Design of microstrip patch antenna with tooth slot

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

- This study presents the design and analysis of a microstrip patch antenna incorporating a tooth slot to enhance its performance characteristics. The proposed antenna aims to achieve improved bandwidth, gain, and radiation efficiency compared to traditional patch designs. The tooth slot geometry is strategically introduced to create additional resonant modes, which broaden the operational bandwidth and optimize the return loss. The simulation results indicate that the proposed antenna operates in the frequency range of [insert frequency range], demonstrating a notable increase in gain and a significant reduction in the size of the radiating element. Additionally, the radiation pattern is analyzed, revealing a desirable omnidirectional characteristic. This design approach highlights the effectiveness of slot modifications in microstrip antennas, making it suitable for various wireless communication applications, including Wi-Fi, IoT, and satellite communications. Future work will focus on further optimizing the tooth slot dimensions to maximize performance metrics.

CHAPTER 1

INTRODUCTION

1.1 Introduction to microstrip antenna

Microstrip antennas, also known as patch antennas, have gained significant popularity in recent years due to their numerous advantages, making them ideal for a variety of applications in modern communication systems. These antennas are typically constructed from a thin rectangular or circular conductive patch placed on a dielectric substrate, which is then backed by a ground plane. The simplicity of their design, lightweight nature, and ease of fabrication contribute to their widespread use in mobile devices, satellite communications, and wireless networks. Overall, microstrip antennas represent a versatile solution for meeting the demands of contemporary wireless communication systems, balancing performance, size, and manufacturability. As technology continues to advance, ongoing research in this field aims to enhance their capabilities, making them even more integral to future communication infrastructures. One of the key benefits of microstrip antennas is their low profile, allowing for easy integration into compact electronic devices. They can be manufactured using standard printed circuit board (PCB) techniques, facilitating cost-effective production and scalability. Additionally, the planar structure allows for a diverse range of shapes and configurations, enabling the design of antennas tailored for specific frequency bands and applications.

1.2 DIFFERENT TYPES OF FEEDING SYSTEM

1.Microstrip line feed

2.Inset feed

3.Co-axial feed

4.Aperture coupled

5.Proximity coupled feed

1.3 DESIGN EQUATION

1.Patch Length (L)

The length of the patch can be calculated using the following equation:

$$L = \frac{c}{2f_r}\sqrt{\frac{\varepsilon_r + 1}{2}} - 2\Delta L$$

Where:

- c = speed of light in vacuum(≈3×10^8 m/s)
- fr = resonant frequency of the antenna
- εr = relative permittivity of the dielectric substrate
- h = height of the dielectric substrate

  W = width of the patch

2. Patch Width (W)

The width of the patch is determined by:

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

3.Effective Dielectric Constant (εeff)

The effective dielectric constant accounts for the fringing effects and is given by:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + 12\frac{h}{W}}}\right)$$

4. Input Impedance (Z)

The input impedance of the microstrip patch antenna can be approximated as:

$$Z \approx \frac{Z_0}{1 + j\frac{(f - f_0)}{BW}}$$

Where:

- fo = resonant frequency
- BW = bandwidth
- Zo = characteristic impedance

5. Radiation Pattern and Gain

The gain (G) of the antenna can be estimated using:

$$G \approx 10 \log_{10}\left(\frac{4\pi A_e}{\lambda^2}\right)$$

Where:

- Ae= effective aperture area
- λ = wavelength in the dielectric medium

6. Bandwidth

The bandwidth (BW) of the microstrip patch antenna can be approximated by:

$$BW \approx \frac{f_0}{Q}$$

Where Q is the quality factor, typically influenced by the antenna dimensions and substrate properties.

ADVANTAGES OF MICROSTRIP PATCH ANTENNA

1. **Wideband Performance**: Supports a broader frequency range, suitable for various applications.
2. **Low Profile**: Compact design makes it ideal for integration into space-constrained devices.
3. **Ease of Fabrication**: Simple manufacturing processes reduce production costs.
4. **Lightweight**: Materials used are generally lightweight, beneficial for portable applications.
5. **Directional Radiation Pattern**: Can be designed to focus energy in specific directions, enhancing performance.

DISADVANTAGES OF MICROSTRIP PATCH ANTENNA

1. **Limited Gain**: Generally lower gain compared to other antenna types, which may affect long-range communication.
2. **Radiation Loss**: Increased radiation loss at certain frequencies can reduce overall efficiency.
3. **Sensitivity to Environmental Factors**: Performance may vary with changes in temperature and humidity.
4. **Complexity in Design**: Achieving desired wideband characteristics can complicate the design process.
5. **Lower Efficiency**: May exhibit lower efficiency, particularly at higher frequencies due to material constraints.

APPLICATIONS OF MICROSTRIP PATCH ANTENNA:

1. **Wireless Communication**: Ideal for Wi-Fi, Bluetooth, and LTE applications.

2. **Satellite Communication**: Suitable for satellite systems requiring wideband capabilities.
3. **Radar Systems**: Useful in radar applications where wideband performance is critical.
4. **Mobile Devices**: Integration into smartphones, tablets, and other portable electronics.

5.**Internet of Things (IoT):** Applicable in IoT devices needing efficient and compact antenna solutions

CHAPTER 2

LITERATURE SURVEY

Richa Sharma et al. [2] introduced an enhanced version of the tooth-like-slot microstrip patch antenna, focusing on its application in 5G networks. This design incorporates an inset feeding technique that not only improves bandwidth but also enhances the antenna's radiation efficiency. The overall dimensions of the antenna are 20 × 28 mm², and it operates effectively in the frequency range of 3.3 GHz to 6.0 GHz. Experimental results showed a peak gain of 6.2 dBi, with the antenna exhibiting a stable radiation pattern suitable for modern communication systems. The study emphasized the importance of optimizing the tooth-like slot

Ankush Verma et al. [1].proposed a novel design for a single-layer wideband tooth-like-slot microstrip patch antenna fed by an inset microstrip line, targeting wireless communication applications. The antenna features a unique tooth-like slot configuration that enhances bandwidth by creating multiple resonant frequencies. The overall dimensions of the antenna are 25 × 30 mm², demonstrating a significant reduction in size compared to conventional patch antennas. The use of a low-cost FR4 substrate ($h = 1.6$ mm, $\varepsilon\_r = 4.3$, $\tan \delta = 0.025$) facilitates easy manufacturing. The measured bandwidth of the antenna spans from 3.1 GHz to 7.5 GHz, achieving a gain of approximately 5 dBi at the center frequency of 5.5 GHz

Deepak Kumar et al. [3] explored the performance characteristics of a single-layer wideband low-profile microstrip patch antenna with tooth-like slots, focusing on its applications in IoT devices. The proposed antenna design measures 22 × 24 mm^2 and operates across a frequency range of 2.5 GHz to 5.5 GHz. By utilizing a defected ground structure, the authors achieved significant improvements in bandwidth and efficiency, with a measured bandwidth of 1.5 GHz. The antenna demonstrated omnidirectional radiation patterns, making it suitable for diverse IoT applications.

CHAPTER 3

DESIGN METHODOLGY

3.1 SOFTWARE REQUIREMENTS

Simulator:ANSYS HFSS Desktop Student v2020

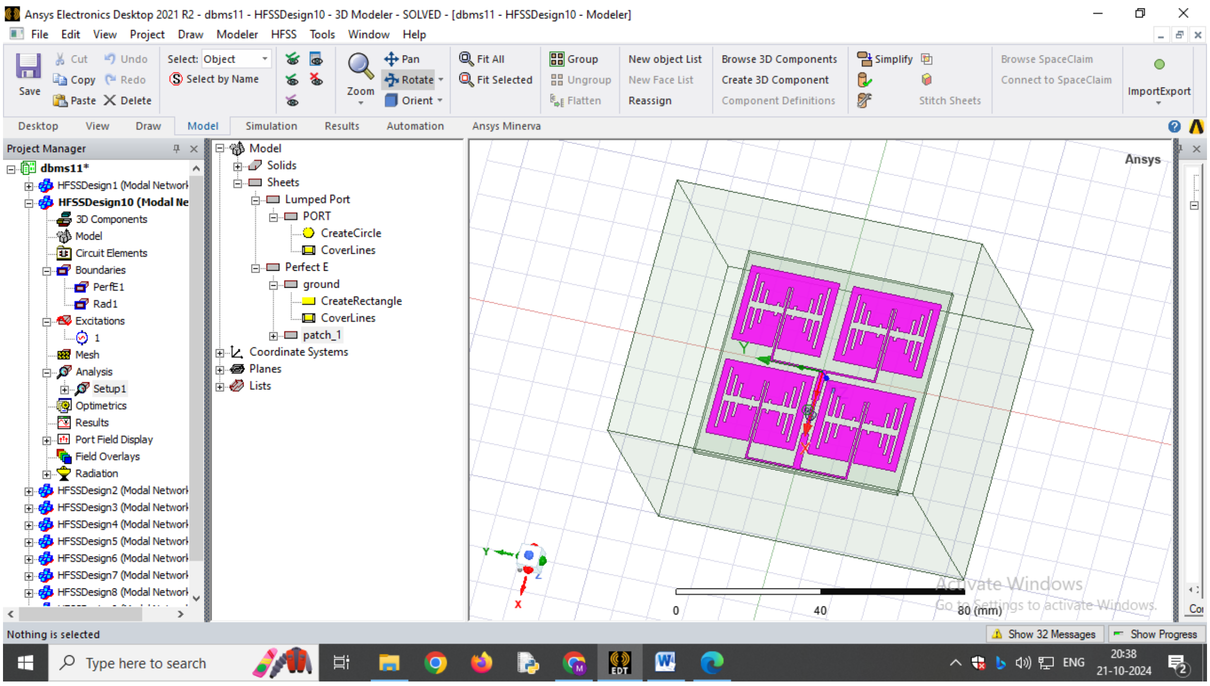
3.1.1 High frequency structure simulator

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 an 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.



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.

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 units as mm
- The length of ground is 30mm
- The breadth of ground is 15mm

Create substrate

- Draw cuboid surface
- Draw sweep at Z axis
- Thickness is 1mm
- X-axis is 30mm
- Y-axis is 15mm
- Assign material as FR4

Create patch:

- Draw a rectangle surface
- Make the axis as Z
- X axis is 19.5mm
- Y axis is 1.6mm

Creating the feed:

- Create a box in the rectangular patch
- Position of the box = 0,-0.8,1.2
- Xsize of the box = 19.5
- Ysize of the box = 1.6
- Axis of the rectangle is Z
- Draw a rectangleabove the feed and named it as cut
- Position of the rectangle = 16,-0.8,1.6

- Axis of the rectangle = Z
- Xsize of the box = 9.7
- Ysize of the box = 2.5
- Select the patch and cut using cut option cut the portion from the patch to make feed.

Create port:

- Create a port on the end of the feed using box
- Position of the box=16,-0.8,1.6
- Axis of the rectangle = X
- Y-axis= 1.6 , Z axis = -1.6
- Select port -> assign excitation -> lumped 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 fast
- Assign the start stop and Step sizes.
- Validation check is ensured.
- By right clicking the HFSS option in the menu
- 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 metamaterialantenna design specifications are discussed below. The step by step procedure for designing theantenna 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

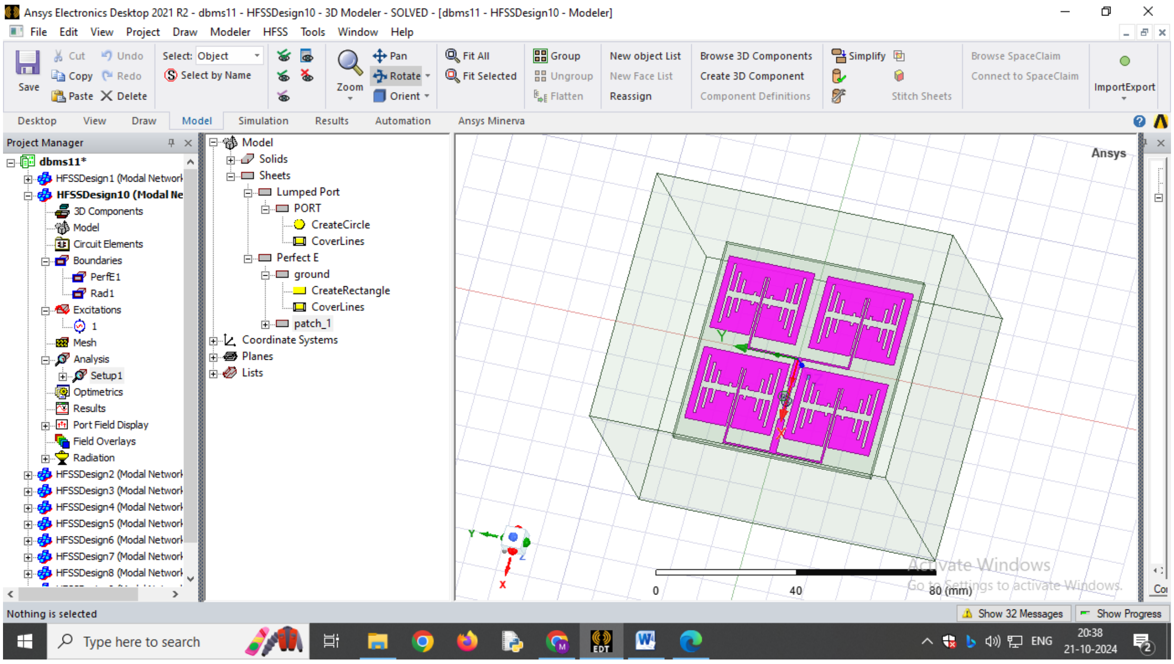
Table 3.1 Design specifications of metamaterial antenna

Design Parameters	Value
Patch length	19.5mm
Patch width	45mm
Feed length	4.8mm
Feed width	1.6mm

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



Geometry of the metamaterialantenna in ANSYS HFSS 3D modeler window

3.4.2 Assignment of boundary

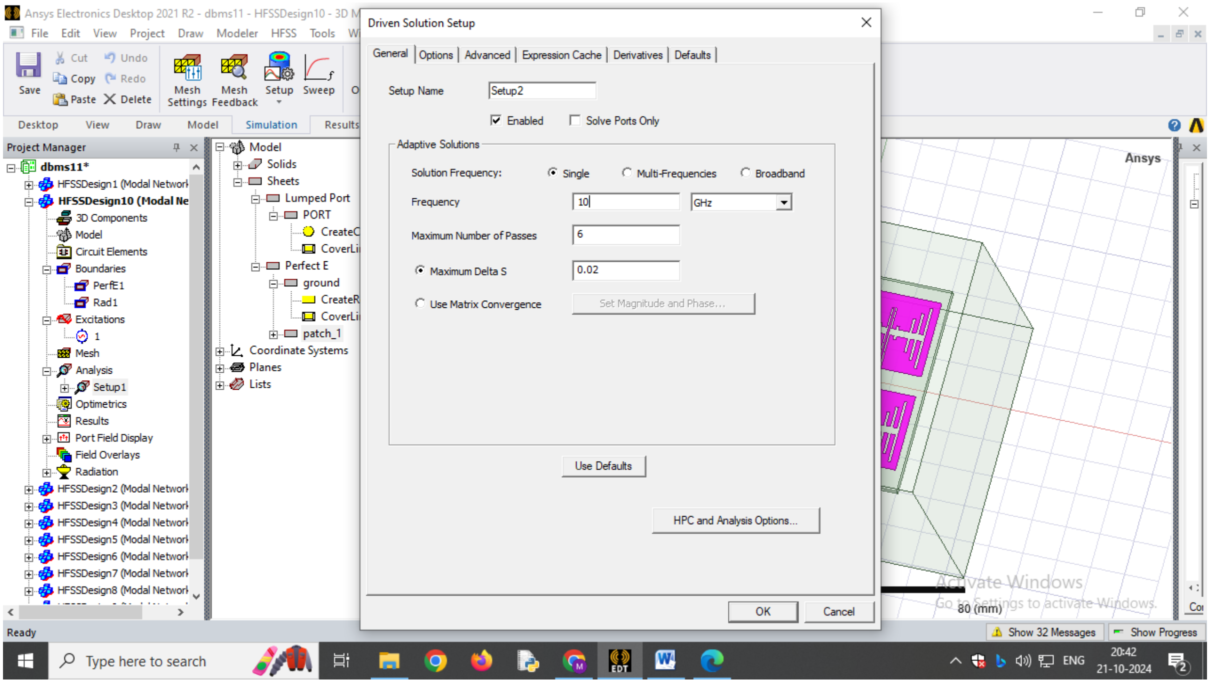
The next step is assigning the boundaries to the antenna structure. The open model in HFSS can be created by assigning the radiation boundaries. While simulating an antenna, the radiation boundary should be positioned in such a way, that it is quarter the wavelength away from the surface of radiation.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

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

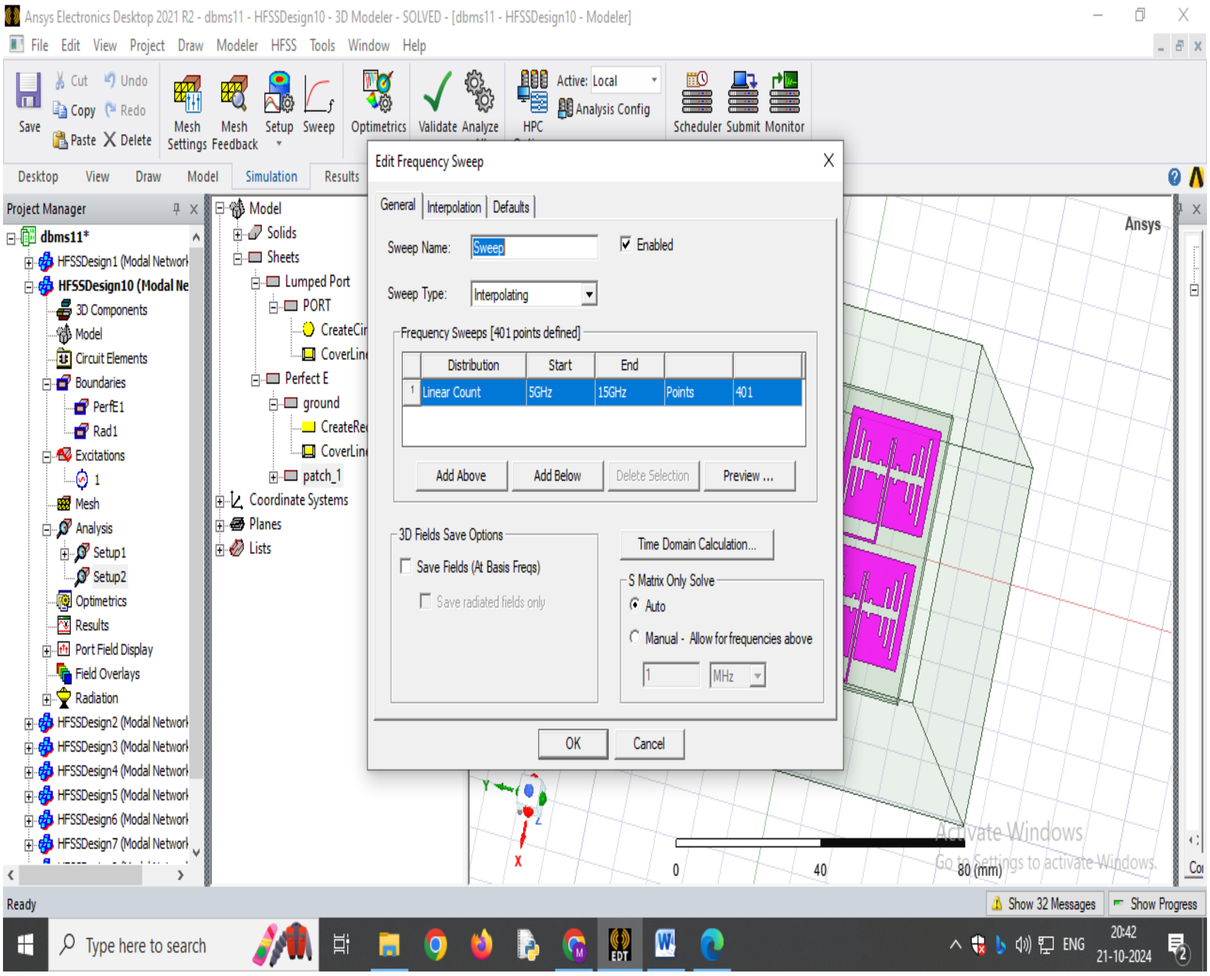
3.4.4 Setting up for solution

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 sweep 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 3.2.



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



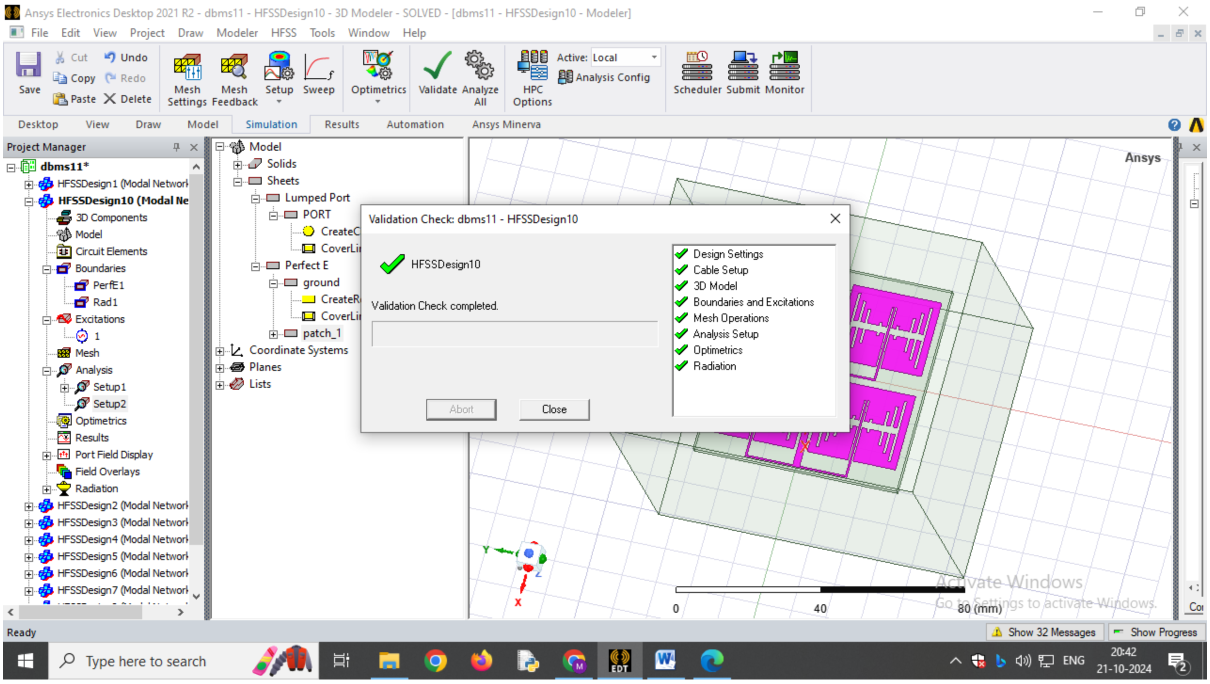
Dialog box showing setting up the sweep frequency

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

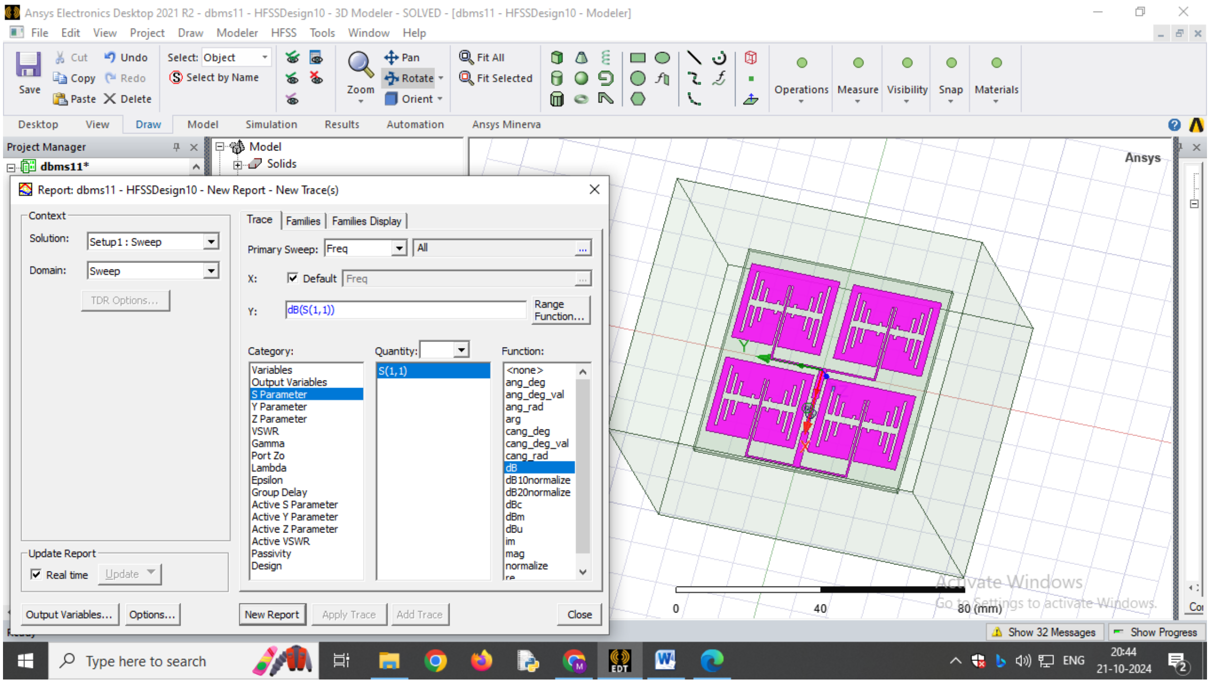
Once after the completion of the above steps by the HFSS user, the model needs to be analyzed and validated. Error will be thrown if any error occurs in the previous steps. The time required for the analysis depends on few factors like the geometry of the antenna; the range of solution frequency, the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

Dialog box showing the above steps validation



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



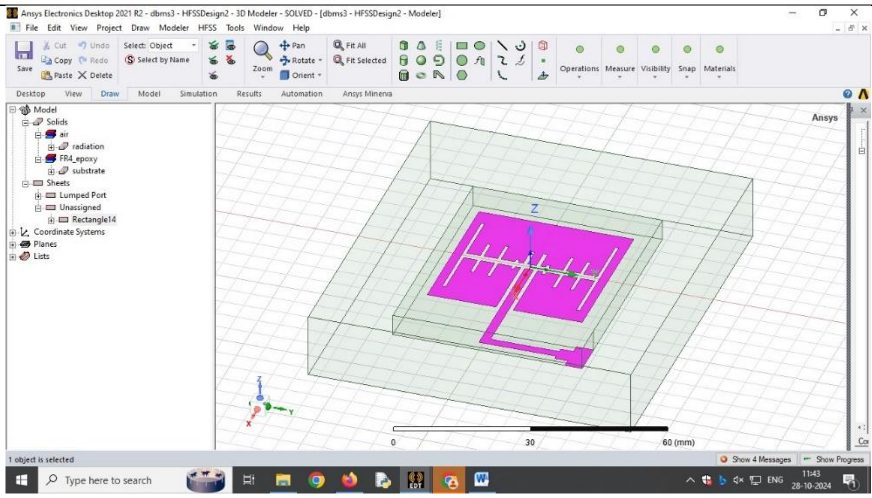
Dialog box for obtaining s-parameter results in HFSS

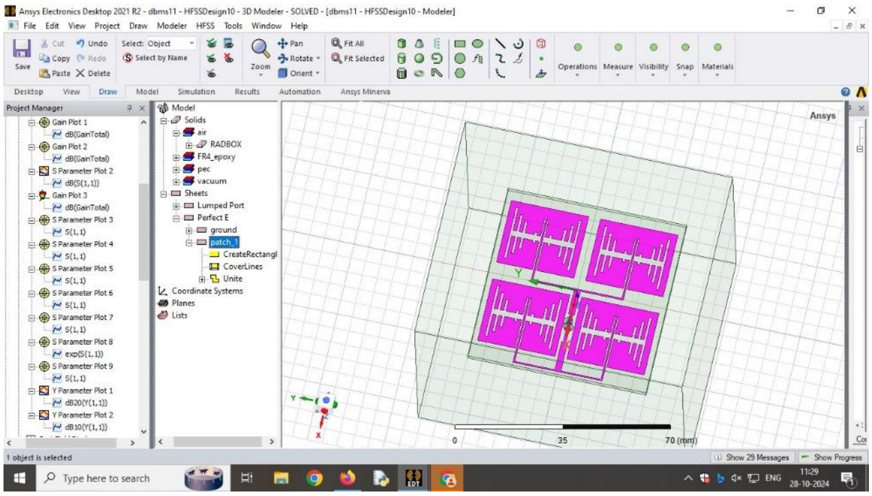
CHAPTER 4

SIMULATION RESULTS

This chapter deals with simulation results obtained from metamaterial antenna using line feed

4.1Parameter analysis for different structures

Structure 1	

Structure 2	

4.2 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,

$$\textbf{RL (dB)} = 10 loglog10\left(\frac{\mathrm{Pincident}}{\mathrm{Preflected}}\right)$$

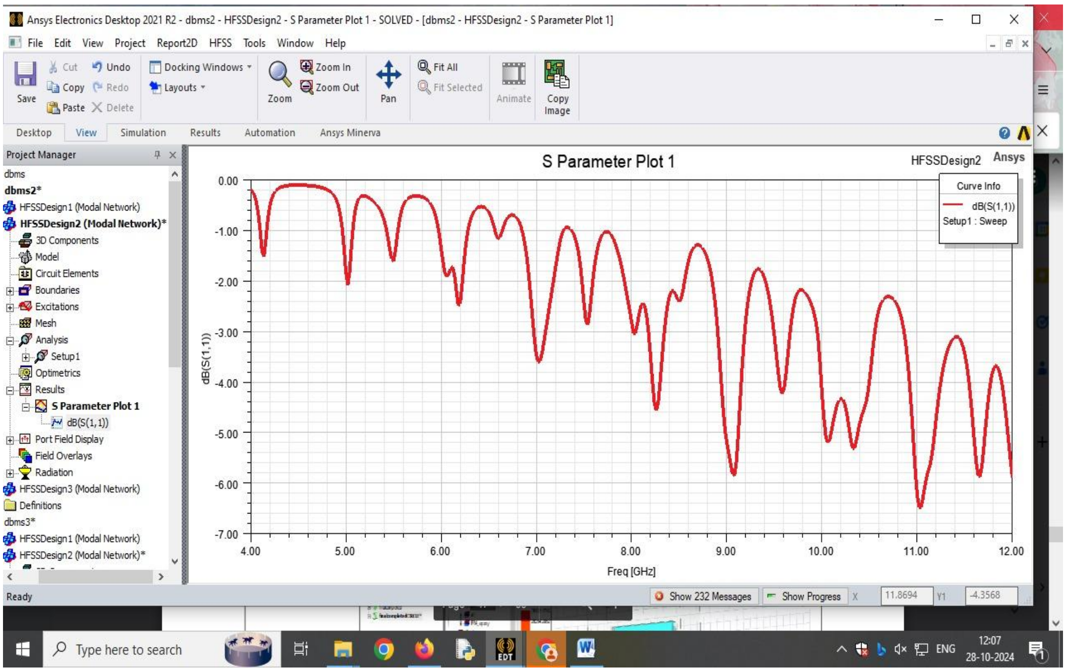
where, RL (dB) is the return loss in terms of dB

$P_{incident}$ is the incident power

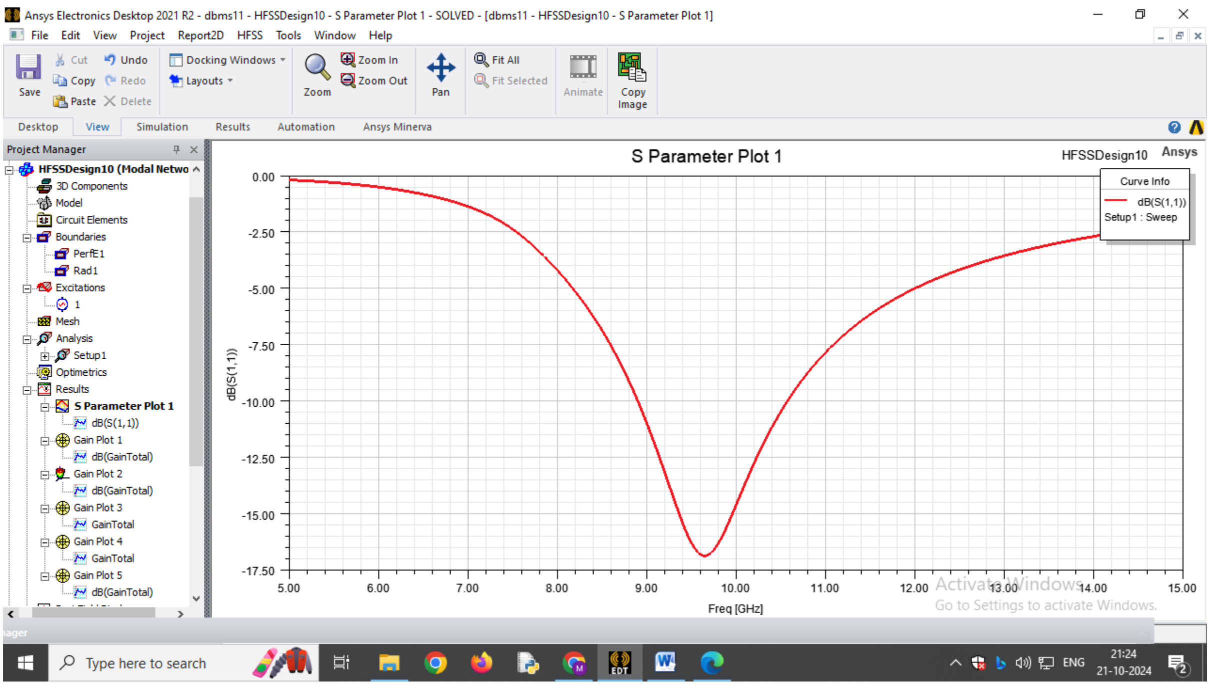
$P_{reflected}$ is the reflected power

Table 4.2Return Loss for different structure

Structure 1



Structure 2

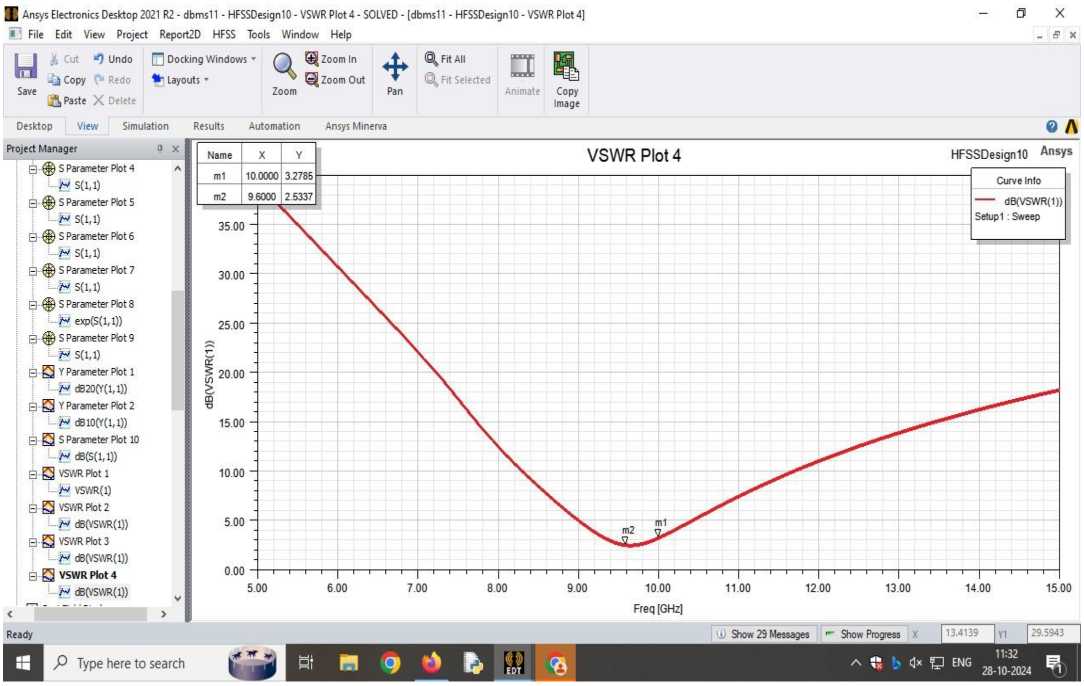


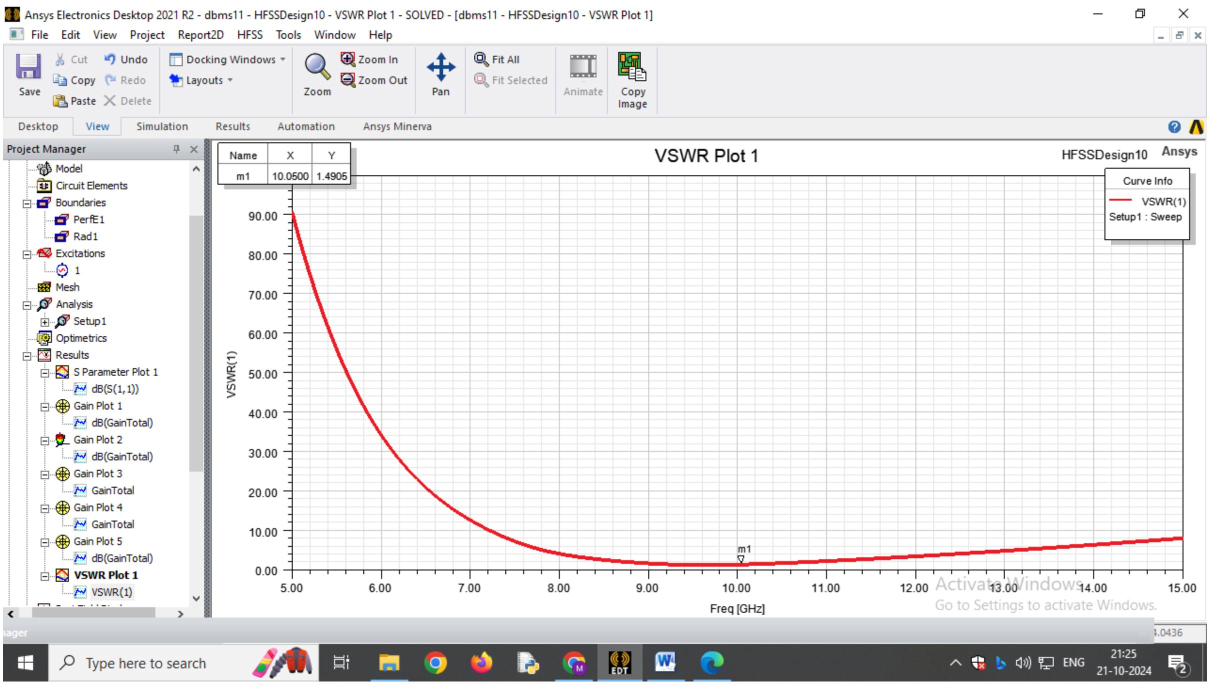
4.3 VSWR

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 4.3VSWR plot for different structures

structure	**VSWR**
structure 1	

Structure 2	

4.5 Antenna gain

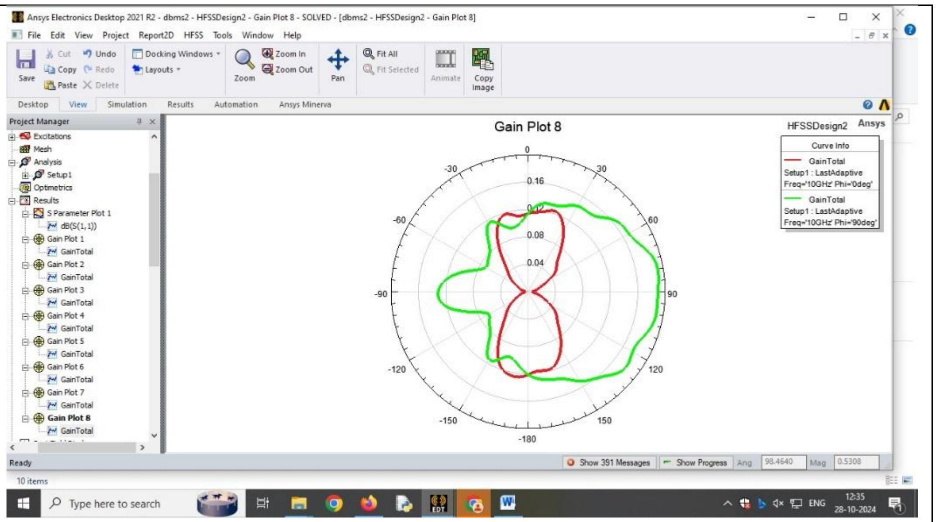
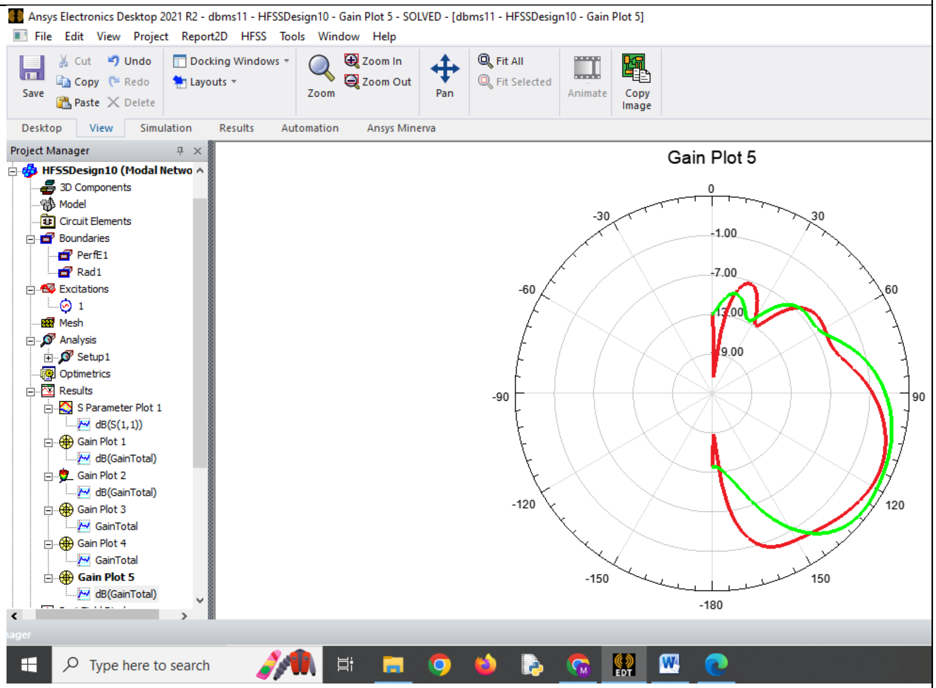
The directionality of the antenna is measured by a factor called Antenna Gain or Gain of an Antenna. In particular, power gain is defined in terms of ratio of radiated intensity of an antenna in a particular direction at a random distance to the radiated intensity by an isotopic antenna at the same distance. 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.

STRUCTURE 1	
STRUCTURE 2	

4.8 3D Gain plot for different structure:

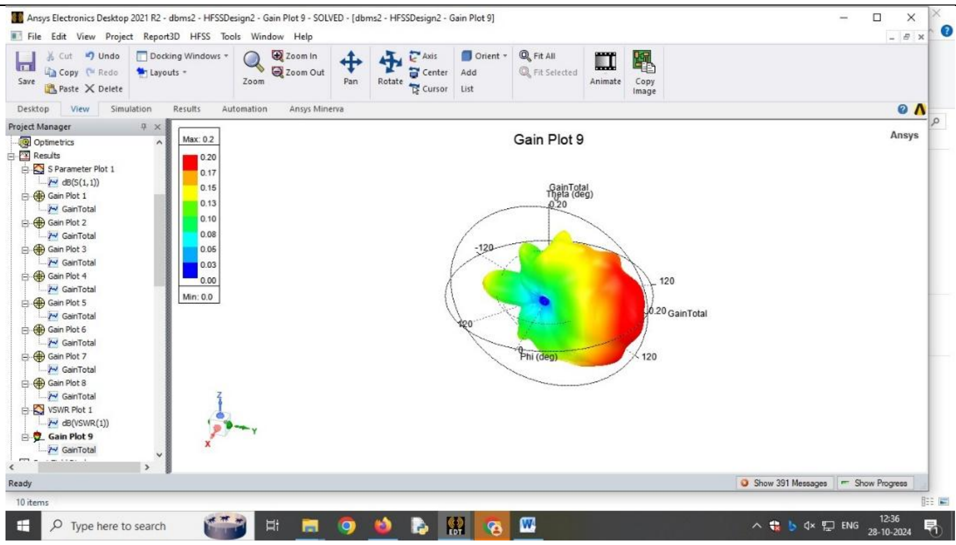
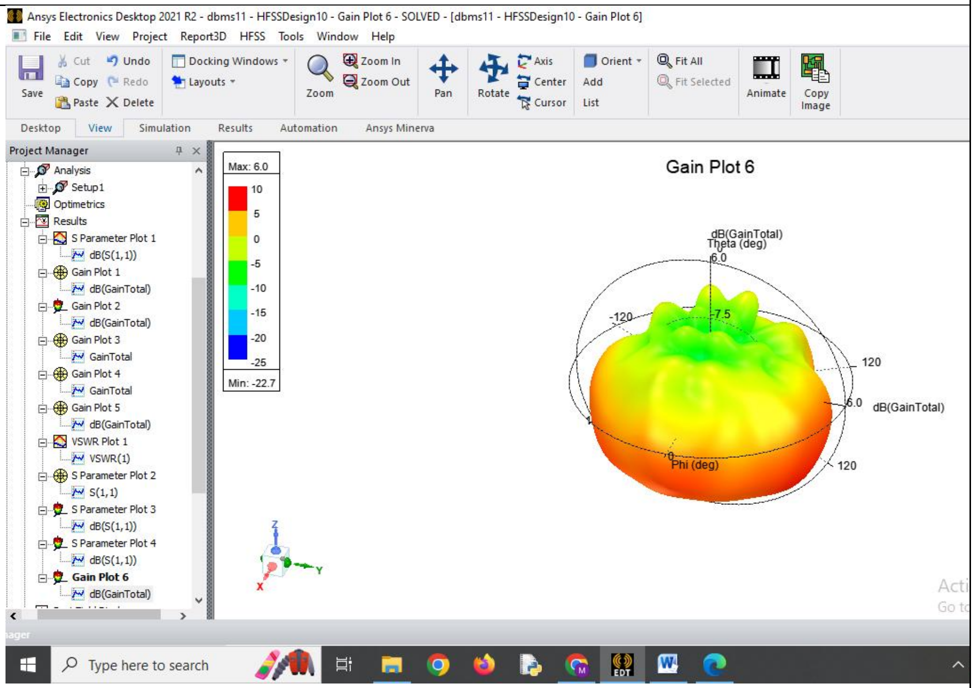
STRUCTURE1	
STRUCTURE 2	

Table 4.9Parameters of microstrip patch antenna

PARAMETER	VALUE
Peak directivity(dB)	3.8092
Peak gain(dB)	3.9648
Radiation efficiency	1.0409
Radiated power	1.0046W
Front to back ratio	6.4837

Table 4.10 Comparison table for parameters

Paramater	Gain	Directivty/bandwidth	Efficiency	Frequency in GHz	Return loss in db
Structure 1					
Structure 2					

Inference:

Microstrip patch antennas are popular for their compact size, lightweight design, and ease of integration with circuit boards, making them ideal for mobile and handheld devices. They can be made in various shapes and sizes, allowing for tailored performance, and can be easily fabricated using standard PCB techniques, keeping costs low. While they typically have directional radiation patterns and a peak directivity of 6 to 9 dBi, their bandwidth can be narrow unless modified through techniques like slotting. These antennas are widely used in applications such as Wi-Fi, GPS, and RFID, balancing performance with design flexibility. Overall, microstrip patch antennas are a versatile choice for modern communication systems

CONCLUSION

In conclusion, microstrip patch antennas offer a versatile and efficient solution for modern wireless communication needs, thanks to their compact size, lightweight design, and ease of fabrication. While they exhibit directional radiation patterns and can achieve moderate directivity, their inherent bandwidth limitations can be addressed through innovative design techniques. Their widespread applicability in fields such as Wi-Fi, GPS, and mobile communications underscores their importance in contemporary technology. Overall, microstrip patch antennas strike an effective balance between performance and practicality, making them a key component in the development of next-generation communication systems.

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