

METAMATERIAL LOADED ANTENNA FOR COMMUNICATION APPLICATIONS

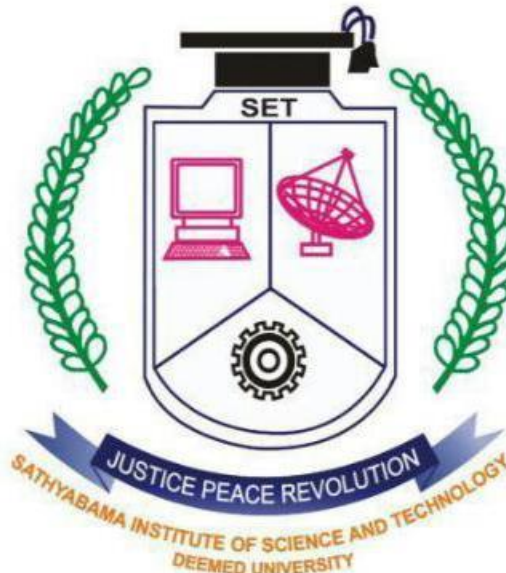
A Project Report Phase – II

Submitted in partial fulfilment of the requirements for the award of
Bachelor of Engineering Degree in Electronics and Communication Engineering

by

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**DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING
SCHOOL OF ELECTRICAL AND ELECTRONICS**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

Accredited with Grade "A" by NAAC

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APRIL - 2023



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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the Bonafide work of ARUN KUMAR REDDY RAMIREDDY (39130040) and BETHAM VEERA REDDY (39130065) who carried out the project entitled "METAMATERIAL LOADED ANTENNA FOR COMMUNICATION APPLICATIONS" under our supervision from November 2022 to April 2023.

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DECLARATION

We **ARUN KUMAR REDDY RAMIREDDY (39130040)** and **BETHAM VEERA REDDY (39130065)** hereby declare that the Project Report entitled “**Metamaterial Loaded Antenna for Communication Applications**” is done by us under the guidance of **Dr. L. MAGTHELIN THERASE M.E., Ph.D.**, is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in **Electronics and Communication Engineering**.

SIGNATURE OF THE CANDIDATES

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ABSTRACT

Microstrip antennas are becoming more popular due to its use in high frequency and highspeed data communication applications. A novel circular ring metamaterial structure has been proposed for its operation over the frequency range 8-12 GHz (X-band). The metamaterial structure is placed on the top of the substrate as a patch. The structure is designed using lossy FR4(Flame Retardant 4) substrate material. The proposed antenna is analysed, simulated and optimized using HFSS. The various antenna parameters such as return loss, voltage standing wave ratio (VSWR), Gain and Directivity are simulated.

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CHAPTER – 1

INTRODUCTION TO ANTENNAS

1.1 INTRODUCTION:

Humans initially communicate with one another using speech and sound. When the requirement for slightly longer distance communication arose, instruments like drums were utilized, followed by some visual techniques like flags and smoke signals. These optical communication systems, naturally, use the electromagnetic spectrum's light as range. The use of radio to communicate throughout the electromagnetic radiation beyond the visible range is a relatively recent invention in human history.

1.2 CONCEPT OF ANTENNAS

1.2.1 Need of Antennas:

An antenna performs the electrical function of converting electrical power into radio waves and back again. It frequently works in conjunction with a radio transmitter or radio receiver. When transmitting, An electrical current that oscillates at radio frequencies is fed into the antenna's terminals by a radio transmitter, and the antenna emits the electricity that results from the electrical current as electromagnetic radiation. On the other hand, during reception, an antenna absorbs a portion of the energy from an electromagnetic wave and generates a tiny voltage at its terminals that may be amplified and transferred to a receiver.

The electromagnetic spectrum is among humanity's most significant natural assets, and the antenna has played a crucial role in exploiting this resource. A device called an antenna is made to efficiently transmit and receive electromagnetic waves. Consider critical antenna characteristics including radiation patterns, gain, directivity, and polarisation when choosing the right antenna for your purposes.

An antenna serves as the radiating component of an RF system, enabling the transmission and connection of signals from one end of the system to the other wirelessly. Several scientific theories exist to explain the radiation of antennas, some of which have been both approved and mathematically demonstrated.

According to the theories presented in Maxwell's theorem, antennas work by transforming electrical impulses into electromagnetic waves. As early as the first half of the 20th century, Nikola Tesla was among the first to conceive of wireless energy transfer, at a time when using copper cables for transmission was the norm. Tesla observed that when an electric coil is energized, it generates radiation that extends into the surrounding space, leading him to consider the possibility of transmitting information through the air.

Tesla constructed a tower and conducted experiments to test his theories on information transfer. Although he achieved success in his experiments, they were not widely accepted due to the lack of mathematical proof for his theories. However, Tesla's theorems were later used by Maxwell, who created mathematical relationships between the magnetic and electrical fields around an energised coil.

1.2.2 Working of Antenna

The metal patch is energised and generates a magnetic flux in line with the Maxwell's equation when an analogue feed is applied to the antenna strip. The electrical circuit is completed by using the ground. A magnetic field is created between the two levels of the antenna by the radiation that the patch emits when it emerges at the ground. The kind and thickness of the dielectric material utilised determines the amount of radiation produced, and the substrate material is used to regulate the flux merging into the ground. It emits a field of magnetism, and the ensuing electric field is orthogonal to the field of magnetism that formed it. This creates a new field of magnetism, and so on. This is the way electromagnetic waves go through a particular material.

1.3 TYPES OF ANTENNAS

Antennas are divided into a variety of categories, which are listed below:

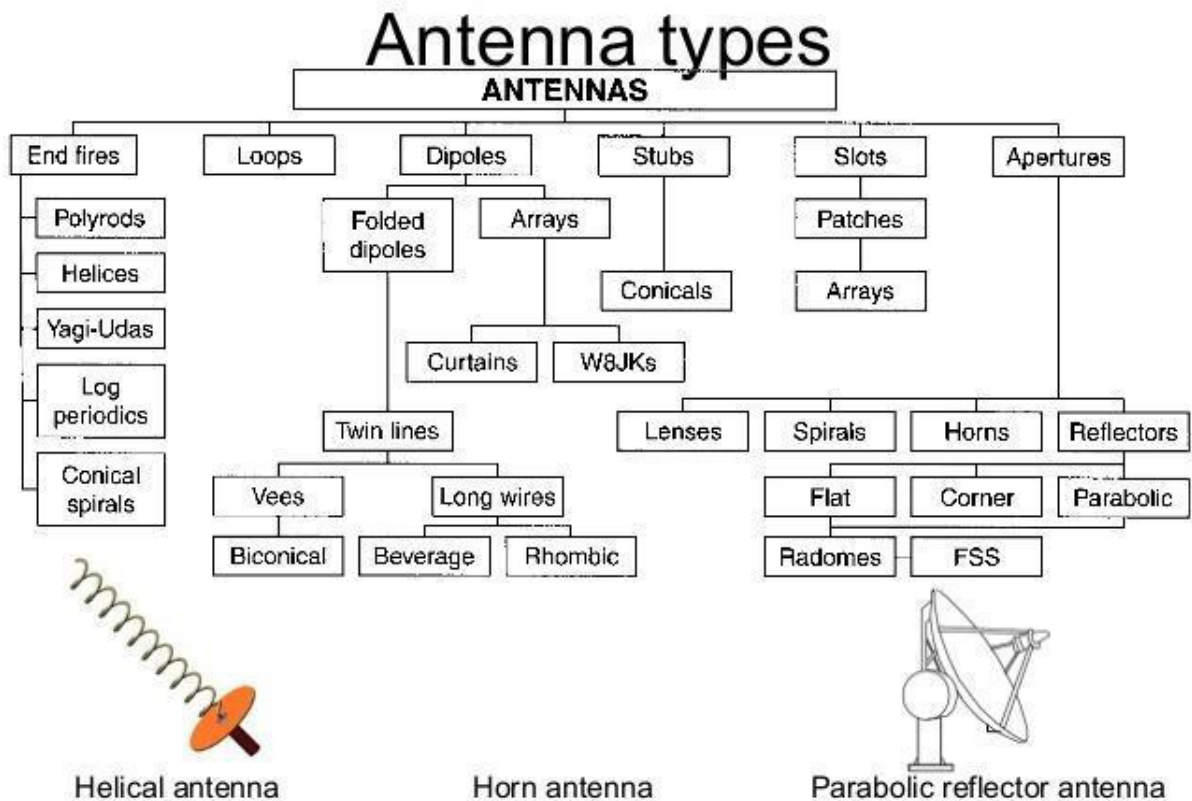


Fig 1.1 Types of Antennas

1.3.1 Based on Radiation:

- *Omni-directional antennas*: which broadcast and receive essentially in all directions, are also known as weakly directional antennas.
- *Directional antenna*: They transmit and receive radiation in a specific direction and are also known as beam antennas. In order to enhance electromagnetic interaction in the direction of the station receiving it or to cover a certain region, directional antennas are used.

1.3.2 Based on Aperture:

- *Wire Antennas*: This type of antennas is ubiquitous and may be seen on vehicles, structures, ships, aeroplanes, and more, the general public is familiar with these sorts of antennas.
- *Aperture Antennas*: The increasing demand for more sophisticated antenna designs and higher frequency usage has led to greater recognition of these antennas compared to their lesser-known past. Due to their simplicity of

mounting aboard spacecraft and aeroplanes, they are more helpful in certain applications.

- *Microstrip Antennas:* Government, commercial, and space uses all employ these antennas. They are made up of a grounded substrate and a metallic patch. These antennas are mounted on the exterior of high-performance aircraft.
- *Array Antennas:* When a single antenna cannot provide the necessary radiation characteristics, an array, or collection of radiating elements, is utilised. The positioning of the arrays should result in maximum radiation in one or more specific directions and minimal radiation in other directions when the radiation accumulates up.

1.3.3 Based on Polarization:

- *Vertically polarised antenna:* This type of antenna is said to be linearly polarised if it transmits and receives in the vertical E direction. An antenna is referred to as horizontally polarised if it is transmitting or receiving in the horizontal E direction.
- *Circularly polarised antenna:* An antenna is said to as circularly polarised if it can transmit and receive E field vectors in any direction. In today's wireless landscape, the primary requirement is for antennas to be as compact as possible. Therefore, microstrip antennas are the most favourable option among the available antenna structures when considering their application in WLAN.

1.4 ANTENNA PARAMETERS

1.4.1 Radiation Pattern

Antennas output or reception power is a function of its radial distance and angular location. However, E-plane or H-plane diagrams, in which one angle is maintained while the other is modified, are more often employed. These diagrams plot power versus elevation and azimuth angles in three dimensions. The phrase "radiation pattern" refers to a visual depiction of how the properties of antenna radiation change with geographical coordinates. The term "radiation pattern" describes the directionality of the radio wave intensity coming from the antenna.

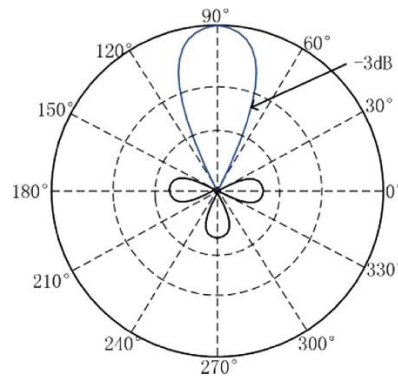


Fig: 1.2: Radiation Pattern

The radiation pattern of a microstrip patch antenna may be calculated easily, but precise calculations depend on locating the source of the electric field radiation at the space between the microstrip element's edge and the ground plane.

1.4.2 Return Loss

When attaching an antenna, return loss is a crucial factor. It's used to explain how signal sources' input and output work. Impedance matching and the maximum transfer of power theory are strongly related to return loss. When there is a mismatch between the generator and the load, not all available power is transferred. The return loss has an impact on how efficiently energy is transferred from the point of origin to the antenna.

The return loss, or RL, displays the signal's intensity in relation to the incident signal in decibels. The amount of power reflected back to the source antenna (P_{ref}) divided by the power incident on the antenna (P_{in}) is used to determine the return loss. The ratio of P_{in} to P_{ref} needs to be high for efficient power transfer. Standing wave phenomena or resonances may occur and cause a gain or frequency ripple if the return loss is low. The return loss, or response of S_{11} vs frequency, is used to build microstrip patch antennas. In most real-world circuits, a return loss value of -10 dB is regarded as adequate.

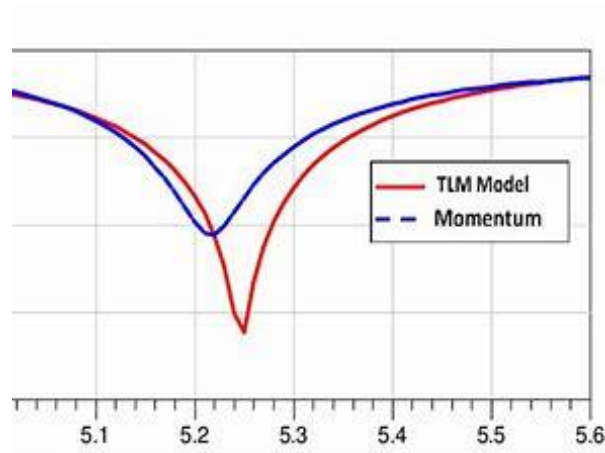


Fig: 1.3: Return loss plot

1.4.3 Gain

An antenna's directivity and electrical efficiency combine to generate its power gain, an important performance parameter in electromagnetics. While the gain of a receiving antenna defines its capacity to convert radio waves coming from a given direction into electrical power, the gain of a transmitting antenna shows its effectiveness in converting input power into radio waves travelling in a specific direction. When no direction is given, "gain" refers to the highest possible value. The gain as a function of direction is illustrated by the radiation pattern.

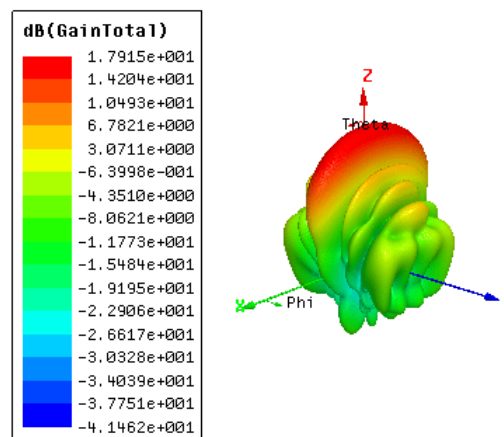


Fig: 1.4: Gain plot

1.4.4 Directivity

Larger values indicate more focused beams whether expressing directivity as a regular number that represents the ratio or in dB. An antenna radiating evenly in all directions would have a directivity of 1 (0 dB). Due to the absence of energy transmitted in the z-direction, the Hertzian dipole previously described has a directivity of 1.5 (1.76 dB).

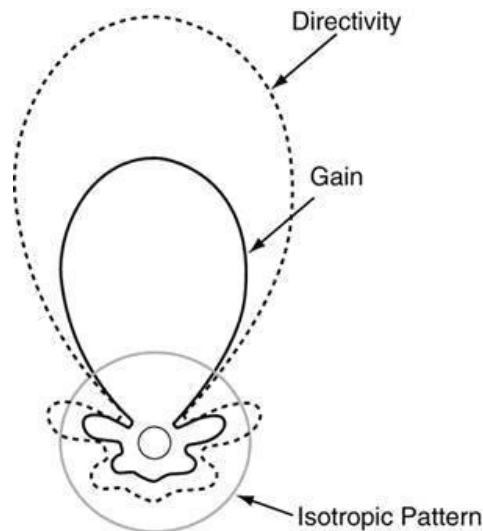


Fig: 1.5: Directivity

Antennas may be used in a broad range of applications depending on their directivity, such as

- Information is transmitted and received from all directions almost equally by low-directivity antennas. Due to the changing direction between the transmitter and receiver in most mobile applications, such antennas prove to be useful.
- High-directivity antennas must be pointed at another antenna in order to send and receive information across longer distances. They are applied in long-term setups like satellite television.

1.4.5 Bandwidth

The frequency range across which an antenna may operate with respectable performance is referred to as its bandwidth, based on a specific standard. This range can be calculated by dividing the upper frequency by the lower frequency of acceptable operation. The frequency difference between the higher and lower

frequencies over the centre frequency is used to express bandwidth for narrowband antennas.

1.4.6 Antenna Efficiency

Antenna efficiency is a simple measurement of how effectively antenna converts its electrical power feed to it into electromagnetic radiation. It is described as the ratio of the power that is radiated to the total input power, which includes the power that is radiated as well as any power that is lost as heat or reflected back to the source. A perfectly efficient antenna would have an efficiency of 100%, meaning that all of the input power is converted into radiated power. However, in reality, no antenna can be perfectly efficient, and some amount of power is always lost due to various factors such as resistive losses, dielectric losses, and mismatch losses. Antenna efficiency is an important parameter to consider in antenna design, as higher efficiency leads to better signal strength, range, and overall performance of the antenna system.

1.4.7 Polarization

An antenna's polarization refers to the polarization of the wave it transmits or radiates. If the direction is not specified, the antenna's polarization will align with the direction of its maximum gain. Generally, a rectangular patch with traditional feeding will emit a linearly polarized wave.

By implementing certain alterations to the feeding techniques or the patch design, a rectangular patch antenna can be transformed into a circularly polarized one. The key benefit of utilizing circular polarization is that the receiver orientation can remain constant, allowing for reliable signal reception from various transmission axes.

1.4.8 Voltage Standing Wave Ratio

As electromagnetic waves move through various segments of the antenna system, they may encounter variations in impedance at different interfaces for instance, from the source to the antenna, then to free space, through the feed line. The quantity of the wave's energy that is reflected back to the source, that is governed by the impedance match, causes a standing wave pattern to appear in the feed line. The voltage standing wave ratio (VSWR), which may be measured, measures the relationship between the wave's greatest and minimum powers. In low-power applications, a VSWR of 1.5:1 is just slightly acceptable, whereas a VSWR of 1:1 is

the ideal result. Improving power transmission across the system by reducing impedance variations at each interface reduces VSWR.

1.4.9 Axial Ratio (AR)

The quality of circular polarization's wave propagation is largely dependent on the axial ratio (AR). The axial ratio is determined as the ratio of a polarisation ellipse's main to minor axis in line with the IEEE standard definition. On the other hand, the axial ratio pattern illustrates the axial ratio of a wave that an antenna emits over a section of its radiation pattern. The axial ratio of a wave that is completely circularly polarised is 1 or 0 dB. The rotational circle of the electric field vector degenerates into a line, leading to linear polarisation, when the amplitude of the right-hand circular polarisation (RHCP) components is equal to that of the left-hand circular polarisation (LHCP) components., and the axial ratio value to approach infinity.

1.4.10 Impedance Matching

Impedance matching involves the design of the antenna's input impedance (Z_{in}) or matching it with the output impedance of the corresponding RF circuitry, which is usually 50 Ω . A match is considered perfect when Z_{in} is equal to Z_o .

1.5 MICROSTRIP ANTENNA

Microstrip patch antennas are extensively utilized in communication systems as a type of antenna. It is a flat, rectangular or circular-shaped antenna that consists of a thin conducting patch of metal (usually copper) mounted on a dielectric substrate (usually made of fiberglass, Teflon or ceramic). A coaxial cable or a microstrip transmission line connected to a feed point on the patch is commonly used to feed the patch.

Because of its low profile, simplicity in construction, and ability to be merged with other electrical parts on a board with printed circuits, micro strip patch antennas are widely used. They may be applied to many different systems, such as radar systems, systems for wireless communication, and satellite communication systems.

The ability to be constructed with a directional radiation pattern, which allows them to broadcast or receive signals in a specified direction, is one advantage of

microstrip patch antennas. This property makes them useful in applications where directional antennas are needed, such as point-to-point communication links.

one of the main disadvantages of microstrip patch antennas is their low efficiency, which can be due to various factors such as substrate losses, conductor losses, and surface waves. Therefore, designers must carefully optimize the design parameters to achieve the desired performance.

1.5.1 Types of Microstrip Patch Antenna

There are several kinds of microstrip patch antennas, and each one has unique characteristics. Some of the most typical varieties are listed below:

1. *Rectangular Microstrip Patch Antenna*: This is the most basic and commonly used type of microstrip patch antenna. It consists of a rectangular patch. It can operate at a wide range of frequencies
2. and has a simple design.
3. *Circular Microstrip Patch Antenna*: It has a circular metallic. It has a wide bandwidth and can be used for applications that require circular polarization.
4. *Triangular Microstrip Patch Antenna*: It has a metal triangular patch on it. Its broad bandwidth makes it suitable for omnidirectional radiation-demanding applications.
5. *Dual-Frequency Microstrip Patch Antenna*: It can run on two separate frequencies thanks to its architecture. It comprises of two rectangular patches on the same substrate that have different sizes.
6. *Stacked Microstrip Patch Antenna*: It consists of two or more patches stacked on top of each other on the same substrate. It has a higher gain and can operate at multiple frequencies.
7. *Patch Array Antenna*: It consists of multiple patch elements arranged in an array on the same substrate. It has a high gain and can be used for applications that require directional radiation patterns.
8. *Reconfigurable Microstrip Patch Antenna*: It has the capacity to instantly alter either its frequency of operation or radiation pattern. It is used in applications that require agile and adaptable communication systems.

1.5.2 Metamaterial Loaded Antenna

A particular sort of microstrip patch antenna called a metamaterial microstrip antenna is created utilising meta materials, which are synthetic materials created to have qualities that do not exist in nature.. Metamaterials can be used to create microstrip antennas with unique and desirable characteristics that are not possible with conventional microstrip antennas.

When antennas are embedded with metamaterial, it improves their efficiency and enables a smaller antenna size compared to those without metamaterial.

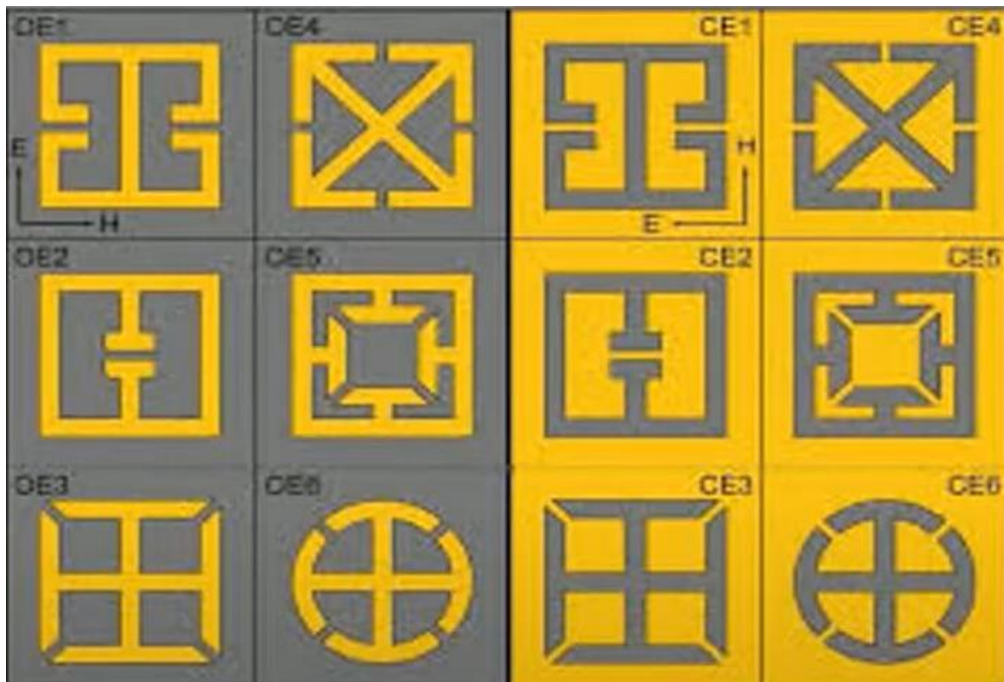


Fig: 1.6: Types of metamaterial structures

Metamaterial microstrip antennas can be classified as a subcategory of microstrip patch antennas, as they share many of the same design principles and operate in the same frequency range. However, they are distinct from conventional microstrip antennas in that they incorporate metamaterials into their design.

It is possible to create metamaterial microstrip antennas with characteristics like negative refractive index, almost zero permittivity, and high-Q resonances., which can improve their performance in certain applications such as radar, wireless communication, and sensing. However, the design and fabrication of metamaterial microstrip antennas can be more complex than conventional microstrip antennas, and they require careful optimization to achieve the desired performance.

Advantages of using metamaterial:

- Improved Antenna Performance: Enhancing an antenna's radiation pattern, gain, and bandwidth can increase its performance, which is possible with the usage of metamaterials.
- Miniaturization: Metamaterials can be designed to have a negative refractive index, which can allow for the creation of very small antennas that still have good performance.
- Flexibility: Metamaterials can be designed to have a wide range of electromagnetic properties, which makes them highly flexible for use in antenna design.

Disadvantages of using metamaterial:

- Cost: Metamaterials are still relatively expensive to manufacture, which can make them prohibitively expensive for some applications.
- Complexity: The design of metamaterials is highly complex and requires specialized expertise in materials science, electromagnetic theory, and antenna design.
- Sensitivity to environmental factors: Metamaterials can be sensitive to temperature, humidity, and other environmental factors, which can affect their electromagnetic properties and therefore, antenna performance.

1.6 WAVEGUIDE FREQUENCY BAND

The frequency bands that a waveguide can transmit depend on its dimensions, shape, and material properties.

Some common frequency bands used in waveguide communication include:

1. C-band: The 4 to 8 gigahertz (GHz) frequency band is often utilized for satellite antennas in regions where signal degradation can occur due to severe weather conditions like heavy rainfall.
2. X-band: This band ranges from 8 to 12 gigahertz (GHz) and is commonly used for military and commercial radar systems.
3. Ku-band: This band ranges from 12 to 18 GHz and is used for satellite communication, including TV broadcasting and broadband internet.

4. K-band: This band ranges from 18 to 27 GHz and is used for satellite communication and radar systems.
5. Ka-band: This band ranges from 26.5 to 40 GHz and is used for satellite communication, including high-speed data transmission and weather monitoring.
6. Q-band: This band ranges from 33 to 50 GHz and is used for radar systems and experimental communication systems.
7. V-band: This band ranges from 40 to 75 GHz and is used for short range communication, such as WLANs.
8. W-band: This band ranges from 75 to 110 GHz and is used for radar systems, wireless communication, and remote sensing applications.
9. D-band: This band ranges from 110 to 170 GHz and is used for experimental communication systems and remote sensing applications.

Choosing the appropriate frequency band depends on the specific usage and the accessibility of the desired bandwidth. Higher frequency bands generally offer higher data rates, but their propagation characteristics may be more challenging due to increased attenuation and scattering.

CHAPTER –2

LITERATURE SURVEY

2.1 INFERENCES FROM LITERATURE SURVEY

The title of the paper published in the year 2022 by Srabonty Soily at University of South Alabama. This article presents a Circularly Polarised Microstrip Patches Antenna for Ka Band Space Communication Based on Double Negative Metamaterial Superstrate. To produce two distinct CP modes, a rectangular patch antenna has shorting pins along two perpendicular diagonals. Using a straightforward coaxial probe-feeding at Ka band, the antenna is energised. A 4 by 4 array of rectangle slotted ring patches with negative dielectric coefficients and permeable at the Ka band is used as the substrate to improve the performance of the antenna. The right-hand CP gain is increased by the use of this DNG growth and increased-based superstrate from 10 dB to 12 dB, yielding an overall height of the antenna of 0.58 times the empty wavelength. The suggested design is ideal for satellite applications since it has a minimum axial ratio of 1.5 dB close to the magnetic repulsion of 28 GHz.

The title of the paper published in the year 2022 by Abhinav Nirkhe at Maulana Azad National Institute of Technology. In this article, For WiMAX applications, a split ring resonance antenna is introduced. It makes use of metamaterial technology. The design is compared with other antenna designs and is specifically tuned to resonate at 3.4 GHz. Waveguide ports along the x-axis excite the resonator, which comprises a piece of the ground plane. The proposed metamaterial antenna has dimensions of 30 x 23 x 1.5 mm³, a relative permittivity of 2.3, and a loss tangent of 0.0009. It is printed on Rogers 5880RT substrate. The feedline is opposite side of the substrate from resonator rings and ground frame. To obtain the requisite metamaterial qualities, a unit cell is proposed. Return loss, gain, permeability, permittivity, and the values of the E and H plane radiation patterns are all analysed along with the suggested design.

The title of the paper published in the year 2021 by Junsu D at Central South University, China. The gain of the microstrip antenna is increased by creating an antenna with a microstrip patch array using an optimised feed network. In order to increase the array's gain even further, an open ring array metamaterial is added to its surface. Compared to the conventional antenna array and individual antenna element, the growth and increased-loaded antenna array exhibits higher directivity and gain properties. With the 2x2 antenna array, the antenna gain increases from 4 dB for the antenna element to 7 dB. After the introduction of the metamaterial, the gain increases to 10.10 dB. The outstanding results of multi-load antennas needed for 5G connectivity, and other applications are made possible by this technical advancement.

The title of the paper published in the year 2021 by Priyal Doshi at Shantilal Shah Engineering College. This work presents a microstrip antenna with a metamaterial component. The antenna's size is decreased while other antenna characteristics, such as efficiency and return loss, are improved by using metamaterial technology. A CSRR is loaded onto the antenna's radiation patch, producing a multifrequency response. The antenna's bandwidths are 6.7%, 10.3%, and 8.15%, respectively, and it works at frequencies of 4 GHz, 5 GHz, and 7 GHz on a Flame Retardant (FR4) epoxy substrate. HFSS is used to simulate the antenna structure.

The title of the paper published in the year 2021 by Akash Rawat at Manipal University Jaipur. This article focuses on the creation and evaluation of a Multiband Metamaterials loaded Substrate Integrating Waveguide (SIW) antenna. The suggested antenna employs a ground configuration through a radiating rectangular patch that faces away from the feed line and a mix of substrate integrated waveguide and metamaterials to enhance its bandwidth, radiation pattern, and minimise its size. A complementary rectangular split ring resonant and substrate integrated wavelength are used to increase the antenna's directivity, gain, and bandwidth. The suggested antenna construction has a $r=4.4$, is composed of FR-4 epoxy, operates between 6 and 18 GHz, and has a frequency that is resonant for wireless local area networks and WIMAX.

The title of the paper published in the year 2020 by SAMIR SALEM AL-BAWRI at University Kebangsaan Malaysia, This article introduces a Planar-patterned, single-layered, 28 GHz millimeter-wave applications, multiple-input multiple-output

antenna with metamaterial. The antenna is made up of split square and hexagonal unit cells that have refractive index characteristics. The properties of the metamaterial were investigated for wave propagation along the y- and x-axes in the two primary directions. With a bandwidth of over 6 GHz, The y-axis wave propagation demonstrated μ -near-zero characteristics, a near-zero refractive index, and epsilon-near-zero properties. On the other hand, the x-axis wave propagation from the frequency range of 27 GHz to 28 GHz revealed a broad negative range of single μ metamaterial. The suggested single antenna, which works in the (24–30 GHz) frequency range, is made up of three metamaterial unit cells. Moreover, With only 4 mm between antenna components, the MIMO antenna offers exceptional separation of over 24 dB. According to the measurements, the MIMO antenna offers a 6 GHz bandwidth and a 12.4 dB peak gain.

The title of the paper published in the year 2022 by Tina E. Maurer at University of Massachusetts Amherst This paper introduces a novel planar Modelling the 2-D electromagnetic environment with polarisation using a microstrip networks metamaterial with an uneven grid. The proposed technique is demonstrated using a Luneburg lens example and its implementation on a PCB is also verified.

The title of the paper published in the year 2022 by Uday A. Patil at Shivaji University. This paper investigates a Filled with surrounding metamaterial that possesses negative permittivity and permeability, the microstrip slot antenna. The field equations for MASA can be expressed using both analytic and computational methods when the metamaterial is present. The surrounding meta material functions as a natural impedance matching network, as shown by the analysis of the electrical gain, reactance proportion, and reactive energy of the MASA., thereby increasing the radiated power of the MASA by 73.66 times compared to when it is surrounded by a dielectric medium. An equivalent circuit model is proposed to justify the metamaterial's role as a natural impedance matching network.

The title of the paper published in the year 2020 by Allam M. Ameen at Electronics Research Institute A novel approach to mitigate mutual coupling between microstrip patch antennas using metamaterial structure is presented in this study. The proposed technique employs complementary split ring resonator (CSRR) loaded

between the two patches to reduce the coupling. The antenna is intended to function at a 28 GHz frequency., suitable for 5G and millimeter-wave applications. The proposed structure exhibits significant improvement in coupling between antennas, achieving a maximum isolation of 31.7 dB by etching the CSRR on the ground of the antenna and on a floated ground between the two patches. The distance between the edges of the patches is $0.4\lambda_0$. Using CST software, the suggested antenna is developed, modelled, constructed, and measured.

The title of the paper published in the year 2020 by Tale Saeidi at University Technology PETRONAS. This article describes a novel, Flexible ultra-wideband antenna for WBAN and the IoT that is wearable and based on meta materials for sub-6G band frequencies. The compact antenna includes an L-shaped slot in an elliptical patch, a stub at the back, and chamfered ground to increase bandwidth and eliminate stopbands. It is constructed of two layers of denim ($10 \times 10 \text{ mm}^2$) and felt ($10 \times 15 \text{ mm}^2$). In order to increase bandwidth, gain, and directivity, six arrays of altered grain rice forms are integrated into a Split Ring Resonator to further optimise the antenna. With a gain and the directivity equal 8 dB and 10 dB, respectively, as well as an effectiveness of over 80% across its operational frequency range, the suggested antenna displays a wide bandwidth. Results demonstrate excellent adherence to the findings of simulations and outperform similar existing antennas in terms of performance while having a smaller footprint.

2.2 EXISTING METHODOLOGY:

It is suggested to use a c-band skillshot-polarization reconfigurable antenna using mushroom-type metamaterial loading. The prototype has a profile of 0.06 GHz, according to simulation and measurement data (where 0 is the working wavelength in free space). The measurements show an impedance bandwidth that is over 33.2%. The suggested antenna may achieve a compromise between low-profile and bandwidth on its foundation of quadra-polarization reconfigurability, according to the findings of simulations and measurements. C band satellite communication can be employed with the suggested antenna.

2.3 DRAWBACK OF EXISTING METHODOLOGY:

Complexity: Penta-polarization reconfigurable antennas are more complex than traditional antennas. They require additional components such as switches, phase shifters, and couplers to enable the reconfigurability of the antenna.

Cost: The additional components required to enable reconfigurability can increase the cost of penta-polarization reconfigurable antennas.

Size: The additional components also increase the size of the antenna, making it bulkier than traditional antennas.

Power consumption: The additional components require power to operate, which can increase the power consumption of the antenna.

Performance degradation: The additional components can introduce losses and reduce the overall efficiency and performance of the antenna.

Overall, while penta-polarization reconfigurable antennas offer some benefits, they may not be suitable for all applications due to their complexity, cost, size, power consumption, and potential performance degradation.

2.4 PROPOSED METHODOLOGY:

Line model Split Ring Resonator (SRR-Metamaterial) is used instead of Cavity model resonator which means the efficiency and gain factor can be enhanced.

An antenna structure comprising of square-shaped ring patch and inductive parallel ground, inspired by Meta materials, is utilized for X-band application to achieve improved results.

CHAPTER 3

AIM AND SCOPE

3.1 AIM

To design a metamaterial loaded microstrip patch antenna with less return loss, high gain and directivity for X-band communication.

3.2 OBJECTIVE

The main objective for designing a microstrip patch antenna using metamaterial and FR4 substrate for X-band application could be to achieve the following:

- **Improve antenna performance:** The use of metamaterials can help to improve the antenna's performance in terms of gain, directivity, bandwidth, and efficiency. The FR4 substrate can provide good mechanical strength, low-cost, and ease of fabrication.
- **Miniaturization:** Metamaterials can be used to miniaturize the size of the antenna while maintaining its performance. This is important for X-band applications where space is limited.
- **Reduction of surface wave losses:** Metamaterials can be designed to reduce surface wave losses, which can improve the antenna's efficiency.
- **Wideband operation:** Metamaterials can be used to design wideband antennas that can cover a range of frequencies within the X-band.
- **Low profile:** The use of metamaterials can help to design low profile antennas that can be used in applications where height is limited.
- **Polarization diversity:** Metamaterials can be used to design antennas with polarization diversity, which can help to mitigate the effects of multipath fading.

The main objective of designing a microstrip patch antenna using metamaterial and FR4 substrate for X-band application is to achieve improved performance, miniaturization, and wideband operation, while maintaining low cost and ease of fabrication. Simulation of Microstrip patch antenna is done by using simulation software such as HFSS. Analysis of various characteristics of Microstrip patch antenna such as Return loss, Voltage Standing Wave Ratio (VSWR), Gain, Radiation pattern are done.

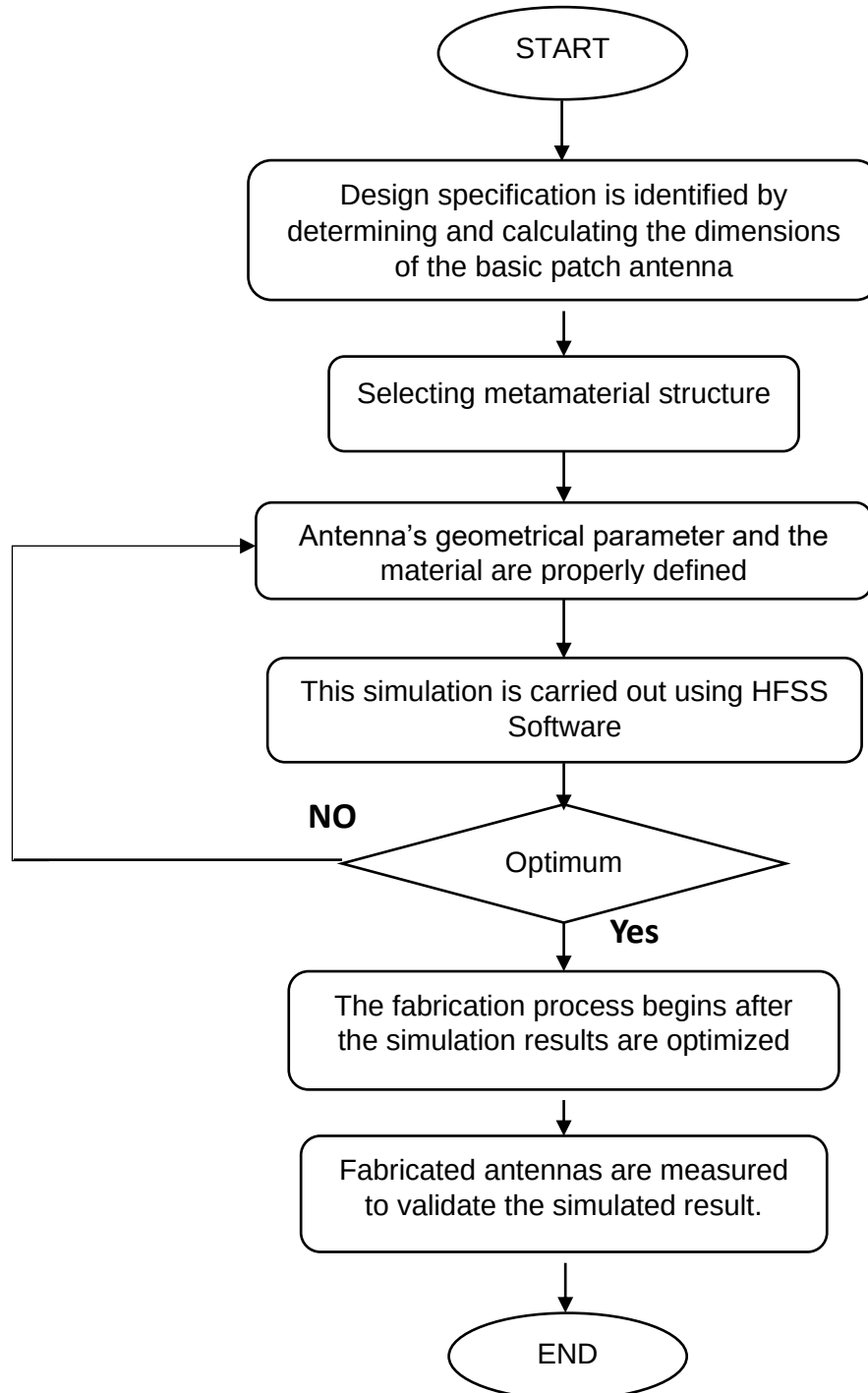
3.3 SCOPE OF THE DESIGN

The primary scope is to achieve favourable results in parameters such as return loss, bandwidth, and gain. By employing a single substrate, the design is simplified and the cost of fabrication is reduced, ultimately aiming to fulfil the needs of communication systems.

CHAPTER 4

DESCRIPTION OF PROPOSED SYSTEM

4.1 DESIGN FLOW CHART



4.2 DESIGN CALCULATION

- The project's software component focused on determining the radiation pattern and return loss curve of a number of straightforward rectangular patch antennas. The main variables for building a microstrip patch antenna with a rectangular shape are:
- Frequency of operation (f): The antenna resonance frequencies needs to be properly chosen.
- Dielectric constant of the substrate (r): The size of the antenna is reduced by employing a substrate with a high dielectric constant.
- Height of dielectric substrate (h): The microstrip patch antenna must be lightweight in order to be employed in some applications (like mobile phones), and in order to do so, the height of the dielectric substrate cannot be greater than a few millimetres.

This patch's operating frequency was chosen to be 9.5 GHz since it is meant for wireless communication and satellite communications. Its parameters are

4.2.1 Patch Calculations:

$$C=3 \times 10^8 \text{ mm/s}$$

$$h = 1.6 \text{ mm}$$

$$f = 9.5 \text{ GHz}$$

C=Velocity of light

f=Frequency in GHz

h=Thickness of material

r=Dielectric constant of material (FR4)

where $r=4.4$

$$f = c/\lambda \quad (4.1)$$

$$\lambda = 31.57 \text{ mm}$$

$$width = \frac{\lambda}{2} \sqrt{\frac{2}{\epsilon_r + 1}} \text{ mm} \quad (4.2)$$

$$w = 9.606 \text{ mm}$$

ϵ_{ref} =Effective Dielectric Constant

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[1 + 12 \frac{h}{W} \right]^{-\frac{1}{2}} \quad (4.3)$$

$$\varepsilon_{reff}=3.6814$$

ΔL = Normalized extension in length

$$\Delta L = 0.412h \frac{(\varepsilon_{eff} + 0.3) \left(\frac{W}{h} + 0.264 \right)}{(\varepsilon_{eff} - 0.258) \left(\frac{W}{h} + 0.8 \right)} \quad (4.4)$$

$$\Delta L = 0.689 \text{ mm}$$

L_{eff} = Effective length

$$L_{eff} = \frac{c}{2f_0 \sqrt{\varepsilon_{eff}}} \quad (4.5)$$

$$L_{eff} = 8.22 \text{ mm}$$

$$L = L_{eff} - 2\Delta L \quad (4.6)$$

$$L = 6.842 \text{ mm}$$

The transmission line model's equations and the previously mentioned parameters allow us to derive

$$\text{Length of the patch} = 6.842 \text{ mm}$$

$$\text{Width of the patch} = 9.606 \text{ mm}$$

4.2.2 Substrate Calculation:

$$h = \frac{0.0606\lambda}{\varepsilon_{reff}} \text{ mm} \quad (4.7)$$

$$h = 1.6 \text{ mm}$$

$$L_g = L + 6h \quad (4.8)$$

$$L_g = 16.442 \text{ mm}$$

$$W_g = W + 6h \quad (4.9)$$

$W_g=19.2$ mm

The substrate calculations values are given as

Length of the substrate= 16.442 mm

Width of the substrate= 19.2 mm

4.2.3 Feed Line Calculation:

$$\lambda_g = \frac{\lambda}{\sqrt{\epsilon_{reff}}} \quad (4.10)$$

$$L_f = \frac{\lambda_g}{4} \quad (4.11)$$

$L_f=4.11$ mm

$$W_f = L_f/2 \quad (4.12)$$

$W_f=1.4$ mm

Length of the feed line= 4.11 mm

Width of the feed line= 1.4 mm

Table 4.1: Design Specifications

SL No.	Description	Symbol	Unit
1	Patch Length	L_p	20mm
2	Patch Width	W_p	49mm
3	Ground Length	L_g	44mm
4	Ground Width	W_g	60mm
5	Feed Line Length	L_f	22mm
6	Feed Line Width	W_f	4mm
7	Substrate Height	H	1.6mm
8	Substrate Length	L	60mm
9	Substrate Width	W	60mm
10	Substrate Material	FR4 epoxy	
11	Resonant Frequency	9.5GHz	
12	Relative Permittivity	ϵ_r	4.4

4.3 SIMULATION SOFTWARE

4.3.1 INTRODUCTION

High-Frequency Structure Simulator (HFSS) is a powerful electromagnetic simulation software tool that is widely used for analysing and designing high-frequency electronic devices and systems. It is developed by Ansys Inc. and is one of the most widely used software tools for electromagnetic analysis.

HFSS uses a finite element method to solve Maxwell's equations, which describe the behaviour of electromagnetic waves in various materials. This makes it a powerful tool for simulating electromagnetic behaviour in a wide range of devices and materials.

HFSS is capable of simulating various electromagnetic phenomena, such as wave propagation, reflection, transmission, scattering, and radiation. It can also simulate the behaviour of various electromagnetic devices, such as antennas, waveguides, filters, couplers, and amplifiers. It provides various features such as:

- Graphical User Interface (GUI) for model creation
- Built-in parametric modelling capabilities
- Advanced meshing algorithms to generate high-quality meshes
- Optimization tools for designing and improving device performance
- Time-domain and frequency-domain analysis capabilities
- Integration with other Ansys simulation tools

4.3.2 STEPS TO DESIGN ANTENNA USING HFSS

The general steps to design an antenna in HFSS:

Define the antenna geometry: The first step is to define the physical geometry of the antenna. This can be done using the 3D modelling tools provided in HFSS. You can create the antenna by using the built-in 3D primitives or import it from CAD software.

Assign material properties: After defining the antenna geometry, you need to assign material properties to it. This includes the substrate material, conductor material, and any other materials that may be used in the antenna.

Create a port: You need to define the excitation port where the electromagnetic signal enters the antenna. This is done by creating a boundary on the antenna surface and assigning it as a port.

Set simulation settings: Once the antenna geometry is defined, you need to set up the simulation settings. This includes the frequency range, solver settings, and mesh settings.

Run the simulation: After setting up the simulation, you can run it to obtain the results. HFSS provides various simulation types, such as S-parameters, radiation patterns, and far-field patterns.

Analyse and optimize the antenna: Once the simulation is complete, you need to analyse the results to determine the antenna performance. Based on the analysis, you can optimize the antenna geometry and re-run the simulation until the desired performance is achieved.

Generate reports: Finally, you can generate reports in HFSS to document the antenna design and simulation results.

It's vital to remember that the individual stages may change based on the needs and antenna design. However, these fundamental procedures offer an excellent place to begin when building an antenna in HFSS.

4.3.3 Applications:

HFSS is used in a variety of applications, such as:

- Design and optimization of antennas
- Simulation of radar systems
- Design of microwave and millimetres-wave circuits
- Simulation of electromagnetic interference (EMI) and compatibility (EMC)
- Design of RF and microwave filters
- Analysis of scattering and propagation of electromagnetic waves
- Simulation of biomedical devices and sensors

HFSS is a powerful electromagnetic simulation tool that is widely used in various industries such as telecommunications, aerospace, Defence, and biomedical. Its

advanced features and capabilities make it a valuable tool for analysing and designing high-frequency electronic devices and systems.

4.4 CHARACTERISTICS OF FR4 SUBSTRATE MATERIAL

FR4 (Fire Retardant 4) is a common substrate material used in the design of printed circuit boards (PCBs) and other electronic components. Here are some of the characteristics of FR4 substrate material:

Dielectric constant: The effectiveness of the antenna is impacted by the FR4 substrate's dielectric constant. The antenna's size will be smaller with a larger dielectric constant, but its bandwidth and radiation pattern may also be impacted..

Loss tangent: FR4 substrate has a loss tangent that affects the antenna's efficiency and signal loss. The lower the loss tangent, the better the performance of the antenna.

Electrical properties: FR4 has good electrical insulation properties, with a low dielectric constant and low dissipation factor. This makes it suitable for high-frequency applications.

Thermal properties: FR4 has good thermal stability and can withstand high temperatures. It has a low coefficient of thermal expansion, which makes it suitable for applications that require stable dimensional stability over a wide temperature range.

Mechanical properties: FR4 has good mechanical strength and stiffness, making it suitable for use in applications that require high structural integrity.

Thickness: The radiation pattern and impedance of the antenna are impacted by the FR4 substrate's thickness. The antenna's bandwidth will expand with a smaller substrate, but its gain can decrease.

Surface roughness: Particularly at higher frequencies, the performance of the antenna might be impacted by the FR4 substrate's surface roughness. The efficiency of the antenna's radiation will increase with a smoother surface.

Thermal stability: The thermal stability of FR4 substrate is important, especially for antennas that may be subjected to high temperatures during operation. FR4 has good thermal stability, but other substrates may be better suited for high-temperature applications.

4.5 DEVELOPMENT OF ANTENNA DESIGN

4.5.1 Top View

Meta material inspired array of square shaped ring patch structure is placed on the top of the FR4 epoxy substrate as shown in Fig 3.1.

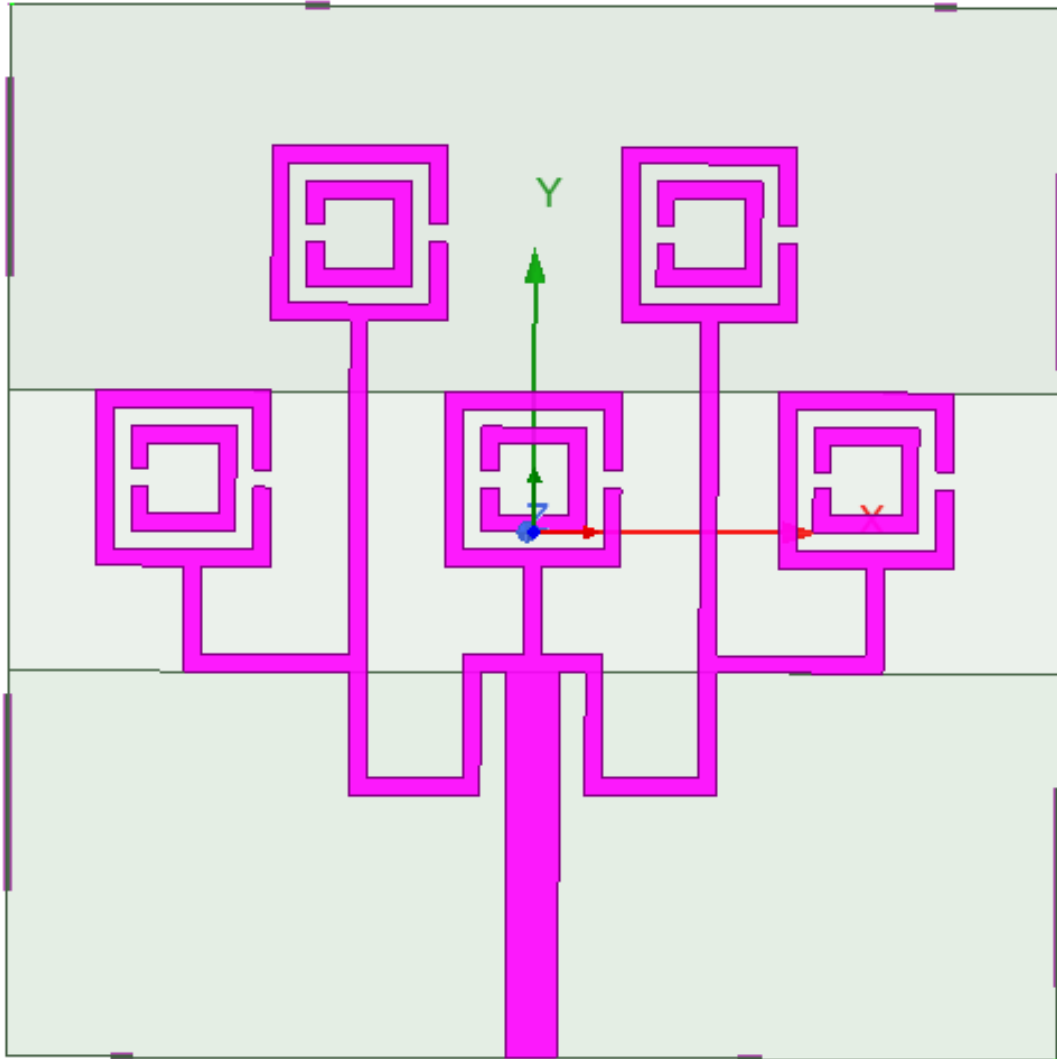


Fig: 4.1: Top view of antenna design

4.5.2 Back View

Parallel inductive ground structure is placed on the bottom of the substrate as shown in Figure 3.2

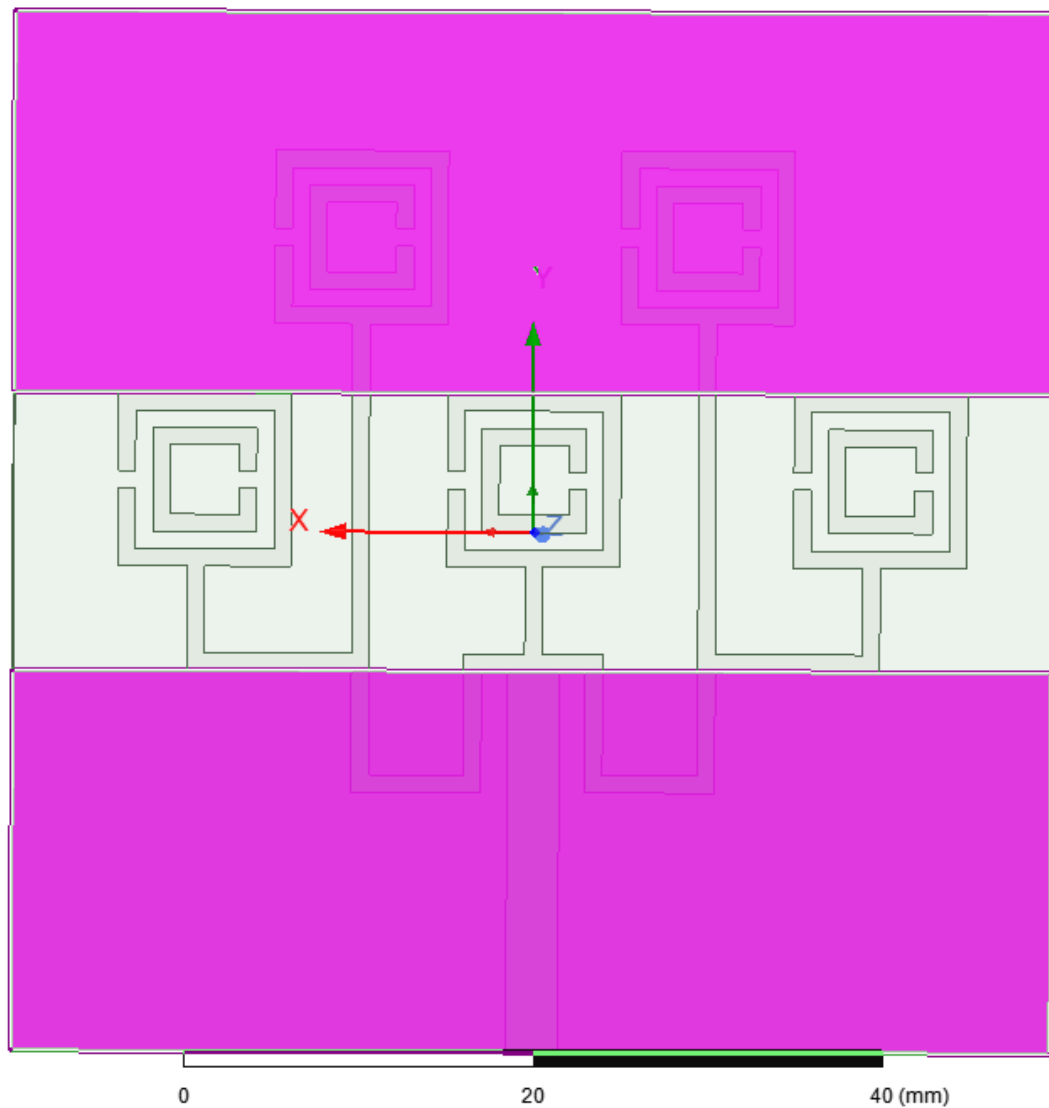


Fig: 4.2: Back view of antenna design

4.6 ANTENNA FABRICATION

Antenna fabrication is the process of creating an antenna structure from various materials such as metal, plastics, or composites. Design, material selection, manufacture, and testing are some of the processes in the procedure.

The design phase involves determining the desired antenna specifications, such as the operating frequency, gain, bandwidth, and radiation pattern. Material selection is also an important step as it affects the performance and durability of the antenna.

In the fabrication process, the antenna structure is created using various techniques such as cutting, drilling, and bending. The specific technique used will depend on

the material and design of the antenna. For example, metal antennas may be fabricated using machining or stamping, while plastic or composite antennas may be fabricated using injection modelling or 3D printing.

After fabrication, the antenna is tested to ensure that it meets the desired specifications. Testing may involve measuring the radiation pattern, gain, and impedance of the antenna. If the antenna does not meet the desired specifications, adjustments may need to be made to the design modelling or fabrication process.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 SIMULATION RESULTS:

5.1.1 Return loss

When an electromagnetic signal finds a mismatch between the path of the transmission line and the load (such as a mobile antenna), return loss—a measurement of how much power returns back to the source—is used to determine how much loss has occurred. It is normally measured at the antenna's input port and is given in decibels (dB).

In antenna simulation, return loss is an important parameter to consider as it helps to assess the performance of an antenna system. A low return loss implies that some of the transmitted power is being reflected back to the source, whereas a high return loss suggests that most of the power is being radiated out into space. which can result in reduced efficiency and performance.

From the figure it is observed that at 9.92 and 13.49 has a very less return loss of -21.38 and -36.91 respectively.

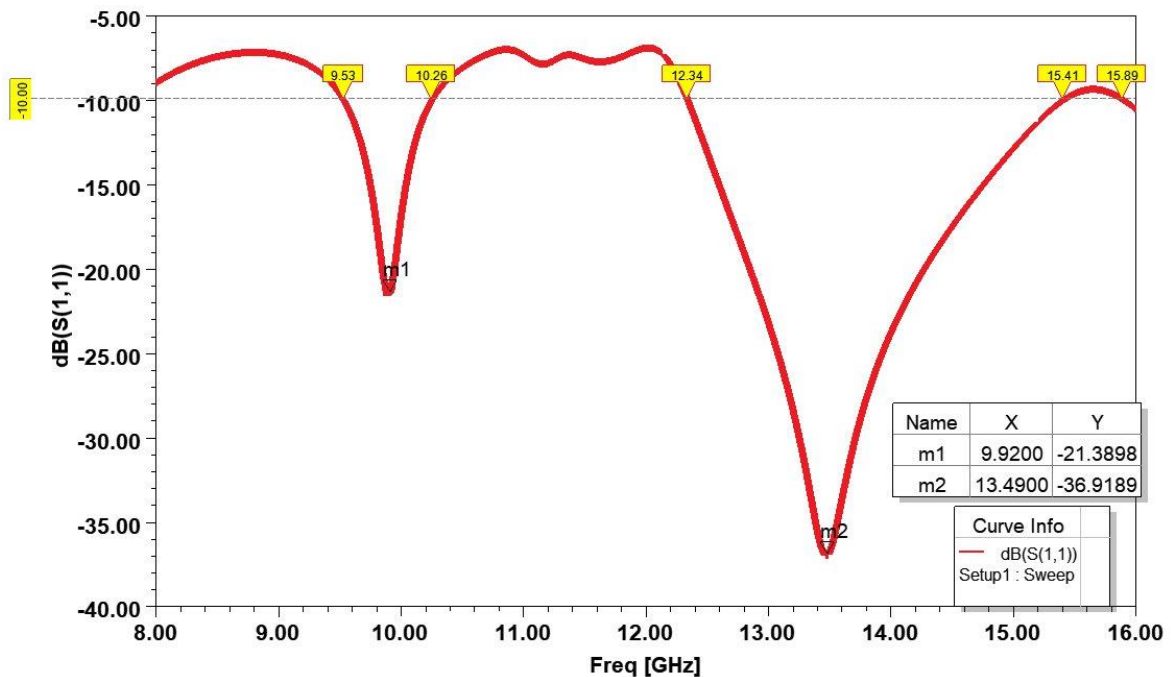


Fig: 5.1: Return loss

5.1.2 VSWR

VSWR (Voltage Standing Wave Ratio), which describes how well an antenna is matched to the transmission line or other system components, is a crucial statistic in antenna modelling. How much energy is reflected back from the antenna as a result of mismatch is measured using the maximum voltage to minimum voltage ratio, or VSWR, of the transmission line.

In an ideal scenario, an antenna would have a VSWR of 1:1, which means that all of the energy from the transmission line is delivered to the antenna and none is reflected back. However, in practice, there are always some mismatches and imperfections in the system that cause a certain amount of energy to be reflected back. A high VSWR indicates that there is a significant mismatch, which can result in reduced efficiency, increased noise, and other performance issues.

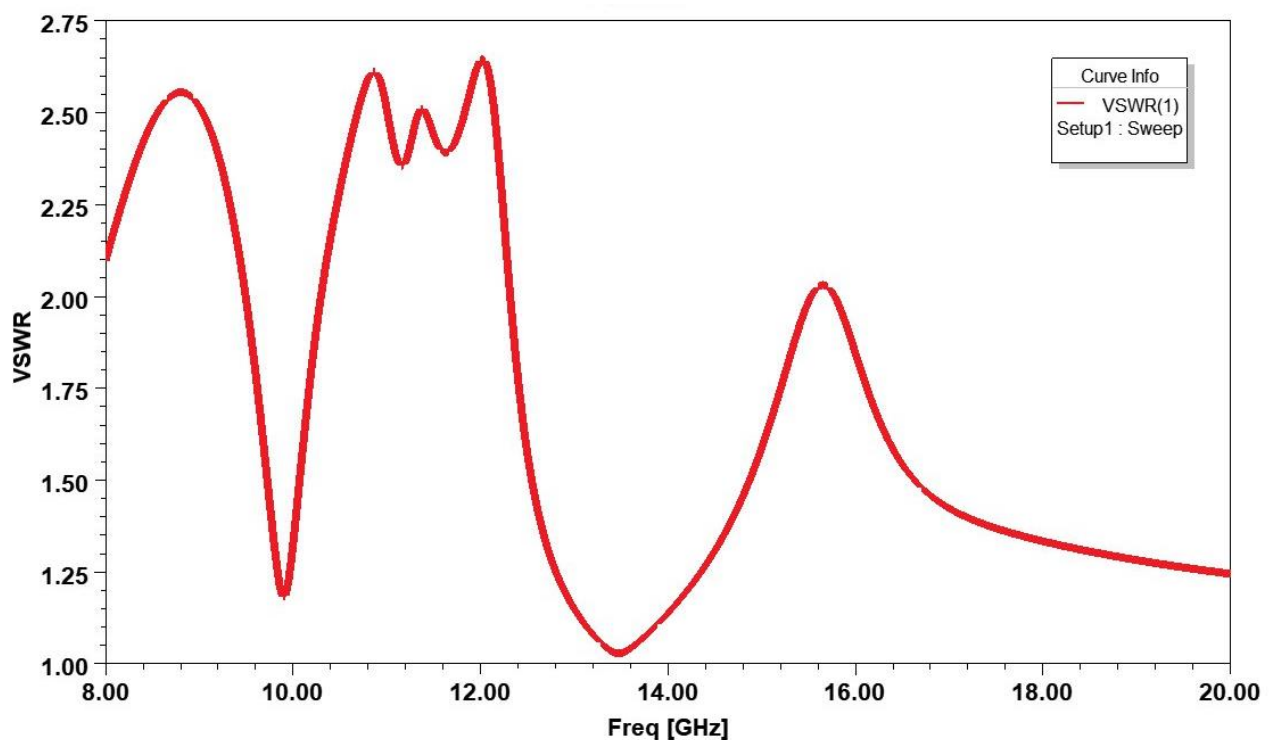


Fig: 5.2: VSWR

5.1.3 Smith Chart

The Smith chart is a graphical tool used in antenna simulation and design to analyse and optimize transmission line and impedance matching networks. It was developed by Phillip H. Smith in 1939 and has since become a standard tool for RF and microwave engineers.

The Smith chart is a polar graph that maps the complex reflection coefficient of a load impedance onto a two-dimensional plane. The centre of the chart represents a perfect match between the load impedance and the transmission line, while the outermost circle represents an infinite mismatch. The chart is logarithmic in scale, allowing engineers to easily analyse and optimize impedance matching networks.

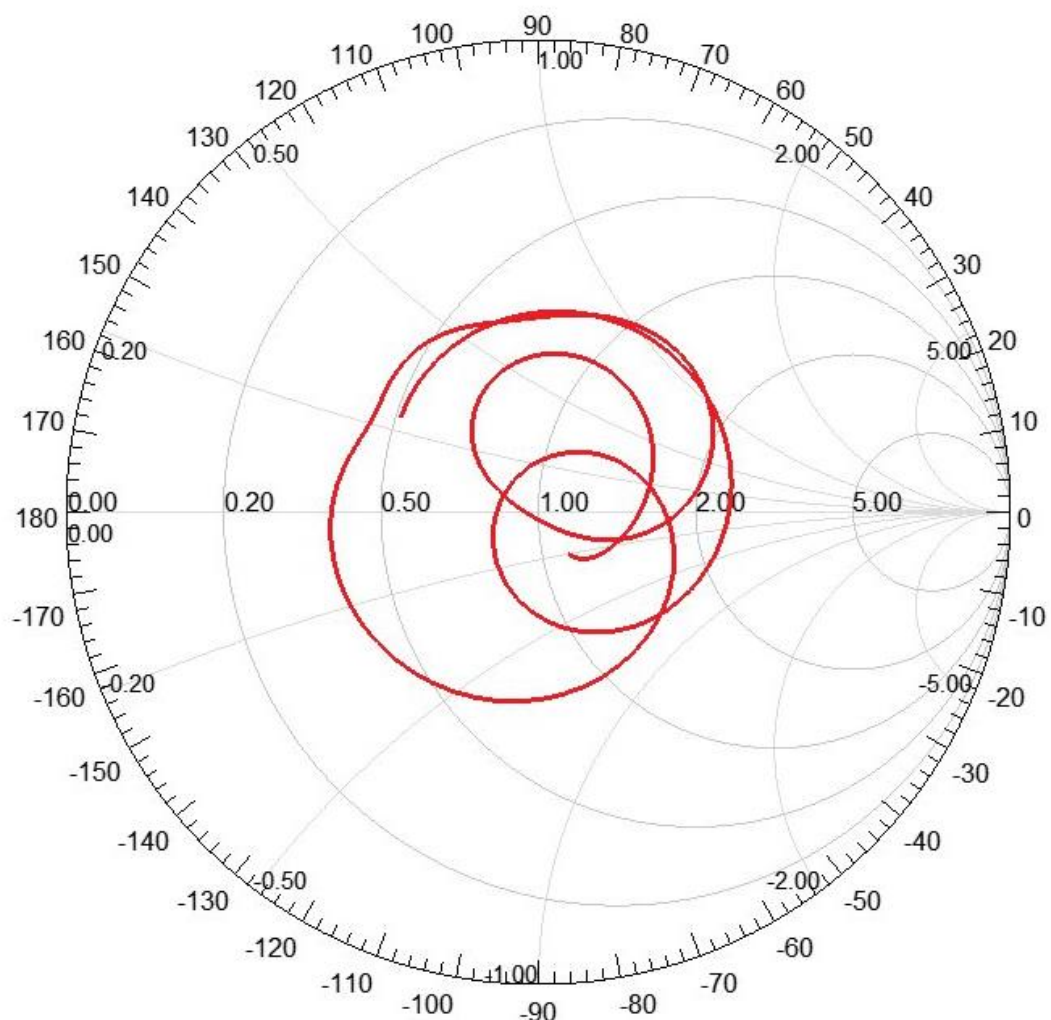


Fig: 5.3: Smith Chart

5.1.4 GAIN

In antenna simulation, the gain of an antenna is shown graphically as a function of radiation direction and operating frequency in a 3D gain plot. It is a visual depiction of the antenna's radiation pattern that offers a thorough analysis of its performance over a spectrum of frequencies.

The 3D gain plot typically shows the gain of the antenna in decibels (dB) on the vertical axis, the direction of radiation on the horizontal axis, and the frequency of operation on the third axis. The direction of radiation is usually specified in terms of the radiation's angular relationship to the antenna's axis or some other reference direction.

Information on the performance of the antenna may be seen in the 3D gain plot, such as its beamwidth, directivity, and sidelobe levels, as well as its frequency response and bandwidth. By visualizing the antenna's gain in three dimensions, antenna engineers and researchers can better understand how the antenna performs in different directions and at different frequencies.

From the below figures it is observed that gain at 9.92 GHz and 13.49 GHz have a value of 5.5 dB and 6.6 dB respectively.

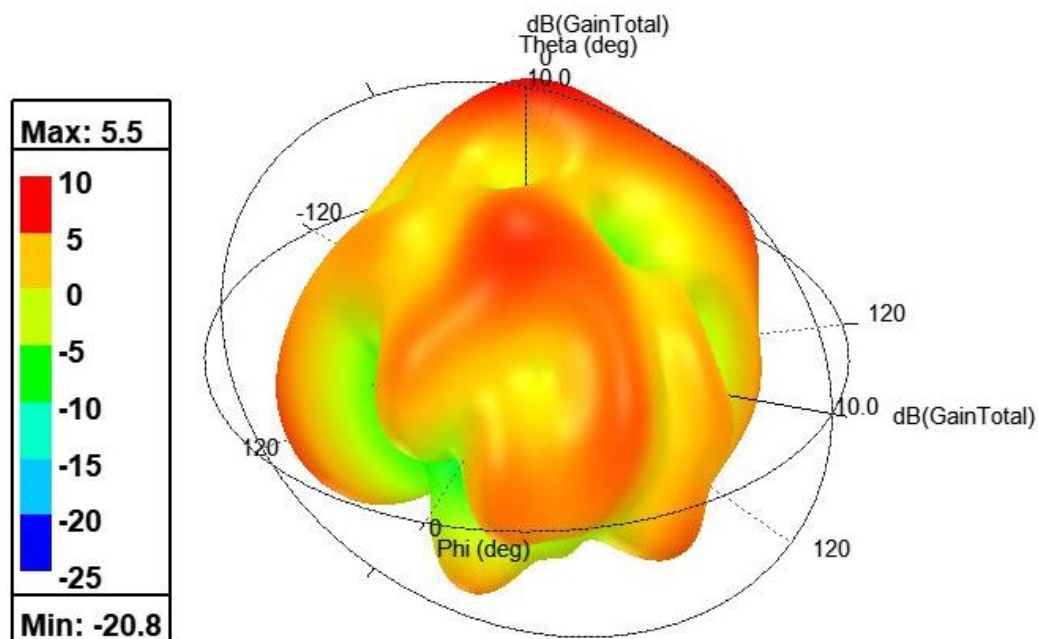


Fig: 5.4: Gain plot at 9.92 GHz

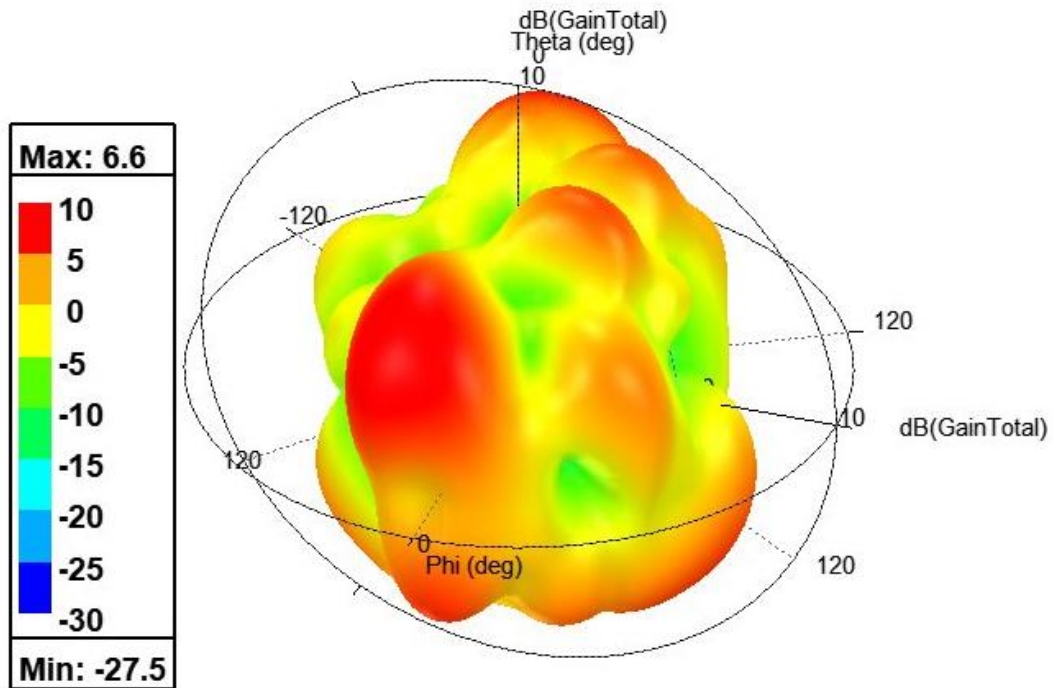


Fig: 5.5: Gain plot at 13.49 GHz

5.1.5 Directivity

Directivity is a measure of how well an antenna focuses its radiation in a particular direction. It is a key parameter in antenna simulation results, as it determines the efficiency and effectiveness of the antenna in transmitting or receiving signals in a particular direction.

In antenna simulation results, directivity is typically expressed in decibels (dB) relative to an isotropic radiator (i.e., an idealized point source that radiates equally in all directions). A higher directivity value indicates that the antenna is more effective at focusing its radiation in a particular direction, while a lower value indicates that it is less effective.

Directivity is related to the antenna's radiation pattern, which shows how the antenna radiates energy into space. The radiation pattern shows the relative strengths and directions of the antenna's radiated fields, typically plotted in a polar graph. By combining the radiation pattern over all angles and comparing the total power emitted in a specific direction to that of an isotropic radiator, the directivity of the antenna can be determined.

From the below figures it is observed that directivity at 9.92 GHz and 13.49 GHz have a value of 5.7 dB and 8.8 dB respectively.

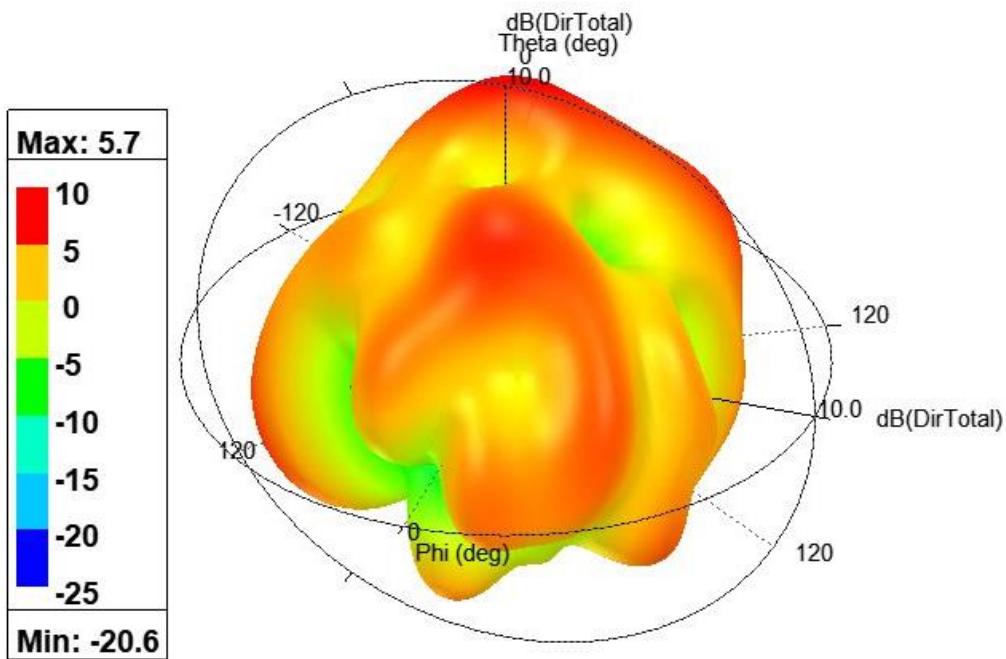


Fig: 5.6: Directivity at 9.92 GHz

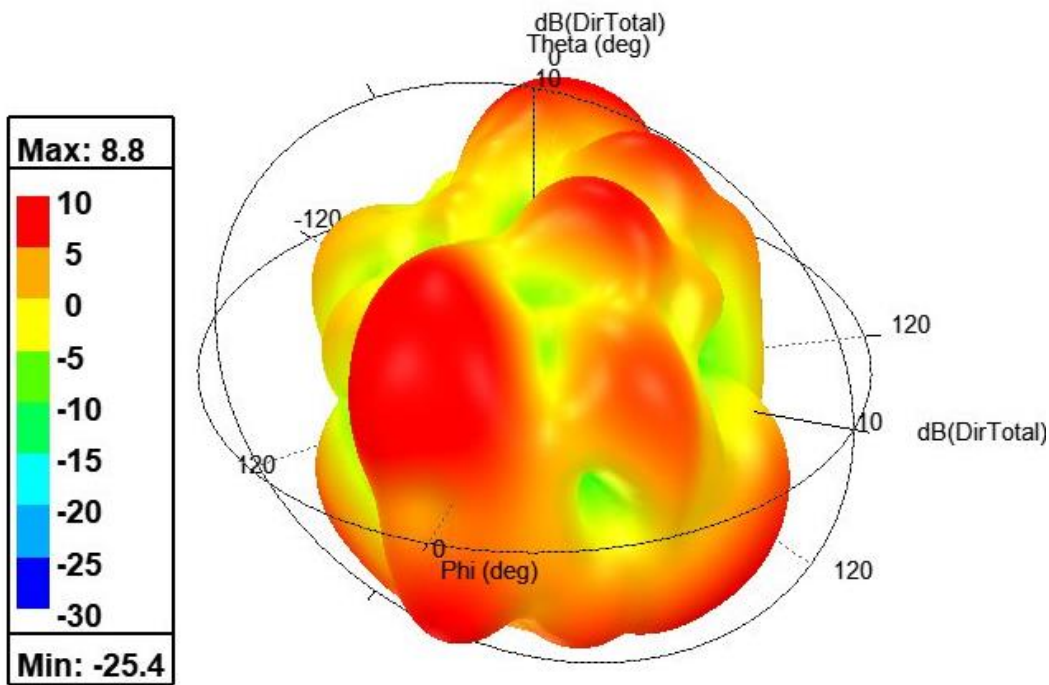


Fig: 5.7: Directivity at 13.49 GHz

5.1.6 Radiation pattern

In antenna simulation, The term "radiation pattern" describes the directional distribution of the electromagnetic waves that the antenna emits. It is a graphical representation of the relative strength of the electromagnetic fields in different directions from the antenna.

Radiation pattern is typically represented using a polar plot, with the antenna located at the origin of the plot. The polar plot shows the strength of the electromagnetic waves in different directions as a function of angle. The strength of the electromagnetic waves is usually represented in decibels (dB), and the angle is usually measured in degrees.

The far-field pattern of radiation and the near-field radiation pattern are the two primary categories of radiation patterns. The electromagnetic wave pattern at a distance from the antenna great enough for the waves to be effectively planar is known as the far-field radiation pattern. The near-field radiation pattern is the pattern of the electromagnetic waves at a distance close to the antenna, where the waves are not effectively planar and are influenced by the antenna structure.

Numerous elements, such as the antenna type and the frequency of the electromagnetic waves, affect an antenna's emission pattern, and the physical characteristics of the antenna structure. By simulating the radiation pattern of an antenna, engineers can evaluate the performance of the antenna and optimize its design for specific applications.

5.1.6.1 Radiation pattern at 9.93 GHz

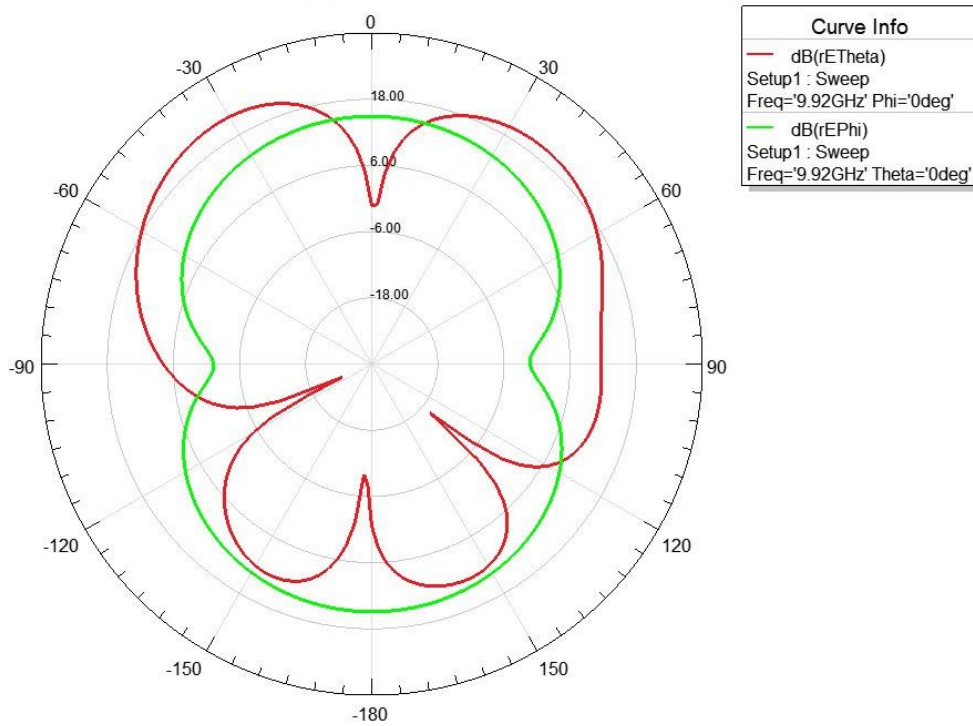


Fig: 5.8: rE plot of theta 0° and phi 0° at 9.92 GHz

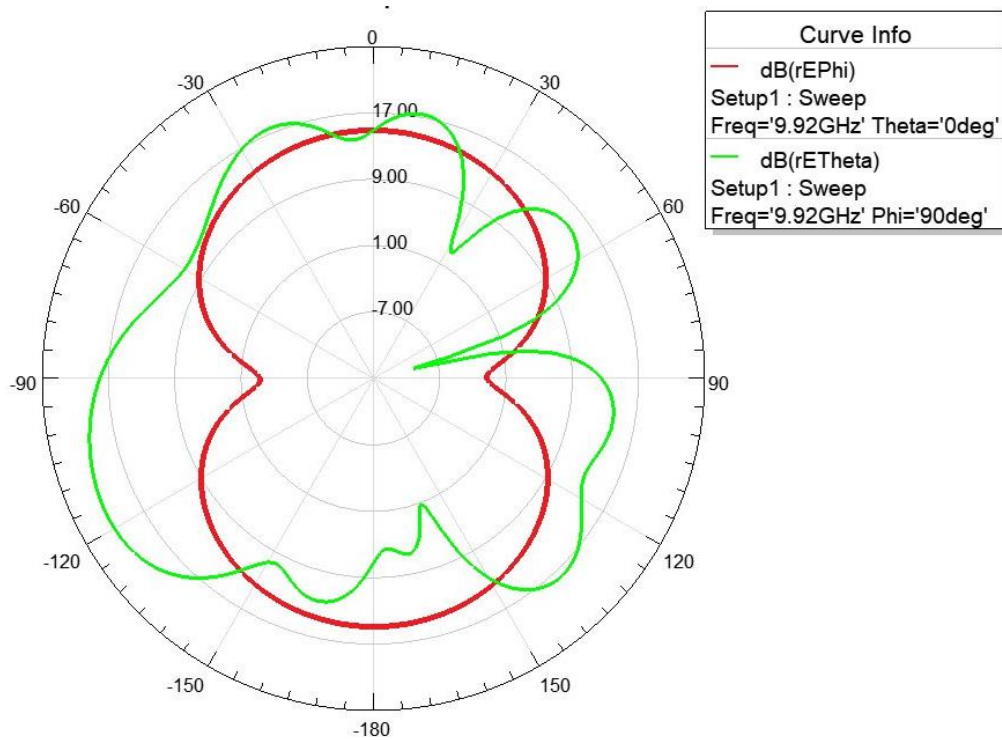


Fig: 5.9: rE plot of theta 0° and phi 90° at 9.92 GHz

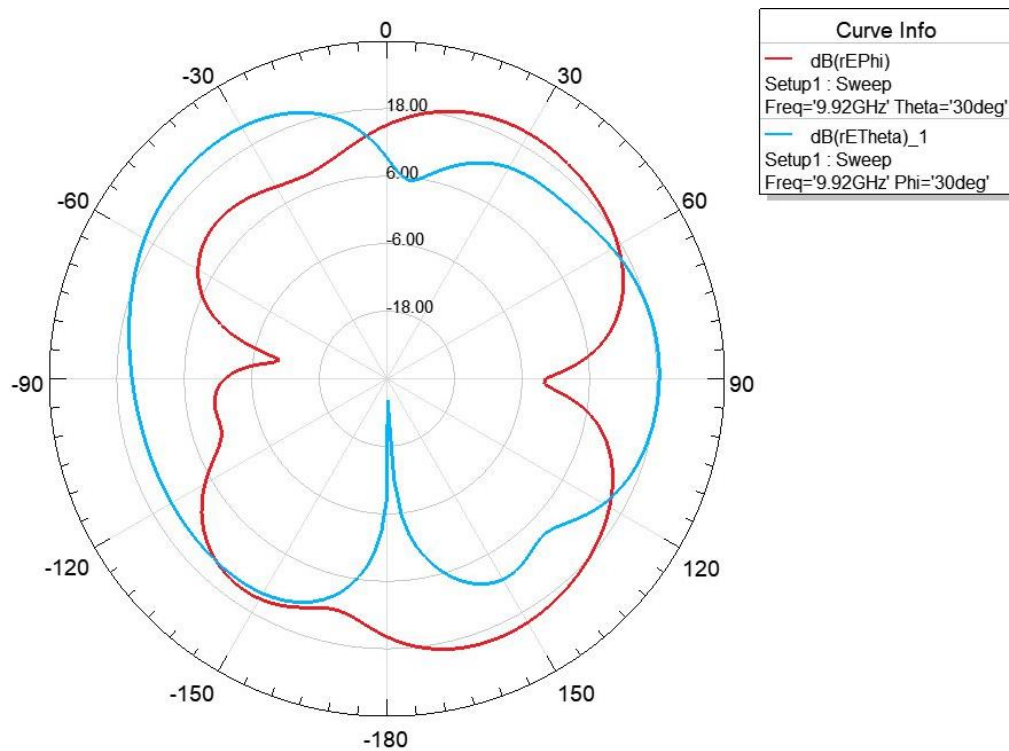


Fig: 5.10: rE plot of theta 30° and phi 30° at 9.92 GHz

5.1.6.2 Radiation pattern at 13.49 GHz

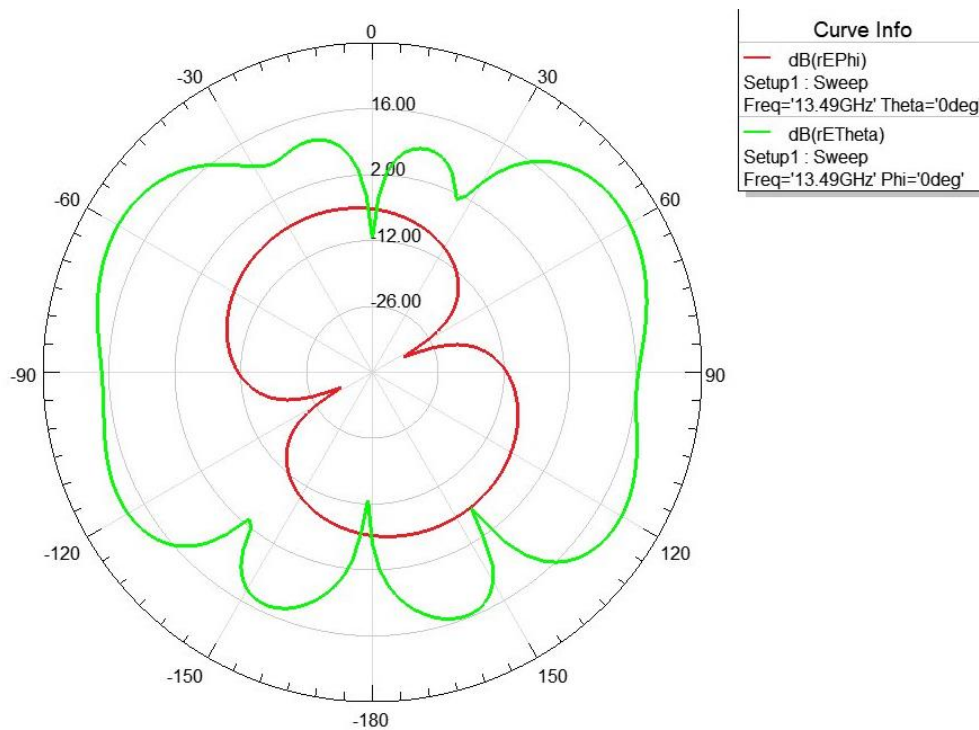


Fig: 5.11: rE plot of theta 0° and phi 0° at 13.49 GHz

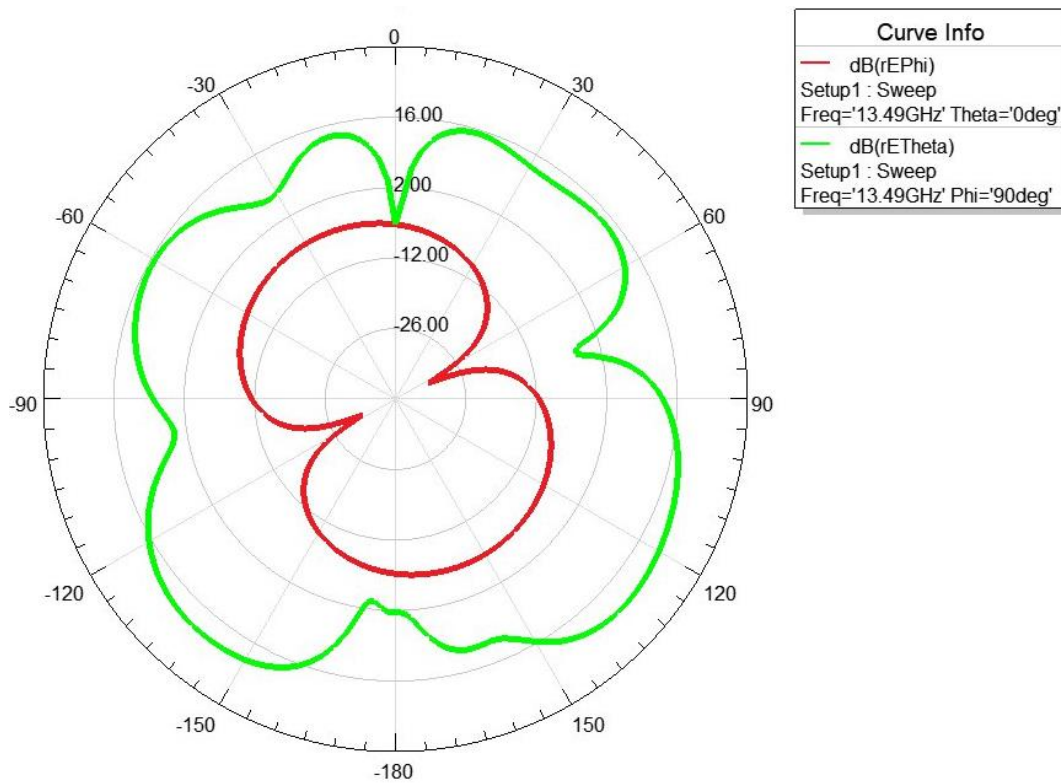


Fig. 5.12: rE plot of theta 0° and phi 90° at 13.49 GHz

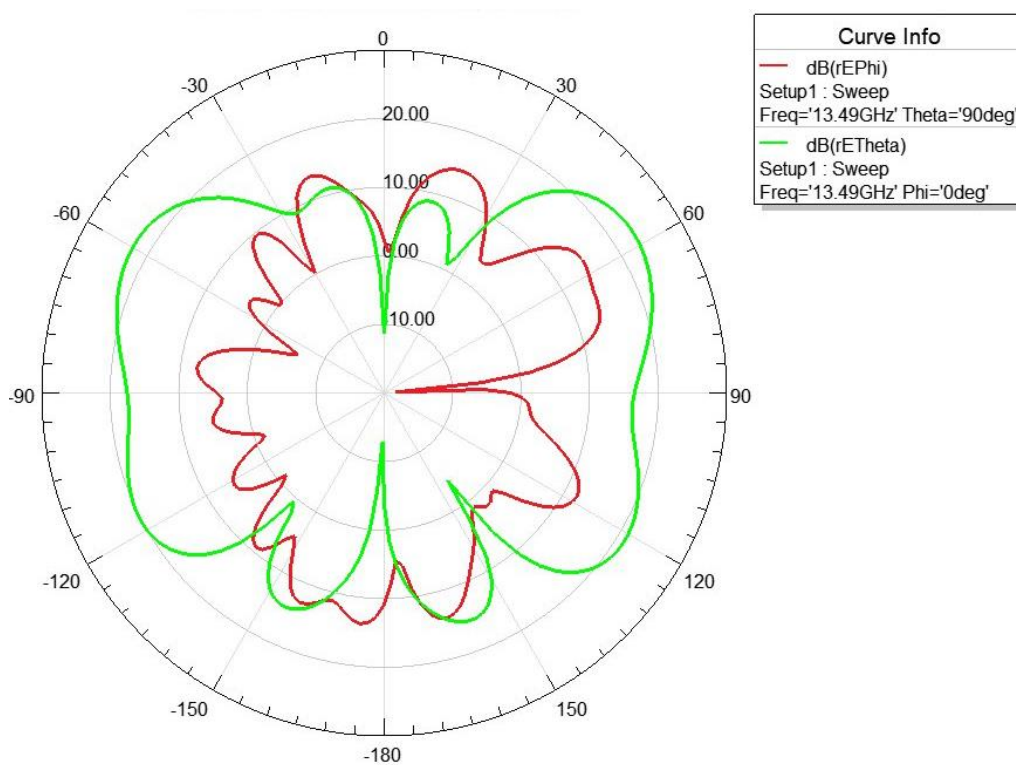


Fig. 5.13: rE plot of theta 90° and phi 0° at 13.49 GHz

5.2 FABRICATED ANTENNA

Antenna which is fabricated has a dimension of 60mm x 60 mm x 1.6 mm. the material which is used as a substrate is FR4.

5.2.1 Design View

5.2.1.1 Front view

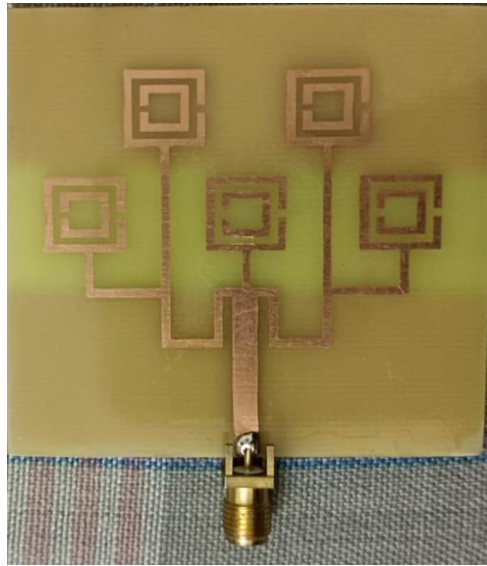


Fig: 5.14: Front View of fabricated antenna

5.2.1.2 Back view

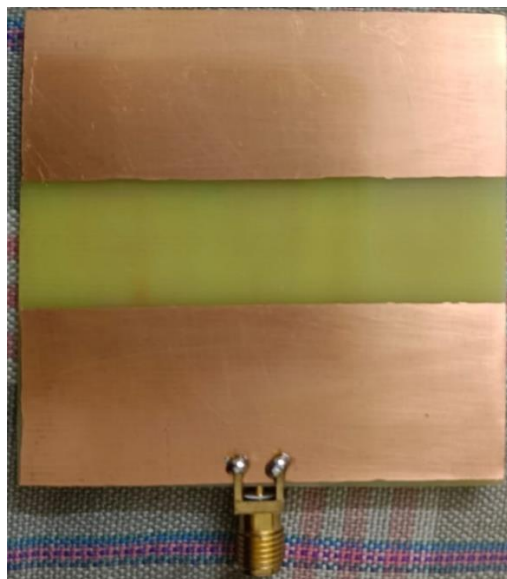


Fig: 5.15: Back View of Fabricated Antenna

5.2.2 Testing Results

5.2.2.1 Return Loss

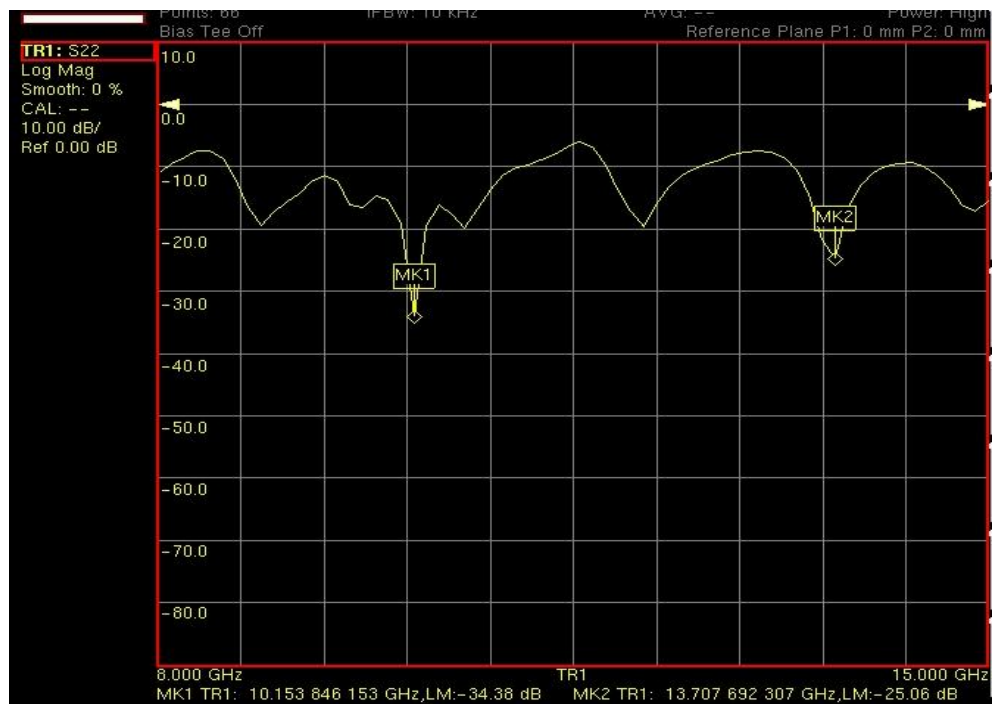


Fig. 5.16: Return Loss of Fabricated Antenna

5.2.2.2 VSWR

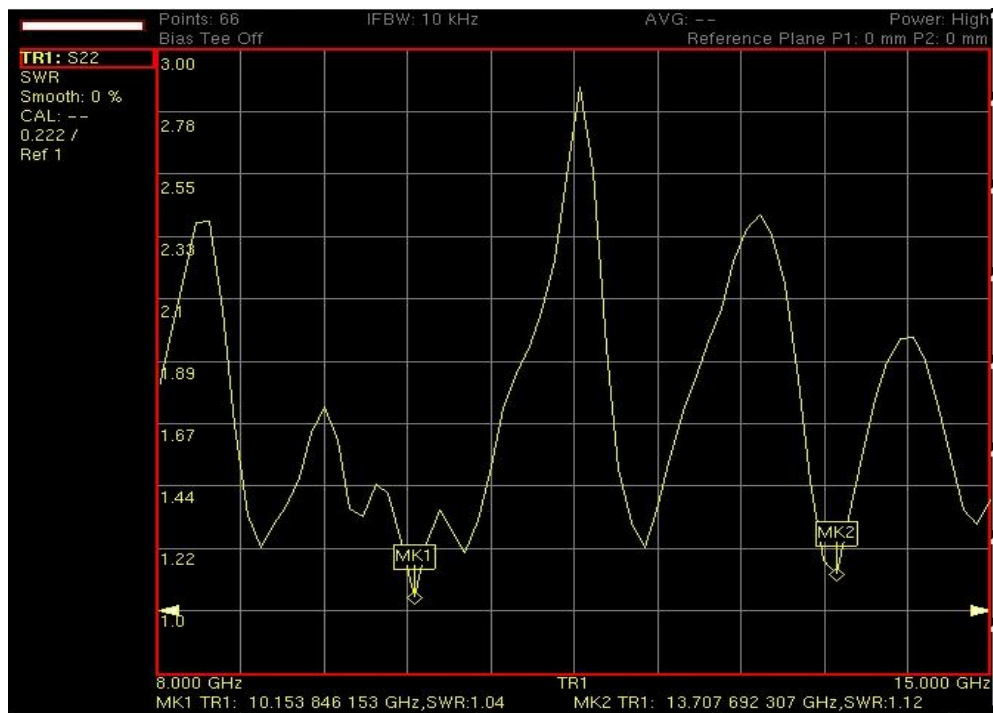


Fig. 5.16: VSWR of Fabricated Antenna

5.2.2.3 Smith Chart

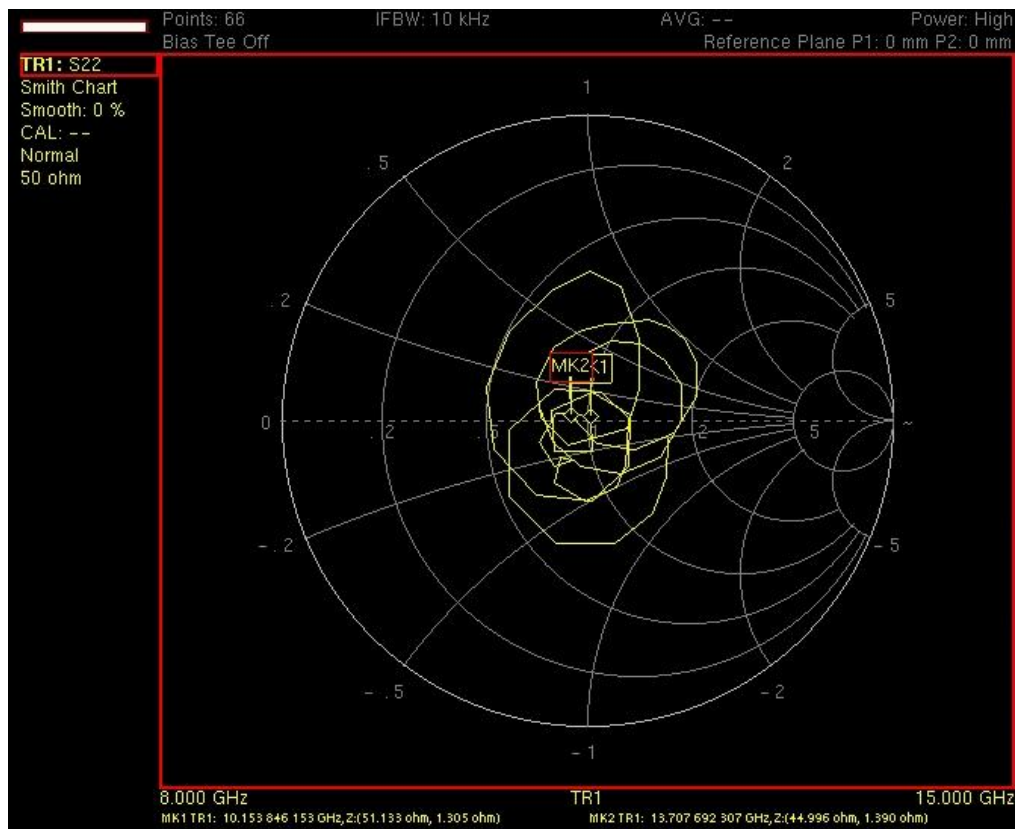


Fig. 5.16: Smith Chart of Fabricated Antenna

CHAPTER 6

CONCLUSION

The proposed antenna is designed with Meta material inspired array of square shaped ring patch structure along with parallel inductive ground structure. The dimensions of 60 mm x 60 mm x 1.6 mm. FR4 epoxy substrate material is used that reduces the fabrication cost and has a relative permittivity(ϵ_r) of 4.4. The proposed antenna has a midrange of frequency approximately at 11.5 GHz. Below 11.5 GHz at 9.96 GHz has a narrow bandwidth and above it at 13.49 GHz has a wide bandwidth. The antenna has better return loss value as -21.38 at 9.96 GHz and -36.91 at 13.49 GHz. Gain value 5.5 dB at 9.96 GHz and 6.6 GHz at 13.49 GHz. Directivity at 9.92 GHz and 13.49 GHz have a value of 5.7 dB and 8.8 dB respectively. The proposed antenna support for a x-band applications and also for KU band applications. The antenna is designed and simulated using HFSS software and plotted many parameters like return loss, VSWR, gain, directivity and radiation pattern. The proposed antenna as many applications like communication systems, especially satellite, radar, and military systems.

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