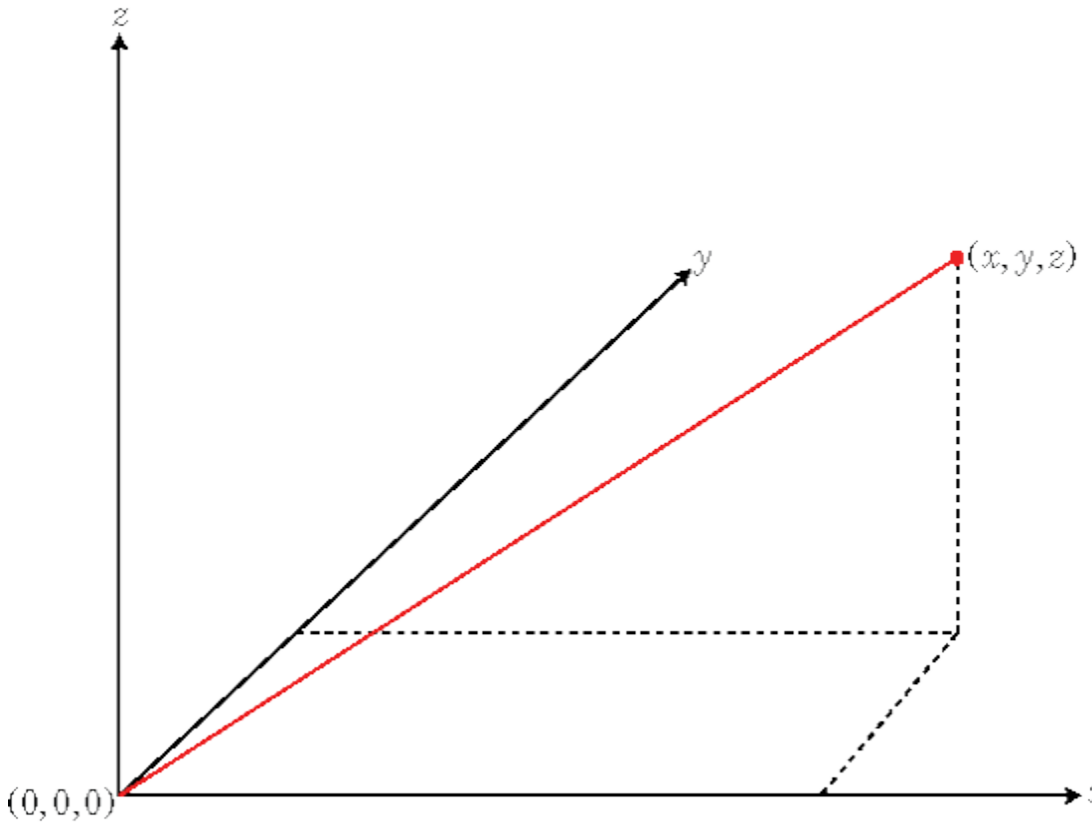
"Rectangular Coordinate System" on page 1-33

"Spherical Coordinate System" on page 1-35

"Conversion Between Rectangular and Spherical Coordinates" on page 1-38

Rectangular 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

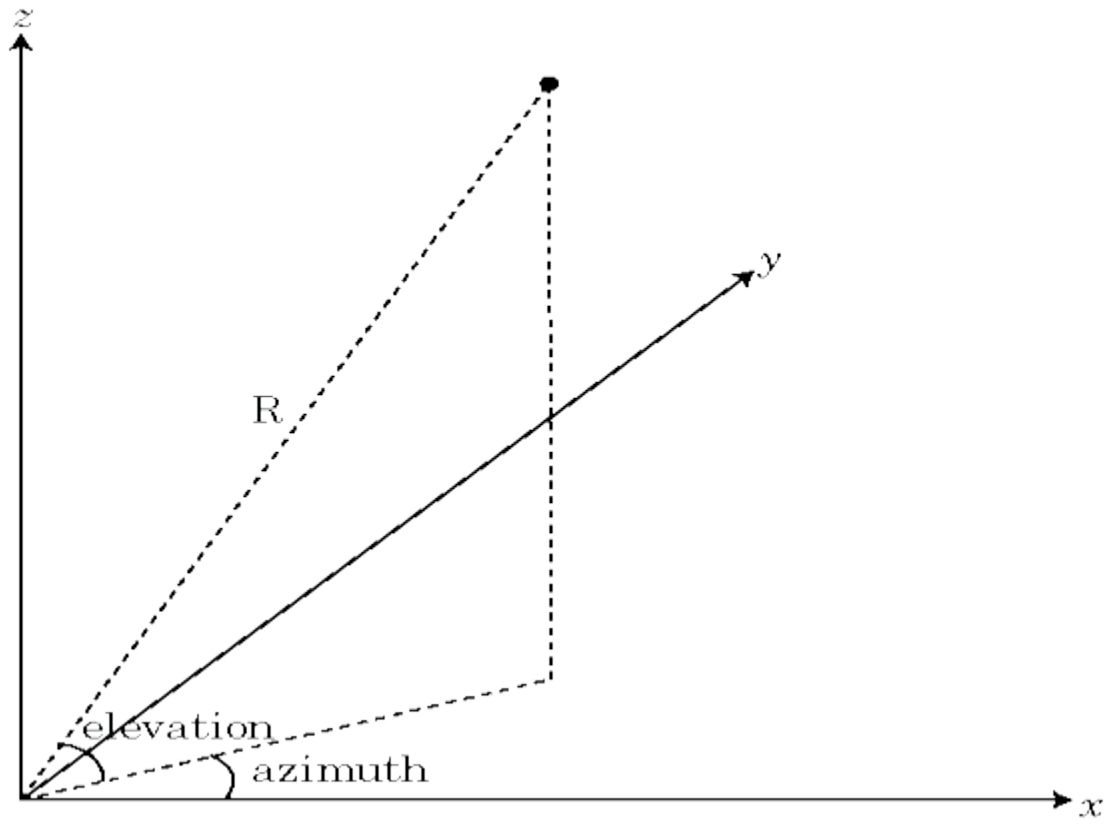
The spherical coordinate system defines a vector or point in space with a distance R and two angles. You can represent the angles in this coordinate system:

- 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.

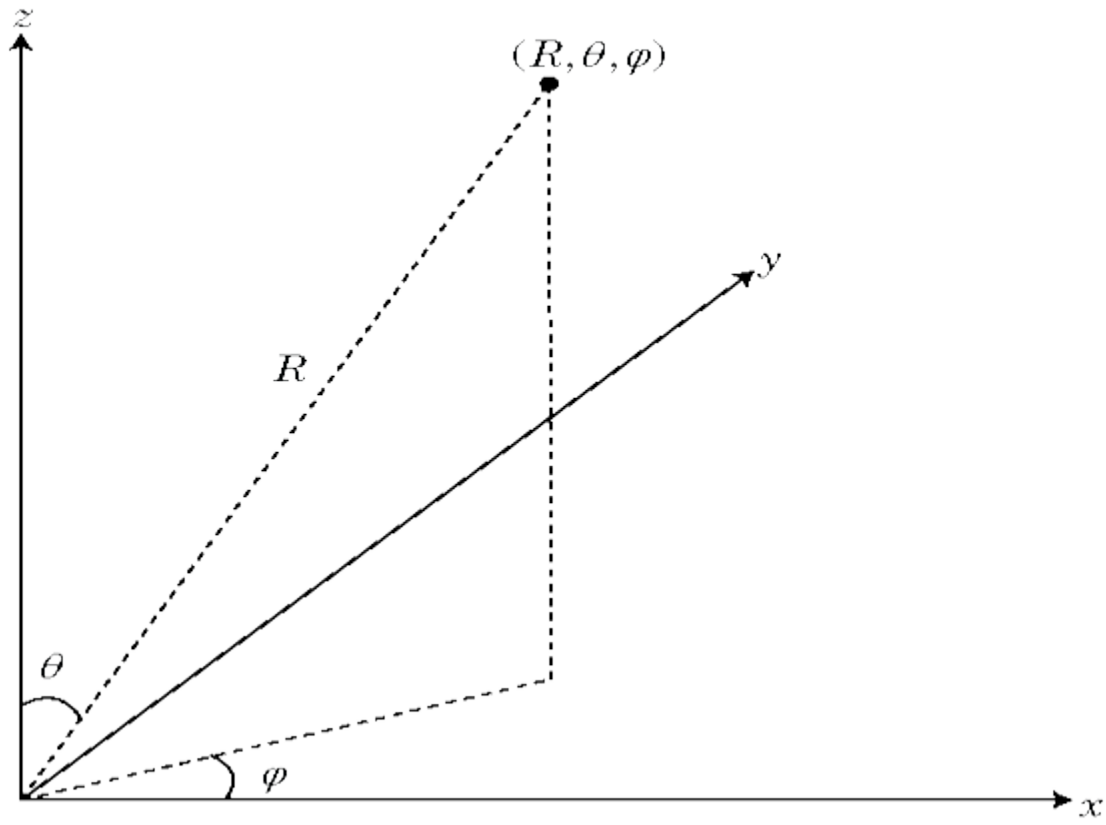


Phi (Φ) and Theta (θ) Angles

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's orthogonal projection on the *xy* plane measured clockwise. The θ angle is in the range 0 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:

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

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:

$$R = \sqrt{x^2 + y^2 + z^2}$$
$$az = \tan^{-1}(y / x)$$
$$el = \tan^{-1}(z / \sqrt{x^2 + y^2})$$

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.

2

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 defualt rectangular antenna array using the rectangularArray class element in the array library. By defualt, this array uses the dipole antenna as element.

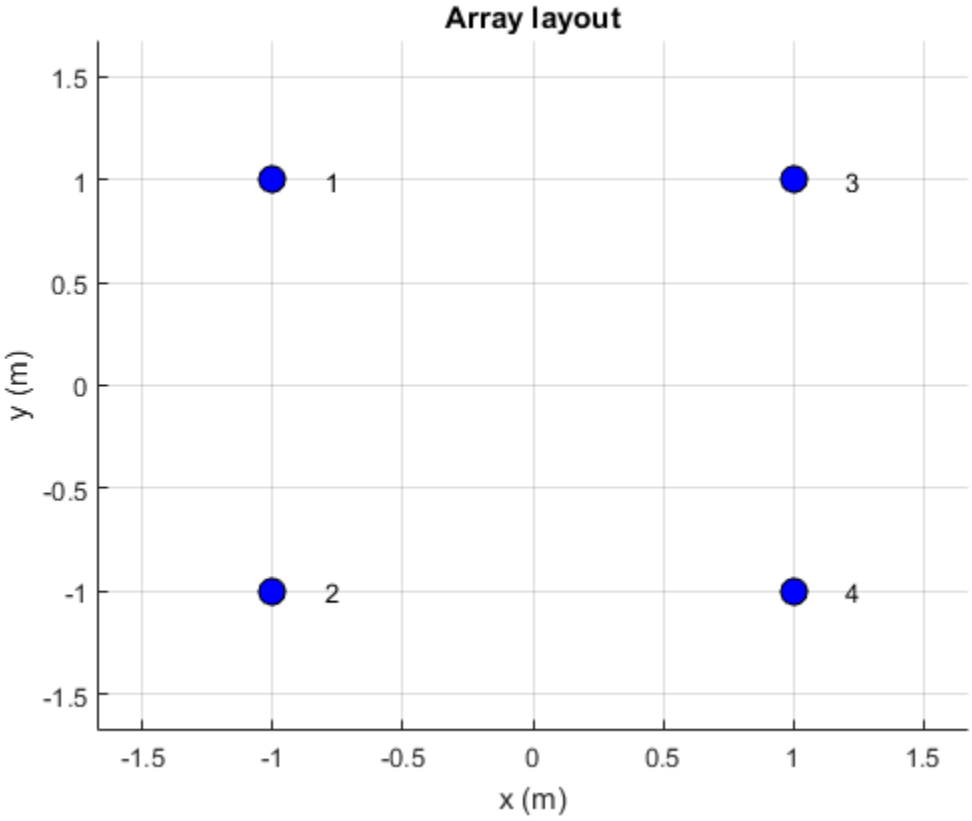
```
ra = rectangularArray
```

```
ra =

  rectangularArray with properties:

          Element: [1x1 dipole]
             Size: [2 2]
       RowSpacing: 2
    ColumnSpacing: 2
          Lattice: 'Rectangular'
   AmplitudeTaper: 1
       PhaseShift: 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.

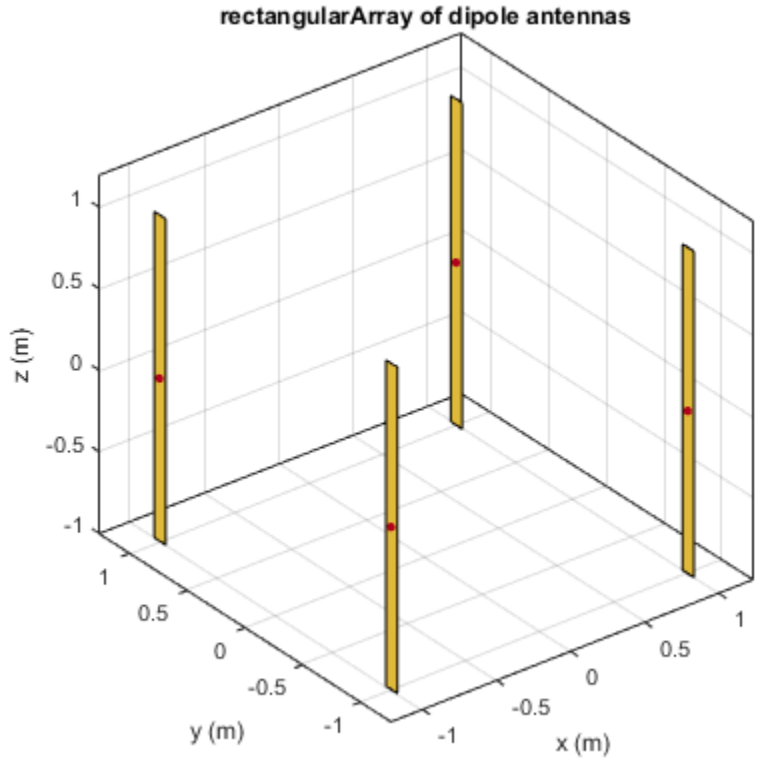
```
layout(ra)
```



Visualize Geometry of Array

Use the show function to view the stucture of the rectangular antenna array.

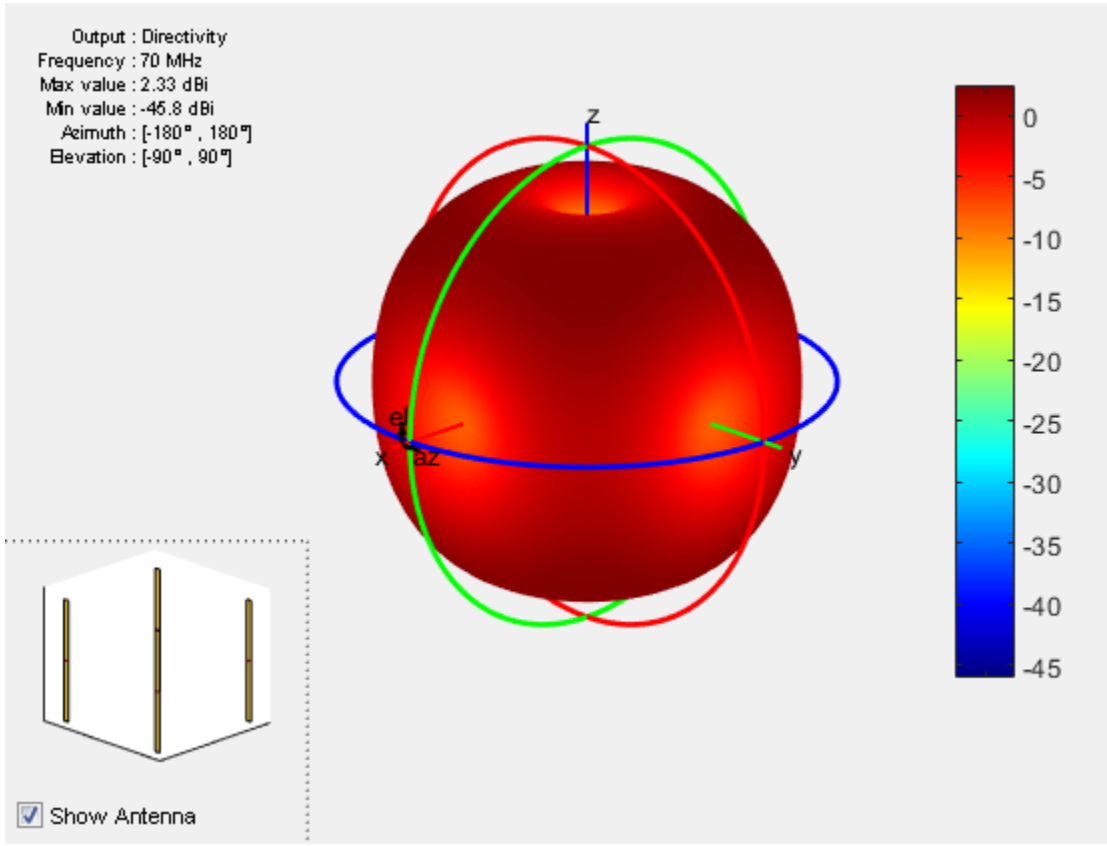
```
show(ra)
```



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 directivit or gain of the array. By default, the pattern function plots the directivity of the array.

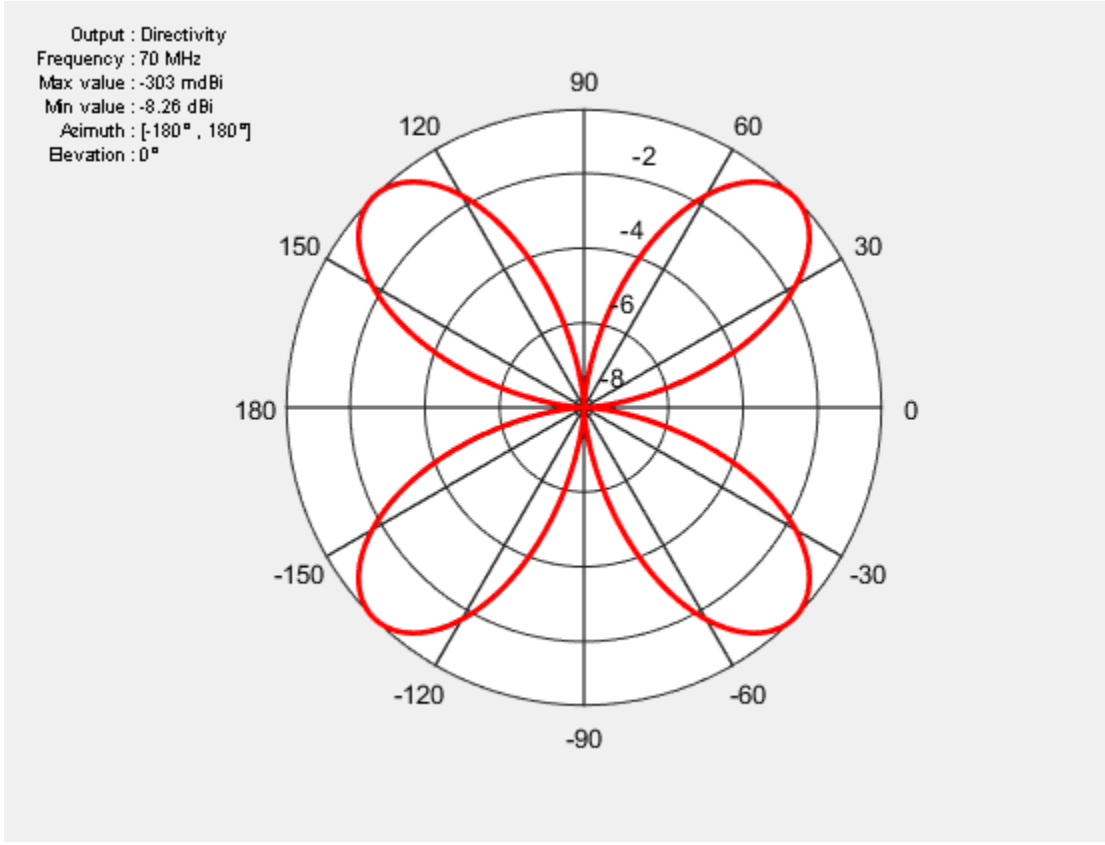
```
pattern(ra,70e6)
```

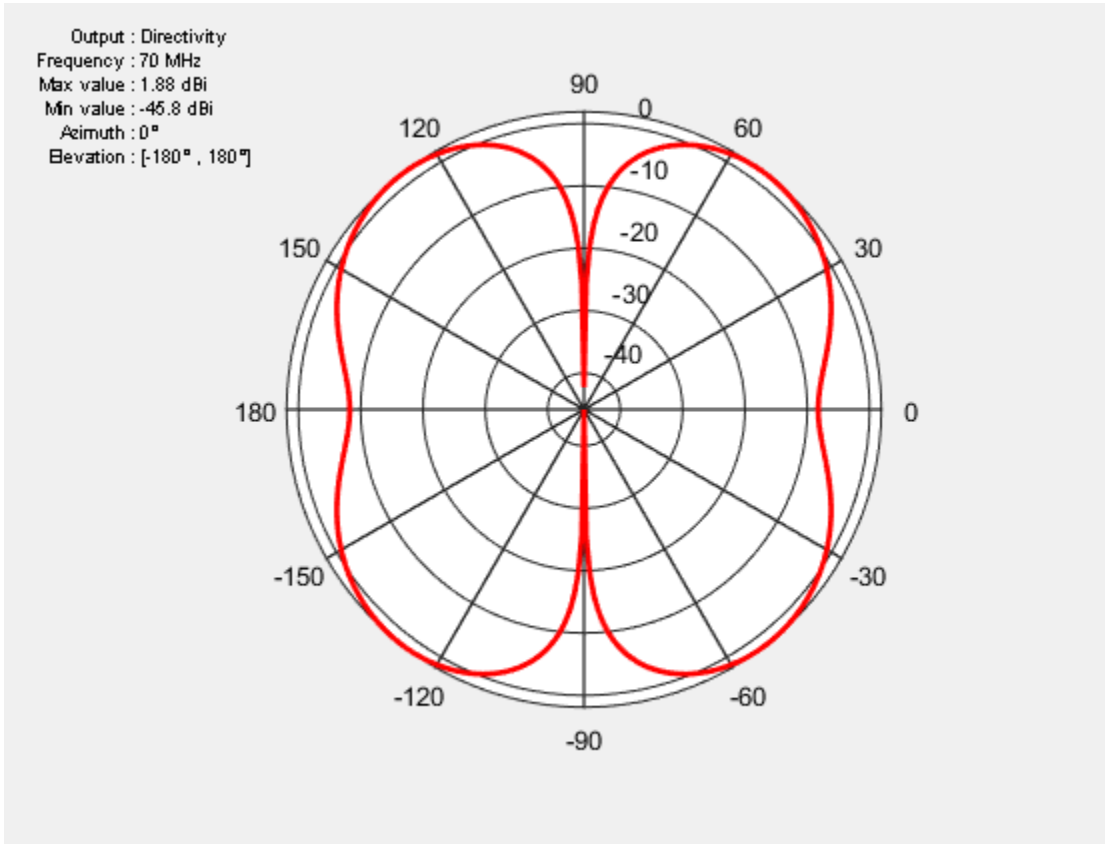


Plot Azimuth and Elevation Pattern of Array

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)
```


Output : Directivity
Frequency : 70 MHz
Max value : -303 mdBi
Min value : -8.26 dBi
Azimuth : [-180°, 180°]
Elevation : 0°
90
120
60
-2
-4
150
30
-6
-8
180
0
-150
-30
-120
-60
-90



Calculate the Directivity of Array

Use Directivity the output of the pattern function to calculate the directivity of the rectangular 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.

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

```
Directivity =

  -42.2474
```

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.

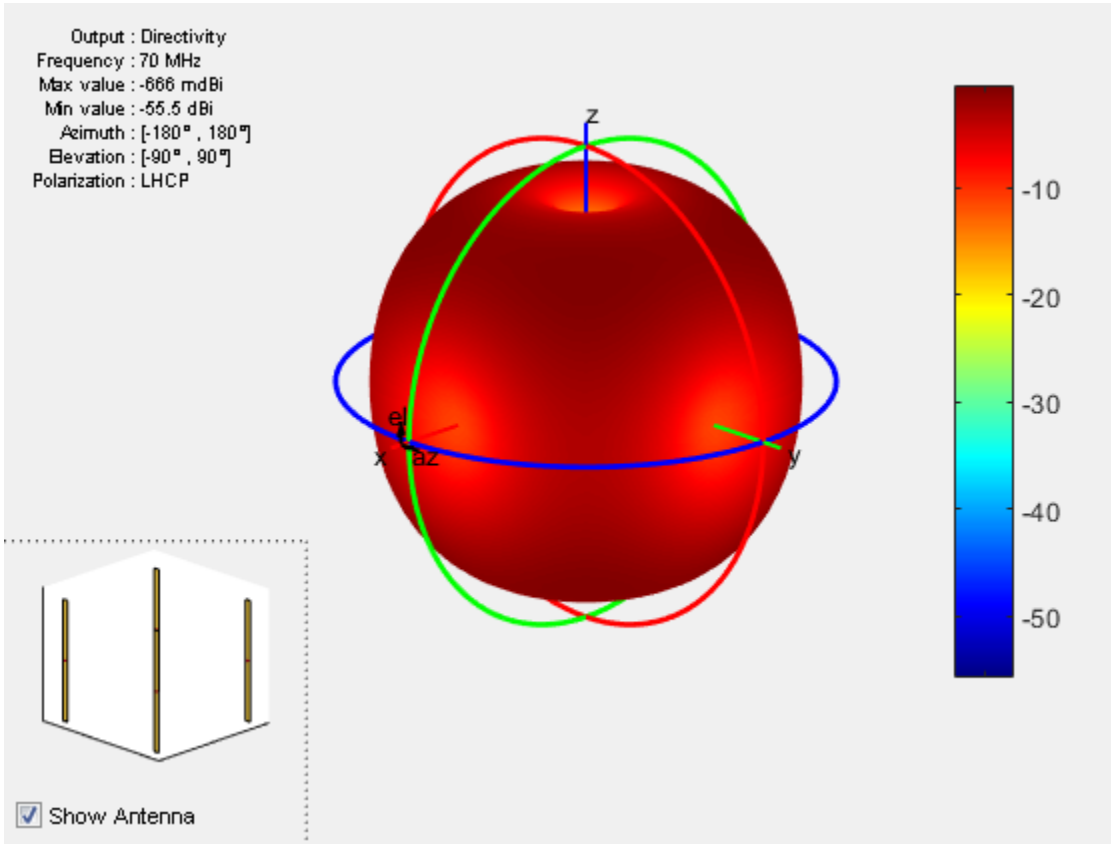
```
[E,H] = EHfields(ra,70e6,[0;0;1])
```

```
E =

  -0.0000 - 0.0000i
  -0.0023 + 0.0017i
  -1.3896 - 0.0428i


H =

   1.0e-05 *

   0.1601 - 0.7689i
  -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')
```



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 plane that contains the direction of main lobe of the array.

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

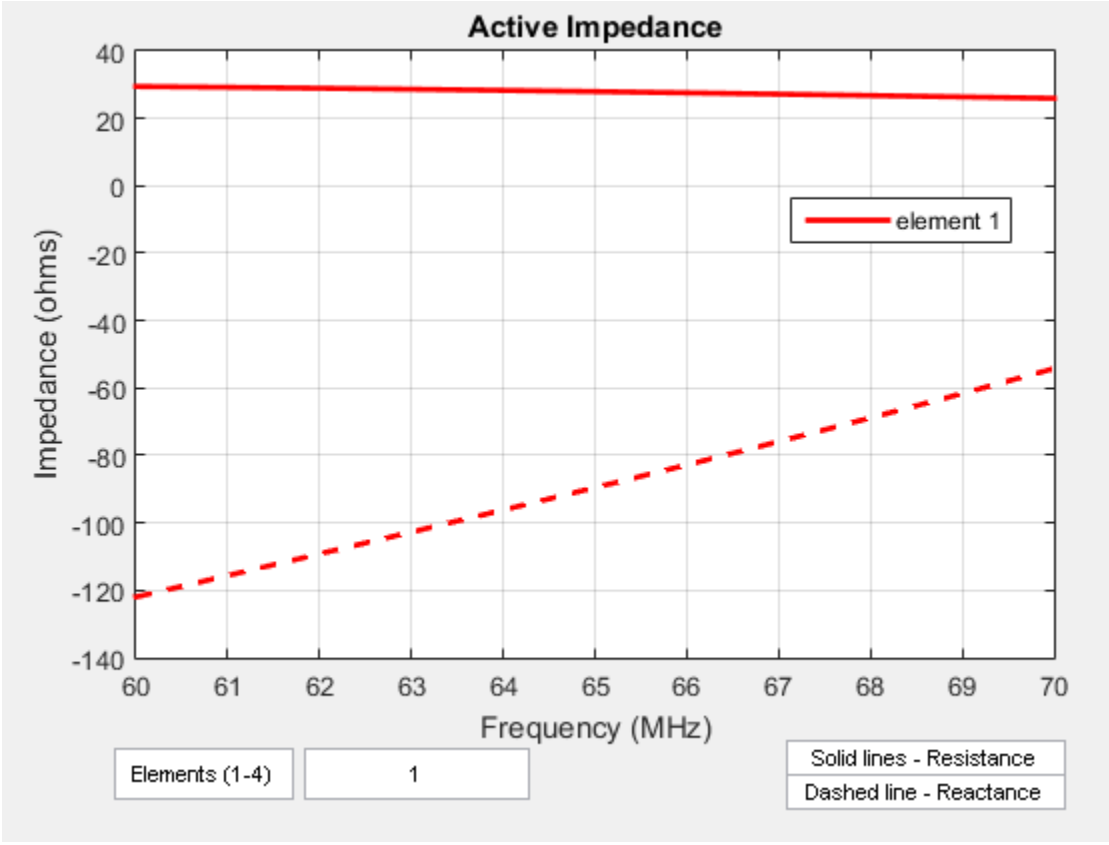
```
bw =

    45
    45
```

```
angles =

   108   153
    28    73
```

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)
```

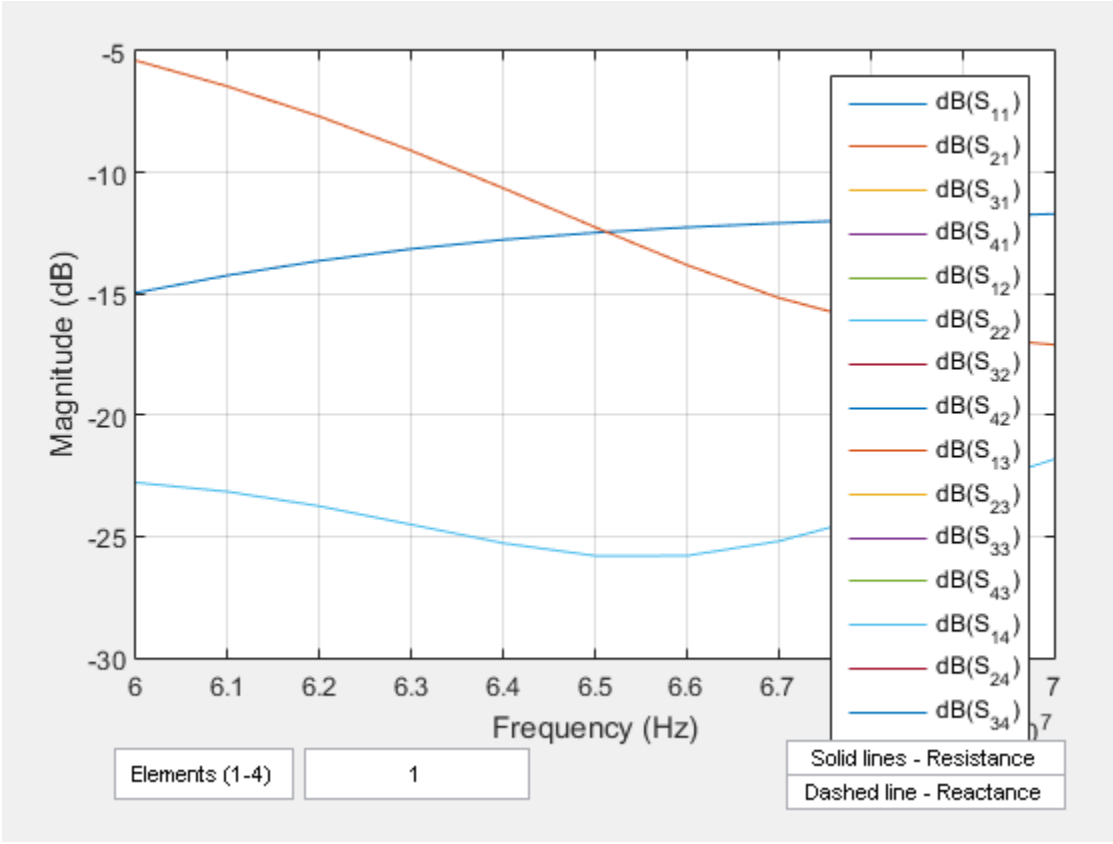


Calculate Reflection Coefficient of Array

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)
rfplot(S)
```

```
S =

  sparameters: S-parameters object

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

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



Calculate Return Loss of Array

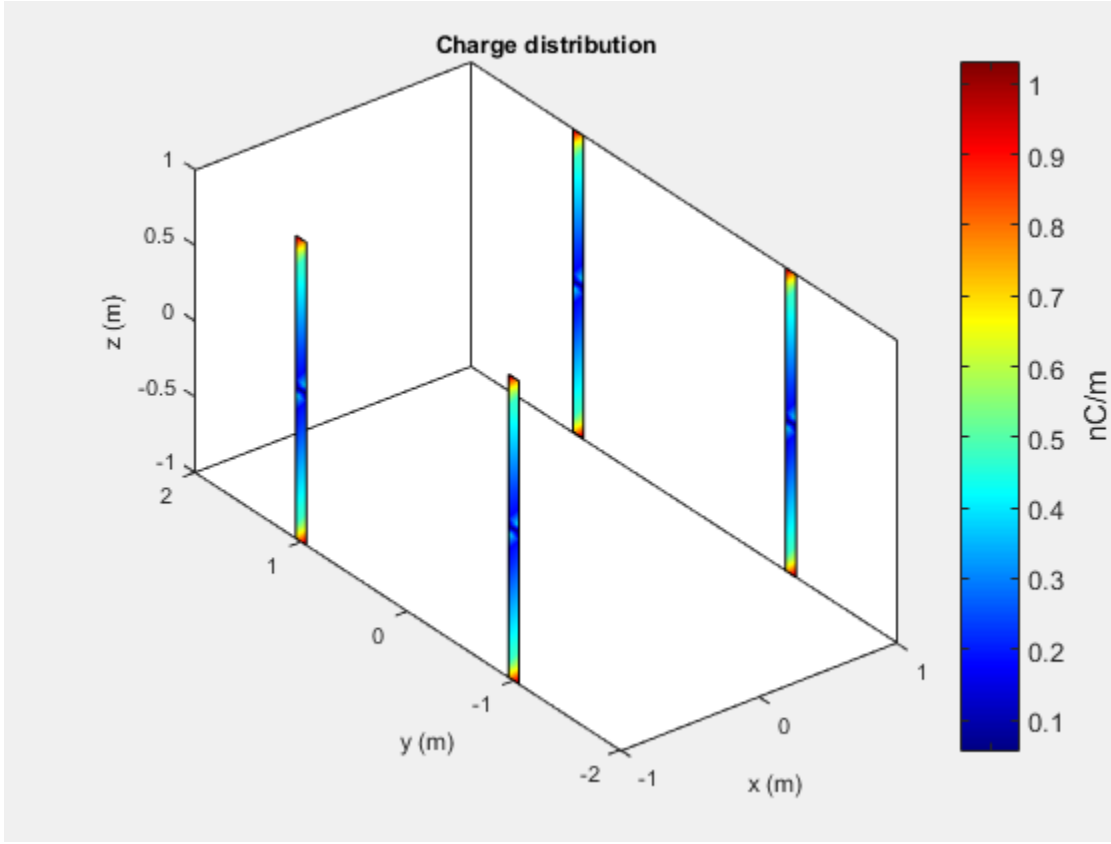
Use the returnLoss function to calculate and plot the return loss of the rectangular array.

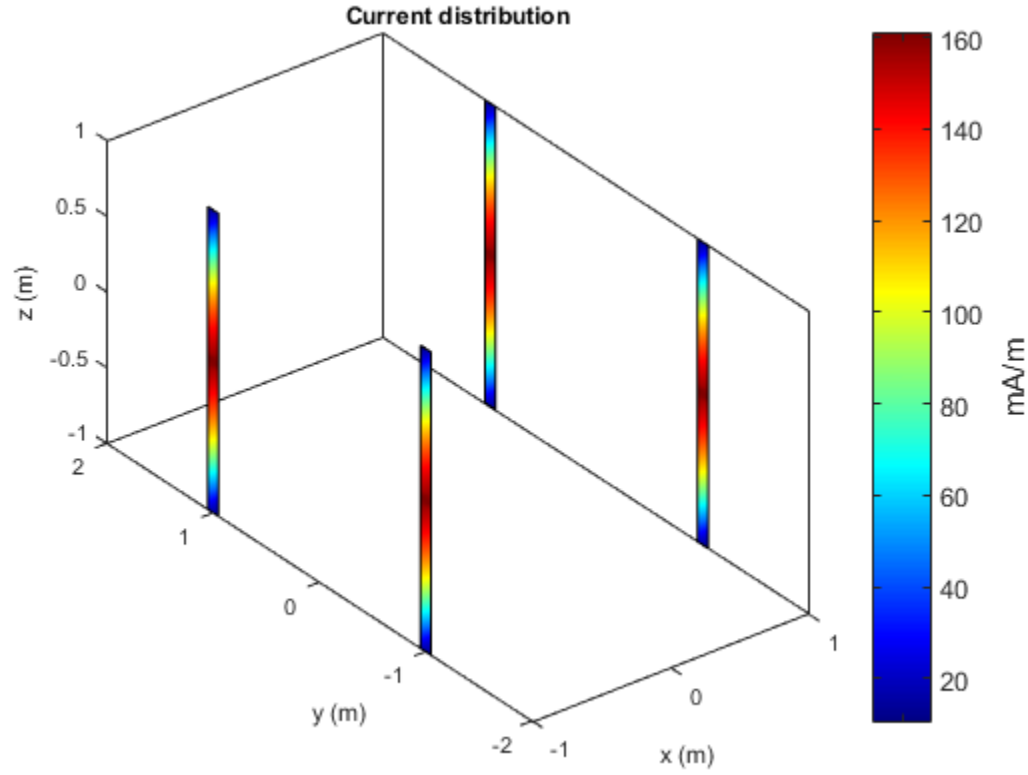
```
returnLoss(ra,60e6:1e6:70e6,72)
```

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)
```

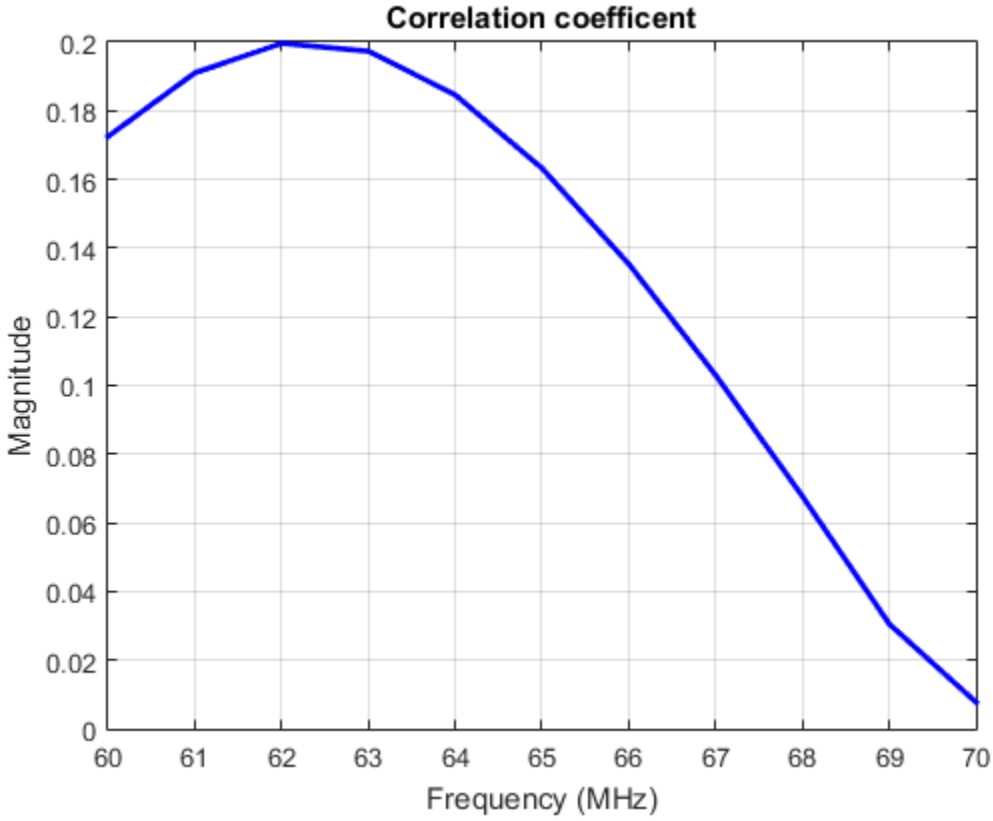

Charge distribution
z (m)
1
0.5
0
-0.5
-1
2
1
0
-1
-2
y (m)
-1
0
1
x (m)
nC/m
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1



Calculate Correlation Coeffecient of Array

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

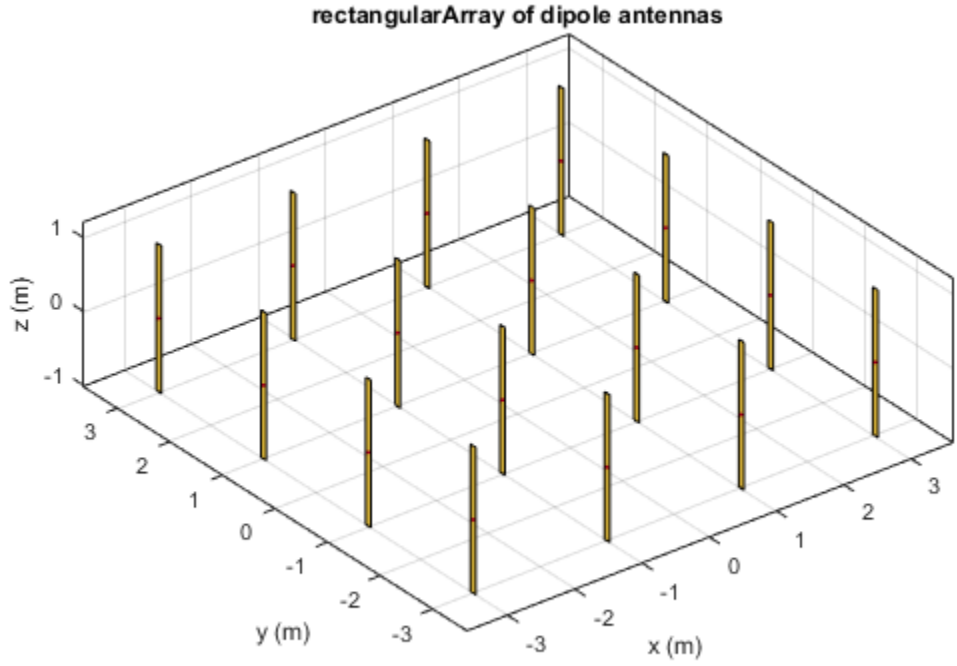
```
correlation(ra,60e6:1e6:70e6,1,2)
```



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)
```



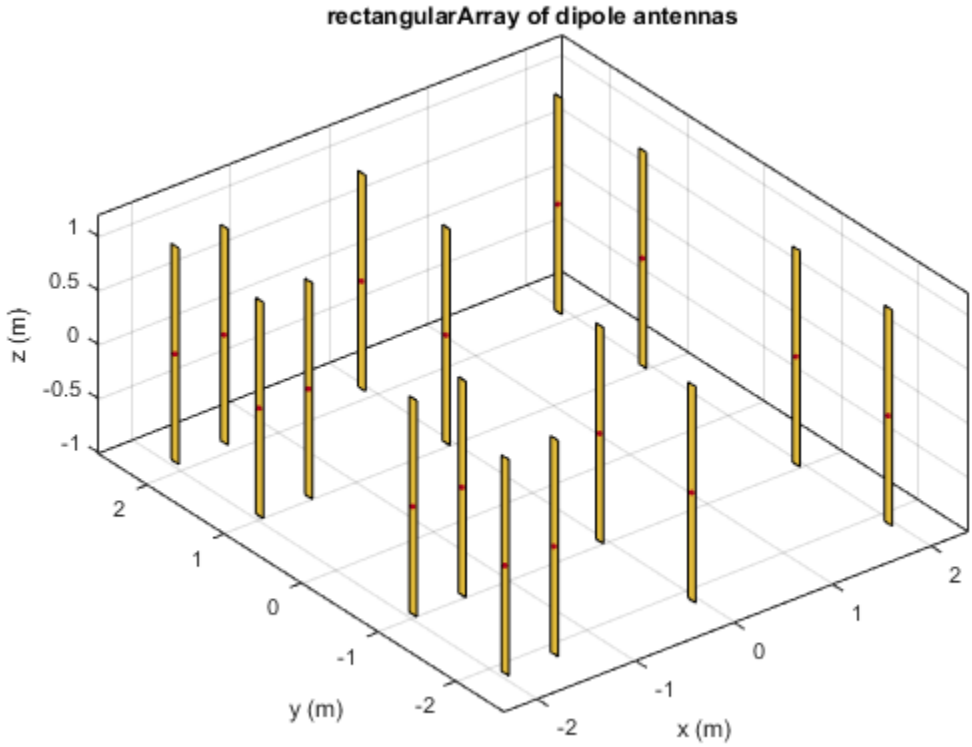
Change Array Elements Spacing To Nonuniform

Use the 'RowSpacing' and 'ColumSpacing' 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]
show(ra)
```

```
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
```



References

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