# Lab Manual

# Electronics Engineering Lab (PG)
# (Modular - II)

# Content

# EXPERIMENT NO. 02

**Objective:** Design and analysis of Dipole antenna.

**Software used:** HFSS or CST software

## Theory:

The dipole antenna or dipole aerial is one of the most important and commonly used types of RF antenna. It is made up of two radiators oriented in the same direction, sharing a common axis, and separated by an air gap. The two radiators are excited by a feed line in the center of the antenna as shown in fig1.1.

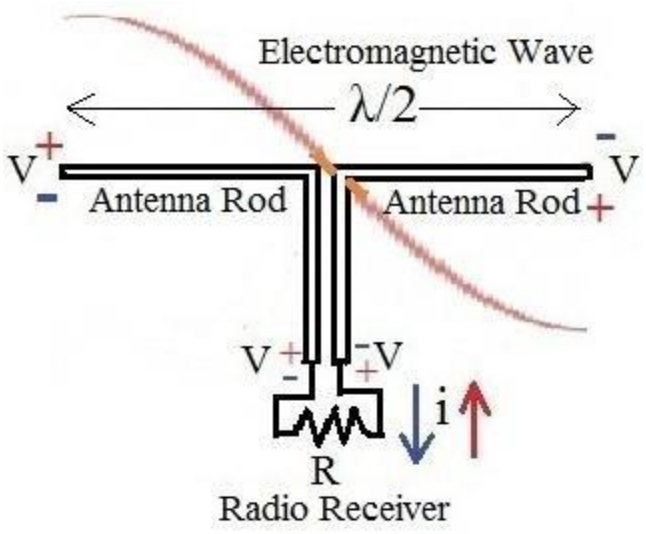


Fig1.1. A basic Dipole antenna.

There are three main parameters that govern the operation of this antenna, they are dipole length, air gap, and dipole radius. The air gap and the dipole radius have only minor effects on the performance of the dipole. Because of this, their size is typically determined based on the antenna manufacturer's requirements, within a reasonable range. That leaves the dipole length as the primary concern when designing antennas of this type. Although the dipole has a physical length, when designing antennas it is often much more convenient to refer to the electrical length of the antenna rather than the nominal value. Electrical length is the distance from one end of the antenna to the other measured in wavelengths of the signal at a specified frequency. Thus, at differing frequencies the same electrical length refers to different nominal lengths. Electrical length is usually stated in terms of wavelengths, denoted by the greek letter lambda, λ.

The most common dipoles for practical use are half-wavelength dipole antennas. One of the primary advantages of half-wavelength dipoles is that their characteristic impedance is 73 Ω, which is very close to the characteristic impedance of commercially available 75 Ω transmission lines. In addition, longer dipoles (L > λ) have radiation patterns with multiple lobes, whereas half-wavelength dipoles only have one lobe. A single lobe pattern is usually preferred because multiple lobe patterns can have significant nulls between the lobes, which can be extremely detrimental to antenna performance. Finally, half-wavelength dipoles provide an excellent balance by providing a more compact, material saving design than longer antennas without realizing the sharp performance reduction seen in shorter antennas. These factors have all combined to make half-wavelength dipoles an attractive and popular choice for antenna designers for many years

In order to design the half-wavelength dipole depicted in Figure 1.1, the electrical length of λ/2 must be converted to a nominal value. This can be accomplished through equation (1).

$$L_D = \boldsymbol{\lambda}/2 \tag{1}$$

The electric and magnetic field components of a half-wavelength dipole can be obtained from (2) by letting l = λ/2.

$$E_\theta \cong j\eta \frac{I_0 e^{-jkr}}{2\pi r}\left[\frac{cos(\frac{\pi}{2}cos\theta)}{sin\theta}\right]$$

$$H_\varphi \cong j \frac{I_0 e^{-jkr}}{2\pi r}\left[\frac{cos(\frac{\pi}{2}cos\theta)}{sin\theta}\right] \tag{2}$$

The directivity of the half-wavelength dipole antenna is given by:

$$D_0 = 4\pi \frac{U_{max}}{P_{rad}} \cong 1.643(\text{dimensionless}) \qquad = 2.1\text{ dB} \tag{3}$$

And the radiation resistance, for a free-space medium ($\eta = 120\pi$) is given by

$$R_r = \frac{2P_{rad}}{|I_0|^2} \cong 73 \tag{4}$$

Another advantages of dipole antenna is its radiation pattern. Due their shape and design, dipole antennas can be excited by incident electromagnetic waves from a wide range of angles. In the azimuth, a dipole is a perfectly symmetrical cylinder. This results in a completely Omni-directional (toroidal) radiation pattern.

3-D and 2-d radiation pattern of dipole antenna are shown below:

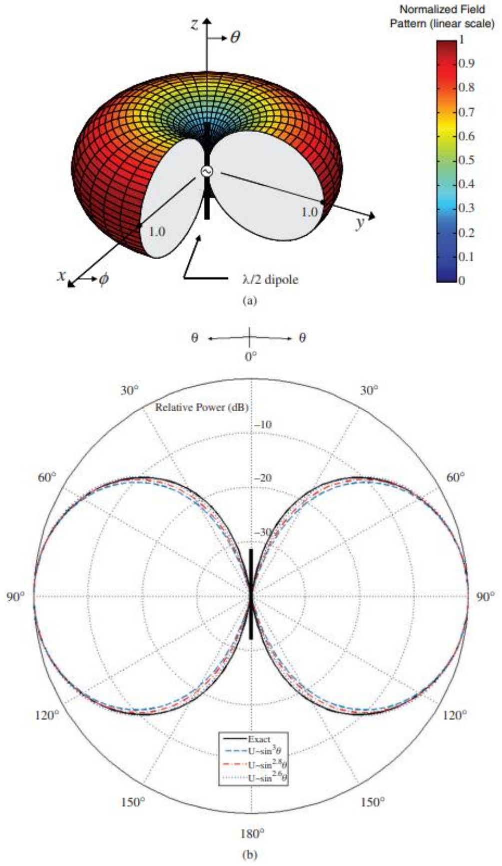


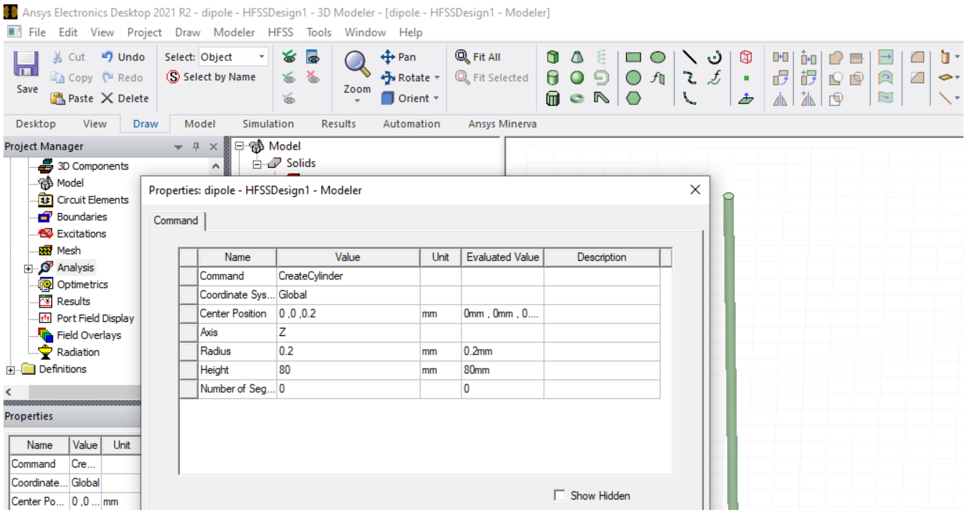
Fig2.1 (a) 3-D pattern, and (b) 2-D pattern of **λ**/2 dipole antenna.

## Design Problem

Design and analysis of Dipole antenna at 900 MHz with 10% IBW (Gain = 2 dB).

## Design Procedure using HFSS software:

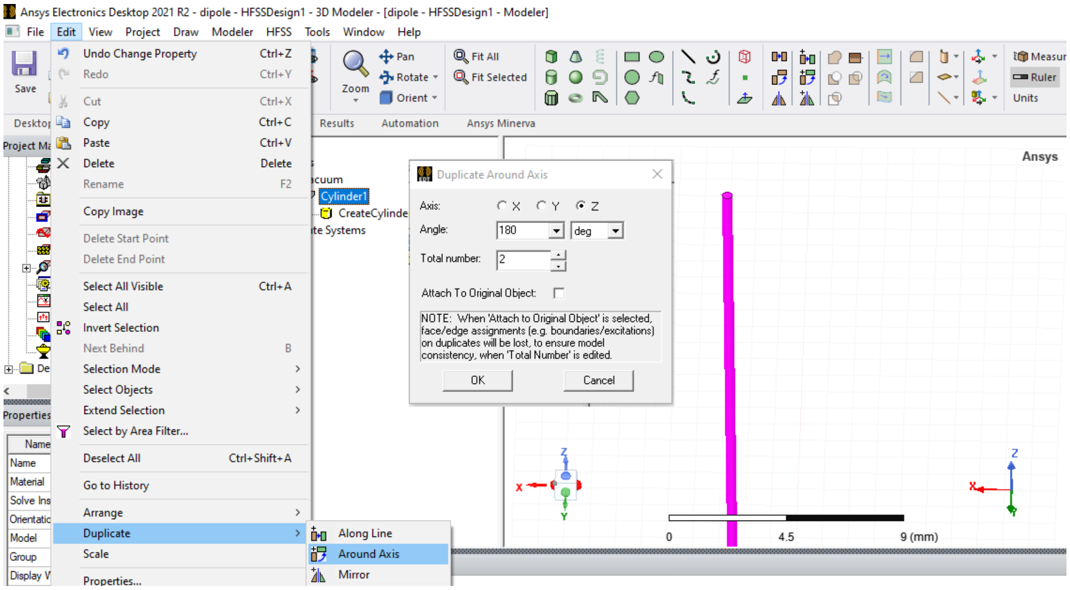
1. Start ANSYS Electronics Desktop. Check (and change if necessary) that the working mode is Driven Modal, HFSS > Solution Type > Modal.
2. Set Modeler length units to mm, Modeler > Units > mm.
3. To draw a dipole element, select Draw > Cylinder and enter calculated values at radius and height position.


Ansys Electronics Desktop 2021 R2 - dipole - HFSSDesign1 - 3D Modeler - [dipole - HFSSDesign1 - Modeler]

Properties: dipole - HFSSDesign1 - Modeler

| Name | Value | Unit | Evaluated Value | Description |
|---|---|---|---|---|
| Command | CreateCylinder | | | |
| Coordinate Sys... | Global | | | |
| Center Position | 0 ,0 ,0.2 | mm | 0mm , 0mm , 0.... | |
| Axis | Z | | | |
| Radius | 0.2 | mm | 0.2mm | |
| Height | 80 | mm | 80mm | |
| Number of Seg... | 0 | | 0 | |

4. After drawing the first element of the dipole we will create the second one by symmetry.


Ansys Electronics Desktop 2021 R2 - dipole - HFSSDesign1 - 3D Modeler - [dipole - HFSSDesign1 - Modeler]

Duplicate Around Axis

Axis: ○ X ○ Y ● Z

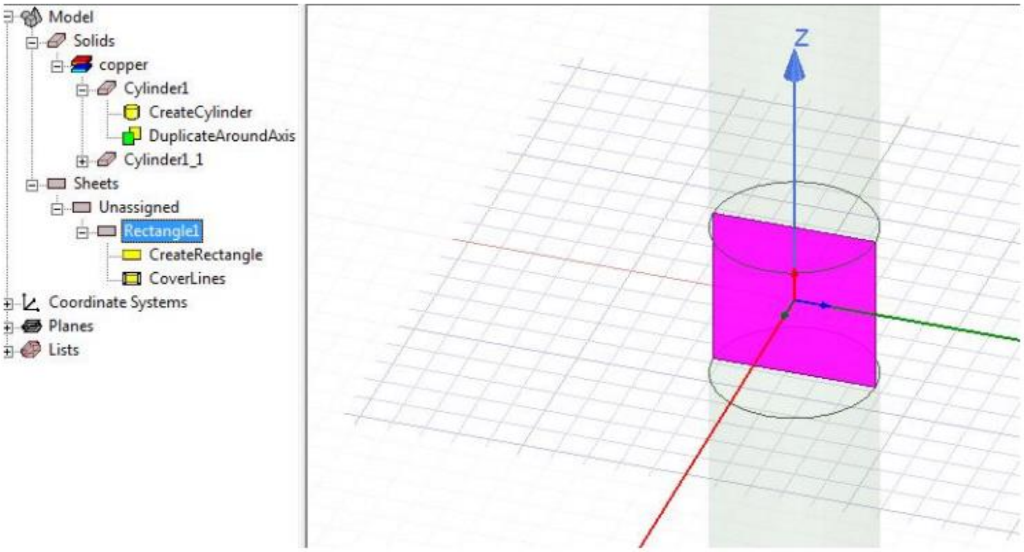
Angle: 180 deg

Total number: 2

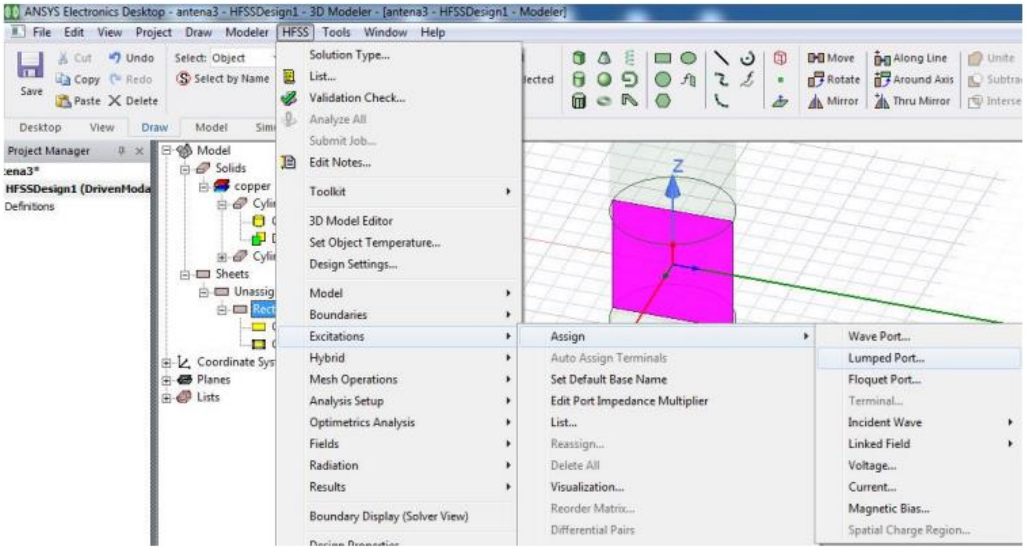
Attach To Original Object: ☐

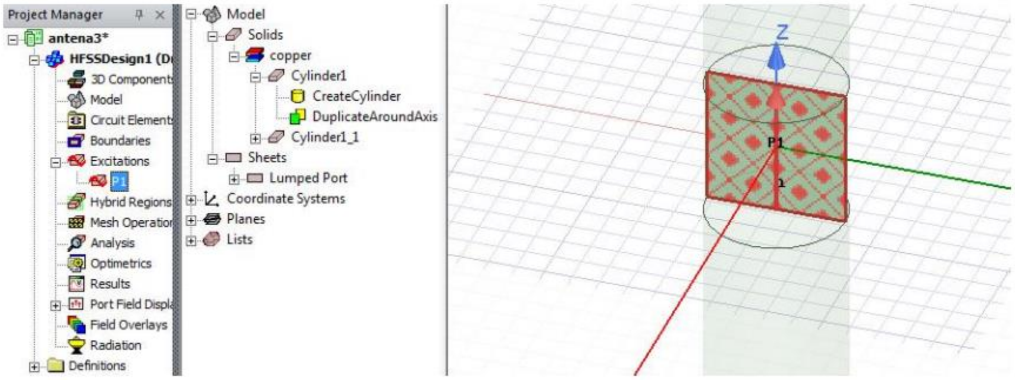
NOTE: When 'Attach to Original Object' is selected, face/edge assignments (e.g. boundaries/excitations) on duplicates will be lost, to ensure model consistency, when 'Total Number' is edited.

5. Select the first cylinder and then select Edit > Duplicate > Around Axis, choose the axis X or Y and enter the angle of 180°, Total number 2.
6. To provide an input source to perform the simulation. Select Draw > Rectangle and draw a rectangle (! it's a surface model not a volume one) between the two wires, as in the figures below.



7. Select the drawn rectangle and define it as the input signal area/port HFSS > Excitations > Assign > Lumped Port.





**8.** Select HFSS > Model > Create Open Region. Choose the frequency of interest (around 900 MHz) and Radiation boundary.
**9.** Add a solution. Select HFSS > Analysis Setup > Add Solution Setup
**10.** After meshing, we define a broadband analysis. Select the previously defined solution (Project Manager > Analysis > Setup1) and add a broadband solution around the frequency corresponding to the single frequency solution HFSS > Analysis Setup > Add Frequency Sweep.
**11.** Select HFSS > Validation Check to verify that all required steps have been completed.
**12.** Select HFSS > Analyze All to start the simulation. Click the Show Progress button to view the progress of the solver.
**13.** Select HFSS > Results > Create Modal Solution Data Report > Rectangular Plot to display the S parameter corresponding to input port P1 (in dB).
**14.** Similarly plot far-fields parameters of the antenna.

**Simulated Results:**

Add various plots for the designed antenna performances:

1. -10 dB impedance bandwidth (in GHz)
2. Gain variations over whole operating BW (in dB)
3. 2-D radiation patterns at resonating frequency.
4. 3-D radiation patterns at resonating frequency.
5. Efficiency over the operating bandwidth.

**Observation Table:**

| **Frequency (GHz)** | **Impedance Bandwidth (GHz)** | **Gain (dB)** | **Efficiency (%)** | **Size ($\lambda^3$)** |
|---|---|---|---|---|
| | | | | |

**Conclusion:**

Various parameters of the dipole antenna are studied using HFSS /CST software.

**Problems:**

1. Design and Analysis of Dipole antenna at 1800 GHz with 10% IBW (Gain = 3dB)

# EXPERIMENT - 2

## OBJECTIVE:

1. To become familiar with the microstrip antenna.
2. To design microstrip patch antenna and study the different antenna parameters.

## SOFTWARE USED:

ANSYS HFSS Software

## THEORY:

### 1. Familiarization with the microstrip antenna:

Microstrip antennas are low profile, comfortable to planar and non-planar surfaces and mechanically robust when mounted on rigid surface. It is also known as “patch antenna”, “internal antenna” or “printed antenna”, which is a narrowband wide beam antenna. Mostly used at microwave frequencies. Fig.1 shows a few possible geometries of single radiating patch antenna. The patch is usually fed along the centreline to symmetry and thus minimizes the excitation of undesirable modes. It is preferred in aircraft, spacecraft, satellite and missile applications, where size, weight, cost, ease of installation and aerodynamic profile are constraints and low profile antennas may be required.

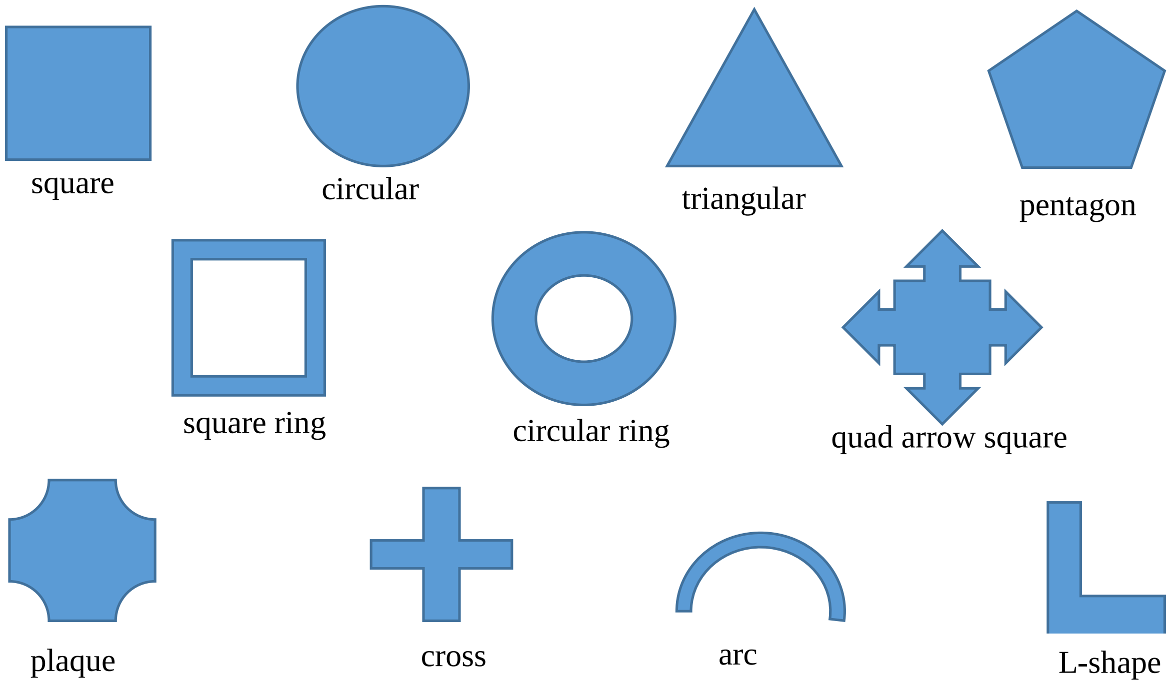
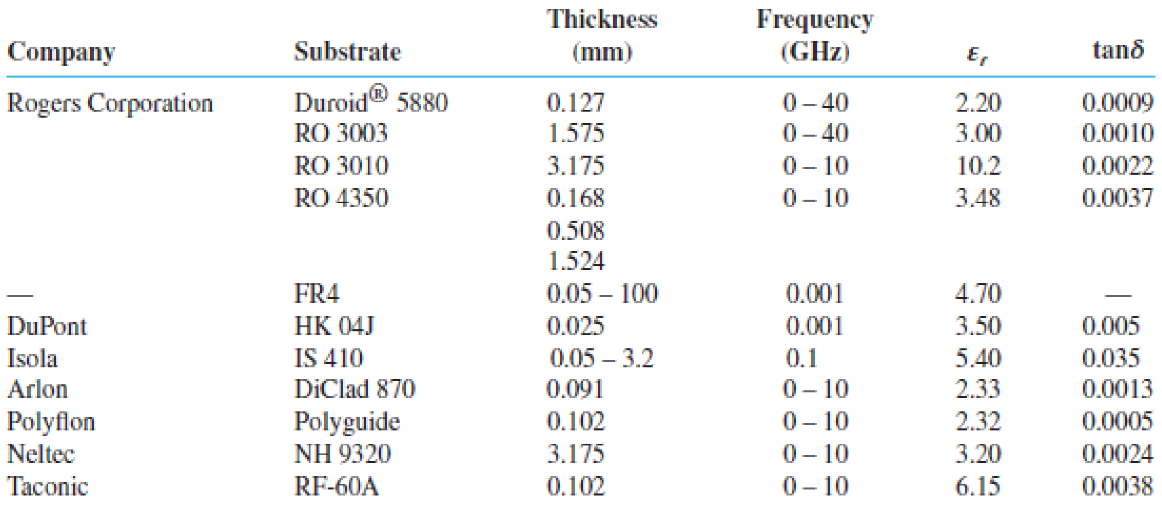


Fig. 1 Geometry of single radiating patch antenna

**Substrates:**

There are a numerous number of substrates that can be used for the design of microstrip antennas whose dielectric constants are usually in the range of $2.2 \leq \varepsilon r \leq 12$. Thick substrates are desirable with lower dielectric constants where because they provide better efficiency, larger bandwidth, loosely bound fields for radiation into space, but at the expense of large element size. Similarly, thin substrates with higher dielectric constants are desirable for microwave circuitry because they require tightly bound fields to minimize undesired radiation and coupling and lead to smaller element sizes. However, because of their greater losses, they are less efficient and have relatively smaller bandwidths. Fig. 2 shows a few examples of substrates with their specification which is used for selection of particular substrates by the antenna designers.



| Company | Substrate | Thickness (mm) | Frequency (GHz) | $\varepsilon_r$ | $\tan\delta$ |
|---|---|---|---|---|---|
| Rogers Corporation | Duroid® 5880 | 0.127 | 0 – 40 | 2.20 | 0.0009 |
| | RO 3003 | 1.575 | 0 – 40 | 3.00 | 0.0010 |
| | RO 3010 | 3.175 | 0 – 10 | 10.2 | 0.0022 |
| | RO 4350 | 0.168 | 0 – 10 | 3.48 | 0.0037 |
| | | 0.508 | | | |
| | | 1.524 | | | |
| — | FR4 | 0.05 – 100 | 0.001 | 4.70 | — |
| DuPont | HK 04J | 0.025 | 0.001 | 3.50 | 0.005 |
| Isola | IS 410 | 0.05 – 3.2 | 0.1 | 5.40 | 0.035 |
| Arlon | DiClad 870 | 0.091 | 0 – 10 | 2.33 | 0.0013 |
| Polyflon | Polyguide | 0.102 | 0 – 10 | 2.32 | 0.0005 |
| Neltec | NH 9320 | 3.175 | 0 – 10 | 3.20 | 0.0024 |
| Taconic | RF-60A | 0.102 | 0 – 10 | 6.15 | 0.0038 |

Fig. 2 Examples of different substrates

**Feeding Techniques:**

Fig. 3 shows the feeding techniques for the microstrip antennas.

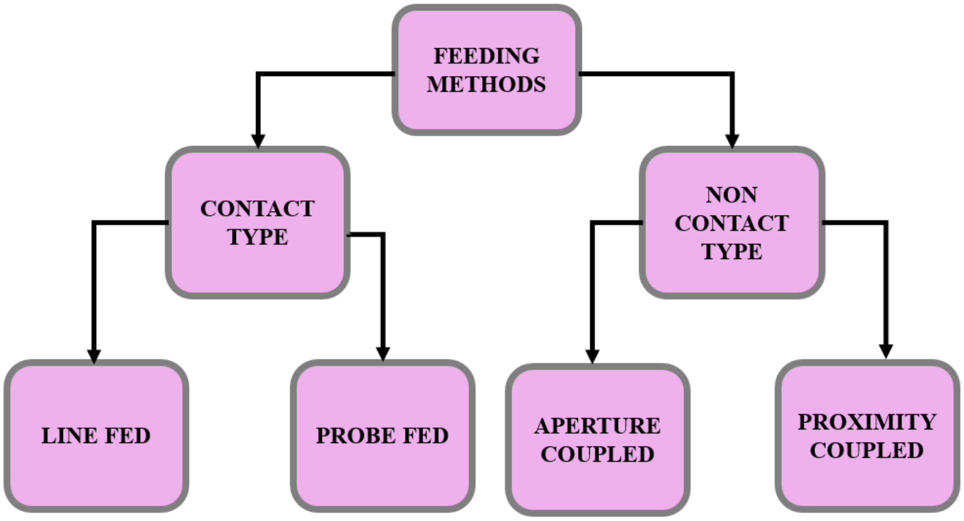


Fig. 3 Feeding methods of microstrip antennas.

**Antenna Parameters:**

The antenna parameters are represented graphically to characterize the antenna by using the simulated and measured data. Some of the typical antenna parameters are:

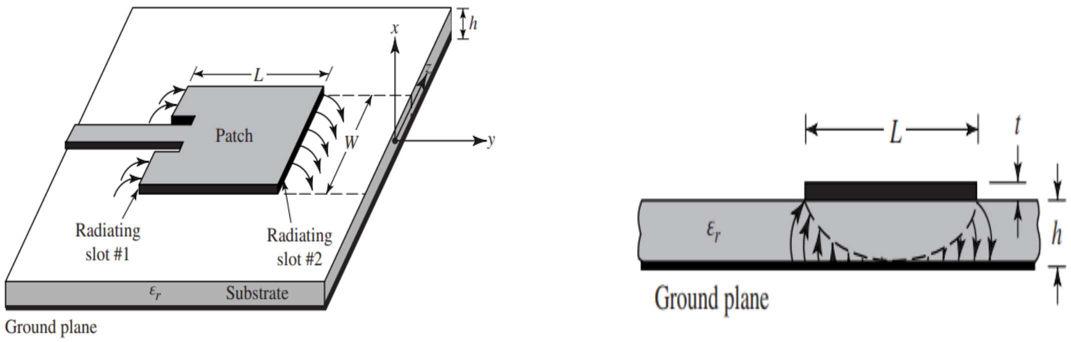
- S-parameters: For one port antenna only reflection coefficient i.e. S11 will be defined. In the context of antennas and feeders, the reflection coefficient is defined as the figure that quantifies how much of an electromagnetic wave is reflected by an impedance discontinuity in the transmission medium.
- VSWR: It is the ratio between transmitted and reflected voltage standing waves in a radio frequency (RF) electrical transmission system. It is a measure of how efficiently RF power is transmitted from the power source, through a transmission line, and into the load (antenna).
- Radiation Pattern: It is graphical representation of radiation properties of the antenna as a function of space. It describes how the antenna radiates energy out into free space (or how it receives energy). It is 3D – pattern, which can be visualized in simulation software like HFSS. It can be also represented in 2D – polar plot from two planes i.e., E-plane and H-plane.
- Gain: Antenna Gain is the ratio of power transmitted in a certain direction with a specific reference point. Relation between gain and efficiency is $G = e * D$ where '$D$' is the directivity and '$e$' if the efficiency
- Efficiency: Antenna efficiency is how much RF power delivered to the antenna (from radio) is actually transmitted into the air.
- Axial ratio: It states about the polarization of the designed antenna.

## 2. Design of a microstrip patch antenna and study the different antenna parameters

The rectangular patch is by far the most widely used configuration. It is very easy to analyse using both the transmission line and cavity models.

The diagram of a basic half-wave patch antenna is shown in Figure 4. It consists of a large patch of metal into which energy is coupled from a microstrip feed. The physical patch dimensions are width W and length L. It is fed by a microstrip feed line with width which is usually chosen so that the characteristic impedance of the feed line is 50 ohms. Like any other device, an antenna has an input impedance. If the feed line shown in the diagram were connected directly to the edge of the antenna, the input impedance at that point would be in the hundreds of ohms, which would be a poor match to the 50 ohm line being connected there. To match the input line (which is 50 ohms) to the high impedance of the patch, a simple quarter-wave transformer is used. Such a transformer is visible on the microstrip patch board.

A single-feed patch antenna like the one shown in Figure 4 resonates at a frequency determined by the length of the antenna L, which is approximately half a wavelength (taking into effect wavelength shortening by the substrate). The radiated polarization is parallel to edges of the patch in the resonant direction. Because the patch is backed by a ground plane, we expect most of the radiation to be on the patch side of the substrate, and very little radiation behind the ground plane.



(a) Top view (b) Side view

Fig. 4 Top view and side view of conventional microstrip patch antenna

## DESIGN PROCEDURE:

Based on the simplified formulation, a design procedure is outlined which leads to practical designs of rectangular microstrip antennas. The procedure assumes that the specified information includes the dielectric constant of the substrate ($'\varepsilon_r'$), the resonant frequency ($'f_r'$), and the height of the substrate ($'h'$). The procedure is as follows:

1. Specify: $'\varepsilon_r'$, $'f_r'$ and $'h'$ .
2. Determine '*W*' and '*L*'.

$$W = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}$$
, where, $'v_o'$ is the free space velocity of light.

3. Determine the effective dielectric constant ($'\varepsilon_{reff}'$)of the microstrip antenna using.

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}[1 + 12\frac{h}{W}]^{-1/2}$$

4. Once W is found, determine the extension of the length ($'\Delta L'$)using:

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)}$$

5. Now, the actual length of the patch can now be determined for '*L*',

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L$$

6. Typical lengths of microstrip patches vary between,

$$L \approx (0.47-0.49)\frac{\lambda_0}{\sqrt{\varepsilon_r}} = (0.47-0.49)\lambda_d$$

, where $'\lambda_d'$ is the guided wavelength in the dielectric.

The smaller the dielectric constant of the substrate, the larger is the fringing. Thus, the length of the microstrip patch is smaller.

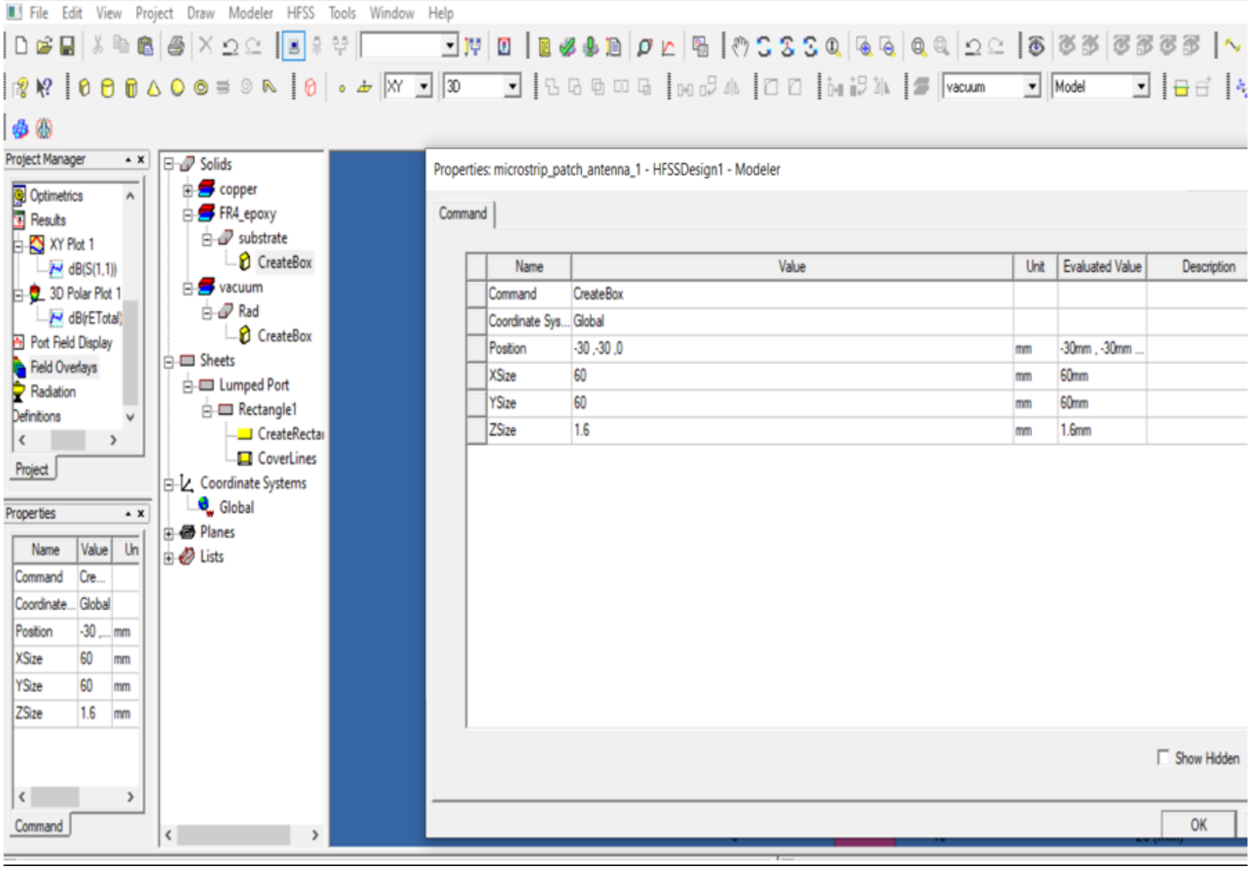
In contrast, the larger the dielectric constant, the more tightly the field are held within the substrate. Thus the fringing is smaller and the length is longer and closer to half wavelength in the dielectric

After calculating the length and width of the patch, design and simulation of rectangular microstrip patch antenna in the ANSYS HFSS software should be done to study the antenna parameters.

## HFSS DESIGN STEPS AND OBSERVATIONS:

This example has been shown for rectangular patch antenna resonating at 2.4 GHz on an FR-4 epoxy substrate of dielectric constant 4.4 and thickness 1.6 mm.

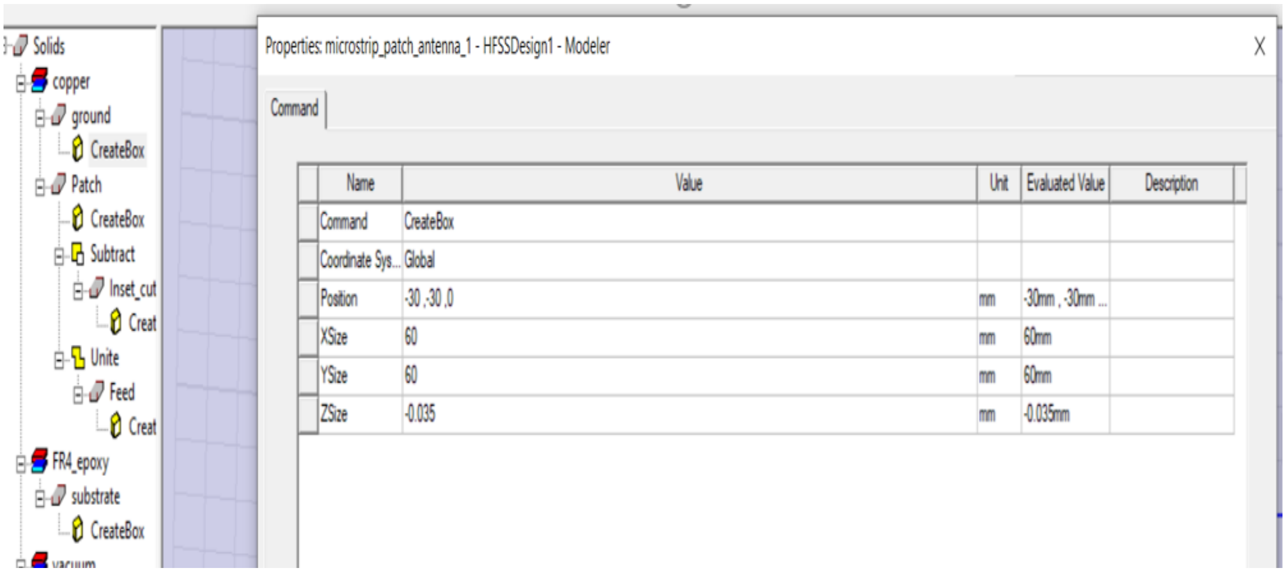
***<u>STEP1:</u> Create a substrate by selecting a Box from upper palate of 60x60x1.6 mm$^3$, substrate is FR4 epoxy.***



Properties: microstrip_patch_antenna_1 - HFSSDesign1 - Modeler

| Name | Value | Unit | Evaluated Value | Description |
|---|---|---|---|---|
| Command | CreateBox | | | |
| Coordinate Sys... | Global | | | |
| Position | -30 ,-30 ,0 | mm | -30mm , -30mm ... | |
| XSize | 60 | mm | 60mm | |
| YSize | 60 | mm | 60mm | |
| ZSize | 1.6 | mm | 1.6mm | |

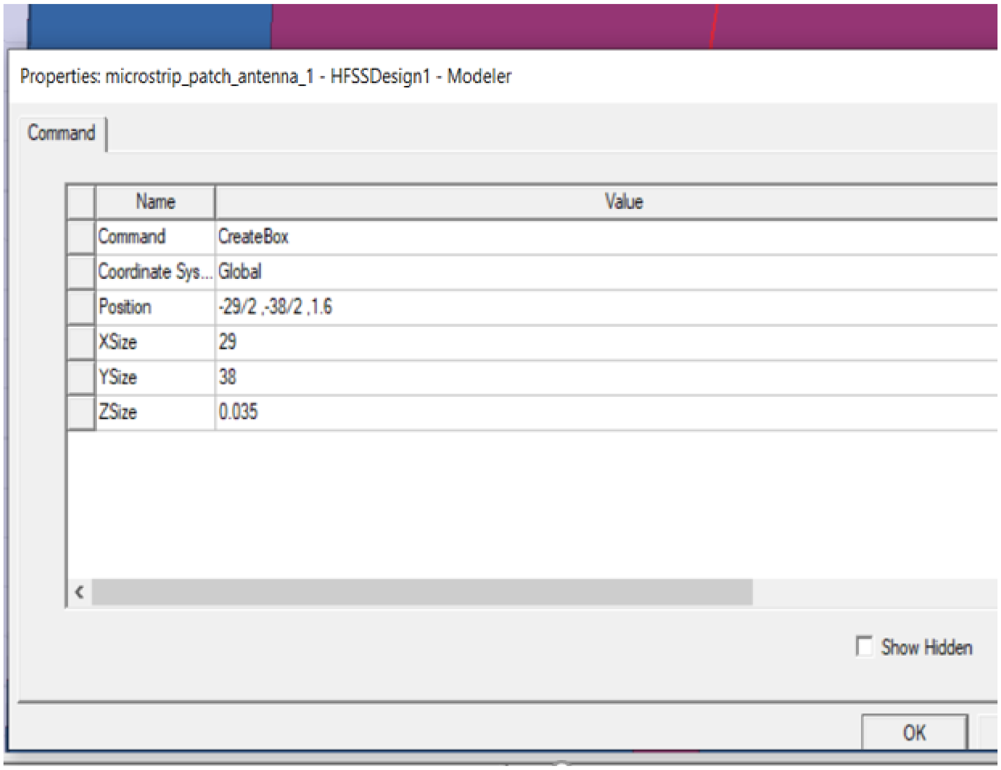
***<u>STEP 2:</u> Create a ground by selecting a Box from upper palate of 60x60x0.035 mm$^3$ , material is copper.***



Properties: microstrip_patch_antenna_1 - HFSSDesign1 - Modeler

| Name | Value | Unit | Evaluated Value | Description |
|---|---|---|---|---|
| Command | CreateBox | | | |
| Coordinate Sys... | Global | | | |
| Position | -30 ,-30 ,0 | mm | -30mm , -30mm ... | |
| XSize | 60 | mm | 60mm | |
| YSize | 60 | mm | 60mm | |
| ZSize | -0.035 | mm | -0.035mm | |

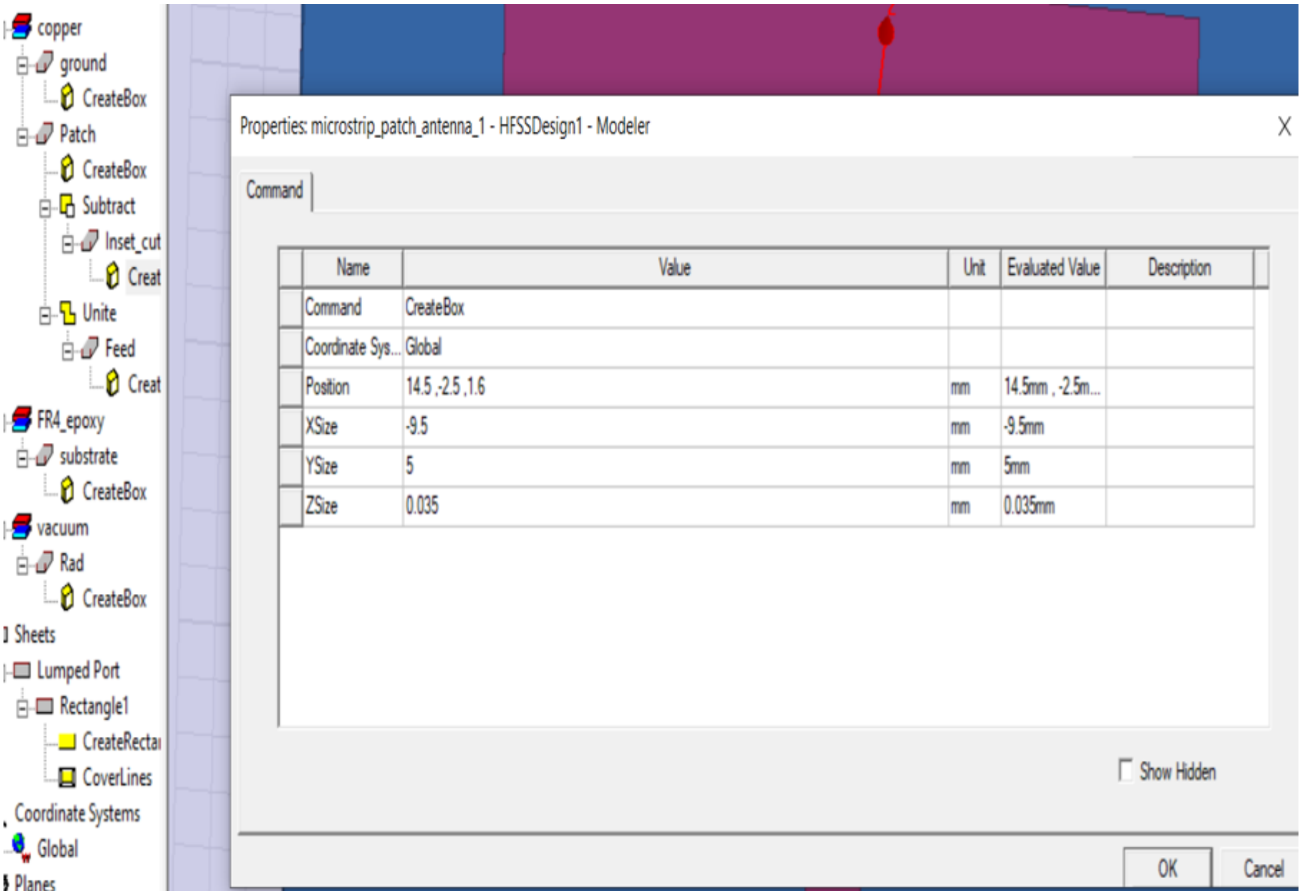
***<u>STEP-3:</u> For modelling of patch ,create a box by selecting a Box from upper palate of 29x38x0.035 mm$^3$ , material is copper.***



Properties: microstrip_patch_antenna_1 - HFSSDesign1 - Modeler

| Name | Value |
|---|---|
| Command | CreateBox |
| Coordinate Sys... | Global |
| Position | -29/2 ,-38/2 ,1.6 |
| XSize | 29 |
| YSize | 38 |
| ZSize | 0.035 |

***<u>STEP-4</u>: For Inset_cut, Create a box by selecting a Box from upper palate of 9.5x5x0.035 mm$^3$ of copper material.***

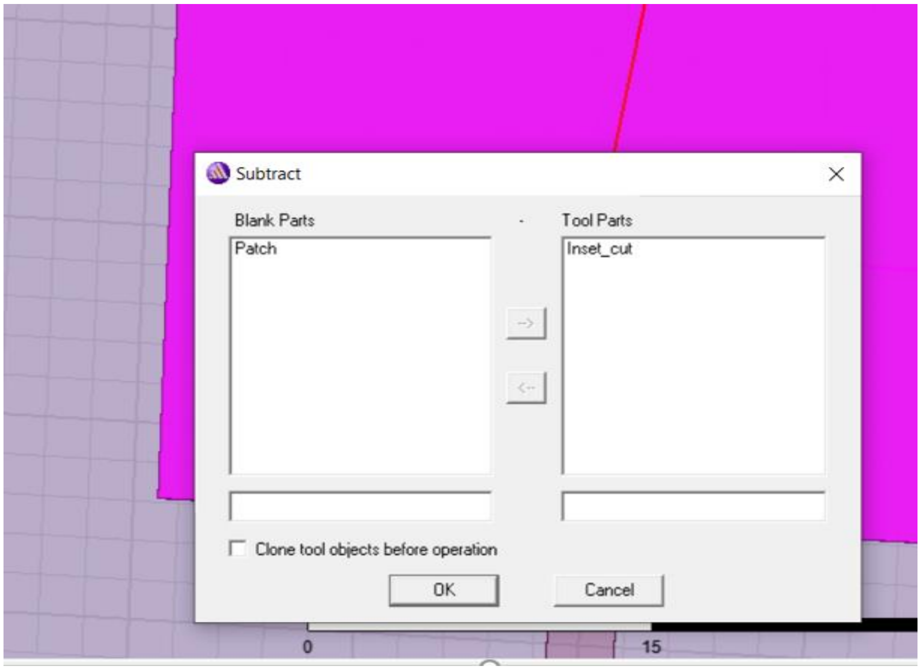


Properties: microstrip_patch_antenna_1 - HFSSDesign1 - Modeler

| Name | Value | Unit | Evaluated Value | Description |
|---|---|---|---|---|
| Command | CreateBox | | | |
| Coordinate Sys... | Global | | | |
| Position | 14.5 ,-2.5 ,1.6 | mm | 14.5mm , -2.5m... | |
| XSize | -9.5 | mm | -9.5mm | |
| YSize | 5 | mm | 5mm | |
| ZSize | 0.035 | mm | 0.035mm | |

☐ Show Hidden

**STEP-5: At last, Subtract Inset_cut box from Patch by selecting both the box.**

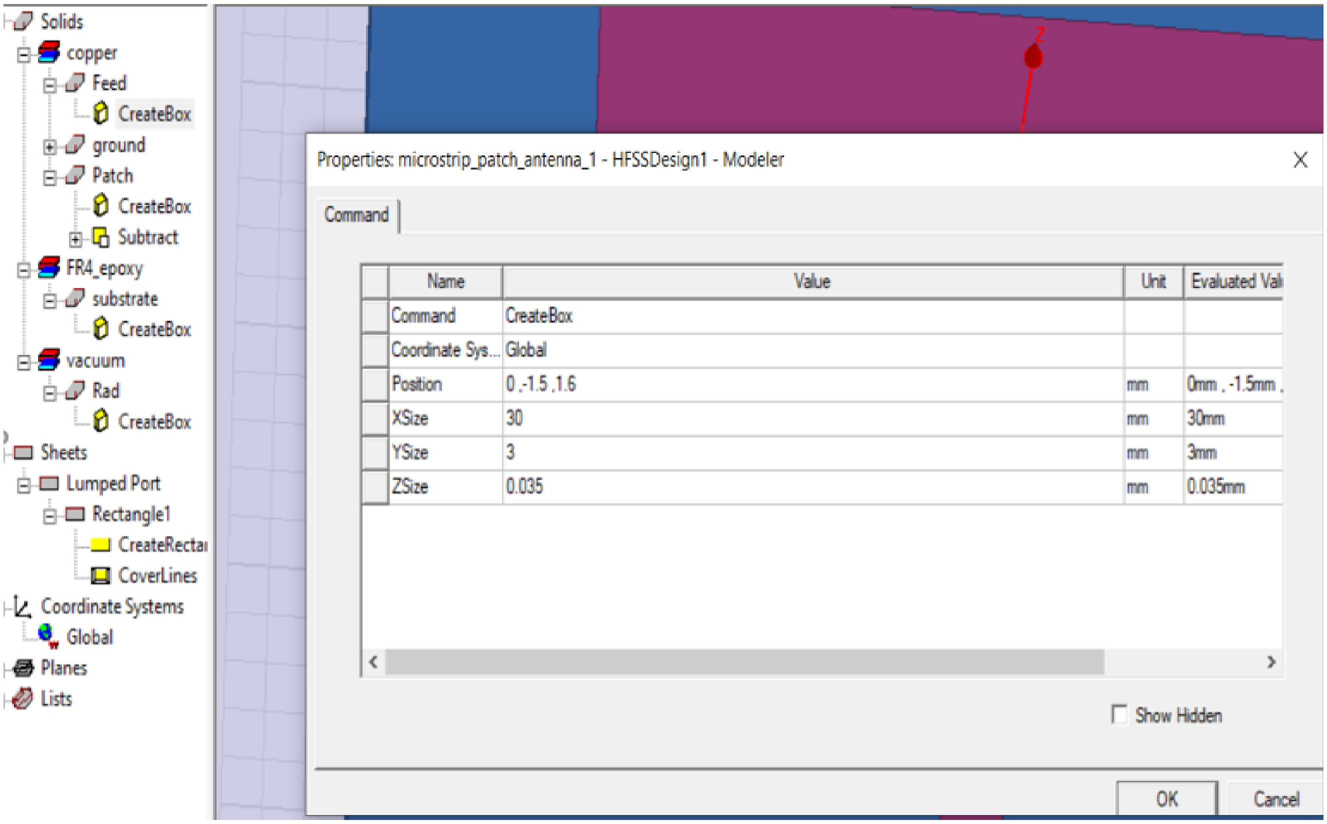


Blank Parts: Patch

Tool Parts: Inset_cut

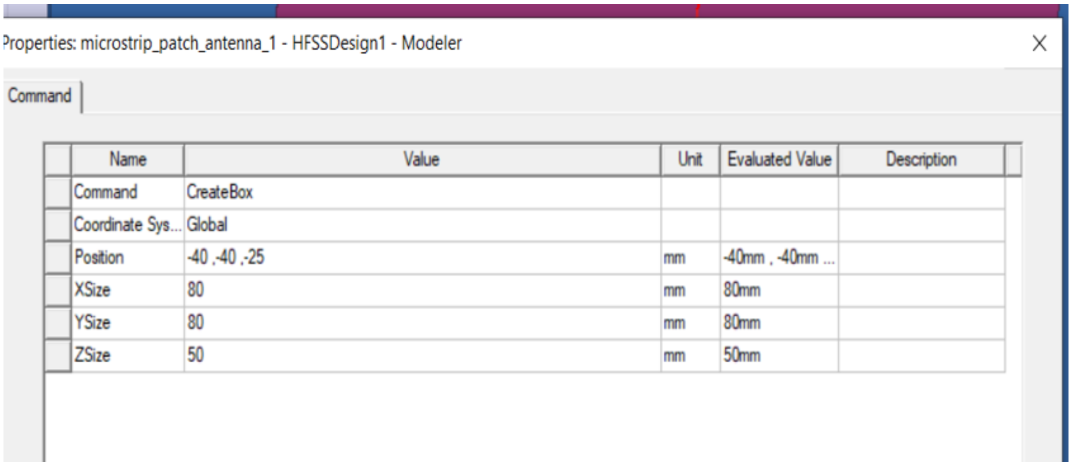
☐ Clone tool objects before operation

***STEP-6: For giving feed to patch we have to create a feedline by selecting a Box of 30x3x0.035 mm$^3$ at the feed point, of copper material. And unite it with the existing patch.***



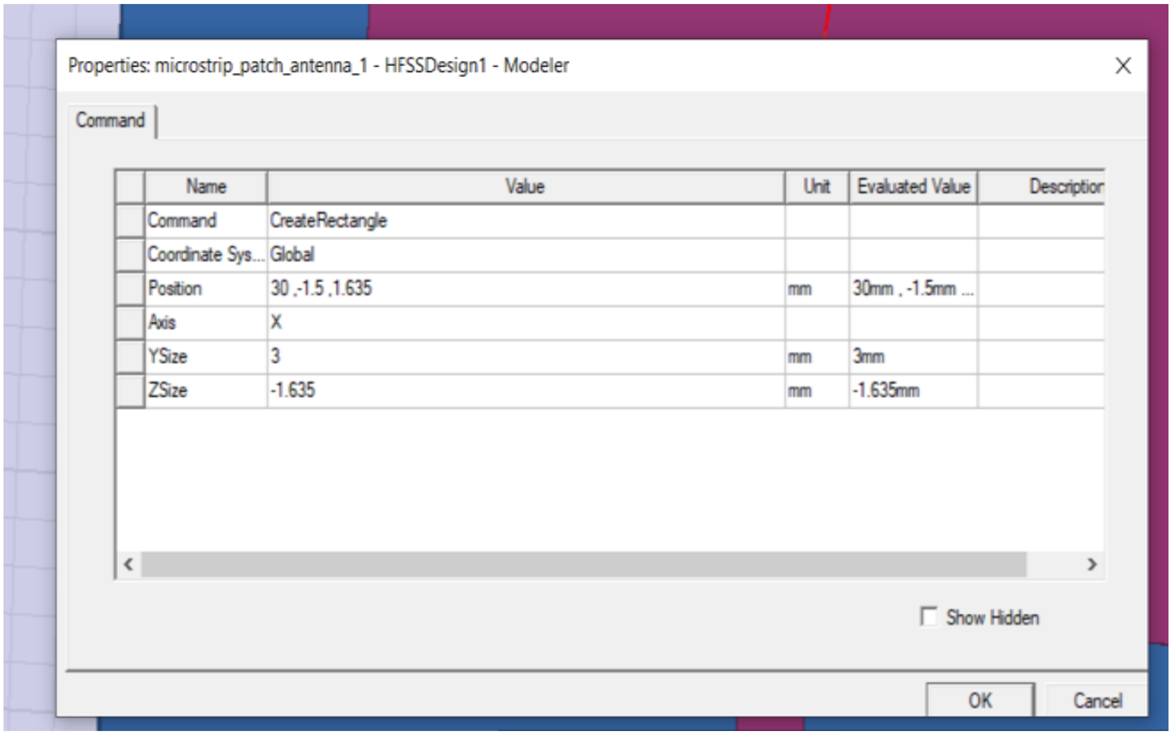
| Name | Value | Unit | Evaluated Val |
|---|---|---|---|
| Command | CreateBox | | |
| Coordinate Sys... | Global | | |
| Position | 0 ,-1.5 ,1.6 | mm | 0mm , -1.5mm , |
| XSize | 30 | mm | 30mm |
| YSize | 3 | mm | 3mm |
| ZSize | 0.035 | mm | 0.035mm |

***STEP-7:*** ***For assigning the radiation boundary. Change the drawing plane to XY, Create a Radiation box by selecting a box of 80x80x50 mm$^3$ , and assign boundary radiation.***



| Name | Value | Unit | Evaluated Value | Description |
|---|---|---|---|---|
| Command | CreateBox | | | |
| Coordinate Sys... | Global | | | |
| Position | -40 ,-40 ,-25 | mm | -40mm , -40mm ... | |
| XSize | 80 | mm | 80mm | |
| YSize | 80 | mm | 80mm | |
| ZSize | 50 | mm | 50mm | |

***STEP-8:*** ***For assigning Excitation. Change the drawing plane to YZ. A rectangular sheet has been created at the feed end, and assign the lumped excitation properly.***

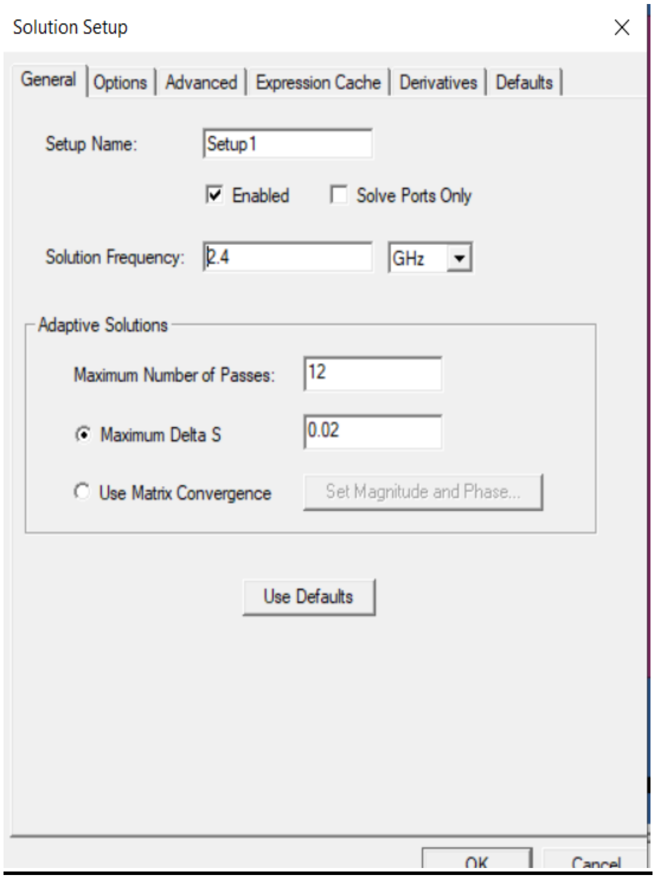


Properties: microstrip_patch_antenna_1 - HFSSDesign1 - Modeler

| Name | Value | Unit | Evaluated Value | Descriptior |
|---|---|---|---|---|
| Command | CreateRectangle | | | |
| Coordinate Sys... | Global | | | |
| Position | 30 ,-1.5 ,1.635 | mm | 30mm , -1.5mm ... | |
| Axis | X | | | |
| YSize | 3 | mm | 3mm | |
| ZSize | -1.635 | mm | -1.635mm | |

☐ Show Hidden

***STEP-9: Complete the solution setup by assigning solution setup and solution frequency as 2.4 GHz.***



Solution Setup

Setup Name: Setup1

☑ Enabled ☐ Solve Ports Only

Solution Frequency: 2.4 GHz

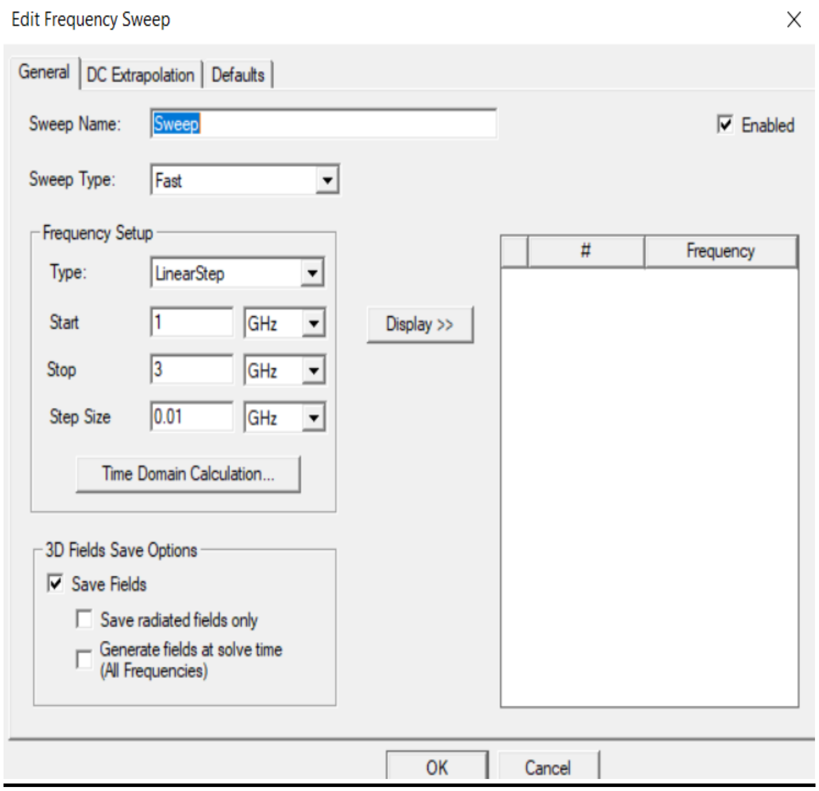
Adaptive Solutions

Maximum Number of Passes: 12

● Maximum Delta S 0.02

○ Use Matrix Convergence

## ***STEP-10**: Add frequency sweep.*



Edit Frequency Sweep

Sweep Name: Sweep

☑ Enabled

Sweep Type: Fast

Frequency Setup

Type: LinearStep

Start 1 GHz

Stop 3 GHz

Step Size 0.01 GHz

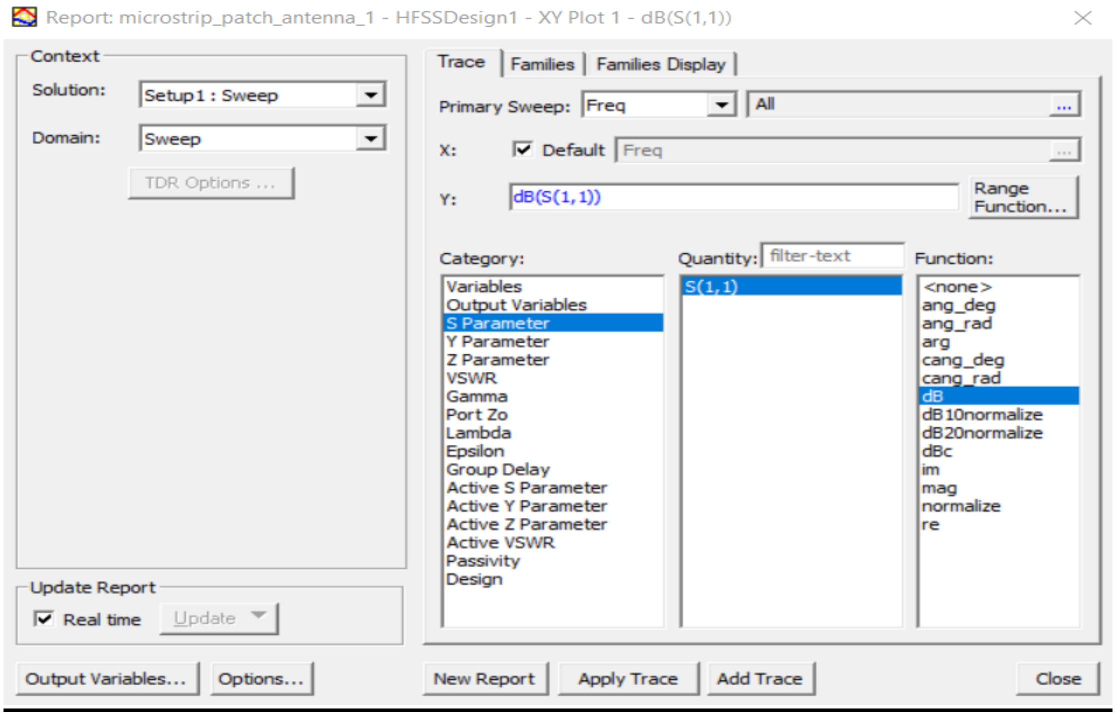
3D Fields Save Options

☑ Save Fields

☐ Save radiated fields only

☐ Generate fields at solve time (All Frequencies)

## ***STEP-11**: Validate the structure and analyse all. For results, go to results section and choose rectangular plot .*



Report: microstrip_patch_antenna_1 - HFSSDesign1 - XY Plot 1 - dB(S(1,1))

Context

Solution: Setup1 : Sweep

Domain: Sweep

Primary Sweep: Freq All

X: ☑ Default Freq

Y: dB(S(1,1))

Category: S Parameter

Quantity: S(1,1)

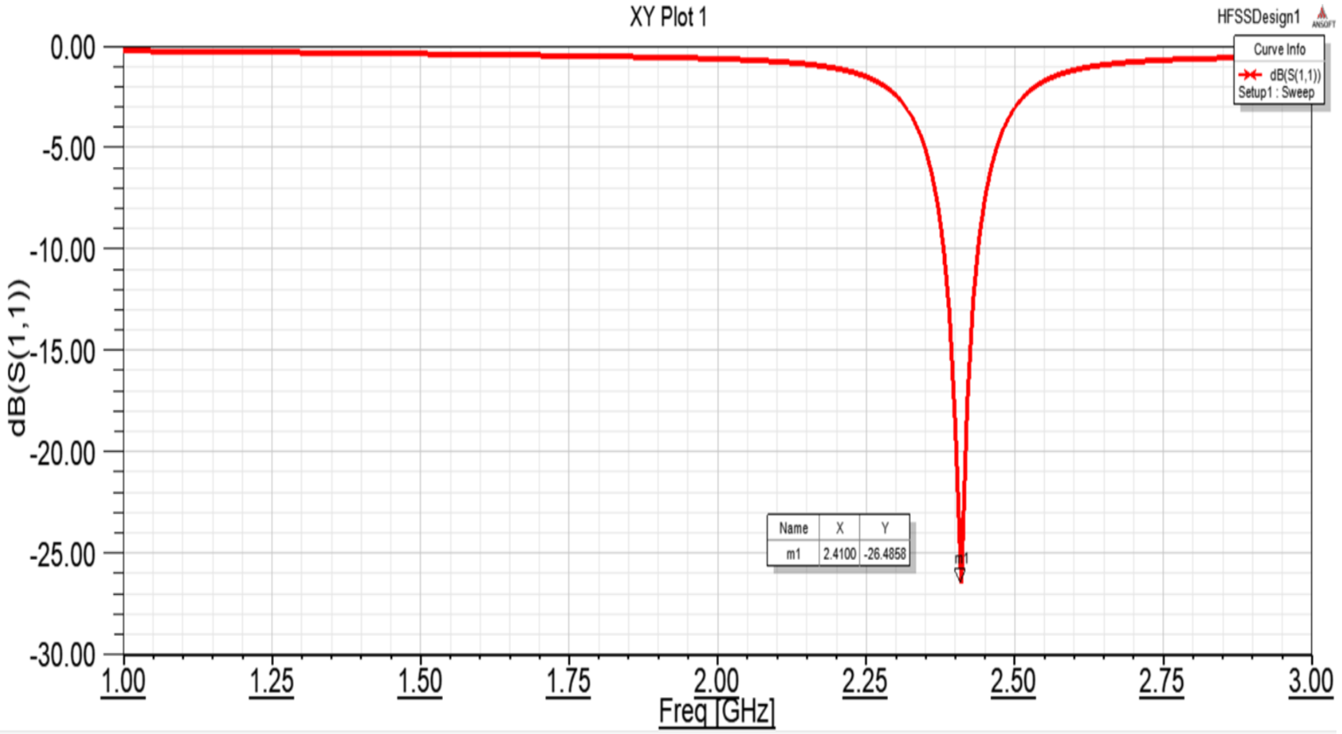
Function: dB

Update Report

☑ Real time

## RESULTS & DISCUSSION:

### ☐ S- Parameter:



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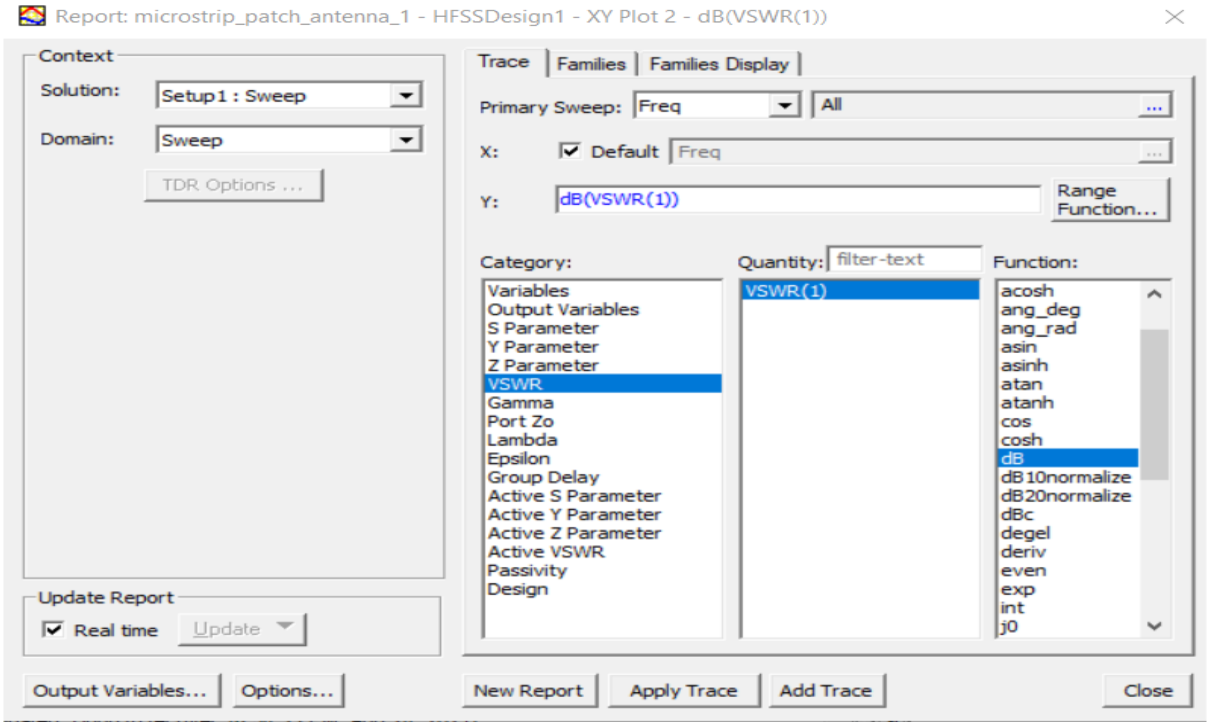
**STEP-12**: ***Validate the structure and analyse all. For VSWR result, go to result section and choose rectangular plot.***


Report: microstrip_patch_antenna_1 - HFSSDesign1 - XY Plot 2 - dB(VSWR(1))

Context

Solution: Setup1 : Sweep

Domain: Sweep

Primary Sweep: Freq | All

X: ☑ Default | Freq

Y: dB(VSWR(1))

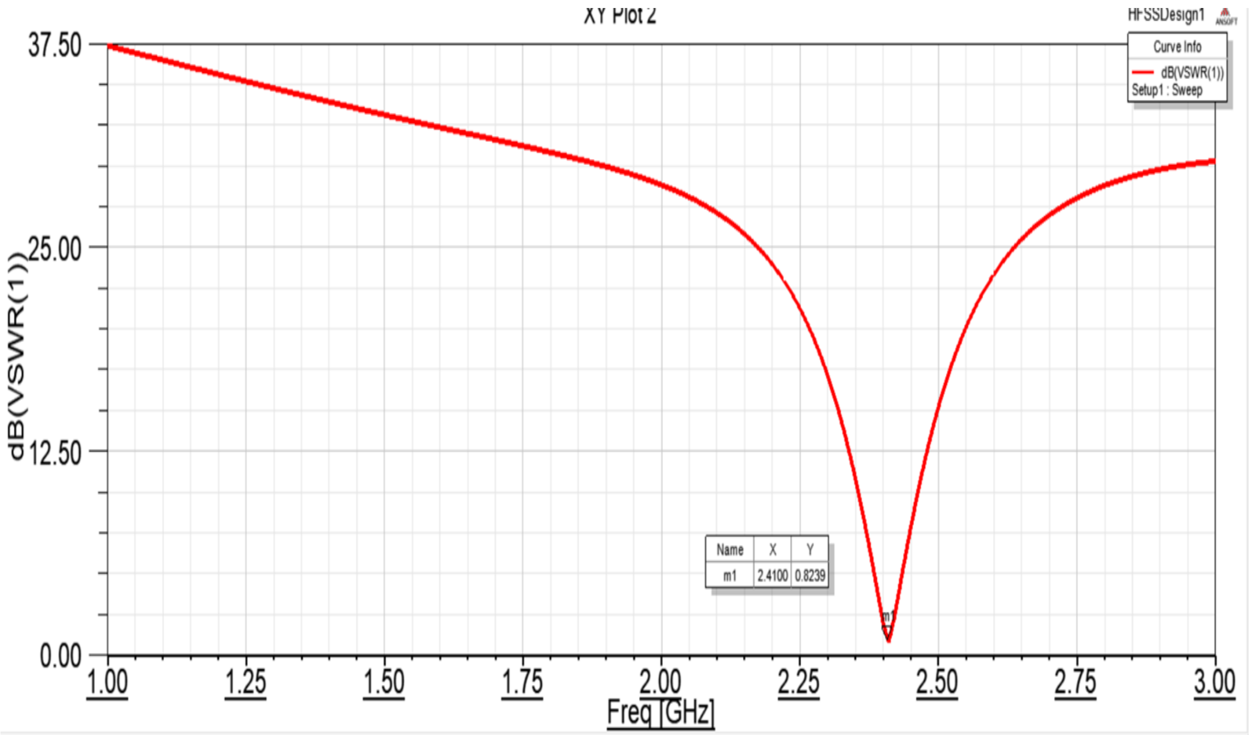
Category: VSWR

Quantity: VSWR(1)

Function: dB

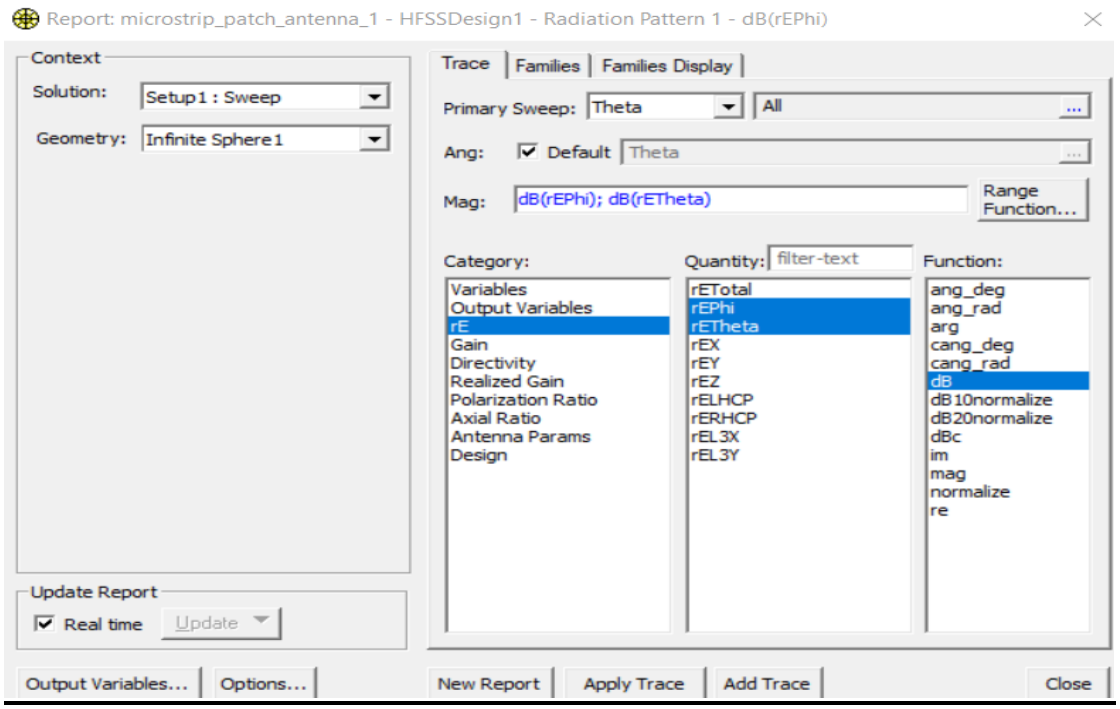
Update Report: ☑ Real time

### ❑ VSWR- Parameter:



### ❑ 2D- Radiation Pattern:

***STEP-13_1: Define the infinite sphere. Assign proper trace. From the results section in the create farfield report. Rectangular plot***



Report: microstrip_patch_antenna_1 - HFSSDesign1 - Radiation Pattern 1 - dB(rEPhi)

Solution: Setup1 : Sweep

Geometry: Infinite Sphere1

Primary Sweep: Theta All

Ang: ☑ Default Theta

Mag: dB(rEPhi); dB(rETheta)

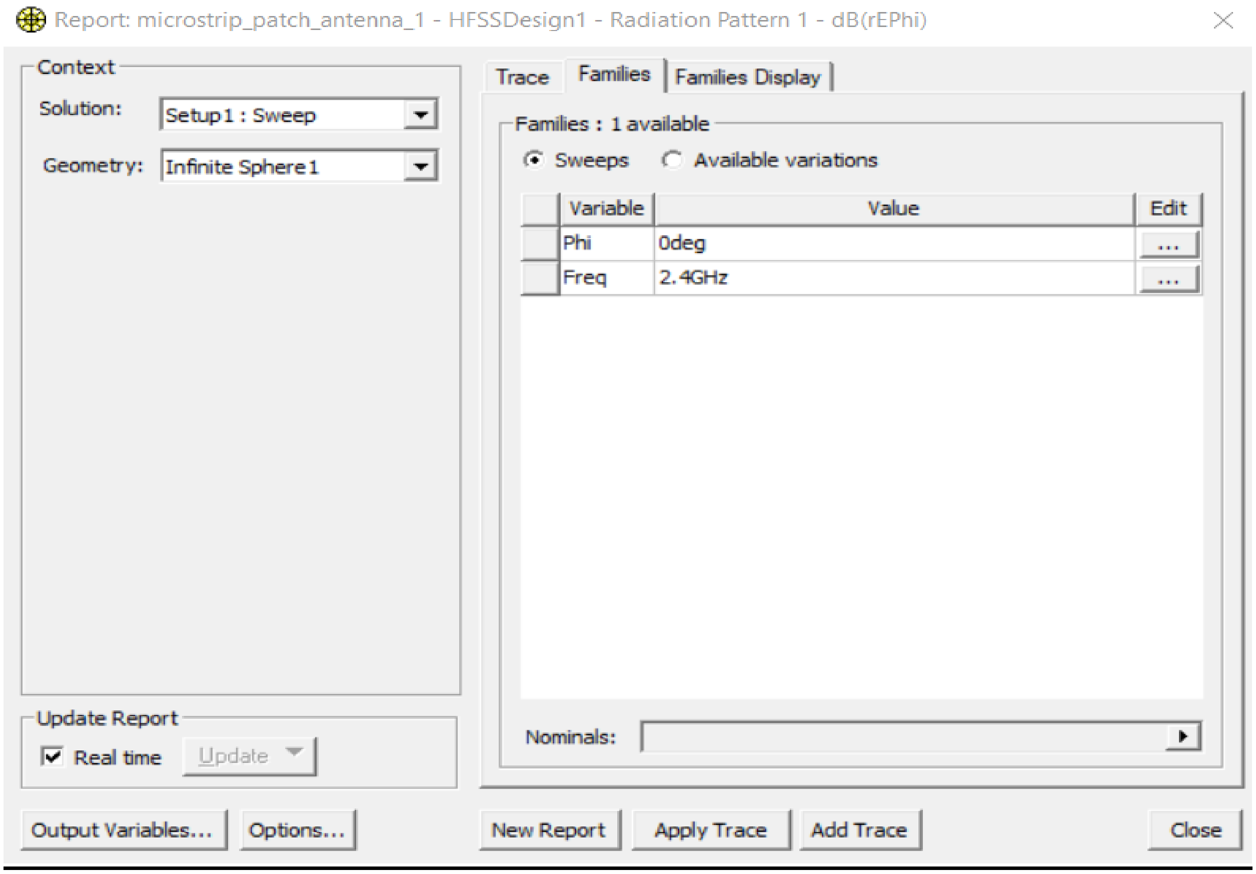
Category: rE

Quantity: rEPhi, rETheta

Function: dB

Update Report: ☑ Real time

***STEP-13_2**: Change in Families*



Report: microstrip_patch_antenna_1 - HFSSDesign1 - Radiation Pattern 1 - dB(rEPhi)

Context

Solution: Setup1 : Sweep

Geometry: Infinite Sphere1

Families : 1 available

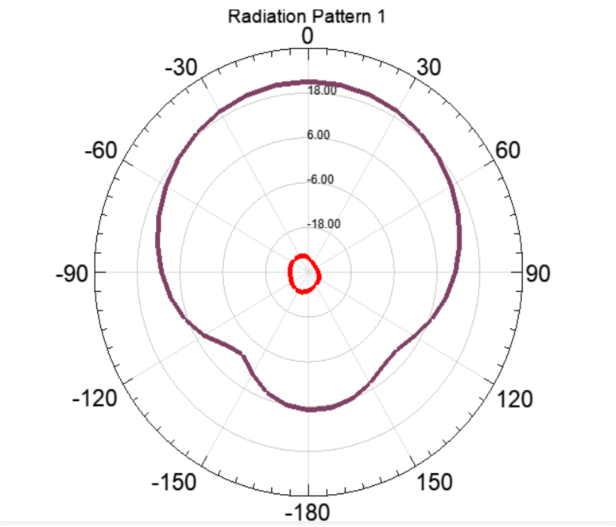
● Sweeps ○ Available variations

| Variable | Value | Edit |
|---|---|---|
| Phi | 0deg | ... |
| Freq | 2.4GHz | ... |

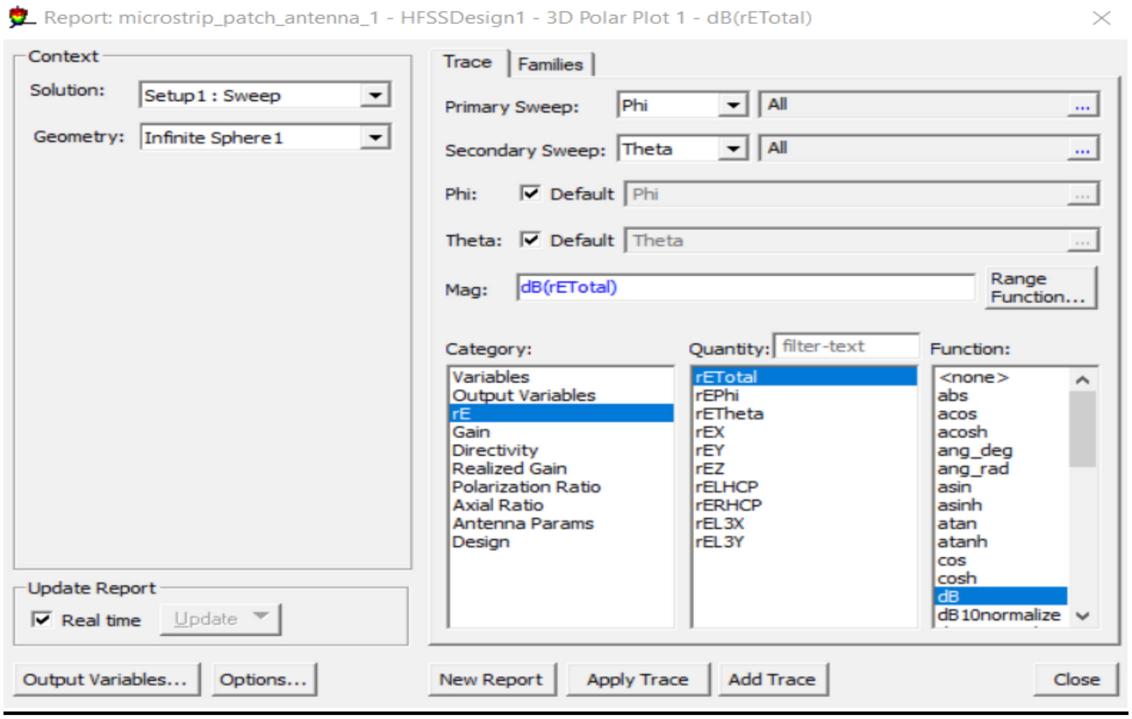
Nominals:

Update Report

☑ Real time



***STEP-14**: 3D- Polar plot setting. From the results section in the create far field report. 3D polar plot.*



Report: microstrip_patch_antenna_1 - HFSSDesign1 - 3D Polar Plot 1 - dB(rETotal)

Context

Solution: Setup1 : Sweep

Geometry: Infinite Sphere1

Trace | Families

Primary Sweep: Phi — All

Secondary Sweep: Theta — All

Phi: ☑ Default — Phi

Theta: ☑ Default — Theta

Mag: dB(rETotal)

Range Function...

Category:
- Variables
- Output Variables
- rE
- Gain
- Directivity
- Realized Gain
- Polarization Ratio
- Axial Ratio
- Antenna Params
- Design

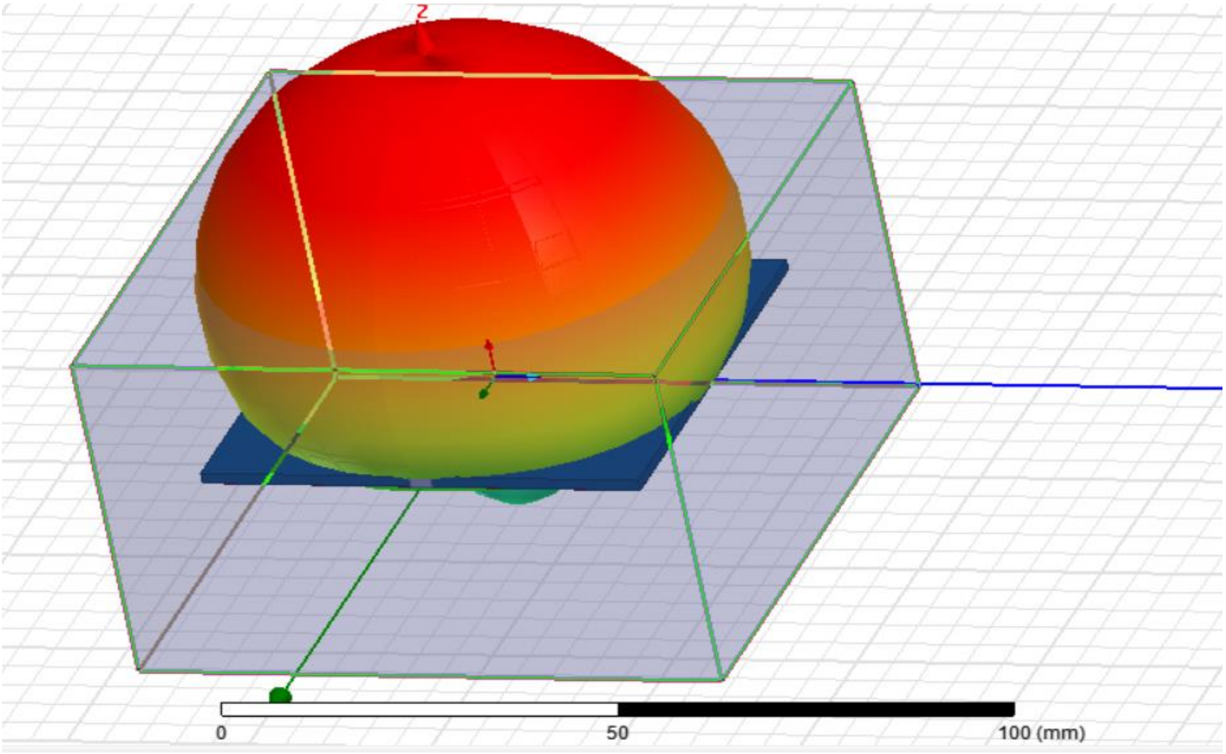
Quantity: filter-text
- rETotal
- rEPhi
- rETheta
- rEX
- rEY
- rEZ
- rELHCP
- rERHCP
- rEL3X
- rEL3Y

Function:
- <none>
- abs
- acos
- acosh
- ang_deg
- ang_rad
- asin
- asinh
- atan
- atanh
- cos
- cosh
- dB
- dB10normalize

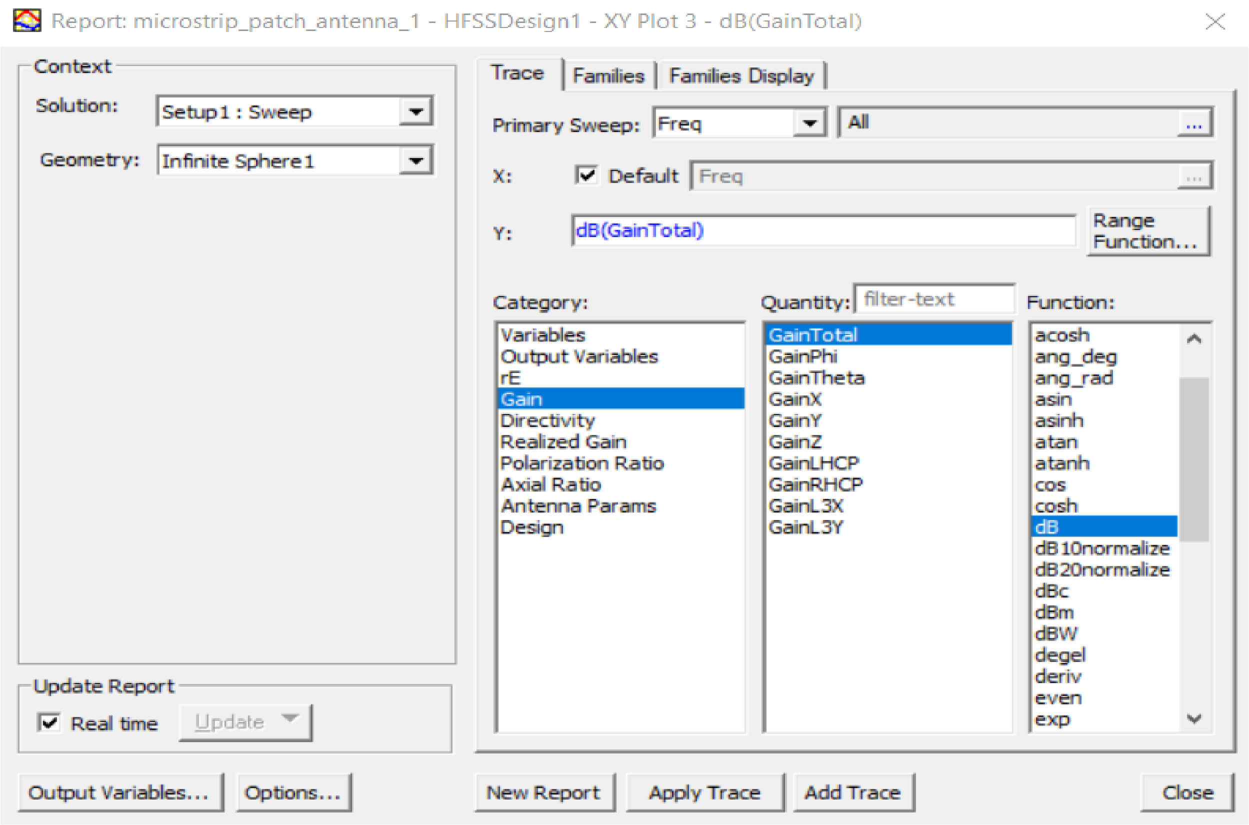
Update Report

☑ Real time — Update

- ☐ **3D Polar Plot:**



***STEP-15_1:*** ***Gain plot setting. Assign in Trace. From the results section in the create farfield report. Rectangular plot***



Report: microstrip_patch_antenna_1 - HFSSDesign1 - XY Plot 3 - dB(GainTotal)

Context

Solution: Setup1 : Sweep

Geometry: Infinite Sphere1

Trace

Primary Sweep: Freq | All

X: ☑ Default | Freq

Y: dB(GainTotal)

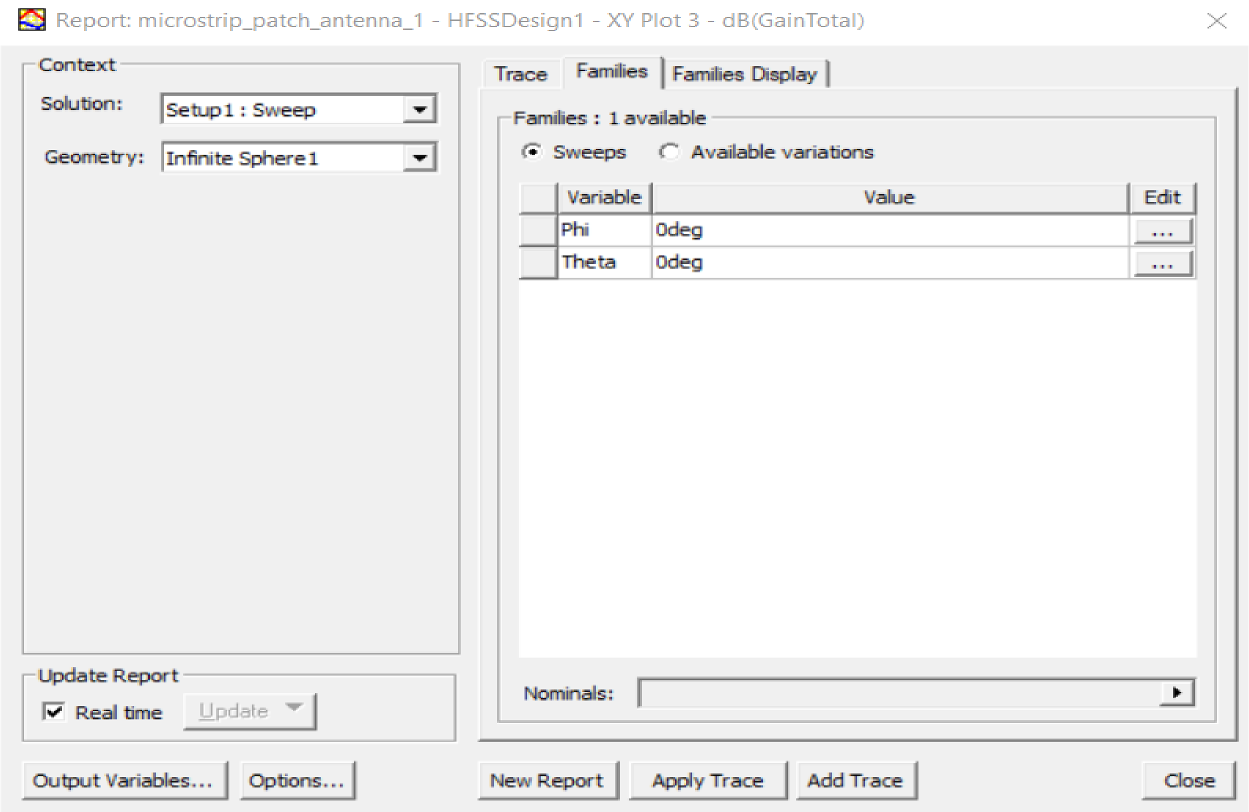
Category: Gain

Quantity: GainTotal

Function: dB

Update Report: ☑ Real time

## ***STEP-15_2:*** *Assign in Families*



Report: microstrip_patch_antenna_1 - HFSSDesign1 - XY Plot 3 - dB(GainTotal)

Context

Solution: Setup1 : Sweep

Geometry: Infinite Sphere1

Families : 1 available

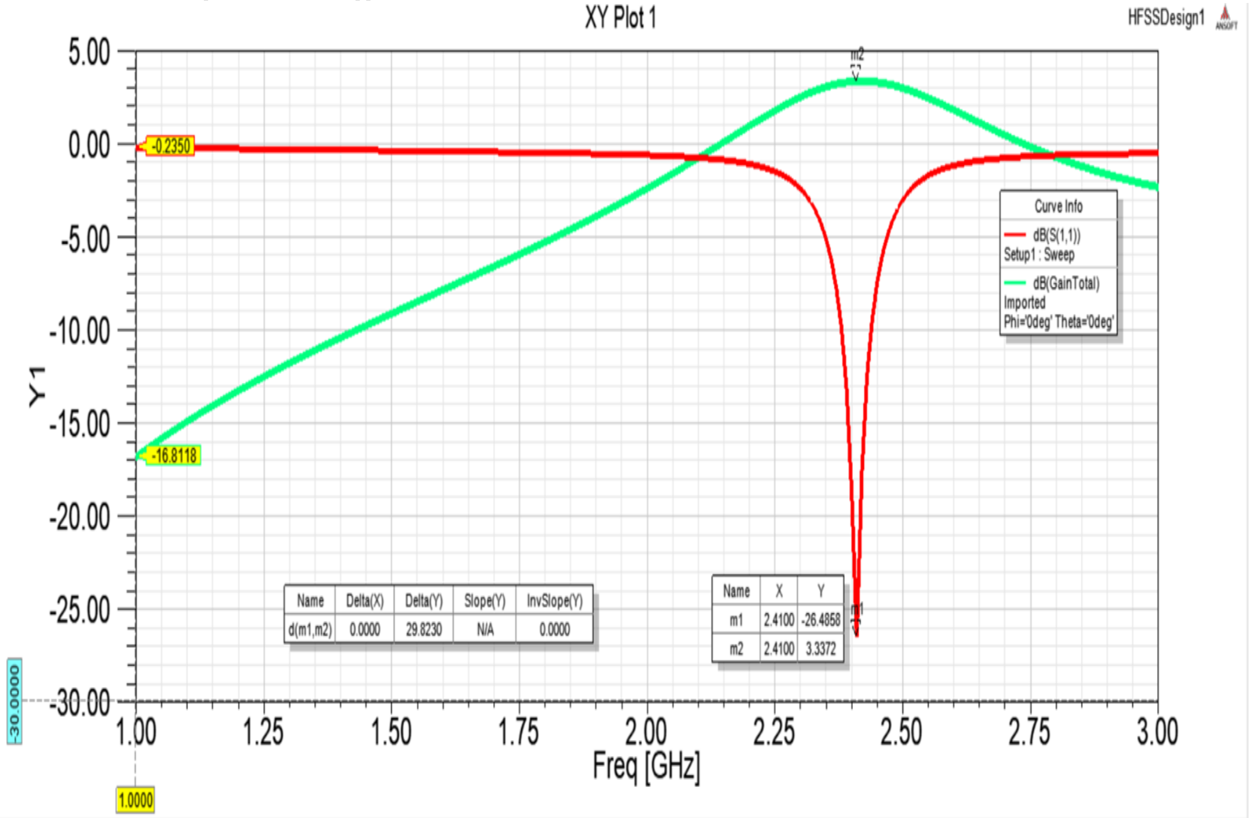
● Sweeps ○ Available variations

| Variable | Value | Edit |
|---|---|---|
| Phi | 0deg | ... |
| Theta | 0deg | ... |

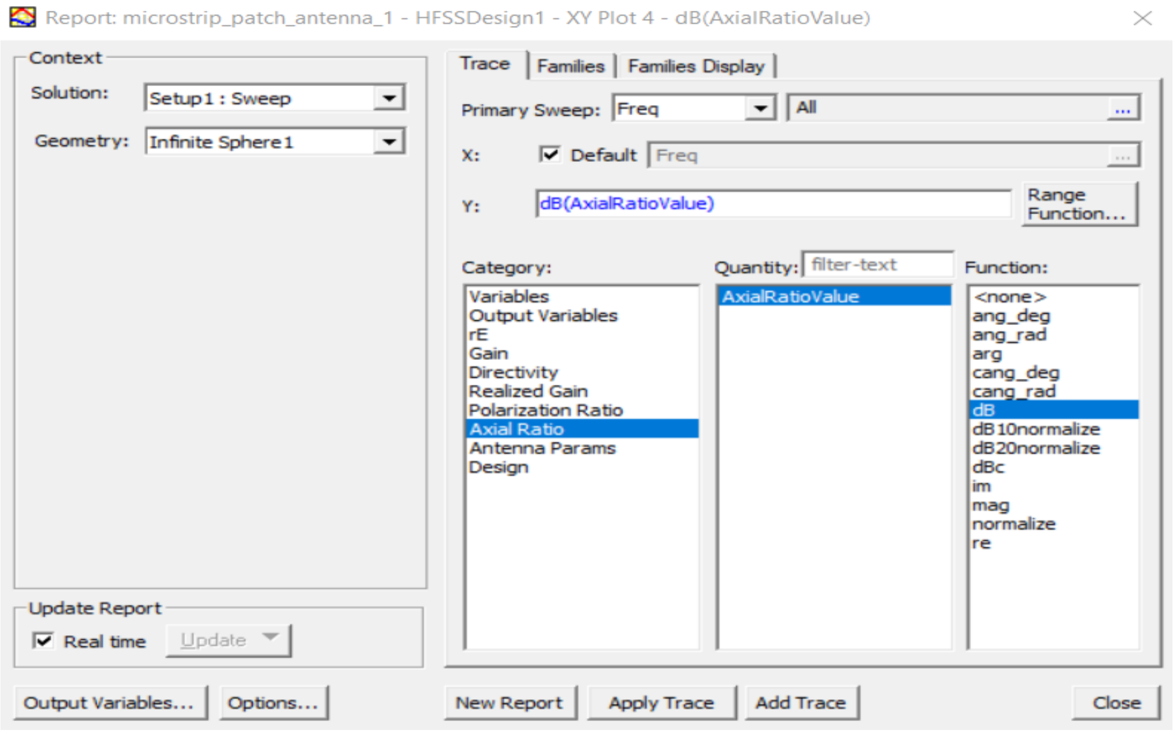
Nominals:

Update Report: ☑ Real time

- ❑ ***Gain Plot & Reflection coefficient***



***<u>STEP-16_1:</u> Assign in Traces. From the results section in the create farfield report. Rectangular plot.***



Report: microstrip_patch_antenna_1 - HFSSDesign1 - XY Plot 4 - dB(AxialRatioValue)

Context

Solution: Setup1 : Sweep

Geometry: Infinite Sphere1

Primary Sweep: Freq | All

X: ☑ Default Freq

Y: dB(AxialRatioValue)

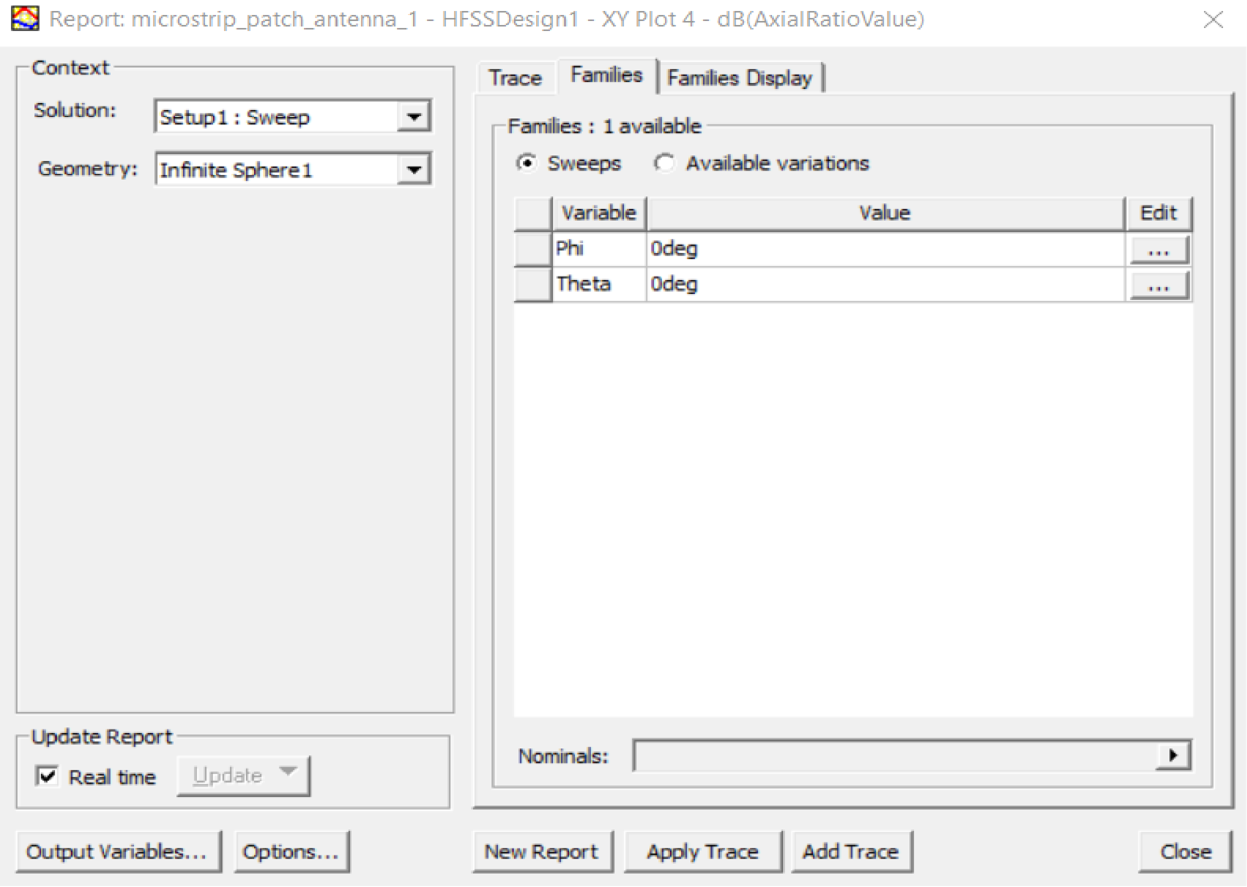
Category: Axial Ratio

Quantity: AxialRatioValue

Function: dB

Update Report: ☑ Real time

## ***<u>Step-16_2</u>: Assign in Families.***



Report: microstrip_patch_antenna_1 - HFSSDesign1 - XY Plot 4 - dB(AxialRatioValue)

Context

Solution: Setup1 : Sweep

Geometry: Infinite Sphere1

Families : 1 available

● Sweeps ○ Available variations

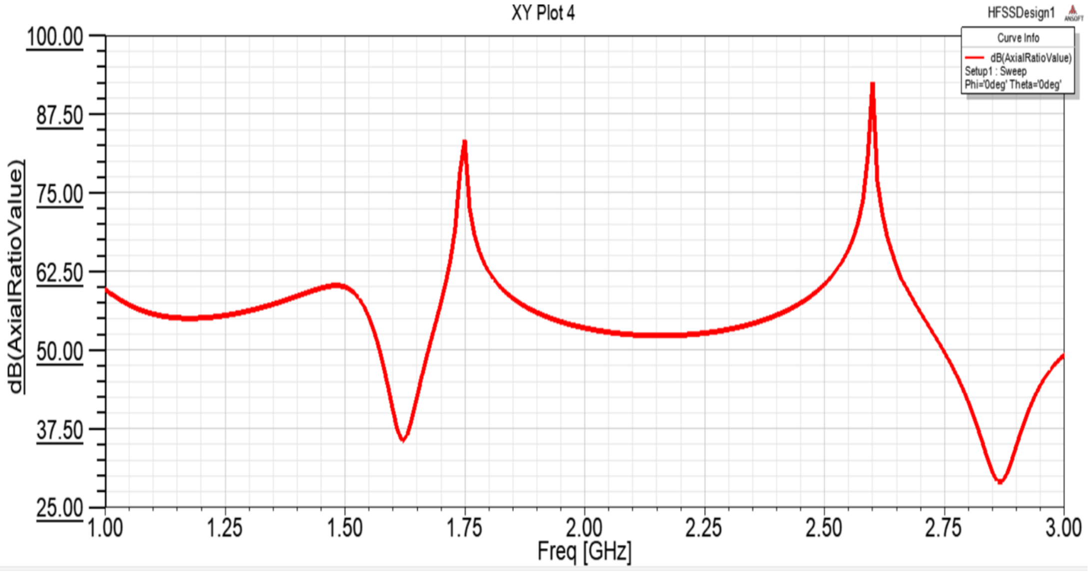
| Variable | Value | Edit |
|---|---|---|
| Phi | 0deg | ... |
| Theta | 0deg | ... |

Nominals:

Update Report

☑ Real time

- ***Axial Ratio***



## PRECAUTIONS:

1. Save the HFSS file before designing the antenna.
2. Define infinite sphere and simulate again for far-field results.
3. Choose the radiation box at least quarter wavelength from each side of the antenna geometry.

## DESIGN TASKS:

1. Microstrip patch antenna design at 400 MHz with 20% IBW.

2. Microstrip patch antenna design at 900 MHz with 20% IBW.

3. Microstrip patch antenna design at 1800 MHz with 20% IBW.

4. Microstrip patch antenna design at 3 GHz with 20% IBW.

# Experiment no: 4

## Objective: Design and analysis of a 2x2 antenna array using HFSS simulation software for 3.5 GHz

**Software used:** Ansys HFSS EM software

## Theory:

In the present world of communication, an antenna is one of the critical parts. An antenna is a resonating structure, radiating electromagnetic field waves in free space. Antenna shows a property known as reciprocity, which implies that it can be transmitting or receiving. Antennas are utilized as a part of any communication frameworks, Viz., wireless LAN, space investigation, and radar, etc. Antennas usually work in air or outer space, but can also be operated underwater or even through soil and rock at specific frequencies for short separations.

Military applications, Radar applications, Satellite applications, and Airborne applications need a high gain antenna in the field. Antenna gain is the ability to focus radiation from an antenna. So, for high gain application, we need an antenna with higher gain, higher directivity, relatively lesser half-power beamwidth (HPBW). As we know, for a single antenna element, the radiation pattern is relatively broad, and each element provides low values of directivity (gain). So, for high gain, either we have to enlarge the dimensions of the single element, often leads to more directive characteristics with the drawback of higher fabrication cost, impractical size, weight, and it requires more power to operate. Another way to enlarge the dimensions of the antenna, without necessarily increasing the size of the individual element, is to form an assembly of radiating elements in an electrical and geometrical configuration. This new antenna, formed by multi-elements, is referred to as an array. The signals from the antennas are combined or processed in order to achieve improved performance over that of a single antenna. Such as, Side lobe level, Beam width, Directivity & Gain etc.

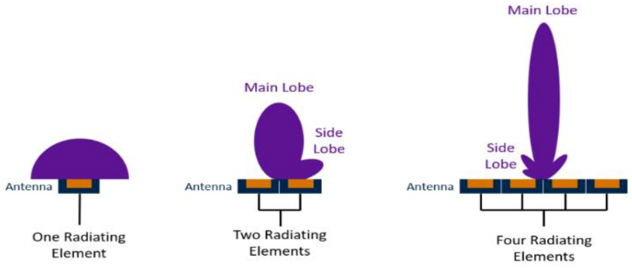


Fig. 1. Antenna array evolution from single element to array

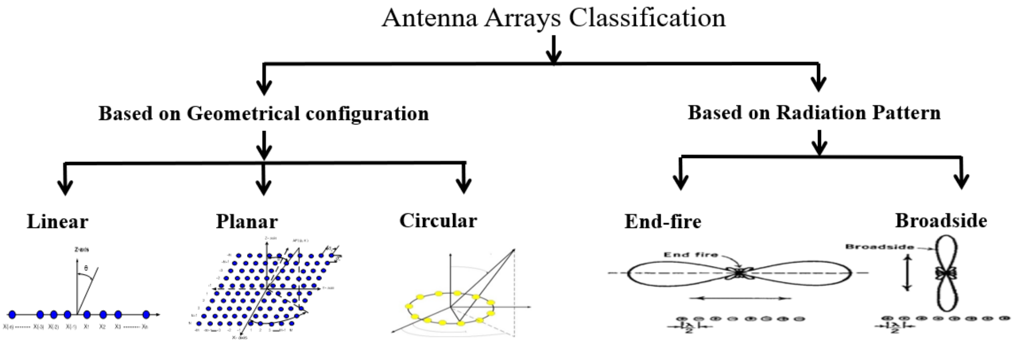


Fig. 2. Antenna array classification

NOTE:

- Radiation characteristics of antenna array is dependent on excitation coefficients and spacing of individual elements in the array
- Uniformly spaced arrays with spacing λg/2 give a SLL of -13.26 dB. Where, λg is the guided wavelength.

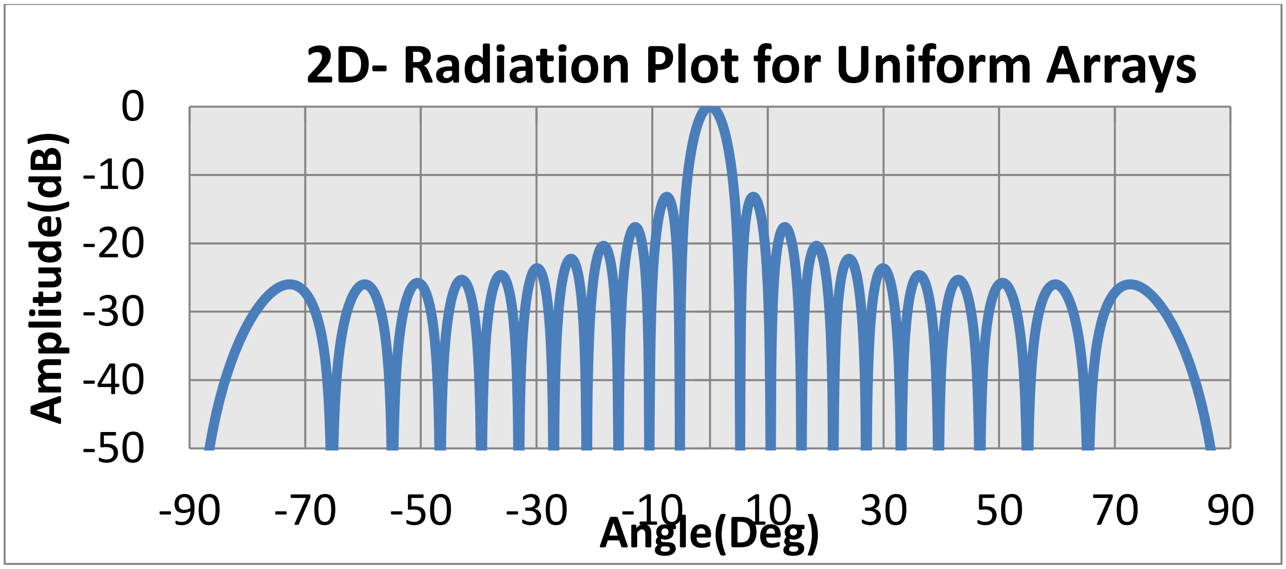


Fig. 3. 2D radiation plot of uniform array

The electric field strength is given by

$$E(\theta) = E(element).AF(\theta)$$

where $E(\theta)$=Total radiated field, $E(element)$= Radiation pattern of antenna element, $AF(\theta) =$ Array Factor

Variation for spacing has exponential effect on the Array Factor, i.e.,

$$AF(\theta) = \sum\nolimits_{n=1}^{N} A_n \exp[\,j\,(k \sum_{i=1}^{n} d_i \cos(\theta) + \varphi_n)]$$

Where,

$$k = \frac{2\pi}{\lambda}$$

$\lambda$ is free space wavelength

$\theta$ is angle of incident wave with respect to x axis

$d_i$ is the inter element spacing between (i-1)$^{th}$ and the i$^{th}$ elements

$A_n$ is the amplitude of the n$^{th}$ element

$\varphi_n$ is the phase of the nth element

**Design of a simple T- Junction Power Divider at 3.5 GHz:**

1. Selected an appropriate substrate of thickness (h) and dielectric constant ($\varepsilon_r$ ) for the design of the power divider.
2. Calculate the wavelength $\lambda_g$ from the given frequency specifications as follows: $\lambda_g = \frac{c}{\sqrt{\varepsilon_r * f}}$

   Where, c is the velocity of light in air.

   $f$ is the frequency of operation of the coupler.

   $\varepsilon_r$is the dielectric constant of the substrate.

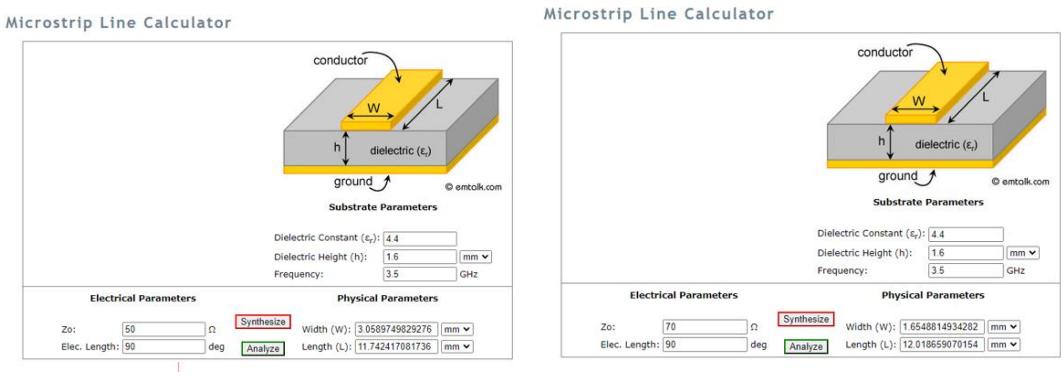
3. Synthesize the physical parameters (length & width) for the λ/4 lines with impedances of $Z_0$ and √2 $Z_0$ ($Z_0$ is the characteristic impedance of microstrip line which is = 50 Ω).

4. Calculate the physical parameters of the T-Junction power divider from the electrical parameters like $Z_0$ and electrical length using the above given design procedure.

## ○ SIMULATION (ANSYS HFSS):

### ➢ Power Divider Simulation at 3.5 GHz

First of all, we have to calculate the dimensions of the 50 Ohm and 70.7 Ohm microstrip line width lengths. Use online microstrip line calculator for the calculation.


Microstrip Line Calculator

Substrate Parameters
Dielectric Constant (εr): 4.4
Dielectric Height (h): 1.6 mm
Frequency: 3.5 GHz

Electrical Parameters
Zo: 50 Ω
Elec. Length: 90 deg

Physical Parameters
Width (W): 3.0589749829276 mm
Length (L): 11.742417081736 mm

Microstrip Line Calculator

Substrate Parameters
Dielectric Constant (εr): 4.4
Dielectric Height (h): 1.6 mm
Frequency: 3.5 GHz

Electrical Parameters
Zo: 70 Ω
Elec. Length: 90 deg

Physical Parameters
Width (W): 1.6548814934282 mm
Length (L): 12.018659070154 mm

Fig. 4. Microstrip Line calculator

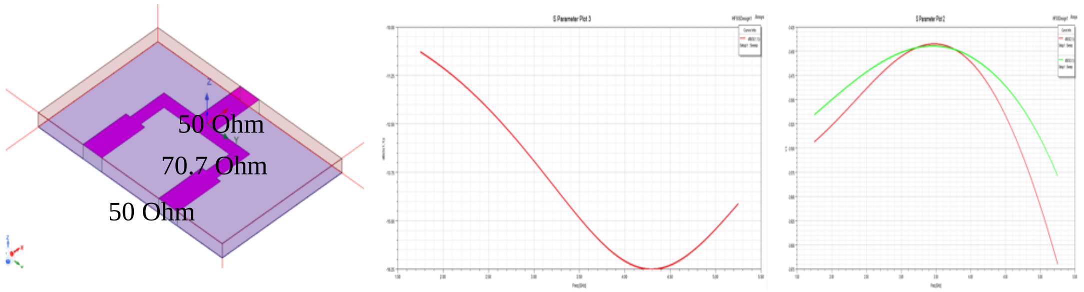
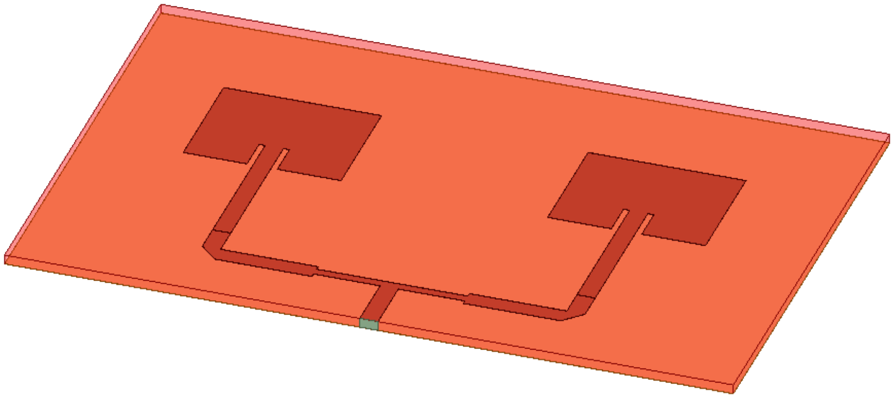


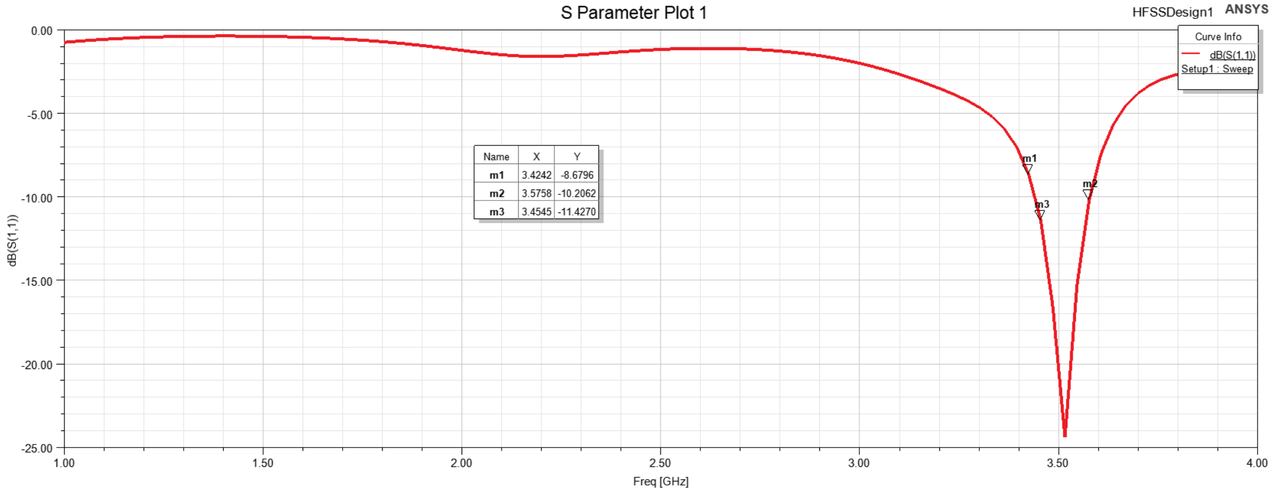
Fig. 5. 2-way Power divider HFSS structure, reflection coefficient and transmission parameter

### ➢ 1x2 Antenna Array Simulation at 3.5 GHz



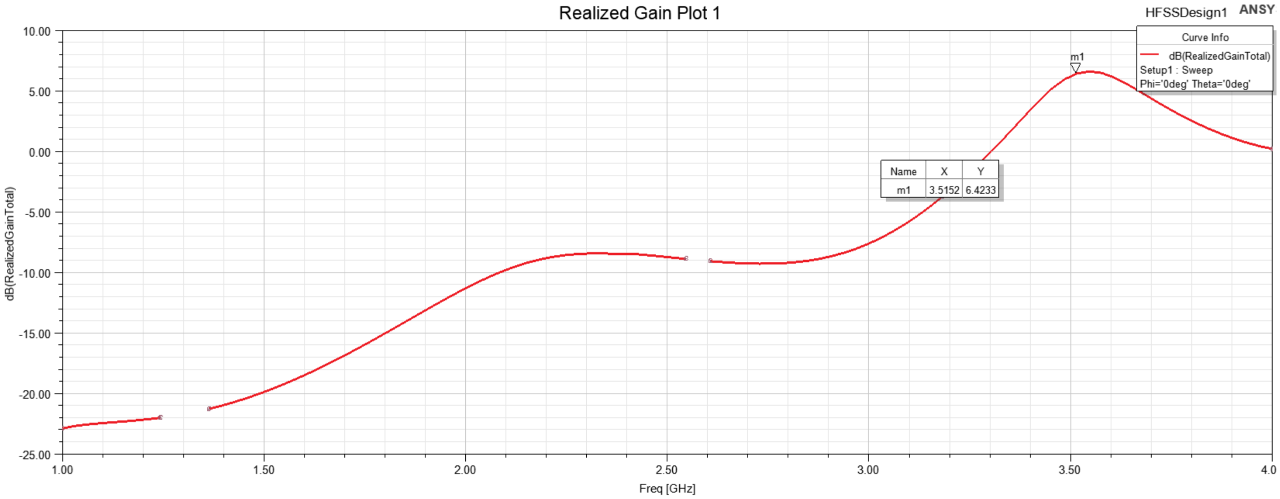
- Results for 1x2 Antenna Array

- S-Parameter:



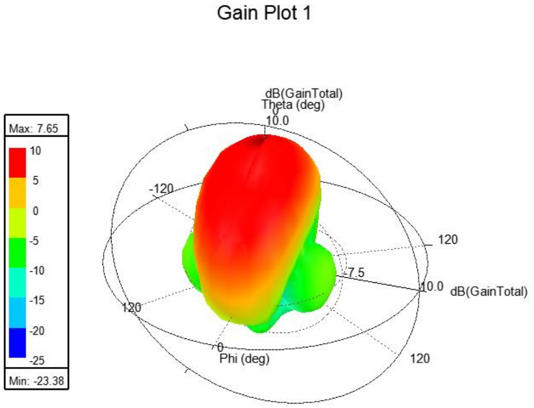
| Name | X | Y |
|---|---|---|
| m1 | 3.4242 | -8.6796 |
| m2 | 3.5758 | -10.2062 |
| m3 | 3.4545 | -11.4270 |

- Realized Gain:

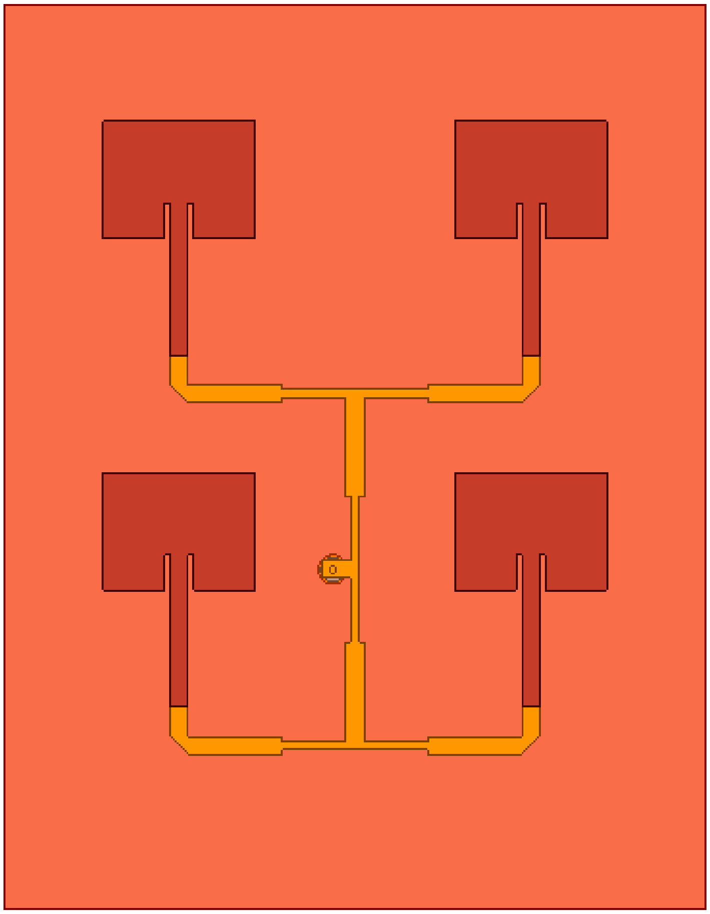


| Name | X | Y |
|---|---|---|
| m1 | 3.5152 | 6.4233 |

- 3D-Polar Plot:

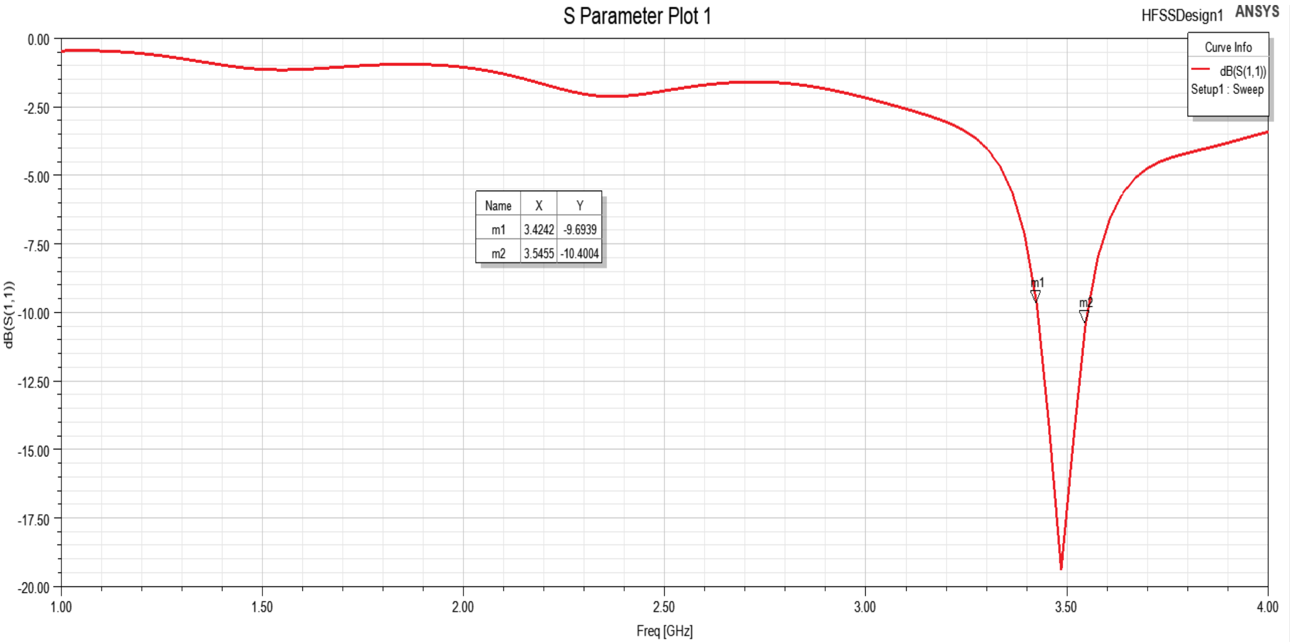


- **Final 2x2 Antenna Array Simulation at 3.5 GHz**

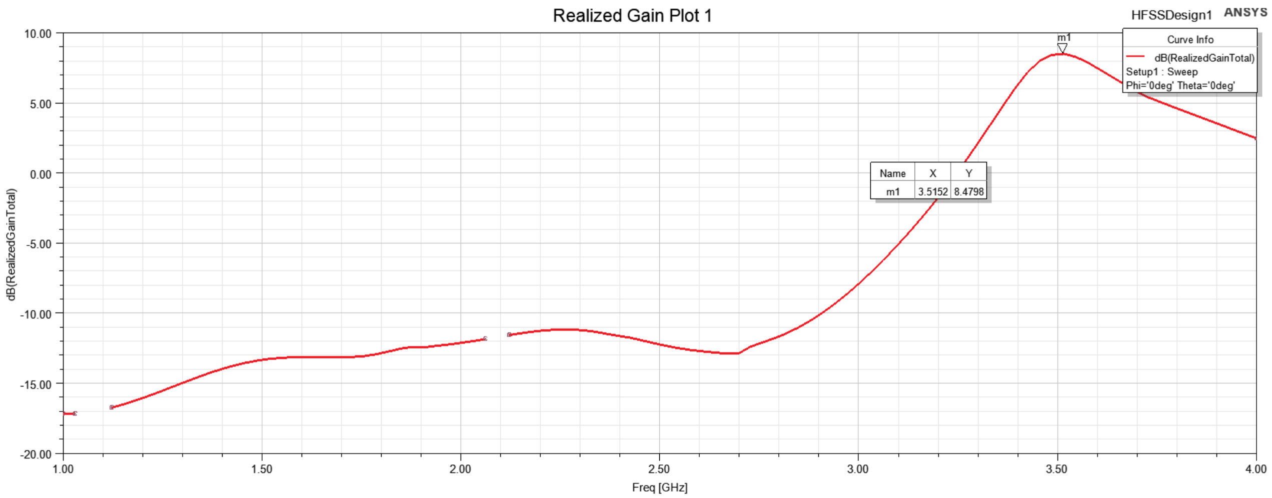


- Results for 2x2 Antenna Array

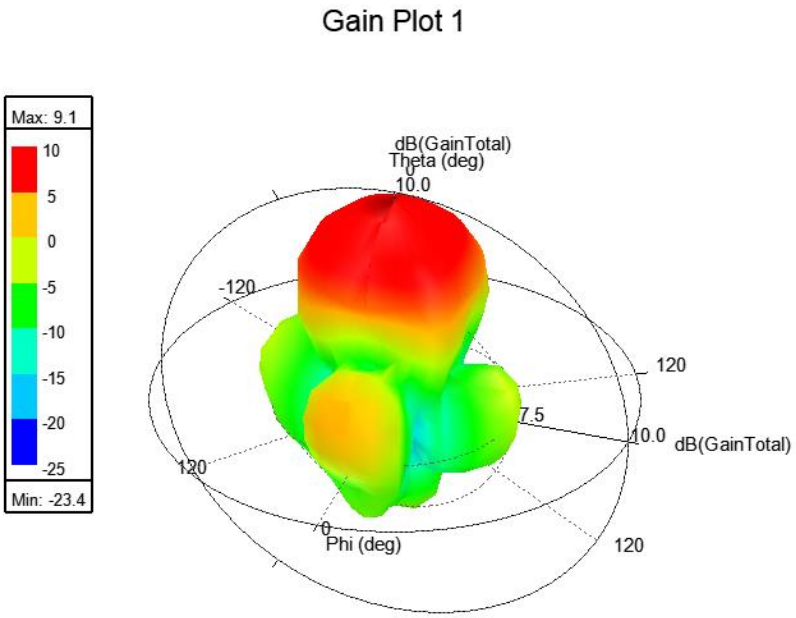
- S-Parameter:



- Realized Gain:



- 3D-Polar Plot:



An advantage of antenna arrays is that since they have directive beams with high gain properties, they can operate over a radar, military applications, etc. The primary benefits of antenna array are given below:

- The signal strength increases.
- High directivity is obtained.
- Minor lobes are reduced much.
- High Signal-to-noise ratio is achieved.
- High gain is obtained.
- Power wastage is reduced.
- Better performance is obtained.

## Simulated results:

Add various plots for the proposed antenna performance:

1. -10 dB impedance bandwidth (BW in GHz)

2. Gain variations over whole operating BW (in dB)
3. 2-D radiation patterns at different resonating frequencies
4. VSWR plot
5. 3-D radiation patterns at different resonating frequencies
6. Efficiency over the operating band

## Observation Table:

| Frequency range of the antenna array (-10dB BW) | Gain variations over the band | VSWR | Efficiency |
|---|---|---|---|
| | | | |

## Conclusions:

Please add some comments on these particular experiments related to the difficulties you have faced during simulation and also related to observation from variations of results with respect to different design parameters. Also mention some points related to necessary precaution that need to consider during simulation for getting desired results.

# Experiment no: 3

## Objective: Design and analysis of conventional antennas like Waveguide based horn antenna.

**Software used:** HFSS software.

## Theory:

A horn antenna is an antenna that consists of a flaring metal waveguide shaped like a horn to direct radio waves in a beam. Horns are widely used as antennas at UHF and microwave frequencies, above 300 MHz. They are used as feed antennas (called feed horns) for larger antenna structures such as parabolic antennas, and as directive antennas for devices like radar guns, automatic door openers, and microwave radiometers. Their advantages are moderate directivity, broad bandwidth, and simple construction and adjustment.

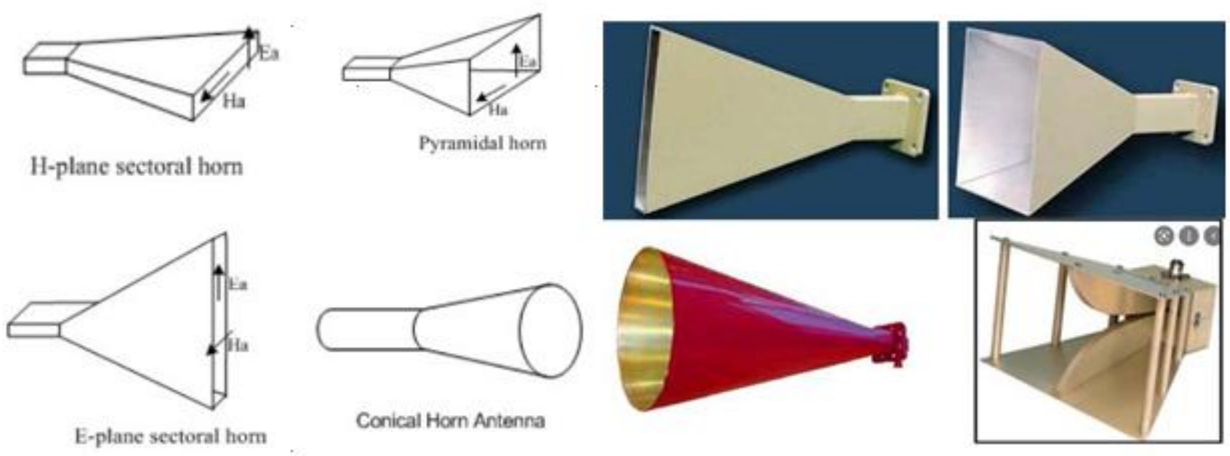
The horn antenna is a simple development of the waveguide transmission line. Using some simple theory, it is easy to learn the operation of horn antenna. It is quite possible to leave a waveguide open and let signal radiate from this. However this is not particularly efficient. Signals passing along the waveguide see a sudden transition from the waveguide to free space which has an impedance of around 377Ω. The result of this sudden transition is to cause signals to be reflected back long the waveguide as standing waves as this is exactly the same as for poor matches at the end of coaxial or other forms of wire based transmission lines. To overcome this issue, the waveguide can be tapered out or flared. This has the effect of providing a gradual transition from the impedance of the waveguide to that of free space. In effect it acts like a progressive matching transformer. The flare functions similarly to a tapered transmission line, or an optical medium with a smoothly varying refractive index. In addition, the wide aperture of the horn projects the waves in a narrow beam. The waves of the signal will propagate down the horn antenna towards the aperture. As they travel along the flared opening, the waves travel as spherical wave fronts. As the phase front progressing along the horn antenna is spherical, the phase increases smoothly from the edges of the aperture plane to the centre. The difference in phase between the centre point and the edges is called the phase error. This increases with the flare angle reducing the gain, but increasing the beam width. As a result horn antennas have wider beam widths when compared to similar-sized plane-wave antennas like parabolic reflectors. In order to provide a narrow beam width a longer horn is required, i.e. having a smaller angle of flare. This enables the phase angle to be kept more constant.

As the frequency used by a horn antenna increases, so does the gain and directivity (beam width decreases). The reason for this is that the aperture of the horn remains constant in terms of physical dimensions (obviously), but increases in terms of the number of wavelengths, i.e. it is electrically larger. As the flare angle is increased, the reflection at the mouth decreases rapidly and as a result the gain of the horn antenna increases. The horn antenna can operate very effectively. The flare of the horn antenna provides a smooth match between the waveguide and free space and its angle affects many properties including the gain and directivity.

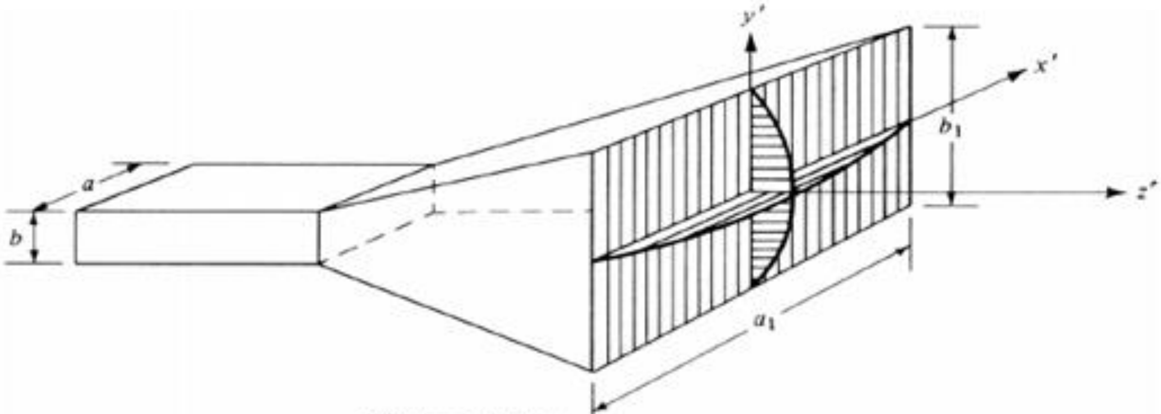
An advantage of horn antennas is that since they have no resonant elements, they can operate over a wide range of frequencies, a wide bandwidth. The uses of horn antenna are given below:

1. The horn is widely used as a feed element for large radio astronomy, satellite tracking, and communication dishes found installed throughout the world.
2. In addition to its utility as a feed for reflectors and lenses, it is a common element of phased arrays.
3. It serves as a universal standard for calibration and gain measurements of other high-gain antennas.
4. Its widespread applicability stems from its simplicity in construction, ease of excitation, versatility, large gain, and preferred overall performance.

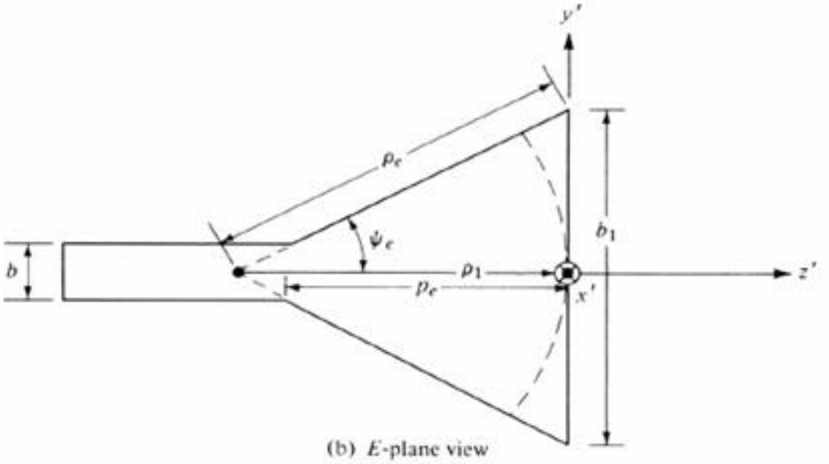
Different types of horn antennas are shown in below figure.



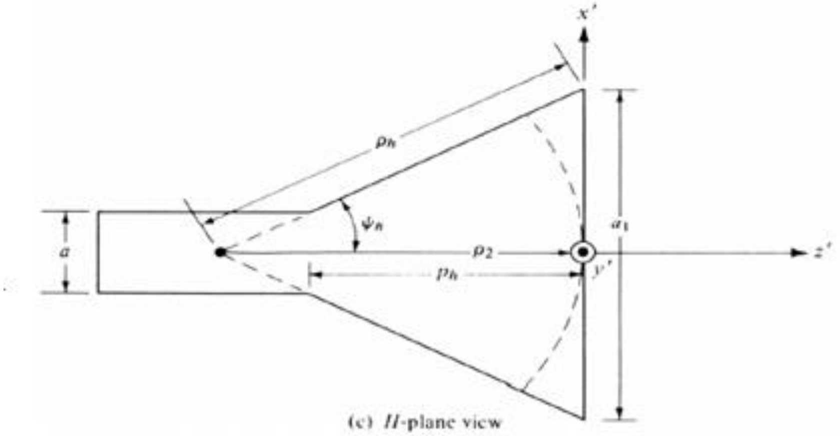
The cross-sectional view (E-plane and H-plane) of a pyramidal horn antenna is shown below.



(a) Pyramidal horn



(b) E-plane view



(c) H-plane view

Design Procedure of Pyramidal horn antenna:

To design a pyramidal horn, one usually knows the desired gain G0 and the dimensions a, b of the rectangular feed waveguide.

The objective of the design is to determine the remaining dimensions (a1, b1, ρe , ρh , Pe , and Ph ) that will lead to an optimum gain.

The design equations are derived by firsts electing values of a1 and b1that lead to optimum directivities for the E and H plane sectoral horns.

$$\boxed{a_1 \simeq \sqrt{3\lambda\rho_2}} \qquad \boxed{b_1 \simeq \sqrt{2\lambda\rho_1}}$$

Since the overall efficiency (including both the antenna and aperture efficiencies) of a horn antenna is about 50%. The gain of the antenna can be related to its physical area. Thus it can be written by

$$G_0 = \frac{1}{2}\frac{4\pi}{\lambda^2}(a_1 b_1) = \frac{2\pi}{\lambda^2}\sqrt{3\lambda\rho_2}\sqrt{2\lambda\rho_1} \simeq \frac{2\pi}{\lambda^2}\sqrt{3\lambda\rho_h}\sqrt{2\lambda\rho_e}$$

Since for long horns ρ2 ≈ ρh and ρ1 ≈ ρe. For a pyramidal horn to be physically realizable, Pe and Ph must be equal. Using this equality, it can be shown that gain reduces to

$$\boxed{\left(\sqrt{2\chi}-\frac{b}{\lambda}\right)^2(2\chi-1)=\left(\frac{G_0}{2\pi}\sqrt{\frac{3}{2\pi}}\frac{1}{\sqrt{\chi}}-\frac{a}{\lambda}\right)^2\left(\frac{G_0^2}{6\pi^3}\frac{1}{\chi}-1\right)}$$

Where,

| |
|---|
| $\frac{\rho_e}{\lambda}=\chi$ |
| $\frac{\rho_h}{\lambda}=\frac{G_0^2}{8\pi^3}\left(\frac{1}{\chi}\right)$ |

…………………..(1)

This Equation is the horn design equation.

1. As a first step of the design, find the value of χ which satisfies eqn. (1) for a desired gain $G_0$ (Dimensionless). Use an iterative technique and begin with a trial value of

$$\chi\,(\text{trial})=\chi_1=\frac{G_0}{2\pi\sqrt{2\pi}}$$

2. Once the correct χ has been found, determine ρe and ρh using eqn. (1).
3. Find the corresponding values of a1 and b1.

$$a_1=\sqrt{3\lambda\rho_2}\simeq\sqrt{3\lambda\rho_h}=\frac{G_0}{2\pi}\sqrt{\frac{3}{2\pi\chi}}\lambda$$

$$b_1=\sqrt{2\lambda\rho_1}\simeq\sqrt{2\lambda\rho_e}=\sqrt{2\chi\lambda}$$

4. Then find the value of pe and ph using following equations.

$$p_e=(b_1-b)\sqrt{\left(\frac{p_e}{b_1}\right)^2-\frac{1}{4}}$$

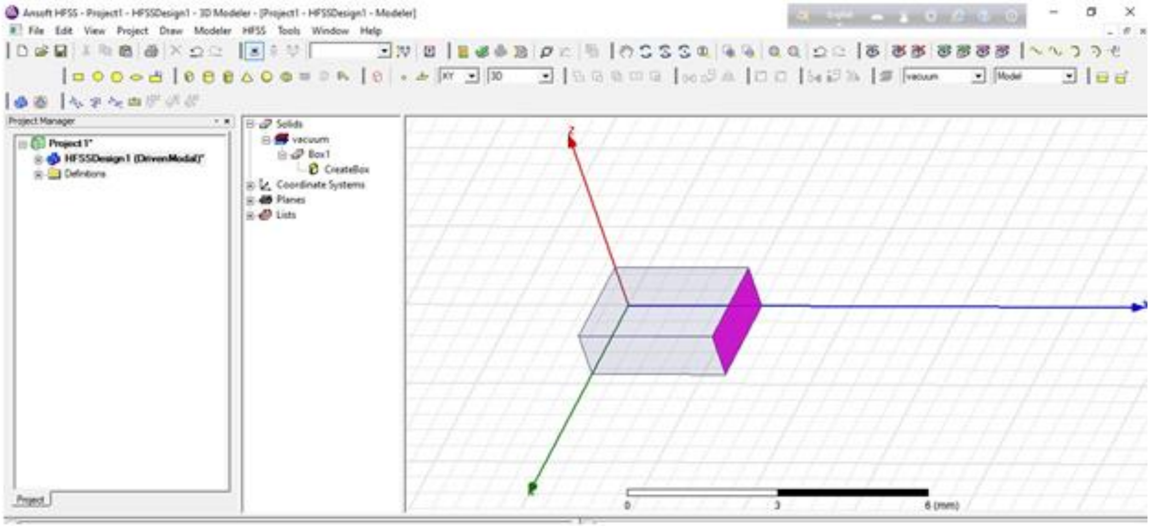
$$p_h=(a_1-b)\sqrt{\left(\frac{p_h}{a_1}\right)^2-\frac{1}{4}}$$

## Design Problem:

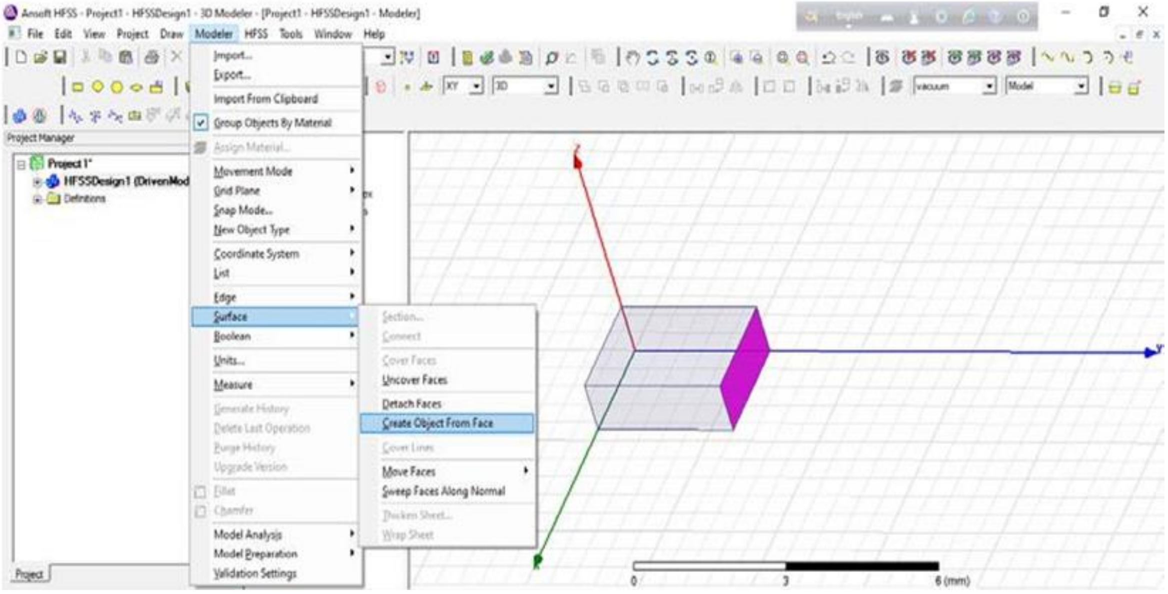
Design an X-band Horn antenna with the specifications as given below: Given: X-band (8.2 – 12.4 GHz), f = 11 GHz Horn and Gain = 22.6 dB. Here, a = 0.9 inch, b = 0.4 inch. Find the dimensions of Pyramidal Horn antenna and then simulate that structure using HFSS software.

## Design procedure using HFSS software:

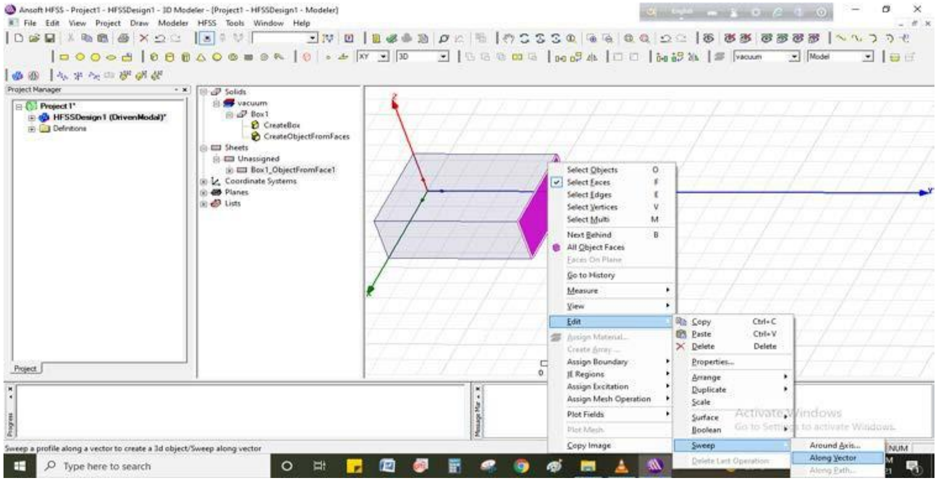
1. After opening of the HFSS software, design the wave guide feeding section as shown below.



2. Then, select the face and then “Modeler” – “Surface” – “Create object from face”.

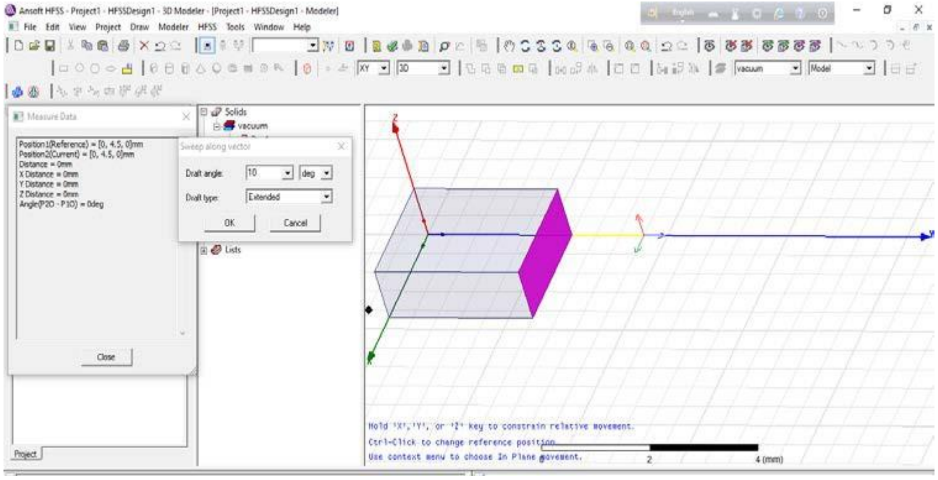


3. Then right click on the surface and “Edit” – “Sweep” – “Along Vector”.



Sweep a profile along a vector to create a 3d object/Sweep along vector

4. Choose “Draft angle” and “Draft type”.



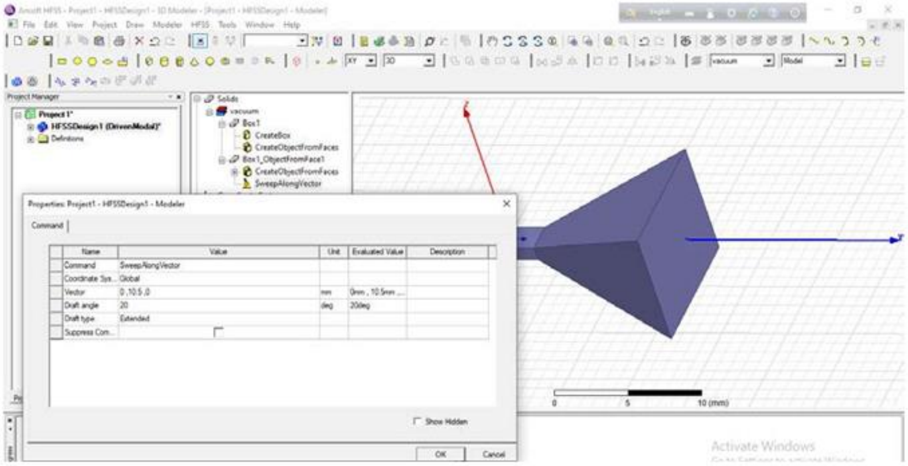
Position1(Reference) = [0, 4.5, 0]mm
Position2(Current) = [0, 4.5, 0]mm
Distance = 0mm
X Distance = 0mm
Y Distance = 0mm
Z Distance = 0mm
Angle(P2D - P1D) = 0deg

Draft angle: 10 deg

Draft type: Extended

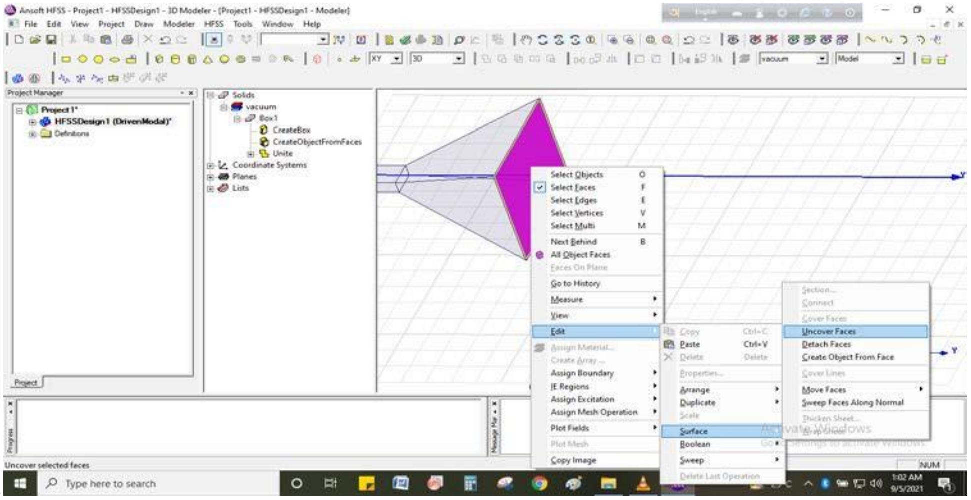
Hold 'X','Y', or 'Z' key to constrain relative movement.
Ctrl-Click to change reference position.
Use context menu to choose In Plane movement.

5. Choose the length and angle from “Sweep along Vector”.

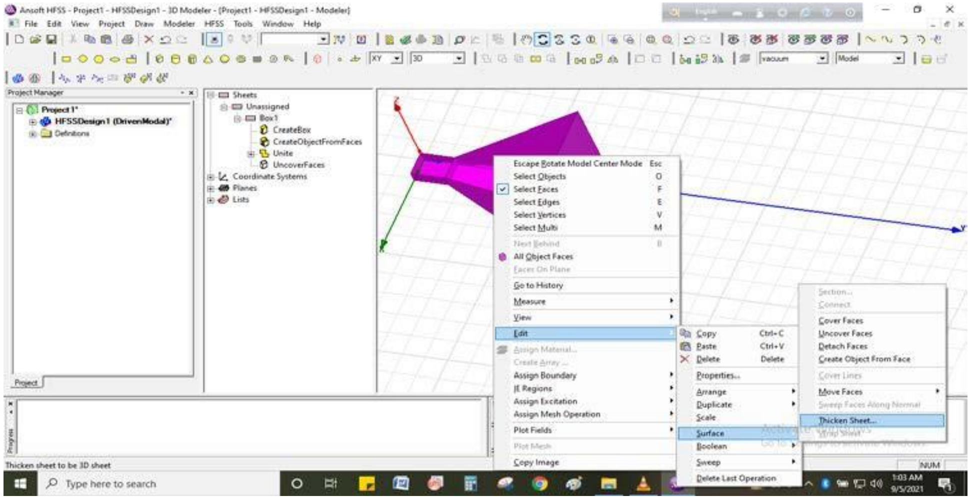


| Name | Value | Unit | Evaluated Value | Description |
|---|---|---|---|---|
| Command | SweepAlongVector | | | |
| Coordinate Sys... | Global | | | |
| Vector | 0 ,10.5 ,0 | mm | 0mm , 10.5mm ... | |
| Draft angle | 20 | deg | 20deg | |
| Draft type | Extended | | | |
| Suppress Com... | ☐ | | | |

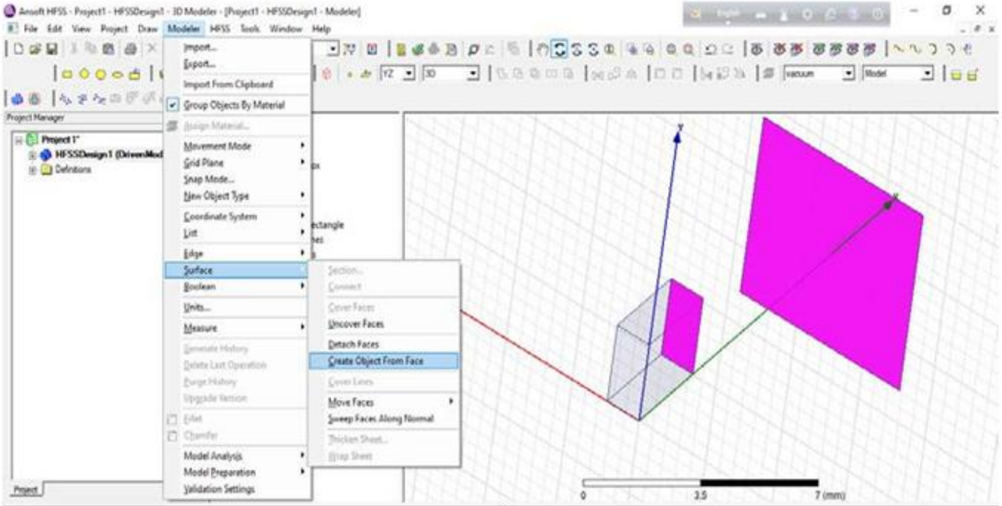
6. Then select the surface and "Edit" – "Surface" – "Uncover Faces".



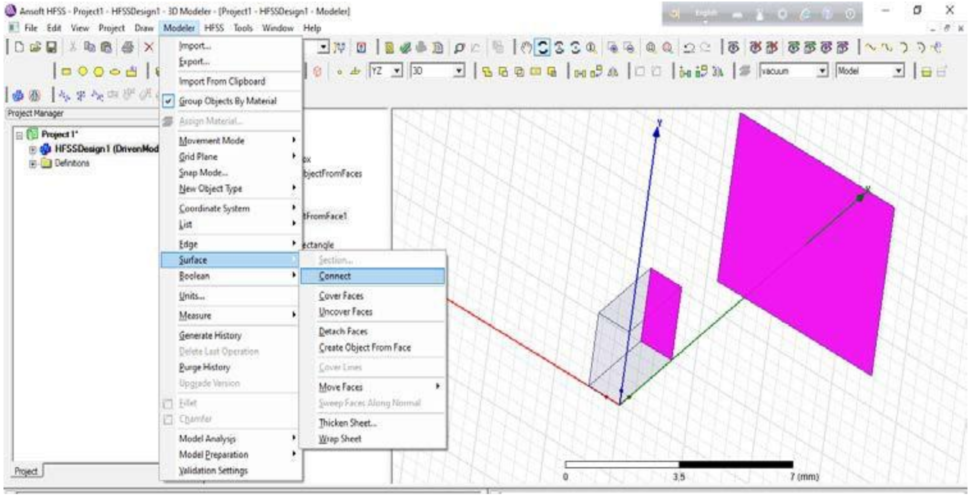
7. Then unite the structure and select it. After that "Edit" – "Surface" – "Thicken Sheet".



8. An alternate approach to design:



9. Go to “Modeler” – “Surface” – “Connect” to create the horn antenna geometry and then follow the same steps as shown before.



## Simulated results:

Add various plots for the proposed antenna performance:

1. -10 dB impedance bandwidth (BW in GHz)
2. Gain variations over whole operating BW (in dB)
3. 2-D radiation patterns at different resonating frequencies
4. VSWR plot
5. 3-D radiation patterns at different resonating frequencies
6. Efficiency over the operating band

## Observation Table:

| **Frequency range of the Horn antenna (-10dB BW)** | **Gain variations over the band** | **VSWR** | **Cross- polarization suppression at different frequencies** | **Efficiency** |
|---|---|---|---|---|
| | | | | |

## Conclusions:

Please add some comments on this particular experiments related to the difficulties you have faced during simulation and also related to observation from variations of results with respect to different design parameters. Also mentioned some points related to necessary precaution that need to consider during simulation for getting desired results.