Design and Analysis of an Inset Feed X-Band Microstrip Patch Antenna

A Project and Thesis submitted in partial fulfillment of the requirements
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Certification

This is to certify that the thesis entitled, "**Design and Analysis of an Inset Feed X Band Microstrip Patch Antenna**" submitted by **Md. Nahid Hasan, Ripon PK.** & **Md. Abrar Mohasin** in partial fulfillment of the requirements for the award of Bachelor of Science Degree in ELECTRICAL AND ELECTRONIC ENGINEERING at the Daffodil International university, Ashulia is an authentic work carried out by him under my supervision and guidance. To the best of my/our knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any degree or diploma.

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Dedicated to

Our Parents

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LIST OF ABBREVIATIONS

RMPA	Rectangular Microstrip Patch Antenna
MPA	Microstrip Patch Antenna
GHz	Giga Hertz
EM	Electro-Magnetic
GPS	Global Positioning System
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
RF	Radio Frequency
VSWR	Voltage Stanting Wave Ratio
PCB	Printed Circuit Board
MP	Microstrip Patch
WiMAX	Worldwide Interoperability for Microwave Access
RFID	Radio Frequency Identification
MIMO	Multiple Input Multiple Output
MHz	Mega Hertz
NASA	National Aeronautics and Space Administration
2D	Two Dimensional
3D	Three Dimensional
Dg	Directivity Gain
Rp	Radiation Intensity for Particular Angle of Antenna
Ra	Average Radiation Intensity
Bw	Bandwidth
Fu	Upper Frequency
Fl	Lower Frequency
Fc	Center Frequency
RL	Return Loss

LIST OF SYMBOLS

λ	Wavelength
π	Pie
f	Frequency
c	Speed of light
Γ	Reflection coefficient
ρ	Magnitude coefficient
R	Resistance
L	Inductance
C	Capacitance
G	Conductance
Z0	Impedance
εr	Relative dielectric constant
ε_{reff}	Effective dielectric constant
tanδ	Loss tangent
h	Height
fr	Resonant frequency
V0	Velocity of light
$Leff$	Effective length
φ	Angle
W	Width

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ABSTRACT

Newer microwave and millimeter-wave systems are in higher demand to satisfy emerging communications difficulties in terms of size, bandwidth, and gain. As a result, antennas are commonly utilized to meet satellite communication demands. Different applications are accessible in different frequency ranges in satellite communication. Researchers are constantly trying to enhance the bandwidth and gain for Microstrip Patch antennas (MPAs). Using the Ansys HFSS and CST Studio Suite 3D EM simulation software a new optimized MPA is designed. The proposed antenna is an inset feed partial ground MPA structure that has resonance frequencies of 8.45 GHz, 9.95 GHz, and 13.17 GHz, with a bandwidth of 6.7 GHz. It operates at frequencies ranging from 7.9 GHz to 14.6 GHz covering the complete X-band and lower portion of K_u band. The planned antenna is 23.8×28.2×1.6 mm3 in size, with FR-4 Epoxy as the substrate which has a dielectric constant of 2.2 and loss tangent of 0.02. The antenna can be used for terrestrial broadband, uplink and downlink of satellite, mobile-satellite service, broadcasting satellite services, secure military communication, military satellite communication, direct broadcast satellite TV relay, fixed satellite service, amateur radio, weather monitoring , air traffic control, maritime vessel traffic control and radar application.

CHAPTER 1

Introduction

1.1 Introduction

Wireless communication has become the fastest rising segment and even the most essential technological portion in the telecommunication industry. In this modern era, it has become so omnipresent in the communication field and unavoidable for our daily lives. Moreover, wireless communication is a revolutionized way of doing almost everything even it gives us easement and an unprecedented sense of mobility. However, a couple of centuries ago, long-distance communications were so difficult and even it took additional time to reach. With the expectation, long-distance communication became easier, such as optical communication. It has been a vital portion of human lives for a couple of decades and even it is continuously evolving. Later, in the recent modern history of communication, the electromagnetic (EM) spectrum is used for the wireless communication system and it is continuously growing. Nowadays, the wireless communication system is using as a vital part for many new applications such as Arduino based home automation system, automated traffic and factories, remote telemedicine service, robotic vehicles etc. In the wireless communication system, an Antenna is the most essential part. An antenna is an array of conductor or electrical component that is essential to transmit or receive an electromagnetic (EM) beam spectrum or radio signal from the space circumfluent it. In transmission, the antenna terminal takes the electric energy and then radiates the signal as an electromagnetic wave to the space surrounding it. And then, the Antenna receives electromagnetic signals from all horizontal directions or any specific direction. Especially, in the wireless communication system, the antenna is used to establish a wireless connection between two or more devices. The antenna's performance depends on some terms such as antenna gain, bandwidth, polarization, radiation pattern, impedance. On the basis of electromagnetic wave wavelength and radiation frequency, the antenna can operate for all kinds of application in the wireless communication system such as mobile phone, GPS receiver, satellite, base station wireless local area network connections (WLAN), radar system etc. However, the range of operating frequency of an antenna depends on the materials such as steel plate, flex, ceramic, RT duroid, or wire material. In the present era, the demand for optimization of the size of an antenna and the improvement of the performance, new artificial material has been introduced known as a met material. However, the antenna one of the most complicated aspects of radio frequency (RF) design and even it is the most overlooked part of a radio frequency (RF) design. Because the range and the performance of radio frequency critically depend upon the antenna.For a decade, antenna design become a significant part of telecommunication researchers. Especially, antenna size minimization and the multifunctional system has become the most important and interesting part. The demand for size optimization and versatile antennas is increasing day by day for the different frequency range. To fulfil the demand, Microstrip Patch Antenna (MPA) has become the most popular antenna design due to its compressed structure. Compared with the other conventional antenna, MPA has more multilateral advantages for designing such as the ability to work UFH or HF or more frequency range, inexpensive to manufacture, easy to assemble in integrated circuit technology [1].By applying various techniques to design MPA opens the possibility in the enhancement of antenna characteristic such as antenna bandwidth, gain, directivity, small size, tunable operational frequency and etc.

1.2 Background

The abstract idea of the Microstrip Patch Antenna (MPA) was first introduced by G.A. Deschamps in the 1950s [1-3].After 20 years, the MPA concept was first practically developed by Howell and Munson in the 1970s after the evolution of the printed circuit board (PCB) technology [1-3].By the early 1980s, basic microstrip antenna elements and arrays were fairly well known in terms of design and modelling, and developers were turning their attentions to developing antenna performance features (e.g. bandwidth), and to increase the application of MPA of the technology. Basically, the microstrip patch antenna consists of two substrate, one of them is conducting patch (metallic patch on a thin, grounded dielectric substrate) of any non-planar or planar geometry that is located on one side of the dielectric substrate. And the second one is the ground plane on another side. The MPA has been widely utilized due to the integration with the microstrip technology and the planer configuration. The basic and most commonly used microstrip antennas are rectangular and circular patches. For having the advantage of inexpensive, easy for fabricating, and not having difficulty for integration with external circuitry like microwave monolithic integrated circuits (MMICs) and probably all integrated circuit, the application of MPA is so wide for civilians and military applications such as television broadcasting, Wi-Max, multiple-input multiple-output (MIMO) systems mobile system, radio-frequency identification (RFID), Wi-Fi, global positioning system (GPS), satellite communications, surveillance systems, vehicle collision avoidance system, direction founding, radar systems, remote sensing, biological an application like biological imaging, missile guidance, and so on and still the work is carried on the microstrip antennas for finding new applications of it by having more integration [2], [3].

The area of research of MPA for designing and implementation is an ongoing process. For getting desirable resonant frequencies of MPA modified configuration and various shapes such as rectangular or triangular with a different dimension of length (L) can help. The bandwidth of MPA strongly depends on the gap between the conducting patch and the ground plane. A smaller gap between the conducting patch and the ground plane stores more energy in the patch capacitance and inductance and radiates less. As a result, increases the quality factor (Q) of the antenna, indicating a narrow radiation bandwidth. By increasing the thickness of the dielectric substrate, Q can be reduced, but the problem is increasing the thickness of the dielectric substrate reduced efficiency since the large portion of the input power is dissipated in the resistor which takes away the available Power that can be radiated by the antenna. It can also affect low power gain and the extra radiation from its junction and junction feeds points. The resonant bandwidth and gain can be affected by the substrate permittivity (εr) of the microstrip antenna [4]. It is really hard to get a standard antenna gain and bandwidth characteristic in the same MPA[3].

1.3 Literature Review

Microstrip patch antennas are well known for their benefits, which include light weight, low fabrication costs, mechanical robustness when placed on hard surfaces, and the capacity to operate at dual and triple frequencies [5]. The antenna's limited bandwidth, on the other hand, proved to be its worst drawback. To alleviate this problem, many strategies have been used, such as increasing the substrate thickness, introducing parasitic elements (co-planar or stack arrangement), or changing the patch's shape. Designing an E-shaped patch antenna [14],[15] or a U-slot patch antenna [8],[16] is one way to change the shape of the patch. The authors claim in [15] that a U-slot microstrip antenna can enhance bandwidth by up to 30%, while an E-shaped patch antenna can increase bandwidth by more than 30% over a standard rectangular patch antenna. When comparing the two designs, the E shaped is significantly easier to make because it only requires changing the length, width, and position of the slots. [17] Contains all basic microstrip patch antenna calculations. Figure 2.1(a) shows a wideband single patch antenna proposed in this paper. As a design reference, the design is based on a reconfigurable patch antenna in [9], but there is no switch in this design. The major goal of this work is to improve the fundamental design in [9] in order to increase bandwidth. The voltage standing wave ratio (VSWR) of this single patch antenna is less than 2 (VSWR 2).

[18] Proposes an ultra-wideband and tri-band antenna for satellite applications in the C, X, and Ku bands with a dimension of 1451.66 mm3. A modified rectangular radiating element with a distorted ground plane makes up the ultra-wideband antenna, which has a bandwidth of 5 to 16 GHz. The U-shaped slots in the radiating patch were used to generate a tri-band frequency response that covered the C, X, and Ku bands independently. 4.9-7 GHz, 7.92-11.08 GHz, and 11.85-15.94 GHz were the frequency ranges that were achieved. Across the whole bandwidth, the antenna gain varied from 2.3 to 4.5 dBi. [15] Proposes a large Ku-band microstrip patch antenna with a defective patch and ground with a patch size of 1311 0.035 mm3. Two semi-U shaped slots on the patch, three U shaped slots on the patch, and one rectangular hole in the ground were added to improve the antenna's return loss and bandwidth. The suggested antenna has a wide band frequency range of 15.27 to 16.51 GHz, with a resonance frequency of 15.8 GHz, a VSWR ≤ 1.1, gain of 4.45 dB, and directivity of 5.17 dBi. In [19], a patch antenna with inverted U-slot and L-slot has been proposed for X, C, and K-band applications, with seven resonant frequencies of 8.25 GHz, 9.7 GHz, 11.93 GHz, 14.19 GHz, 16.52 GHz, 18.7 GHz, and 20.75 GHz in the X, C, and K bands. The suggested antenna had a volume of 49.4141.6 mm3 and a gain of 6.18 dBi. Using a folded-patch feed, E-shaped patch, one shorting pin on the edge of the aperture, and an E-shaped edge to boost the bandwidth, the suggested basic antenna has an impedance bandwidth of 92 percent in the frequency range 3.94–10.65 GHz [20]. With the use of two shorting pins and a V-shaped-slot

patch fed by a folded patch, a small wideband antenna functioning in the range of 4–14.4 GHz was also obtained. The upgraded antenna's patch measured 15 15 mm2, whereas the basic antenna's patch measured 18 15 mm2 on an air substrate with a total thickness of 7 mm. Dual band Microstrip Patch antennas (MPAs) [2] have been widely employed in several domains of communication in recent years due to their small size, adaptability, low cost, and great performance. They're mostly employed for their frequency difference operation. They have the ability to emit many patterns. System performance may be improved by employing this dual band antenna, and the antenna designer can link various communication devices to this antenna for transmitting and receiving signals with confidence. The dual band E-shape antennas are used in satellite communication and radar systems for applications such as secure communication, multi-frequency communication, object detection, vehicle speed testing, and more. Distinct switch states for different frequencies of radiation can be used in advance to achieve dual frequency setup. Various radio frequencies have been designed for various communication purposes. Microwave frequencies range from 3 to 30 GHz. This antenna is designed to operate in the microwave frequency ranges of C-band and X-band. The resonant frequencies include 4.8 GHz with 167.7 MHz bandwidth, 6 GHz with 58 MHz bandwidth, and 9.2 GHz with 326 MHz bandwidth. Two parasitic layers are used to increase the bandwidth of this antenna. Satellite communications, full-time satellite TV networks, and raw satellite feeds all employ the C-band microwave frequency spectrum. Because it is less vulnerable to rain fade than the Ku band, this C-band is widely employed in places subject to tropical rainfall. It operates at a frequency range of 4 to 8 GHz. In military communication systems, the X-band of microwave frequency spectrum is utilized. It's also suitable for radar applications. It operates at a frequency of 8-12 GHz.

1 . 4 Aim and Objectives

The goal of this study is to improve the MPA characteristics' performance in the X band. The goals are highlighted in the table below.

- Design a microstrip patch antenna with improved bandwidth
- Gain enhancement of the designed antenna
- To reduce antenna return loss.

1 . 5 Methodology

All of MPA's performance improvements have been made in the X and K_u band frequency domain. The use of two different sorts of slots in MPA results in a significantly enhanced result. Step-by-step strategies for achieving our desired outcomes have been outlined.

Step1: Defining the length (L) and width (W) of a simple rectangular microstrip patch antenna with basic structure (W).

Step2: Using Rectangular shape in the antenna to increase the bandwidth.

Step3: Modifying and Optimizing the widths and lengths of the inset slot and partial ground for better results

Step4: To analysis the performance of all designed antenna individually in term of antenna characteristic especially antenna gain, antenna return loss and antenna bandwidth.

Step5: Optimizing the widths and lengths of the inset slot and partial ground for better results

Step6: Comparing the proposed antenna parameters with recent literature

1.6 Thesis Organization

This thesis is divided into 5 main chapters and the reference section.

Chapter 1 discusses about the introduction, literature review, objectives and scope of the thesis.

Chapter 2 explains brief literature studies of the microstrip antenna in order to get its basic fundamentals. It also discusses the relevant literatures on designing wideband microstrip patch antenna using slot.

Chapter 3 describes the design procedure of wideband high gain Microstrip patch antenna using microstrip feed line technique. A series of antenna configuration with optimization has been discussed in this chapter. To increase the gain of the proposed antenna array configuration has been introduced.

Chapter 4 includes comparison between HFSS studio and CST, return loss graphs, bandwidth for all individual antennas, average and vector current distribution, 2D and 3D radiation patterns for the proposed single patch antenna. Gain of the various array configurations has also been compared in this chapter. The simulation is done using HFSS studio CST of rectangular microstrip patch antenna. A brief comparative study also has been made between proposed antenna and other previously designed antennas in terms of various antenna parameters.

Finally, **Chapter 5** gives a conclusion of the work and scope for future work considerations.

CHAPTER 2

Literature Reviews

2.1 Antenna Parameters

An antenna is a device that converts electrical energy into electromagnetic (EM) energy like a transducer (vice versa).For designing an antenna, some measurable parameters should be considered to comprehend the strength and weakness of that device. An antenna has a different kind of parameters to understand the good or bad antenna performance, and the parameters depend on one another. Moreover, it should be confirmed that all the parameters are more optimized for designing an antenna. For example, the return loss should be -10dB or less and the VSWR should be 2 or less.

2.1.1 Antenna Field regions

Although not an antenna parameter in and of itself, understanding antenna field regions is essential for determining how far away from the antenna the antenna actually radiates. The fields that surround an antenna are separated into three main areas:

- Radiating Near Field or Fresnel Region
- Far Field or Fraunhofer Region
- Reactive Near Field

The far field region is the most essential since they influence the antenna radiation pattern and most of the other parameters. Antennas, on the other hand, is utilized to establish long-distance communication. So this is the significant region of operation for most types of antennas.

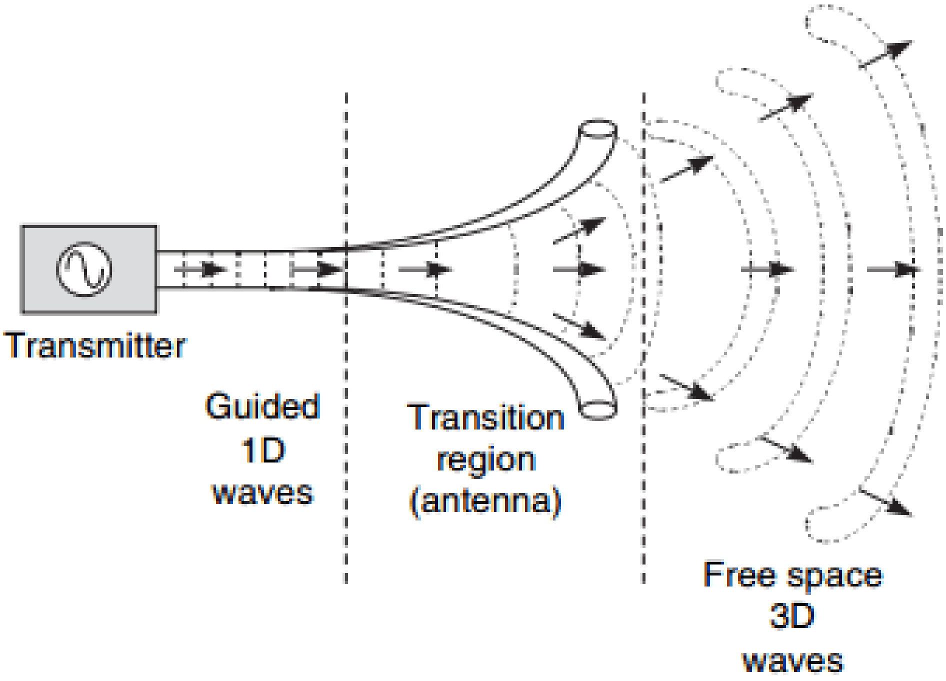


Figure 2.1(a) Antenna Radiation flow

An antenna, the two field components are present in the electric field and magnetic field equations. Those are known as radiative fields and reactive fields. In the denominator of the equation, there is usually a distance ‘r' of the order of two or higher in the reactive field components. In the radiative component, there is a distance component with ‘r' of the first order as well. As a result, the reactive component of the field dies as distance rises, but the radiative component remains, which dies at a far greater distance than reactive fields. There isn't much radiation available in the near field since the reactive field is stronger. However, this distance, on the order of $R < \lambda_0$ (Wavelength at the operating frequency), which is measured in mm and cm at microwave frequencies, is too small for us to notice. As a result, unless it is requested that it be done in the near field region, every parameter of an antenna is discussed in the far field region because radiation only exists there.

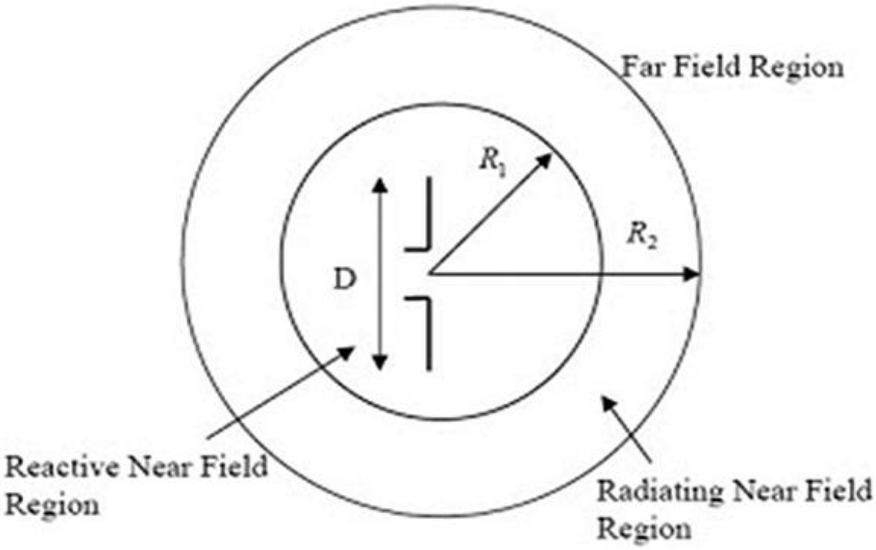


Figure 2.1(b) Field Regions

2.1.2 Radiation pattern:

An antenna's radiation pattern is a graphical depiction of the antenna's radiation intensity in relation to space co-ordinates, usually in a spherical co-ordinate system. Antennas are classified as directional or omnidirectional based on their radiation pattern. The term omnidirectional antenna refers to an antenna that radiates uniformly along the azimuthal angle but fluctuates sinusoidally with regard to elevation angle. On the other hand, an antenna is said to be directional if it radiates with stronger directivity at a specific angle compared to other angles. The term "directivity" is used to describe an antenna's directionality. A 3D plot, 2D plot, or Polar plot can be used to depict a radiation pattern. Analytical objectives necessitate the use of 2D and Polar graphs. The pattern of the antenna radiating in different directions can be seen graphically in these illustrations.

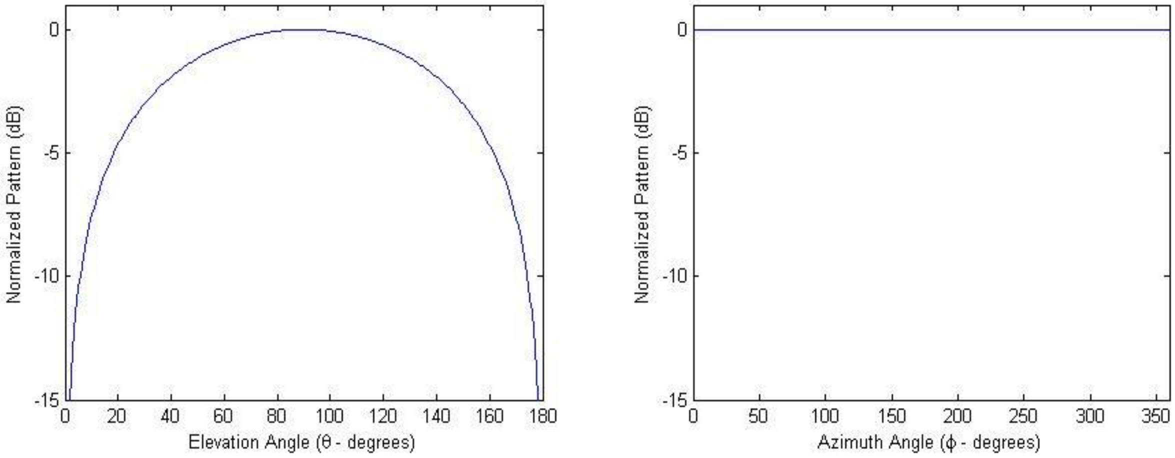


Figure 2. 1(c) Radiation pattern

2.1.3 Directive Gain:

Another antenna that radiates differently at different angles is the directional antenna. Directive gain is the ratio of an antenna's radiation intensity at a specific angle to the average radiation intensity in all directions. It's written as dBi.

$$\text{Directive Gain at an angle} = \frac{\text{Radiation intensity at that particular angle}}{\text{Average radiation intensity}}$$

2.1.4 Directivity:

A directional antenna always has a radiation angle where the intensity of the radiation is higher than in all other directions. The directivity of an antenna is the directive gain of a directional antenna in the direction of maximum radiation.

2.1.5 Antenna Efficiency:

At least two types of losses are always connected with an antenna. One is due to an impedance mismatch between the feed line and the antenna, while the other is due to an impedance mismatch between the antenna and the free space. Another reason is that because the antenna is a conductor, it suffers losses. As a result, the antenna will not be able to emit the entire input power. The efficiency of an antenna is the ratio of its output power to its input power.

$$\text{Antenna Efficiency} = \frac{\text{Output power}}{\text{Input Power}} \times 100\%$$

2.1.6 Antenna Gain:

Antenna gain is the antenna's directivity when the antenna efficiency is taken into account. An antenna's directivity can be thought of as the ideal case, whereas gain is the real case. As a result, if all of an antenna's input powers are radiated, the gain and directivity will be the same. There will always be losses associated with antennas in the real world; gain is always less than directivity.

$$Antenna\ Gain = Antenna\ Efficiency \times Directivity$$

2.1.7 Voltage Standing Wave Ratio:

There will always be some impedance mismatch between antenna and generator because it is impossible to match the impedance perfectly. Because of the impedance mismatch, some of the signal will be reflected back to the generator from the antenna. The waveguide contains both the forward wave to the antenna and the reflected wave from the antenna. Inside the waveguide, these two voltages combine to generate a 'Standing Wave'. There is a maximum and a minimum for this wave. The Voltage Standing Wave Ratio is the ratio of the maximum and minimum voltages inside the waveguide (VSWR).

$$\text{VSWR} = \frac{\text{Maximum voltage of standing wave}}{\text{Minimum Voltage of standing wave}}$$

When there is no mismatch between the generator and the antenna, the VSWR value is 1. It indicates a wave that is 100 percent radiated and 0 percent reflected. Normally, a VSWR of 2 is considered a good match because it represents around 10% of the reflected power.

2.1.8 Return Loss / S11 Parameter:

Another measure that conveys information about impedance mismatch is return loss. Although it provides the same information as VSWR, it is the most commonly used metric in antenna literature to characterize impedance mismatch and resonance. The reflected power to incident power ratio is known as the reflection coefficient. The following equation is used to compute it:

$$\text{Reflection Co} - \text{efficient}, \tau = \frac{\text{zA} - \text{zo}}{\text{zA} + \text{zo}}$$

Where, zA = Antenna impedance
zo = Transmission Line impedance

When the antenna and line impedances are perfectly matched, the reflection coefficient is zero, indicating that there is no reflection. Return loss is the decibel value of the reflection coefficient. The following is the relationship between the Reflection Coefficient and the VSWR:

$$\text{VSWR} = \frac{1 + \tau}{1 - \tau}$$

Table 2.1 provides a comparative understanding of VSWR and Return Loss. The following equation in decibels gives the return loss. To conform with the IEEE specification, the negative sign ensures that the return loss value remains positive. The s11 parameter is the minus value of the return loss.

$$\text{Return Loss} = -20\log\frac{\text{VSWR}-1}{\text{VSWR}+1}\,dB$$

2.1.9 Input Impedance

The impedance presented by an antenna at its terminals, or the ratio of voltage to current at a pair of terminals, is known as input impedance. Maximum power transfer is accomplished when the transmission line and antenna input impedances are matched. If it is not matched, the entire system efficiency will suffer. Because a reflected wave is formed at the antenna terminal and travels back to the energy source, this is the case.

In order to ensure maximum energy transfer between transmission line and patch, the input impedance for this parameter must match the transmission line's characteristics impedance. If the input impedances are not equal, a reflected wave is formed at the antenna terminal and returns to the energy source. The overall system efficiency is reduced as a result of energy reflection. Only this lost efficiency will occur if the antenna is utilized to transmit or receive energy.

2.1.10 Antenna Bandwidth:

Different types of bandwidths exist in antennas, depending on certain characteristics. The s11 parameter bandwidth refers to a range of frequencies where return loss is less than -10dB. Radiation pattern bandwidth is defined as the range of frequencies throughout which the radiation pattern remains consistent. Antenna bandwidth is defined as a frequency range in which all antenna characteristics are within an acceptable range.

2.2 Introduction of Microstrip Patch Antenna

Microstrip antennas are one of the most common antenna types in the microwave frequency range, and they're also common in the millimeter-wave frequency range [2, 5, 6]. Microstrip antennas are typically too large to be practical below 1 GHz, and other forms of antennas, such as wire antennas, predominate. Microstrip patch antennas, also known as patch antennas, are made out of a metal patch on top of a grounded dielectric substrate with a thickness h and relative permittivity and permeability εr and μr, as indicated in Figure 2.1 (typically μr = 1). The metallic patch can come in a variety of shapes, the most frequent of which are rectangular and circular.

The lightweight, conformability, and low cost of microstrip antennas make them appealing. These antennas can be used with active devices and printed strip-line feed networks. In antenna engineering, it is a relatively recent field. Since the mid-1950s, the radiation properties of micro strip structures have been known. When conformal antennas were required for missiles in the early 1970s, this type of antenna was developed. Microstrip resonant patches, both rectangular and circular, have been widely used in a variety of array topologies. The present revolution in electronic circuit downsizing brought about by improvements in large scale integration is a major contributor to recent advances in microstrip antennas. Microstrip antennas based on photolithographic technology are seen as an engineering achievement because traditional antennas are frequently big and expensive parts of an electronic system [7].

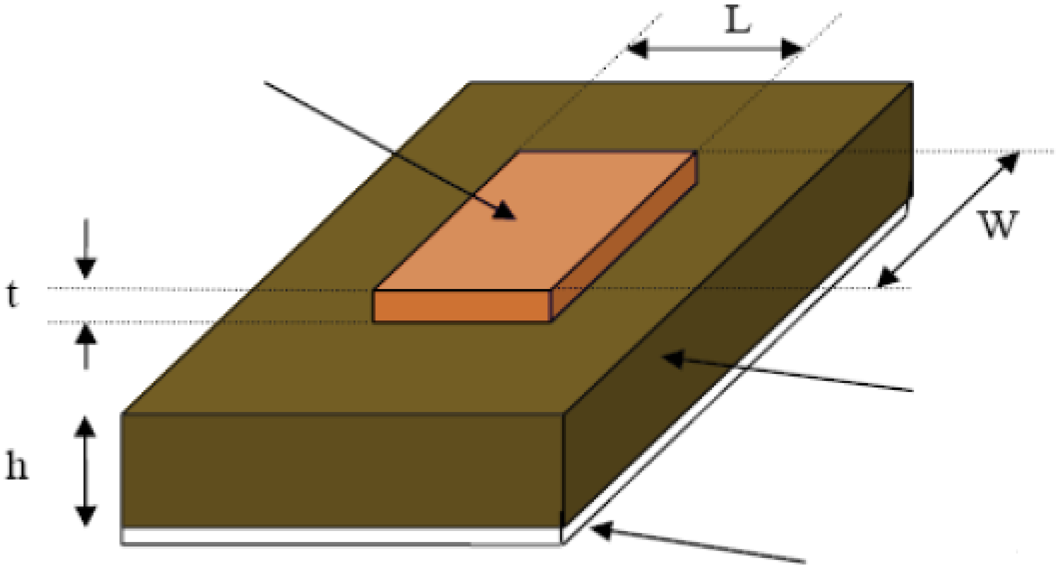


Figure 2.2(a) Patch antenna

A Microstrip Patch antenna, in its most basic form, comprises of a radiating patch on one side of a dielectric substrate and a ground plane on the other, as shown in Figure2.2 (a). The patch is usually made of conductive metals like copper or gold and can be manufactured into any shape. On the dielectric substrate, the radiating patch and feed lines are normally photo etched.

The patch is often square, rectangular, circular, triangular, elliptical, or some other common shape to simplify analysis and performance prediction, as shown in Figure 2.2. (b). The length L of a rectangular patch is typically $0.3333\lambda_0 < L < 0.5\ \lambda_0$, where λ_0 denotes the free-space wavelength. The patch is chosen to be very thin such that $t \ll \lambda_0$ (where t is the patch thickness). The height h of the dielectric substrate is usually $0.003\lambda_0 \leq h \leq 0.5\lambda_0$. The dielectric constant of the substrate (εr) is typically in the range $2.22 \leq \varepsilon r \leq 12$.

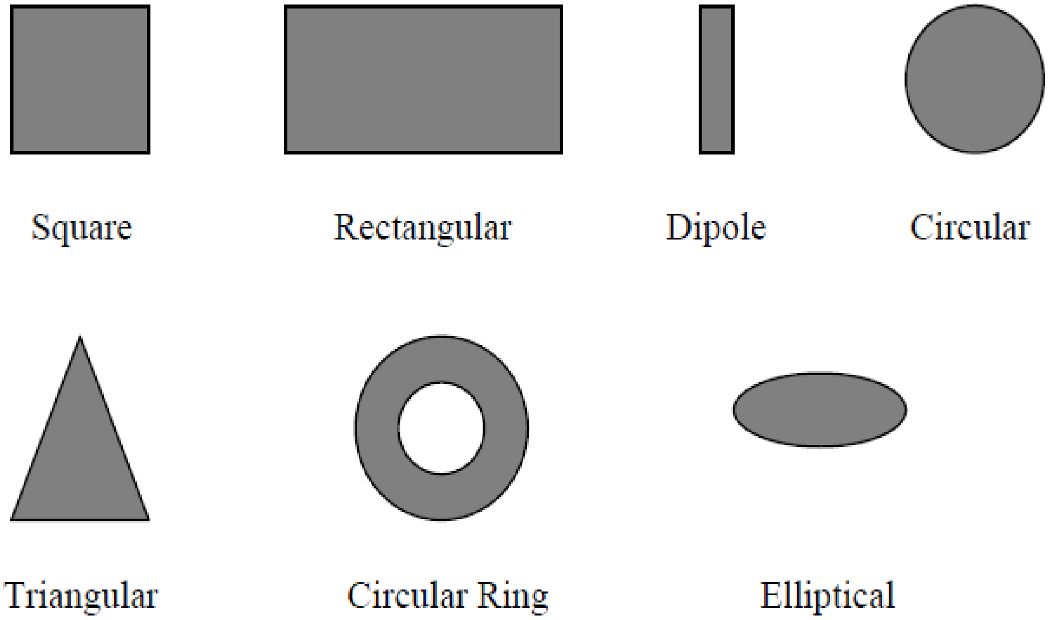


Figure 2.2(b) Different shapes of Patch elements

The fringing fields between the patch edge and the ground plane are what cause microstrip patch antennas to emit. A thick dielectric substrate with a low dielectric constant is desired for superior antenna performance because it gives better efficiency, larger bandwidth, and better radiation [8]. However, such a setup necessitates a larger antenna. To make a compact Microstrip patch antenna, higher dielectric constant substrates must be employed, which are less efficient and result in a narrower bandwidth. As a result, a trade-off between antenna size and antenna performance must be made.

2.2.1 Advantages and Disadvantages:

Because of its low-profile design, microstrip patch antennas are becoming more common in wireless applications. As a result, they're ideal for integrated antennas in handheld wireless devices like cellular phones and pagers. Microstrip patch antennas are commonly used for telemetry and communication antennas on missiles because they must be tiny and conformal. Satellite communication is another area where they've proven successful.

Some of their principal advantages discussed by are given below:

- Mechanically robust when mounted on rigid surfaces.
- Low volume and light weight.
- Planar configuration with a low profile that can be easily conformed to the host surface.
- Because of the low cost of production, it can be produced in enormous quantities.
- Both linear and circular polarization are supported.
- Microwave integrated circuits can be simply integrated (MICs).
- Dual and triple frequency functioning is possible.

Microstrip patch antennas suffer from more drawbacks as compared to conventional antennas. Some of their major disadvantages discussed by [9] and Garg et al [10] are given below:

- Narrow bandwidth
- Low efficiency
- Low Gain
- Extraneous radiation from feeds and junctions
- Poor end fire radiator except tapered slot antennas
- Low power handling capacity.
- Surface wave excitation

The antenna quality factor of microstrip patch antennas is quite high (Q). It depicts the antenna losses, with a big Q resulting in narrow bandwidth and low efficiency. The thickness of the dielectric substrate can be increased to reduce Q. However, as the thickness of the layer grows, a greater proportion of the overall power given by the source is converted to a surface wave. Because it is scattered at the dielectric bends and causes worsening of the antenna properties, this surface wave contribution might be considered an undesired power loss. Other issues, like as reduced gain and power handling capacity, can be addressed by arranging the elements in an array.

2.3 Basic ‘Principles of Operation’:

In its most basic form, a patch antenna is a flat plate over a ground plane, as shown in the diagram. The feed probe is the central conductor of a cable that couples electromagnetic energy into and out of the patch. Also shown is the electric field distribution of a rectangular patch activated in its fundamental mode.

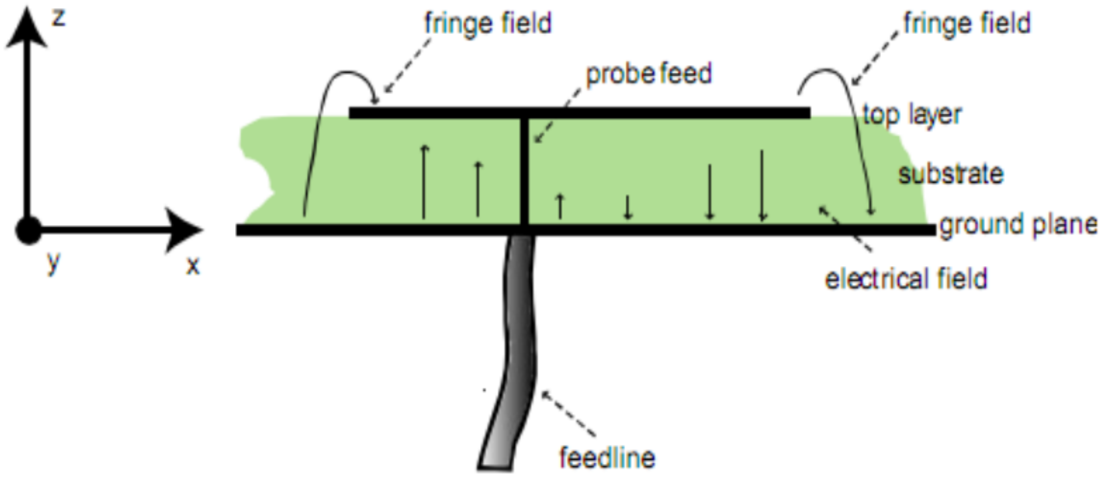


Figure 2.3(a) A Side view of Microstrip Patch Antenna

The electric field is zero at the patch's center, maximal (positive) on one side, and minimal (negative) on the other. It should be noted that the minimum and maximum values change side depending on the applied signal's instantaneous phase.

2.4 Feeding Technique:

MPA use a variety of feeding tactics. Because these antennas have a dielectric substrate on one side and a radiating element on the other, they have a dielectric substrate on one side and a radiating element on the other. These feeding approaches are divided into two groups: contacting and non-contacting. The power is sent directly to the radiating patch through the connecting element, i.e. the microstrip line, in the contacting feed technique. An electromagnetic magnetic coupling is used to transfer power between the microstrip line and the radiating patch in a non-contacting approach. Even if there are numerous novel feed approaches, the microstrip line, coaxial probe, aperture coupling, and proximity coupling are the most popular or widely employed.

2.4.1 Microstrip Line:

The patch antenna's microstrip feed line is linked directly to the patch antenna's edge. This feed concept has the advantage of being etched on the same substrate, keeping the overall structure flat.

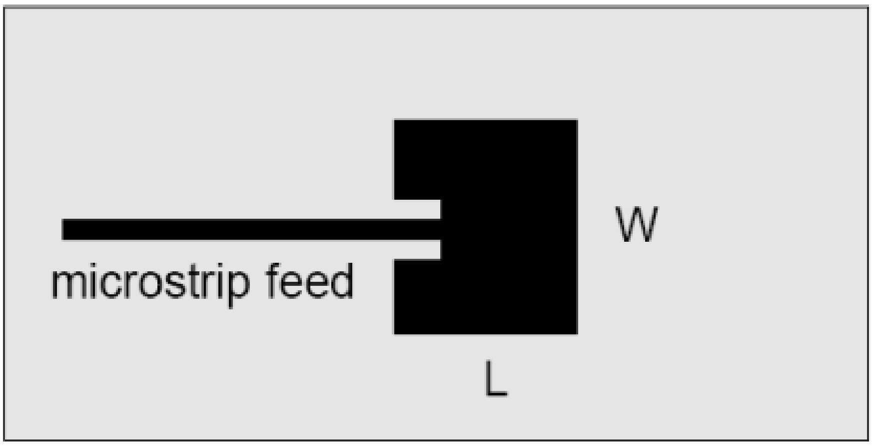


Figure 2.4(a) Microstrip line feed.

It is usually significantly smaller in width than the patch, easy to match, and manufacture by manipulating the inset position [11], as shown in Figure 2.4(a).

2.4.2 Coaxial Feed

Coaxial-line feed, also known as probe feed, is a common technique for feeding microstrip patch antennas nowadays, in which the coaxial's internal conductor is extended through the dielectric and connected to the radiation patch antenna, while the outer conductor is connected to the Ground plane ground plane, as shown in Figure 2.4(b). The main advantage of this feed is that it can be placed in any desired location within the patch to match the patch's input impedance. It's also simple to make and emits little spurious radiation. Its downsides include a restricted bandwidth and a greater difficulty in modeling [12].

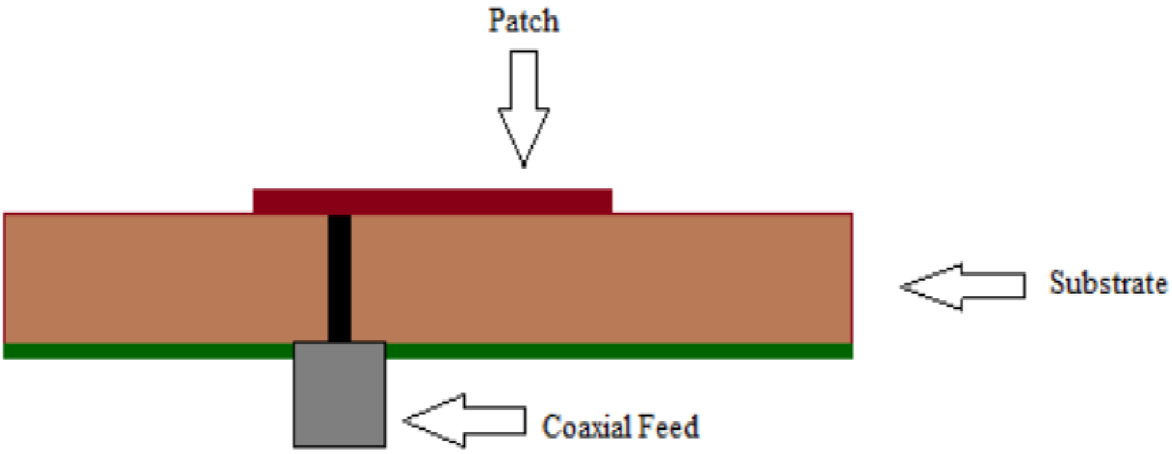


Figure 2.4(b) Probe-fed patch antenna.

2.4.3 Aperture-Coupled Feed

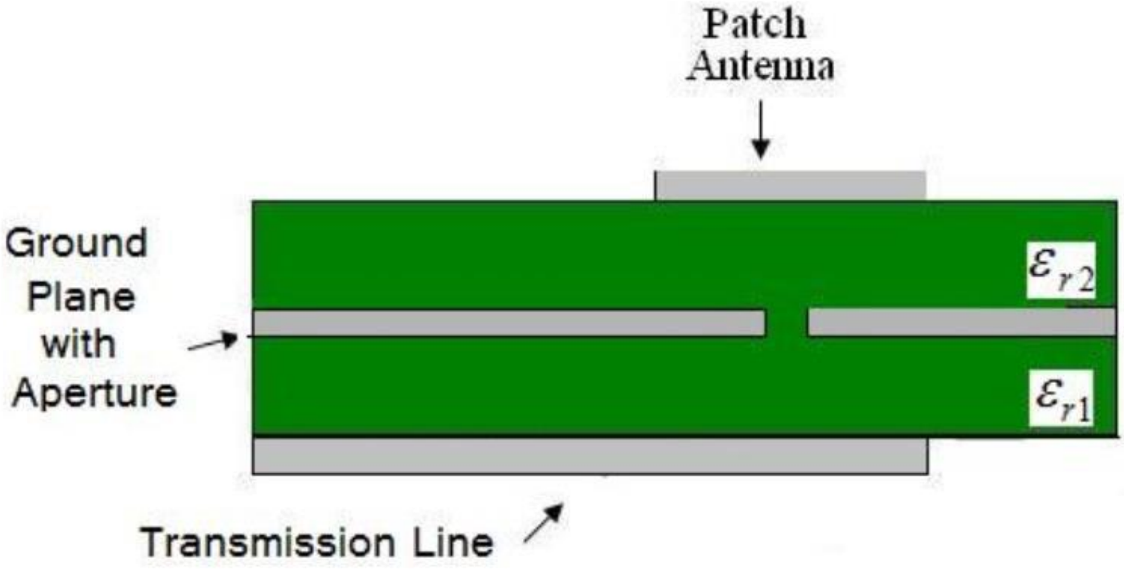


Figure 2.4(c) Aperture-Coupled Feed

The aperture-coupled structure, which consists of two substrates separated by a ground plane, is a popular feeding configuration in microstrip patch antennas. Furthermore, the lower substrate is visible from the bottom. As shown in Figure 2.4, there is a microstrip feed line whose energy is linked to the patch during a slot on the ground plane separating the two substrates (c). The bottom substrate is made of a high dielectric material, whereas the top substrate is made of a thick low dielectric constant substance. In addition to isolating the feed from the radiating element, the ground plane between the substrates lowers spurious radiation interference for pattern development and polarization purity. This feeding system has the disadvantage of being difficult to construct and having a narrow band. It is, on the other hand, easy to predict and has a moderate amount of spurious radiation [12].

2.4.4 Proximity Coupled Feed

Electromagnetic coupling is a term used to describe this type of feeding mechanism.
As illustrated in Figure 2.4(d), the feeding line is placed between the ground plane and the patch, which is separated by two dielectric media.

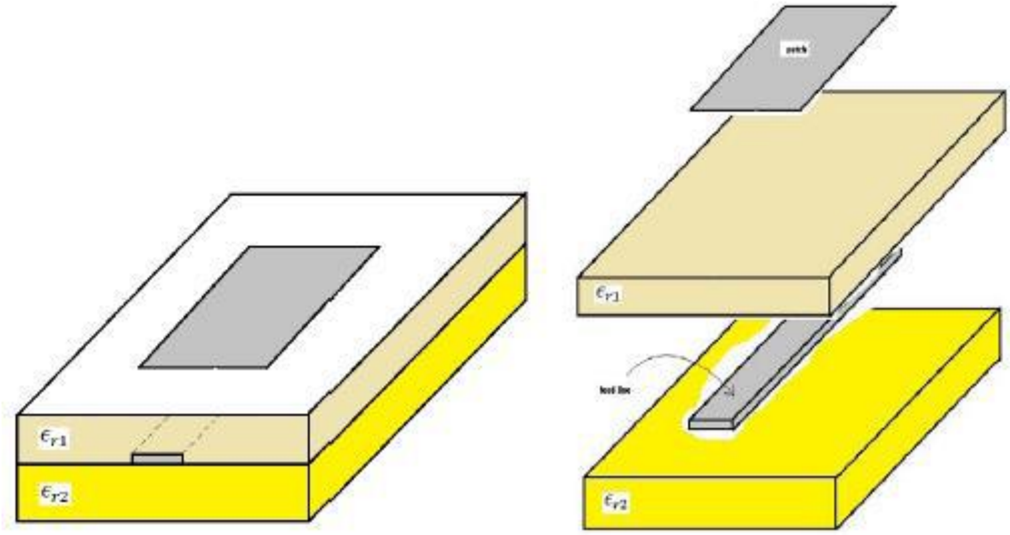


Figure 2.4(d) Proximity Coupled Feed

Between the patch and the feeding line, energy is exchanged via electromagnetic coupling. The removal of spurious feed-network radiation and the improvement in bandwidth owing to the increased overall substrate thickness are two advantages of this feeding design. The primary disadvantages of this feeding technology are that it is difficult to manufacture since two layers must be precisely aligned [12].

Following the selection of the L and W patch dimensions for the specified substrate, the feed point must be calculated in order to create a satisfactory impedance match between the generator impedance and the patch element's input impedance. As a result of the change in feed location, the input impedance changes, providing a simple way for impedance matching. The feed point is chosen so that the input resistance Rin is equal to the impedance of the feed line, which is commonly 50 ohm.

2.5 Feed Point Location

Following the selection of the L and W patch dimensions for the specified substrate, the feed point must be calculated in order to create a satisfactory impedance match between the generator impedance and the patch element's input impedance. As a result of the change in feed location, the input impedance changes, providing a simple way for impedance matching.

The feed point is chosen so that the input resistance Rin equals the feed line impedance, which is commonly 50 ohm.

2.5.1 Polarization

When used in the dominant mode, the polarization of a rectangular patch antenna is linear and directed along the resonating dimension. Patch antennas with a large bandwidth can also operate in the higher order mode. These modes can have different emission patterns and polarization than the dominant mode. The fringing field along the no radiating edges is another source of cross-polarization. The fields at the radiating edges are orientated 90 degrees away from these fields. In the E and H planes, they have little effect on the radiation fields. Even the perfect, single mode patch will radiate cross-polarized fields in the intercardinal planes. With increasing substrate thickness, the level of cross-polarization rises. The antenna's polarization can be altered mechanically or electrically. PIN diodes or varactor diodes can be used for electronic tuning. In mobile communications, polarization 24 diversity is used to adjust for signal strength loss due to fading [13].

Table 2.1 Comparison between Different Feeding Techniques

Characteristics	**Microstrip Line Feed**	**Coaxial Feed**	**Aperture Coupled Feed**	**Proximity Coupled Feed**
Spurious feed radiation	More	More	Less	Minimum
Reliability	Better	Poor due to soldering	Good	Good
Ease of fabrication	Easy	Soldering and drilling needed	Alignment required	Alignment required
Impedance Matching	Easy	Easy	Easy	Easy
Bandwidth	2-5%	2-5%	2-5%	13%

CHAPTER 3

DESIGN OF THE PROPOSED PATCH ANTENNA

The primary objective of this thesis is to design a wideband microstrip patch antenna that can operate at full X band (8 GHz -12 GHz) and possibly some portion of K_u band (12GHz – 18 GHz). Due to absence of concise mathematical formula to design a wideband MPA it is challenging task to design one that can provide required bandwidth. This inset feed partial ground wideband MPA design strategies and full process of iterative modification of the antenna design along with gradual enhancement of the bandwidth are presented chronologically in this chapter.

Ansys HFSS simulation software is used to get the improved bandwidth and desired antenna performance. Another EM analysis simulation software, CST Microwave Suite is used to verify the antenna performance. Both results confirmed that the antenna has the full capability to operate at complete X band and lower portion of K_u band.

3.1 Basic Parameters

Three primary parameters are shown below that are selected to design the antenna. These parameters are chosen with specific design goal in mind that will be discussed later in this chapter. These parameters not subject to modification for design optimization.

- The frequency of operation: X band frequency domain has been selected for MPA operation.

- Dielectric constant: FR-4 Epoxy substrate with dielectric constant of 4.4 has been selected as dielectric material for MPA.

- Height of substrate: Generally, MPAs are very compact devices so for basic configuration of MPA standard thickness has been selected as 1.6 mm.

3.2 Substrate Selection

The two most significant characteristics to consider when designing patch antennas are substrate permittivity and loss tangent. The microstrip patch antenna's most serious limitations are its narrow bandwidth and poor gain. As a result, choosing the right substrate permittivity decreases surface wave losses and increases antenna performance, particularly impedance bandwidth and radiation efficiency [22]. A thicker substrate will enhance radiated power, minimize conductor loss, and improve impedance bandwidth, in addition to being mechanically stronger. However, it will add weight, as well as dielectric loss, surface wave loss, and unwanted radiation from the probe feed. A Substrate with low dielectric constant will enhance the fringing field at the patch periphery. As a result, the antenna's radiated power will be enhanced as well. Therefore, a lower dielectric constant is preferred, however it will increase antenna size so the substrate material should be chose accordingly. The antenna's dielectric loss increases with a large substrate loss tangent, lowering its efficiency.

The permittivity of the most often used dielectric substrate materials for printing patch antennas ranges from roughly 2 to 10 depending on the application. The antenna gain increases as the permittivity decreases. This is because the traveling wave of a higher permittivity substrate slows down as it passes through the antenna.

3.3 Microstrip Patch Antenna Dimension

Patch width has a modest impact on the antenna's resonance frequency and radiation pattern. However, it has a greater impact on input resistance and bandwidth. A larger patch width improves the amount of power radiated, resulting in lower resonant resistance, more bandwidth, and higher radiation efficiency. The production of grating lobes in antenna arrays is a limitation against a wider patch width. To achieve good radiation efficiency, it has been suggested that the length to width ratio of the path should be between one and two (1 L/W 2). Because of the patch's intrinsic narrow bandwidth, the patch length affects the resonant frequency and is a significant parameter in the design. The length of a microstrip patch (L) can be estimated as,

$$L = \frac{c}{2\, f_r \sqrt{(\varepsilon r)}} \qquad \ldots\ldots\ldots\ldots\ldots 3.1$$

Where c, fr and εr represents speed of light in free space, resonant frequency and dielectric constant of the substrate respectively.

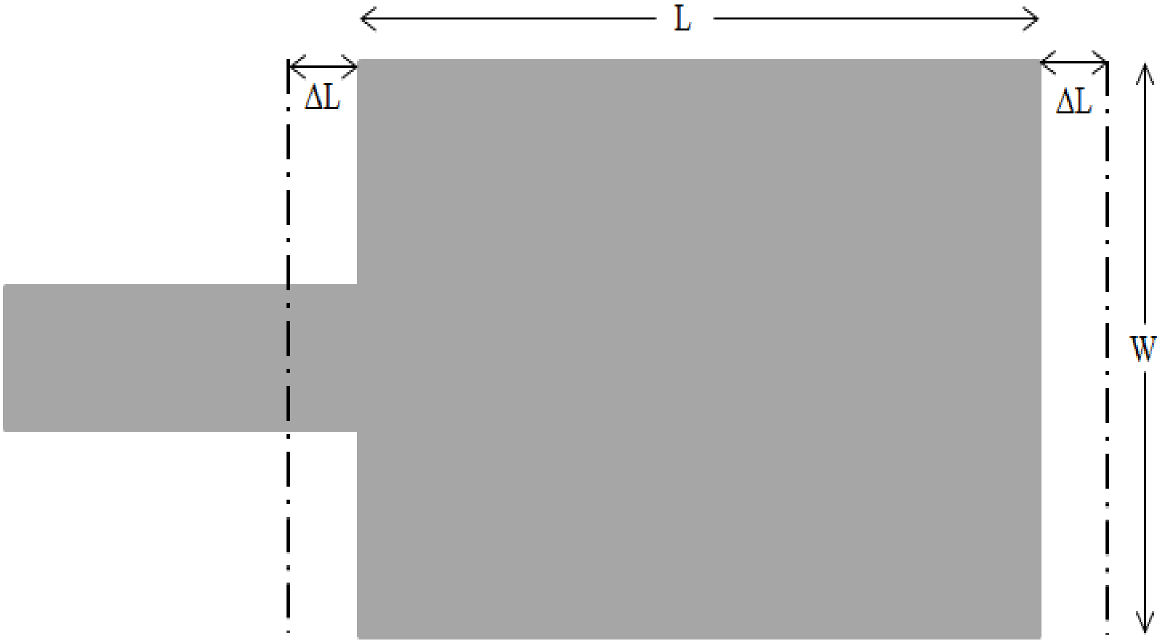


Figure 3.3(a) Microstrip Patch Antenna Dimension

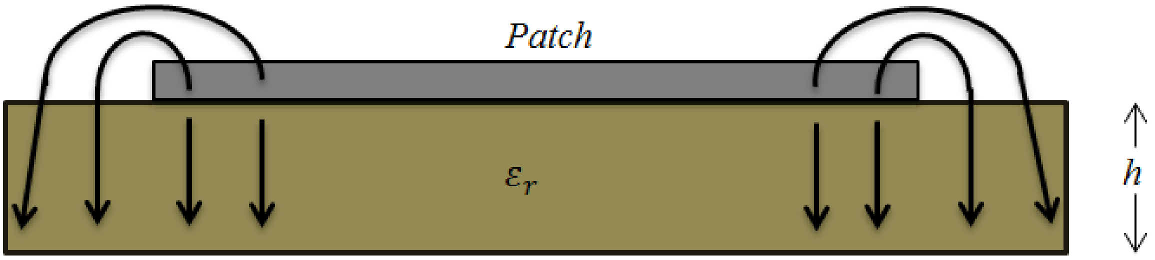


Figure 3.3(b) Microstrip Patch Antenna Dimension

The fields are not limited to the patch in practice. As illustrated in figure 3.3(a), a portion of the fields lay outside the patch's physical dimensions (LW). The fringing field is what it's called.

The influence of the fringing field along the patch width, W, can be taken into account using the effective dielectric constant ε_{reff} for a microstrip line of width W on the given substrate.

$$\varepsilon_{reff} = \frac{\varepsilon r + 1}{2} + \frac{\varepsilon r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{1/2} \quad ....(3.2)$$

Where h is the dielectric substrate's height. The influence of the fringing field along the patch length L can be stated as [20] by adding a line length to either end of the patch length.

$$\frac{\triangle L_{eff}}{h} = 0.412\frac{(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)} \quad ....(3.3)$$

The effective length is given by –

$$L_{eff} = L + 2\triangle L_{eff} \quad ....(3.4)$$

The resonant frequency is expressed as –

$$f_r = \frac{c}{2L_{eff}\sqrt{(\varepsilon_{eff})}}$$ ………………(3.5)

For efficient radiation the width *W* is given by –

$$W = \frac{c}{2f_r\sqrt{(\frac{\varepsilon_r + 1}{2})}}$$ ………………(3.6)

It is necessary to have a finite ground plane for practical reasons. If the size of the ground plane is bigger than the patch dimensions by approximately six times the substrate thickness all around the periphery, similar results can be obtained for finite and infinite ground planes. As a result, the ground plane dimensions for this design are [21].

$$L_g = 6h + L$$ ………………(3.7)

$$W_g = 6h + W$$ ………………………..(3.8)

3.4 Design of RMPA

The design process and bandwidth improvement of the MPA is shown in this section. The primary parameter is to look for is the S11/return loss, VSWR, Bandwidth, Directivity and Gain. To get a better idea about MPA parameters a 2.4 GHz WiFi band antenna design is shown in the figure 3.3 (a)

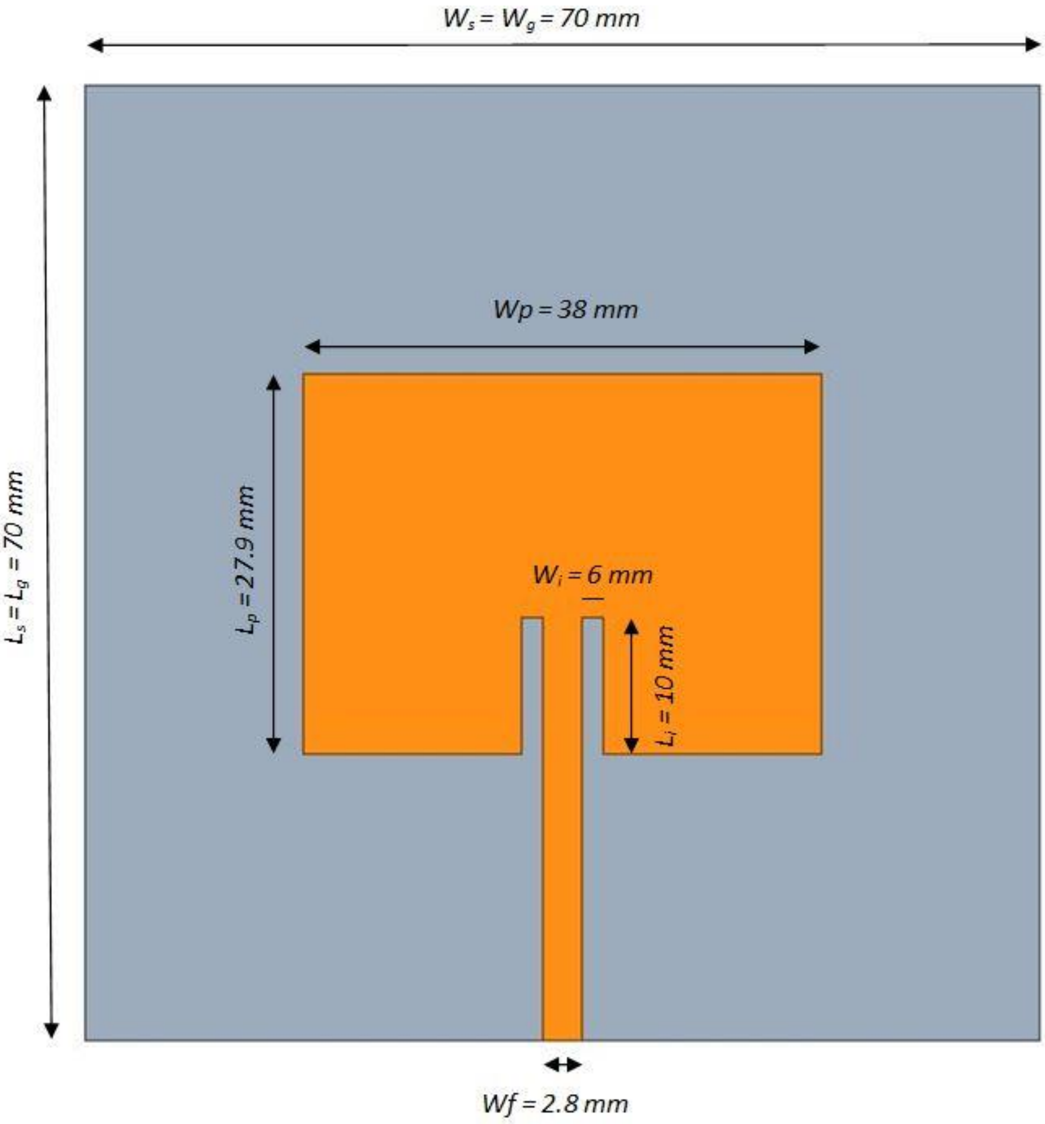


Figure 3.4 (a): 2.4 GHz WiFi band Microstrip Patch Antenna

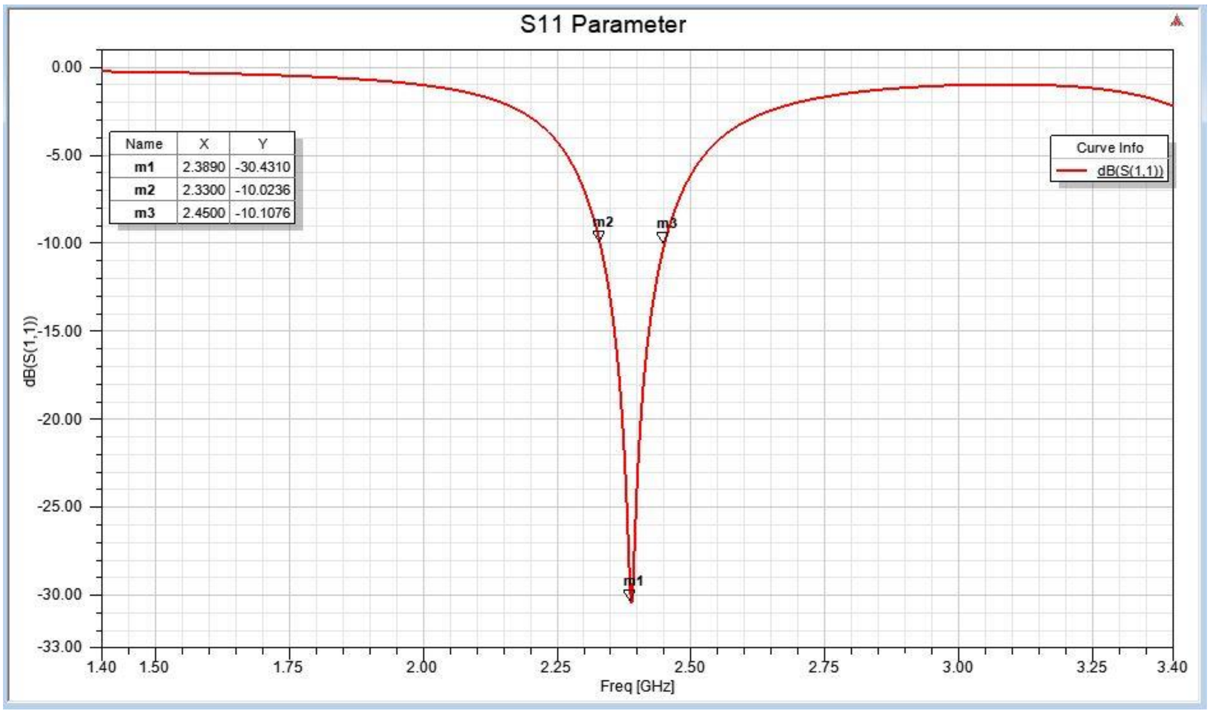


Figure 3.4 (b): S11 Parameter of 2.4 GHz WiFi band MPA

This 2.4 GHz WiFi band antenna is a full ground inset feed MPA. The substrate size, patch length and width, Feed Line width can be directly calculated from the mathematical expression mentioned in chapter 2. However with the calculate value the resonance frequency is not exactly 2.4 GHz. With some little modification of patch dimension the result reached satisfactory level. From S11 parameter plot we can observe that the antenna is resonating at 2.39 GHz with lowest return loss of -30.4 dB. The m2 and m3 marker of the plot indicating S11 of -10 dB at 2.33 GHz and 2.45 GHz .So we can conclude from the graph that the antenna provides 120 MHz of bandwidth.

To get the optimized antenna at first we calculated the dimension of the patch, ground and feedline using mathematical expressions [6]. With this calculated dimension we designed a simple rectangular MPA using Ansys HFSS EM simulation software. FR-4 Epoxy with dielectric constant of 4.4 and loss tangent of 0.02 is selected as substrate material. For FR-4 Epoxy substrate optimized thickness is found to be 1.5 mm to 1.6 mm [22]. We used thickness of 1.6 mm because FR-4 is widely available in this size. Substrate length and width are selected 23.8 mm and 28.2 mm respectively. For patch length is 13.8 mm and width is 19 mm. A 50 Ohm microstrip line with a width of 3 mm used to feed the antenna. Lumped port is used to provide excitation for the antenna.

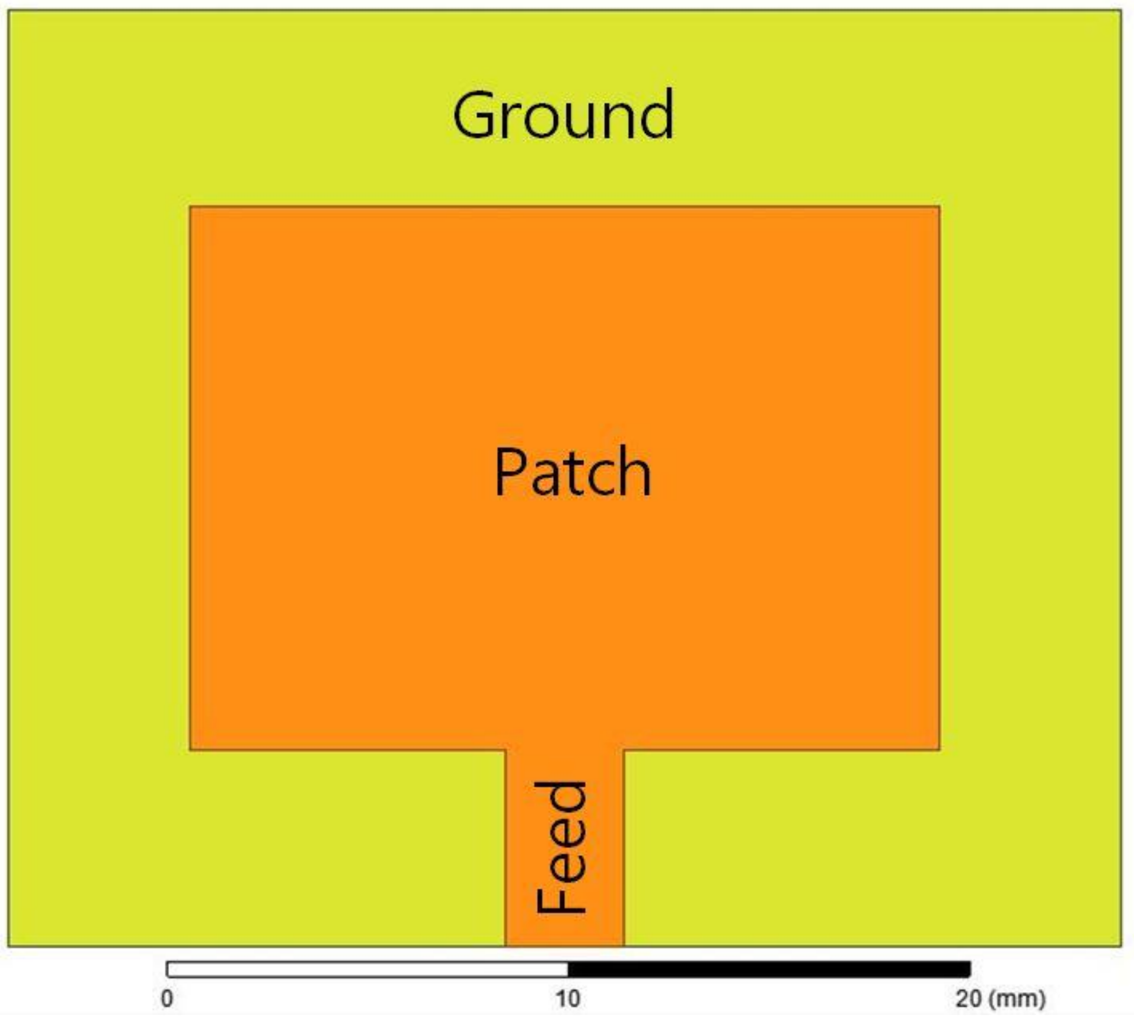


Figure 3.4 (c): Designed Simple Rectangular MPA

The S11 parameter plot of the designed MPA indicates resonance at 12.47 GHz with S11 value of -47.3 dB. The resulted resonance frequency is very different from the expected one. The difference between calculated and simulated resonance frequency is due to the imperfect nature of the empirical equations. Although resonance frequency is not in X band it is very close to it and a starting point for our desired antenna. Iterative design optimization can be done to get the antenna with intended performance

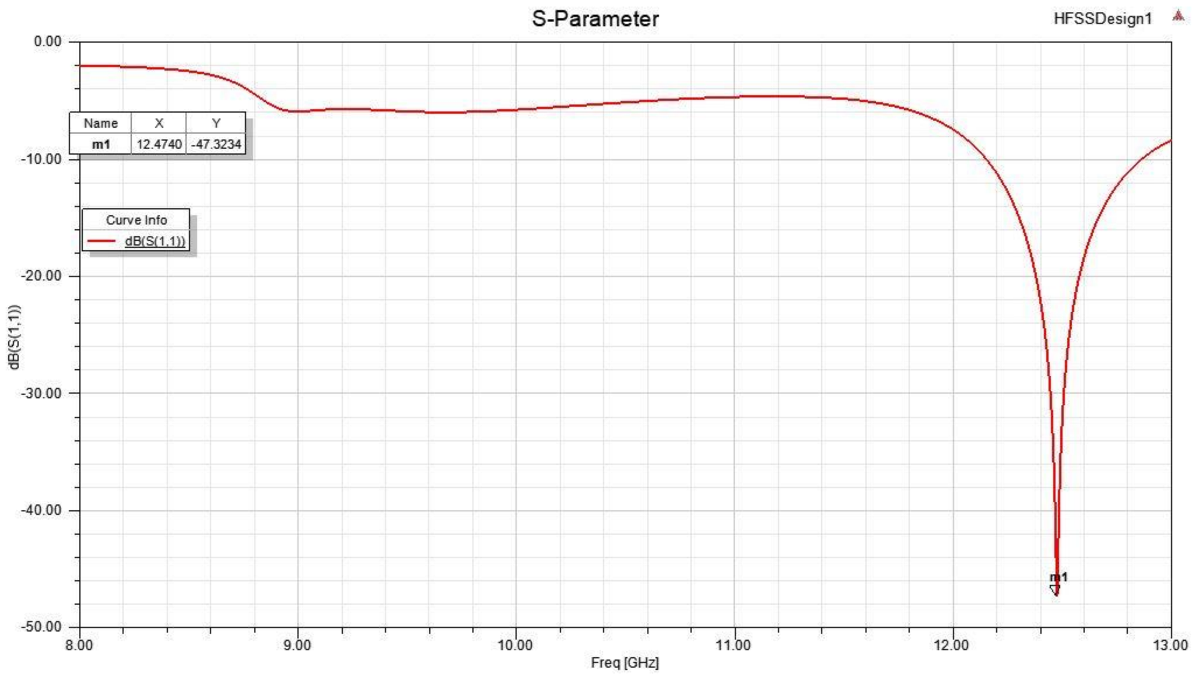
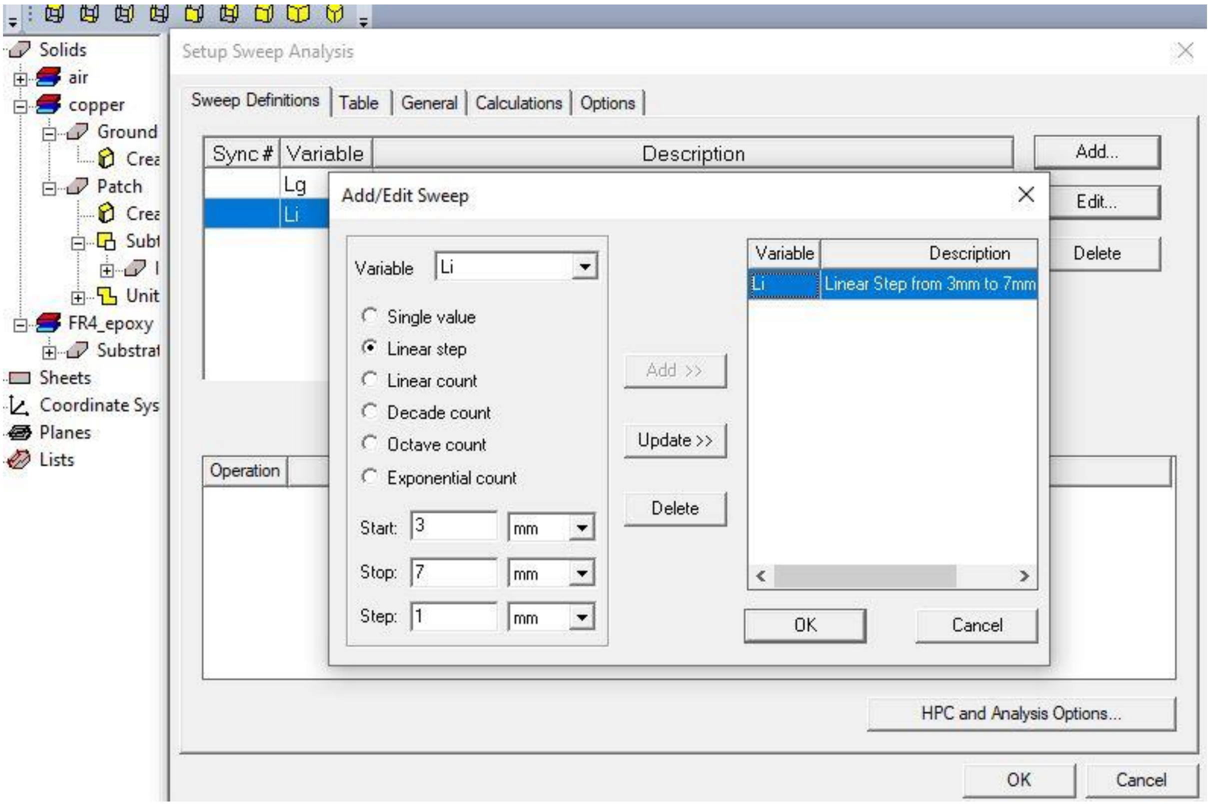


Figure 3.4 (d): S11 parameter of designed Rectangular MPA

3.5 Optimization

The antenna optimization process begins with a trial-and-error step in which we determine how different factors affect the antenna's behavior. It has been demonstrated that, in order to position a resonant frequency at a different operational frequency, a first practical method can be used. Using an optimization strategy necessitates determining the values of several parameters or components.[23]

When dealing with complicated problems, traditional search and optimization methods have a variety of drawbacks. When one algorithm is used to tackle a variety of issues, the major challenge occurs. This is because each classical approach is designed to efficiently tackle only a specific class of problems. As a result, these methodologies lack the flexibility to address the wide range of difficulties that designers and practitioners face. Furthermore, most traditional approaches lack a global viewpoint and frequently converge to a locally optimal solution.



Sync #	Variable	Description
	Lg	
	Li	

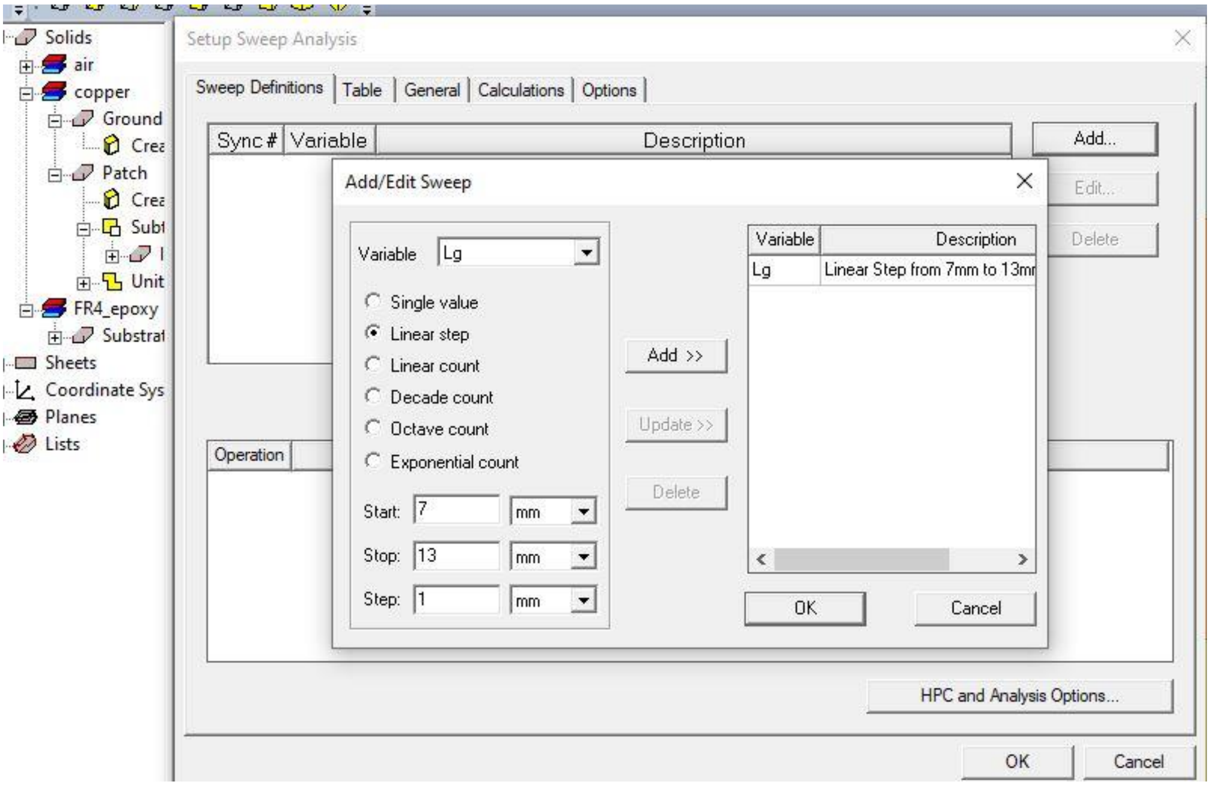
Variable: Li

○ Single value
● Linear step
○ Linear count
○ Decade count
○ Octave count
○ Exponential count

Start: 3 mm
Stop: 7 mm
Step: 1 mm

Variable	Description
Li	Linear Step from 3mm to 7mm

Figure 3.5 (a): Dimension sweep of the inset



Variable: Lg

○ Single value
● Linear step
○ Linear count
○ Decade count
○ Octave count
○ Exponential count

Start: 7 mm
Stop: 13 mm
Step: 1 mm

Variable	Description
Lg	Linear Step from 7mm to 13m

Figure 3.5 (b): Variation of partial ground plane length

There wasn't much of a theory or equation presented to discover an optimal antenna geometry among the numerous methods described. Various arbitrary forms with varied lengths and widths were presented. Designers of rectangular-shape patch antennas attempted to come up with equations. According to the problem, the easiest way to find the best MPA solution is to use a trial and error or optimization method.

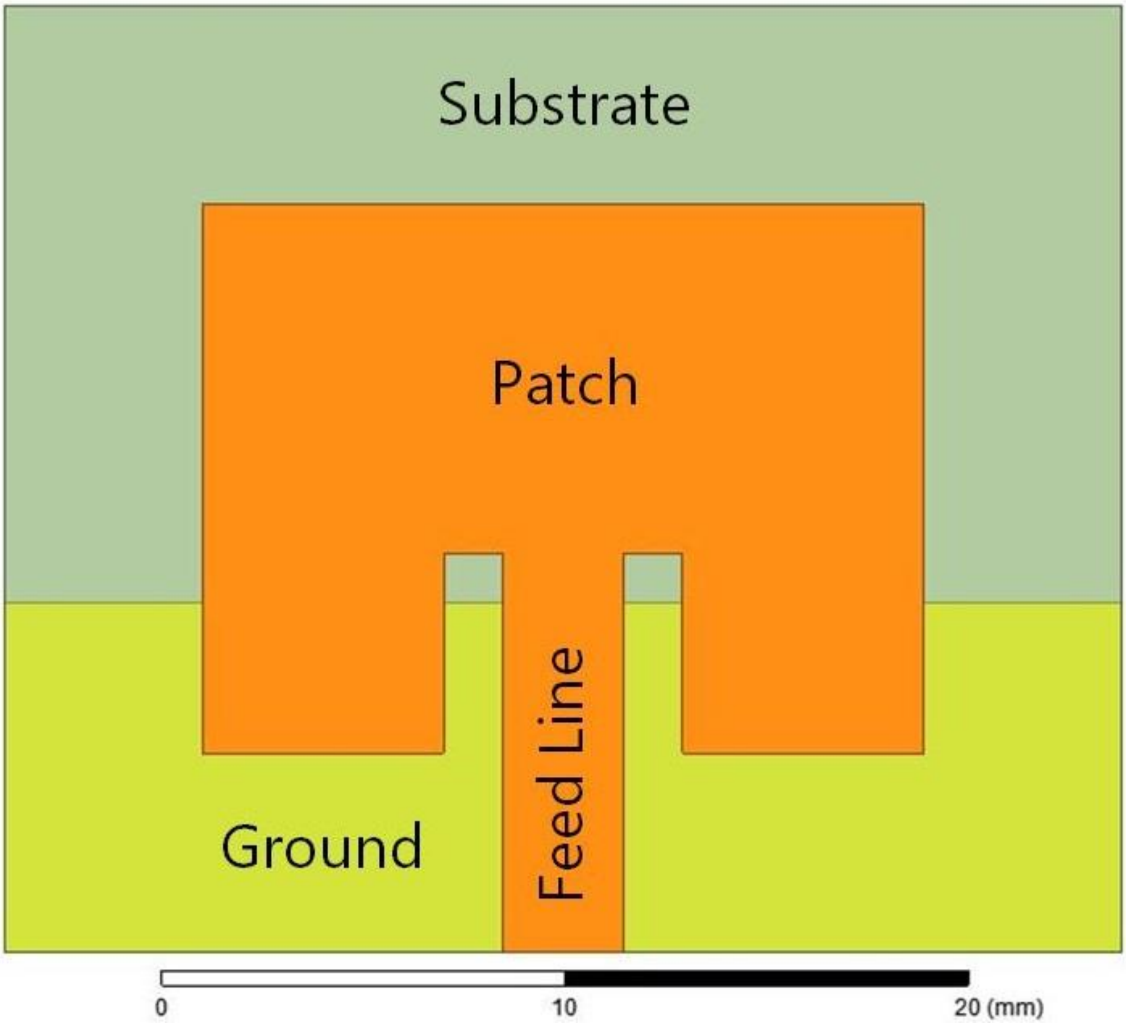


Figure 3.5 (c): Resulted design after introduction of inset and partial ground

Introduction of inset slot and partial ground with a varying dimension resulted very good outcome compare to initial findings. S11/Return loss plot now showing a wideband response with frequency ranging from 9.7 GHz to 13.9 GHz. With current optimization the antenna now covers a good portion of X band. To cover the full X band more optimization needs to be done.

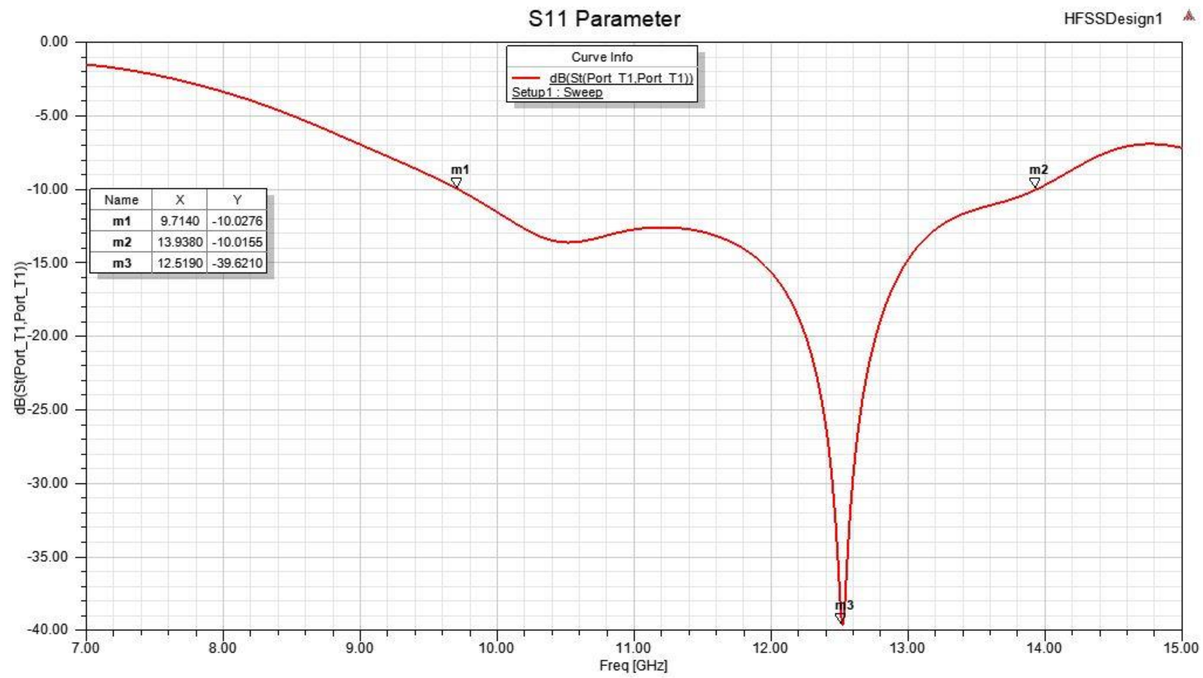


Figure 3.5 (d): S11 parameter after introduction of inset and partial ground

Different approaches have the advantages of being very straightforward to construct, requiring no additional elements to be put in the device, and making the device's area compact. In one of the works, a quarter wave monopole theory was developed, in which a slot was cut in the edge so that it might operate as a monopole when joined with free space [24]

To use an advancement system, we must first choose our estimates for various factors or variables. It also necessitates the use of a fitness function to calculate the fitness of several solutions and arrive at the best outcome. The purpose of this study is to construct a fitness function that will allow the antenna to reach the desired bandwidth. Using the preceding equations and approaches, the following Rectangular shape MPA(ESMPA) was obtained, which was initially un optimized. Given the non-desired current values of the antenna's length and operational frequency, this rule can be used to compute the length that the antenna must have in order to attain the predicted resonant frequency.

Following the procedures in "First optimization," a variety of parameter combinations were tested, using the previously indicated criterion as a guideline to position the resonant frequencies in the ideal location while balancing the other design parameters.

After carrying out all the design optimization using variety of parameter combination our final design is presented below.

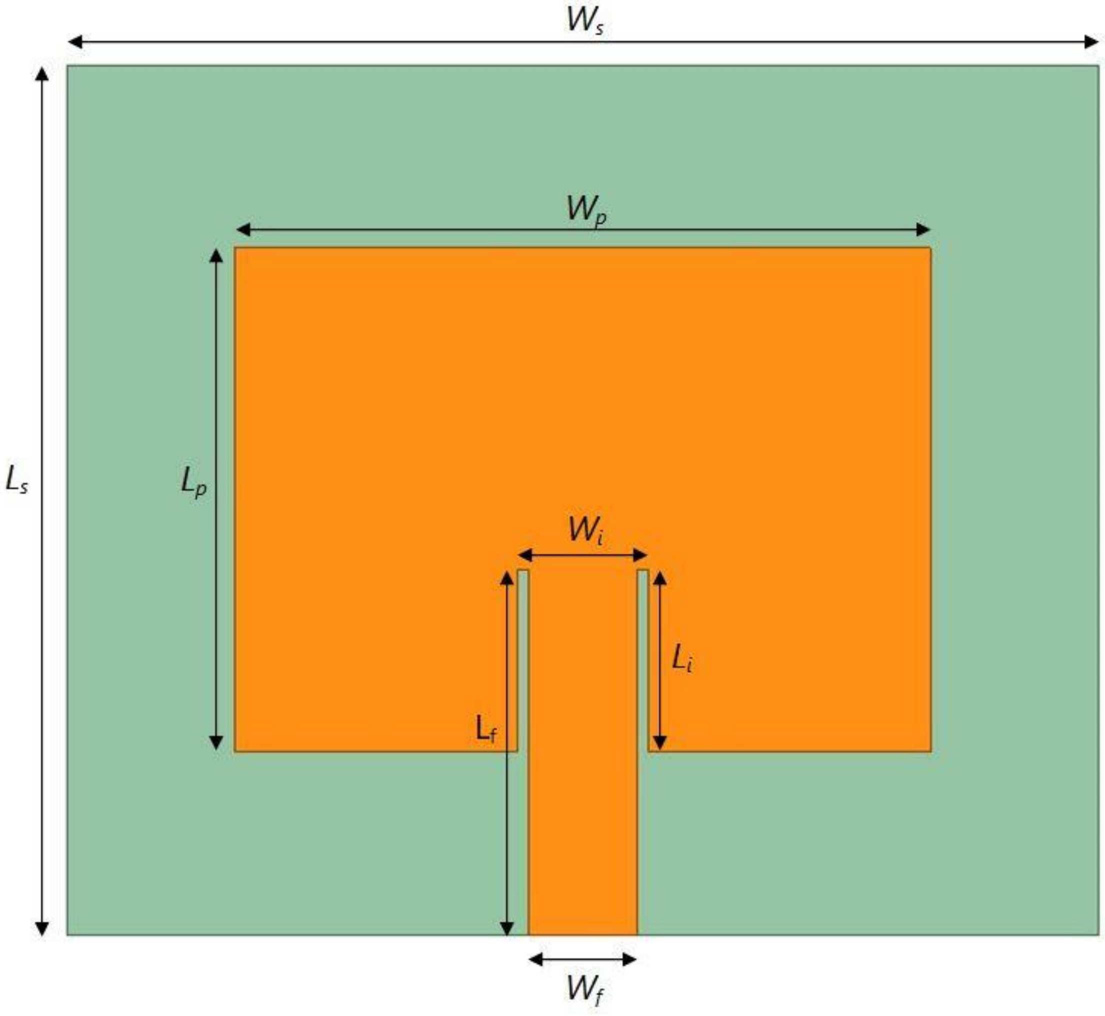


Figure 3.5 (e): Dimensions of substrate, patch and feedline of the proposed X band MPA

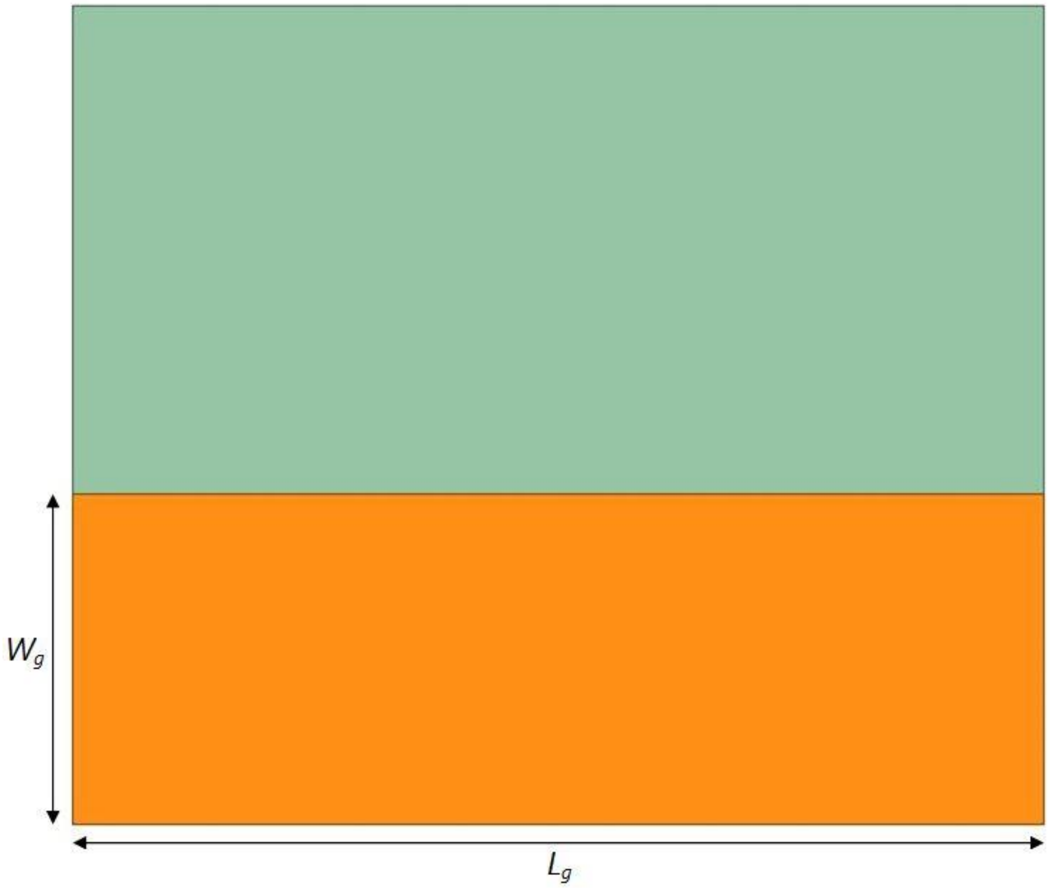


Figure 3.5 (f): Partial ground dimension of the proposed X band MPA

Table 3.5: Dimensions of the Proposed X band MPA

Parameters	**Dimensions (mm)**
L_s	**23.8**
$W_s=L_g$	**28.2**
W_g	**9.6**
L_p	**13.8**
W_p	**19**
L_f	**10**
W_f	**3**
L_i	**5**
W_i	**3.6**

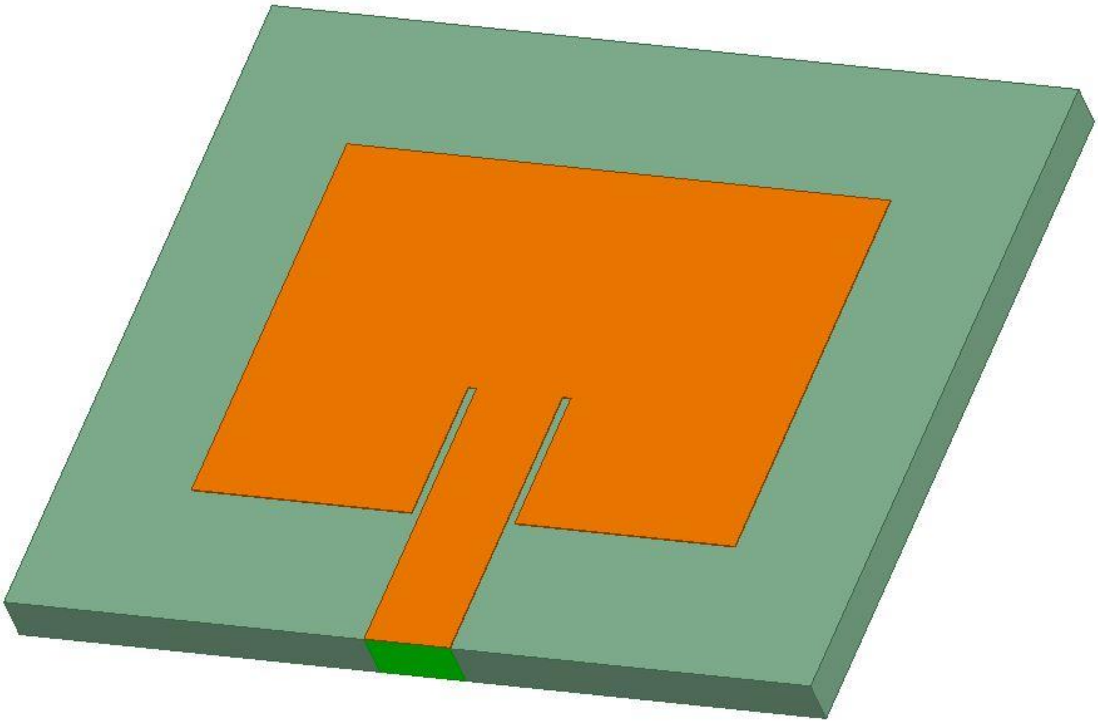


Figure 3.5 (g): Simulated 3D view of the proposed MPA in Ansys HFSS

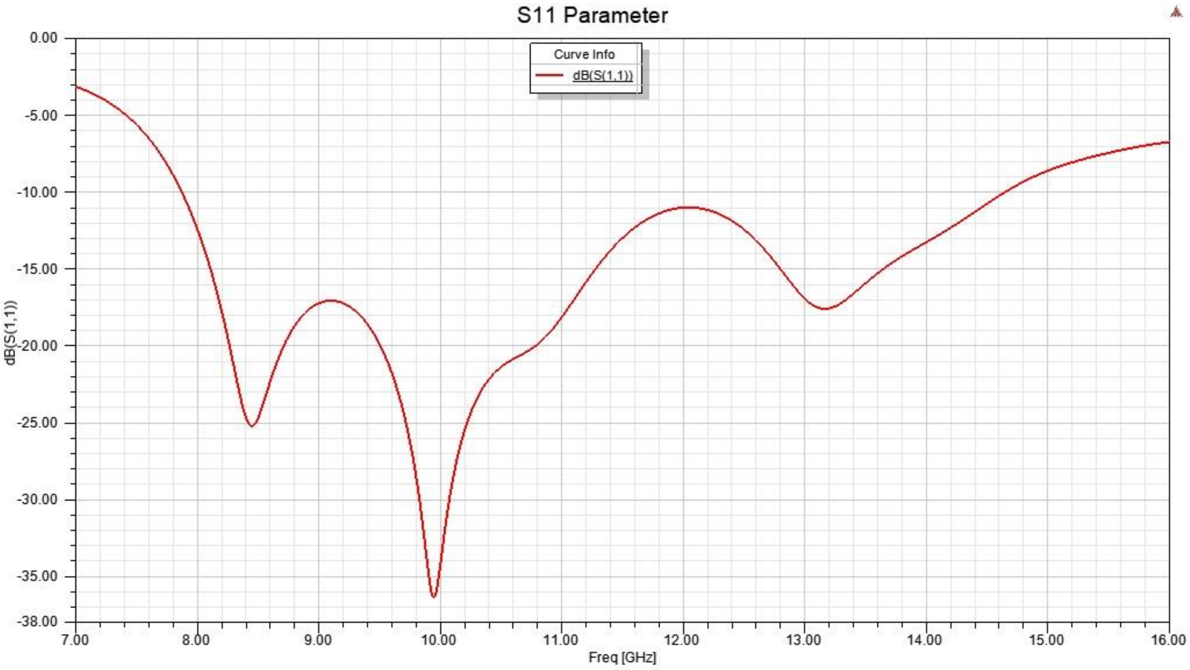


Figure 3.5 (h): Return loss of the proposed X band MPA

After final optimization antenna resonance frequency is lowered from 12.5 GHz to 9.95 GHz with minimum S11 vale of -36.4 dB. Antenna now covers full X band and lower portion of K_u band. Proposed Antenna S11 -10 dB points are 7.9 GHz and 14.6 GHz. So the antenna fully supports the entire X band (8-12 GHz) and it has a bandwidth of 6.7 GHz.

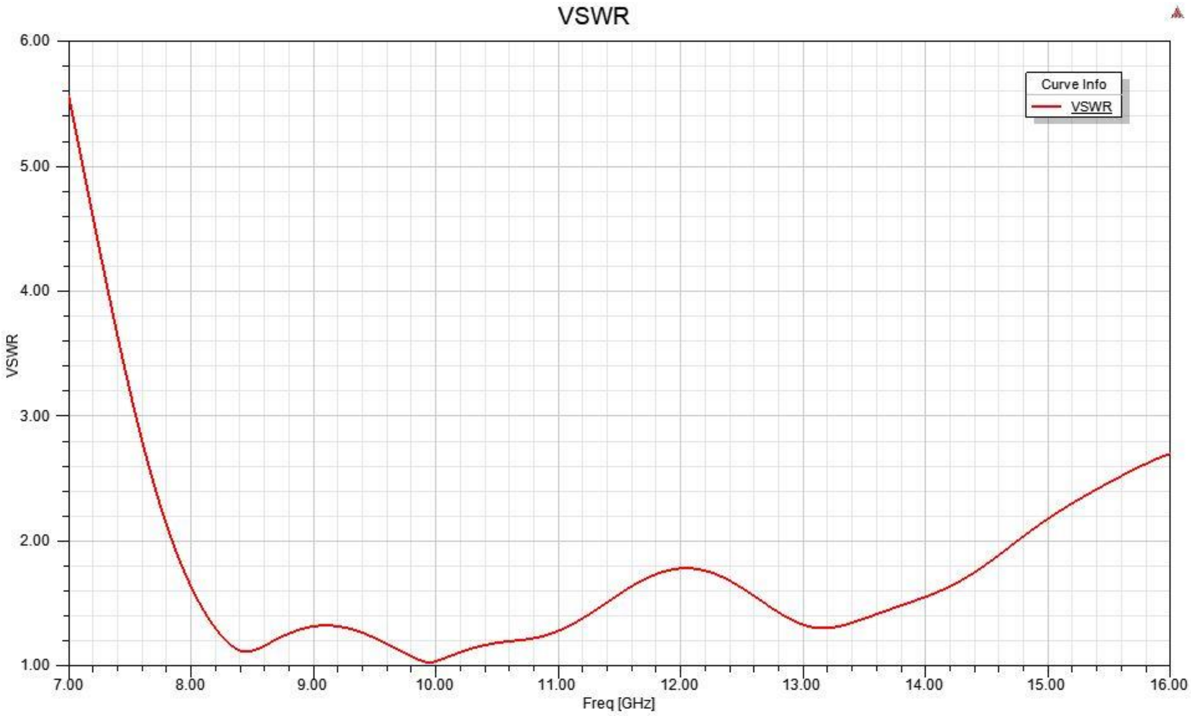


Figure 3.5 (i): VSWR of the proposed X band Antenna

CHAPTER 4

Result and Analysis

4.1 Results and Discussion of the Proposed Antenna using Ansys HFSS

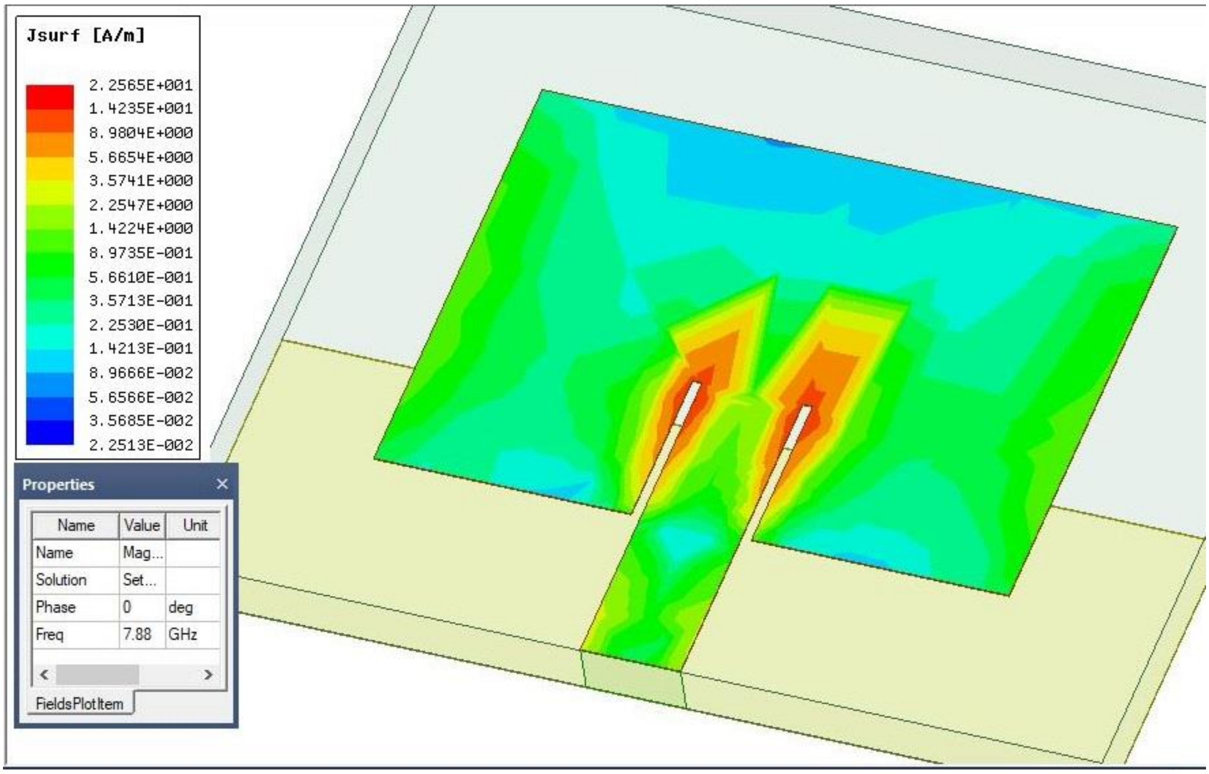
To achieve the thesis's main goal, extensive simulations were run to determine the most optimized antenna for X band operation. Many antennas and array configurations were created, and a progressive increase in bandwidth was noticed. For enhanced antenna properties, the proposed antenna inset slots cutting and partial ground approach has been applied. Because of the features of inset slots, partial ground the bandwidth has expanded exponentially. The proposed antenna has a bandwidth of 6.7 GHz and covers full X band frequency range and 12-14.6 GHz portion of the K_u which means it can support terrestrial broadband, uplink and downlink of satellite, mobile-satellite service, broadcasting satellite services, secure military communication, military satellite communication, direct broadcast satellite TV relay, fixed satellite service, amateur radio, weather monitoring , air traffic control, maritime vessel traffic control and radar application.

The antenna performance metrics such as bandwidth, return loss, average current distribution, vector current distribution, 2D, 3D radiation patterns of gain and directivity are simulated using Ansys HFSS 3D EM simulator. The same performance metrics are also simulated using CST Studio Suite 3D EM simulation tool for comparison purpose that will be discussed in the section.

The current distribution depicts the antenna structure and aids in determining the density and direction of current movement inside the patch at various frequencies. It also demonstrates how different parts of the antenna respond to various operating frequencies. The power radiated by an antenna as a function of the direction away from the antenna is shown graphically in 2D and 3D radiation patterns. 2D radiation pattern provides 3D rotatable view of antenna directivity and gain with emission style in terms of axial ratio, azimuth, and elevation for both polar and cartesian form, whereas 3D radiation pattern provides 3D rotatable view of antenna directivity and gain with emission style in terms of axial ratio, azimuth, and elevation for both polar and cartesian form. Simulations for suggested design antennas at various resonance frequencies have been performed, allowing for a better understanding of antenna parameters.

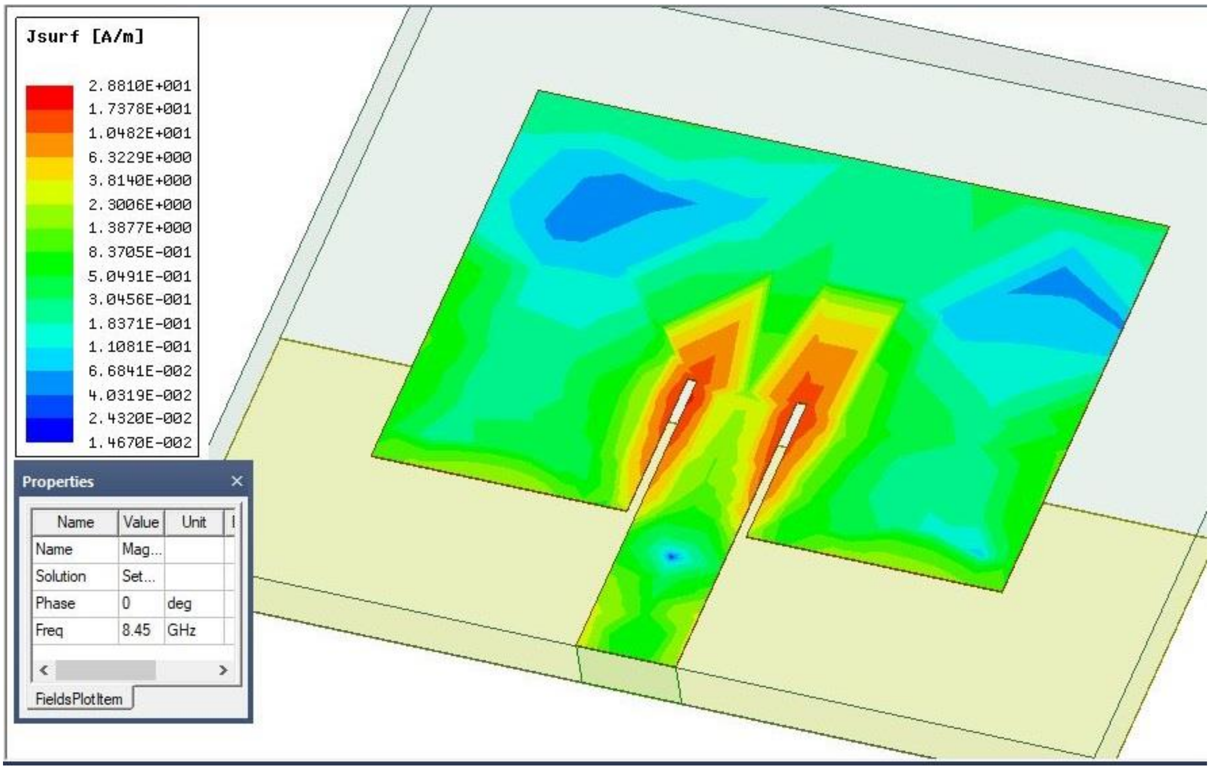
4.1.1 Average Current Distribution

The average current distribution shows which side is radiating and which is non-radiating. Normally, an antenna resonates at a half wavelength length. Current maximum occurs at the centre of a half wavelength in patches and dipoles, and minimum offers at the edges where the conductor ends. Current is greatest (bright red) in the center of the radiating side and lowest at the margins. It is clear which side is radiating or acting as length and which side is non-radiating or acting as breadth in this case. On the non-radiating side, there is no current density, as can be seen.



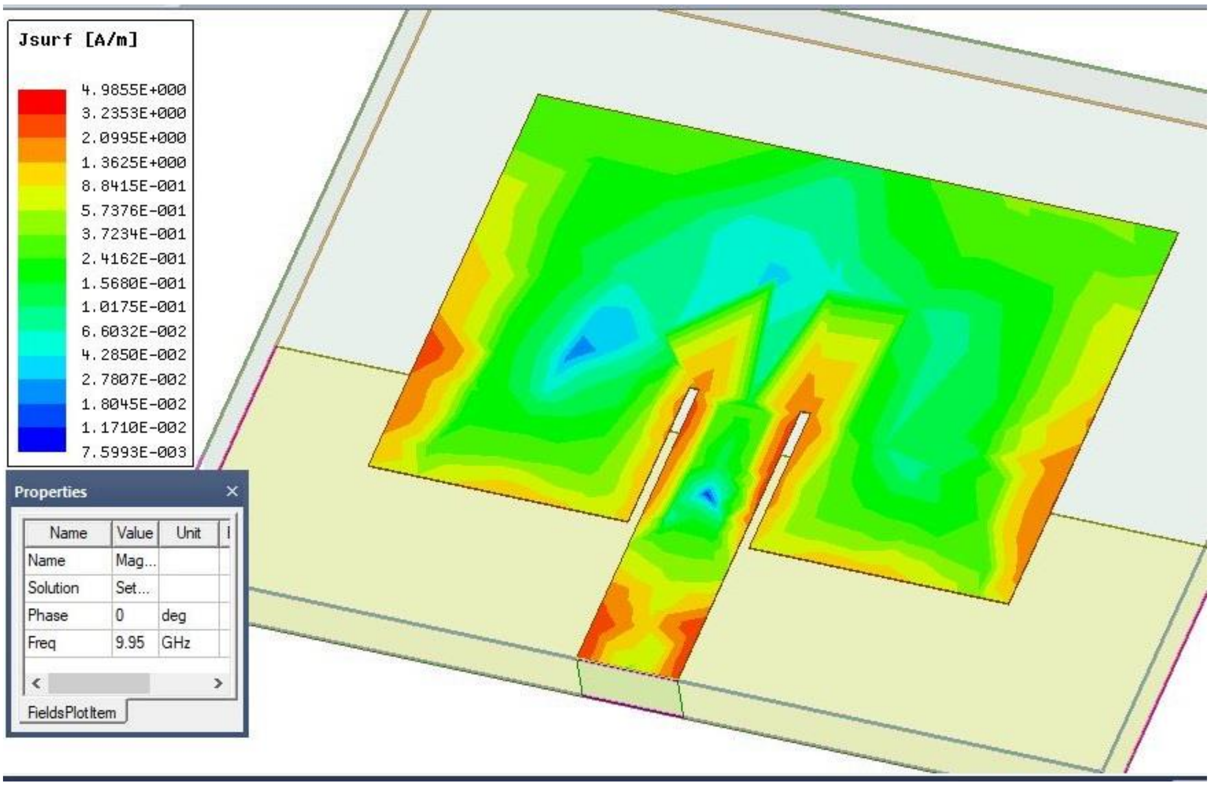
Name	Value	Unit
Name	Mag...	
Solution	Set...	
Phase	0	deg
Freq	7.88	GHz

Figure 4.1(a): Average current distribution of proposed MPA at 4.88 GHz



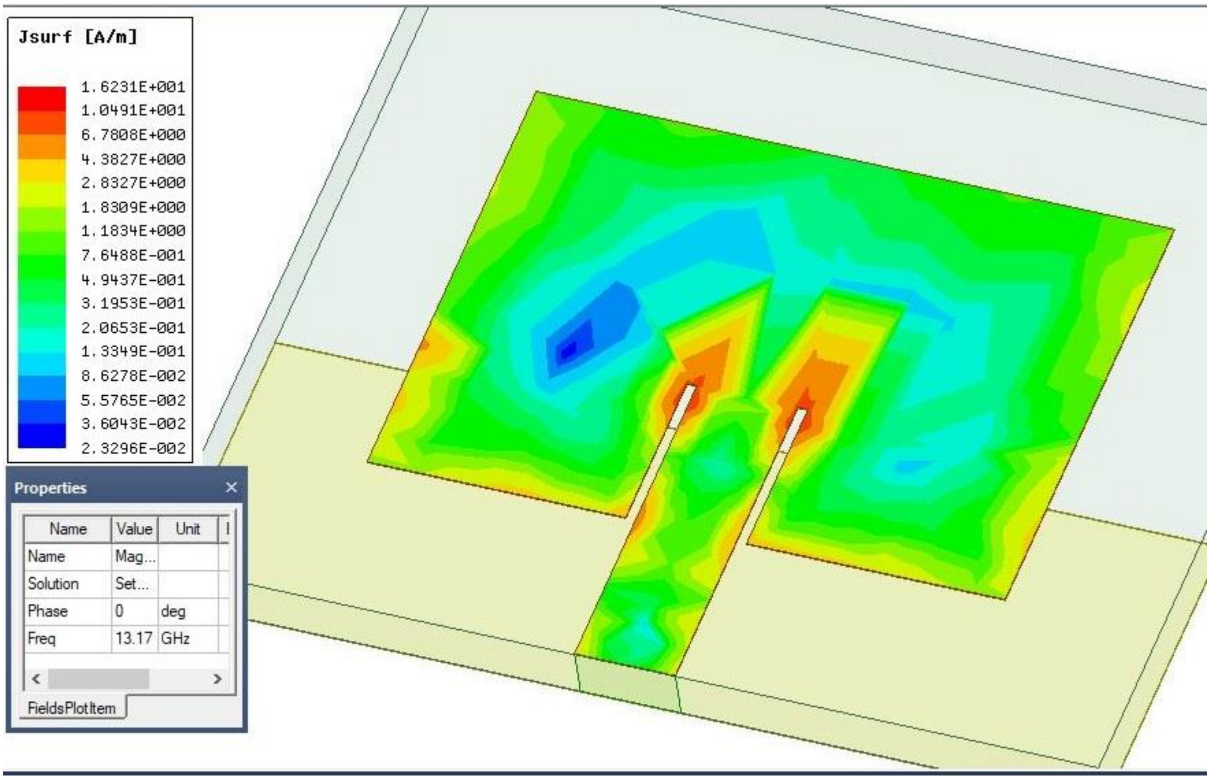
Name	Value	Unit
Name	Mag...	
Solution	Set...	
Phase	0	deg
Freq	8.45	GHz

Figure 4.1(b): Average current distribution of proposed MPA at 8.45 GHz



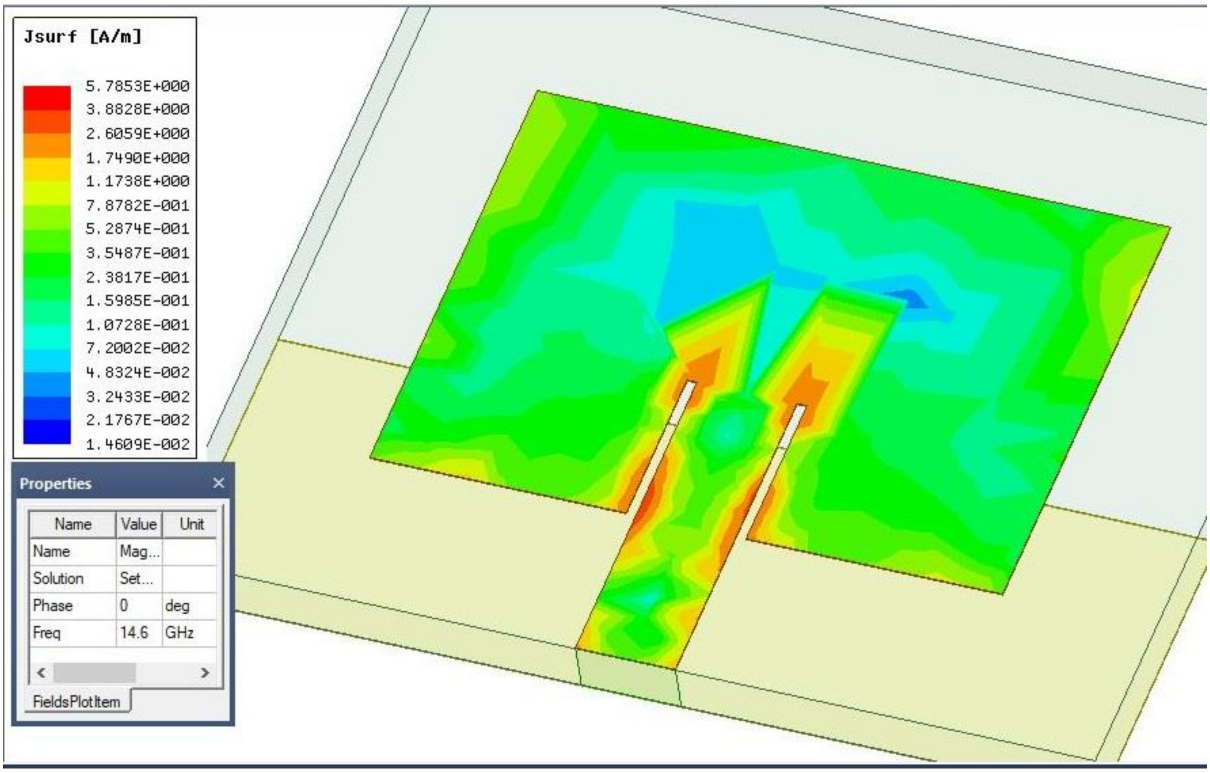
Name	Value	Unit
Name	Mag...	
Solution	Set...	
Phase	0	deg
Freq	9.95	GHz

Figure 4.1(c): Average current distribution of proposed MPA at 9.95 GHz



Name	Value	Unit
Name	Mag...	
Solution	Set...	
Phase	0	deg
Freq	13.17	GHz

Figure 4.1(d): Average current distribution of proposed MPA at 13.17 GHz



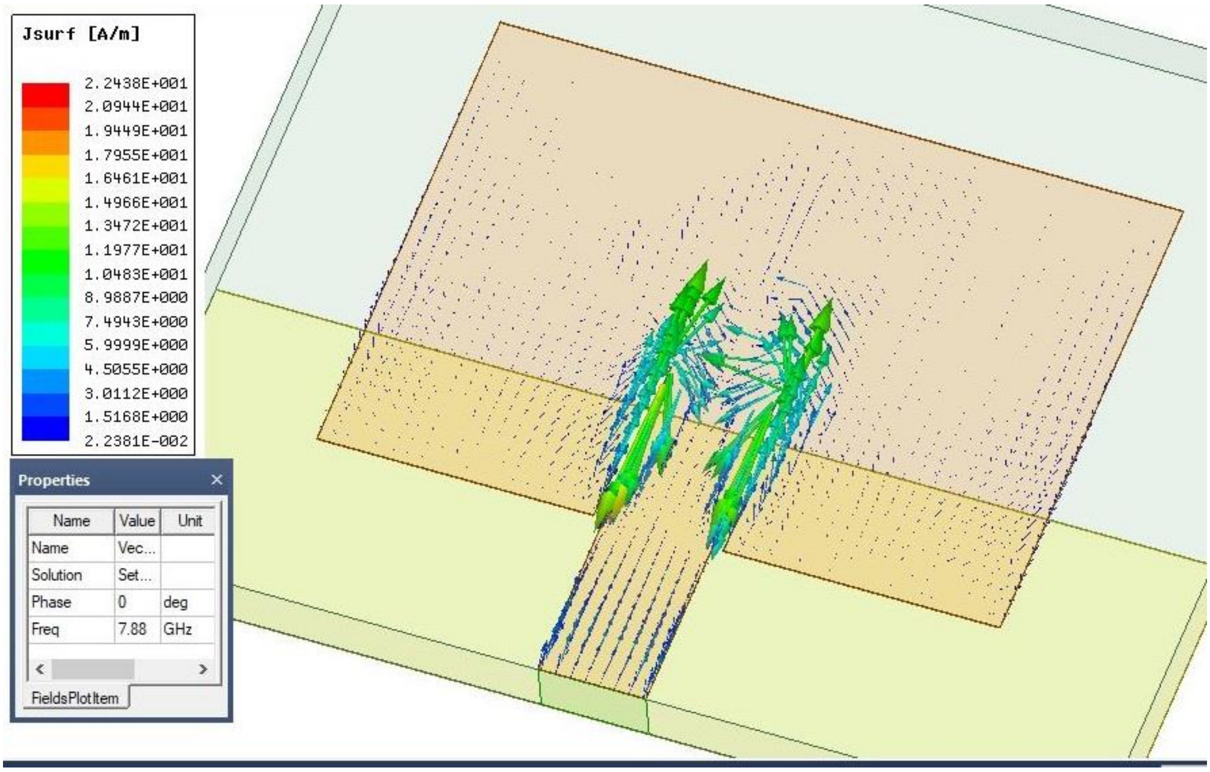
Name	Value	Unit
Name	Mag...	
Solution	Set...	
Phase	0	deg
Freq	14.6	GHz

Figure 4.1(e): Average current distribution of proposed MPA at 14.6 GHz

At 7.88 GHz, 8.45 GHz, 9.95 GHz, 13.17 GHz and 14.6 GHz, the average current density on the surface of all antennas is shown in the diagram above. The maximum current density is shown in red in these figures, while the minimum current density is shown in blue in the patch of the MPA.

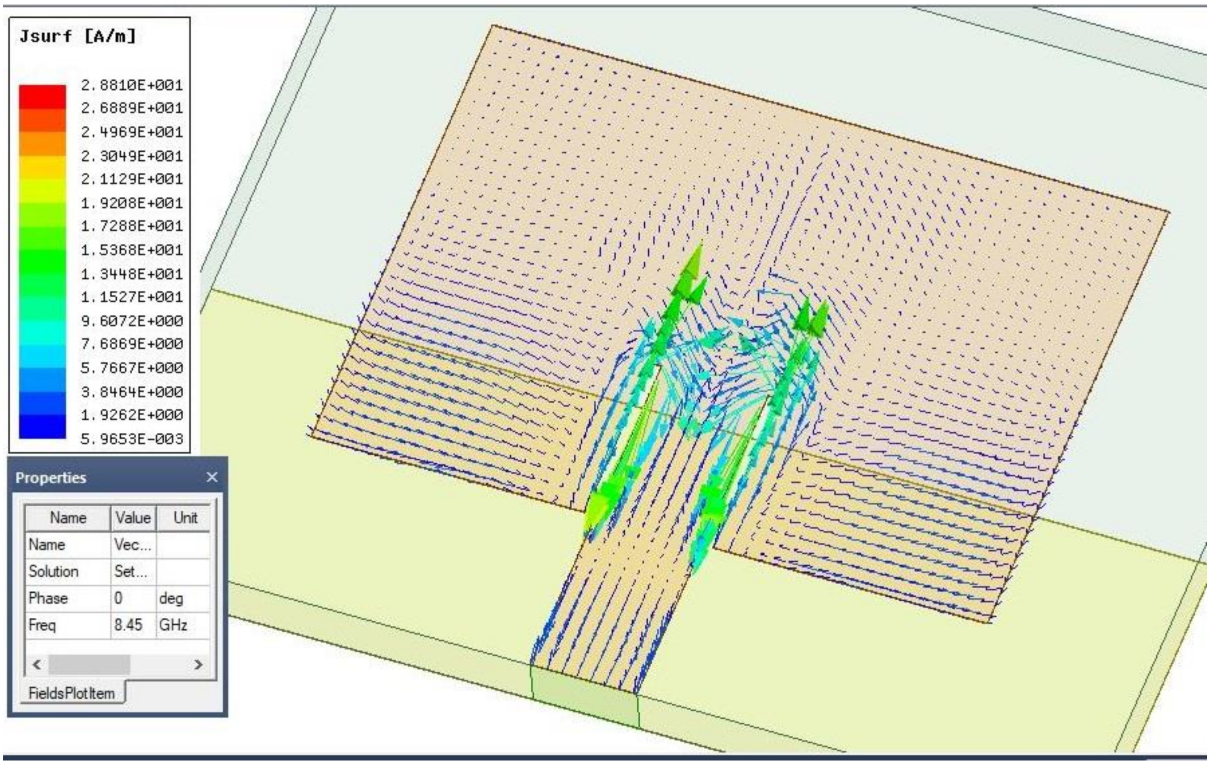
4.1.2 Vector Current Distribution

The vector current distribution depicts how the current is spread and flowing in the antenna's surface. It aids in determining the antenna's polarization. The figure shows that current follows a linear path in the surface, which corresponds to the antenna's linear polarization. The antenna's highest current is in the middle of its length, and it’s smallest near the edges, according to the distribution.



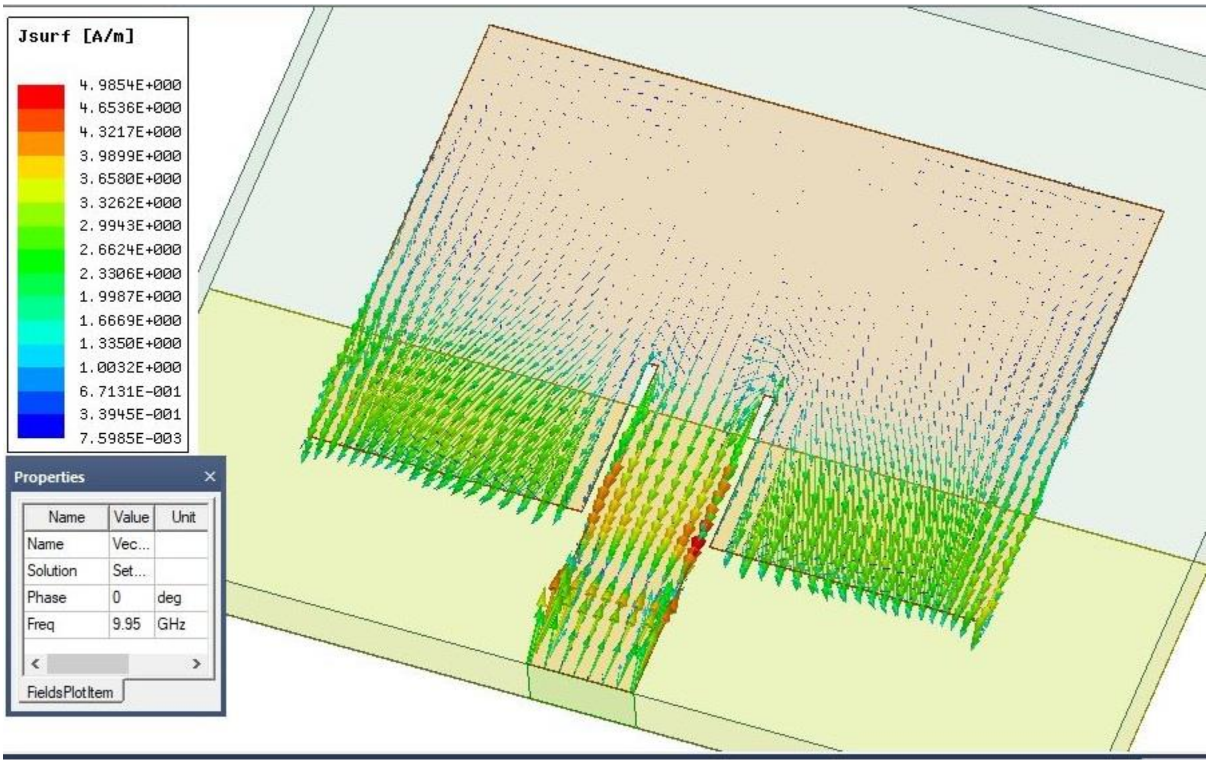
Name	Value	Unit
Name	Vec...	
Solution	Set...	
Phase	0	deg
Freq	7.88	GHz

Figure 4.1(f): Vector current distribution of proposed MPA at 7.88 GHz



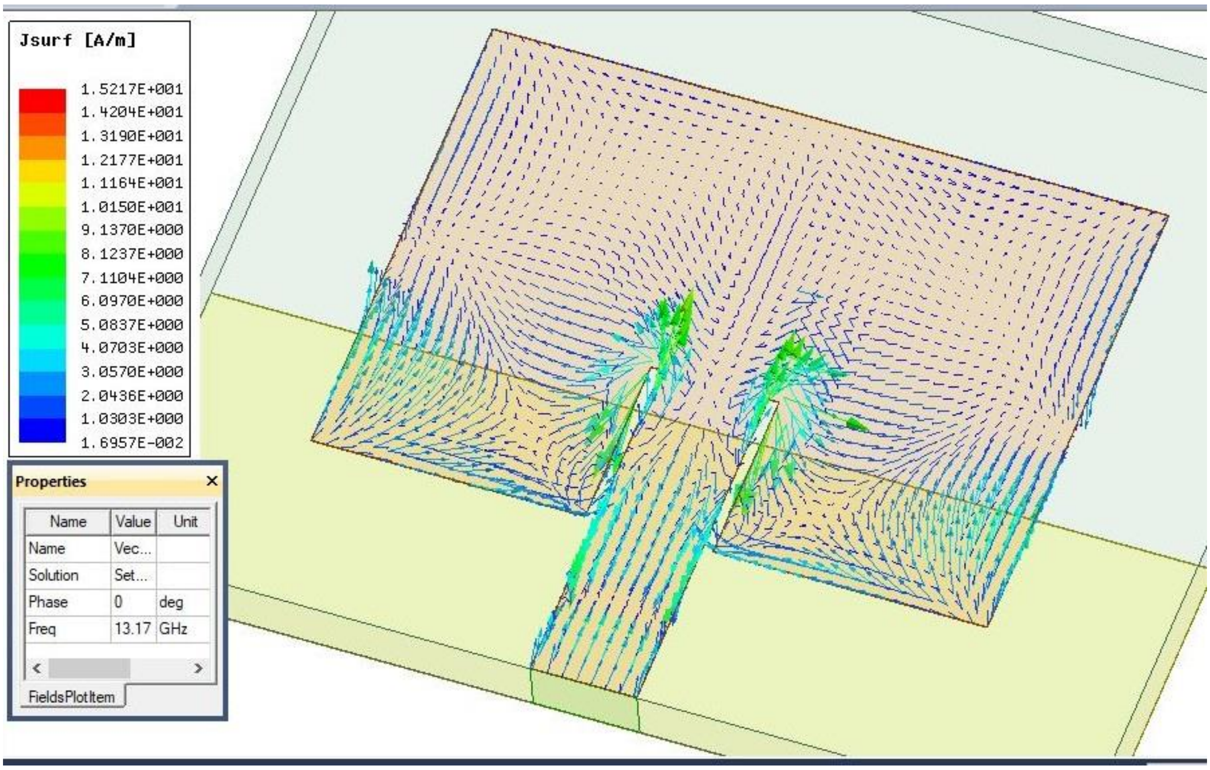
Name	Value	Unit
Name	Vec...	
Solution	Set...	
Phase	0	deg
Freq	8.45	GHz

Figure 4.1(g): Average current distribution of proposed MPA at 8.45 GHz



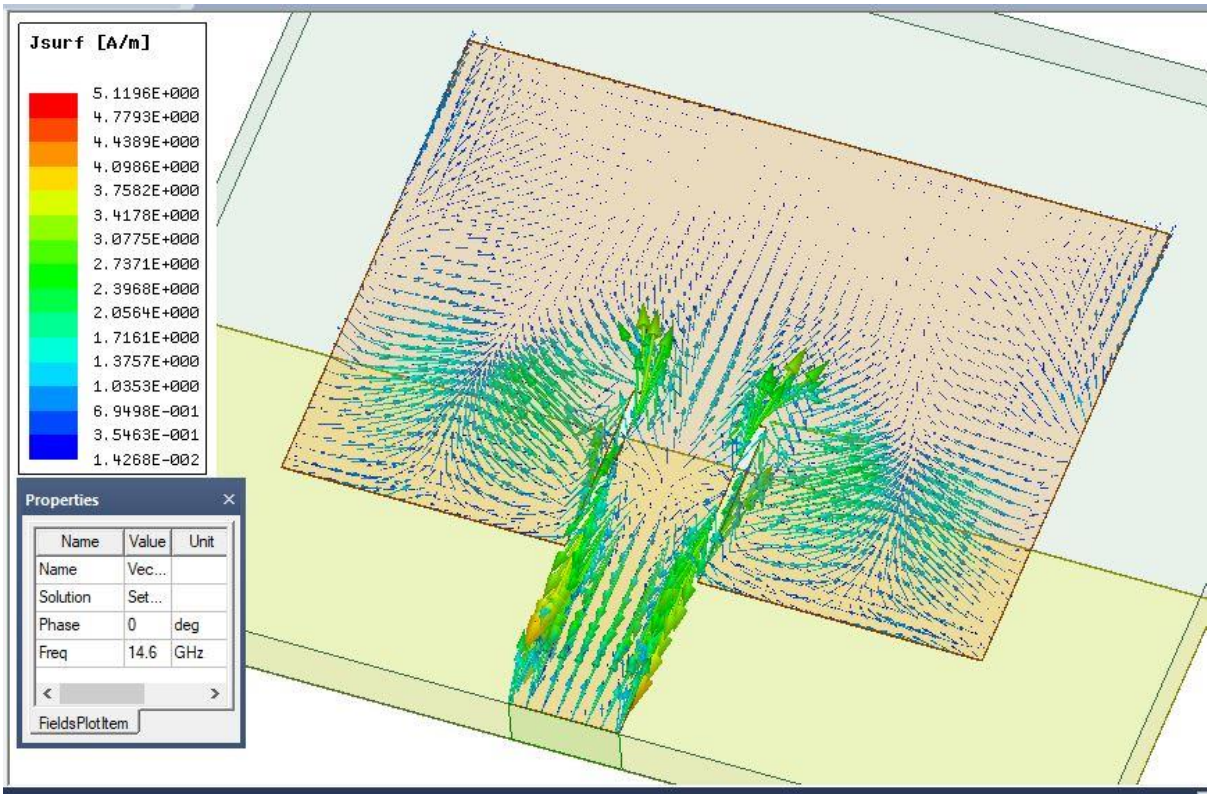
Name	Value	Unit
Name	Vec...	
Solution	Set...	
Phase	0	deg
Freq	9.95	GHz

Figure 4.1(h): Average current distribution of proposed MPA at 9.95 GHz



Name	Value	Unit
Name	Vec...	
Solution	Set...	
Phase	0	deg
Freq	13.17	GHz

Figure 4.1(i): Average current distribution of proposed MPA at 13.17 GHz



Name	Value	Unit
Name	Vec...	
Solution	Set...	
Phase	0	deg
Freq	14.6	GHz

Figure 4.1(j): Average current distribution of proposed MPA at 14.6 GHz

Figures 4.1 (f) to 4.1 (j) illustrate the vector current distribution over the surface of all patch antennas at primary and secondary resonant frequencies as well as -10 dB points. The magnitude of the current density at a certain location at a specific time is indicated by the size of the vectors..

4.1.3 2D Radiation Pattern

The 2D radiation pattern aids in understanding how the antenna radiates in 3D. Due to the difficulty of displaying a 3D pattern on a 2D surface, the 2D radiation pattern is utilized for analytical purposes. A good antenna should keep its radiation pattern consistent over the whole frequency range it covers. The radiation pattern of the proposed antenna is shown below at 7.88 GHz, 9.95 GHz and 14.6 GHz.

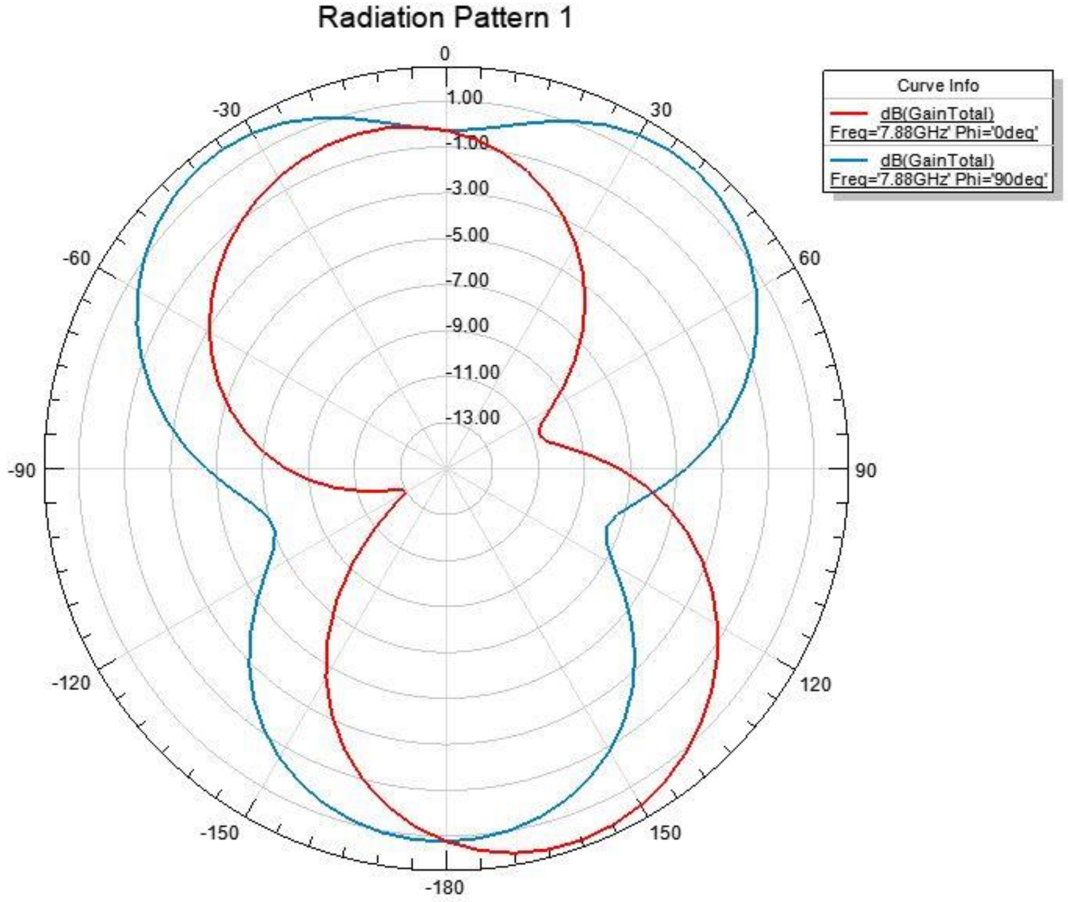


Figure 4.1(k): Radiation pattern of proposed MPA at 7.88 GHz

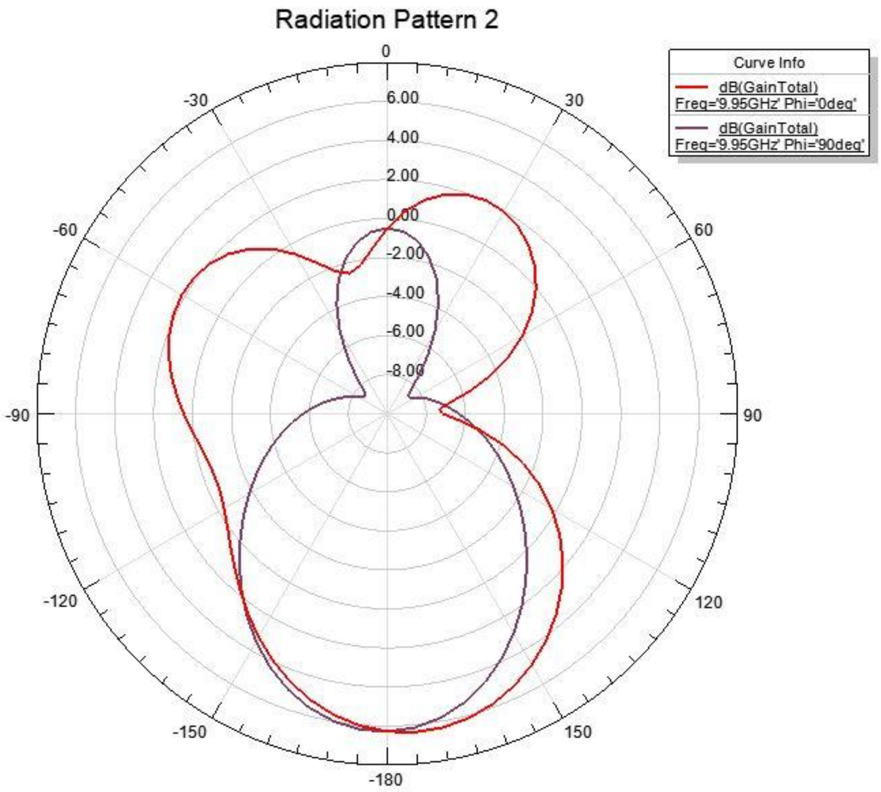


Figure 4.1(l): Radiation pattern of proposed MPA at 9.95 GHz

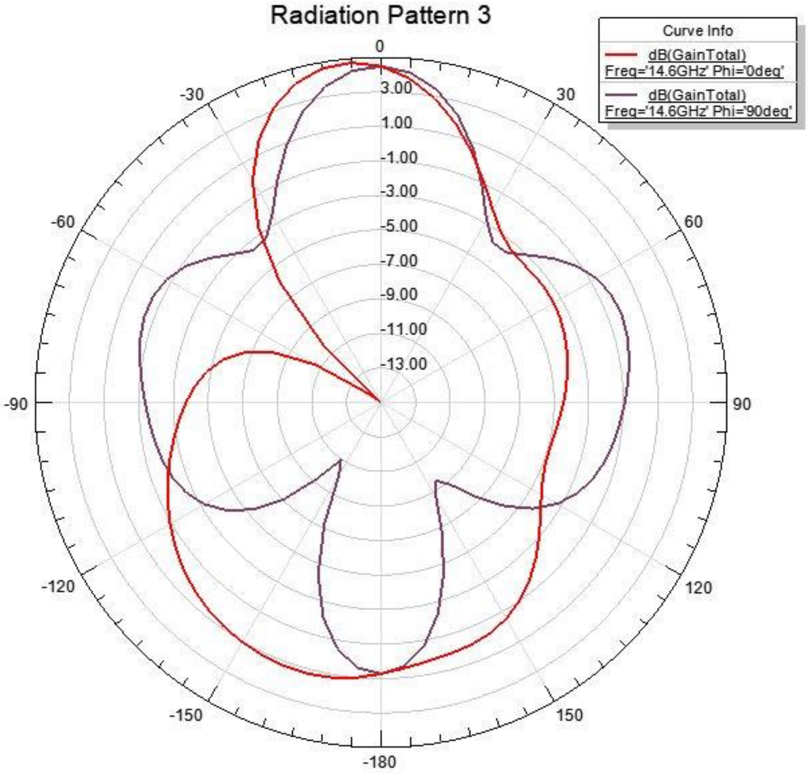


Figure 4.1(m): Radiation pattern of proposed MPA at 14.6 GHz

4.1.4 3D Radiation Pattern:

Although the 3D radiation pattern cannot be used to derive much information, it has been included in the book to help understand the 2D patterns. A better understanding of antenna power radiation direction can be gained by looking at a 3D radiation pattern. Figure 4.1(n) to 4.1(o) depicts actual 3D radiation patterns of the proposed single element inset feed MPA at 7.88 GHz, 8.45 GHz and 14.6 GHz frequencies. They represent the pattern in 3D space. The strength of the field at a certain (theta, phi) angle is represented by the size of the pattern from the origin.

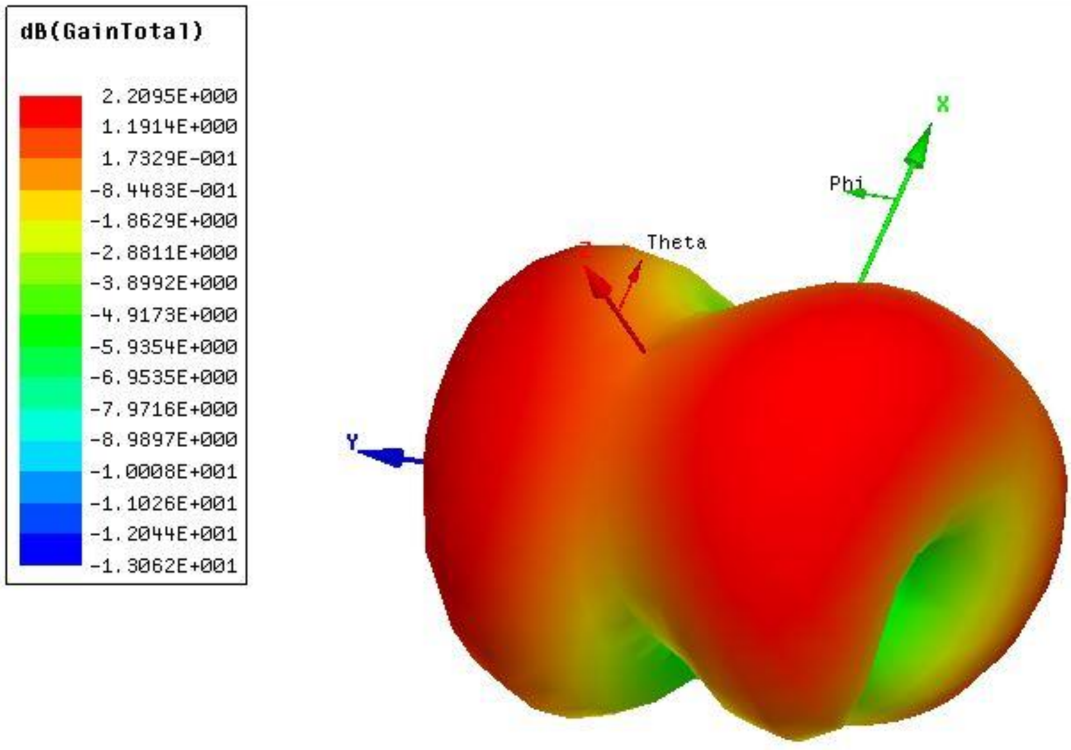


Figure 4.1(n): 3D Radiation pattern of proposed MPA at 7.88 GHz

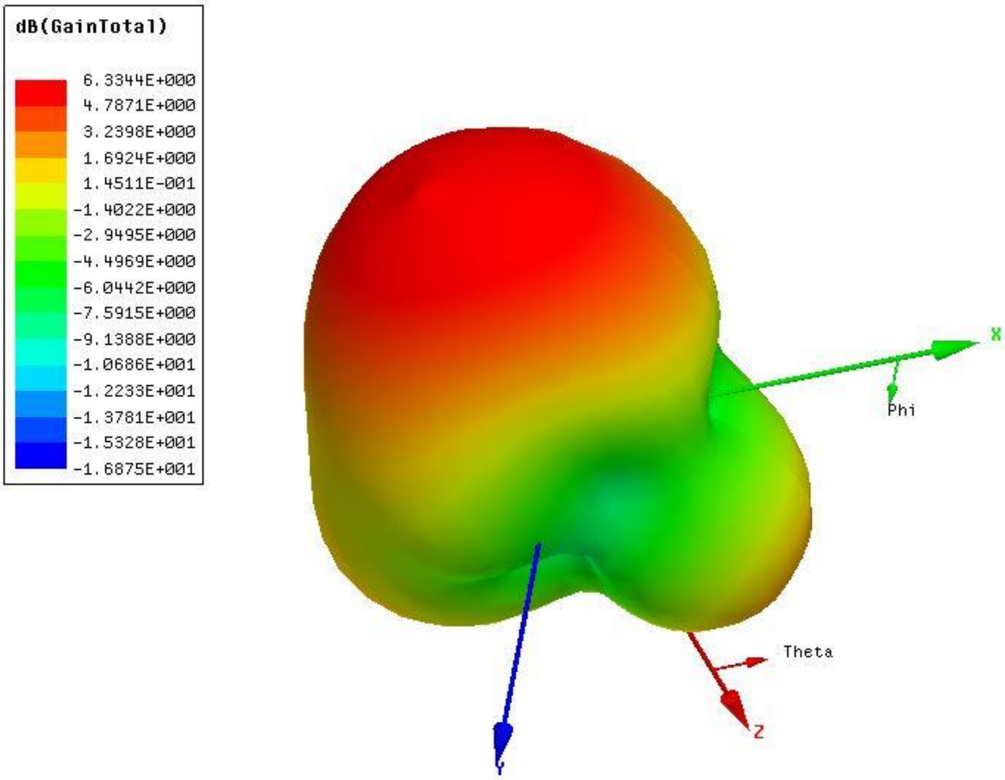


Figure 4.1(o): 3D Radiation pattern of proposed MPA at 8.45 GHz

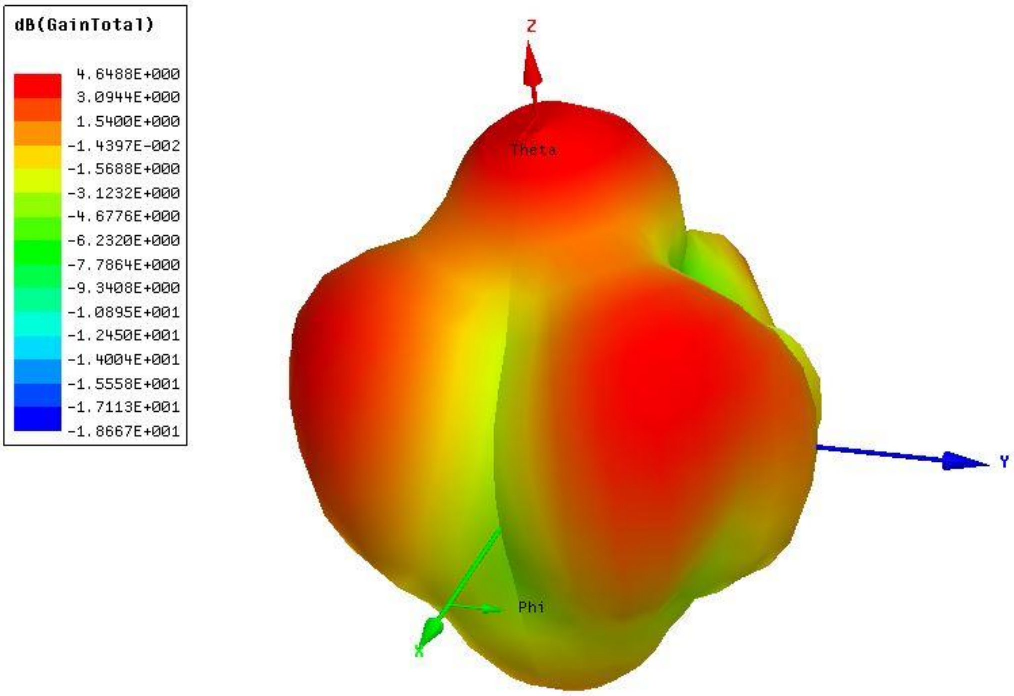


Figure 4.1(p): 3D Radiation pattern of proposed MPA at 7.88 GHz

Directivity compares the power density radiated by an ideal isotropic radiator (which emits uniformly in all directions) radiating the same total power to the power density radiated by the antenna in the direction of its strongest emission. Figure 4.1 (q) to 4.1(s) depicts directivity of our proposed MPA at three frequencies of 7.88, 9.95 and 14.6 GHz. The antenna provides a maximum gain of 6.33 dB at 8.45 GHz and it has a maximum directivity of 7.08 dBi.

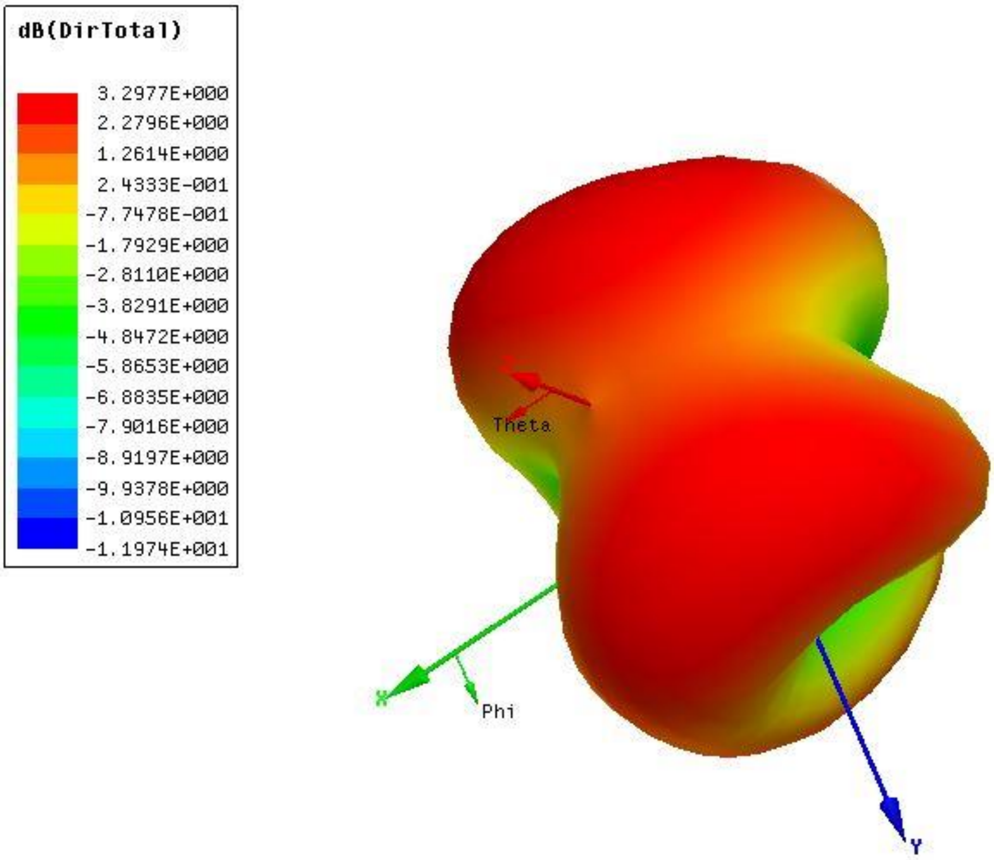


Figure 4.1(q): Directivity(3D) of proposed MPA at 7.88 GHz

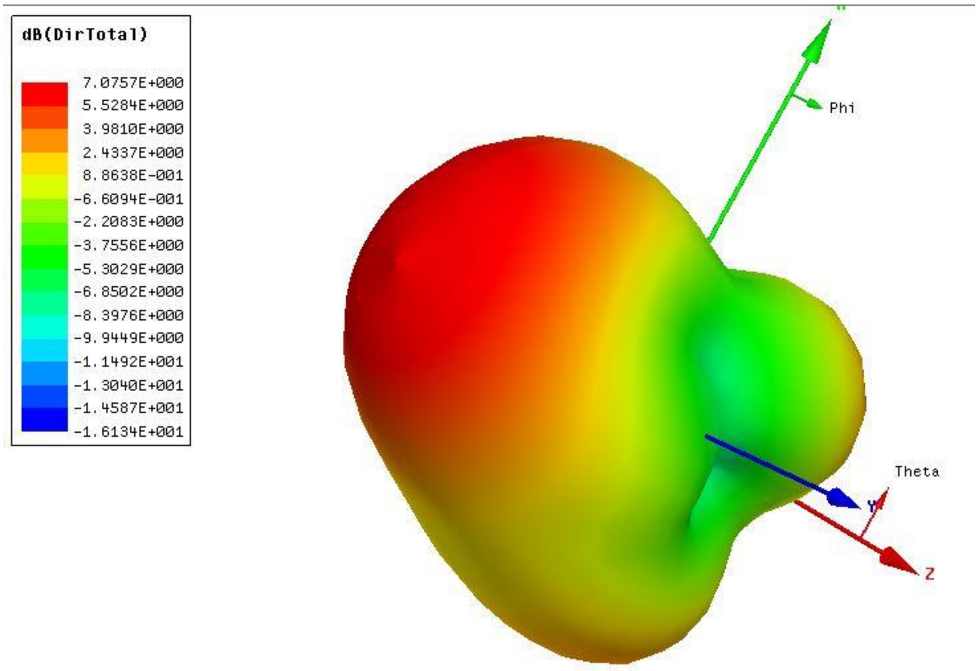


Figure 4.1(r): Directivity(3D) of proposed MPA at 9.95 GHz

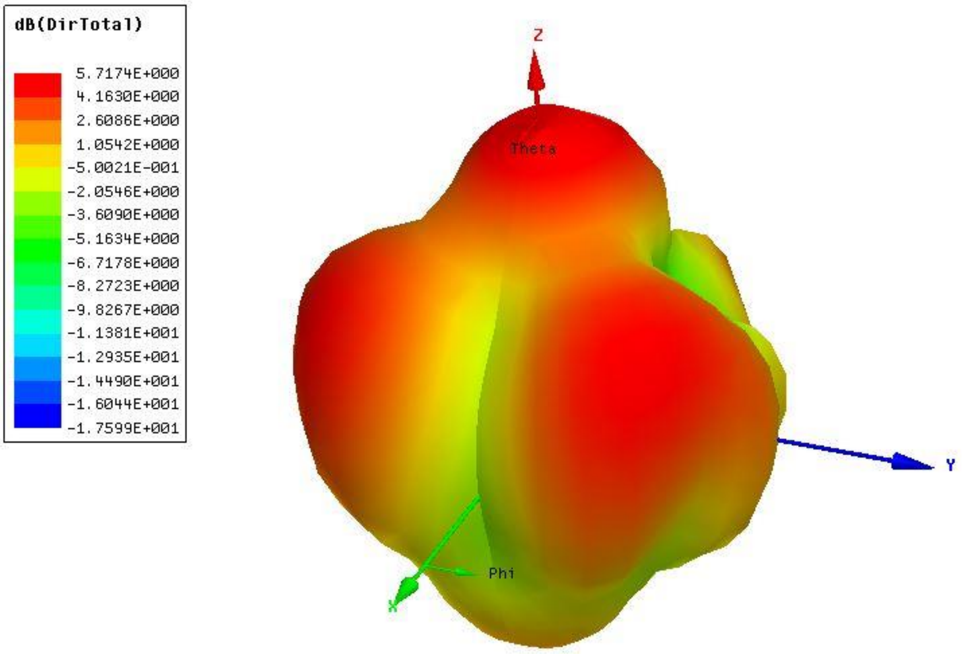


Figure 4.1(s): Directivity(3D) of proposed MPA at 14.6 GHz

4.2 Simulated Results of the Proposed Antenna using CST Microwave Studio

To verify the result that we got from Ansys HFSS, we designed the antenna in CST Studio Suite using the exact same materials and parameters. However exact same simulation configuration can’t be used due to some dissimilarities between two software. The obtained result from CST Studio Suite is presented here.

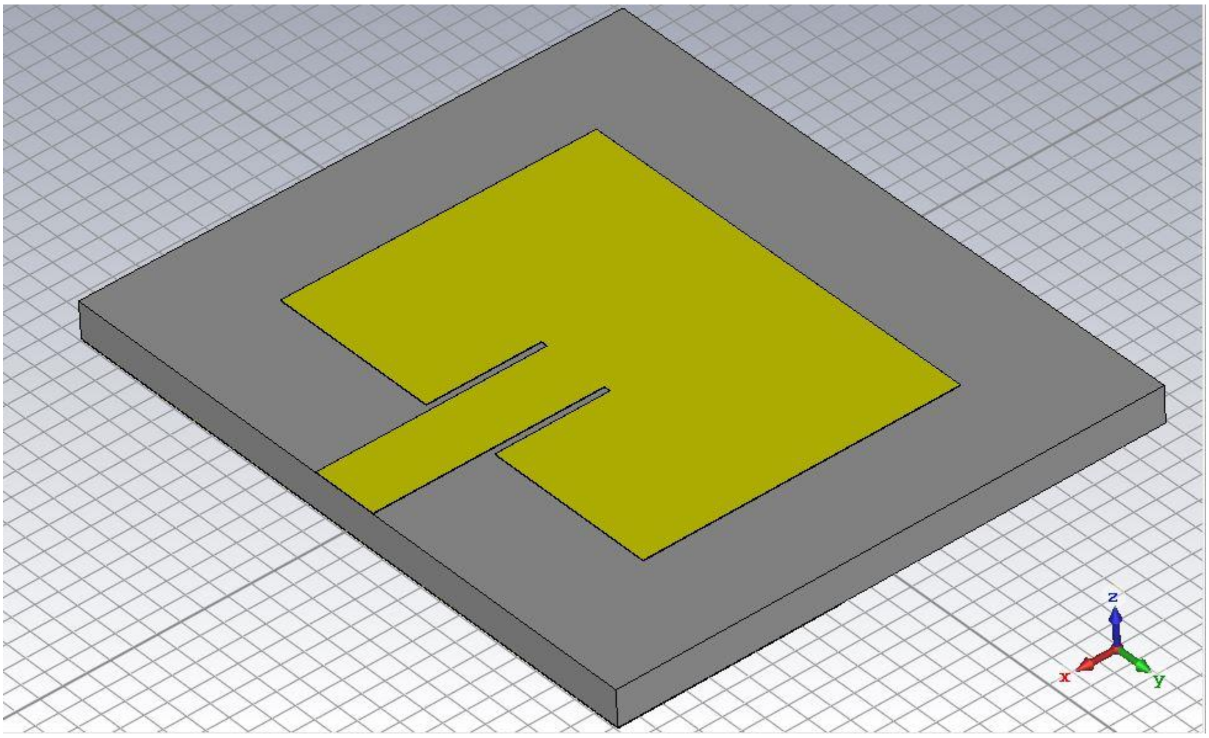


Figure 4.2(a): Simulated 3D view of proposed MPA using CST

Figure 4.2 (b) shows the of the S11 parameter (return loss) of the planned antenna using CST Studio Suite. The S11 parameter is very important because it determines how well the antenna impedance matches the reference transmission line impedance. In general, the antenna is modeled with 50 Ohm reference impedance. When the antenna impedance is perfectly matched to the reference 50 ohm impedance, the antenna port reflects less power and the antenna radiates maximum power in the direction of the main lobe.

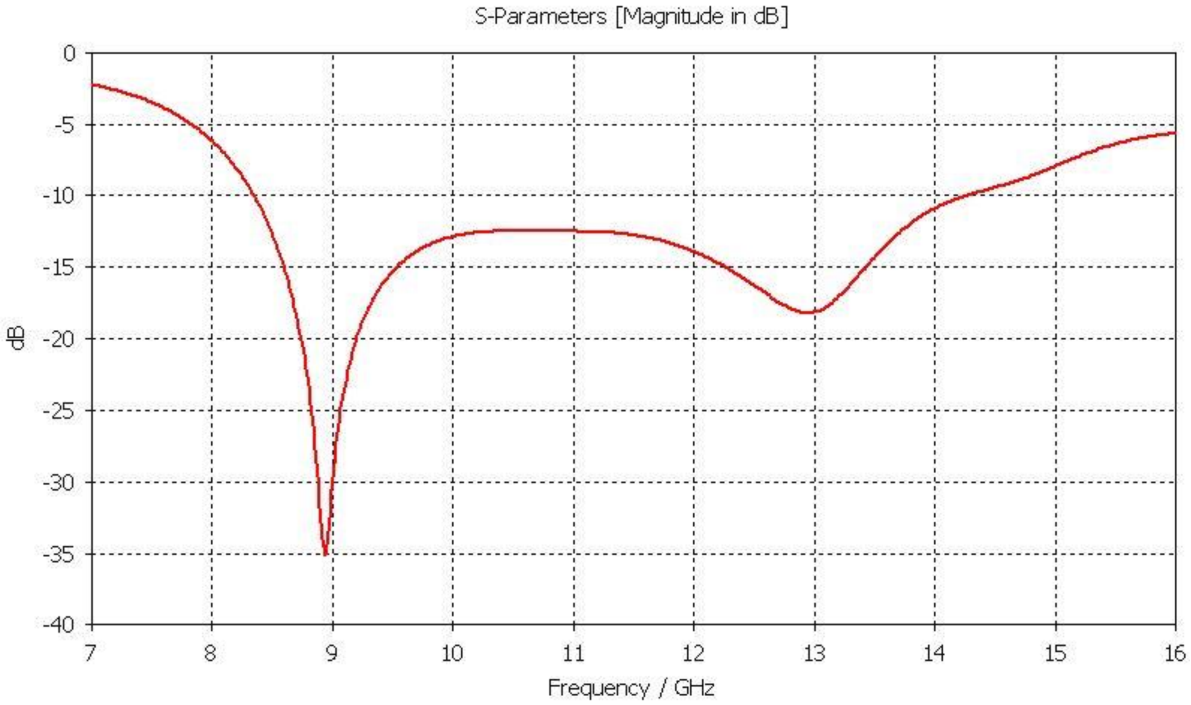


Figure 4.2(b): S11 parameter of proposed MPA using CST

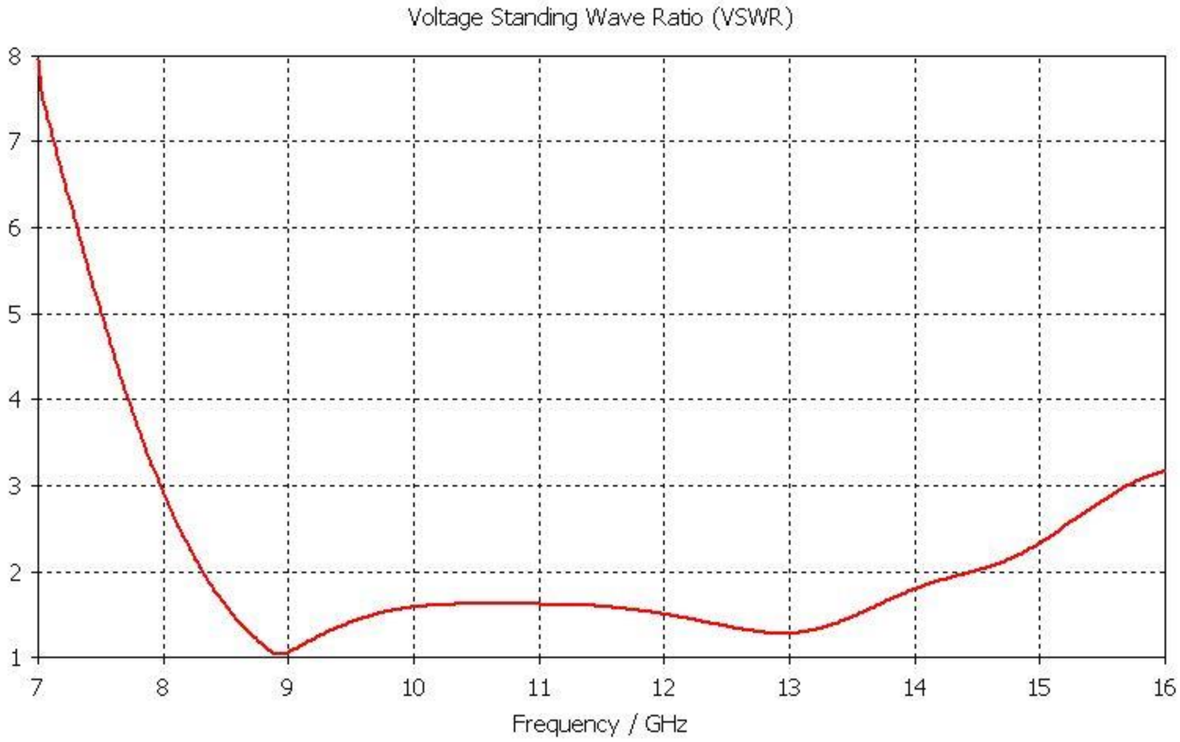


Figure 4.2(c): VSWR of proposed MPA using CST

The antenna impedance is well matched with the reference transmission line impedance due to the large amount of return loss in the negative direction. The plot shows -35.11 dB of return loss at 8.93 GHz which indicates only 0.031 percent of power reflection due to mismatch.

Figure 4.2(c): shows simulated VSWR of the proposed antenna using CST Studio Suite. It has lowest value of 1.036 at 8.93 GHz and since it is very close to 1 therefore VSWR plot also suggests a near perfect impedance matching.

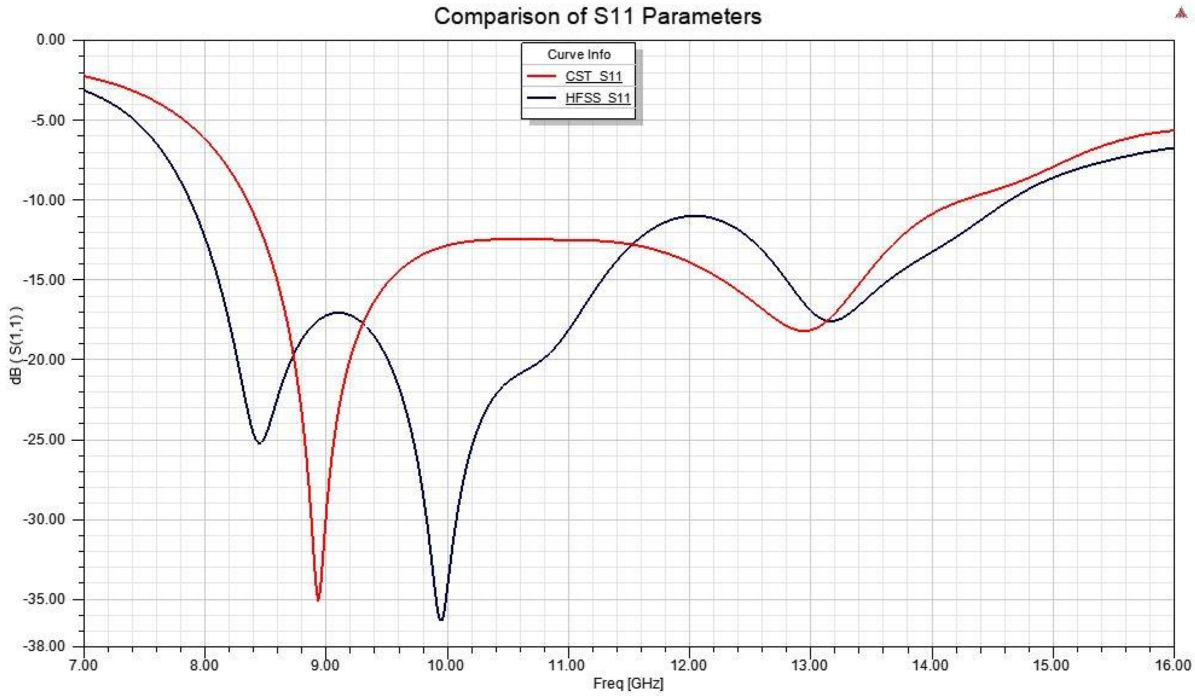


Figure 4.2(d): Comparison of simulated S11 Parameter using HFSS and CST

Comparison between simulated return loss(S11) of the proposed antenna using both Ansys HFSS and CST Studio Suite is presented in the figure 4.2(d). The comparison plot demonstrates a good similarity between two results. Both results show very good impedance matching. Lowest S11 of HFSS CST result is -36.37 dB and -35.11 dB. The Antenna resonates at 9.95 GHz for HFSS and 8.93 GHz for CST. Operating frequency range of the proposed antenna is 7.88 GHz to 14.6 GHz and 8.35 GHz to 14.25 GHz for HFSS and CST respectively. The antenna offers 6.7 GHz and 5.9 GHz according to HFSS and CST result consecutively. Although there is some minor dissimilarity between two results, it is not unexpected. Due to some fundamental difference between two EM simulation software, minor dissimilarity is very reasonable.

Table 4.2.1: Comparison of the simulated results using Ansys HFSS and CST Studio Suite

Parameters	Ansys HFSS	CST Studio Suite
Resonance Frequency	9.55 GHz	8.93 GHz
Lower cut-off frequency	7.88 GHz	8.35 GHz
Higher cut-off frequency	14.6 GHz	14.25 GHz
Bandwidth	6.7 GHz	5.9 GHz
Return loss	-36.37 dB	-35.11 dB
VSWR	1.0309	1.0358
Gain	6.33 dB	4.9 dB
Directivity	7.08 dBi	7.19 dBi

Table 4.2.2: Comparison between proposed design and references based relevant works

Parameters	References					Proposed
	25	27	28	26	29	
Bandwidth (GHz)	2.14	1.48	.71	1.59	1.56	6.7
Return Loss	-40.99	-42.23	-29.21	-17.14	-32.5	-36.37
Width(mm)	N/A	N/A	20	N/A	20	19
Length	N/A	N/A	14.6	N/A	20	13.8
Substrate height (mm)	1.6	1.6	2.5	1.6	3	1.6
Gain (dB)	2.08	3.33	5.01	4.31	4.6	6.33
Directivity (dBi)	3.46	5.57	No info	5.5	No info	7.08

CHAPTER 5

Conclusion & Future Works

5.1 Major Contributions of the Thesis

Patch antennas are widely used due to their low profile, small weight, and inexpensive cost. They provide a number of benefits over traditional antennas. The two significant issues, however, are limited bandwidth and low gain.

The narrow bandwidth and low gain challenge for a single band patch microstrip antenna has been investigated in this thesis. Partial ground as well as inset slot cutting approach used to increase its bandwidth. Because slot has an effect on the electromagnetic properties of the host media, it has the potential to improve bandwidth and gain in antenna design. From the RMPA to the suggested antenna, this thesis illustrates a gradual improvement in antenna characteristics. All of the development process of the antenna has been briefly addressed, and it function in the X and K_u band frequency range, allowing it to support advanced satellite communication, satellite broadcasting, and other fascinating operations in this area. The suggested antenna's bandwidth is primarily boosted by inset slot and partial ground, and it can be further improved by inserting two rectangular slots and modifying the substrate material. The antenna is 23.8 x 28.2 mm2 in size, with a substrate height of 1.6 mm. With three resonance frequencies of 8.45 GHz, 9.95 GHz, and 13.17 GHz, the proposed single element patch antenna covers the whole X band and lower portion of K_u band. At these frequencies, the reflection coefficient or return loss is -25.23 dB, -36.37 dB, and -17.60 dB, respectively, and the VSWR is less than 2 across the whole X band and lower portion of K_u band. The structure's maximum gain and directivity are 6.33 dB and 7.08 dBi, respectively.

To verify the output, we had to compare it to two well-known programs Ansys HFSS and CST Studio Suite. The return loss is nearly same, as is the gain. The VSWR value ranges between 1 and 2. To understand the effects of various factors on each other in terms of bandwidth, return loss, gain, directivity, and size, a comparative research with current literature was conducted. The outcomes of the results are positive and satisfying. In comparison to previous antennas, the suggested proposed antenna shows promise in terms of bandwidth coverage and gain characteristics. This proposed antenna can be employed in X band and lower K_u band application.

5.2 Future Scope of Work

The influence of slot and rectangular slots on the bandwidth of a rectangular patch antenna was investigated in this thesis. Future work could include experimenting with different slot structures and modifying the antenna type (including antenna form and substrate dielectric). To increase impedance bandwidth, an impedance matching network might be utilized.

Various techniques can also be used in future to design optimized antennas which are as Follows:

- Split-Ring Resonator Structure (SRRS)
- Electromagnetic Band Gap Structure (EBG)
- Metamaterials

Fabrication of the antenna can be done in the future to observe their real-time performance. The antenna structure is very simple and FR-4 Epoxy substrate is widely available. So it can easily be manufactured with a very affordable cost. Other commonly used techniques on the suggested antenna could be used to improve antenna characteristics further.

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