
ACDA6019

ADVANCED RF SYSTEMS

BY ALEXANDER GRAVATT

(2217176)

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Abstract

In this report the author shows a selection of different types of antennas such as patch antenna dipole and horn and evaluated how the antennas transmit rf and how they perform covering directivity and gain using the far field structure and what they would be used for as well as why they perform best in that function. The also covers the method of construction and how to calculate different antennas.

Introduction

In this report the author will design a patch antenna using industry standard software. As well as demonstrate the differences in types of antennas.

Antennas are used to proper gate signals through air over long distances they are designed to reduce the cost of long ranged data transmission. Each antenna has its own calculation related to how it is constructed. The key t calculating most of these is wave length which has the calculation.

$$\lambda = C/F$$

with F being the frequency and C being the speed of light in the authors calculations they take the number as 3×10^8 .

all antennas after the patch antenna are designed in Matlab antenna design toolbox.

The Matlab antenna design toolbox allowed the author to put their frequency in and get a rough estimate of size, impedance, far-field pattern, directivity and current.

This is to demonstrate that the differences between a high frequency structured simulation(HFSS) software and a mathematical calculation in data clarity and efficiency.

Methodology

Patch antenna

Patch antennas are used in embedded computing applications where the device needs highly directional power with small antenna sizes. Patch antennas are regularly used in home security systems that have a wireless communication system this is because they are relatively small for their directivity.

The author created the patch antenna on CST studio a software developed by dassult systems and widely used in industry the software models the antenna by calculating mesh squares that are formed around the antenna the authors version is limited due to the license type and as such this antenna is the best the model will create with this type of licence but due to its simplicity their should be very minimal changes if the mesh size was to be increased.

The author started by collecting all the calculations they would need for making the antenna.

They used “antenna theory”[1] and pasternack patch antenna calculator[2] antenna theory provided the basis for the construction while pasternack gave the function of the calculations and the numbers to aim for with the calculations the author was performing.

The author then set constants in CST these where:

- C is the speed of light constant set above
- H is the height of the dielectric substrate 1.6 mm
- F is the frequency in GHz
- Er is the permittivity of FR4 4.4

3D		Schematic	
Parameter List			
Name	Expression	Value	Description
w	= 41.4941331443308	41.4941331443308	width of patch
al	= 30	30	length of patch
h	= 1.6	1.6	
wg	= W+6*h	51.0941331443308	width of ground plane
lg	= al+6*h	39.6	length of ground
hg	= 0.05	0.05	height of pec
PIMC	= 34.4693189466833/2	17.2346594733417	impedance matching cuts
erff	= (er+1)/2+(er-1)/2*1/sqr(1+12*(h/pw))	2.77894468080688	
er	= 4.4	4.4	
C	= 3*10^8	300000000	speed of light
F	= 2.2	2.2	frequecny in ghz
fh	= F*10^9	2200000000	frequecny in hz
pw	= C/((2*fh)*sqr((er+1)/2))	4.14941331443308e-02	base width
deltaL	= 0.824*h*(((erff+0.3)*((pw/h)+0.264))/(erff-0.2...	0.385593690432632	
leff	= C/((2*fh)*sqr(erff))	4.09005009657986e-02	
l	= deltaL-leff	0.344693189466833	calc length
fw	= (46.3909870188704) * h	74.2255792301926	
<new parameter>			

Figure 1: CST parameter list

- Hg the height of the ground plane

These were crucial for calculating the width and length of the antenna.

$$eff = \frac{er+1}{2} + \frac{er-1}{2} \times \left[\frac{1}{\sqrt{\left(1+12 \times \left(\frac{h}{w}\right)\right)}} \right]$$

Length calculations

$$C \frac{c}{2 \times fo \sqrt{eeff}} - 0.824 \left(\frac{(eeff + 0.3) \times \left(\left(\frac{W}{H}\right) + 0.264\right)}{(eeff - 0.258) \times \left(\left(\frac{W}{H}\right) + 0.8\right)} \right)$$

width calculations

$$\text{width} = \frac{C}{2 \times f 0 \sqrt{\left(\frac{er+1}{2}\right)}}$$

construction

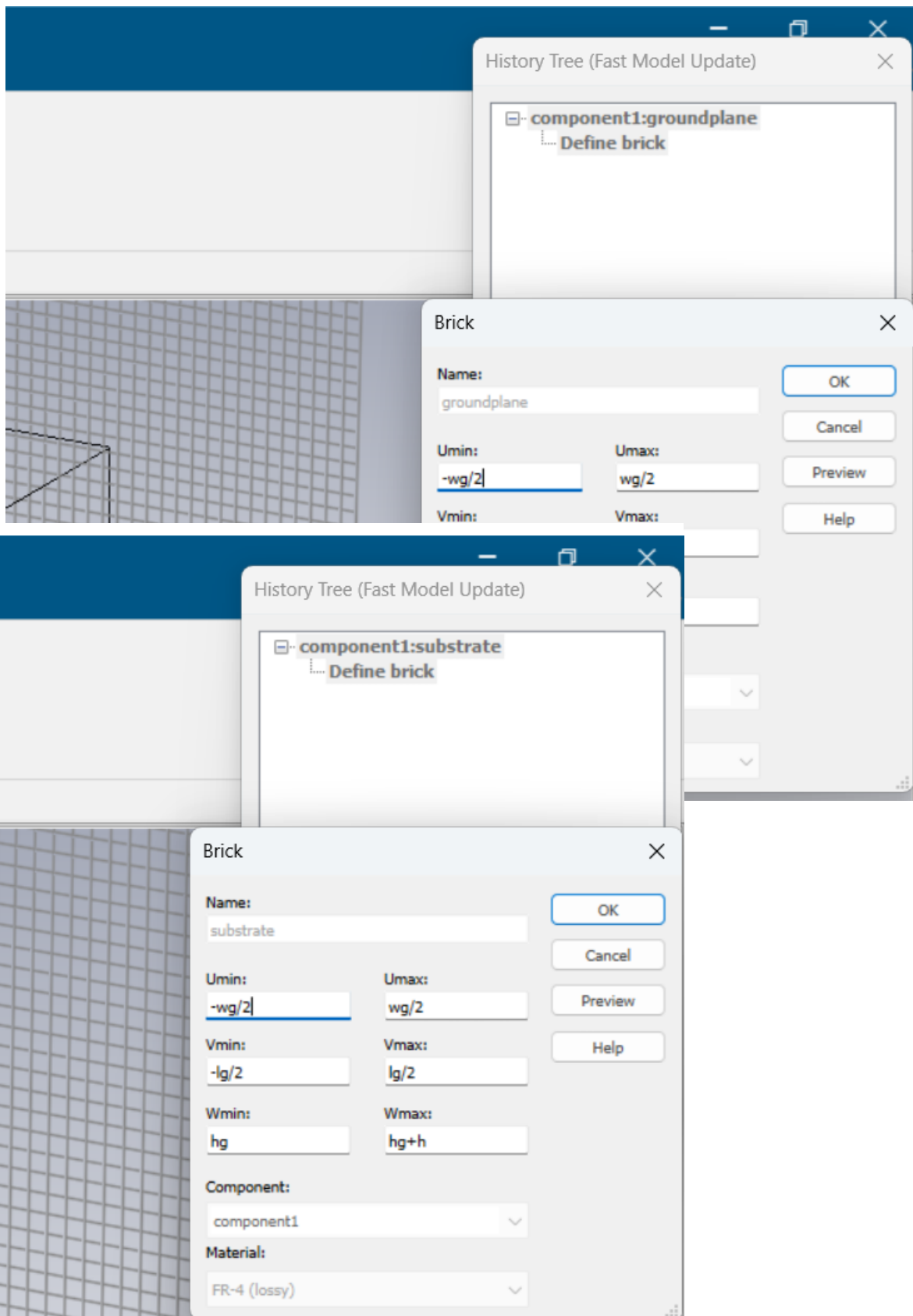


Figure 3: substrate construction

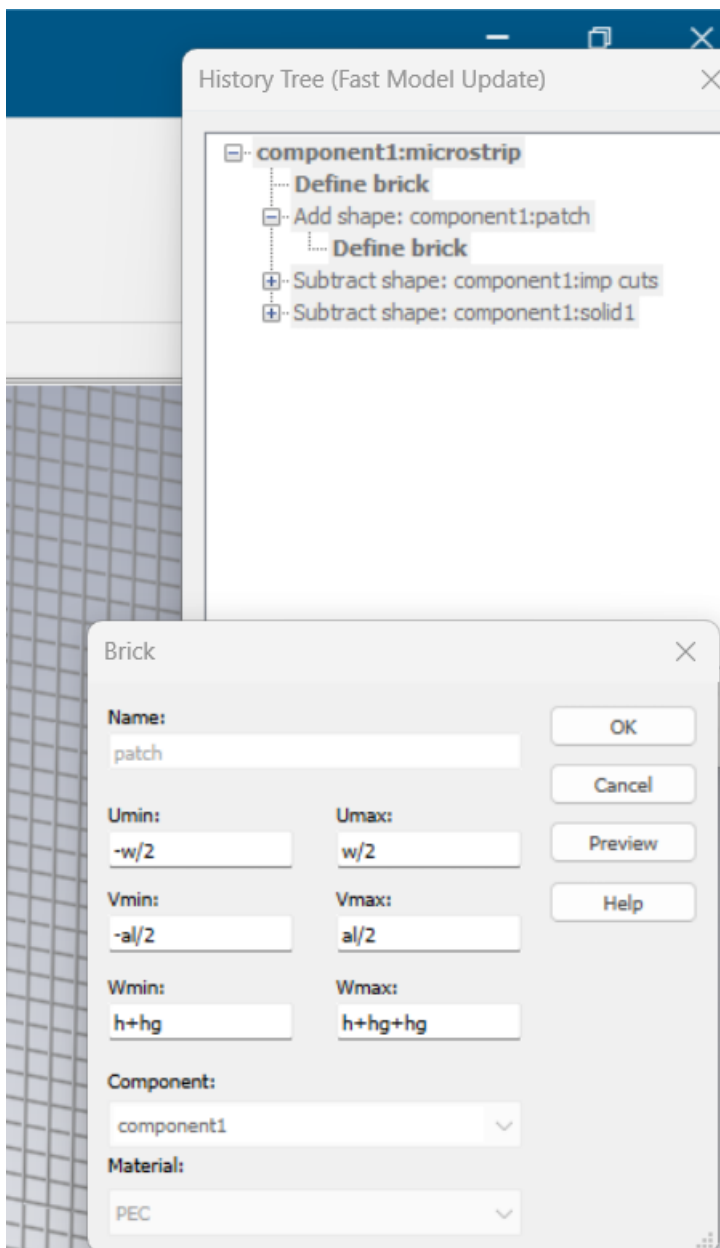
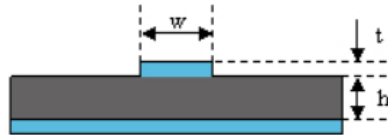


Figure 4: patch construction

The microstrip below is defined by the 50 Ohms desired impedance and this calculation shown below



Formula:

$$w = \frac{7.48 \times h}{e^{\left(\frac{Z_0 \sqrt{\epsilon_r + 1.41}}{87} \right)}} - 1.25 \times t$$

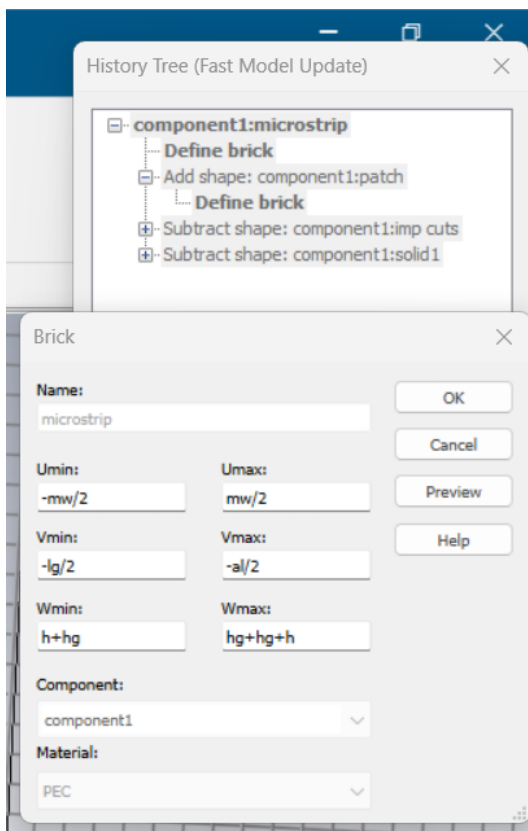


Figure 6: microstrip construction

the cuts made here provide the power a greater depth to get into the antenna before the signal is returned to it the author could improve this by making it more truncated to allow a wider width into the antenna.

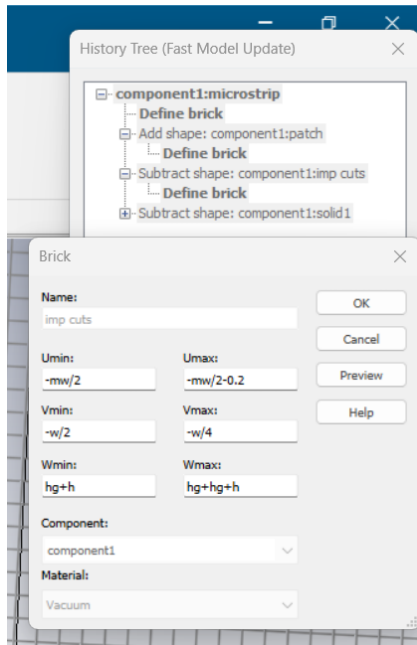


Figure 7: micro-strip cuts

port construction

when creating the port the author selected the face on the side shown below.

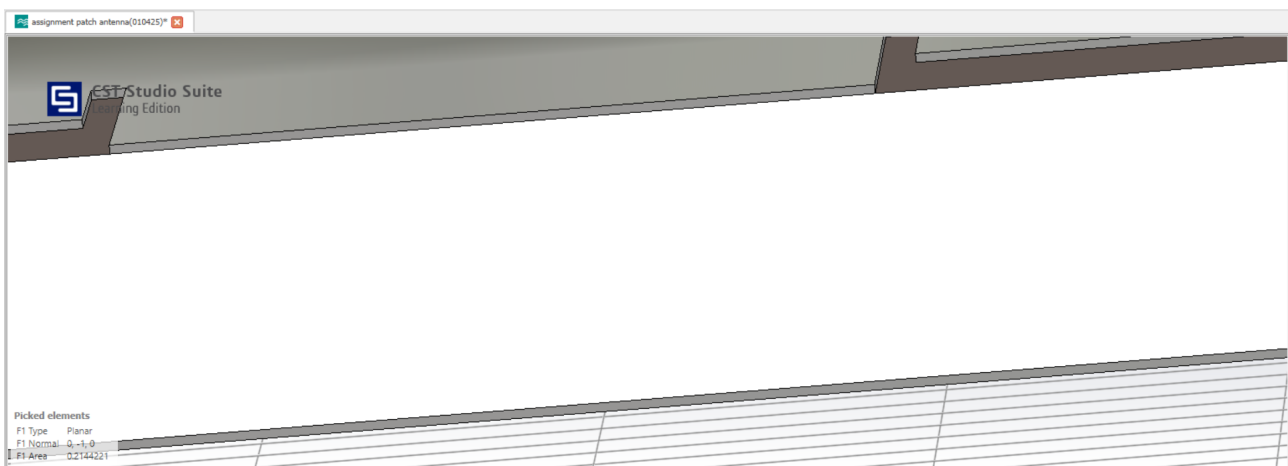


Figure 8: port face selection

And then went to the home section and used the VBA macro for port creation to produce the port. tuning the antenna.

After creating the antenna the author ran the simulation and it gave an S parameter plot shown below.

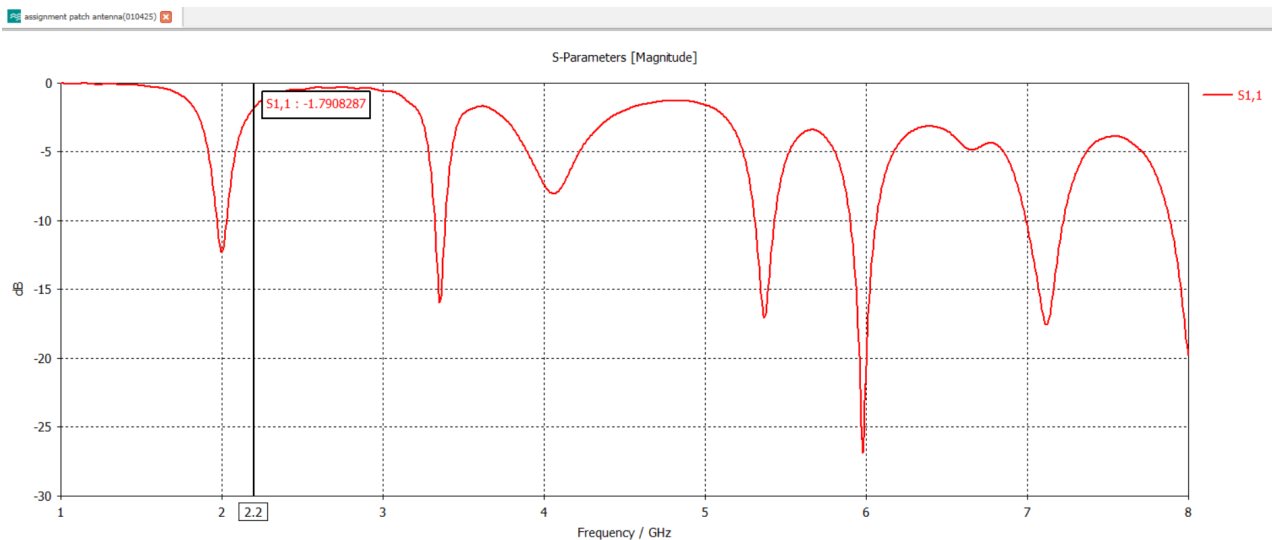


Figure 9: sParamater

As can be seen above this antenna has 2 GHz as its fundamental frequency and as such it should be defined as a 2 GHz patch but below using the CST sweep function the author tuned the antenna to meet the 2.2 GHz desired frequency

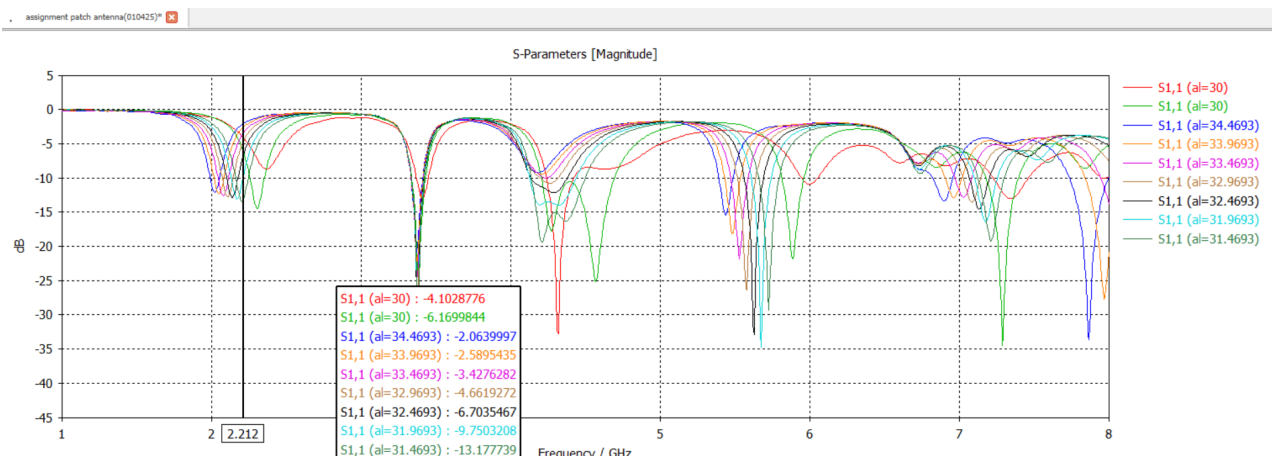


Figure 10: sParamater tuned

This was close to the calculation that pasternack had produced indicating that the author and pasternack use different assumptions for constants such as speed of light and gap from patch antenna to the edge of the dielectric.

The authors calculation also came out 2 mm larger than pasternacks indicating a difference In constant for one of the calculations.

Circular Dipole

Usage

circular dipole antennas are used in hand held radios and air band communication in general any communication type where the user needs a small antenna with good omnidirectional transmission.

Dipoles are defined as wire based as they can be seen as a wire feed from the centre.

Calculations

short dipoles length defined as with $\lambda/10$

Half wavelength dipoles are defined as $\lambda/2$

Full length dipoles are defined as their length is λ .

Dipoles input impedance is directly related to their length.

Their radius defines the bandwidth but there is no specific calculation to work this out that is widely defined instead the designer is expected to have a desired spread and then change the original 1mm width up or down to meet their requirements. Note that if a dipole is too thin it will melt all the same as if it was a wire.

Folded Dipole

Folded dipoles are used in similar ways to cylindrical dipoles as they are omni directional but with a greater level of power emitted due to its larger surface area to emit power.

Folded dipoles are constructed of a dipole its ends looped onto each other.

They are resonant at multiples of the wavelength normally defined as $(0.5\lambda, 1.5\lambda, \dots)$ [1] they are designed for and their impedance is calculated as 2 short circuited transmission lines and with offset feed lines the folded dipole will be resonate at $(1.0, 2.0, \dots)$ [1]

So you make the antenna match the centre λ you want.

And then it will be resonant at the wavelengths defined by the feed point. As the frequencies wavelength gets further from the designed one the ability to radiate and accept power reduces.

Z_d = the dipole impedance using the dipole calculation

$$Z_t = jZ_0 \tan \frac{\beta L}{2}$$

Figure 11: folded dipole impedance Calc [1]

The input impedance is defined by below

$$Z_A = \frac{4Z_t Z_d}{Z_t + 2Z_d}$$

Figure 12: folded dipole input impedance Calc[1]

Horn Antenna

Usage

horn antennas are very directional as such are used in cases where you want to cover a very specific area such as input to a wave guide or point to point transmissions.

Calculations

for a horn antenna you have three major types e plane, h plane and pyramidal horn

the main difference between the three is the constants for the e plane the width is constant.

For the h plane the height is constant.

For the pyramidal it is defined by its width and height with most resorting to width>height

the difference between the two is you swap which is larger based on if you want a dominant e or h plane shown in the two above.

[1]

the basic calculation for a rectangular horn antenna is as such

Formulas & theory for horn antenna apertures

For a rectangular horn antenna the formulas are:

$$\text{Aperture}_E = \sqrt{2 \lambda L_E}$$

$$\text{Aperture}_H = \sqrt{3 \lambda L_H}$$

Figure 13: horn antenna Calc[8]

is the field

where aperture# is the width of the aperture

L# is the slant length of the field.

And lambda is the wave length.

Helix Antenna

usage

are commonly used for long distance communication due to their circular polarity and transmitting up to satellites as the polarisation allows it to get through the ionosphere

calculations

helical antennas require the designer to calculate the diameter, circumference, vertical separation pitch angle, number of turns and total height to get the best out of their antenna.

diameter

is the diameter of the helix in one turn

circumference

the circumference of a turn on the helix.

C, $f = \pi \cdot D$

that then defines the wavelength that can be used based on the following equation.

$$\frac{3\lambda}{4} \leq C \leq \frac{4\lambda}{3}$$

Figure 14: horn
antenna wavelength
Calc [1]

The lowest frequency that can be handled will be defined by the largest wavelength that fits into the equation above.

vertical

the separation of the helix turns is defined as S

Pitch angle

controls how far the helix antenna grows in the z direction.

$a = \tan^{-1} S/C$

number of turns

the number of times the helix turns around its centre is defined as N

height

total height of helix antenna $H=N*S$

Helix array antenna

usage

helical array antennas are used to create satellite high data rate communication paths to assist in the users in getting data from high orbit down to the surface and the same is true of the opposite.

calculations

the first calculations needed are the numbers for the individual antennas this is defined in helix antenna section.

Next you need to define the number of elements needed and the ideal power and directionality needed as well as max size you can use.

The array is defined as below with n being the number and the XYZ being the coordinates.

$$\mathbf{d}_n = [x_n \ y_n \ z_n]$$

Figure 15: helix array
antenna Calc [1]

with x y z being the distances

the output of the array is defined as

$$Y = \sum_{n=1}^N w_n X_n$$

Figure 16: helix array antenna output Calc[1]

with n being the number of elements w being the element wavelengths and x being the antenna types output.

Results

Patch antenna

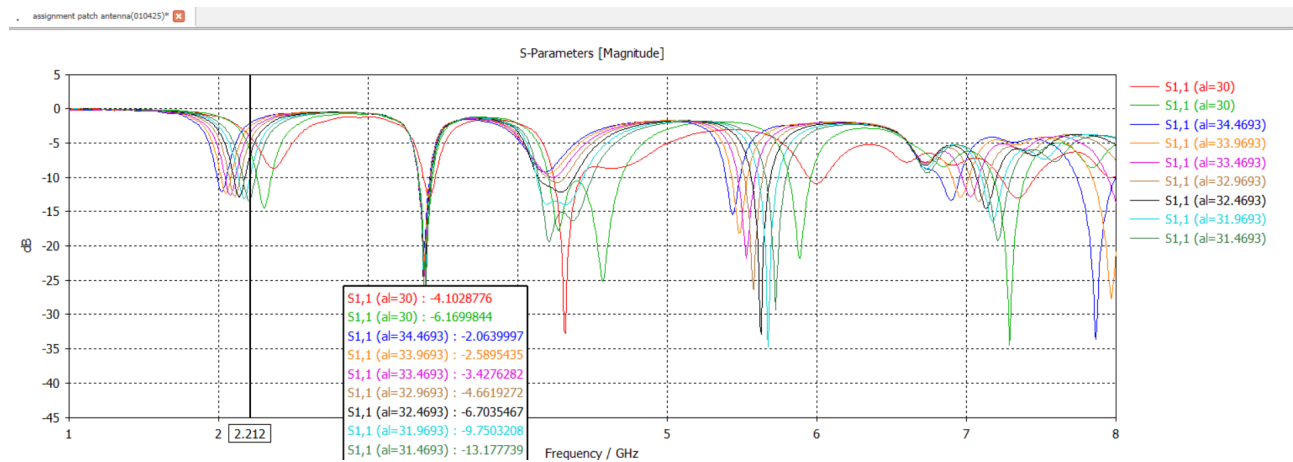


Figure 17: sParamater of patch antenna

s1.1 light blue shows the antenna has a -13 dB acceptance at 2.2 GHz for the patch antennas a rule given is anything below -10 is resonant in this case the 2.2 GHz is the fundamental frequency and 5.6 GHz frequency is the most resonant frequency.

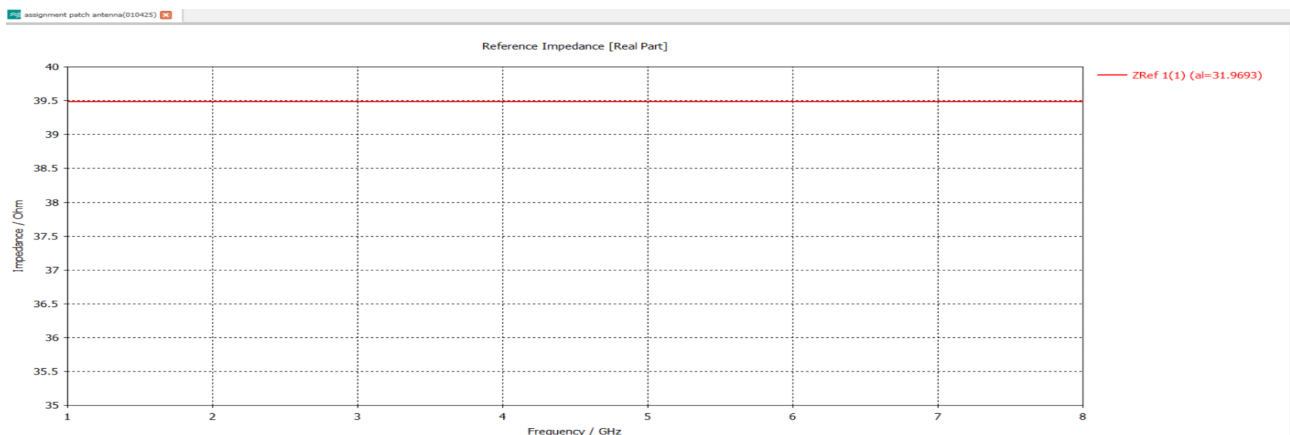


Figure 18: impedance of patch antenna

The reference impedance for this is 39.5 ohms.

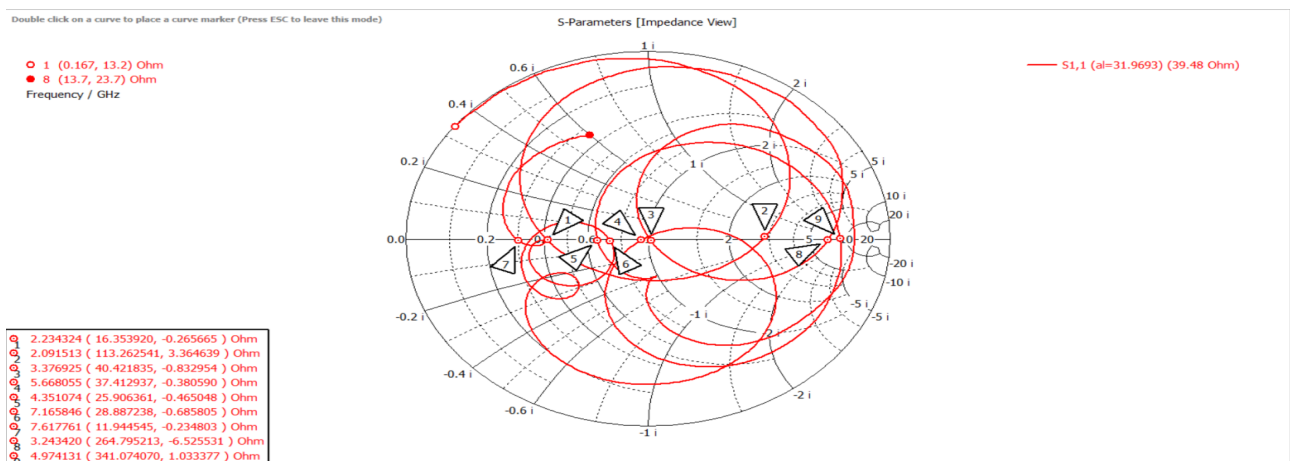


Figure 19: smith chart of patch

The smith chart shows how the antenna impedance changes in frequency as can be seen the antenna starts at 1 GHz and is a very poor antenna as it increases in frequency the antenna general gets more capable until it reaches 8GHz where it stops sweeping and is only a little better than the 1GHz.

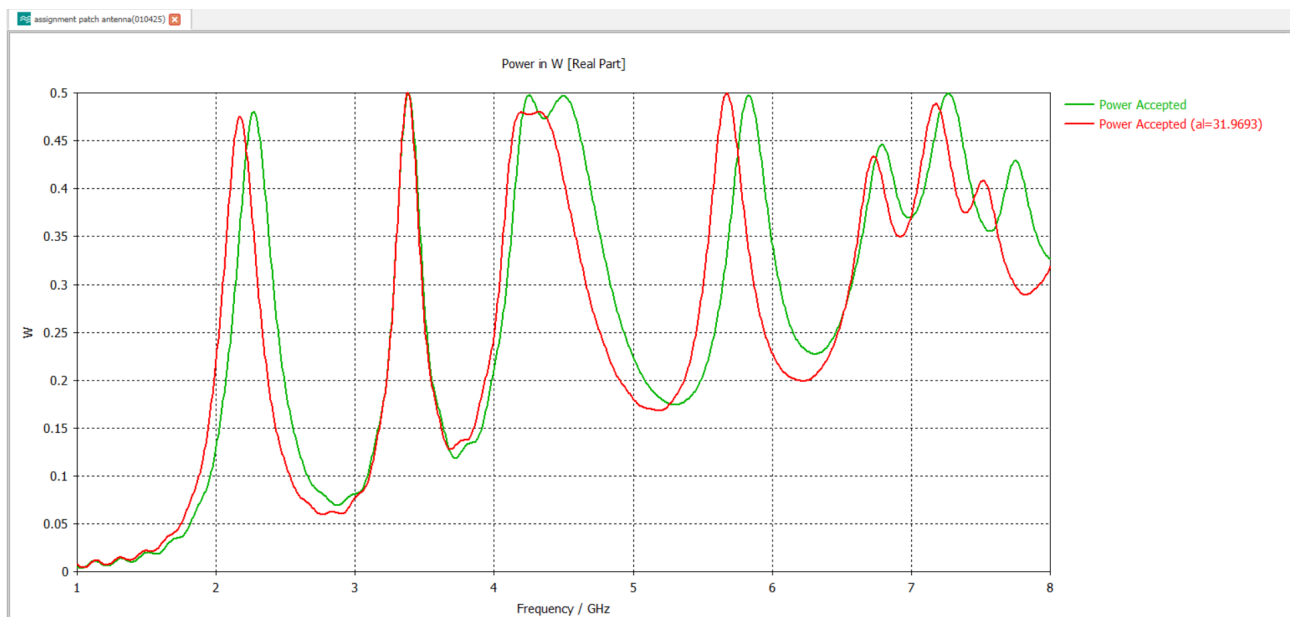


Figure 20: power of patch antenna

This indicates that at 2.2 GHz, 2.4 GHz, 4.1-4.5 GHz, 5.9 GHz and around 7.2 GHz the antenna accepts power effectively where as in the low points it does not.

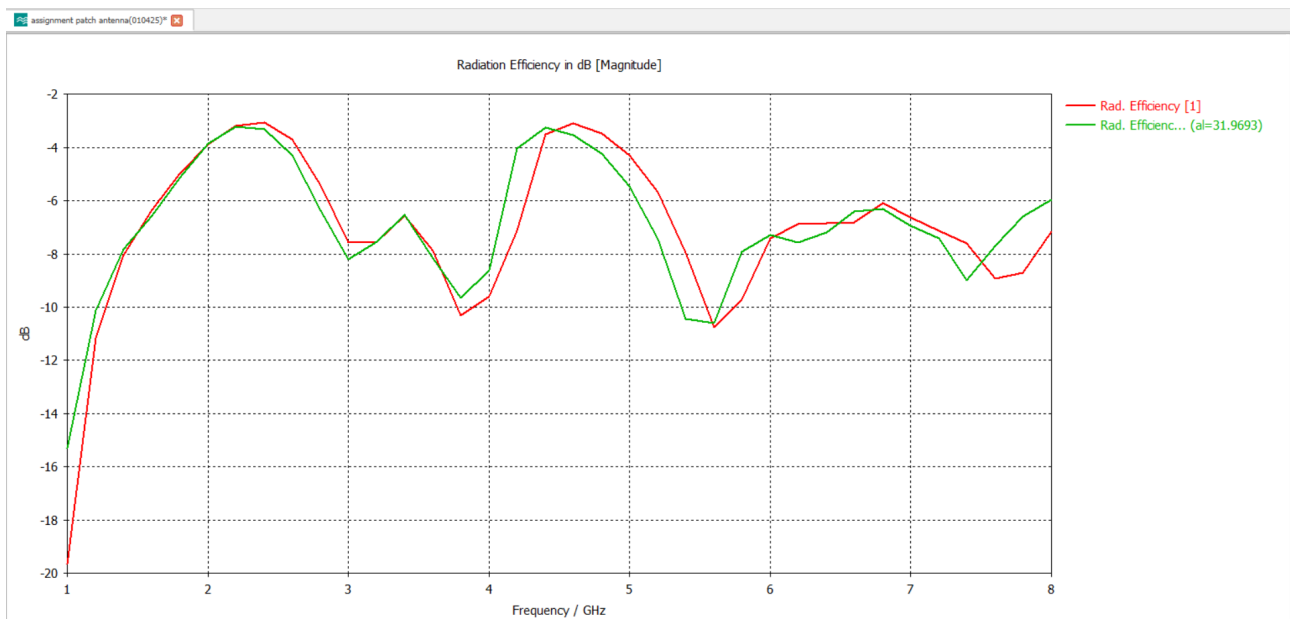


Figure 21: radiation efficiency of patch

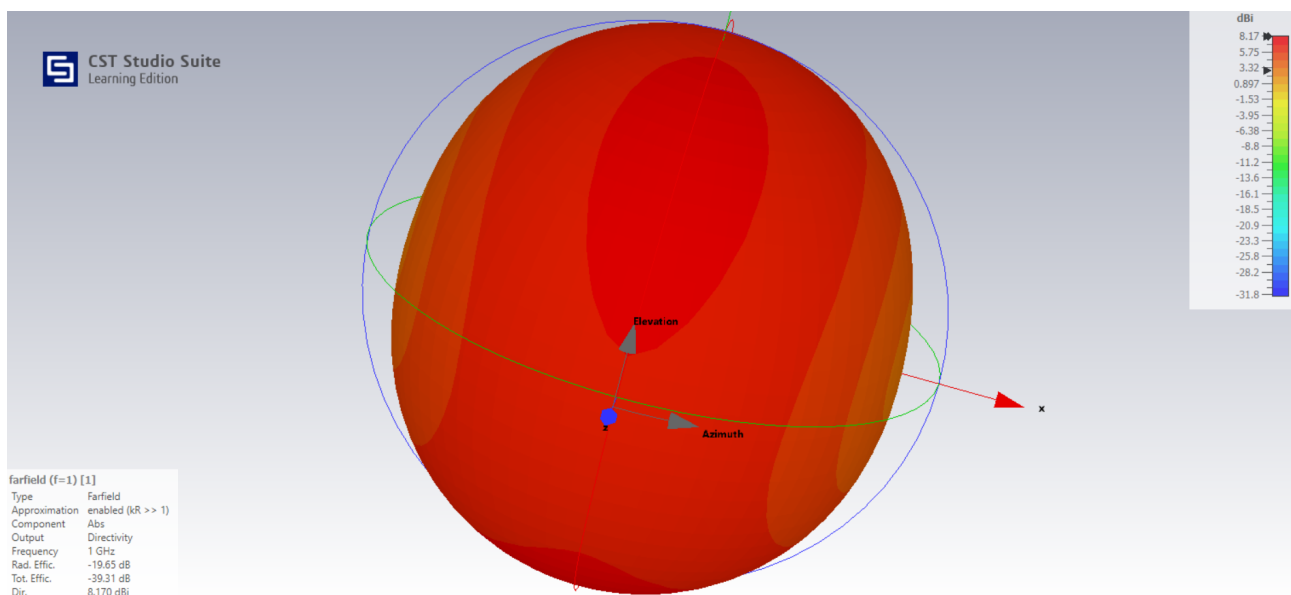


Figure 22: 1GHz farfield patch

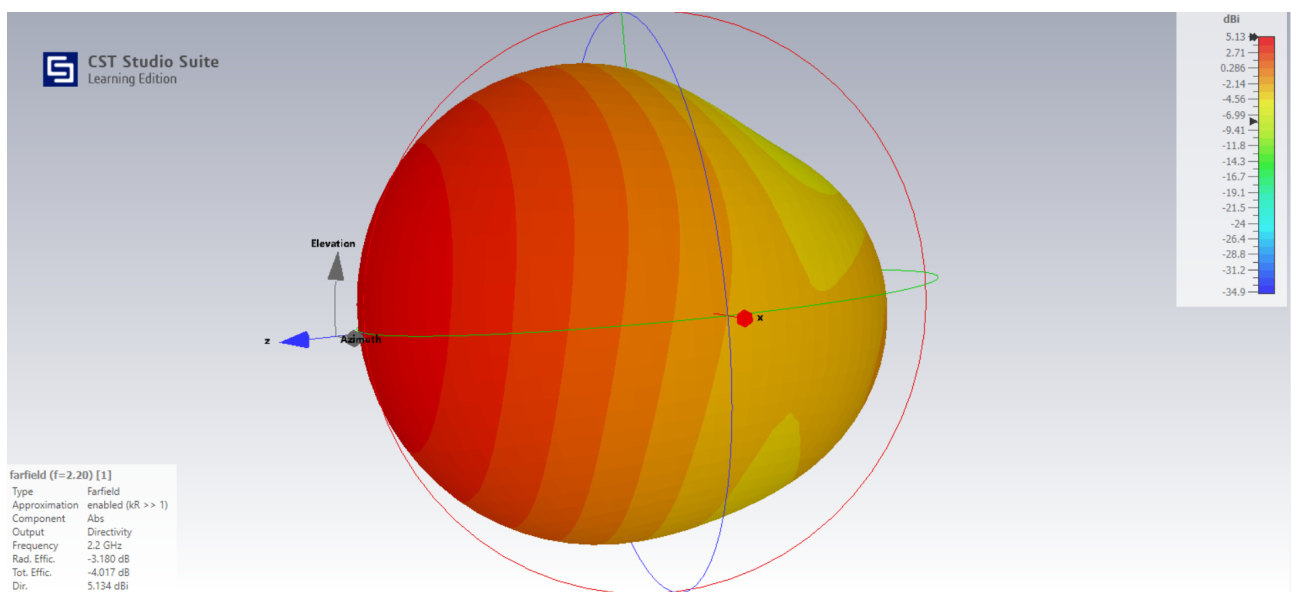


Figure 23: 2.2GHz farfield patch

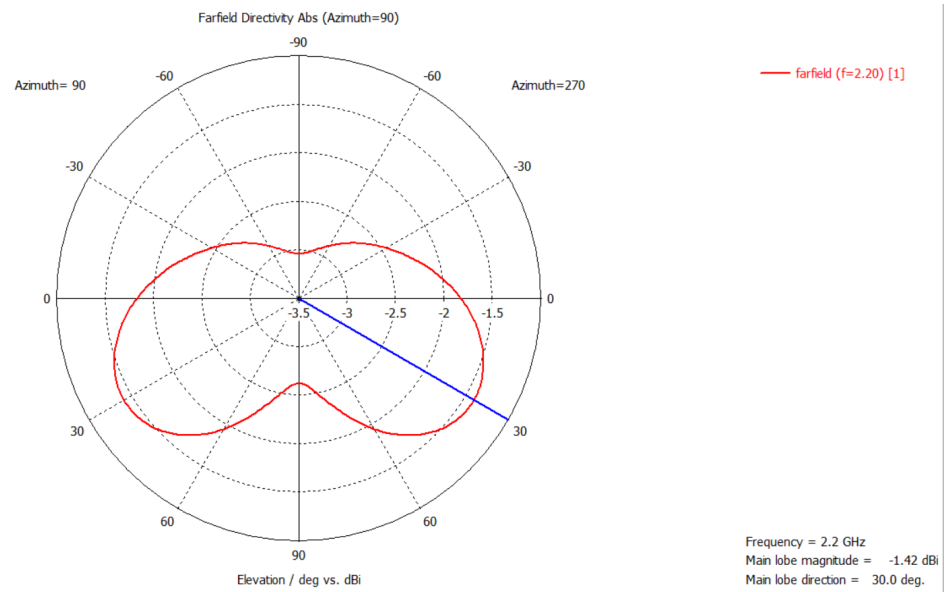


Figure 24: 1D farfield patch

Cylindrical dipole

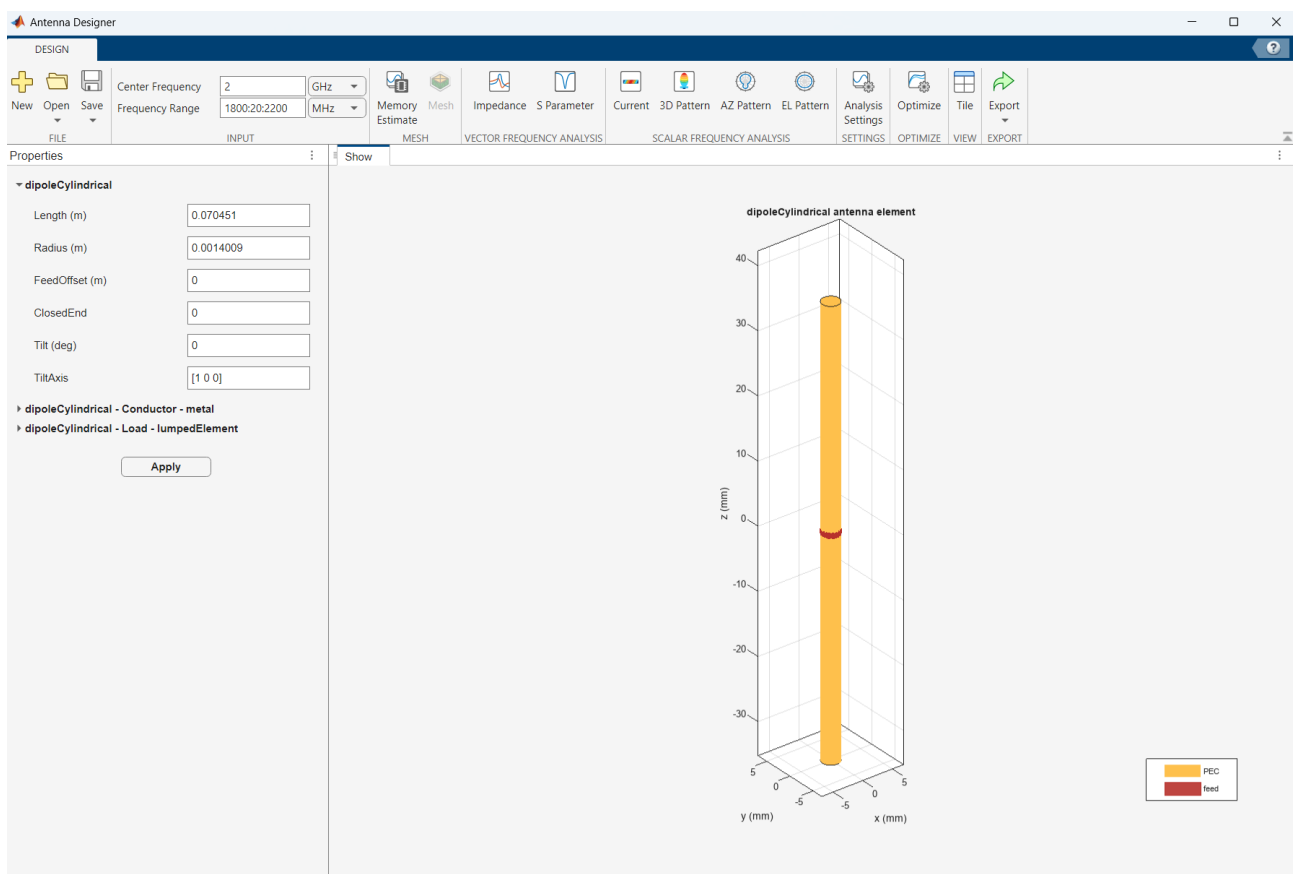


Figure 25: cylindrical dipole

This is the cylindrical dipole antenna size for a 2 GHz centre frequency.

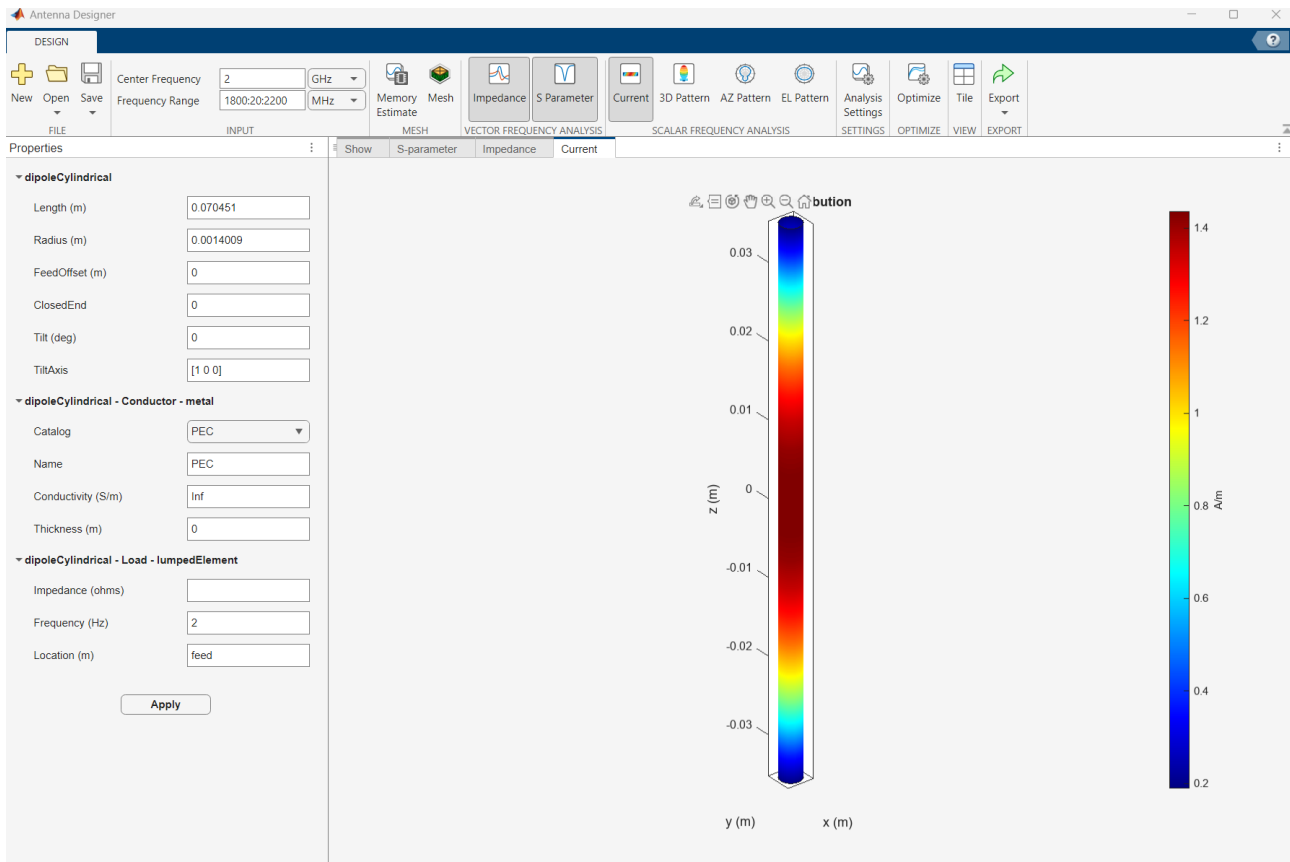


Figure 26: cylindrical dipole power

This is the current map of the dipole as is visible the dipole has limited current flow at the ends where as its current flow is high near the feed this is expected behaviour.

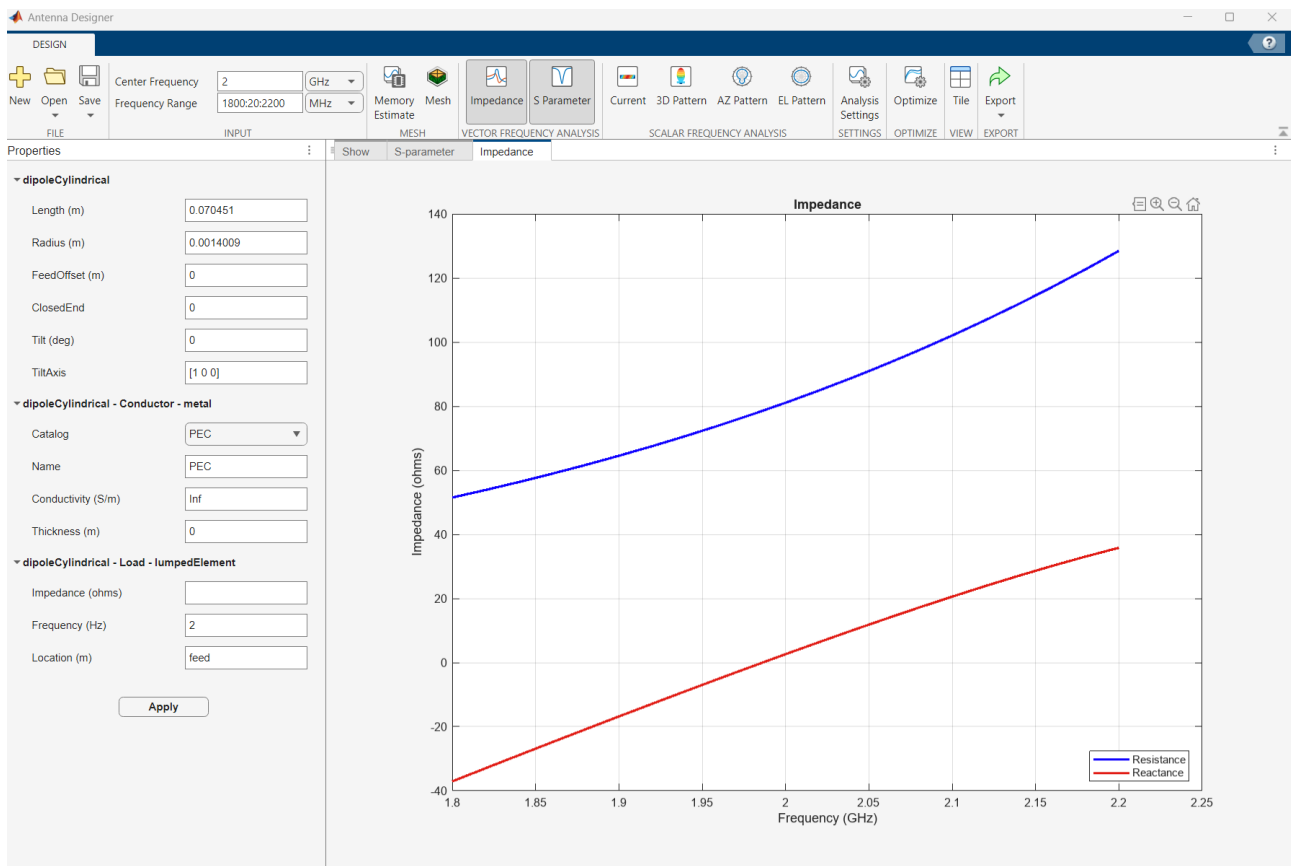


Figure 27: cylindrical dipole impedance

This is the S parameter map showing that its design works best just before 2ghz this is normal for the basic calculations and with a small amount of changing the length or radius would easily cover the 2 GHz point.

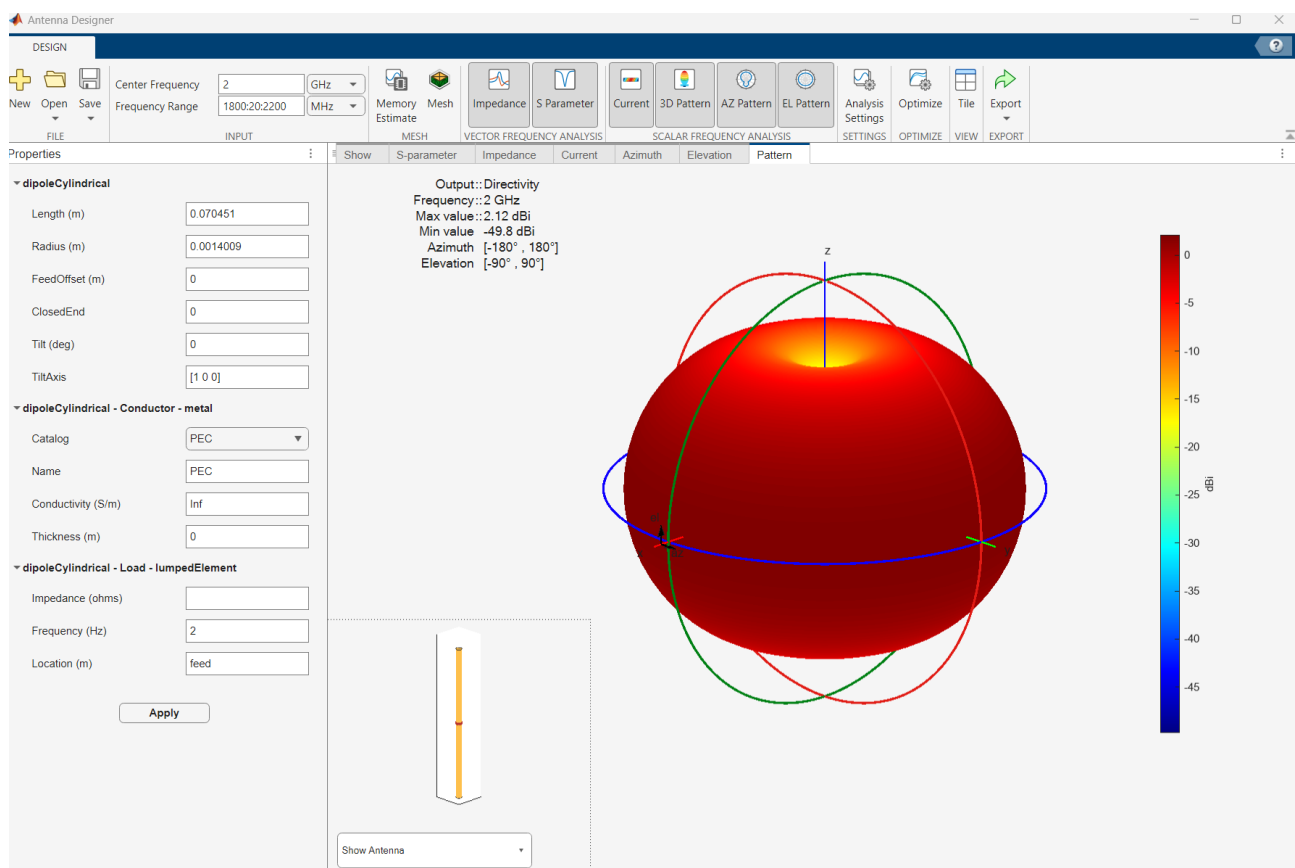


Figure 29: far field of cylindrical dipole

This is the far field and is exactly what a dipole should look like this shape is what gives it its near perfect omni directional capabilities.

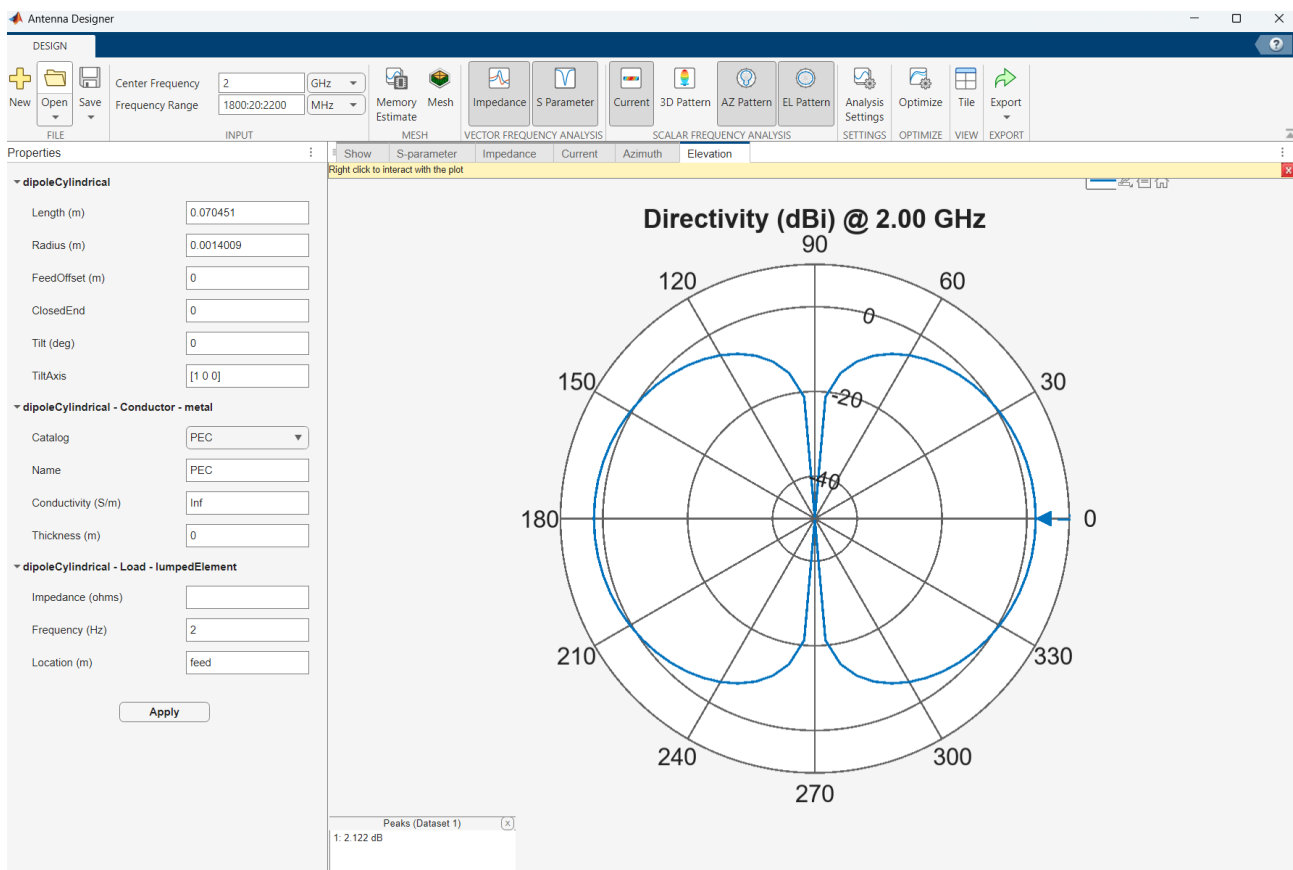


Figure 29: directivity of cylindrical dipole in elevation

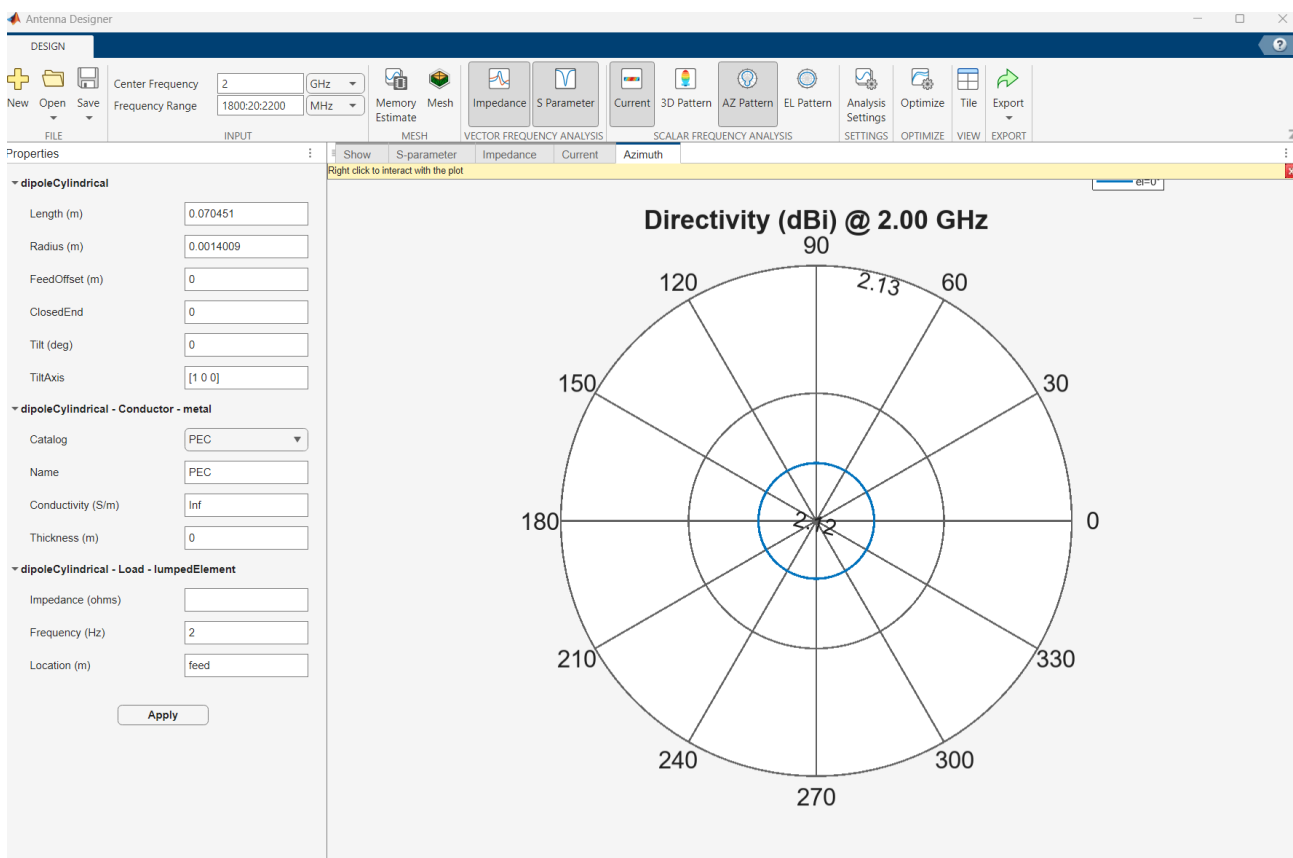


Figure 30: directivity of dipole in azimuth

folded dipole

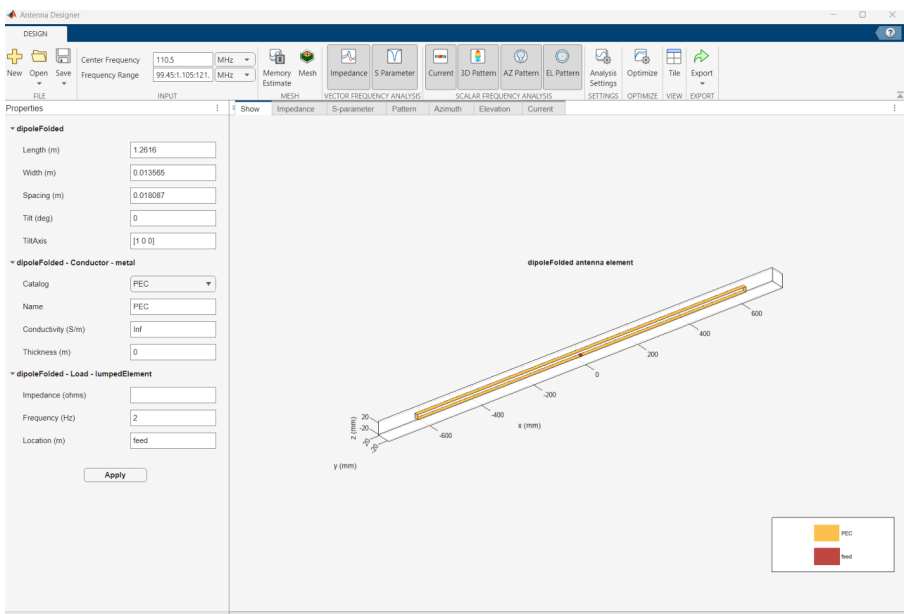


Figure 31: folded dipole

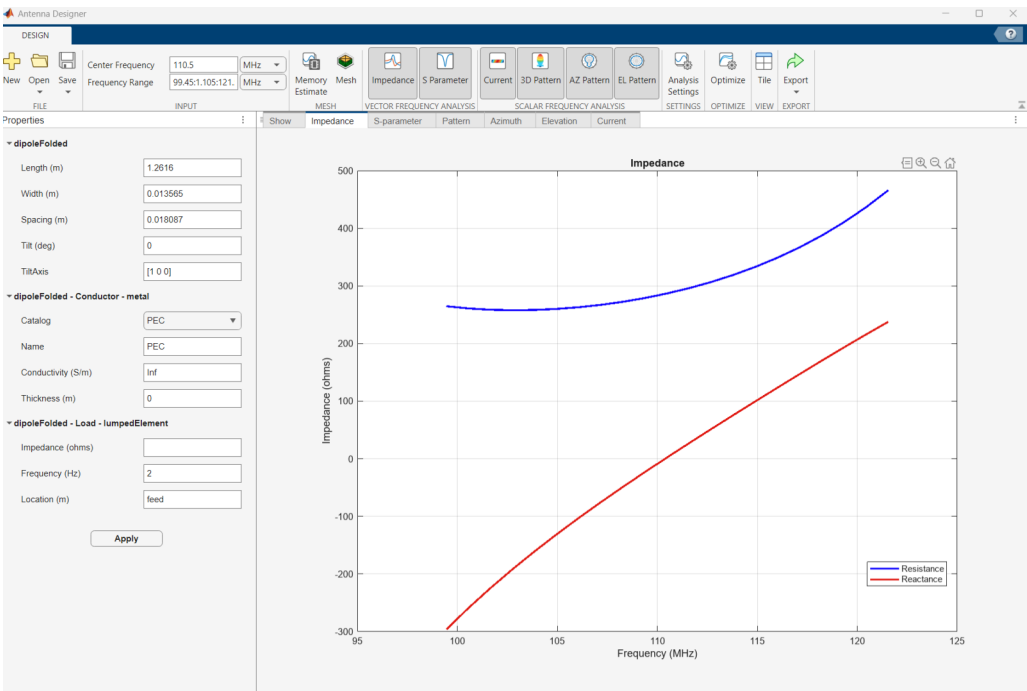


Figure 32: folded dipole impedance

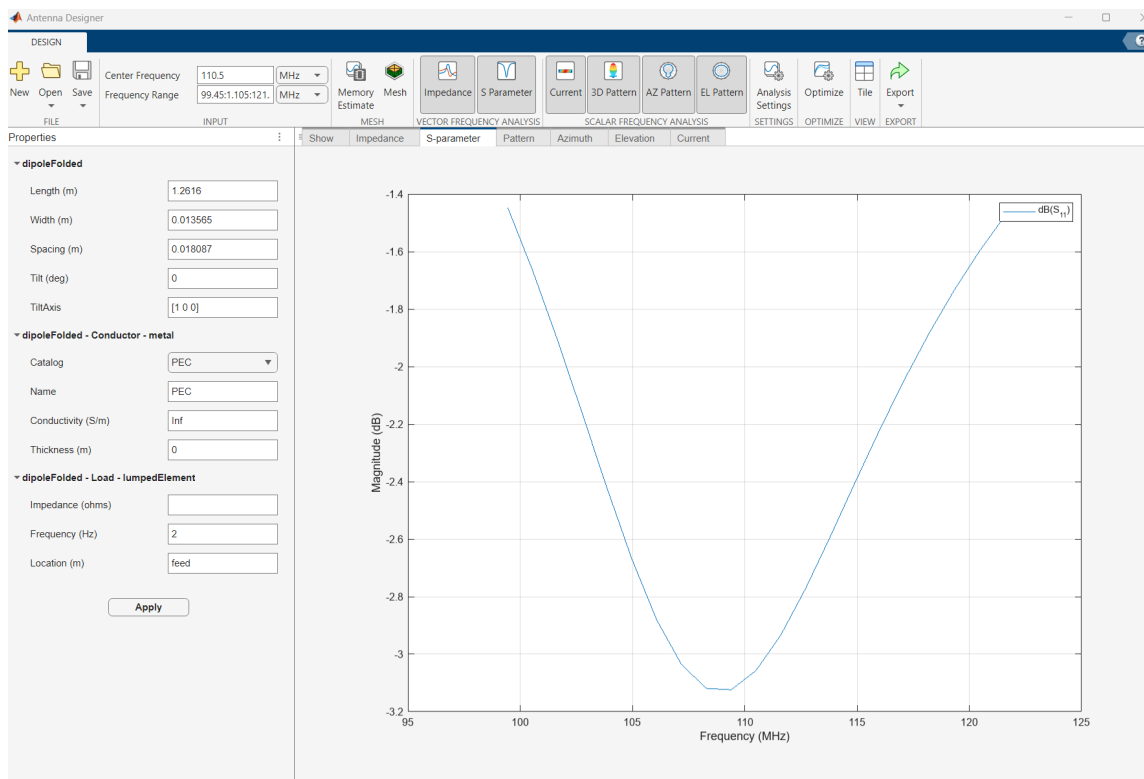


Figure 33: sParameter of folded dipole

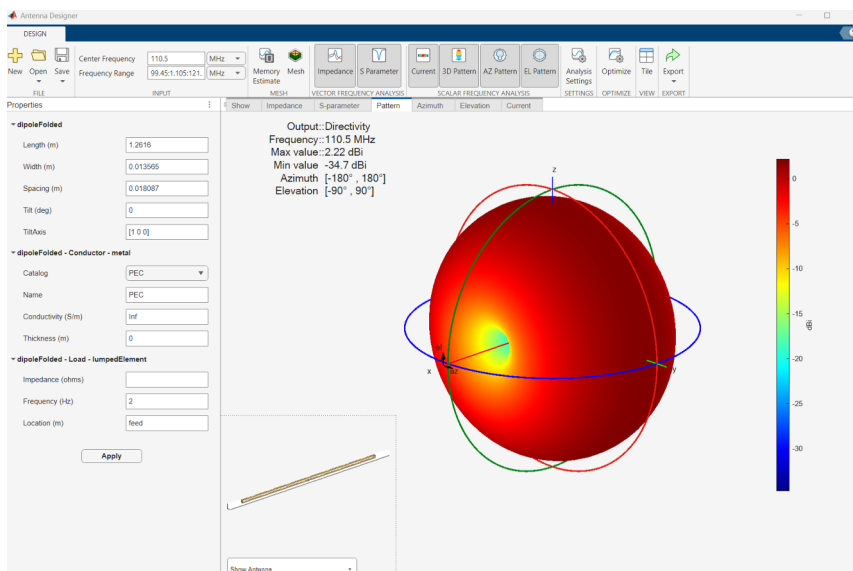


Figure 34: far field of a folded dipole

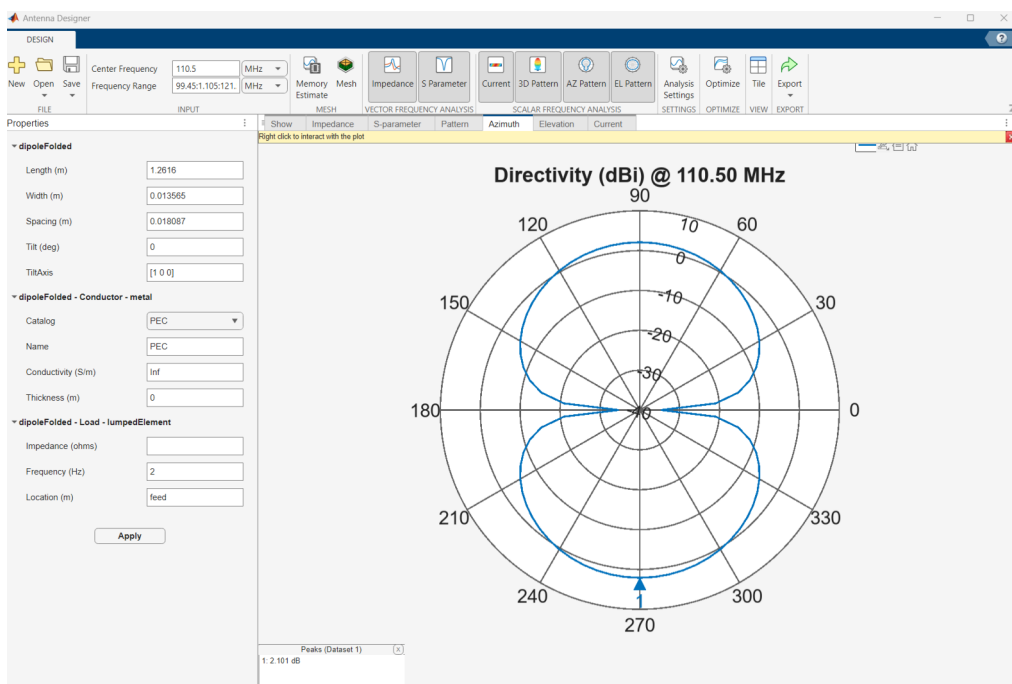


Figure 35: folded dipole directivity azimuth

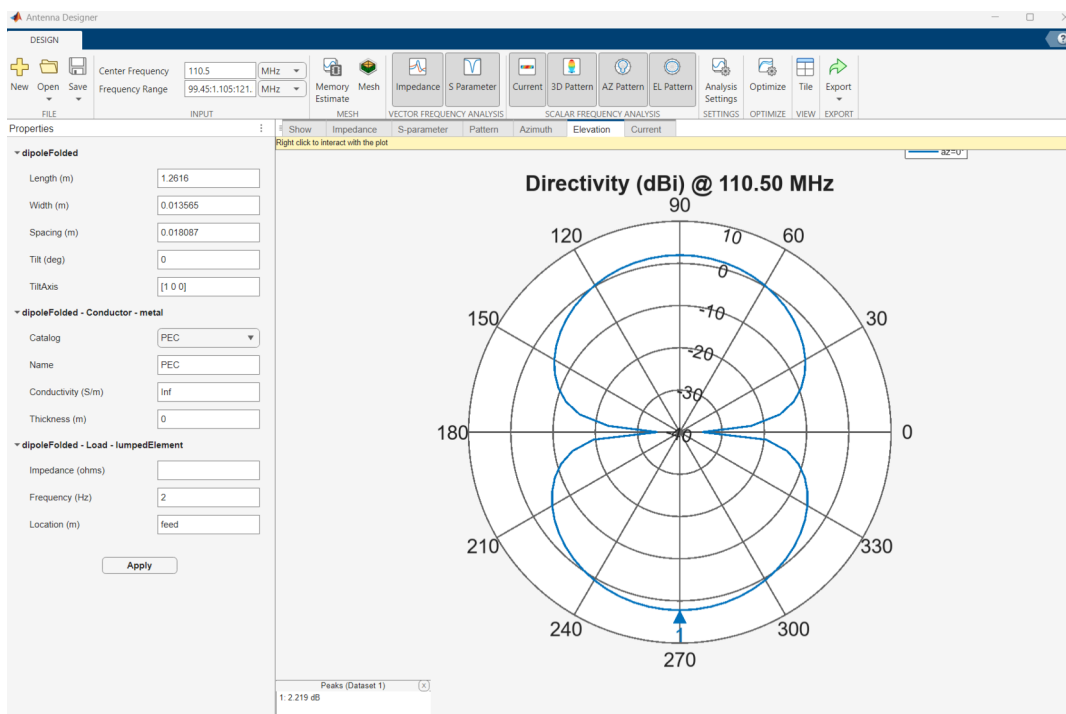


Figure 36: folded dipole directivity elevation

horn antenna

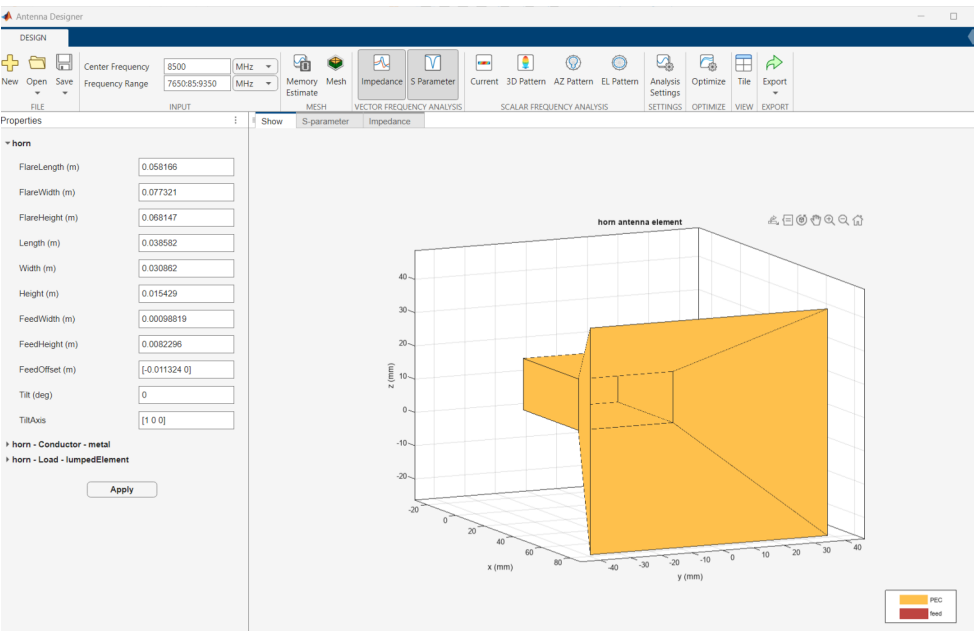


Figure 37: horn antenna

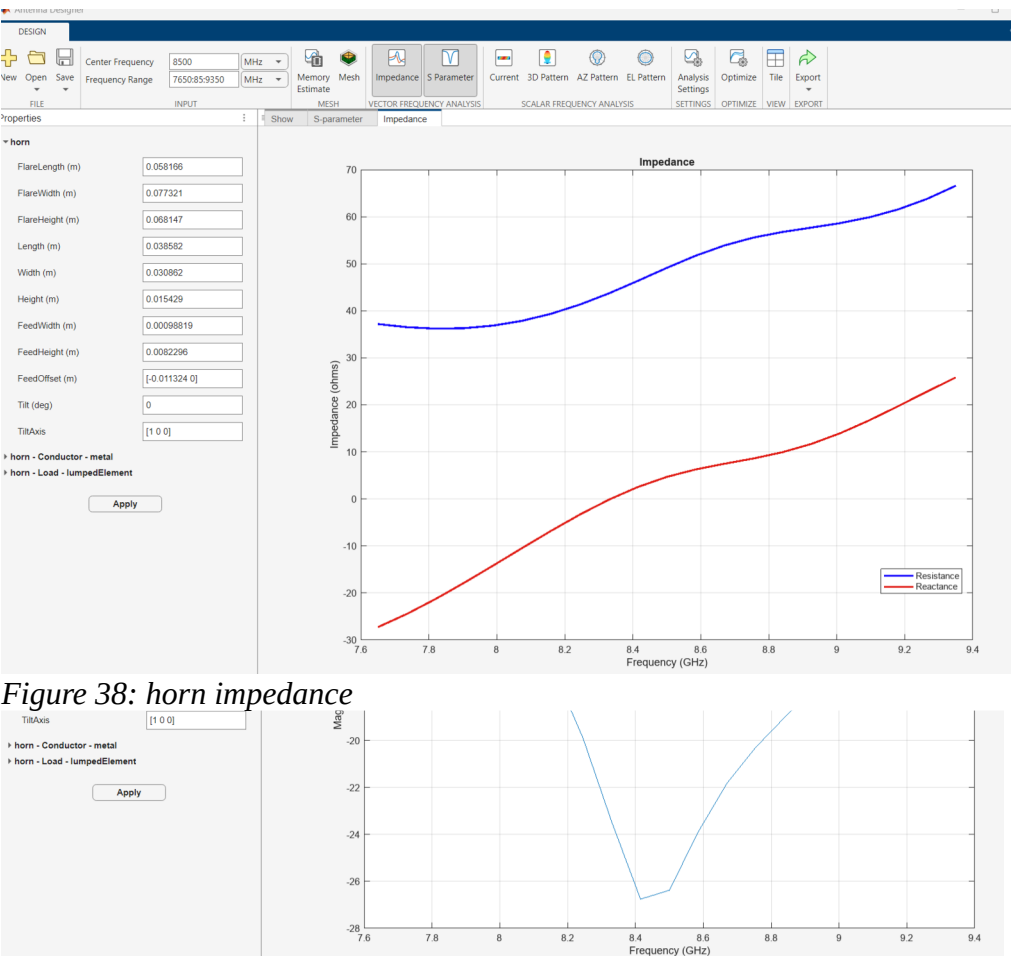


Figure 38: horn impedance

Figure 39: sParamater of horn

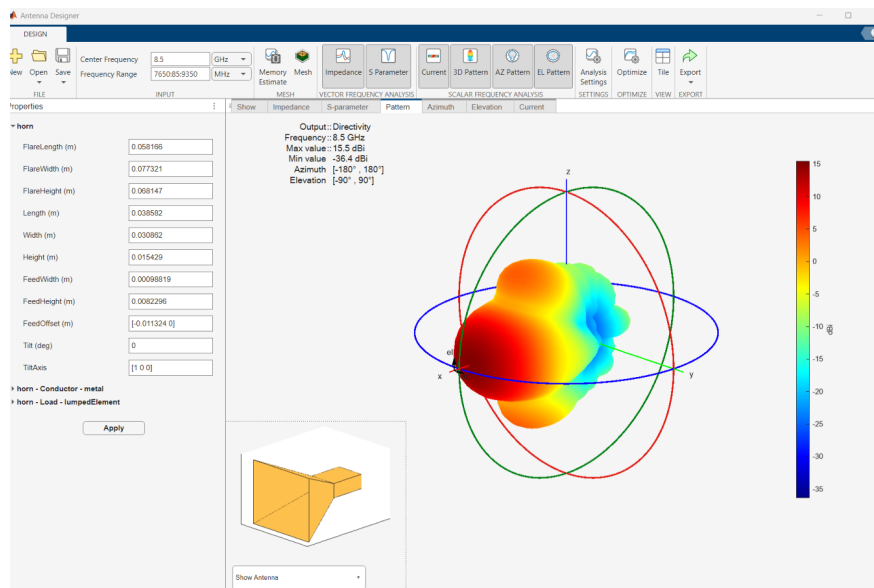


Figure 40: far field of horn

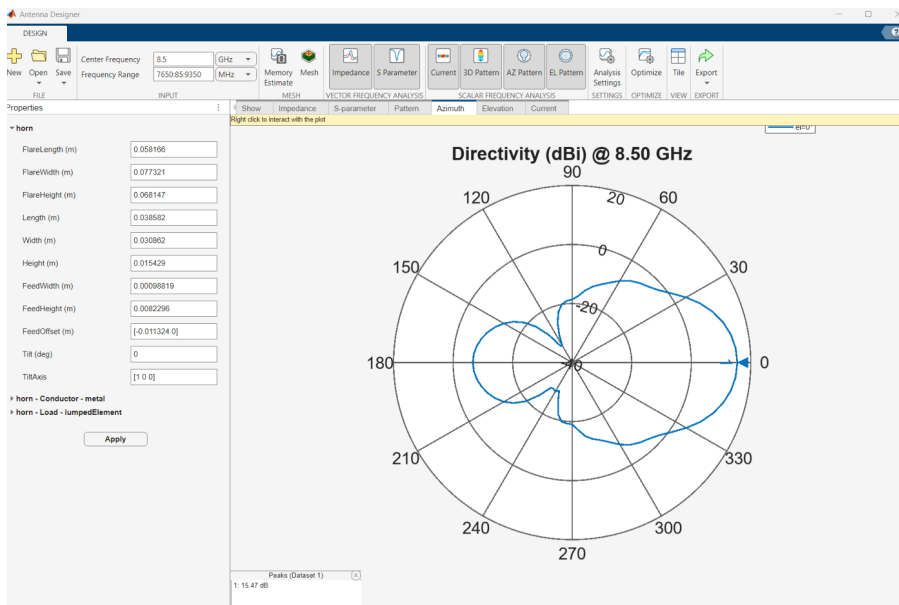


Figure 41: horn directivity azimuth

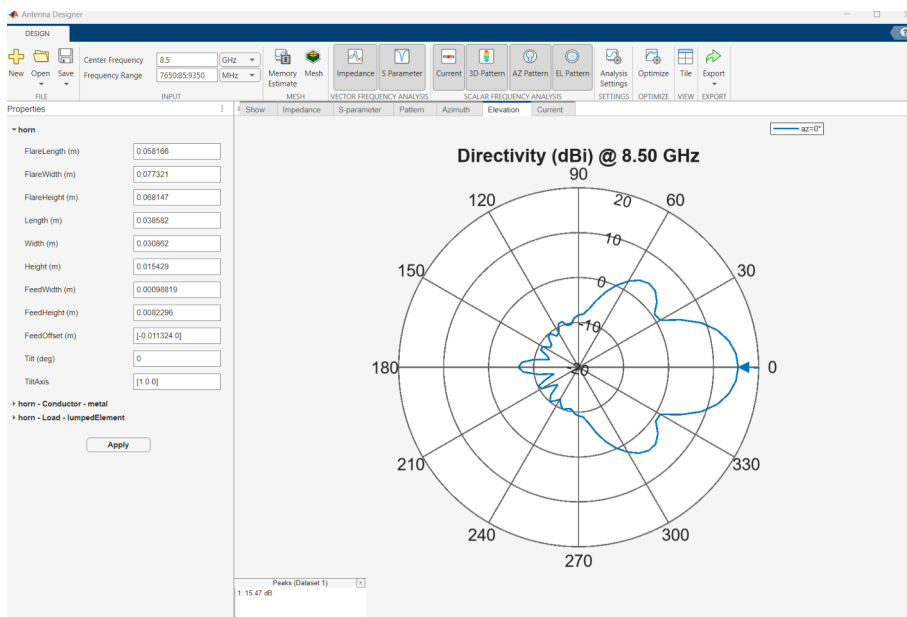


Figure 42: horn directivity elevation

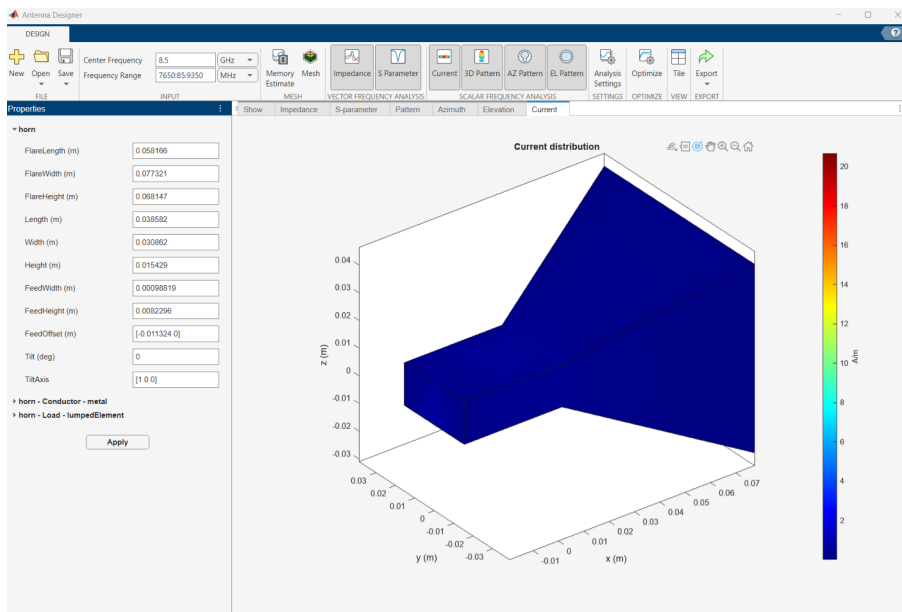


Figure 43: conduction on horn

Helix antenna

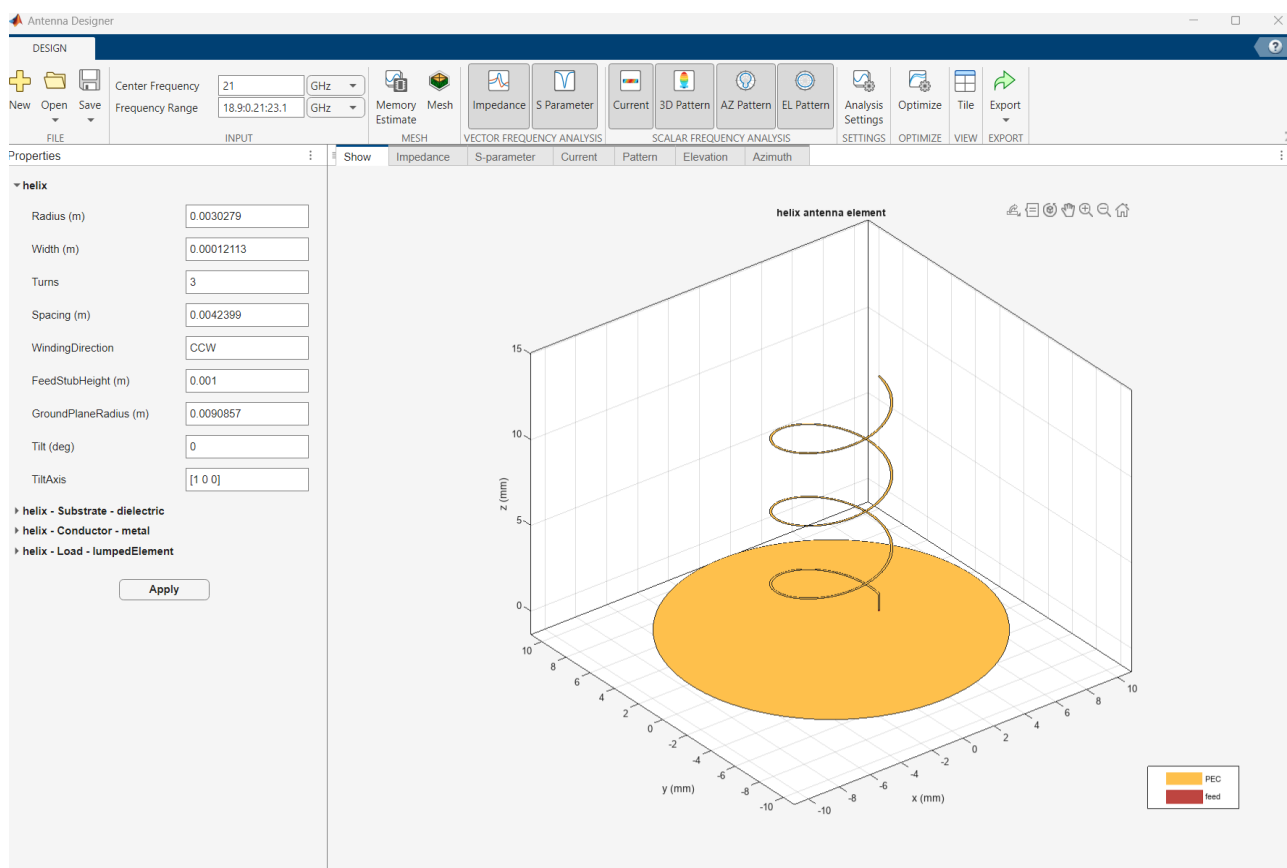


Figure 44: helix antenna

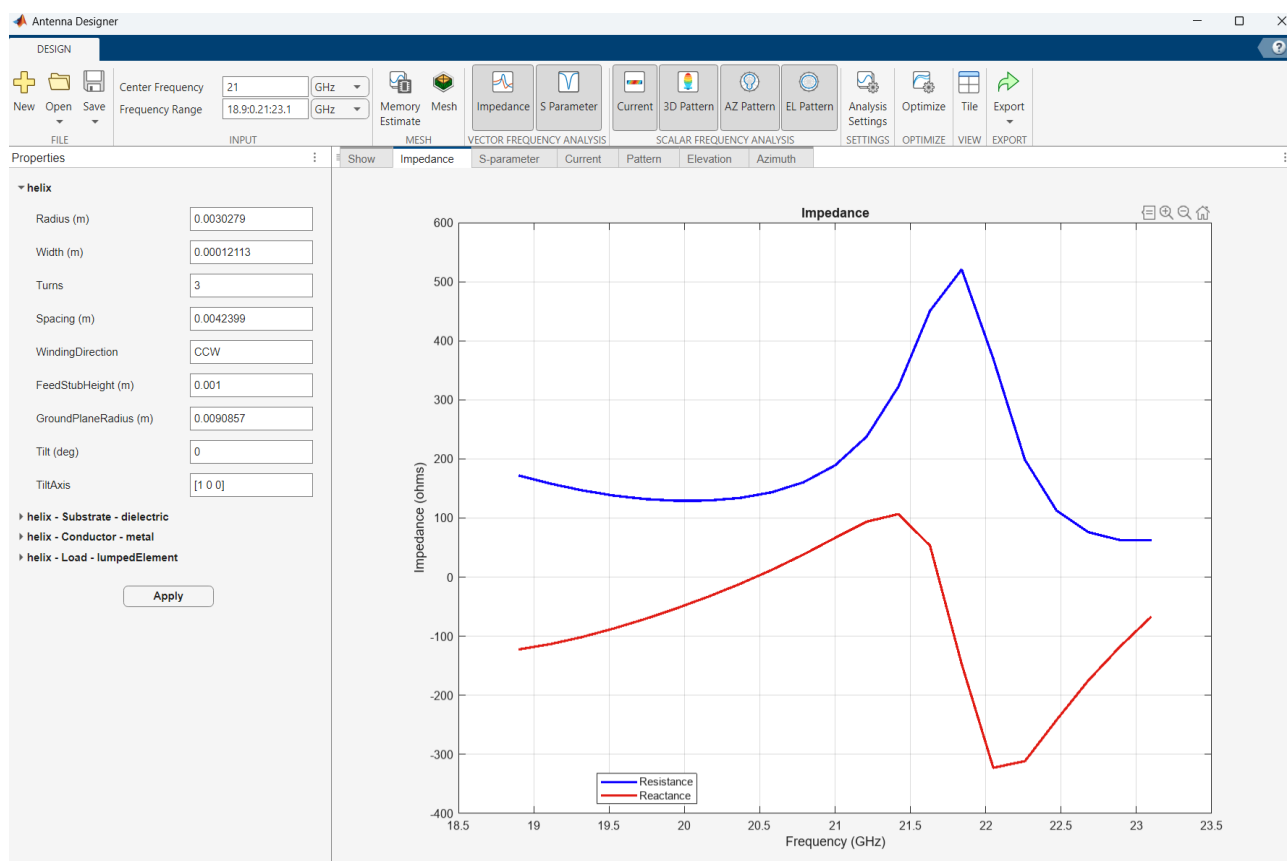


Figure 45: impedance of helix antenna

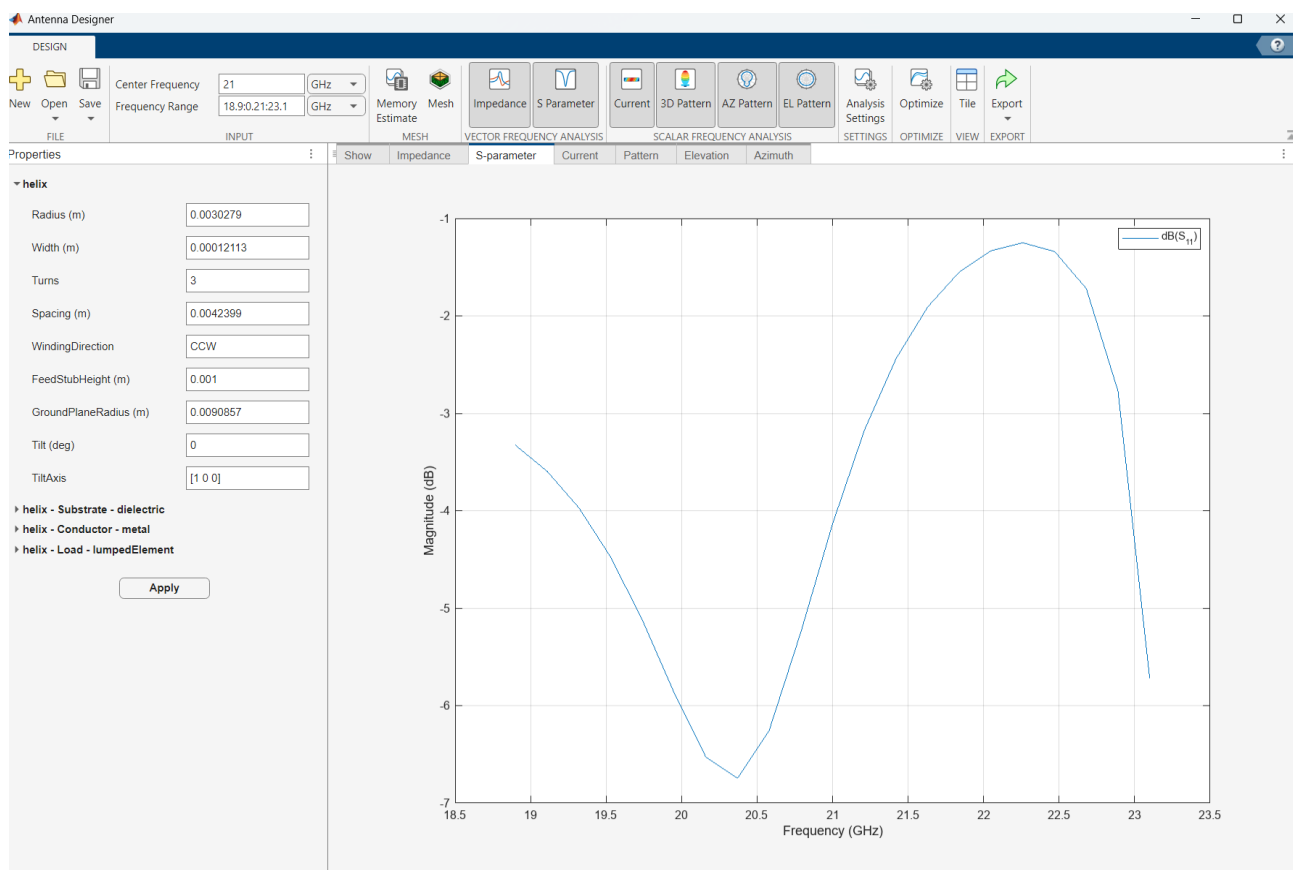


Figure 46: sParamater of helix antenna

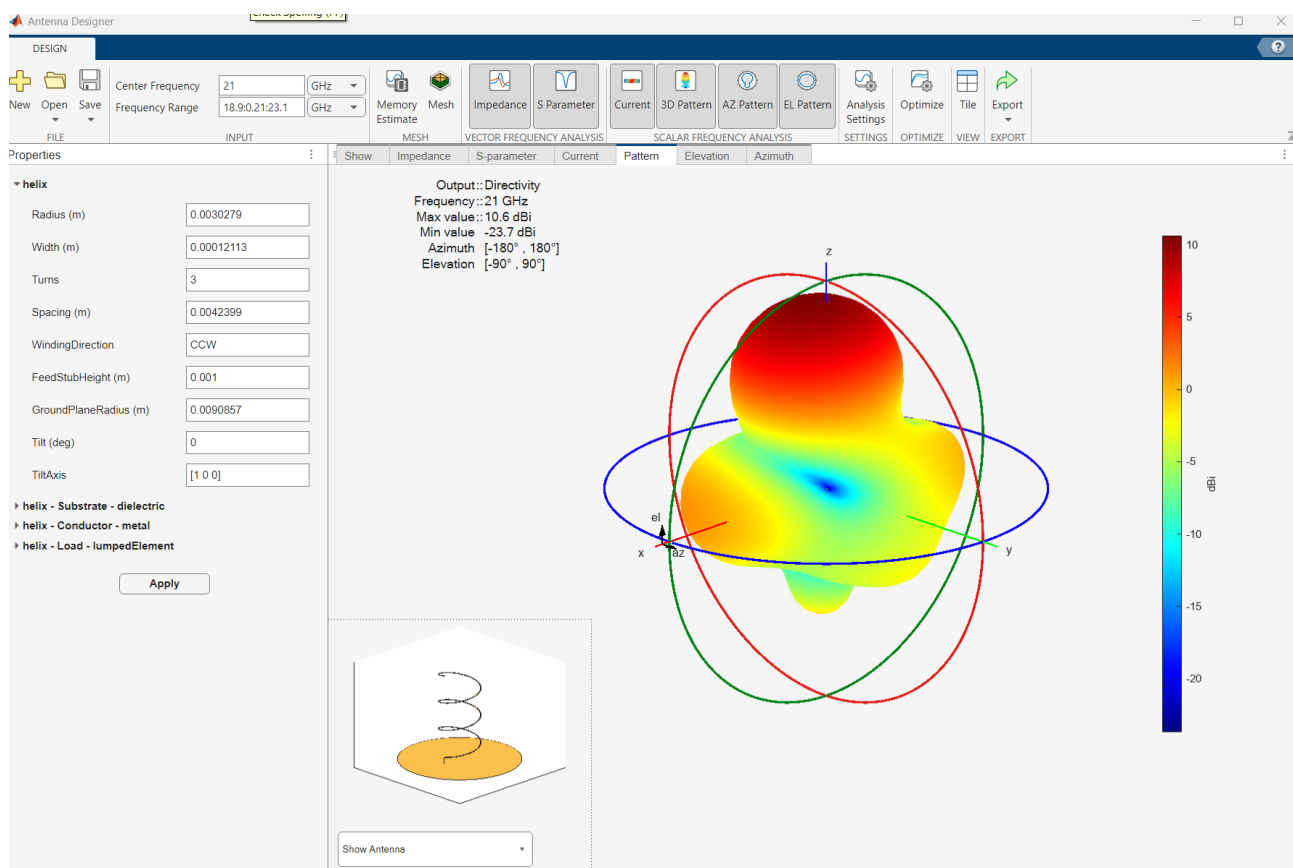


Figure 47: far field helix antenna

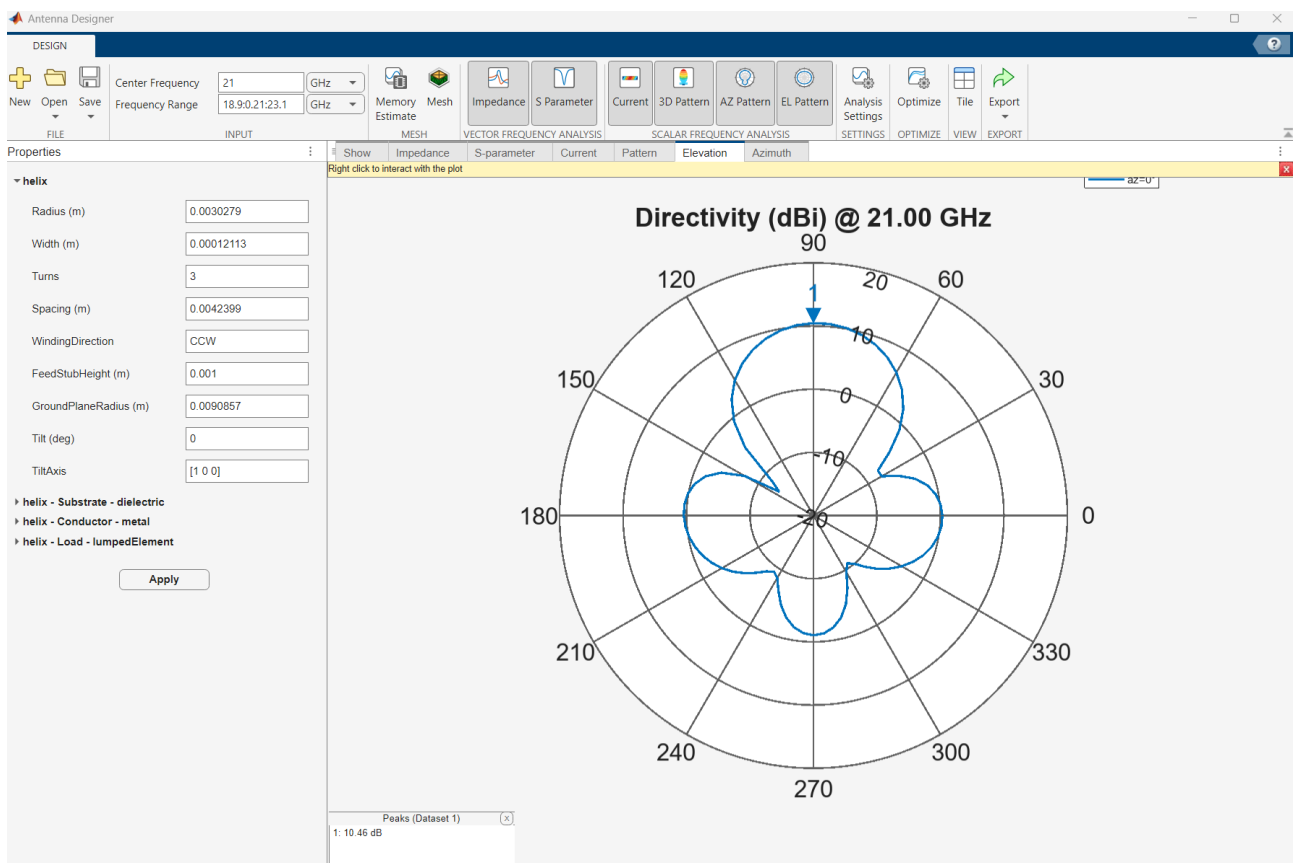


Figure 48: helix directivity elevation

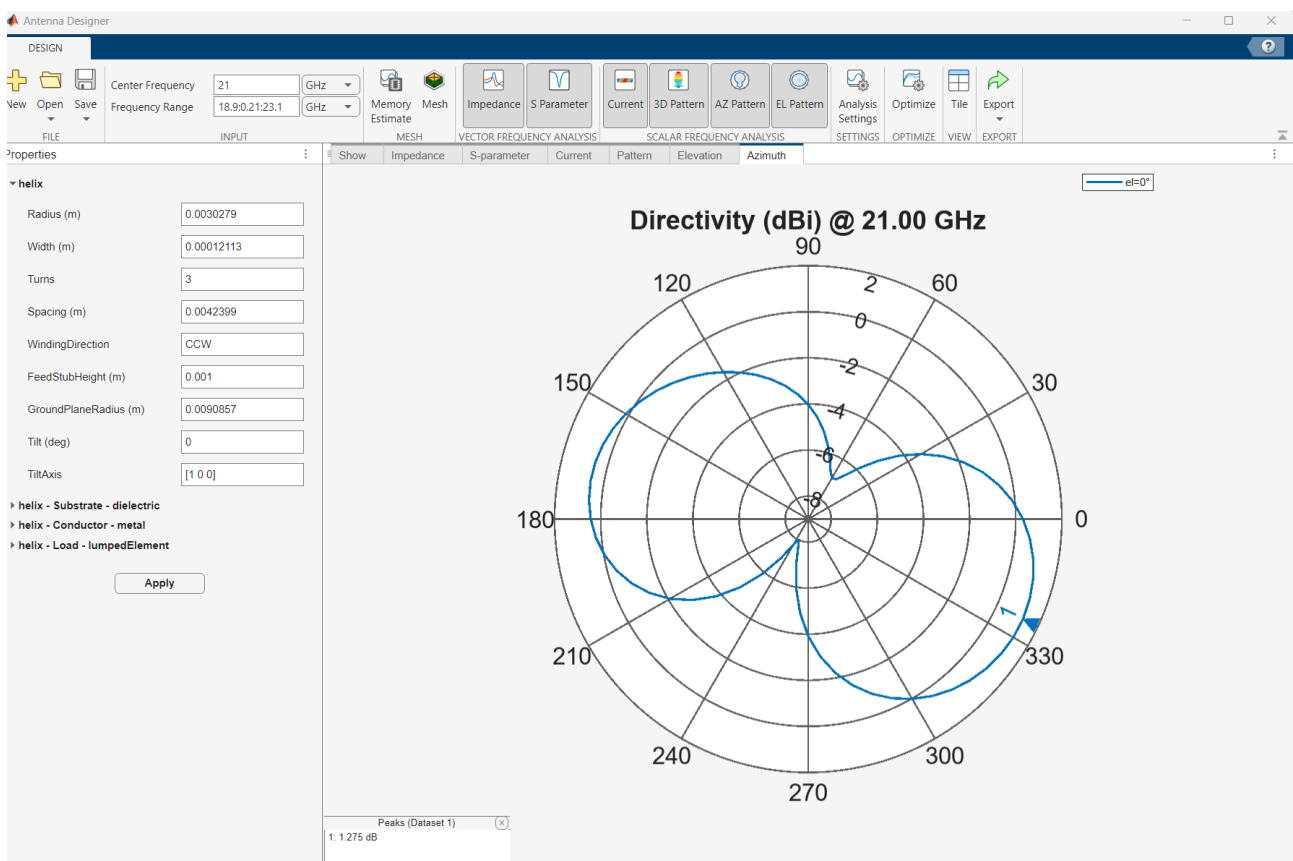


Figure 49: helix directivity azimuth

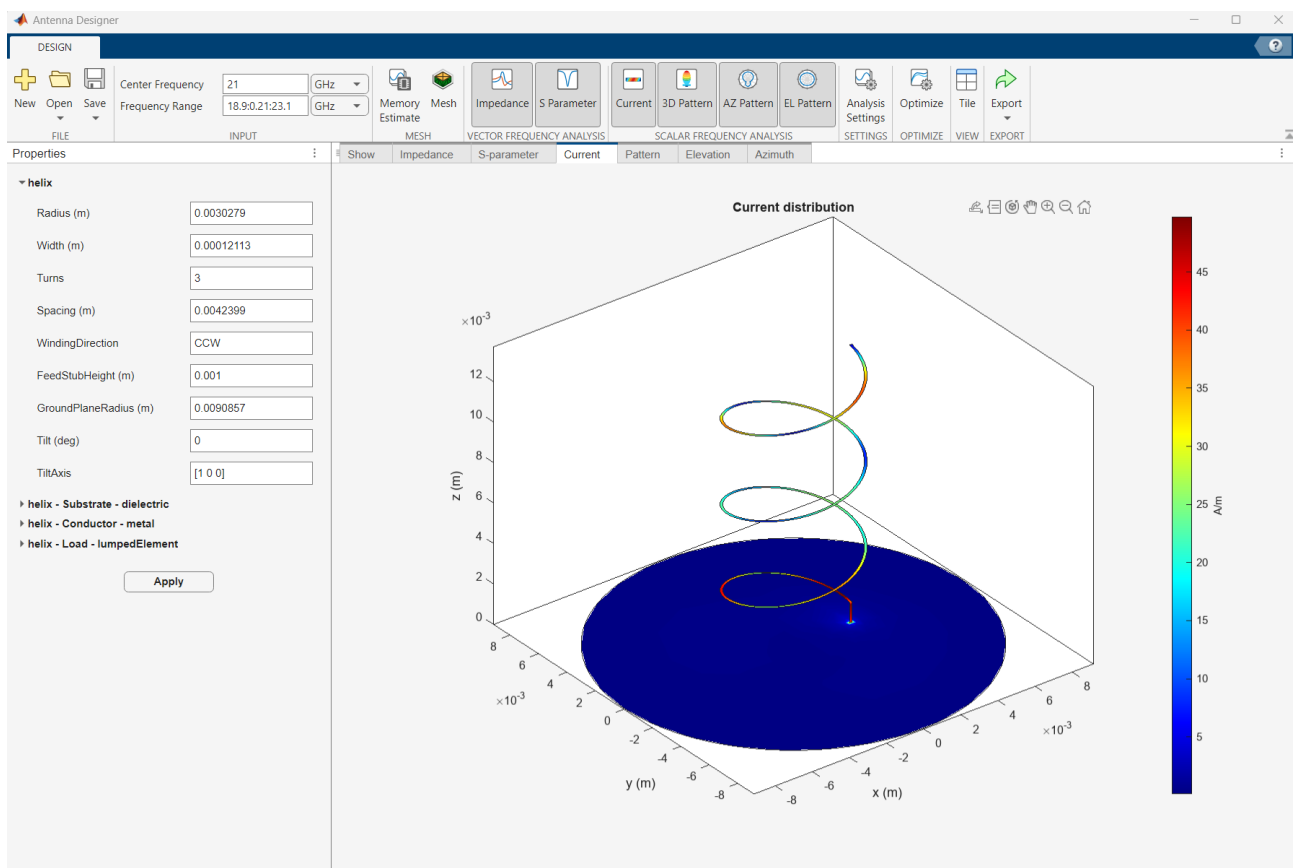


Figure 50: conductivity of helix antenna

helix array antenna

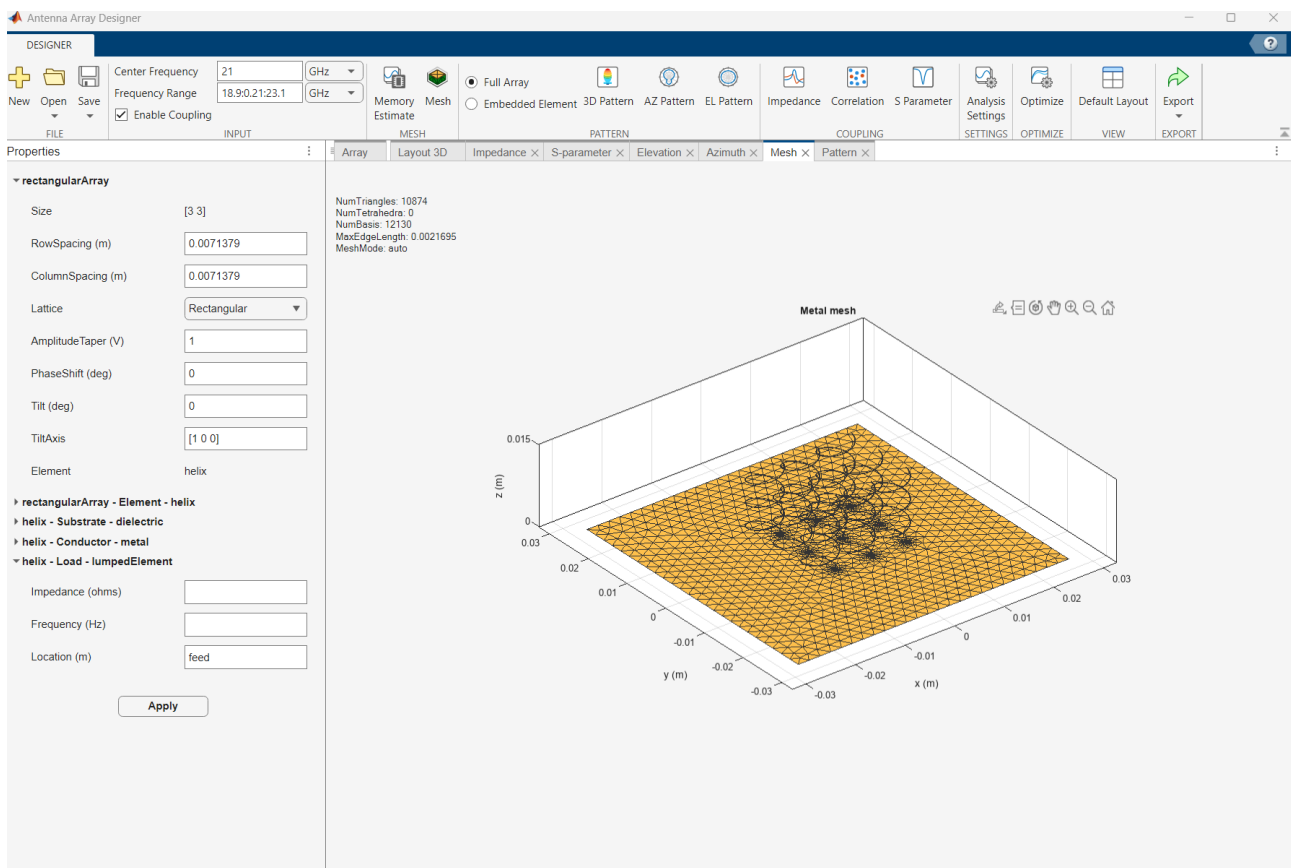


Figure 51: helix array antenna

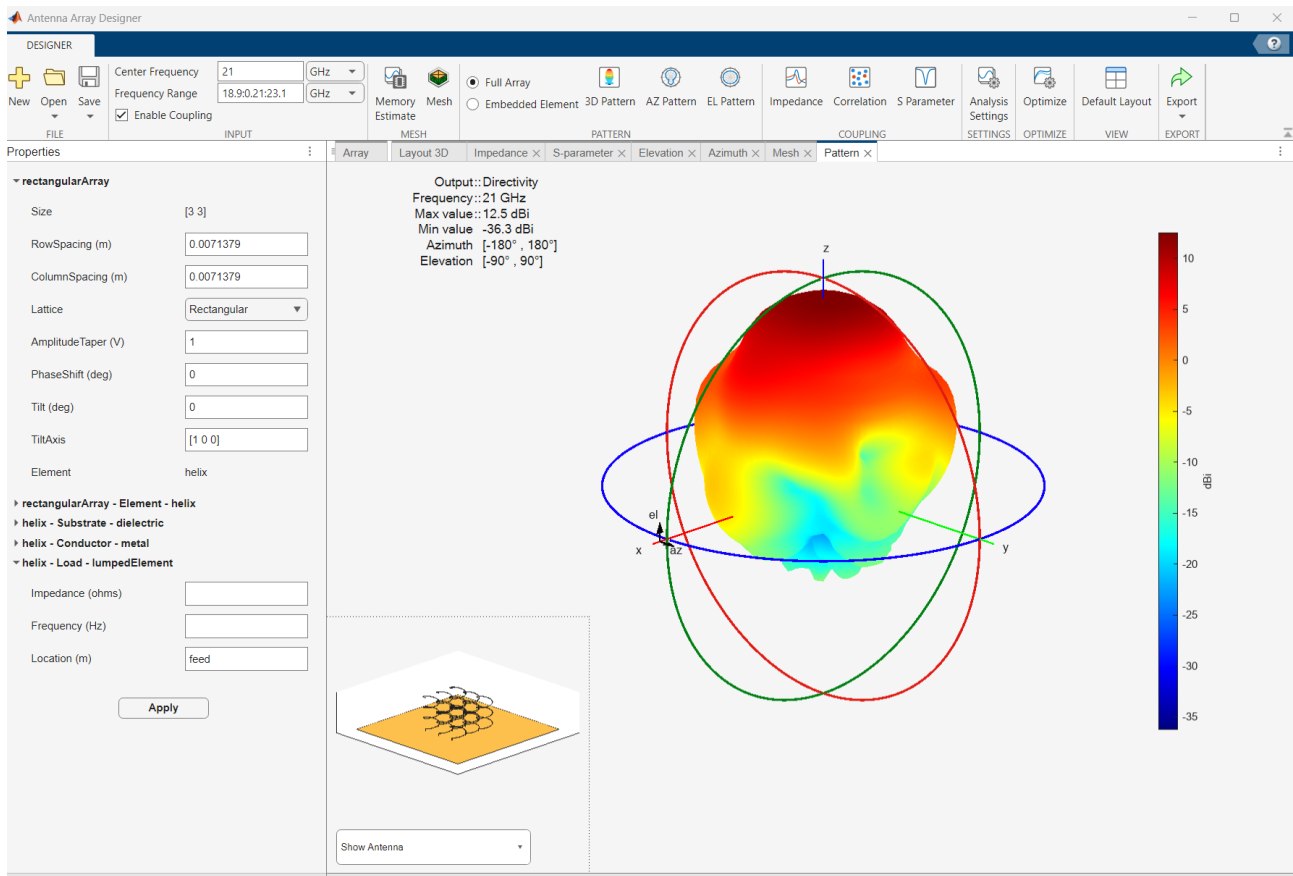


Figure 52: helix far field antenna

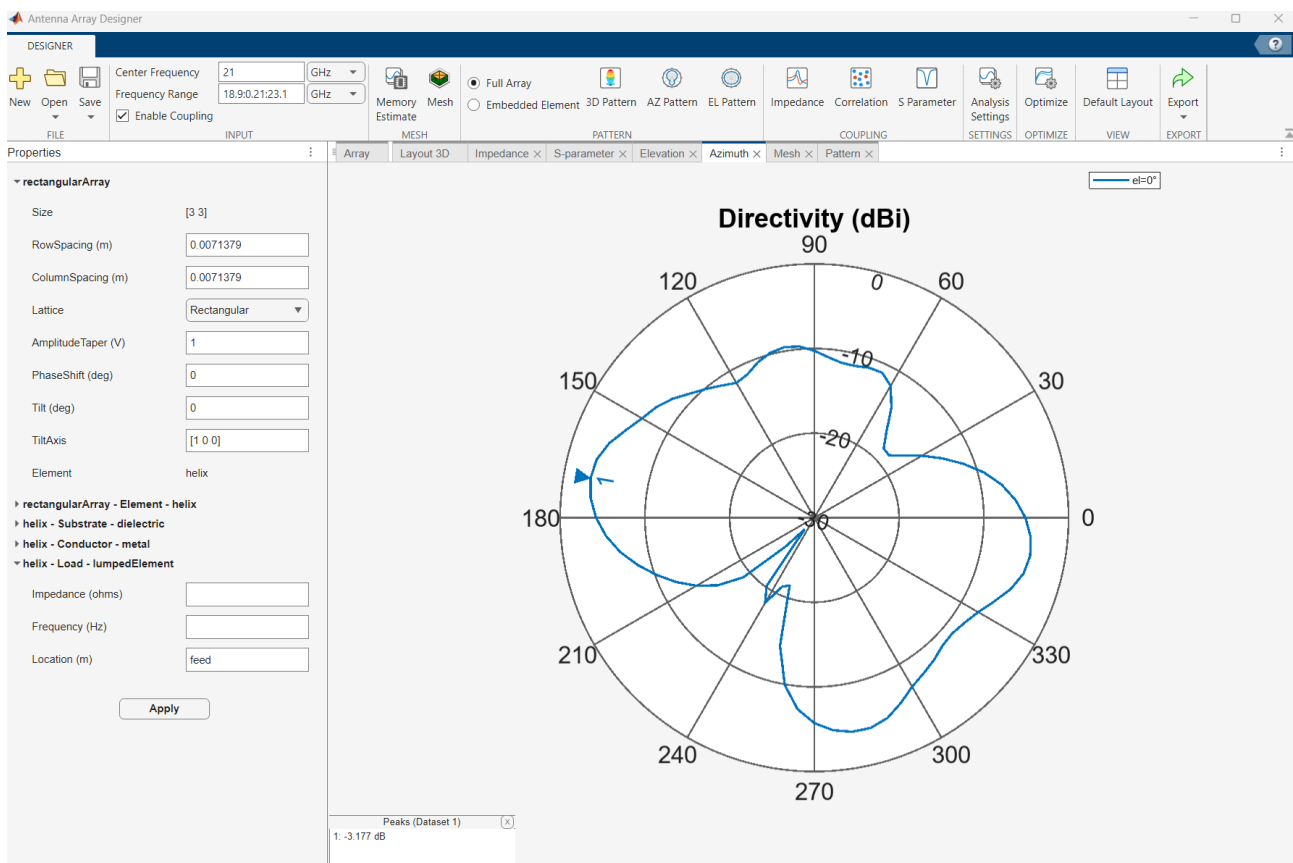


Figure 53: directivity of array antenna azimuth

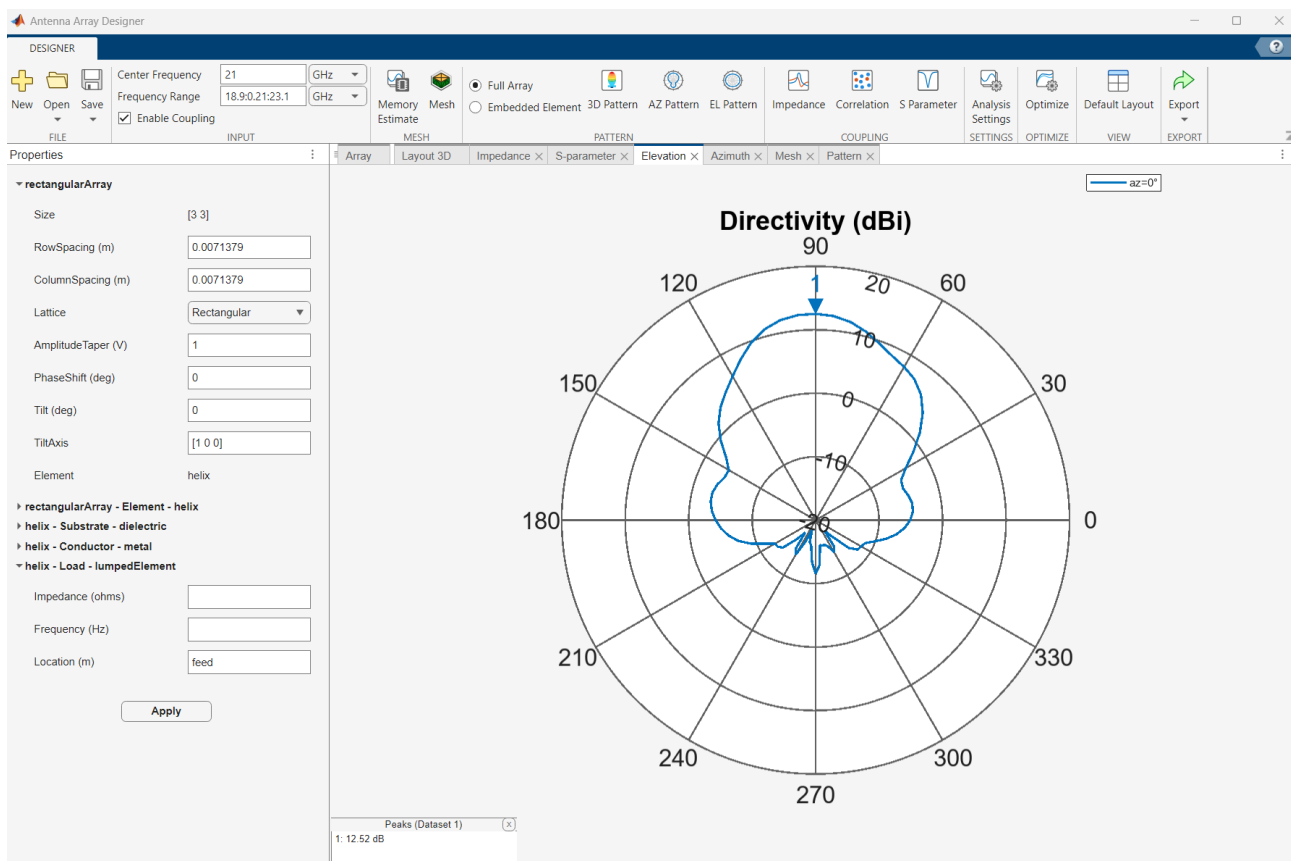


Figure 54: directivity elevation array antenna azimuth

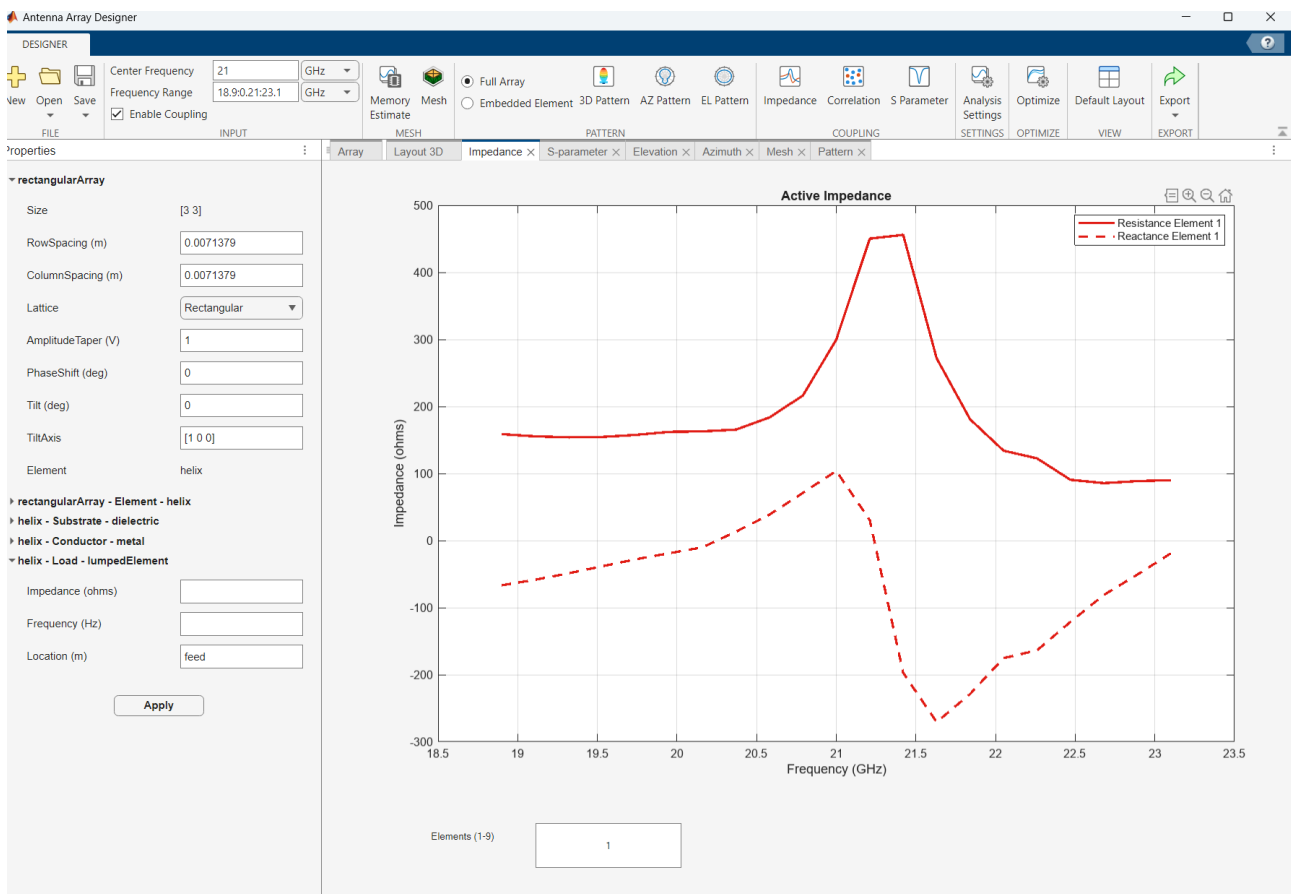


Figure 55: helix array antenna impedance

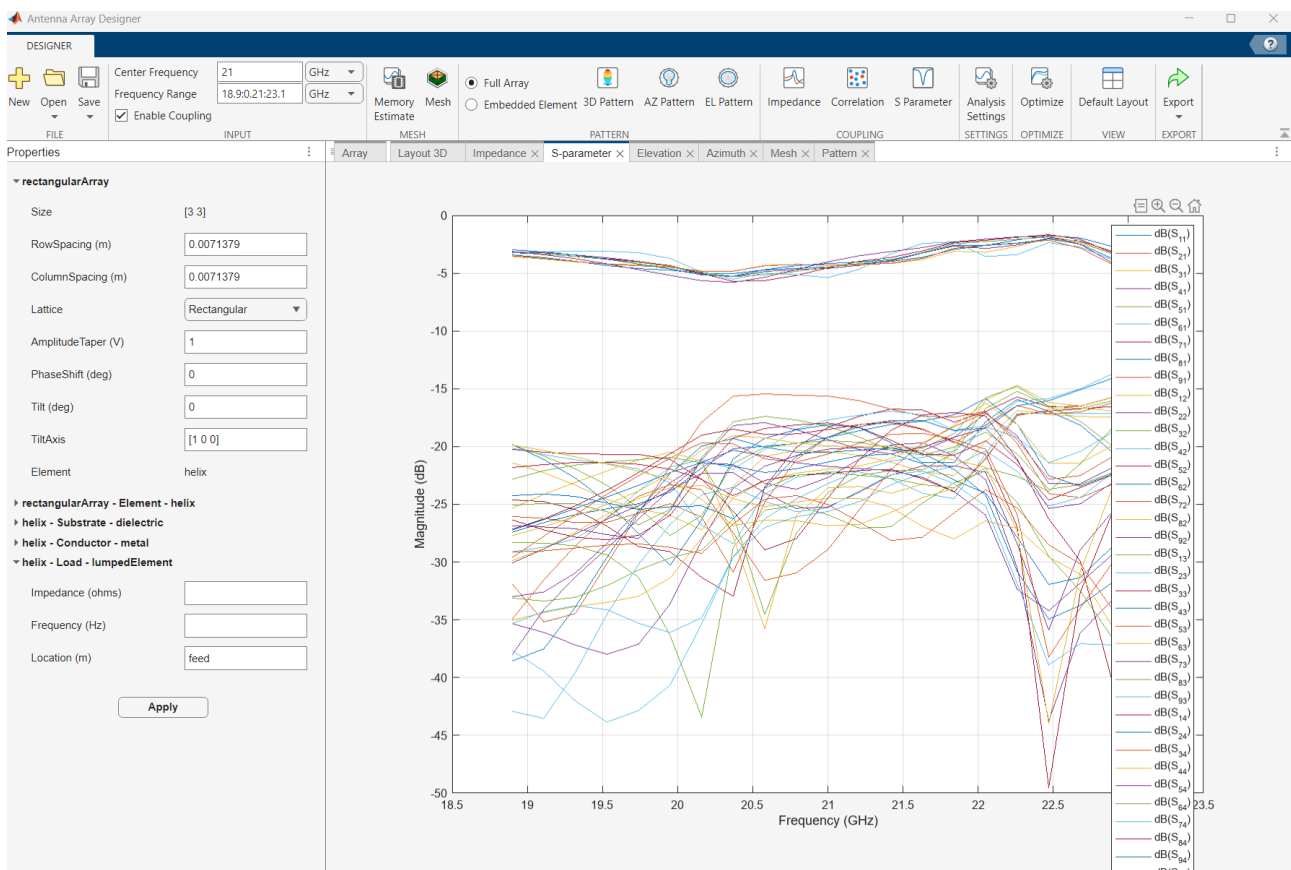


Figure 56: sParameter helix array antenna

Analysis of antennas

Patch antenna

the patch antenna is capable as a directional antenna as shown by its farfield plot but as also demonstrated by its incapability of omnidirectional power in its basic form. Due to vertical or horizontal polarisation the antenna struggles at long distance transmission.

Cylindrical dipole

cylindrical dipole is effective at omnidirectional radiating shown by its farfield but not directional. Dipoles are horizontally or vertically polarized but prefer vertical due to ground propagation

folded dipole

folded dipole is capable of omnidirectional power but at greater strengths than dipole due to its longer elements.

horn antenna

horn has a high amount of directionality but it lacks the polarisation of helix antennas its very similar to patch antenna its more directive but due to its size it would be difficult or impossible to incorporate on a PCB board.

Helix antenna

helix antennas is a highly directional circularly polarised antenna that can communicate through the ionosphere to satellites in space this is due to its circular polarity allowing it to pass through the ionosphere without the interference of the ionosphere damaging the signal significantly.

helix array antenna

The array antenna produces the same type of output as a helix antenna the array format amplifies the power and directionality as there are more antennas working at the same frequency and same polarity together. This could allow the antenna to communicate significantly further.

software

CST design studio gives a very detailed look at the patch antenna and can simulate many different materials the author simulated perfect electrical conductor(PEC) to keep the data similar to the MATLAB data and make it easier to compare but the CST software could easily model copper as such its much more flexible and the antenna will be more similar to its real world counterpart.

Matlab calculates the antenna size and capabilities faster than CST as its only using maths equations with significant details. Matlab give limited controls over the antennas dimensions and sub part size.

Ethics around antennas and their usage

antennas are rather simple on their ethics to do with construction as they are just metal items constructed in a calculated manner. The usage however is can be more problematic for standard usage such as data transmission their will be no issue but antennas can be connected to any radio device as such they can be used for jamming and damage of property or person if designed in such a way. This is not their normal usage but its a usage. In general you must follow in the UK of Communications guidance on rf spectrum usage and some of this guidance covers what antennas can be used and where. See ofcoms website [7]

antennas also have limits on their emission based on their directivity this is shown by the uk HSE[9]

Conclusion

The author showed a selection of different types of antennas and evaluated how the antennas function and what they would be used for as well as why they perform best in that function.

Each antenna has its own individual use case if a user was to try to use a dipole for a satellite Communications broadcast it would not work very effectively as such it is advised that the user know the use of the antenna before they start designing and the size constraints.

If a user needs more power and directionality it would be advisable to look into producing an array of the antenna to give a greater output of power and directionality.

This report indicates that Matlab is a good software for quick calculations or starting a cst model but the user should ensure that they understand that Matlab does not take a lot of information into account and its assumptions are designed to give a quick mostly correct response rather than a near perfect output unlike a HFSS software such as CST. CST will give a very close to actual antenna that could be copied to the real world with limited changes although CST will take much longer to simulate and tune to the frequency as you are constructing from the base up rather than from frequency down.

In final conclusion an antenna designed using purely mathematical calculations will have issues related to frequency and power limits this is due to maths having rounding errors and no relation to material limits if a designer wants to use only maths and design software to create an antenna they will need to understand the limits of their design and alter the design after the system is created.

After developing these antennas the author advises when designing antennas its advisable to use Matlab to produce the rough numbers then use CST to produce the more specific design.

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