A Compact Planar Monopole Antenna for Wi-Fi and UWB Applications

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BONAFIDE CERTIFICATE

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Examiner-1

Examiner-2

ABSTRACT

Ultrawideband (UWB) antennas are widely used as core devices in high-speed wireless communication. A novel compact UWB monopole antenna with an additional narrow band for Wi-Fi applications comprising a metamaterial (MTM) is proposed in this paper. The antenna has a compact size of 27×33 mm^2 and consists of a V-shaped slot with two rectangular slots in the radiation patch. The inductance and capacitance develop due to the V-shaped slot in the radiation patch. The proposed antenna has −10 dB bandwidths of 3.2 GHz to 14 GHz for UWB and 2.38 GHz to 2.57 GHz for narrowband, corresponding to 144% and 7.66% fractional bandwidths, respectively. The measured gain and efficiency meet the desired values for UWB and Wi-Fi applications. To verify the performance of the antenna, the proposed antenna is fabricated and tested. The simulated and measured results agree well at UWB frequencies and Wi-Fi frequencies, and the antenna can be used as a smart device for portable IoT applications. Return loss of 18 dB has been obtained with gain of 1.86 dB and efficiency of 50% .

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION TO UWB ANTENNA

Antenna is defined as an electromagnetic waves device or transducer that transforms an RF signal. It acts as a means of transmitting radio waves and receiving them. Antennas play a major role in wireless communications. The types of antennas include parabolic reflectors, patch antennas, slot antennas, and folded dipole antennas. These types are unique in properties and usage. A type of telecommunication technology called an ultra-wideband (UWB) is used to provide a typical solution for short-range wireless communication due to large bandwidth and low power consumption in transmission and reception.

1.2 DESIGN EQUATION

1) $w = \frac{C_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}}$ = 26.5mm

2) $\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1 + 12\frac{h}{w}\right]^{-1/2}$ = 3.21

3) $L = \frac{\lambda}{2} - 2\Delta L$ = 13.2mm

4) $\frac{\Delta L}{h} = \left(\frac{\varepsilon_r+0.3}{\varepsilon_r-0.258}\right)\left(\frac{\frac{W}{h}+0.264}{\frac{W}{h}+0.8}\right)$ = 0.83

1.3 ADVANTAGES OF UWB ANTENNA

The UWB antenna has wide applications and few are listed below

- Low Power
- Good noise immunity
- Signals can penetrate variety of materials easily
- High immunity to multipath fading
- Potentially very high data rates

1.4 DISADVANTAGES OF UWB ANTENNA

Though UWB antenna provides variety of applications it lags with few properties and are listed below

- Tags for UWB-based location and pairing system are more expensive than tags used in other technologies such as Bluetooth and RFID.
- It cannot replace Bluetooth and Wi-Fi technologies for large data transfers because of its low data transmission rate, thus making it unsuitable for streaming large data.
- The technology supports carrier less transmission. However, transmitting data or signal without a carrier has the following disadvantages: complex signal processing, inapplicability of super-resolution beamforming, and antenna form factor.
- It still has the potential to interfere with existing systems since it uses a spectrum that is also allocated for various military, civilian, and commercial applications.

1.5 APPLICATIONS OF PARABOLIC REFLECTOR ANTENNA

There are many areas in which the V-SHAPED SLOT UWB ANTENNA is used. In some areas it is the form of antenna that is used virtually exclusively because of its characteristics.

- Used in military communications.
- Available in premium Galaxy S20 and S21 series of smartphone.
- Google has added UWB support to Android 12 which gives other.
- Use UWB are iPhone 11 series, iPhone12 series, iPhone 13 series, and Air Tags.

CHAPTER 2

LITERATURE SURVEY

Adnan Khurshid et.al[1] proposes that he measurement results indicate that the designed antenna can operate over 2.38 to 2.57 GHz for narrowband and 3.2 to 14 GHz for ultrawideband with 90% efficiency.

Guangliang et.al[1] states the proposed antenna successfully rejects three co-existing bands while keeping good performance over the entire passband. We can make a conclusion that TOA based UWB localisation is faster than Zig-bee.

Adam R. H. Alhawari et.al[1] proposes that the designed antenna shows a wide working BW between a 1.3 GHz and 7.2 GHz frequency band and fractional BW of 138.8% (f1 = 1.3 GHz, f2 = 7.2 GHz, f3 = 4.25 GHz). The proposed UWB antenna can be a reliable candidate for underwater communications since a good agreement exists between the simulated and measured reflection coefficient in various environments.

Richa Bharadwaj, et.al[1].speaks that the proposed Sufficiently accurate two-dimensional (2-D) localization with reasonable resolution for the intended application is achieved using a compact and low-cost antenna (TSA). Average localization accuracy as small as 1–2 cm.

Refernce	Return loss	Isolation loss	Gain	Efficiency
Adnan khurshid	2.54GHz	6db	11.6db	82
Guangliang	2.46 GHz	NA	NA	91.4
Adam R.H Alwari	6 GHz	NA	11db	88
Richa Bharadwaj	3.3 GHz	NA	8.2db	87

CHAPTER 3

DESIGN METHODOLOGY

3.1 SOFTWARE REQUIREMENTS

Simulator: ANSYS HFSS Desktop Student v2020

3.1.1 High frequency structure simulator

To compute the electrical behavior of the higher frequency and high-speed components, ANSYS HFSS software uses a 3D full wave Finite Element Method. HFSS is a commercial tool that can also be utilized for the design of RF electronic circuits like filters. Tetrahedron is the basic mesh element. This software can be used in the calculation of antenna parameters such as S-parameters, gain, voltage standing wave ratio, radiation pattern, current and field distributions, antenna efficiency, impedance matching and so on. ANSYS HFSS is a user-friendly software. High accurate results can be obtained with the use of HFSS software. It provides facility to assign boundary, excitations, range of frequencies for precise results. HFSS is the platform where we can model, simulate and can automate easily. Optimization of the antenna performance by simulating and analyzing the parameters separately can be done. The results can be viewed as either as tabular or graphical format. Most options in the HFSS tool are self-explanatory. It also has inbuilt techniques like optimization. For engineers to optimize the designed antenna to a desired dimension, the parametric set up existing in HFSS is highly helpful.

3.1.2 User interface of HFSS

A GUI comprises of,

- 3D Modeler window: The model/ geometry can be created in this region. The framework or the model view region exists in this window.
- Properties window: Two tabs are there in this window – attribute tab and command tab. The selected object’s property and the information regarding the material are displayed in the attribute tab. The selected action in the history tab to modify an object or create an object is displayed in the command tab.

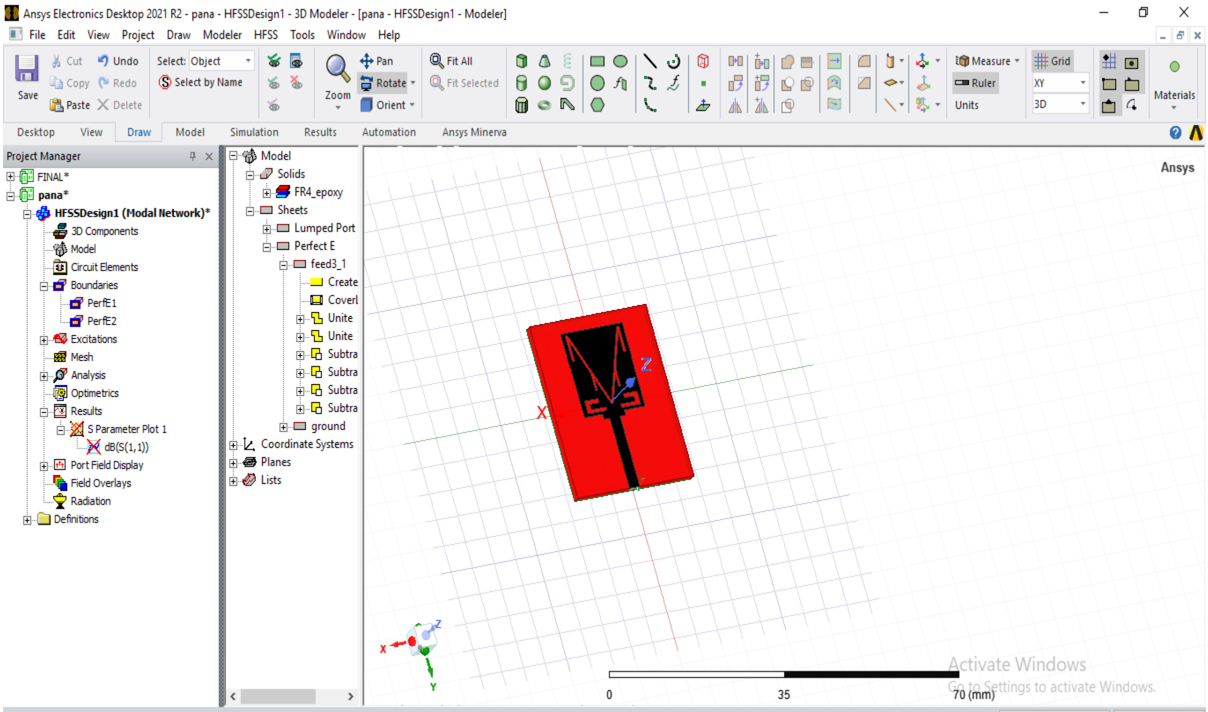


Fig 3.13D modeler window of HFSS

- Project manager: The details of project which are currently open get displayed in the project manager window. Each project contains the geometric model of the antenna and the assigned boundaries and excitations and the obtained report in table and graphical format.
- Progress window: The progress of the analysis can be viewed through this window. The percentage of solution or the state of execution can be viewed through this window.
- Message manager: This window displays the progress in written form or text format i.e., whether simulation has completed or not or if there is any error.
- New features and enhancement: Selection, Healing, Visibility, 3D user interface options and 3D modeler options are some of the new features.
    - Selection helps in selecting the connected edges, vertices, faces. Healing removes the faces, edges and vertices.
    - Visibility is used to show/ hide the objects in certain view.

Also there exist features to arrange, duplicate and scale objects.

3.2 WORKFLOW IN HFSS

Design creation involves the following,

a. Parametric Model Generation of the creation of the geometry's, boundaries citations.

b. Analysis Setup–here the definition of the solution setup and frequency sweeps are given.

c. Results –the corresponding 2D reports and field plots are created.

d. Solve Loop - the full automation of the solution process is done.

3.3 ANTENNA MODEL

The process of creating antenna model is given below.

Patch antenna

Open new project

In an Ansys HFSS modular window, from standard toolbar, select the New HFSS Design.

Set solution type

- Choose Terminal as Solution Type.

Add variables

- Select the materials.
- Draw the ground as per measurements in the 3D model using shapes.

Create reflector

- Draw equation-based curve.
- Draw sweep at Z axis.
- Sweep angle 360°.
- Draft angle= 0.
- Draft type = round.

Assign PEC

- Assign boundaries=perfect E.

Patch antenna

Creating the feed

- Lumped port is created using rectangle.
- Position of the rectangle is placed near the created patch.
- X-size of the box = 0.43mm.
- Y-size of the box = 0.44mm.
- Z-size of the box = 1.6mm.
- To make V-shaped slot antenna, a rectangle was initially created.
- Next, another rectangle was created and it is shaped by subtracting a triangle form it.
- Set thickness = 1.6mm.
- Select perfect conductor from material library.

Assign material

- A radiation box is created for the patch.
- A FR4 Epoxy Duroid is selected as the material.
- An excitation is provided to the port.

Radiation box

- Draw -> Box
- Choose the material as Air
- Assign the position and size for the radiation box.
- Select the radiation box. HFSS -> Boundaries -> Assign -> Radiation.

Analysis setup

- HFSS -> Analysis Setup -> Add Solution Setup.
- It will be viewed in the project Manager window. By right clicking and select the option Add Frequency Sweep.
- In that Assign the Sweep type as Discrete
- Assign the start stop and Step sizes.
- In results, each and every parameter results can be viewed.

3.4 DESIGN PROCEDURE

The proposed antenna design has been designed and simulated using ANSYS HFSS software. The V-shaped shaped slot UWB antenna design specifications are discussed below. The step-by-step procedure for designing the antenna is given below. The steps are:

- Creating a model or geometry
- Assignment of boundaries
- Assignment of excitations
- Setting up the solution
- Solve
- Post-processing the results

Table 3.1 Design specifications of Vshaped slot UWB antenna

Design Parameters	Value
Operating Frequency (GHz)	12.5
Length of patch (mm)	13.5
Width of patch (mm)	2.3
Height of Substrate (mm)	1.6
Dielectric Constant (ε_r)	4.4
V- Shaped Slot width(mm)	0.5
Rectangular slots width(mm)	0.6

3.4.1 Creating a model/ geometry

The model creation in HFSS is done by utilizing the 3D modeler available inside the HFSS. The 3D model is fully parametric and will allow a client to construct a structure that is variable in terms of geometric measurements and properties of the material. When the configuration needs to be tuned or when the last measurement is unknown, this parametric structure is much helpful. If structure parameterization is desired, then the imported geometry will need to be manually modified by the user to allow parameterization is shown in the Fig3.2

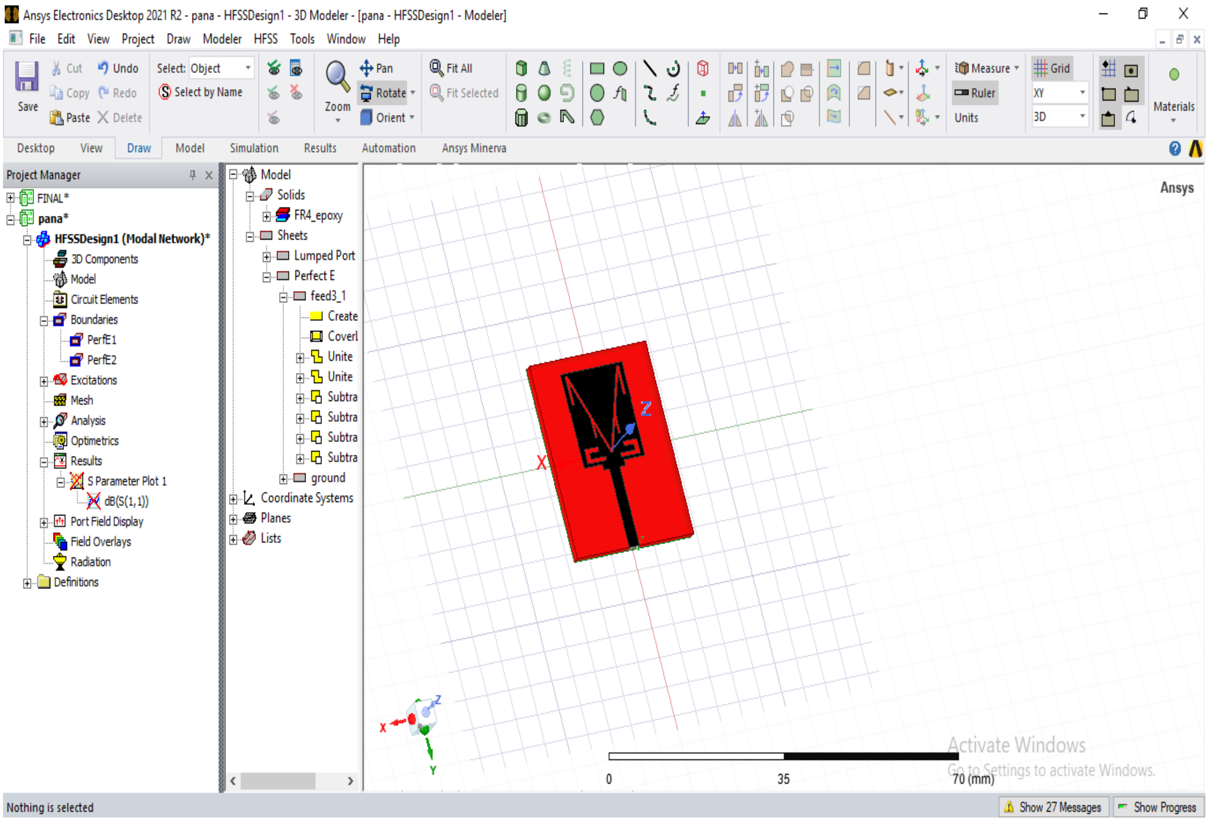


Fig 3.2 Geometry of the V-shaped slot UWB antenna in ANSYS HFSS 3D modeler window

3.4.2 Assignment of boundary

The next step is assigning the boundaries to the antenna structure. The open model in HFSS can be created by assigning the radiation boundaries. While simulating an antenna, the radiation boundary should be positioned in such a way, that it is quarter the wavelength away from the surface of radiation is shown in the fig 3.3. Assignment of boundary to the antenna structure is much essential as it have direct impact on the result provided by the HFSS software

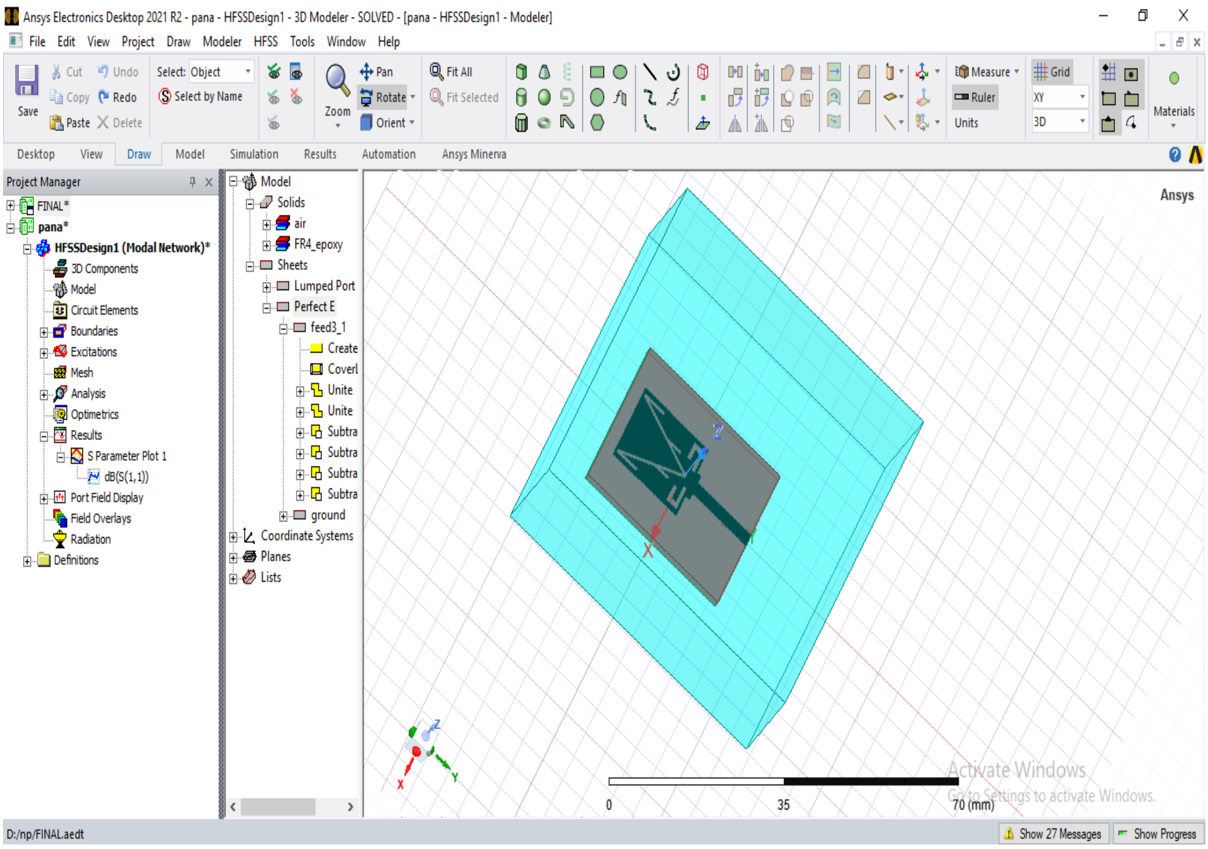


Fig 3.3 Boundary assignment

3.4.3 Assignment of excitation

The excitations or ports needs to be connected after the assignment of boundaries gain this assignment of ports also plays a vital role. The antenna result provided by the HFSS software greatly depends on the assignment of excitations or ports. Hence it is highly recommended that the user needs to take intensive care while assigning the excitations. While assigning excitations care should be taken in assigning the direction to the port is shown in the fig 3.4

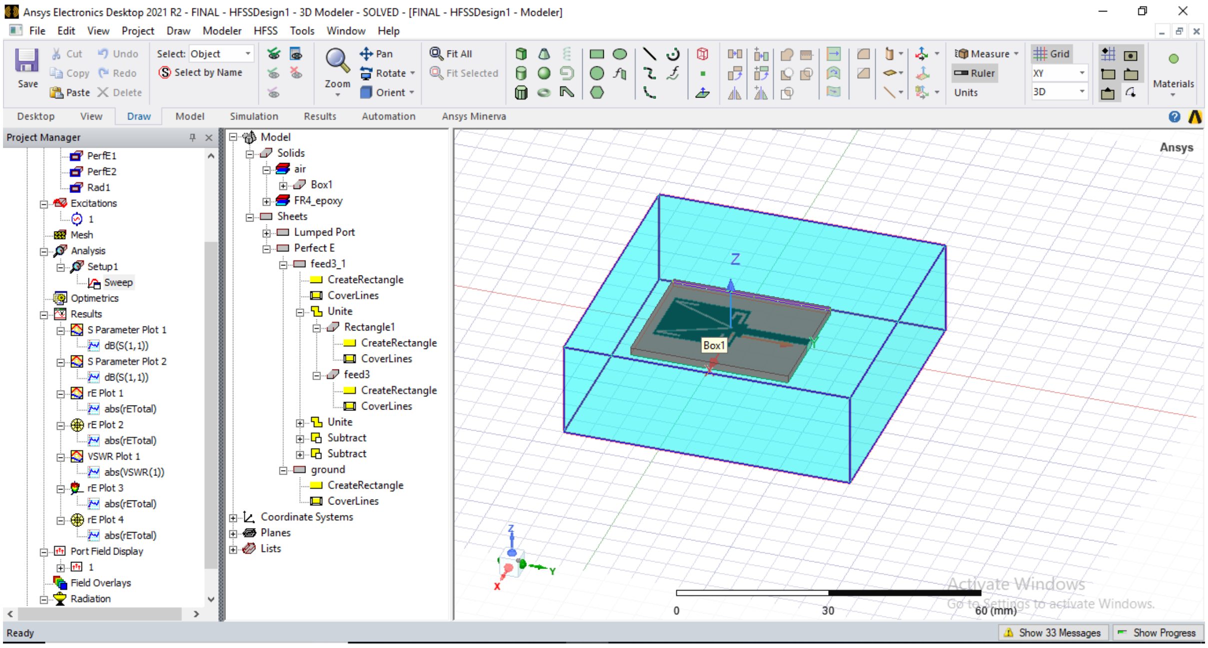


Fig 3.4 Excitation assignment to the feed

3.4.4 Setting up for solution

After assigning the boundaries and excitations to the 2D and 3D model, the parameters need to be analyzed. The change in magnitude between two consecutive passes of the S-parameters gives the Delta-S value. If the magnitude and phase of all S-parameters is reduced to a value which is lesser than the one specified by the user as Delta-S value, then all values get converged and the analysis gets stop. There are three types of sweeps exist in the HFSS software. They are fast, discrete and interpolating. The fast sweep is preferred in simulations that have numerous sharp resonances. To accurately determine the behavior of the antenna near a resonance fast sweep is used. The major advantage of the rapid range is that it allows the user to post-process and show fields at any region within the frequency sweep and also the fields at any frequency. Within the predefined frequency range, the fast field yields a full-field structure. For the entire frequency spectrum, the interpolating sweep calculates the S-matrix solution is shown in the Fig 3.5.

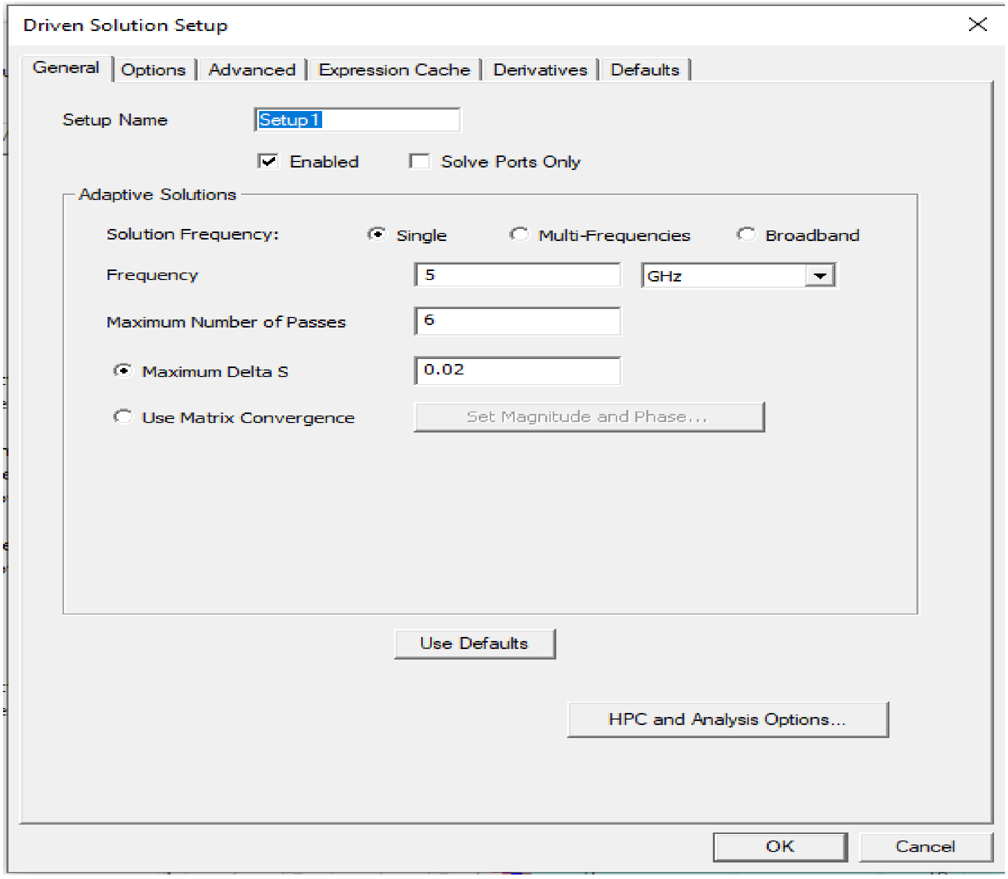


Fig 3.5 Dialog box showing the solution setup

For solving the field solution, the HFSS selects suitable frequency points within the frequency range. The direct sweep solution time directly depends on the total of chosen frequency points. If the number of frequency points in the frequency range is high, then the time to obtain the result also increases. The discrete sweep analysis provides a precise and accurate solution to the user. In the dialog box from the properties window, the frequency of operation and the maximum delta-S value needs to be set is shown in the Fig 3.6

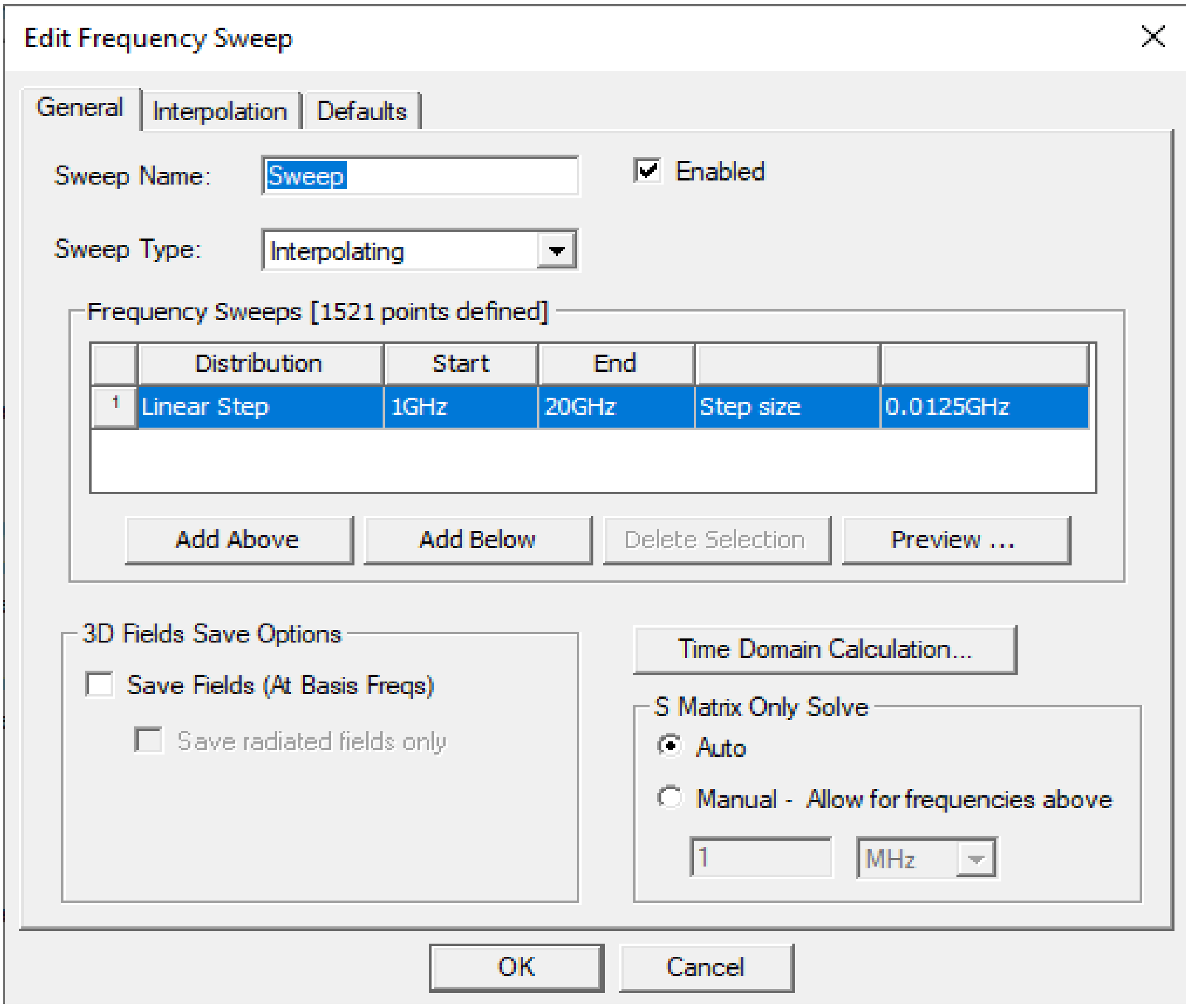


Fig 3.6 Dialog box showing setting up the sweep frequency

The type of sweep to be used and the range of frequency for the analysis should be set in this dialog box.

3.4.5 Solve

Once after the completion of the above steps by the HFSS user, the model needs to be analyzed and validated. Error will be thrown if any error occurs in the previous steps. The time required for the analysis depends on few factors like the geometry of the antenna; the range of solution frequency, the type of sweep used and also depends on the system resources.

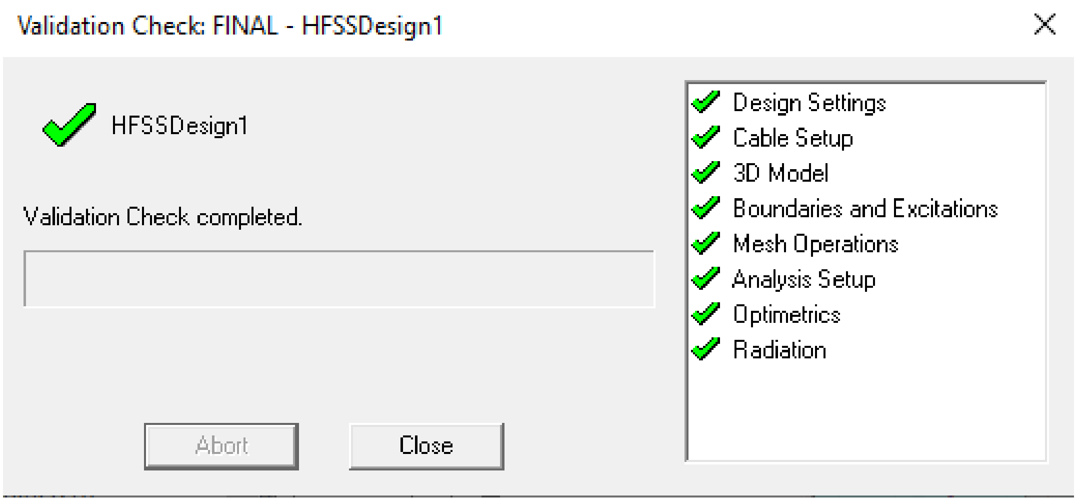


Fig 3.7 Dialog box showing the above steps validation

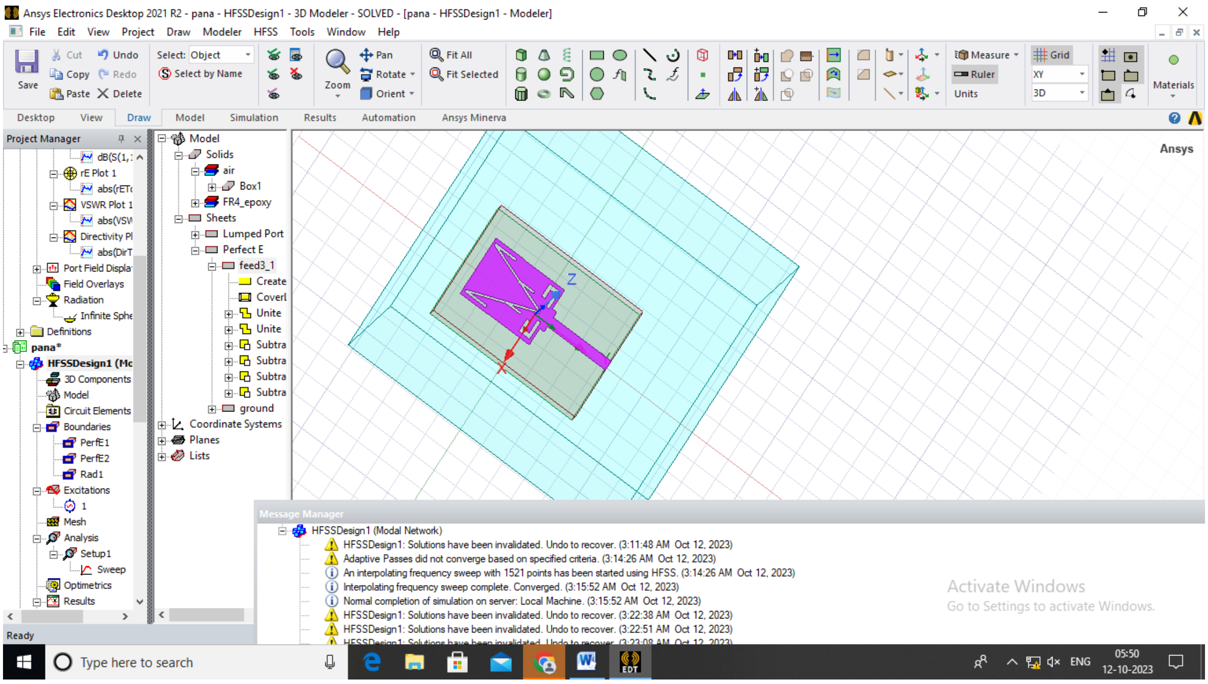


Fig 3.8 Analyses of the designed antenna taking place in the progress window

Click the validate icon (green color exclamation mark) in HFSS, a dialog box is shown in the fig 3.7 will pop up indicating that validation is taking place. The analysis takes certain amount of time to provide the solution is shown in the fig 3.8. The user can view the progress through the progress section which is present at the bottom in the HFSS software.

3.4.6 Post processing

The user can validate the result once after obtaining the solution. Post-processing the results take place once after the validation of result by the user. Post-processing includes analyzing the S, Y, Z parameters is shown in the Fig 3.10. The far-fields produced by the antenna can also be analyzed. The radiation pattern produced by the antenna in the E-plane and H-plane can also be obtained is shown in the Fig 3.9.

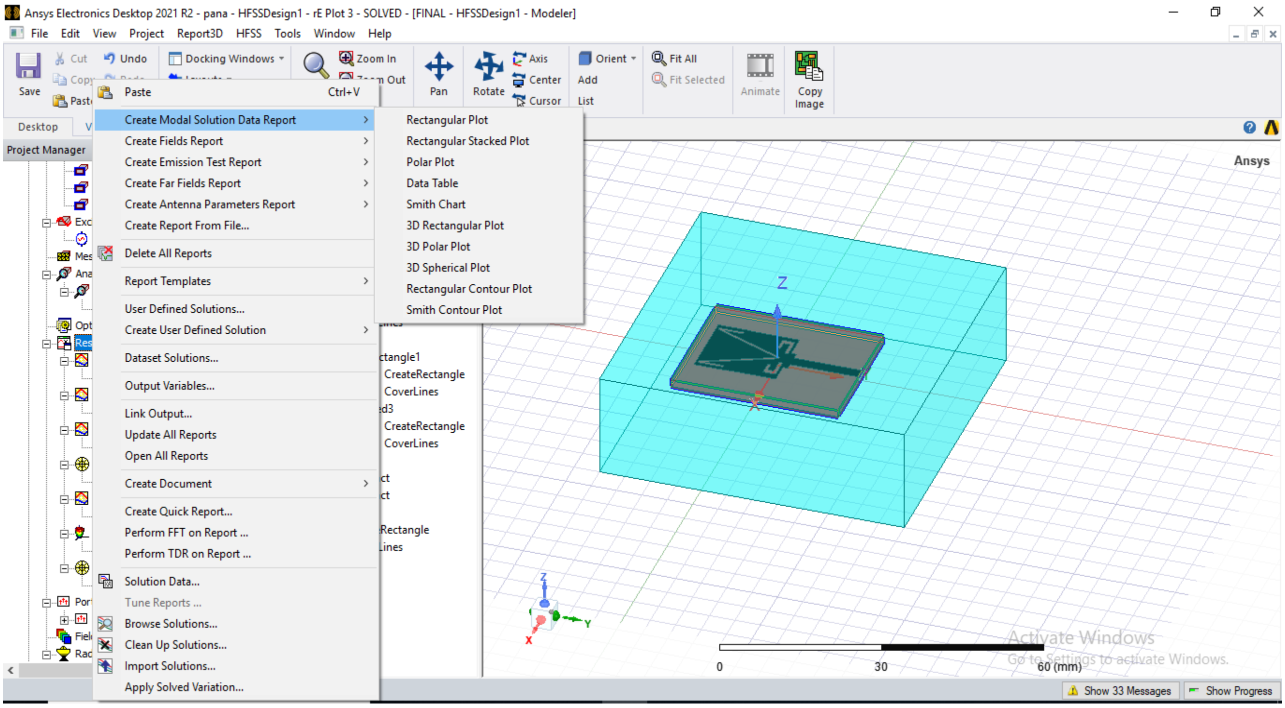


Fig 3.9 Creation of modeler solution data report in HFSS

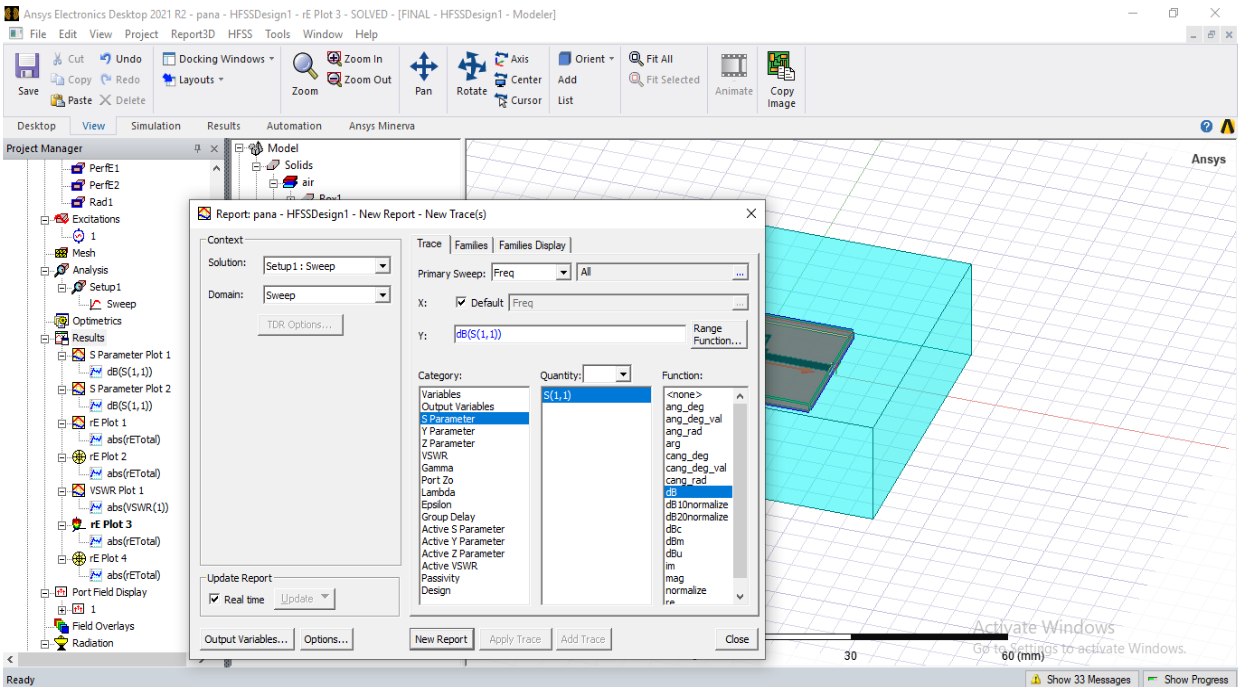


Fig 3.10 Dialog box for obtaining s-parameter results in HFSS

Hence by using ANSYS HFSS one can obtain the S, Y, Z parameters, gain, directivity, return loss or reflection coefficient, Voltage Standing Wave Ratio, Radiation pattern in E-plane and H-plane, Radiation efficiency, Impedance Matching, Field Distribution, Current Distribution. Also, it is possible to analyze the parameters for the same model by changing the frequencies, varying the range of frequencies

CHAPTER 4

SIMULATION RESULTS

This chapter deals with simulation results obtained from parabolic reflector antenna using horn-fed antenna.

4.1 Return loss

Return loss is the power loss in the signal that is reflected or returned in a transmission line or optical fiber by discontinuity. With an inserted device in the line or with the mismatch in the terminating load, this discontinuity can happen. Return loss is given by the equation,

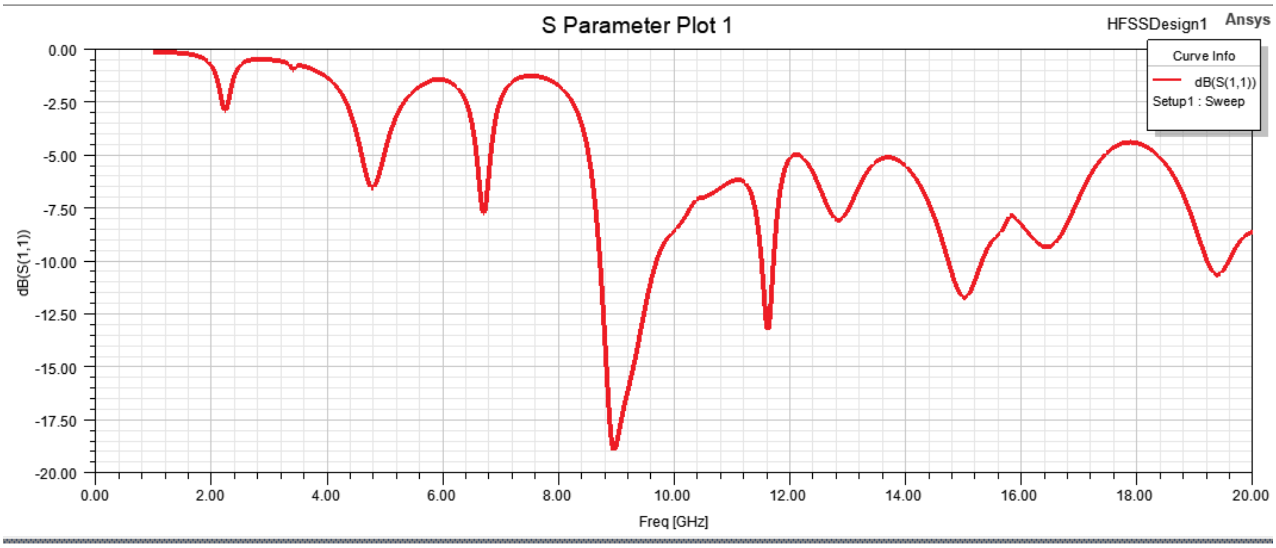
$$\textbf{RL (dB)} = 10 log log 10 \left(\frac{P_{incident}}{P_{reflected}} \right)$$

where, RL (dB) is the return loss in terms of dB

$P_{incident}$ is the incident power

$P_{reflected}$ is the reflected power

Table 4.1 Return Loss for respected frequency

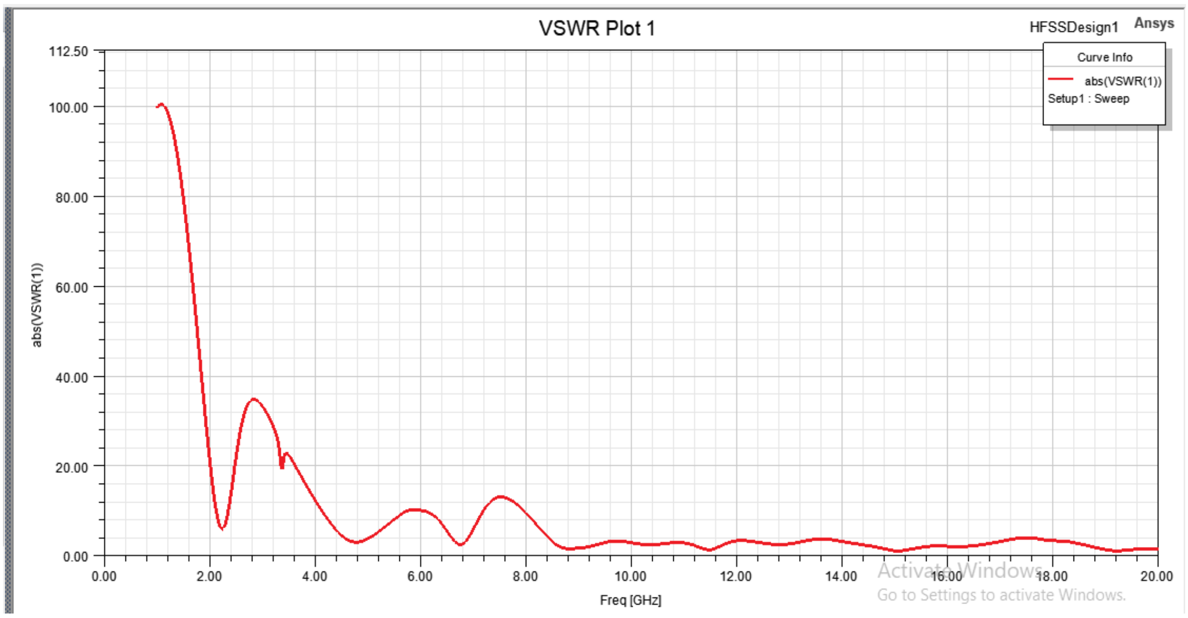
OPERATING FREQUENCY (in GHz)	Return Loss
9	

4.2 VSWR

Usually, the standing wave ratio of an antenna is called as the Voltage Standing Wave Ratio (VSWR). The standing wave ratio in terms of current is called ISWR. Squaring the VSWR yields the Power Standing Wave Ratio. The total power reaching the destination end is prevented by impedance mismatch in the transmission line where the radio wave in the cable is reflected back to the source. An infinite SWR is the complete 14 reflection of power reflected from the cable. SWR meter is the instrument used in the measurement of SWR from transmission lines or cables.

The Voltage Standing Wave Ratio is the measure of loss at the feeder because of mismatch. It normally ranges between 0 to infinite. For practical antennas the value should be less than 2 then the antenna is said to be matched. The VSWR obtained by our proposed antenna at the frequency 4 GHz is 0.00.

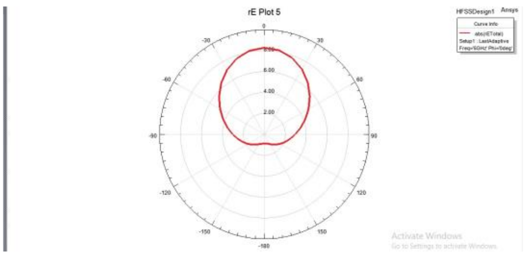
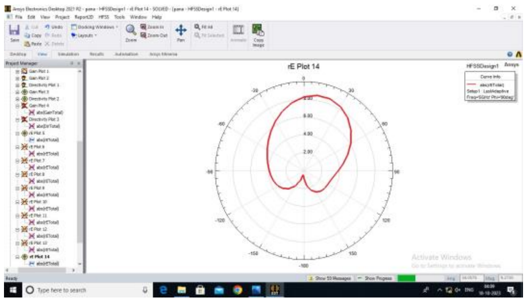
Table 4.2VSWR plot for respected frequency

<table>
<tr><th>OPERATING FREQUENCY (in GHz)</th><th>VSWR</th></tr>
<tr><td>9</td><td>
</td></tr>
</table>

4.3 Radiation pattern

Graphical representation of the relative field strength that the antenna transmits or receives is called radiation pattern. It is indicated with side lobes and back lobes. An antenna's radiation pattern can be defined as the locus of all points in which power emitted per unit surface is equal. The reference in this depiction is usually the best emission angle. The directive gain of the antenna may also be represented as a function of direction. The gain is often represented in decibels. A single graph is sufficient if the antenna radiation is symmetrical about an axis a unique graph is enough i.e., for helical or dipole antennas.

Table 4.3Radiation Pattern for respected frequency

<table>
<tr><th>OPERATING FREQUENCY (in GHz)</th><th>WITH E FIELD
(Phi =0 degree)</th><th>WITH H FIELD
(Phi=90 degree)</th></tr>
<tr><td>9</td><td>
</td><td>
</td></tr>
</table>

From the above graphs, it is inferred that directivity increases with increase in frequency.

4.4 Antenna gain

The directionality of the antenna is measured by a factor called Antenna Gain or Gain of an Antenna. In particular, power gain is defined in terms of ratio of radiated intensity of an antenna in a particular direction at a random distance to the radiated intensity by an isotopic antenna at the same distance. A high gain antenna is normally unidirectional or emits radiation in a specific direction on the other hand the low gain antenna emits radiation equally in all directions. Gain is a dimensionless quantity.

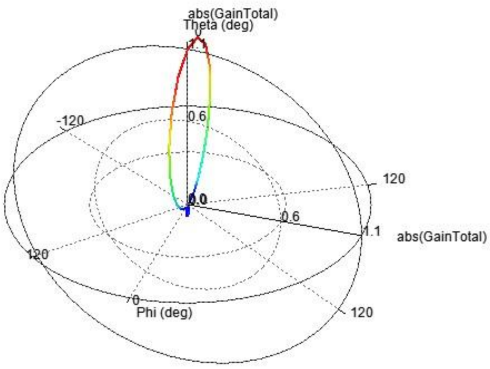
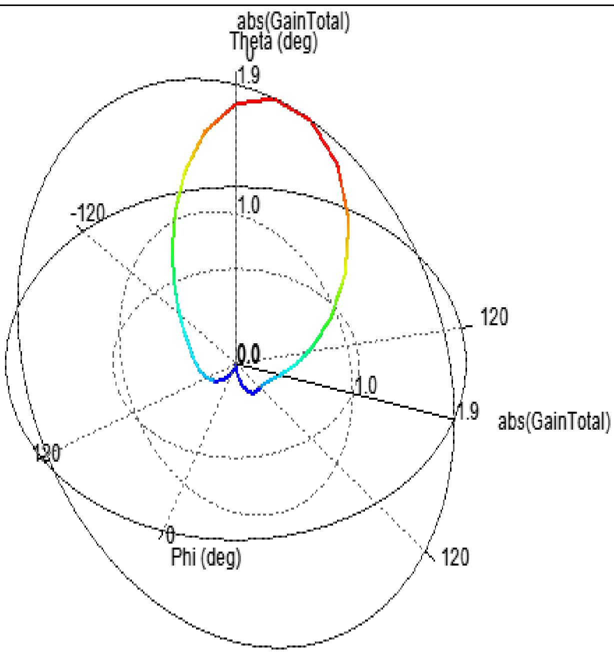
$$G=\frac{(P/S)_{ant}}{(P/S)_{iso}}$$

Gain can also be given by,

Gain = Directivity × Efficiency

If the gain is higher, then in that particular direction the signal strength is higher

Table 4.4Antenna gain for respected frequency

OPERATING FREQUENCY (in GHz)	WITH E FIELD (Phi =0 degree)	WITH H FIELD (Phi=90 degree)
9		

From the above graphs, it is inferred that gain increases with increase in frequency.

4.5 Directivity

Directivity of an antenna is given by the ratio of the maximum intensity of radiation to the average intensity of radiation. Maximum intensity of radiation means power per unit solid angle and average intensity of radiation means average over a sphere. Directivity is given by

$D = 4\pi U/P_{radiated}$

where, $P_{radiated}$ is the power radiated by the antenna.

Directivity for a real antenna can be as small as 1.76 dB but can never be less than 0dB in principle. Normally for an antenna due to low efficiency or losses, the peak gain is low. Electrically smaller antennas usually have gain lesser than -10 dB, also there will be no loss because of impedance mismatch. They are inefficient antennas.

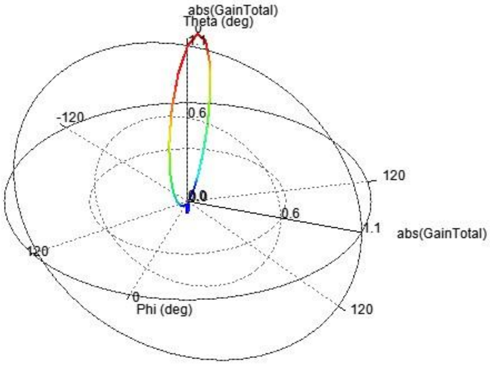
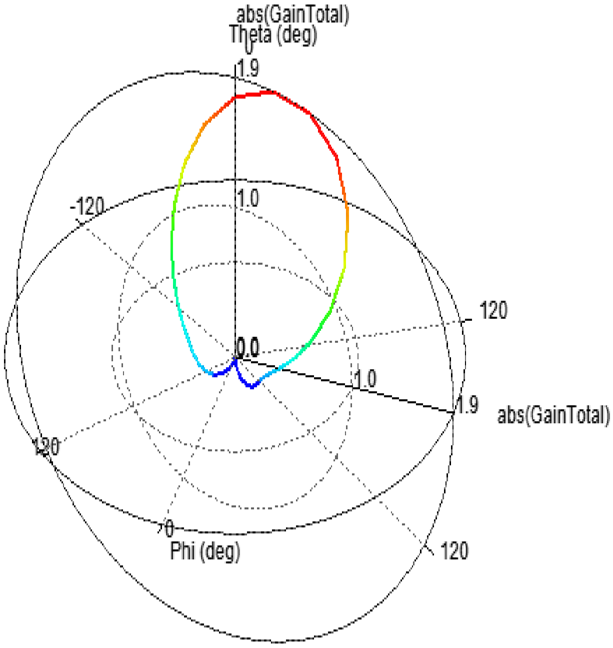
OPERATING FREQUENCY (in GHz)	WITH E FIELD (Phi =0 degree)	WITH H FIELD (Phi=90 degree)
9		

Table 4.6.2 Parameters of UWB antenna for 6GHz frequency

PARAMETER (6GHz)	**VALUE**
Peak directivity(dB)	2.257
Peak gain(dB)	1.684
Radiated Power(dB)	7.064
Beam Area	8.734
Total efficiency (dB)	0.50941

CHAPTER 5

CONCLUSION

The UWB antenna is mainly used in short range communications. It is used in wireless telecommunication systems. It is used in military telecommunications. This V-shaped slot UWB antenna is simulated in Ansys HFSS v2021. According to the simulated results the return loss is -17.202 at 9GHz and gain is 1.86 dB for the V-shaped slot UWB antenna. Thus, the designed antenna can be used for short range communication applications. Thus, optimization of the antenna properties is done successfully over the HFSS software platform.

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