DESIGN OF METAMATERIAL ANTENNA FOR WIDEBAND APPLICATIONS

A PROJECT REPORT

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BONAFIDE CERTIFICATE

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ABSTRACT

Wideband antenna with excellent efficiency is the most important requirement in wireless communication. There are many ways to improve antenna bandwidth, such as using low permittivity substrate, increasing substrate thickness and using different shape radiating patches. However, this cannot attain wideband. This problem can be solved by using metamaterial based microstrip antenna which can attain wideband. The proposed patch antenna has a metamaterial unit cell loading on the top patch and the bottom ground plane. The top unit cell, which consists of a square loop with Complementary Split Ring Resonator (CSRR) and the bottom unit cell, which is square-shaped with a cross-slot (SSCS) is loaded on the patch and ground respectively. The objective is to achieve compact, enhanced radiation characteristic metamaterial loaded antenna and to design a metamaterial antenna for wideband applications. The wideband and high gain properties of the proposed antenna make it suitable for 5G NR FR1 and Wi-Fi 6E and WiMax applications.

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LIST OF SYMBOLS AND ABBREVATION

SYMBOLS	ABBREVATIONS
WLAN	Wireless Local Area Network
WIMAX	Wireless Interoperability for Microwave Access
dB	Decibels
RL	Return Loss
dBm	Decibel milliwatts
GHz	Giga Hertz
MHZ	Mega Hertz
W	Width of the antenna
L	Length of the antenna
H	Height of the antenna
RF	Radio Frequency

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Antennas are key components of any wireless communication system. These are the devices that allow for the transfer of a signal to waves that propagates through space and can be received by another antenna. The receiving antennas are responsible for the reciprocal process which is turning an electromagnetic wave into a signal or voltage at its terminals that can subsequently be processed by the receiver. The receiving and transmitting functionalities of the antenna structure itself are fully characterised by Maxwell's equations.

An antenna system is defined as the combination of the antenna and its feedline. As an antenna is usually connected to a transmission line since the signal from the feedline should be radiated into space in an efficient and desired way. In home applications where space is very limited such as hand portables and aircraft, it is desirable to integrate the antenna and its feedline. In other applications such as the reception of TV broadcasting, the antenna is far away from the receiver and a long transmission line has to be used.

The dipole antenna, a straight wire, fed into the centre by a two-wire transmission line was the first antenna ever used and is also one of the best understood. For effective reception and transmission, it must be approximately half a wavelength. It must be fairly long when used at low frequencies, and even auto higher frequencies its protruding nature makes it quite understandable. Further, its low gain, lack of directionality and extremely narrow bandwidth make it even less attractive.

Requirements for conformal antenna for airborne systems, increased bandwidth requirements, and multi functionality have led to heavy exploitation of printed (patch) or other slot-type antennas and the use of powerful computational tools for designing such antenna. The commercial mobile communications industry has been the catalyst for the recent explosive growth in antenna design needs. Certainly, the past decade has seen an extensive use of antennas by the public for cellular, GPS, satellite, WLAN for computers W i-Fi, bluetooth technology, radio frequency ID devices, WIMAX and so on. However future needs will be even greater when a multitude of antennas are integrated into automobiles for all sorts of communication needs.

1.2 **INTRODUCTION OF MICROSTRIP ANTENNA**

Microstrip or patch antennas are becoming increasingly useful because these can be printed directly onto a circuit board. Microstrip antennas are becoming very widespread within the mobile phone market. Patch antennas are low cost, have a low profile and are easily fabricated. Consider the microstrip antenna, fed by a microstrip transmission line. The patch antenna, microstrip transmission line and ground plane are made of high conductivity metal (typically copper). The patch is of length L, width W, and sitting on top of a substrate (some dielectric circuit board) of thickness h with permittivity permittivity or dielectric constant. The thickness of the ground plane or the microstrip is not critically important. Typically, the height h is much smaller than the wavelength of operation, but should not be much smaller than 0.025 of a wavelength (1140th of a wavelength) or the antenna efficiency will be degraded.

1.3 **CONFIGURATION OF MICROSTRIP ANTENNA**

Microstrip antennas can be divided into three basic categories. Microstrip patch antennas, Microstrip travelling wave antennas, Microstrip slot antennas. Their characteristics are discussed below.

1.3.1 **MICROSTRIP PATCH ANTENNA**

A microstrip patch antenna consists of a conducting patch of any planar or nonplanar geometry on one side of a dielectric substrate with a ground plane on the other side. The basic configurations used in practice. Their radiation characteristics are similar, despite the difference in geometrical shape.

Rectangular and circular patch antennas are widely used. Typically a patch antenna has a again between 5 and 6 dB and exhibits a 3-dB beam width between 70 and 90^0. Some of the other patch shapes are used for special applications. Figure 1.1 shows the different shapes of micro strip patches used widely in antenna design.

Square Rectangular Dipole Circle

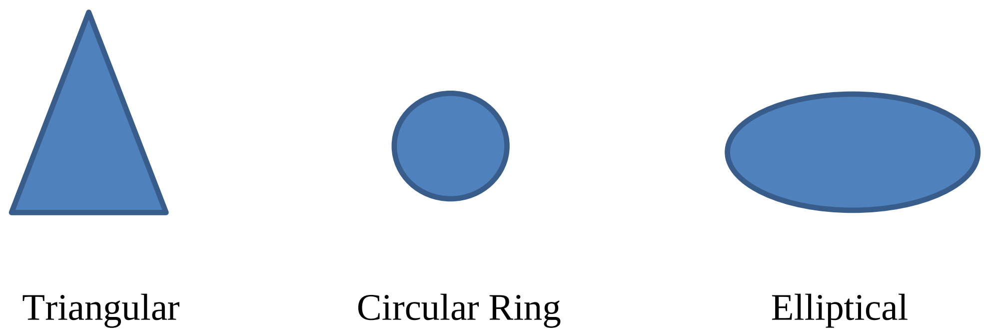

Figure 1.1 Shapes of patches

1.3.2 INTRODUCTION TO METAMATERIAL ANTENNA

The metamaterial antenna is a variation of a regular antenna that incorporates unit cells of metamaterials in the design. Metamaterials are artificially developed materials that have many useful properties which are not found in natural materials. By employing metamaterials in antenna designs, the antennas can be made smaller, cost-effective, and efficient. Moreover, by incorporating metamaterials, the bandwidth of the antenna can be increased to cover a broader spectrum. Typically, metamaterial antennas can be categorized into four classes of designs.

1.3.2.1 TYPES OF METAMATERIAL ANTENNA

Metamaterial antennas are a specific type of antenna that incorporates metamaterial structures to achieve unique electromagnetic properties. Here are some types of metamaterial antennas.

1.3.2.2 METAMATERIAL PATCH ANTENNA

These antennas use metamaterial structures, such as split-ring resonators (SRRs) or fractal patterns, to enhance the performance of patch antennas. Metamaterial patches can provide improved bandwidth, radiation pattern control, and reduced size compared to conventional patch antennas.

1.3.2.3 METAMATERIAL REFLECTOR ANTENNA

These antennas use metamaterial structures as reflectors to focus or shape the radiation pattern. Metamaterial reflectors can provide increased directivity, gain, and efficiency compared to traditional reflectors.

1.3.2.4 METAMATERIAL LENS ANTENNA

These antennas use metamaterial lenses to manipulate the propagation of electromagnetic waves. Metamaterial lenses can focus or collimate the radiation, improve the antenna's gain, and reduce side lobes.

1.3.2.5 METAMATERIAL HORN ANTENNA

Horn antennas enhanced with metamaterial structures can achieve improved performance in terms of bandwidth, gain, and side lobe suppression. Metamaterial horns can provide a compact design with better radiation characteristics.

1.3.2.6 METAMATERIAL HELICAL ANTENNA

Helical antennas incorporating metamaterial structures can exhibit enhanced radiation characteristics and improved bandwidth. Metamaterial helical antennas are used in various applications, including satellite communication and wireless systems.

1.3.2.7 METAMATERIAL ARRAY ANTENNA

Array antennas consisting of metamaterial elements can offer enhanced performance in terms of beam steering, gain, and bandwidth. Metamaterial array antennas can be designed to achieve specific radiation patterns and improved overall system performance.

1.4 SUBSTRATE MATERIALS

The substrate material choice depends on the application. The reconfigurable antennas require flexible substrates; low frequency antennas require high dielectric constant substrates to reduce the size of the antenna. The first design step is to etch the feed in the substrate to provide a planar structure. This is an easy feeding scheme, since it provides ease of fabrication it also provides simplicity in dwelling as well as impedance matching However as the thickness of the dielectric substrate being used increases the surface wave spurious feed radiation also increases, which hampers the bandwidth of the antenna.

1.5 FEEDING TECHNIQUES

Microstrip patch antennas can be fed by a variety of methods. These methods can be classified into two categories- contacting and non-contacting. In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such as a microstrip line. In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch. The four most popular feed techniques used are the microstrip line feed, coaxial probe feed, aperture coupling and proximity coupling. The microstrip line feed and coaxial probe feed belong to contacting method aperture coupling and proximity coupling belongs to non-contacting method.

1.5.1 MICROSTRIP LINE FEED

In this type of feed technique, a conducting strip is connected directly to the edge of the microstrip patch. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure. This is an easy feeding scheme since it provides ease of fabrication. It also provides simplicity in dwelling as well as impedance matching. However, the thickness of the dielectric substrate being used increases the surface wave spurious feed radiation also increases which hampers the bandwidth of the antenna. Figure 1.2 depicts a simple model of microstrip antenna which uses microstrip line feed.

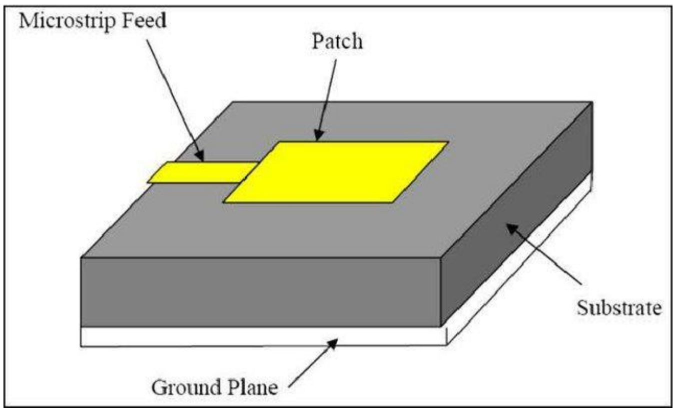

Figure 1.2 Microstrip line feed

1.5.2 COAXIAL FEED

The coaxial feed or probe feed is a very common technique used for feeding microstrip patch antennas. The inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch while the outer conductor is connected to the ground plane. The coaxial feed, using Huygens's principle, can be modeled by a cylindrical band of electric current flowing on the center conductor from the bottom to top along with the annular ribbon of magnetic current in the ground plane. An idealization that simplifies the computation is to replace the electric current by a uniform line current ribbon.

To determine the probe impedance for a microstrip antenna, the canonical problem of a parallel plate waveguide fed by a coaxial line has been analyzed using the integral formulation.

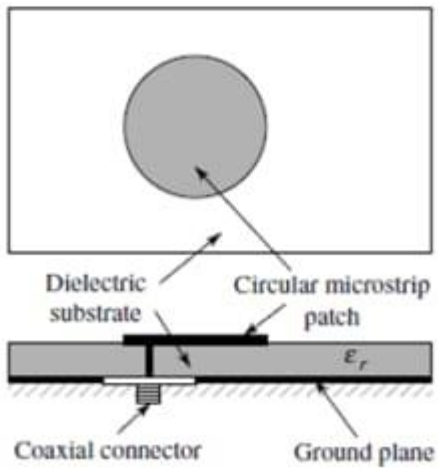

Figure 1.3 Coaxial feed

Figure 1.3 depicts the structure of coaxial feed and how it is drilled through the substrate. The main advantage of this type of feeding scheme is that the feed can be placed at any desired location inside the patch in order to match its input impedance. This feed method is easy to fabricate and has low spurious radiation However, its major drawback is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, thus not making it completely planar for thick substrates.

1.5.3 APERTURE COUPLED FEED

In this type of feed technique, the ground plane separates the radiating patch and the microstrip feed line. The coupling between the patch and the feed line is made through a slot or an aperture in the ground plane. The coupling aperture is usually centered under the patch, leading to lower cross polarization due to symmetry of the configuration. The amount of coupling from the feed line to the patch is determined by the shape, size and location of the aperture.

Since the ground plane separates the patch and the feed line, spurious radiation is minimized.

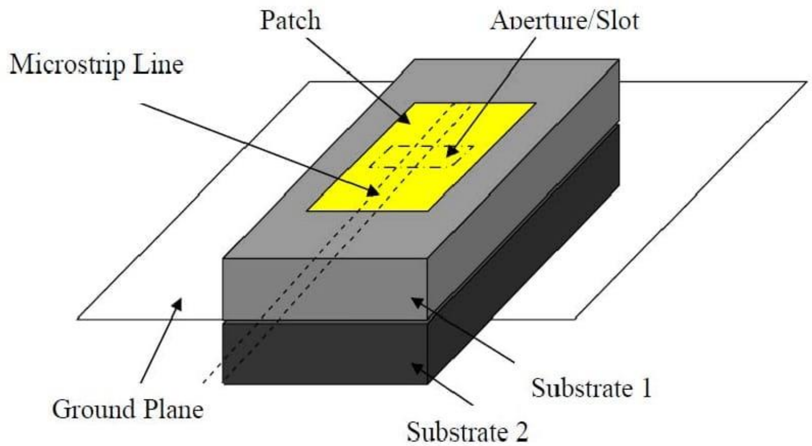

Figure 1.4 Aperture coupled feed

Figure 1.4 depicts the simple model of aperture coupled feed. Generally, a high dielectric material is used for bottom substrate and a thick low dielectric constant material is used for the top substrate to optimize radiation from the patch. The major disadvantage of this feed technique is that it is difficult to fabricate due to multiple layers, which also increases the antenna thickness. This feeding scheme also provides a narrow bandwidth.

1.5.4 PROXIMITY COUPLED FEED

This type of feed technique is also called as electromagnetic coupling scheme. Two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate. The main advantage of this technique is that it eliminates spurious feed radiation and provides very high bandwidth as high as 13 %, due to overall increase in the Thickness if the microstrip patch antenna. This scheme also provides choices between two different dielectric media, one for the patch and the other for the feed line to optimize their individual performance. Matching can be achieved by controlling the length of the feed line and width-to-line ratio of the patch. Figure 1.5 depicts the general structure of proximity coupled feed technique.

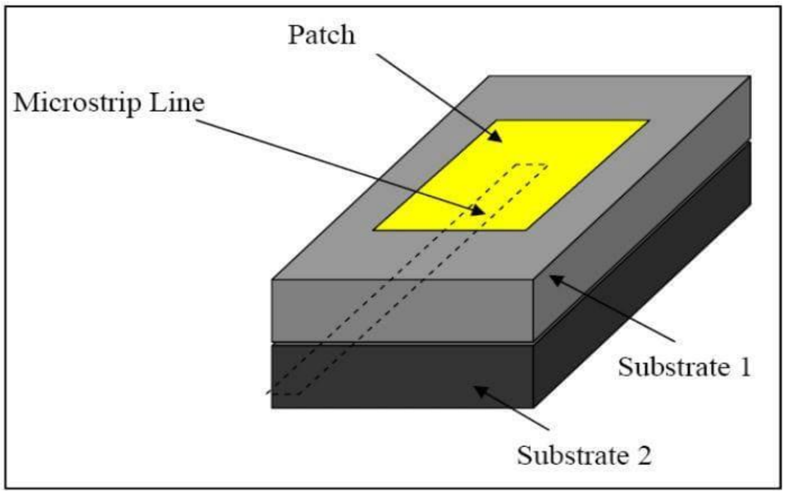

Figure 1.5 Proximity coupled feed

1.5.5 CORPORATE FEED

In the corporate feed configuration, the antenna elements are fed by 1: n power divider network with identical path lengths from the feed point to each element. The advantages of this topology include design simplicity, flexible choice of element spacing, and broader bandwidth, and these are amenable to integration with other devices such as amplifiers and phase shifter. The disadvantage of this type of array is that it requires more space for feed network for large arrays, the length of feed lines running to all elements is prohibitively long, which results in high insertion loss. The insertion loss is even more pronounced at millimeter-wave frequencies, thereby adversely degrading the gain of the array. At higher frequencies, the feed lines laid on the same plane as the patches will also radiate and interfere with the radiation from the patches. It consists of transmission lines, bends, power splitters or T junctions and quarter wave transformers. Figure 1.6 depicts the layout of corporate feed in array antenna.

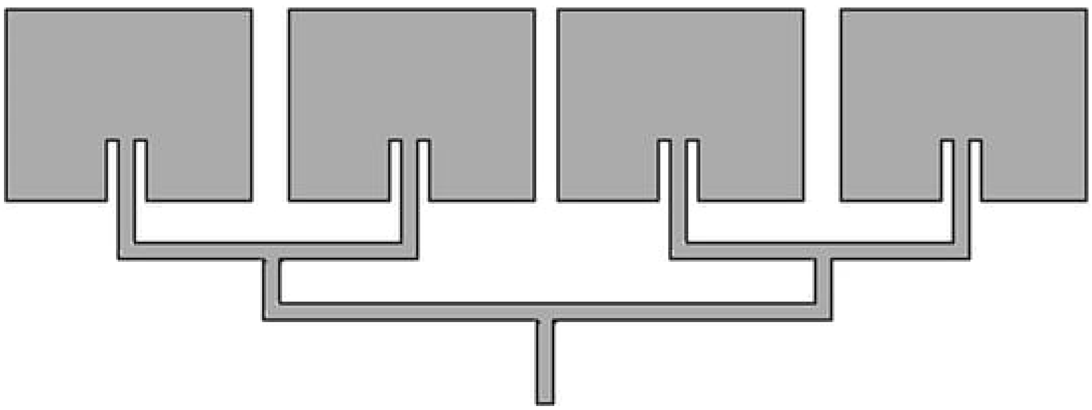

Figure 1.6 Corporate feed

1.6 PROPERTIES OF METAMATERIAL ANTENNA

The electromagnetic property of these metamaterials can be described by Maxwell's equations.

$$\nabla \times \vec{E} = -j\omega\mu\vec{H}\nabla \times \vec{E} = -j\omega\mu\vec{H} \qquad [1.1]$$

$$\nabla \times \vec{H} = j\omega\varepsilon\vec{E}\nabla \times \vec{H} = j\omega\varepsilon\vec{E} \qquad [1.2]$$

where $\vec{E}$ and $\vec{H}$ are the vectors of electric and magnetic fields strengths, respectively; ε and μ are the material permittivity and permeability.

Broadband Performance, metamaterial antennas can be designed to exhibit wideband characteristics, providing enhanced bandwidth compared to traditional antennas. This property allows for efficient communication over a broader range of frequencies. Enhanced Gain and Directivity, by utilizing metamaterial structures, antenna designers can achieve enhanced gain and directivity. Metamaterial antennas can focus and steer radiation more efficiently, resulting in improved signal strength and coverage.

Improved Efficiency, metamaterial antennas can exhibit higher efficiency compared to conventional antennas. The precise control over electromagnetic waves offered by metamaterials enables better utilization of the available energy, resulting in improved overall antenna efficiency. Compact and Low-Profile Design, metamaterial structures can enable the development of antennas with a compact form factor and low profile. This property is advantageous in applications where space limitations or aesthetics are crucial factors.

Frequency Selectivity, metamaterial antennas can be engineered to exhibit frequency-selective properties, allowing for the transmission or reception of specific frequency bands while rejecting others. This property is particularly useful for applications where interference needs to be minimized. Tailored Electromagnetic Properties, metamaterials offer the ability to tailor electromagnetic properties according to specific requirements. By designing the geometric and material properties of the metamaterial structures, antenna designers can achieve desired characteristics such as impedance matching, polarization control, and electromagnetic wave manipulation.

1.7 MERITS AND DEMERITS OF METAMATERIAL ANTENNA

1.7.1 MERITS OF METAMATERIAL ANTENNA

- Miniaturization of antenna designs
- Enhanced performance
- Frequency selectivity
- Wideband operation

- Beam steering and Beamforming
- Flexibility in design
- Improved efficiency
- Novel functionality

1.7.2 DEMERITS OF METAMATERIAL ANTENNA

- Complexity and Fabrication challenges
- Narrow bandwidth
- Sensitivity to Environmental Factors
- Complexity in design optimization
- Manufacturing constraints
- Sensitivity to Incident Angle and Polarization
- Material Losses
- Integration and Compatibility

1.8 APPLICATION OF METAMATERIAL ANTENNA

- Metamaterials enable the design of antennas with high gain, meaning these can focus and direct electromagnetic radiation more efficiently. This property is particularly useful in long-range communication systems, satellite communications, and radar systems where long-distance coverage and precise targeting are required.

- Metamaterials can be used to design compact and miniaturized antennas, enabling their integration into small devices such as smartphones, wearables, and Internet of Things (IoT) devices. This is accomplished by exploiting the unique electromagnetic properties of metamaterials to achieve resonance and radiation in smaller volumes compared to traditional antennas.

- Metamaterials allow the design of antennas that operate over a wide frequency range, making them suitable for applications requiring broadband communication, such as wireless communication systems, broadband Internet access, and wireless sensor networks.

- Metamaterials can be used to design antennas with cloaking capabilities, making them invisible to radar systems. This concept has applications in military and defense, where reducing the radar cross-section of objects such as aircraft, ships, or ground vehicles is desired.

- Antennas can be thought of as absorbers as they need to absorb energy. A known method to make broadband absorbers is to design multiple metamaterial unit elements and arrange them in such a way as to give a broadband absorptance. A similar method can be applied to metamaterial antennas and make UWB metamaterial antenna.

CHAPTER 2

LITERATURE REVIEW

KM Neeshu & Anjini Kumar Tiwary proposed work on “Metamaterial loaded antenna with improved efficiency and gain for wideband application”, a microstrip patch antenna based on metamaterial loading is designed for UWB application. This proposed antenna radiates from 2.88 to 14 GHz due to the bottom loading of the metamaterial unit cell. The antenna miniaturization is achieved by the top unit cell loading in the patch. The radiation efficiency is enhanced by removing partial ground on the backside of the antenna, which eliminates stored energy in antenna. It maintains an average efficiency of 75% and the highest efficiency achieved is 87%. The antenna gives gain greater than 1.5 dBi at a higher frequency and peak gain of 7.2 dBi is achieved at 13.39 GHz. Thus, the antenna shows an apparent enhancement of antenna properties. This antenna can be used in some wireless communication operation similar to UWB, Wi- Max, 5G and Wi- Fi 6E. [1]

Aiting Wu, Furan Zhu, Pengquan Zhang, Zhonghai Zhang, and Boran Guan worked on "Bandwidth enhancement of printed microstrip wide-slot rotating antenna based on eigenshape interleaving algorithm". This paper proposed a self- shape fusion algorithm for antenna bandwidth improvement. This method can be used to ameliorate the bandwidth of various types of antennas. A microstrip Slot antenna based on the proposed algorithm was developed to test its feasibility and efficiency. The shape of the reference antenna was changed then using the self- shape blending algorithm to ameliorate its bandwidth and also compared against the reference antenna to observe its performance. The source shapes were determined by reference to former studies. The shape of patch and slot of the microstrip antenna both affect the bandwidth, so the shape of the patch and Slot can be optimized contemporaneously. The self- shape blending algorithm improves the antenna’s operating bandwidth by importing redundant resonances. The proposed antenna has a wider bandwidth than an analogous reference antenna. [2]

Kabir Hossain, Thennarasan Sabapathy, Muzammil Jusoh, Mahmoud A. Abdelghany, Ping Jack Soh, Mohamed Nasrun Osman, Mohd Najib Mohd Yasin, Hasliza A. Rahim and Samir Salem Al-Bawri proposed an antenna design called "A Negative Index Nonagonal-CSRR Meta Compact flexible planar monopole antenna for ultra-wideband applications using viscose wool felt". A compact textile UWB planar monopole antenna integrated with an MTMUCA featuring ENG and NZRI parcels was proposed and studied. The MTM- integrated antenna prototype was fabricated using flexible polymer viscose- wool felt as the substrate and Shieldit SuperTM as the conductive element. This proposed MTMUC structure consists of a unique combination of square- and nonagonal-structured CSRR- type MTMs. The proposed MTMUCA and MTMUC displayed SNG properties in different frequency bands. The proposed design can potentially be applied for wearable applications, where future research could be carried out to probe the feasibility of on- body application, specifically for breast cancer discovery. [3]

Soumik Dey, Santanu Mondal and Partha P. Sarkar proposed the antenna design on "Single Conductor Circularly Polarized Antenna with Complementary Split Ring Resonator (CSRR)". A CSRR based rectangular microstrip antenna (RMSA) is designed for circular polarization. In the first antenna design, two circular CSRRs are embedded on the ground plane, and for the second antenna design, CSRRs are loaded on the radiating patch. Introduction of CSRRs on ground and patch is used to reduce the antenna size, and it also increases the impedance bandwidth. The impedance bandwidth of the antennas for $S11< -10$ dB is between 2.3 and 2.4 GHz. Minimal axial ratios of the antenna with CSRR loaded on ground and patch are attained as 1.48 dB at 2.35 GHz and 0.5 dB at 2.336 GHz. It is observed that gain variation is below 0.5 dB within the 3 dB axial ratio bandwidth. Higher isolation (> 20 dB) is maintained between co- and cross-polarized factors. The quality factor and efficiency characteristics of the antenna are observed. [4]

Maroli S. Rao and Prabhugoud I. Basarkod proposed "A new complementary slot split ring resonator truncated arc antenna with enhanced performance". The paper has discussed the design from the perspective of numerical and circuit proposition aspect and the results subsequently compared with the measured values. A detailed parametric analysis was conducted to ascertain the values of the design parameters of the patch and the novel CSlSRR. The fabricated antenna resonates at 2.48 GHz and 2.66 GHz in the band of 2.44 to 2.76 GHz. The measured conterminous impedance bandwidth is 320 MHz (12.3). RHCP is generated along the boresight and has a 100 MHz (4.07) axial rate bandwidth. The peak measured gain is 2.476 dBi at 2.75 GHz. The new CSlSRR contributes to miniaturisation and enhancing the bandwidth of the antenna and also produces DNG material parameter response. [5]

Sunil P. Lavadiya, Shobhit K. Patel, Rayisyan Maria C proposed “High gain and frequency reconfigurable copper and liquid metamaterial tooth based microstrip patch antenna”. Tooth based metamaterial enables microstrip patch antenna. The material of the split-ring resonator along with a tooth and without tooth are analysed by changing copper and liquid (water-sea). Simulation results also compared with fabricated copper-based microstrip patch antenna with and without the tooth. There are five switching modes analysed in terms of reflection coefficient, the number of bands, bandwidth, tunability and gain by using copper and liquid (water-sea) in tooth based SRR and without tooth based SRR. It is observed that by putting a switch in the patch at a specific location and by keeping it on and off frequency tunability is achieved. Maximum average bandwidth of 115.14 MHz is achieved in liquid SRR with the liquid tooth. Maximum tunability of 730 MHz is achieved in liquid SRR with the liquid tooth. The maximum gain is achieved in liquid SRR with a liquid tooth of 6.59 dB than all other design. Directivity in liquid-based SRR is better than copper-based SRR. Tooth enable SRR ring antenna structure to provide better bandwidth, tunability and gain. [6]

Khaled Aliqab ,Meshari Alsharari, Ammar Armghan , Malek G. Daher and Shobhit K. Patel proposed “Design and Fabrication of a Low-Cost, Multiband and High Gain Square Tooth-Enabled Metamaterial Superstrate Microstrip Patch Antenna”. They have concluded that, the tooth-added metamaterial superstrate structure with the connected interior and exterior patch provides the multiband operation with a healthy gain. The measured and fabricated results are compared for verification. The system’s performance is analyzed by varying the substrate material, inserting and removing the tooth in the split-ring resonator, and connecting and disconnecting the interior and exterior patch. The results are compared, in terms of many bands, S11, the voltage standing wave ratio and the bandwidth for the proposed four structures, by changing the substrate material Rogers RT Duroid 5880 and FR4. The results are compared with earlier published work. The presented design represents seven frequency bands of operation, a gain of 8.57 dB, and a maximum reflectance response of −33.79 dB. Their proposed structure is appropriate for numerous wireless communication applications, such as radar surveillance, satellite communication and weather monitoring. [7]

CHAPTER 3

ANTENNA CHARCTERISTICS

Antenna is a radiator that converts electric field into radio waves and vice versa in transmission, a radio transmitter supplies an oscillating radio frequency electric current to the antenna's terminals, and the antenna radiates the energy from the current as electromagnetic waves radio waves. In reception, an antenna intercepts some of the power of an electromagnetic wave in order to produce a tiny voltage at its terminals that is applied to a receiver to be amplified. Antenna may be classified based on its application as Omni directional and Directional. In Omni directional, antenna radiates equally in all directions whereas in directional antenna it radiates only in particular direction. Antennas are used in systems such as radio broadcasting, broadcast television, radar, cell phones, and satellite communications, as well as on other devices such as garage door openers, wireless microphones, Bluetooth enabled devices, wireless computer networks, baby monitors, and RFID tags on merchandise.

3.1 GAIN

- Antenna gain is a measure for antennas efficiency.
- Gain is the ratio of the maximum radiation in a given direction to that of a reference antenna for equal input power.
- Generally, the reference antenna is an isotropic antenna.
- Gain is measured generally in "decibels above isotropic (dBi)" or "decibels above a dipole (dBd).
- An isotropic radiator is an ideal antenna which radiates power with unit gain uniformly in all directions. dBi = dBd + 2.15
- Antenna gain depends on the mechanical size, the effective aperture area, the frequency band and the antenna configuration.

- Antennas for GSM1800 can achieve some 5 to 6 dB more gain than antennas for GSM900 while maintaining the same mechanical size.

3.2 DIRECTIVITY

It is the ability of the antenna to transmit maximum power in the desired direction in case of transmission and to receive the maximum energy in from the desired direction in case of reception.

3.3 BANDWIDTH

The antenna's bandwidth is the range of operating frequencies over which the antenna meets the operational requirements, including:

- Spatial properties (radiation characteristics)
- Polarization properties
- Impedance properties
- Propagation mode properties

Most antenna technologies can support operation over a frequency range that is 5 to 10% of the central frequency (e.g., 100 to 200 MHz bandwidth at 2 GHz) due to their resonance characteristics.

3.4 POLARIZATION

- Polarization of the field radiated by the antenna is another important specification. Polarization refers to the path traced by the tip of the electric field vector as a function of time. There are three forms of polarization: linear, circular and elliptic.
- Linear polarization occurs either when there is only one component of the electric field or when there are two components of the electric field and the phase difference between them is 0° or 180°. The pattern traced by the tip of

the electric field vector as time progresses is a line.

- Circular polarization occurs when there are two components of the electric field, and they are equal in magnitude and one of the components leads the other by 90°. Circular polarization can be either right-handed or left handed, depending on the direction in which the rotation of the field occurs with time.
- Elliptical polarization occurs when the components of the electric field do not have the same magnitude and have an arbitrary phase difference between them; the electric field vector traces out an ellipse with time.

3.5 BEAM WIDTH

The angular range of the antenna pattern in which at least half of the maximum power is still emitted is described as a "Beam Width". Bordering points of this main lobe are therefore the points at which the field strength has fallen in the room around 3 dB regarding the maximum field strength. This angle is then described as beam width or aperture angle or half power (-3 dB) angle. The beam width is exactly the angle between the 2 red marked directions in the upper pictures. The angle can be determined in the horizontal plane as well as in the vertical plane.

3.6 RADIATION PATTERN

- The main characteristics of antenna are the radiation pattern.
- The antenna pattern is a graphical representation in three dimensions of the radiation of the antenna as a function of angular direction.
- Antenna radiation performance is usually measured and recorded in two orthogonal principal planes (E-Plane and H-plane or vertical and horizontal planes).
- The pattern of most base station antennas contains a main lobe and several minor lobes, termed side lobes.

- A side lobe occurring in space in the direction opposite to the main lobe is called back lobe.

3.7 RADIATION EFFICIENCY

- An antenna receives electric signals from the transmitter circuits and converts them into electromagnetic waves. The efficiency of the antenna in performing this conversion, known as antenna radiation efficiency, is defined as the ratio of the power dissipated into space to the net power delivered to the antenna by the transmitter circuits.
- During the receive mode of operation, an antenna converts the electromagnetic waves into electric signals. The efficiency of this operation is the same as the antenna radiation efficiency.
- Antenna radiation efficiency is taken into account when antenna gain is calculated. Therefore, many antenna manufacturers choose to provide only antenna gain information, which is sufficient for most applications.

3.8 VOLTAGE STANDING WAVE RATIO

The parameter VSWR is a measure that numerically describes how well the antenna is impedance matched to the radio or transmission line it is connected to. VSWR stands for Voltage Standing Wave Ratio, and is also referred to as Standing Wave Ratio (SWR). VSWR is a function of the reflection coefficient, which describes the power reflected from the antenna. If the reflection coefficient is given by Γ, then the VSWR is defined by the following formula:

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \qquad [3.1]$$

The reflection coefficient is also known as $S_{11}S_{11}$, or return loss. The VSWR is always a real and positive number for antennas. The smaller the VSWR is, the better the antenna is matched to the transmission line and the more power is delivered to the antenna. The minimum VSWR is 1.0. In this case, no power is reflected from the antenna, which is ideal.

Often antennas must satisfy a bandwidth requirement that is given in terms of VSWR. For instance, an antenna might claim to operate from 100-200 MHz with VSWR<3. This implies that the VSWR is less than 3.0 over the specified frequency range. This VSWR specifications also implies that the reflection coefficient is less than 0.5 (i.e., $\Gamma<0.5$) over the quoted frequency range.

3.9 AXIAL RATIO

The axial ratio is the ratio of orthogonal components of an E-field. A circularly polarized field is made up of two orthogonal E-field components of equal amplitude (and 90 degrees out of phase). Because the components are equal magnitude, the axial ratio is 1 (or 0 dB).

The axial ratio for an ellipse is larger than 1 (>0 dB). The axial ratio for pure linear polarization is infinite, because the orthogonal components of the field is zero. Axial ratios are often quoted for antennas in which the desired polarization is circular. The ideal value of the axial ratio for circularly polarized fields is 0 dB. In addition, the axial ratio tends to degrade away from the mainbeam of an antenna, so the axial ratio may be indicated in a spec sheet (data sheet) for an antenna as follows: "Axial Ratio: <3 dB for +-30 degrees from mainbeam". This indicates that the deviation from circular polarization is less than 3 dB over the specified angular range.

3.10 EFFECTIVE ISOTROPIC RADIATED POWER

EIRP is Effective Isotropic Radiated Power, also called the Equivalent

Isotropic Radiated Power. In antenna measurements, the measured radiated power in a single direction is known as the EIRP.

Typically, for an antenna radiation pattern measurement, if a single value of EIRP is given, this will be the maximum value of the EIRP over all measured angles. EIRP can also be thought of as the amount of power a perfectly isotropic antenna would need to radiate to achieve the measured value. The EIRP can be related to the power transmitted from the radio ($PtPt$), the cable losses (possibly including antenna mismatch) L, and the antenna gain (GG) by:

$$EIRP = Pt - L + G \qquad [3.2]$$

Often the cable losses L can be neglected, as they are generally a small fraction of a dB. Total (full 3D) Measurements from a Single-Point (single-direction) Measurement. If the peak EIRP and the directivity (D) are known for an antenna, then the Total Radiated Power (TRP) can be found from the equation:

$$TRP = EIRP - D \qquad [3.3]$$

In this manner, if the directivity and peak angle for an antenna are known in advance, the measurement time can be greatly reduced by using equation [3.3].

3.11 TOTAL RADIATED POWER

Total Radiated Power (TRP) is a measure of how much power is radiated by an antenna when the antenna is connected to an actual radio (or transmitter). TRP is an active measurement, in that a powered transmitter is used to transmit through the antenna. The total received power is calculated and summed up over all possible angles (hence, it is a spherical or 3D measurement) and the result is the total radiated power.

The total radiated power is the spherical integral of R, which meanstheta and phi are integrated across every angle possible:

$$TRP = \int_0^{2\pi} \int_0^{\pi} R(\theta, \varphi) sin\theta d\theta d\varphi \quad [3.4]$$

Equation [3.4], units of TRP is Watts [W]. Now, when measuring the Total Radiated Power in an anechoic chamber, EIRP is measured at every angle, and then averaging it over the sphere (recall that the surface area of a sphere is 4*pi). Hence, TRP is calculated from EIRP:

$$TRP = \frac{1}{4\pi} \int_0^{2\pi} \int_0^{\pi} EIRP(\theta, \varphi) sin\theta d\theta d\varphi \qquad [3.5]$$

To make things more complicated, the vertical and horizontal (or theta and phi component) polarization power for our antenna has to be measured to accurately capture the radiated poisr. Hence, equation [3.5] can be rewritten by breaking it down in terms of the linear polarization powers:

$$TRP = \frac{1}{4\pi} \int_0^{2\pi} \int_0^{\pi} \left(EIRP_\theta(\theta, \varphi) + EIRP_\varphi(\theta, \varphi) \right) sin\theta d\theta d\varphi \quad [3.6]$$

Note that TRP has to be calculated from a set of sampled values of the EIRP, this can be approximated with a summation as in Equation [3.7]:

$$TRP \approx \frac{\pi}{2NM} \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} \left(EIRP_\theta\left(\theta_{n,} \varphi_m\right) + EIRP_\varphi(\theta_n, \varphi_m) \right) sin\theta_n \quad [3.7]$$

In Equation [3.5], EIRP is sampled at N locations along the theta axis and M locations along the phi axis (for a total of N*M point measurements).

CHAPTER 4

ANTENNA DESIGN

4.1 Unit Cell Design

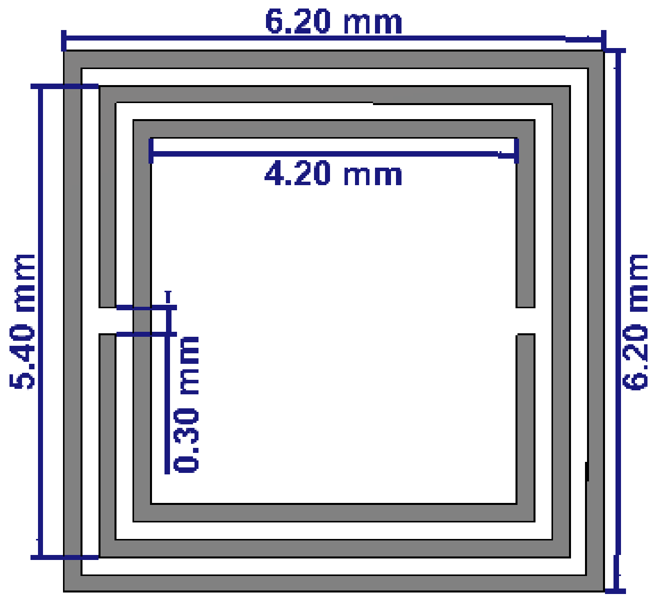

Figure 4.1 Top unit cell

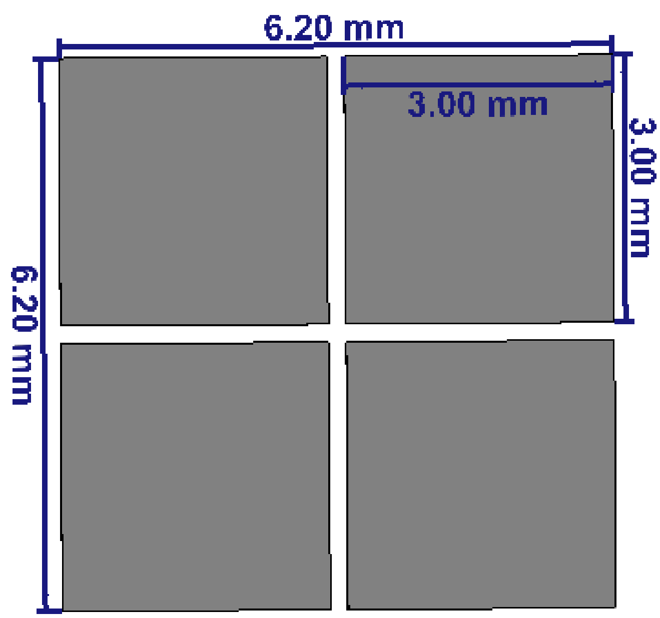

Figure 4.2 Bottom unit cell

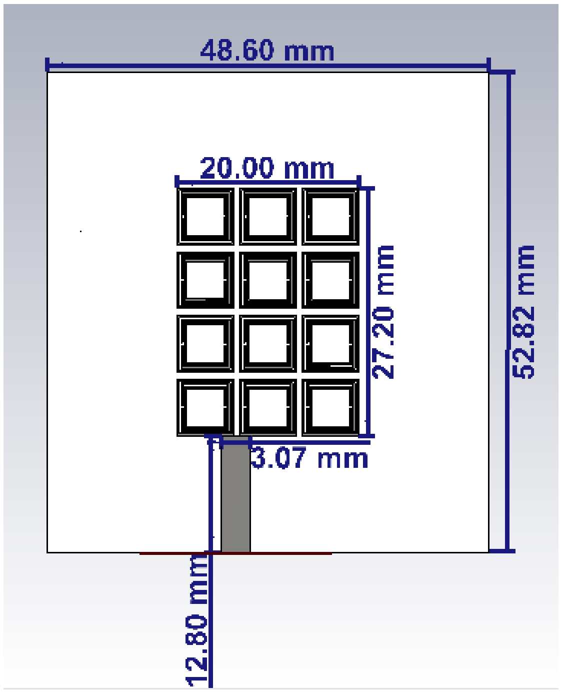

Figure 4.3 Top View

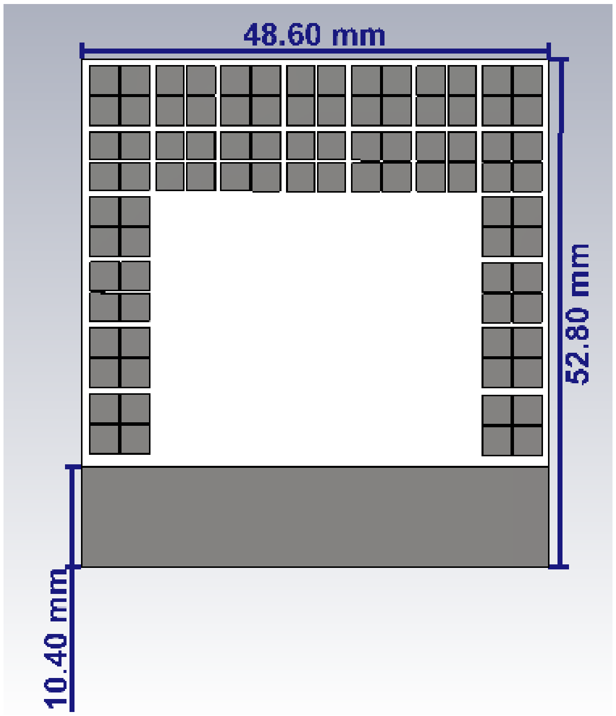

Figure 4.4 Bottom View

The dimensions of the proposed unit cell are L = 6.20mm, W = 6.20mm which gives a wide response. Three square rings are designed in each unit cell. The difference in size of each square ring is 0.8mm. The top unit cell consists of a square loop with Complementary Split Ring Resonator (CSRR). The bottom unit cell is square-shaped with a cross-slot (SSCS) is loaded on the patch and ground respectively.

A metamaterial loaded planar patch antenna is proposed and shown in Figure 2 & 3 has a top view and bottom view, respectively. The FR4 substrate of relative permittivity $\varepsilon r = 4.4$, loss tangent 0.025, and thickness (h) 1.6 mm is used to fabricate the proposed antenna of size 48.6 mm × 52.8 mm. This antenna comprises loading of CSRR and SSCS in the patch and ground plane, respectively. The partial ground plane of length 12.8 mm underneath the input port of the antenna. Top patch of antenna is loaded with 4 × 3 CSRR unit cells and to improve the radiation efficiency, a window is etched on the backside of patch antenna. The optimized dimensions of antenna are W = 48.6 mm, L = 52.8 mm.

4.2 STRIPLINE FEEDING

4.2.1 INTRODUCTION

The performance of the antenna is critical in determining the quality and reliability of the wireless communication system. Meta material antennas have gained significant attention in recent years due to their unique properties, such as the ability to control the electromagnetic properties of materials.

One of the critical components of a meta material antenna is the feed network, which connects the antenna elements to the transmission line. The feed network plays a crucial role in determining the performance of the antenna, including its radiation pattern, impedance matching, and bandwidth.

Strip line feed is a type of feed network commonly used in meta material antennas due to its low-loss transmission characteristics, good impedance matching, and high radiation efficiency. The strip line feed consists of a strip conductor that is sandwiched between two ground planes, which provides a low-impedance return path for the signal.

4.2.2 WORKING OF A STRIP LINE FEED

The working of strip line feed can be explained as follows:

- Impedance matching: The strip line feed is designed to provide impedance matching between the antenna and the transmission line. This is achieved by adjusting the width and spacing of the strip conductor.

- Signal propagation: The signal travels along the strip conductor, which is sandwiched between two ground planes. The ground planes provide a low impedance return path for the signal.

- Radiation: The signal is radiated from the antenna elements, which are placed above the strip line feed. The radiation pattern and impedance characteristics of the antenna are determined by the design of the strip line feed.

4.2.3 DESIGN CONSIDERATIONS

The design of strip line feeds requires careful consideration of several factors, including:

- Impedance matching: The strip line feed should be designed to provide impedance matching between the antenna and the transmission line.

- Frequency range: The strip line feed should be designed to operate over the desired frequency range.
- Signal loss: The strip line feed should be designed to minimize signal loss due to dielectric losses, conductor losses, and radiation losses.
- Ground plane dimensions: The dimensions of the ground planes are critical in determining the impedance and radiation characteristics of the antenna.

4.2.4 ADVANTAGES OF STRIP LINE FEED

- Low loss: Strip line feeds provide low-loss transmission lines, which are essential in high-frequency applications.
- Impedance matching: Strip line feeds provide good impedance matching between the antenna and the transmission line.
- Compact design: Strip line feeds are compact in design, which makes them ideal for use in small and portable devices.
- High radiation efficiency: Strip line feeds provide high radiation efficiency, which results in a stronger and more reliable signal.

CHAPTER 5

RESULTS

5.1 SIMULATED RESULTS

5.1.1 CST STUDIO SUITE

CST Studio Suite is a high-performance 3D EM analysis software package for designing, analysing and optimizing electromagnetic (EM) components and systems.

Electromagnetic field solvers for applications across the EM spectrum are contained within a single user interface in CST Studio Suite. The solvers can be coupled to perform hybrid simulations, giving engineers the flexibility to analyse whole systems made up of multiple components in an efficient and straightforward way. Co-design with other SIMULIA products allows EM simulation to be integrated into the design flow and drives the development process from the earliest stages.

Common subjects of EM analysis include the performance, efficiency and installed performance of antennas and filters, electromagnetic compatibility and interference (EMC/EMI), exposure of the human body to fields, electro- mechanical effects in motors and generators, and thermal effects in high-power devices.

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CST Studio Suite is used in leading technology and engineering companies around the world and offers considerable product to market advantages, facilitating shorter development cycles and reduced costs. Simulation allows the use of virtual prototyping by industry leaders, which means that device performance can be optimized, potential compliance issues can be identified and mitigated early in the design process, the number of physical prototypes required can be reduced, and the risk of test failures and recalls minimized.

5.1.2 RETURN LOSS

Return loss is related to both standing wave ratio (SWR) and reflection coefficient (I). Increasing return loss corresponds to lower SWR. Return loss is a measure of how well devices or lines are matched. A match is good if the return loss is high. A high return loss is desirable and results in a lower insertion loss. Figure 5.1 shows the simulated results shows that, the antenna operates at 7.5 GHz with the return loss of -18.519 dB respectively.

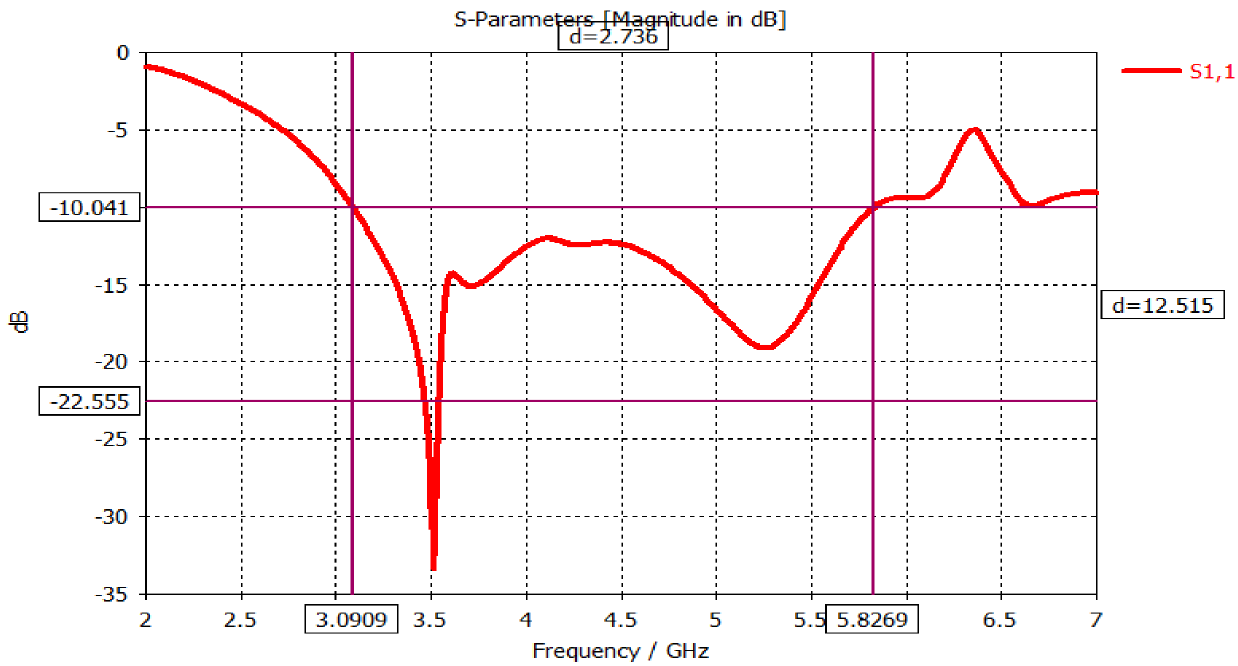

Figure 5.1 Return loss

Generally, bandwidth of the antenna is found from the return loss graph. Bandwidth is obtained from the intersection of return loss graph with -10 dB of the graph. The difference between the upper cut-off frequency and lower cut-off frequency gives the bandwidth of the antenna.

5.1.3 GAIN

Gain is a measure of the ability of the antenna to direct the input power into radiation in a particular direction and is measured at the peak radiation intensity. An isotropic antenna radiates equally in all directions. An isotropic radiator is considered to be 100% efficient. The gain of an actual antenna increases the power density in the direction of the peak radiation.

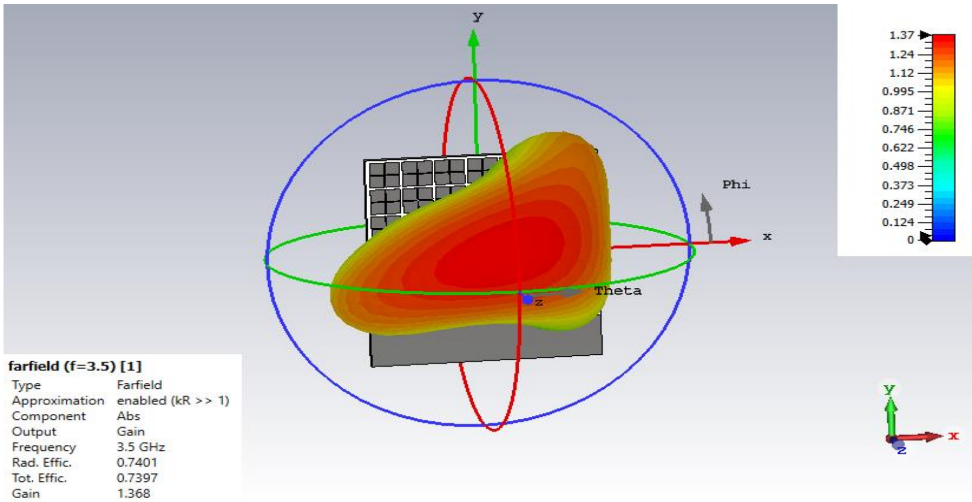

Figure 5.2 - Gain at f = 3.5 GHz

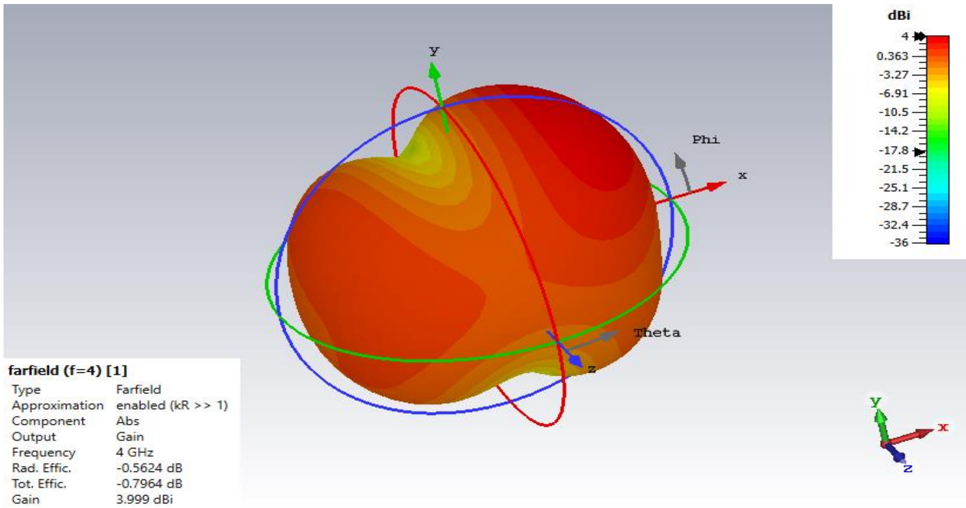

Figure 5.3 - Gain at f = 4 GHz

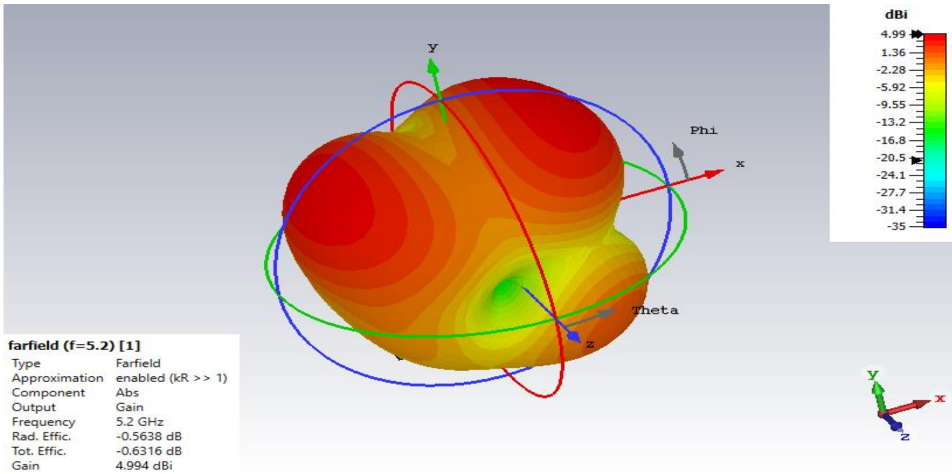

Figure 5.4 - Gain at f = 5.2 GHz

5.1.4 DIRECTIVITY

Directivity measures the power density the antenna radiates in the direction of its strongest emission, versus the power density radiated by an ideal isotropic radiator radiating the same total power.

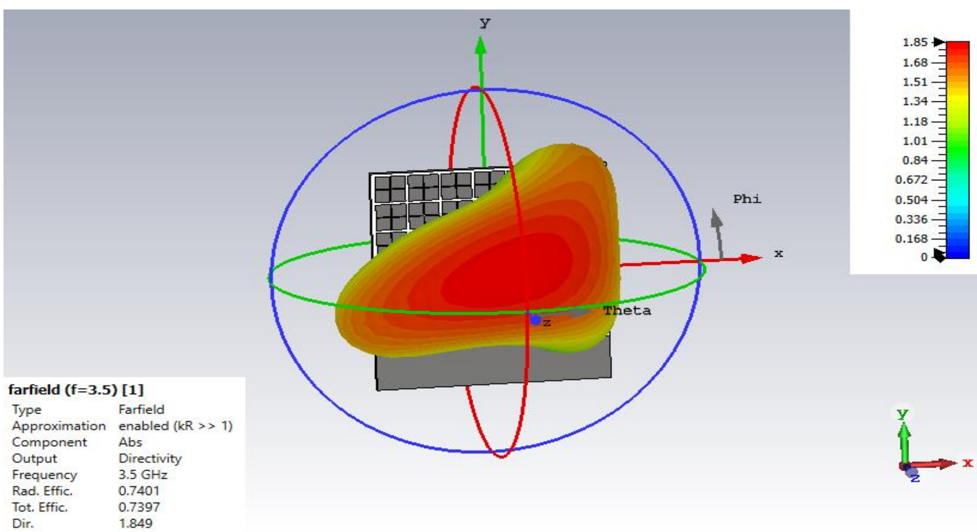

Figure 5.5 - Directivity at f = 3.5 GHz

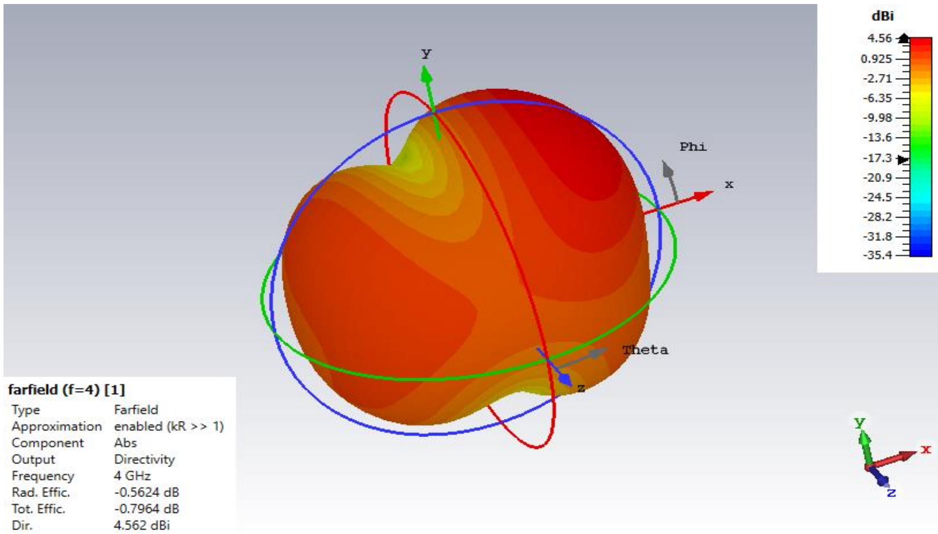

Figure 5.6 - Directivity at f = 4 GHz

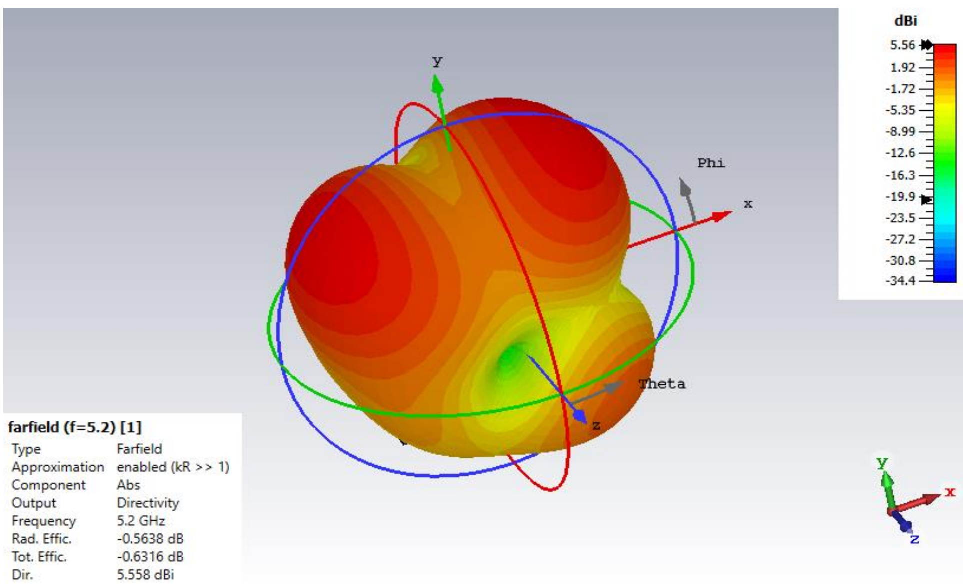

Figure 5.7 - Directivity at f = 5.2 GHz

5.1.5 VSWR MEASUREMENT

VSWR is a function of the reflection coefficient, which describes the power reflected from the antenna. Figure 5.8 depicts the antenna yields minimum VSWR value of 1.269 at the operating frequency 7.5 GHz. The VSWR table shows that, only 2% of power is reflected from the antenna, which increases antenna efficiency.

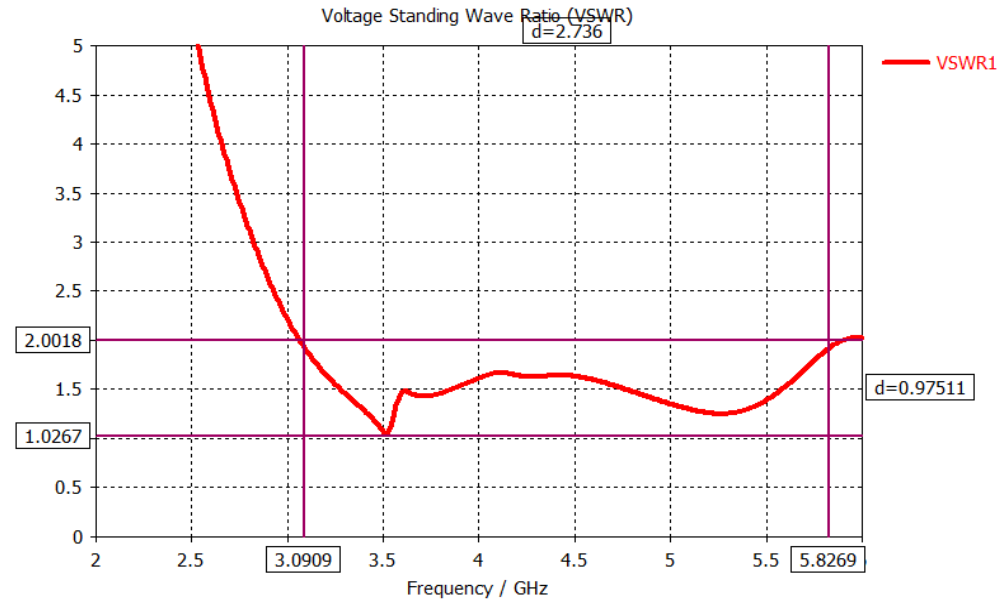

Figure 5.8 VSWR

5.2 MEASURED RESULTS

The fabricated Microstrip Antenna is tested and the results are measured using network analyzer.

5.2.1 NETWORK ANALYZER

A network analyzer is an instrument that measures the network parameters of electrical networks. Today, network analyzers commonly measure scattering parameters(s-parameters), because reflection and transmission of electrical networks are easy to measure at high frequencies, but there are other network parameter sets such as y-parameters, z-parameters, and h-parameters. Network analyzers are often used to characterize two-port networks such as amplifiers and filters, but they can be used on networks with an arbitrary number of ports.

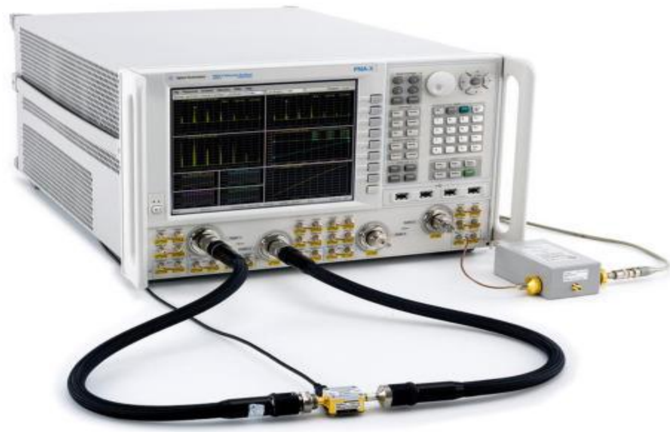

Figure 5.9 Network Analyzer

Network analyzers are used mostly at high frequencies, operating frequencies can range from 5 Hz to 1.05 THz. Special types of network analyzers can also cover lower frequency ranges down to 1 Hz. These network analyzers can be ed as an example for the stability analysis of open loops or for the measurement of audio and ultrasonic components. The two basic types of

- Scalar network analyzer (SNA) – measures amplitude properties only
- Vector network analyzer (VNA) – measures both amplitude and phase properties.

A VNA may also be called a gain-phase meter or an automatic network analyzer. An SNA is functionally identical to a spectrum analyzer in combination with a tracking generator. As of 2007, VNAs are the most common type of network analyzers, and so references to an unqualified "network analyzer" most often mean a VNA. Three prominent VNA manufacturers are Agilent, Anritsu, and Rohde & Schwarz. Another category of network analyzer is the microwave transition analyzer (MTA) or large signal network analyzer (LSNA), which measure both amplitude and phase of the fundamental and harmonics.

5.2.2 SIGNAL GENERATOR

The network analyzer needs a test signal, and a signal generator or signal source will provide one. Older network analyzers did not have their own signal generator but had the ability to control a standalone signal generator. For example, a GPIB connection. Nearly all modern network analyzers have a built- in signal generator.

5.2.3 TEST SET

The test set takes the signal generator output and routes it to the device under test, and it routes the signal to be measured to the receivers. It often splits off a reference channel for the incident wave. In a SNA, the reference channel may go to a diode detector (receiver) whose output is sent to the signal generator's automatic level control. The result is better control of the signal generator's output and better measurement accuracy. In a VNA, the reference channel goes to the receivers, which is needed to serve as a phase reference.

5.2.4 RECEIVER

The receivers make the measurements. A network analyzer will have one er more receivers connected to its test ports. The reference test port is usually labelled R, and the primary test ports are A, B, C, etc. Some analyzers will dedicate a separate receiver to each test port, but others share one or two receivers among the ports. The R receiver may be less sensitive than the receivers used on the test ports. There are some VNA architectures (six-port) that infers, phase and magnitude from just power measurements.

5.2.5 PROCESSOR AND DISPLAY

With the processed RF signal available from the receiver/detector section a is necessary to display the signal in a format that can be interpreted. With the levels of processing that are available today, some very sophisticated solutions are available in RF network analyzers. Here the reflection and transmission data is formatted to enable the information to be interpreted as easily as possible. Most RP network analyzers incorporate features including linear and logarithmic sweeps, linear and log formats, polar plots, Smith charts etc.

5.2.6 CALIBRATION

A network analyzer, like most electronic instruments, requires periodic calibration typically this is performed once per year and is performed by the manufacturer or by a 3rd party in a calibration laboratory. When the instrument is calibrated, it will usually have a sticker fixed to the outside, stating the date it was calibrated and when the next calibration is due. A calibration certificate will be issued. A vector network analyzer achieves highly accurate measurements by meeting for the systematic errors in the instrument, the characteristics of cables, adapters, and test fixtures. The process of error correction, although commonly just called calibration, is an entirely different process, and may be performed by an engineer several times in an hour. Sometimes it is called user calibration, to indicate the difference from periodic calibration by a manufacturer.

5.2.7 SMA FEMALE CONNECTOR

The SMA connector is the workhorse of the RF and microwave industries. The basic design uses a 4.2-millimeter diameter outer coax, filled with PTFE dielectric. About a zillion companies make SMA-style connectors.

Figure 5.10-SMA female connector

Their upper frequency limit is anywhere from 18 to 26 GHz, depending on the tolerances held during manufacturing. However, you should always inspect and gage and SMA connector that you will be mixing with the more expensive connectors to be sure that you don't damage them.

5.2.8 RETURN LOSS (S11)

Figure 5.11 depicts the measurement of the return loss. It depicts the value of frequency 3.3 GHz with gain of -18.61 dB, 3.8 GHz with gain of -20.63 dB and 5.9 GHz with gain of -5.7 dB.

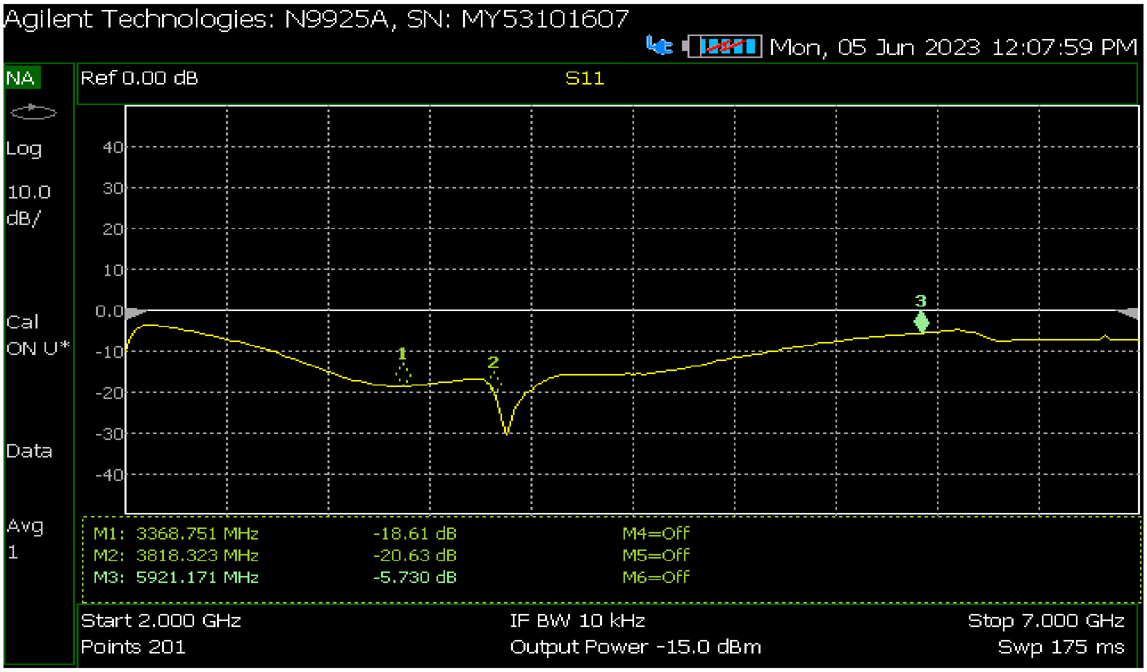

Figure 5.11 Return loss

5.2.9 VOLTAGE STANDING WAVE RATIO (VSWR)

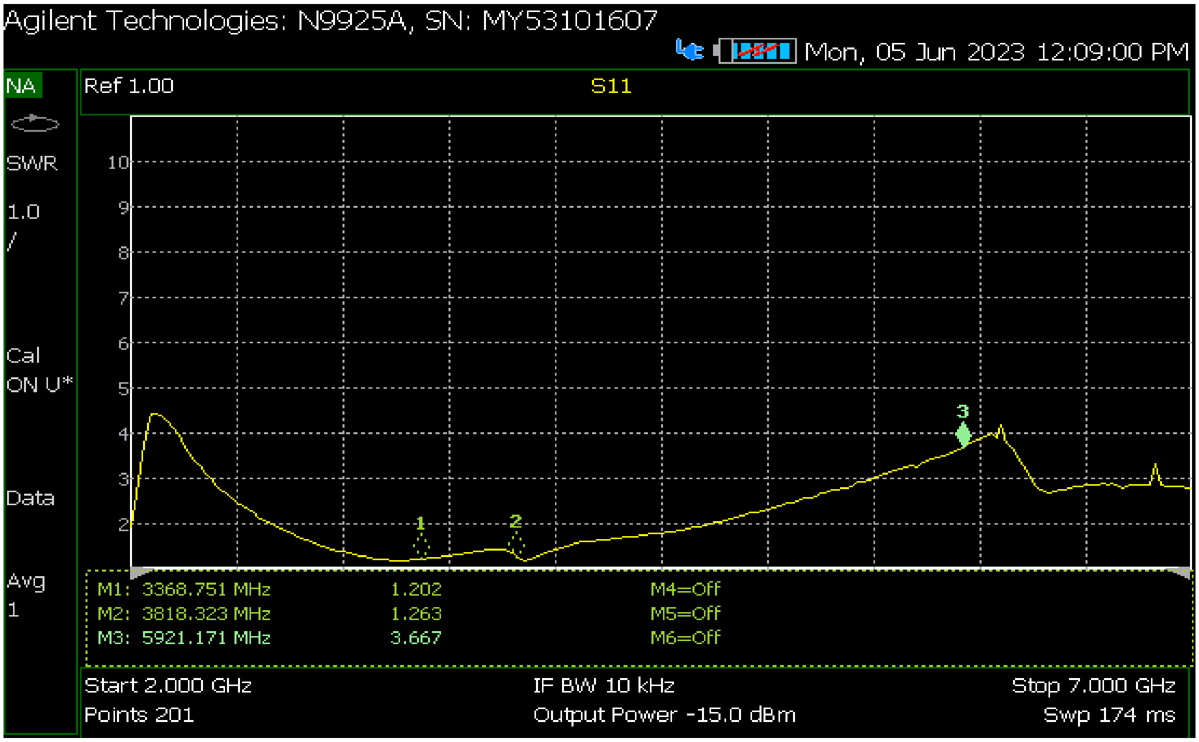

Figure 5.12 VSWR

Figure 5.12 depicts the measurement of VSWR. It depicts the value of frequency 3.3 GHz with VSWR value of 1.202, 3.8 GHz with VSWR value of 1.263 and 5.9 GHz with VSWR value of 3.667.

5.2.10 SMITH CHART

The Smith Chart is a fantastic tool for visualizing the impedance of a transmission line and antenna system as a function of frequency. Smith Charts can be used to increase understanding of transmission lines and how they behave from an impedance viewpoint. Smith Charts are also extremely helpful for impedance matching. The Smith Chart is used to display an actual (physical) antenna's impedance when measured on a Vector Network Analyzer (VNA).

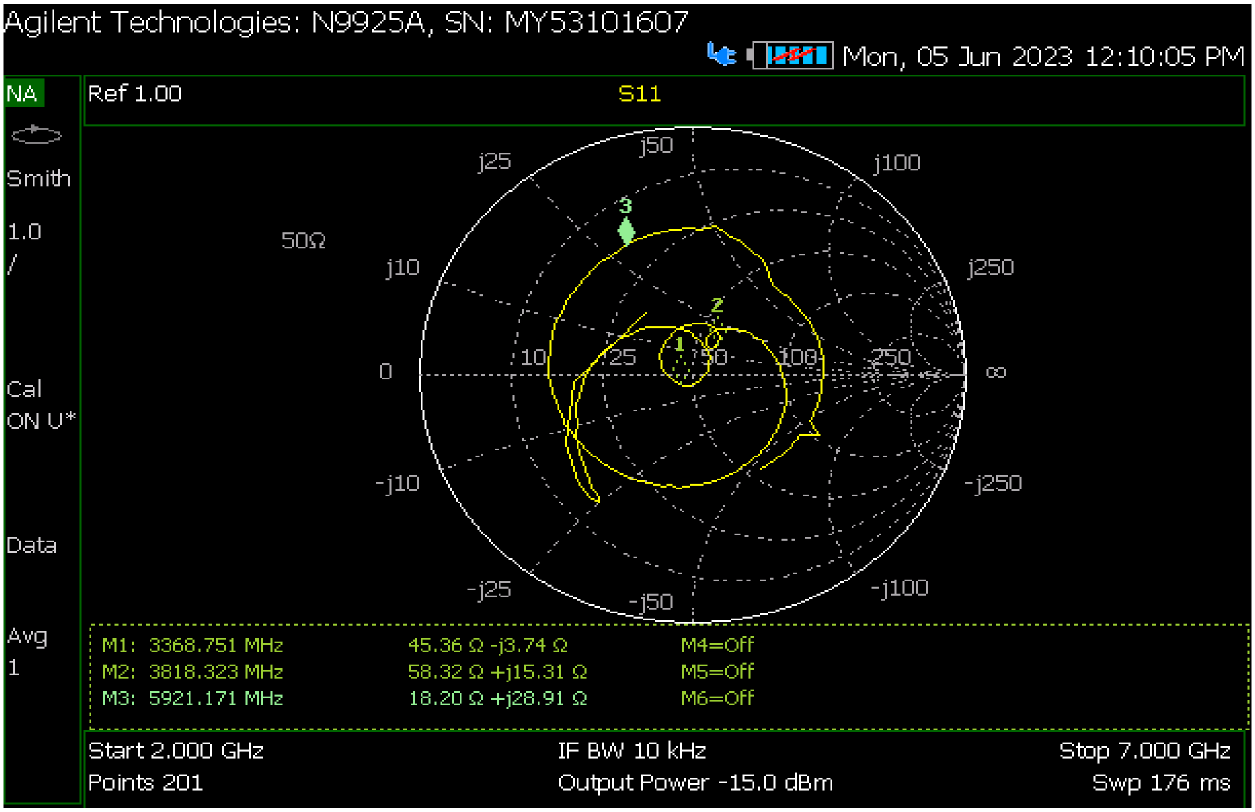

Figure 5.13 Smith chart

Figure 5.13 depicts the smith chart representation of the designed antenna. It depicts the Smith chart value for the frequency of 3.3 GHz along with the impedance matching value of 45.36 ohms -j3.74 ohms, 3.8 GHz along with the impedance matching value of 58.32 ohms +15.31 ohms and 5.9 GHz along with the impedance matching value of 18.20 ohms +28.91 ohms.

Figure 5.14 Testing Setup

CHAPTER 6
CONCLUSION

The crucial requirement of wideband antennas with excellent efficiency in wireless communication systems has been addressed in this work. While various methods to increase antenna bandwidth, such as using low-permittivity substrates, increasing substrate thickness, and using differently shaped radiating patches, have been explored, these approaches often fall short of the required wideband performance. The primary goal of this research was to develop a compact antenna with improved radiation characteristics, taking advantage of metamaterial patch. The results have shown that the proposed antenna exhibits wideband performance along with high gain characteristics. These features make it highly suitable for applications in 5G NR FR1 and Wi-Fi 6E systems, where wideband communication is of paramount importance. From the practical measurement results, it can be observed that it is similar to that of the simulated results.

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Design Of Metamaterial Antenna For Wideband and Application

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