DESIGN AND ANALYSIS OF A HIGH GAIN MICROSTRIP PATCH ANTENNA FOR X-BAND SATELLITE APPLICATIONS

by

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A thesis
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CHAPTER 1

INTRODUCTION

1.1 Background

Antenna plays an important role in wireless communication system which function is to transmit and receive radio frequency signal. However, most conventional antennas are not suitable for the wireless communication system because the antennas have rigid structure, big size and high cost manufacturing. Therefore, microstrip antenna is introduced into the wireless communication system due to its flexibility, robustness and light weight.

Microstrip Antennas have attracted much attention since 1970s, although the concept of a microstrip patch antenna first developed in 1953 [1] and a patent in 1955 [2]. In modern era, for microwave and wireless engineering, it is one of the most demandable topics in antenna theory and design. Moreover, due to the high demand for smaller electronic devices and especially smaller portable communication devices, more and more small microstrip antennas are required [3]. Among various kinds of antenna, MPA have attracted much concentration due to their low profile nature, lightweight, low cost, easy to fabricate, and conformity etc. [4],[5]. Microstrip antennas consist of a very thin metallic strip (patch) placed a small friction of a wavelength above a dielectric plane. The patch and the ground plane are separated by a dielectric material (called the substrate) [6]. The microstrip patch antenna is usually designed as a broadside radiator (its pattern is normal to the patch). This can be accomplished by properly choosing the mode of excitation beneath the patch. The radiating patch shape may be square, rectangular, thin strip (dipole), circular, elliptical, triangular, or any other configuration [6]. However, square, rectangular, dipole (strip), and circular patches are most common because of easy analysis and fabrication. Microstrip antennas can be feed by different feeding techniques. These are microstrip line feed, coaxial probe feed, aperture coupling feed or proximity coupled feed [6].

1.2 Problem Statement

Despite of having so many advantages, microstrip patch antenna suffers from various disadvantages like-narrow bandwidth, low gain, limited power capacity and poor polarization polarity [7]-[9]. Among them narrow bandwidth and low gain are its main drawbacks. There are three types of losses which are responsible for the lower gain of MPA. These are conductor loss, dielectric loss, surface wave loss. By selecting better quality of conductor and dielectric substrate can reduce the conductor and dielectric losses which can improve the gain. The gain also can be enhanced by suppressing surface waves [12]. Many researcher have proposed and investigated many technique to overcome the problem of narrow bandwidth and low gain like using meta-material, multiple dielectric layer, partial substrate methods, using resonator etc. [10]-[16].

1.3 Objectives

Based on the above problem statement, the following objectives are determined for the study covered in this thesis:

1. To design, simulate and analyze Microstrip Patch Antenna.
2. To operate the microstrip patch antenna in between the frequency range of 8 GHz to 12 GHz for X band satellite applications.
3. To increase the gain of the proposed microstrip patch antenna.

1.4 Motivation

Wireless operation enable services, such as long-range communications, which are impractical or impossible to implement with the use of wires. The term is frequently used in the telecommunications industry to refer to telecommunications system (e.g. radio transmitters and receivers, remote controls etc.) which use some type of energy (e.g. radio waves, acoustic energy, etc.) to transmit information without the use of wires. Information is passed on in this manner over both short and long distances. In recent years, the need to miniaturize electronic circuitry has shown a sharp and rapid increase. To meet this goal, smaller microstrip antennas have become an unavoidable choice. Several miniaturization techniques have been developed to miniaturize antennas [17]. Although good size reduction rates have been achieved as in [18]-[20], this comes at the expense of the antenna gain.

1.5 Outlines of The Thesis

The thesis is composed of 6 chapters and organized as follows:

Chapter 1 Concentrates on the background of the microstrip patch antenna, major drawbacks of the microstrip patch antenna. The objectives are defined out for the thesis work carried out. Also motivation has been discussed briefly.

Chapter 2 Provides an insight about microstrip patch antenna related Literature review with significance of microstrip patch antenna in satellite communications, and also with review on high gain microstrip patch antenna design. Basic properties of the microstrip patch antenna discussed briefly. Advantages , Disadvantages and various applications of microstrip patch antenna is also discussed.

Chapter 3 Work flow of this study discussed with flow chart for better understanding. Provides an insight into microstrip patch antenna related methodology with models for analysis and different shapes of the patch and different feeding techniques of the microstrip patch antenna. Choosing of models for analysis and feeding techniques discussed with proper reason. Different gain enhancement techniques and selection of gain enhancement for this study discussed briefly.

Chapter 4 Complete design of microstrip patch antenna discussed and showed with figure briefly. For designing the antenna, design specifications, procedure and flowchart are discussed with parameters selections. Optimization of microstrip patch antenna and using multiple dielectric material used for improving the gain also discussed and showed with figure briefly. The Simulation of antennas are showed for justification. finally, the proposed microstrip patch antenna for X band satellite applications is presented.

Chapter 5 Results of microstrip patch antenna with multiple layer dielectric are discussed. Parametric study of different dielectric has been shown and discussed briefly. Finally, the results of proposed antenna are shown through different radiation pattern of E-field and H-field with co-polarization and cross-polarization, plots of return loss, gain etc.

Chapter 6 Concludes the work carried out in this thesis with future scope of works of the proposed microstrip patch antenna.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The concept of microstrip antenna was first proposed by Deschamps in 1953 [1]. A patent was issued in France in 1955 in the Names of Gutton and Baissionot [2]. After the 1970s research publications started to flow with the appearance of the first design equation. Since then different researchers started their investigation on microstrip patch antenna. In this chapter, we will clarify about microstrip patch antenna along with their properties. A short review about high gain microstrip patch antenna is also discussed. Finally, the advantages and disadvantages of microstrip patch antenna and their application is discussed briefly.

2.2 Antenna

An antenna is defined by Webster's Dictionary as "a usually metallic device (as a rod or wire) for radiating or receiving radio waves." The IEEE standard definitions of an antenna is "a means for radiating or receiving radio waves." In other words antenna is the transitional structure between a free space and a guiding device, which is shown in **Fig. 2.1**.

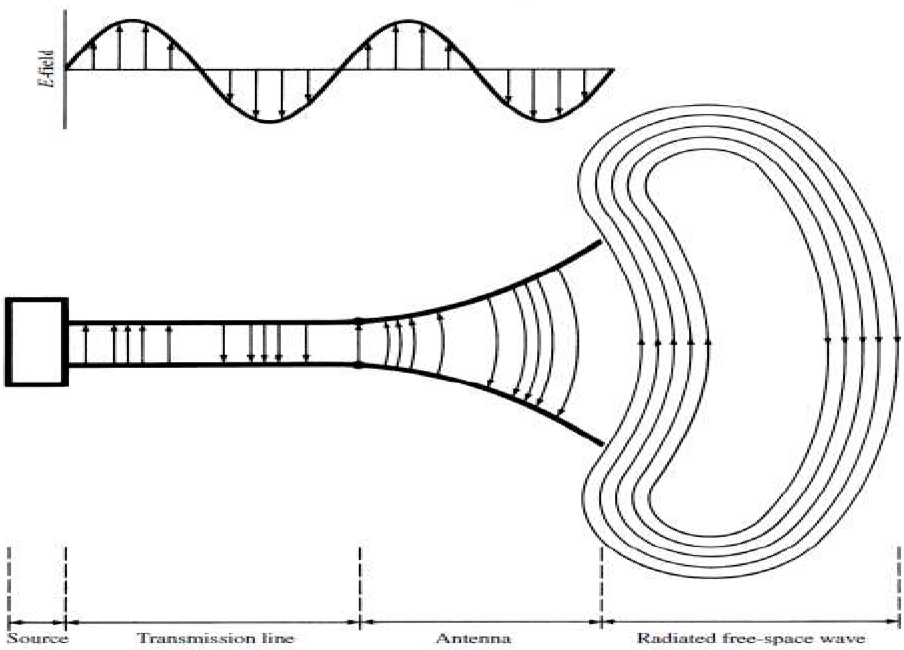


Fig. 2.1 Antenna as a transition device [6].

The guiding device or transmission line may take the form of a coaxial line or a hallow pipe (waveguide). Antenna is used to transport electromagnetic energy from the transmitting source to the antenna, or from the antenna to the receiver. Transmitter - Radiates electromagnetic energy into space and Receiver - Collects electromagnetic energy from space.

2.3 Significance of Microstrip Patch Antenna in Satellite Communications

Satellite communications has made remarkable progress since the world's first communication satellite was launched in 1960. Today the whole world is interconnected by satellite communication networks. A satellite is usually linked to an earth station by a microwave signal, which is transmitted through antennas. Microstrip patch antenna attracted much concentration than other antennas because of light weight, low profile, compatibility with integrated circuit technology, structural conformity etc. [4], [5]. The significance of microstrip patch antenna in satellite communication is immeasurable. Some reasons are given below:

- It occupies very little volume of the satellite on which it is mounted.
- Planar structure.
- Antenna can be integrated with active components and circuits into one module.
- Easy to realize circular polarization, dual frequency, and dual polarization operations.
- An array of patch element can be fabricated together by simple etching process which leads to cost reduction of fabrication.

2.4 Microstrip Patch Antenna

Among various types of antenna, microstrip patch antenna is one of them. A microstrip patch antenna basically consists of a radiating patch on the top of a dielectric substrate which has a ground plane under the dielectric substrate as shown in **Fig. 2.2**. The patch is generally made of conducting material such as copper or gold. The radiating patch and feed lines are usually photo etched on the dielectric substrate.

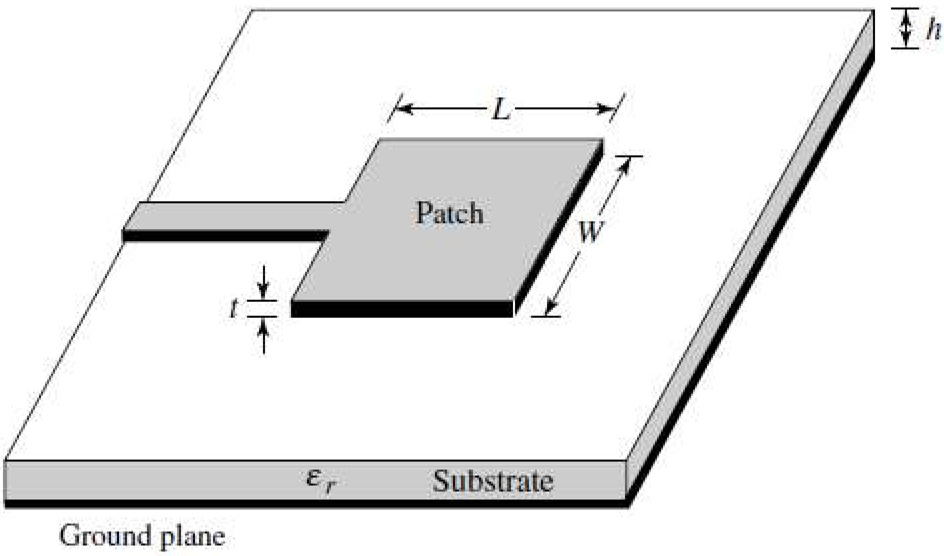


Fig. 2.2 Microstrip patch antenna [6].

The radiating patch shape may be square, rectangular, thin strip (dipole), circular, elliptical, triangular, or any other configuration [6]. However, square, rectangular, dipole (strip), and circular patches are most common because of easy analysis and fabrication. Microstrip antennas can be feed by different feeding techniques. These are microstrip line feed, coaxial probe feed, aperture coupling feed or proximity coupled feed [6].

2.5 Review on High Gain Microstrip Patch Antenna Design

The different techniques to increase the gain of microstrip patch antenna has been reviewed. Many researchers had performed different techniques to increase the bandwidth and gain of microstrip patch antenna. Layers of dielectric are stacked above the patch in resonance gain method [21]-[23]. For a three layer electromagnetically (EM) coupled structure, an air layer is always used in between of a substrate and an superstrate [24],[25]. The patch is mounted on top of the surface of a grounded substrate, and a coupled patch is on top [24] or bottom [25] surface of the superstrate. The gain of the patch antenna can be increased by tuning the thickness of the air layer [24],[25].

A W shaped MPA is designed with radiating patch dimensions of 5.55×3.5×1.5 mm^3 thickness without ground plane [26]. Although The bandwidth is high but the gain is low. Another W shaped [27] MPA is presented which dimension is 50×72×16 mm^3 thickness to achieve good result but the antenna size is so big that it is not suitable to incorporate it with satellite. A dual polarized MPA is designed with dimension of 15×15×1.57 mm^3 thickness [28]. Using two ports for dual polarization is not easy for fabrication. An X band antenna with dimension of 40×40×1.6 mm^3 using FR4 dielectric with microstrip feed line is presented [29]. Although the bandwidth is high but gain is low. A compact microstrip antennas loaded with multiple corrugated split ring resonators is presented [30]. The gain is high and fabrication procedure is not easy. Double E shaped slot antennas is presented with CPW and microstrip feed with a dimension of 80×80×1 mm^3 [31]. The problem is too large to incorporate with satellite communication.

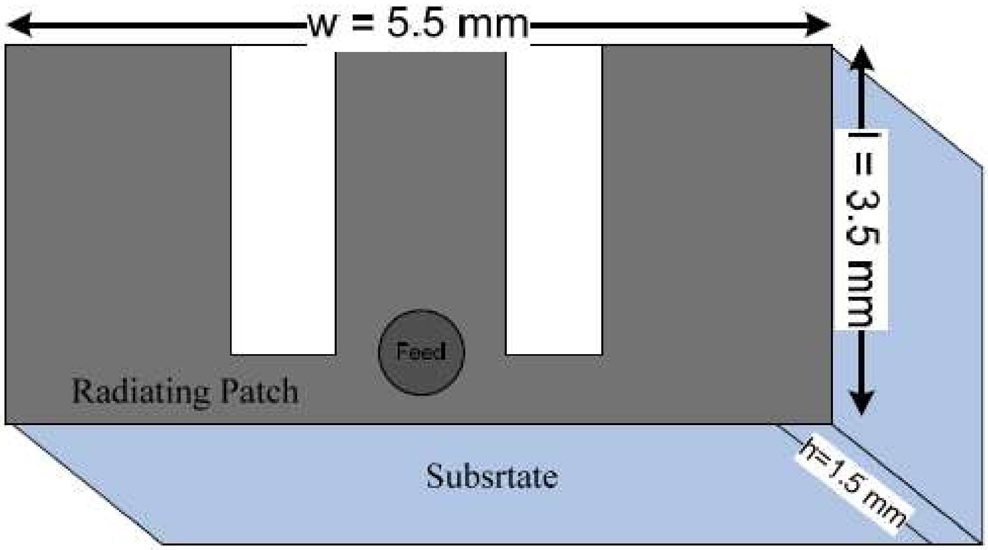


Fig. 2.3 3D view of W shaped antenna geometry [26].

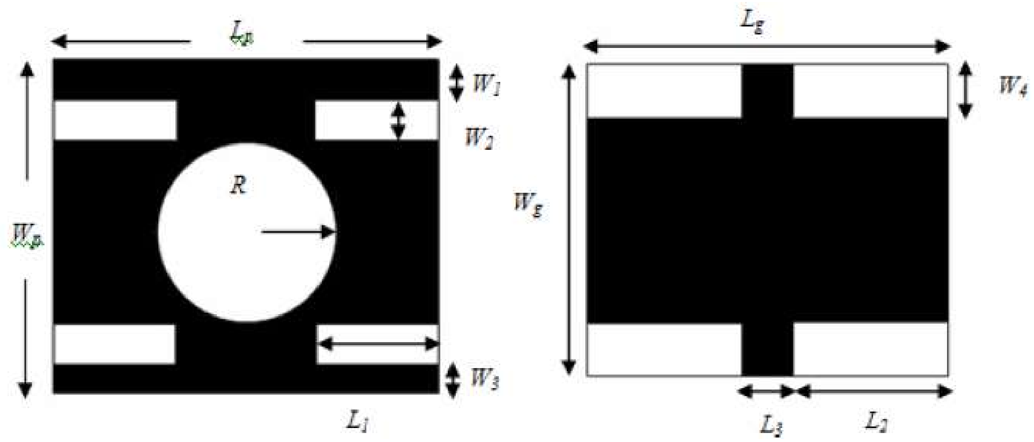


Fig. 2.4 Proposed antenna (a) Front view (b) Back view [29].

2.6 Properties of Microstrip Patch Antenna

To describe the performance of an antenna, definitions of various parameters are necessary. These parameters can be called as the properties of antenna. Some basic properties of microstrip patch antenna are discussed below:

2.6.1 Reflection Co-efficient

Reflection co-efficient describes the relationship between input and output ports of an electrical system. This is the parameter by which the quality regarding impedance match between the sending end(source) and the receiving end(measured load) is determined. When the impedance of transmitter and antenna do not match, some portion of the transmitted waves reflects back which leads to standing waves. This S1,1 has to be below -10 dB to obtain good mode of radiation. A simple reflection co-efficient curve is shown in **Fig. 2.5**.

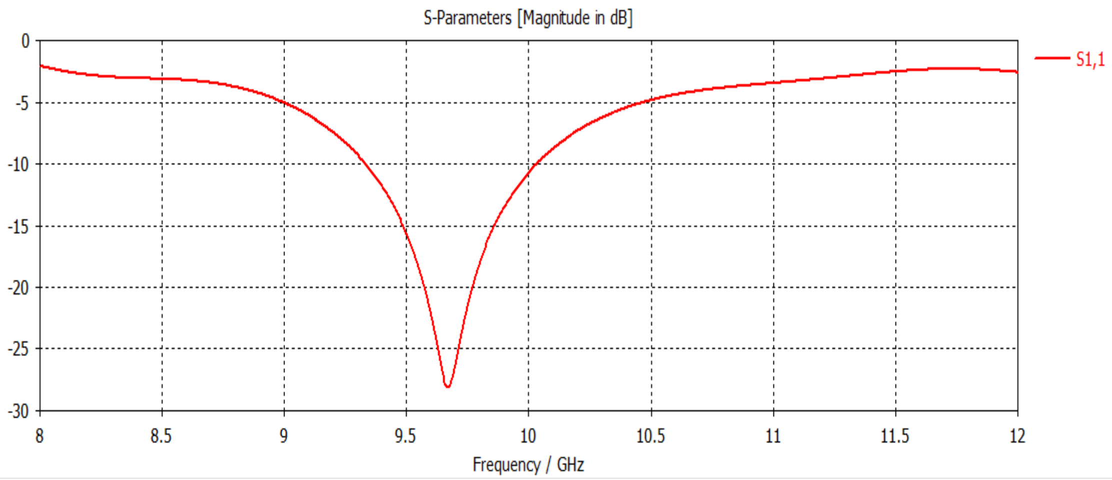


Fig. 2.5 Simple reflection co-efficient curve.

2.6.2 Radiation Pattern

An antenna radiation is defined as "a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates." Radiation pattern shows the antenna radiates more power in a certain direction than other direction. It is determined in the far-field region and is represented as a function of the directional co-ordinates. It graphically depicts the relative field strength of the transmitting or receiving antenna. A sample radiation pattern is shown in **Fig. 2.6**.

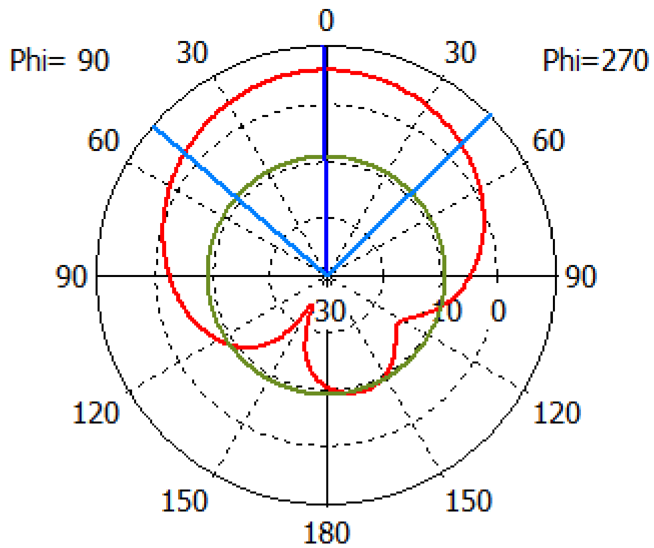


Fig. 2.6 Simple radiation pattern.

This pattern is taken at only one frequency, one polarization and plane cut.

2.6.3 Directivity

Directivity of an antenna is defined as "the ratio of radiation intensity of in a given direction from the antenna to the radiation intensity of that antenna averaged over all directions and it is dimensionless [6]. It can be represented mathematically as:

$$D = \frac{U}{U_0} = \frac{4\pi U}{P_{rad}}$$

where,

U = radiation intensity (Ω/unit solid angle)

U_0 = radiation intensity of isotropic source (Ω/unit solid angle)

P_{rad} = total radiated Power (W)

So far, the Directivity has been defined with respect to an isotropic source and hence has the unit dBi. An isotropic source radiates an equal amount of power in every directions. Quite often, the antenna directivity is specified with respect to the directivity of a dipole. The directivity of a dipole is 2.15 dBi with respect to an isotropic source. The directivity expressed with respect to the directivity of a dipole has dBd as its unit.

2.6.4 Gain

Gain of an antenna (in a given direction) is defined as "as the ratio of radiation intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically.." Since the radiation intensity from a isotropic antenna equals the power accepted(input) to the antenna divided by a solid angle of 4π radians, we can write the following equations:

$$\text{Gain} = 4\ \frac{radiation\ intensity}{total\ input(accepted)\ power}$$

$$\text{Gain} = 4\ \frac{U(\emptyset,\theta)}{P_{in}} \quad \text{(dimensionless)}$$

2.6.5 Polarization

The plane where the electric field varies is also known as the polarization plane. The basic patch covered until now is linearly polarize since the electric field only varies in one directions. The polarization can be either vertical or horizontal depending on the orientation of the patch. A transmit antenna needs a receiving antenna with the same polarization for optimum operation. The patch mentioned yields horizontal polarization, as shown. When the antenna is rotated 90^o, the current flows in the vertical plane and is then vertically polarized.

A large number of applications, have trouble with linear polarization because orientation of the antenna is variable or unknown. There is another kind polarization which is Circular polarization. In a circular polarized antenna, the electric field varies in two orthogonal planes (x and y direction) with the same magnitude and a 90^o phase difference. The result is the simultaneous excitation of two modes, i.e. the TM_{10} mode (mode in x direction) and the TM_{01} (mode in the y direction). One of the modes is excited with a 90^o phase delay with respect to the other mode. A circularly polarized antenna can either be Right hand Circular Polarized (RHCP) or Left Hand Circular Polarized.

2.6.6 Voltage Standing Wave Ratio (VSWR)

VSWR is the most important parameter considered during the installation and tuning of transmitting antennas. When an antenna connects the transmitter to the feed line, their impedance needs to be match exactly so that the maximum energy transfer takes place. When the impedances of antenna and feed line do not match, some portion of electrical is not transferred from feed line to the antenna. This portion of energy which is not transferred to antenna reflects back to the transmitter. These reflected waves interact with the forward waves and results into standing wave patterns. An impedance transformer is used to match the impedance of the feed line to that of the antenna. This impedance transformer can be installed in between the transmitter and feed line or between feed line and the antenna. In both the cases, the transmitter can operate at low VSWR. The value of VSWR must lie in range of 1-2.

2.6.8 Bandwidth

Another important parameter of any antenna is the bandwidth it covers. Only impedance bandwidth is specified most of the time. However, it is important to realize that several definitions of bandwidth exists as Impedance bandwidth, Directivity bandwidth, Polarization bandwidth, and Efficiency bandwidth. Directivity and Efficiency are often combined as Gain bandwidth.

2.6.8.1 Impedance Bandwidth

Impedance bandwidth is just an ordinary bandwidth of an antenna. normally this is defined as the range of frequencies over which the return loss(reflection co-efficient) is acceptable.

2.6.8.2 Directivity / Gain Bandwidth

This is the frequency range where the antenna meets a certain directivity / gain requirement (e.g., 1 dB gain flatness).

2.6.8.3 Efficiency Bandwidth

This is the frequency range where the antenna has reasonable (application dependent) radiation / total efficiency.

2.6.8.4 Polarization Bandwidth

This is the frequency range where the antenna maintains its polarization.

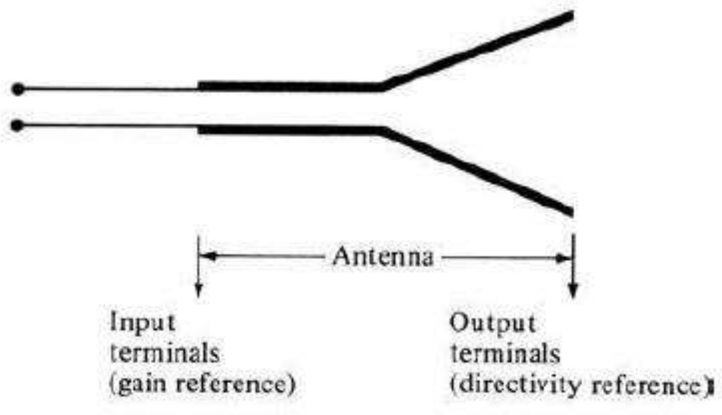
2.6.8.5 Axial Ratio Bandwidth

This bandwidth is related to the polarization bandwidth and this number expresses the quality of the circular polarization of an antenna.

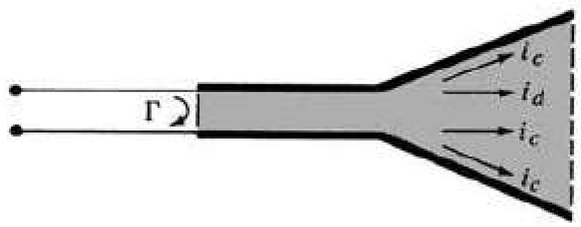
2.6.9 Efficiency

Associated with an antenna are a number of efficiencies and can be defined using **Fig. 2.7**. The total efficiency e_0 is used to take into account losses at the input terminals and within the structure of the antenna. Such losses may be due, referring to **Fig. 2.7(b)**, to

1. reflections because of the mismatch between the transmission line and the antenna
2. I^2R losses (conduction and dielectric)



(a) antenna reference terminals



(b) Reflection, conduction and dielectric losses

Fig. 2.7 Reference terminals and losses of an antenna [].

In general, the overall efficiency can be written as:

$$e_0 = e_r \, e_c \, e_d$$

where

e_0 = total efficiency (dimensionless)

e_r = reflection (mismatch) efficiency

e_c = conduction efficiency

e_d = dielectric efficiency

2.7 Advantages & Disadvantages

MPA are mostly used wireless and satellite applications due to their low profile structure. Therefore they are extremely compatible for embedded antennas in handled wireless devices such as cellular phones, pagers etc.

Some of the principal advantages are given below:

1. Light weight and less volume.
2. Low fabrication cost, therefore can be manufactured in large quantities.
3. Supports both, linear as well as circular polarization.
4. Low profile planar configurations which can be easily made conformal to host surface.
5. Can be easily integrated with microwave integrated circuits (MICs).
6. Capable of dual and triple frequency operations.
7. Mechanically robust when mounted on rough surface.
8. Feed lines and matching networks can be fabricated.

Microstrio patch antenna suffer from a number of disadvantages as as compared to conventional antennas. Some of their major disadvantages are given below:

1. Narrow bandwidth.
2. Low efficiency.
3. Low gain.
4. Low power handling capacity.
5. Excitation of surface waves.
6. Extraneous radiation from feeds and junctions.
7. Poor end fire radiator except tapered a slot antennas.
8. Complex feed structures require high performance arrays.
9. Large ohmic loss in the feed structure of arrays.
10. Polarization purity is difficult to achieve.

Microstrip patch antennas have a very high antenna quality factor (Q). It represents the losses associated with the antenna where a large Q leads to narrow bandwidth and low efficiency.

Q can be decreased by increasing the thickness of dielectric substrate. But as the thickness increases, an increasing fraction of total power delivered by the source goes into a surface wave. This surface wave contribution can be counted as an unwanted power loss since it is ultimately scattered at the dielectric bends and causes degradation of the antenna characteristics.

2.8 Applications

Microstrip patch antennas are well known for their performance and their robust design, fabrication and their extent usage [32]. Microstrip patch antenna has several applications. Some of these applications are discussed below:

Mobile and Satellite Communication application: Mobile communication requires small, low-cost, low profile antennas. Microstrip patch antenna meets all requirements and various types of microstrip antennas have been designed in mobile communication system. In case of satellite communication circularly polarized radiation patterns are required and can be realized using either square or circular patch with one or two feed points [33].

Global Positioning System (GPS) applications: Now a days microstrip patch antennas with substrate having high permittivity sintered material are used for global positioning system. These antennas are circularly polarized, very compact and quite expensive due to its positioning. It is expected that millions of GPS receiver will be used by the general population for land vehicles, aircraft and maritime vessels to find their position accurately.

Radio Frequency Identification (RFID) applications: RFID uses Microstrip antennas in different areas like mobile communication, logistics, manufacturing, transportation and health care. RFID system generally uses frequencies between 30Hz and 5.8 GHz depending on its application. Basically RFID system is a tag or transponder and a transceiver or reader.

Worldwide Interoperability for Microwave Access (WIMAX) applications: The IEEE 802.16 standard is known as WIMAX. It can reach up to 30 mile radius theoretically and data rate 70 Mbps. MPA generates three resonant modes at 2.7, 3.3 and 5.3 GHz and can, therefore be used in WIMAX compliant communication equipment.

Radar applications: Radar can be used for detecting moving targets such as people and vehicles. It demands a low profile, light weight antenna subsystem, the microstrip antennas are an ideal choice. The fabrication technology based on photolithography enables the bulk production of microstrip antenna with repeatable performance at a lower cost in a lesser time frame as compared to the conventional antennas [34].

Rectenna applications: Rectenna is a rectifying antenna, a special type of antenna that is used to directly convert microwave energy into DC power. Rectenna is a combination of four subsystems i.e. Antenna, Pre rectification filter, Rectifier, Post rectification filter. In Rectenna applications, it is necessary to design antennas with very high directive characteristics to meet the demands of long-distance links. Since the aim is to use the Rectenna to transfer DC power through wireless links for a long distance. This can be only accomplished by increasing electrical size of the antenna.

Telemedicine applications: In telemedicine applications, antenna is operating at 2.45 GHz. Wearable microstrip antenna is suitable for Wireless Body Area Network (WBAN). The proposed antenna achieved a higher gain and front to back ratio compared to the other antennas, in addition to the semi directional radiation pattern which is preferred over the omni-directional pattern to overcome unnecessary radiation to the user's body and satisfies the requirement for on-body and off-body applications. An antenna having gain of 6.7 dB and an F/B ratio of 11.7 dB and resonates at 2.45 GHz is suitable for telemedicine applications.

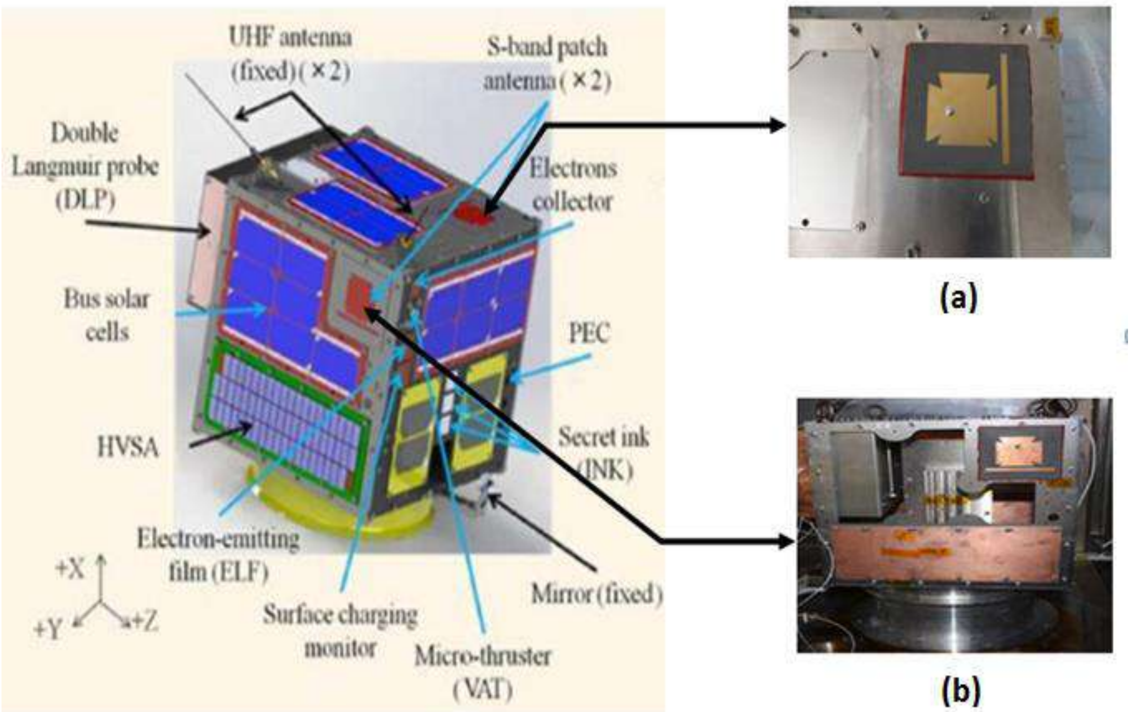


Fig. 2.8 Pictorial view of the HORYU-IV satellite (a) top view of MPA (b) Side view of MPA [54].

In the next Chapter 3, microstrip patch antenna related methodology discussed briefly with models of analysis, feeding techniques etc.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, a brief description of work flow of this study is discussed with flow chart in the section 3.2 . In section 3.3, discussion is included on shapes of the patch. Section 3.4 gives an insight of modeling techniques that are most popular to design the antenna. In section 3.5, different feeding techniques are discussed with proper figure for better understanding. In section 3.6, choosing of modeling techniques and feeding techniques for this work has discussed. Section 3.7 relates the simulation techniques that is used in this work. In section 3.8 and section 3.9, different gain enhancement techniques has discussed and selection of gain enhancement techniques for this thesis discussed briefly.

3.2 Work Flow of the Thesis

In this work, our aim is to design a microstrip patch antenna and then enhance the gain of designed microstrip patch antenna.

Table 3.1 Shape and desired gain of this thesis.

Shape	Frequency Band	Dielectric Layer	Desired Gain
Square	8 - 12 GHz	Single layer	5 - 6 dB
Square	8 - 12 GHz	Multiple Layer	8 - 9 dB

The full work flow of the thesis is shown by a flow chart in **Fig. 3.1**.

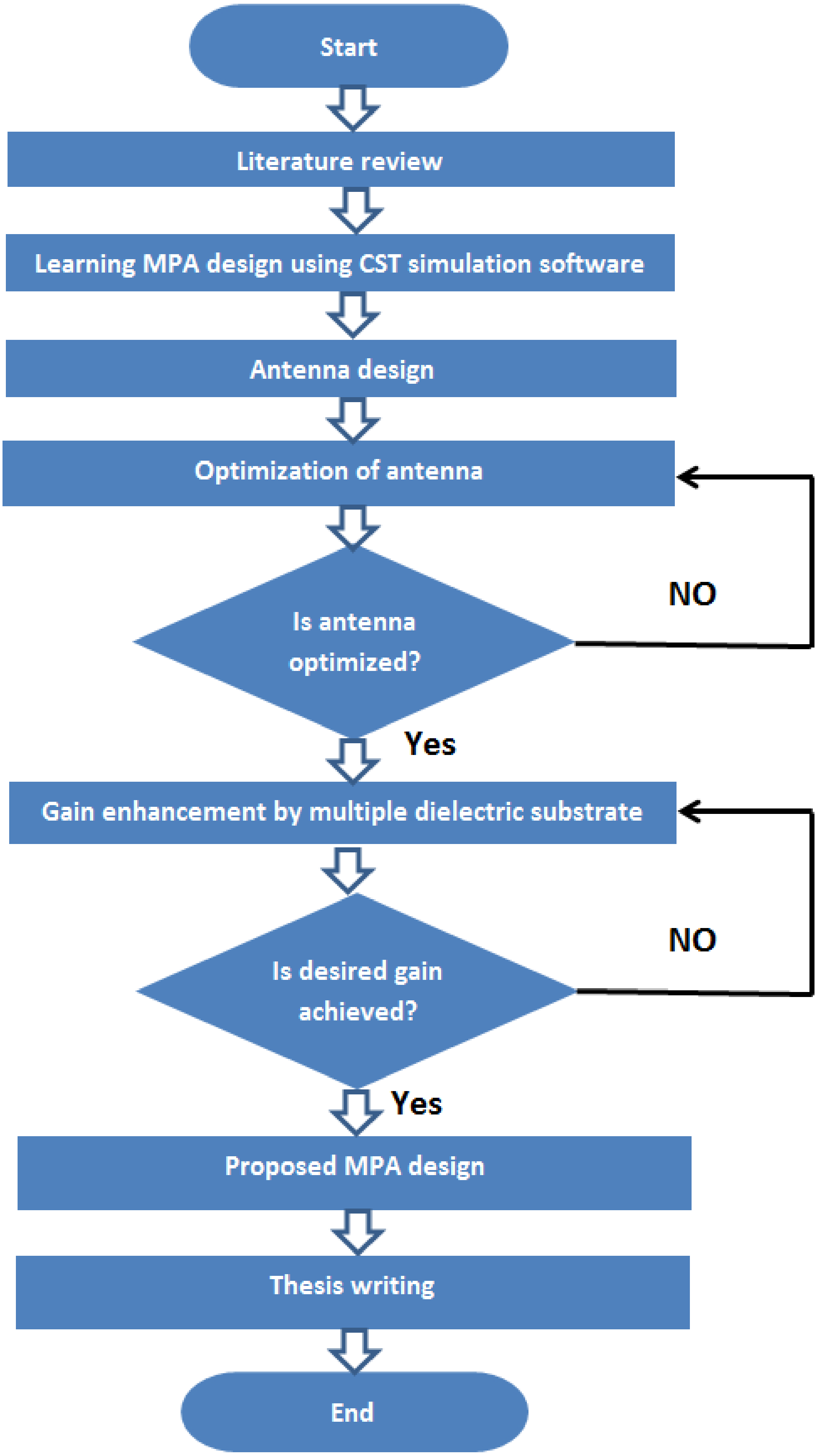


Fig. 3.1 Flow chart of the work flow of the thesis.

3.3 Shapes of Patch

Microstrip antennas are also referred to as Patch antennas. The radiating elements and the feed lines are usually photo etched on the dielectric substrate. The radiating patch may be square, rectangular, thin strip (dipole), circular, elliptical, tri-angular, or any other configuration [6]. These and others are shown in **Fig. 3.2**. Square, rectangular, dipole (strip), and circular are the most common because of ease of analysis and fabrication, and their attractive radiation characteristics, especially low cross-polarization radiation. Linear or circular polarizations can be achieved with either single elements or arrays of microstrip antennas. The patch is of length L, width W and sitting on the top of a substrate of thickness h with permittivity ϵ_r. Typically the height h is much smaller than the wavelength of operation, but not much smaller than 0.05 of a wavelength or the antenna efficiency will be degraded.

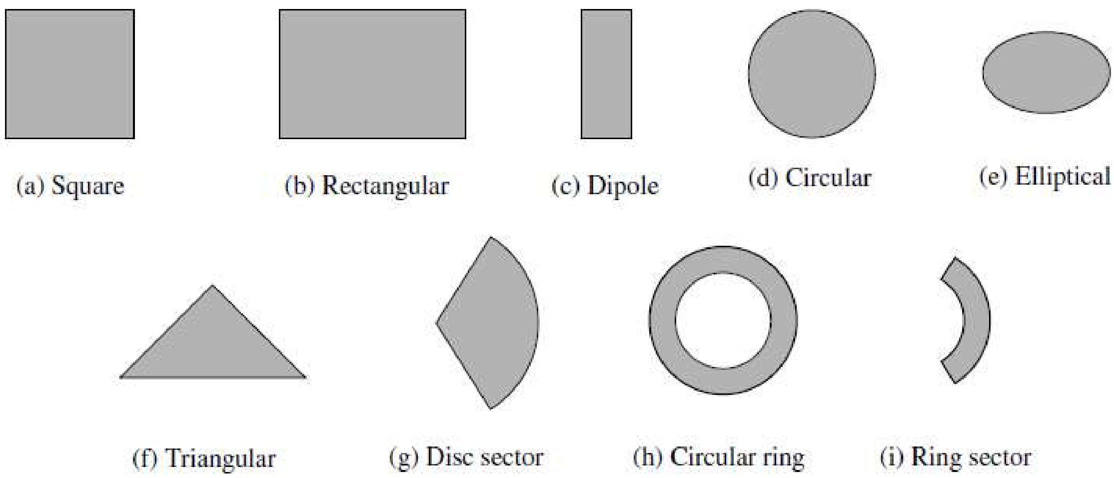


Fig. 3.2 Different shapes of microstrip patch elements [6].

3.4 Models for Analysis of Microstrip Patch Antenna

The most popular methods that can be used to model and analyze the microstrip patch antennas fall into one of two broad categories:

1. Approximate methods
2. Full wave methods

The approximate methods include the transmission line method [6], [35], [36], Cavity method [6], [37], [38]. The approximate methods are easy to implement for single element antenna, which gives good physical insight with very small simulation time, but has the limitation of less accurate. It becomes more complex for modeling coupling between elements, with these methods. The most popular full wave methods that can be used to model the microstrip patch antenna are the Method of Moment (MoM), the Finite Element Method (FEM), and the Finite Difference Time Domain (FDTD) method.

There is an abundant literature on the theoretical analysis of microstrip patch antennas. Hence, only brief reviews of the most popular methods which are used in the present study i.e. the transmission line method, the cavity method and the method of moments are included in this section.

3.4.1 Transmission Line Model:

The transmission line model is the easiest of all but it yields the less accurate results and it lacks the versatility. This model represents the microstrip antenna by two slots with width W and height h, separated by a low impedance transmission line of Length L. The microstrip is a non-homogenous line of two dielectrics, typically the substrate and the air. Due to the finite length and width of the microstrip patch antenna, the fields along the edge of the patch under goes fringing as shown in **Fig. 3.3**. The amount of fringing is a function of the dimensions of the patch and the height of the substrate. The fringing influences the resonant frequency of the microstrip patch antenna, so it must be taken into account into the microstrip patch antennas calculation.

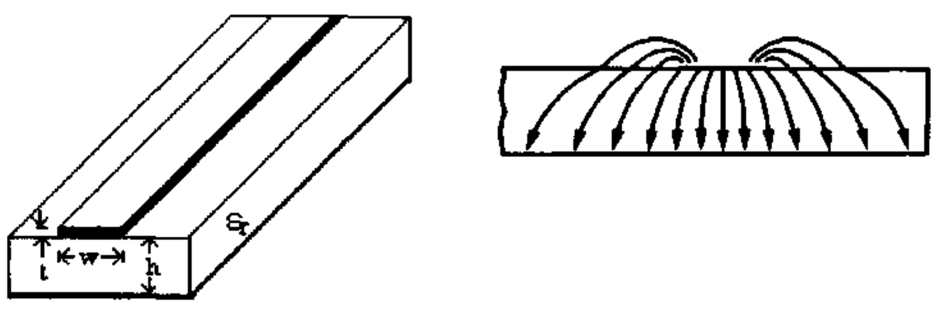


Fig. 3.3 Microstrip line and its electric field lines [6].

As seen from **Fig. 3.3**, most of the electric field lines reside in the substrate and parts of some lines exist in air. Hence the fringing makes the microstrip line looks wider electrically compared to its physical dimensions. As a result, this transmission line cannot support pure Transverse Electric-Magnetic (TEM) mode of transmission, Since the phase velocities would be different in the air and the substrate. Instead, the dominant mode of propagation would be the quasi-TEM mode. Hence, an effective dielectric constant ϵ_{reff} must be obtained in order to account for the fringing effect and the wave propagation in the line. For air dielectric substrate, the effective dielectric constant ϵ_{reff} has the range of $1 << \epsilon_{reff} << \epsilon_r$ and the value of the actual dielectric constant ϵ_r of the substrate. The effective dielectric constant ϵ_{reff} is a function of frequency. At high frequency of operation, most of the electric field lines concentrate in the substrate, hence the effective dielectric constant approaches the value of the dielectric constant of the substrate. The expression for ϵ_{reff} is giben by [6]:

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \quad (3.1)$$

where,

ϵ_{reff} = effective dielectric constant

ϵ_r = dielctric constant of the substrate

h = height of the dielectric substrate

W = width of the patch

Fig. 3.4 shows a rectangular microstrip patch antenna of length L, width W, resting on a substrate of height h considering that the length is along the X direction, width is along Y direction and the height is along Z direction.

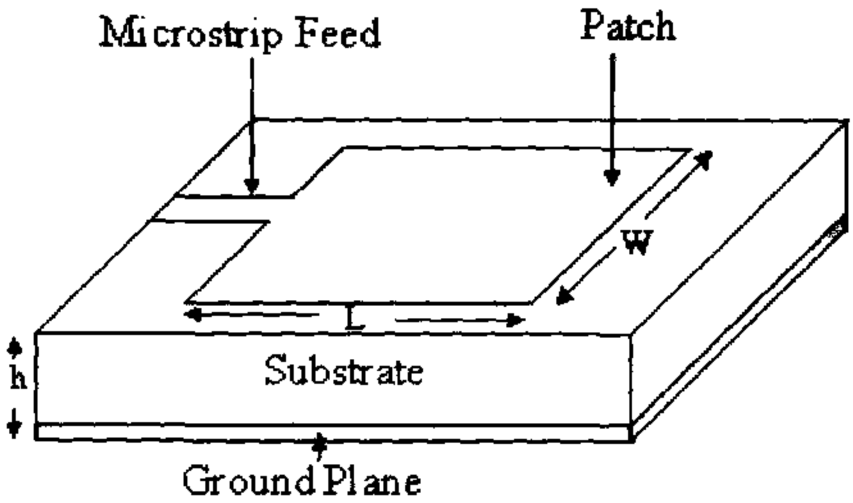


Fig. 3.4 Rectangular microstrip patch antenna [6].

For a microstrip patch antenna to be operated in fundamental TM_{10} mode, the length of the patch must be slightly less than λ/2 where λ is the wavelength in the dielectric medium and is equal to $\lambda_0/\sqrt{\epsilon_{reff}}$ where, λ_0 is the free space wavelength. The TM_{10} mode implies that the field varies one λ/2 cycle along the length, and there is no variation along the width of the patch.

In the **Fig. 3.5**, which is shown below, the microstrip patch antenna is represented by the two slots, separated by a transmission line of length L and open circuited at both the ends. Along the width of the patch, the voltage is maximum and current is minimum due to open ends. The fields at the edge can be resolved into normal and tangential components with respect to the ground plane.

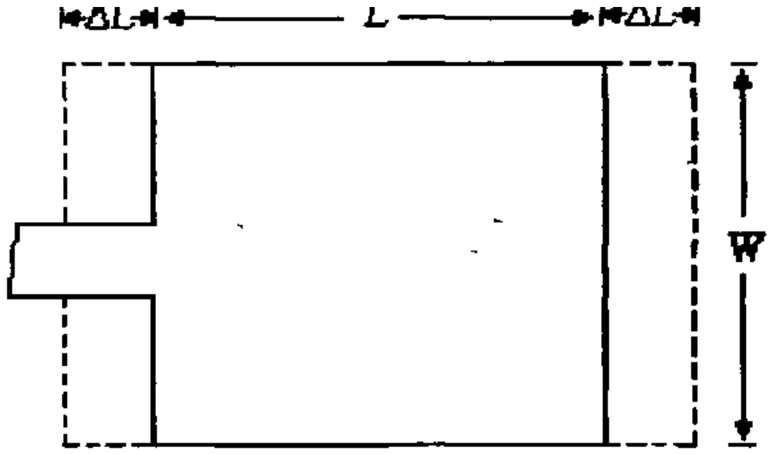


Fig. 3.5 Physical and effective length of rectangular microstrip antenna [6].

From **Fig. 3.6**, which is shown below, it is seen that the normal component of the electric field at the two edge along the width are in opposite directions and thus, out of phase, since the path is λ/2 and hence, they cancel each other in the broadside directions.

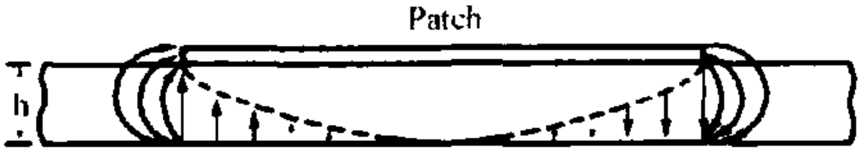


Fig. 3.6 Side view of microstrip patch with electric field component [6].

The tangential components in phase are means that the resulting field combine to give maximum radiated field normal to the surface of the structure. Hence, the edge along the width can be represented as two radiating slots, which are λ/2 apart and excited in phase and radiating in the half space above the ground plane. The fringing fields along the width can be modeled as radiating slots and electrically patch of the microstrip antenna looks greater than its physical dimension. The dimension of the patch along its length have now been extended on each end by a distance ΔL, which is a function of the effective dielectric constant ϵ_{reff} and the width to height ratio (W/h).

To calculate the normalized extension of the length , the equation is given by [6] as:

$$\Delta L = 0.412h \frac{(\epsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\epsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)} \tag{3.2}$$

For a given resonance frequency f_r, the actual length of the patch is given by [6] as:

$$L = L_{eff} - 2\Delta L \tag{3.3}$$

hence,

$$L_{eff} = \frac{c}{2f_r\sqrt{\epsilon_{reff}}} \tag{3.4}$$

For an efficient radiator, the practical width W is given by [6] as:

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\epsilon_r + 1}} \tag{3.5}$$

The step by step procedure is given:

Step 1: Calculation of Width (W):

The width of the patch is calculated by:

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

Step 2: Calculation of Effective Dielectric Coefficient (ϵ_r):

The effective dielectric constant is given by:

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}}$$

Step 3: Calculation of Effective Length (L_{eff}):

The effective length is given by:

$$L_{eff} = \frac{c}{2f_r\sqrt{\epsilon_{reff}}}$$

Step 4: Calculation of Length Extension (ΔL):

Before calculation of "L", ΔL will be calculated by**,**

$$\Delta L = 0.412h \frac{(\epsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\epsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)}$$

Step 5: Calculation of Actual Length Patch (L):

Thus, the actual length of radiating patch is obtained by**,**

$$L = L_{eff} - 2\Delta L$$

Step 6: Calculation of Ground Dimensions (Wg, Lg):

The transmission line model is applicable to infinite ground planes only. However, for practical considerations, it is essential to have a finite ground plane. It has been shown by that similar results for finite and infinite ground plane can be obtained if the size of the ground plane is greater than the patch dimensions by approximately six times the substrate thickness all around the periphery [39], [40]. Hence, for this design, the ground plane dimensions given as

$$W_g = 6h + W; \; L_g = 6h + L \tag{3.6}$$

3.4.2 Cavity Model

The simplest Analytical method to use in microstrip patch antenna is transmission line model. But transmission line model have numerous disadvantages like, it is useful only for patch antenna of rectangular shape, it ignores field variations along the radiating edge and is not adaptable to inclusion of the field. The cavity model for microstrip patch antenna [6], [37], [38] offers considerable improvement over the transmission line model.

The cavity model for the microstrip antennas is based on the following observations for thin substrates ($h \ll \lambda$).

1. The closed proximity between the microstrip antenna and the ground plane suggest that E has only the Z-component and H has only the xy-components in the region bound by the microstrip and the ground plane.
2. The field in the aforementioned region is independent of the z-coordinate for all frequencies of interest.
3. The electric current in the microstrip must have no component normal to the edge at any point on the edge, implying a negligible tangential component of H along the edge.

With this, in the cavity model, the interior region of the dielectric substrate is modeled as a cavity bounded by a magnetic wall along the edge and by electric walls on the top and bottom.

As the microstrip patch is energized, a charge distribution is seen on the upper and lower surfaces of the patch and at the bottom of the ground plane as shown in the **Fig. 3.7**.

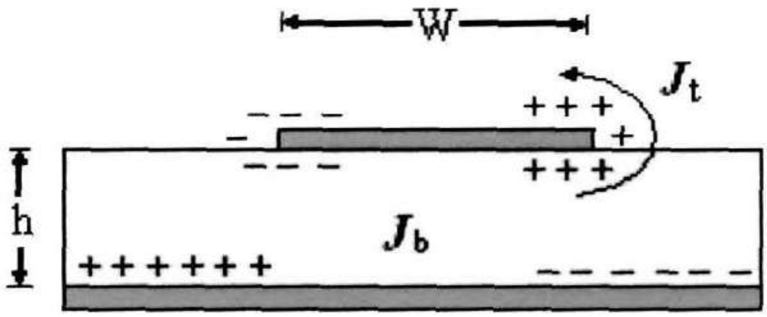


Fig. 3.7 Charge distribution and current density creation on the microstrip patch [6].

This charge distribution is controlled by two mechanism: an attractive mechanism and a repulsive mechanism. The attractive mechanism is between the opposite charge on the bottom side of the patch, and the ground plane. This attraction tends to keep the patch charge concentration intact at the bottom of the patch. The repulsive mechanism is between the like charges on the bottom surface of the patch. This tends to push some of the charge around the edge of the patch on to its top surface. As a result of this charge movement, current flows at the top and the bottom surface of the patch. The cavity model assumes that the height to width ratio i.e. height of the substrate and the width of the patch) is very small and as a result of this attractive mechanism dominates and causes most of the charge concentration and the current to be below the patch surface. Much less current would flow on the top surface of the patch would be almost equal to zero, which would not allow the creation of any tangential magnetic field component to the patch edge. Hence, the four sidewalls could be modeled as perfectly magnetic conducting surfaces. This implies that the magnetic fields and the dielectric field distribution beneath the patch would not be disturbed. However, in practice, a finite width to height ratio would be there and this would not make the tangential magnetic fields to be completely zero, they being very small, the sidewalls could be approximated to the perfectly magnetic conducting.

The impedance function for the microstrip antenna has complex poles. The imaginary parts of these poles account for the power lost by radiation and by dielectric and conduction losses. The microstrip antenna is model to make it more resemble with cavity by addition of loss to the cavity dielectric by appropriately adjusting the loss tangent to the cavity dielectric. Though the impedance function for the ideal cavity has only real poles, now in microstrip antenna modeling the imaginary parts of the poles of the cavity filled with the lossy dielectric will no longer be zero. A lossy cavity would now present in antenna and for the cavity with perfectly conducting electric and magnetic walls, the loss is taken into account by the effective loss tangent (). At any frequency f near a resonance, the quality factor is given by[6],

$$Q = \frac{2\pi f\ (average\ total\ stored\ energy)}{(average\ power\ dissipated)} = \frac{1}{\delta_{eff}} \tag{3.7}$$

hence,

$$\delta_{eff} = \frac{1}{Q_T}$$

where, Q_T is the total antenna quality factor and has been expressed by [],

$$\frac{1}{Q_T} = \frac{1}{Q_d} + \frac{1}{Q_c} + \frac{1}{Q_r} \tag{3.8}$$

Here,

Q_d represents quality factor of the dielectric and is given as:

$$Q_d = \frac{\omega_r W_T}{P_d} = \frac{1}{tan\,\delta}$$

where,

Ɠ$_r$ is te angular resonant frequency

W_T is the total energy stored in the patch at resonance

P_d is the dielectric loss

tan δ is the loss tangent of the dielectric

And, Q_c represents the quality factor of the conductor and is given as:

$$Q_c = \frac{\omega_r W_T}{P_c} = \frac{h}{\Delta}$$

where,

P_c is the conductor loss

Δ is the skin depth of the conductor

h is the height of the substrate

And, Q_r represents the quality factor for radiation and is given as:

$$Q_r = \frac{\omega_r W_T}{P_r}$$

where,

P_r is the power radiated from the patch.

Substituting equations .. , .. and .. in equation .. , we get

$$\delta_{eff} = \tan\delta + \frac{h}{\Delta} + \frac{P_r}{\omega_r W_T}$$

Thus, equation .. describes the total effective loss tangent for the microstrip patch antenna.

Once " Q " is known, the antenna can be analyzed as if it is a lossy cavity. This is significant since the most commonly used patch antenna shapes corresponds to cavities having a separable geometry amenable to simple analytical treatment. This is the basic idea used in the cavity model approximation.

3.4.3 Full Wave Method - Moment Method

The most popular method, that provides the full wave analysis for the microstrip patch antenna, is the moment method. In mathematical literature, Moment method is known as Weighted residuals and can be applied to the solution of both differential and integral equations. The method owes its name to the process of taking moments by multiplying the function with an appropriate weighting function on integrating. On microstrip antenna analysis with this method, the surface currents are used to model the microstrip patch and the volume polarization currents are used to model the fields in the dielectric slab. It has been shown by Newman and Tulyathan [41] how an integral equation is obtained for these unknown currents and using the method of moments , these electric field integral equations are converted into matrix equations which can be solved by various techniques of algebra to provide the result. In, electromagnetic theory, the method become popular after the pioneering work done by R.F.Harrington in 1967. Since then, it has been one of the most popular methods for solving the electromagnetic boundary value problems. A brief overview of the moment method is given below [42]:

The basic from of the equation to be solved by the method of moment is:

$$F(g) = h \tag{3.9}$$

where, F is a known linear operator, g is an unknown function, and h is the source or excitation function. The aim here is to find g, when F and ha are known. The unknown function g can be expanded as a liner combination of N terms to give:

$$g = \sum_{n=1}^{N} \alpha_n g_n = \alpha_1 g_1 + \alpha_2 g_2 + \dots\dots + \alpha_n g_n \tag{3.10}$$

where, α_n are unknown constants and g_n are known functions usually called a basis functions or expansion functions.

If the number of turns in equation 3.10 is infinite, we shall obtain an exact solution. But for computational purposes, the number of terms are finite and we obtain approximate solution.

Substituting equation 3.10 in 3.9 and using the linear property of operator F, we can rewrite equation 3.7 as:

$$\sum_{n=1}^{N} \alpha_n F(g_n) = h \tag{3.11}$$

The basis function g_n must be selected in such a way that each $F(g_n)$ in the above equation can be calculated. the unknown constant α_n cannot be determined directly because there are N unknowns, but only one equation. One method of finding these constant is the method of Weighted residuals. In this method, a set of trial solution is established with one or more variable parameters. the residuals are a measure of the difference between the trial solution and the true solution. The variable parameters are selected in a way which guarantees a best fit of the trial functions based on the minimization of the residuals. This is done by defining a set of weighting (or testing) functions $\{W_m\} = W_1, W_2, ... W_N$ in the domain of the operator F. Taking the inner product of equation 3.11 with each weighting functions W_m, m = 1, 2, 3 ...... N, this lead to:

$$\sum_{n=1}^{N} \alpha_n \{w_m F(g_n)\} = \{w_m, h\} \tag{3.12}$$

where, m = 1, 2, 3 ...... N

Writing in matrix form, the set of equation 3.12 may be written as:

$$[F_{mn}][\alpha_n] = [h_n] \tag{3.13}$$

where,

$$[F_{mn}] = \begin{pmatrix} \{w_1F(g_1)\} & \{w_1F(g_2)\} \ldots\ldots\ldots\ldots & \{w_1F(g_N)\} \\ \{w_2F(g_1)\} & \{w_2F(g_2)\} \ldots\ldots\ldots\ldots & \{w_2F(g_N)\} \\ \vdots & & \\ \{w_NF(g_1)\} & \{w_NF(g_1)\} \ldots\ldots\ldots\ldots & \{w_NF(g_N)\} \end{pmatrix} \tag{3.14}$$

$$[\alpha_n] = \begin{pmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \vdots \\ \alpha_N \end{pmatrix} \tag{3.15}$$

$$[h_n] = \begin{pmatrix} (w_1, h) \\ (w_2, h) \\ (w_3, h) \\ \vdots \\ (w_N, h) \end{pmatrix} \tag{3.16}$$

The unknown constants can now be found using algebric techniques as LU decomposition or Gaussian elimination. ait must be remembered that the weighting functions must be selected appropiately, so that elements of $\{W_n\}$ are not only linearly independent but they also minimize the computations required to evaluate the inner product. One such choice of the weighting functions may be to let the weighting and the basic function be the same, that is, $W_n = g_n$. This is called as the Galerkin's metods as described [43].

From the antenna theory point of view, we can write the electric field integral equation as:

$$E = f_e(J)$$

where,

E is the known incident electric field

J is the unknown induced current

f_e is the linear operator

The first step in the moment method solution process would be to expand J as a finite sum of basis function given as:

$$J = \sum_{n=1}^{M} J_i b_i \qquad (3.17)$$

where, b_i is the i^{th} basic function and J_i is an unknown coefficient.

The second steps involves the defining of a set of M linearly independent weighting Functions, W_j . Taking the inner product on both sides and substituting equation 3.17 in equation 3.16, we get:

$$(w_j, h) = \sum_{n=1}^{N} \{w_j, f_e(J_i, b_i\} \qquad (3.18)$$

where, j = 1, 2, 3 ..... M

Writing in matrix form as:

$$[Z_{ij}][J] = [E_j] \qquad (3.19)$$

where,

$Z_{ij} = (w_j , f_e(b_i))$

$E_J = (w_j , H)$

J is the current vector containing the unknown quantities.

The vector E contains the known incident field quantities and the terms of the Z matrix are functions of geometry. The unknown coefficients of the induced currents are the terms of the Z vector. Using any of the algebric schemes mentioned earlier, these equations can be solved to give the current and then the other parameters such as the scatteres electric and magnetic fields can be calculated directly from the induced currents. Thus, the moment method has been briefly explained for use in antenna problems.

3.5 Techniques of Feeding

The excitation of radiating element is an essential and important factor, which requires careful consideration in designing a most appropriate antenna for a particular application. A wide variety of feed methods are available, not just for coupling energy to individual elements, but also for the controlled distribution of energy to linear or planner array elements. These methods can be classified into two categories: contacting feed and non-contacting feed methods. In the contacting feed method, the radiating patch is directly fed with RF power. The popularly used contacting feed methods are microstrip line feed and co-axial feed. On the other hand, in the non-contacting method, the radiating patch of the antenna is indirectly fed with RF power and the RF power is transported to the patch through electromagnetic coupling. The most commonly used non-contacting feeding methods are aperture coupled feed and proximity coupled feed. Now a days, there are available ample literature on the feeding technique [6], [44]. Therefore, a brief overview is given only on these four most popular feed techniques. These are:

3.5.1 Microstrip Line Feed

In this technique, a conducting strip is linked directly to the boundary of the microstrip patch. The conducting strip is having smaller width as compared to the patch.

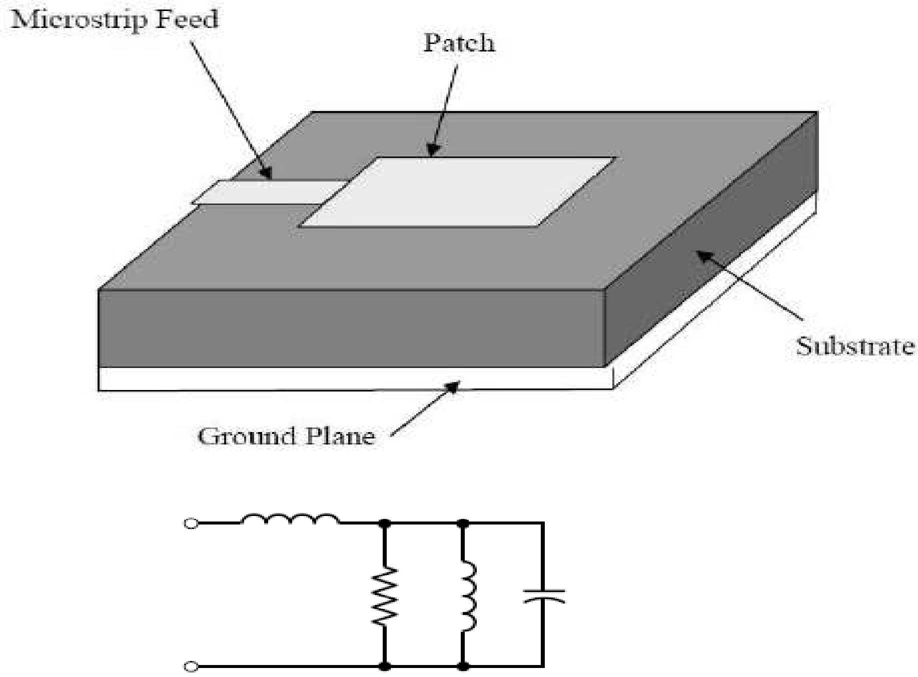


Fig. 3.8 Microstrip line feed patch antenna and its equivalent circuit [44], [6].

The key advantage of this technique is that the feed line and the patch can be etched on same substrate which makes it a planar structure. Although it can be transformed into inset cut patch. The purpose of the inset cut in the patch is to match the impedance of both the feed line and the patch. It doesn't require any supplementary matching element. Inset cut position and dimensions should be adjusted properly to achieve perfect impedance matching [45]. Since it is an easy feeding scheme, it also give an ease of fabrication and simplicity in modeling. The major hindrance in this feeding technique is, if the thickness of the substrate is increased then surface waves and spurious feed radiation also increases, which directly hampers the bandwidth of the antenna [46].

3.5.2 Co-axial Line Feed

The co-axial line feed also called probe feed is one of the broadly used technique for feeding microstrip patch antenna for various application. In this technique, the internal conductor of the co-axial connector is pulled out through the dielectric and soldered on the radiating patch, whereas the external conductor is attached to ground plane.

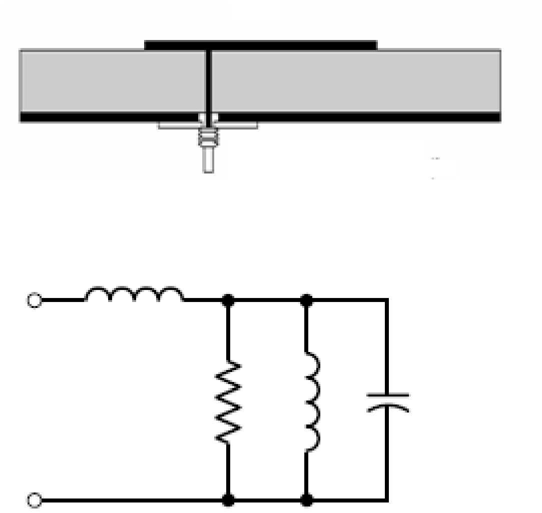


Fig. 3.9 Co-axial feed patch antenna and its equivalent circuit [44], [6].

The main advantage of this co-axial feeding is that it can be placed at any desired positiin inside the patch to faciliate its match with input impedance. However, main hindrance to this feeding technique is that it is complicated to model. since a hole has to be drilled in the substrate and the connector stick outside the ground plane, which is not making it a complete planar structure for thick substrates. Also for thicker substrates, the augmented prove length makes the input imepedance more inductive that leads to impedance matching problems [47].

3.5.3 Aperture Coupled Feed

In aperture coupling, feed and ground plane with aperture is sandwiched between two different substrates, to provide electromagnetic coupling from feed to the radiating patch structure. The radiating patch element is etched on the top of the antenna substrate and the microstrip feed line is etched on the bottom of the feed substrate in order to obtain aperture coupling. The thickness and dielectric constants of these two substrates would be chosen separately to optimize the different electrical functions of radiation and circuitry. The coupling aperture is placed preferably at the centre location under the patch that leads to lesser cross-polarization due to symmetric in configuration.

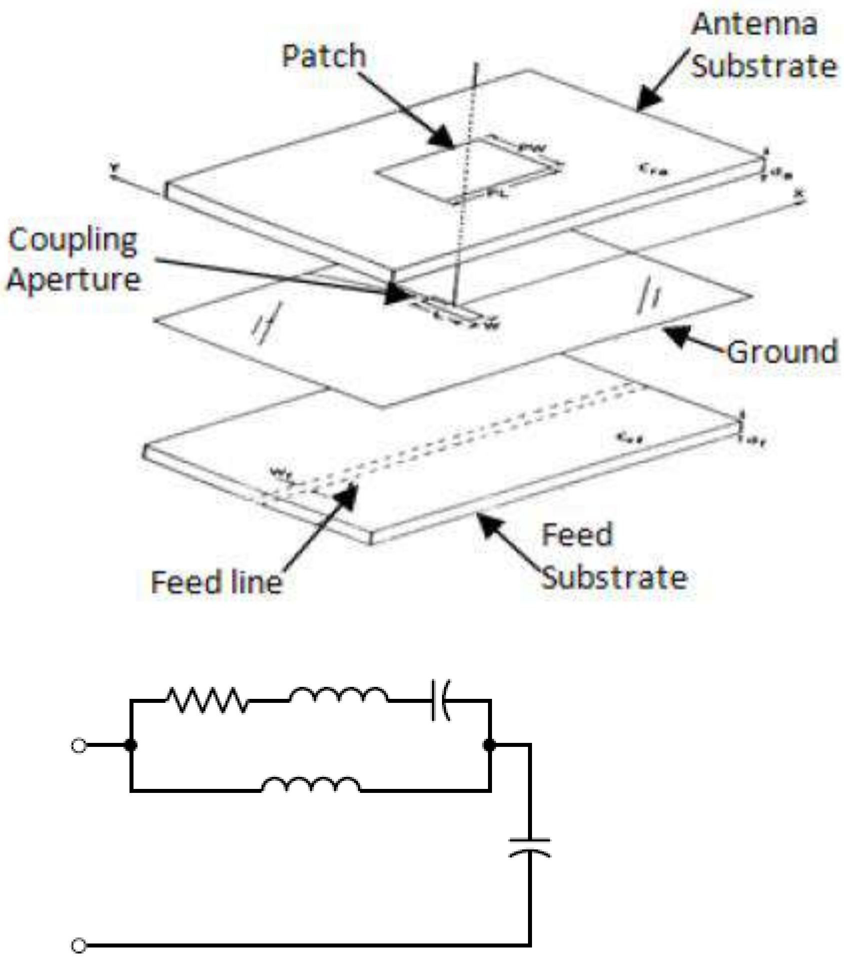


Fig. 3.10 Aperture coupled feed patch antenna and its equivalent circuit [44], [6].

The percentage of coupling from the feed line to the patch is determined by the shape, size and position of the aperture. Since the ground plane isolates the patch and the feed line, it leads to minimization of the spurious radiation. Generally, a high dielectric material is utilized for bottom substrate and a thick low dielectric constant material is employed for the top substrate to optimize the radiation of the patch [48].The major disadvantage of this technique is complication in fabrication of the design due to its alignment problem in multiple layers.

3.5.4 Proximity Coupled Feed

Proximity couples feed is also known as the electromagnetic coupling scheme. In this technique, two dielectric substrates are used such that the feed line is placed between the two substrates and the radiating patch is located on top of the upper substrate. The special feature is that the feed line is no longer located to an open surface and there is no need to solder different conductors, unlike co-axial feed.

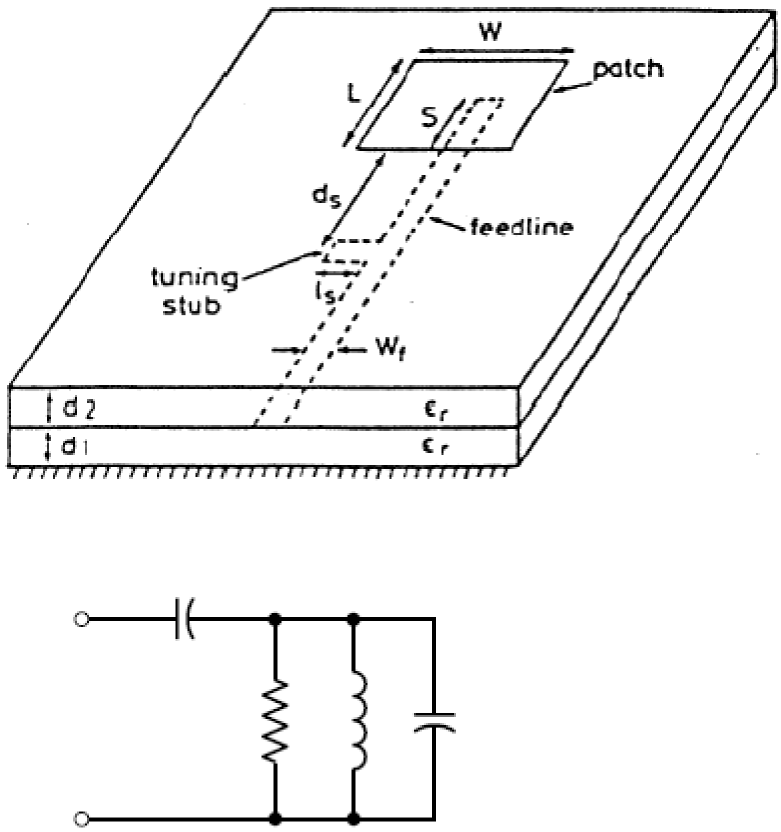


Fig. 3.11 Proximity coupled feed patch antenna and its equivalent circuit [44],[6].

The major advantage of this feeding technique is that it eliminates spurious feed radiation and provides very high bandwidth. This scheme also provides alternative between two different dielectric media, one for the patch and another one for the feed line to optimize the individual performances. The major hindrance of this feeding technique is that it is complex to fabricate because both the dielectric layers need proper alignment [49].

3.6 Choosing of Model of Analysis & Feeding Technique

To design microstrip patch antenna, we have chosen transmission line model (TEM). The initial geometry of the proposed antenna is designed by implementing the equation from transmission line model (TEM) in which patch radiating element is viewed on a transmission line resonator with no transverse field variations. Transmission line model is easy to understand and it is the easiest technique for designing a microstrip patch antenna.

From various feeding techniques which are discussed in Section 3.6, we uses microstrip line feed to fed power to the microstrip patch antenna. The key advantage of this technique is that the feed line and the patch can be etched on same substrate which makes it a planar structure. A co-axial connector is used at the end of the feed line for feeding power. Impedance transformer can be used to match the 50Ω impedance of co-axial connector and feed line.

3.7 Different Gain Enhancement Techniques

Many researchers had performed different techniques to increase the gain of microstrip patch antenna. Some of these techniques are listed below:

1. Gain enhancement by using Meta-material [10].
2. Gain enhancement by using Partial Substrate method [12].
3. Gain enhancement by using Multiple Dielectric substrate [15].
4. Gain enhancement by using Parasitic Radiator [11].
5. Gain enhancement by using Modified Ground planes [13].
6. Gain enhancement by using Hybrid Substrates [14].
7. Gain enhancement by using Reflecting Layer [16].

3.8 Selection of Gain Enhancement Technique

From various techniques of gain enhancement, we choose multiple dielectric substrate method. We also analyze partial substrate method and modified ground plane method for our designed antenna, but the results was not good enough. For a particular resonant frequency, the bandwidth increases with the increase of size of microstrip patch antenna for a high dielectric [50]. Microstrip patch antenna having low dielectric has moderate bandwidth but large size [51]. Bandwidth decreases with the increase of dielectric substrate. Therefore, multiple substrates are used to maintain the standard dielectric to maintain a good bandwidth [52]. Thus we adapted multiple dielectric substrate technique to increase the gain of the microstrip patch antenna.

3.9 Simulation Tool

In this work, CST Studio Suite 2015 software is used for the design and simulation of the microstrip patch antenna. CST Studio Suite is a package of tools for designing, simulating and optimizing electro-magnetic systems, and is used in leading technology and engineering companies around the world. Accuracy, Speed and Usability are the three main reason for choosing it around the world.

From various applications of CST Studio suite, we used CST Microwave Studio for designing and simulation of the microstrip patch antenna.

In the next Chapter 4, microstrip antenna design is shown step by step and design for enhancement of gain and simulation also shown and discussed briefly.

CHAPTER 4

MICROSTRIP PATCH ANTENNA DESIGN

4.1 Design Specifications

The three essential parameters for the design of a rectangular microstrip patch antenna are:

1. **Desired Resonant Frequency (f_r):** The resonant frequency of the Antenna must be selected appropriately. The Satellite communication system for X band uses the frequency range from 8 GHz to 12 GHz, hence the antenna design must be able to operate in this frequency range. The resonant frequency selected for this design is 10 GHz.
2. **Dielectric Constant of the Substrate (ϵ_r):** The dielectric Constant selected for this design is FR4 (lossy) which has a dielectric constant of 4.3. A substrate with a high dielectric constant has been selected since it reduces the dimensions of the antenna.
3. **Height of the Dielectric Substrate(h)**: For the microstrip patch antenna to be used in satellite communication, it is essential that the antenna has a compact size and is not bulky. Hence, the height of the dielectric substrate is selected as 1.6 mm.

Therefore, the essential parameters of the design are:

- f_r = 10 GHz
- ϵ_r = 4.3
- h = 1.6 mm

4.2 Design Procedure

The design process is shown below by flow chart:

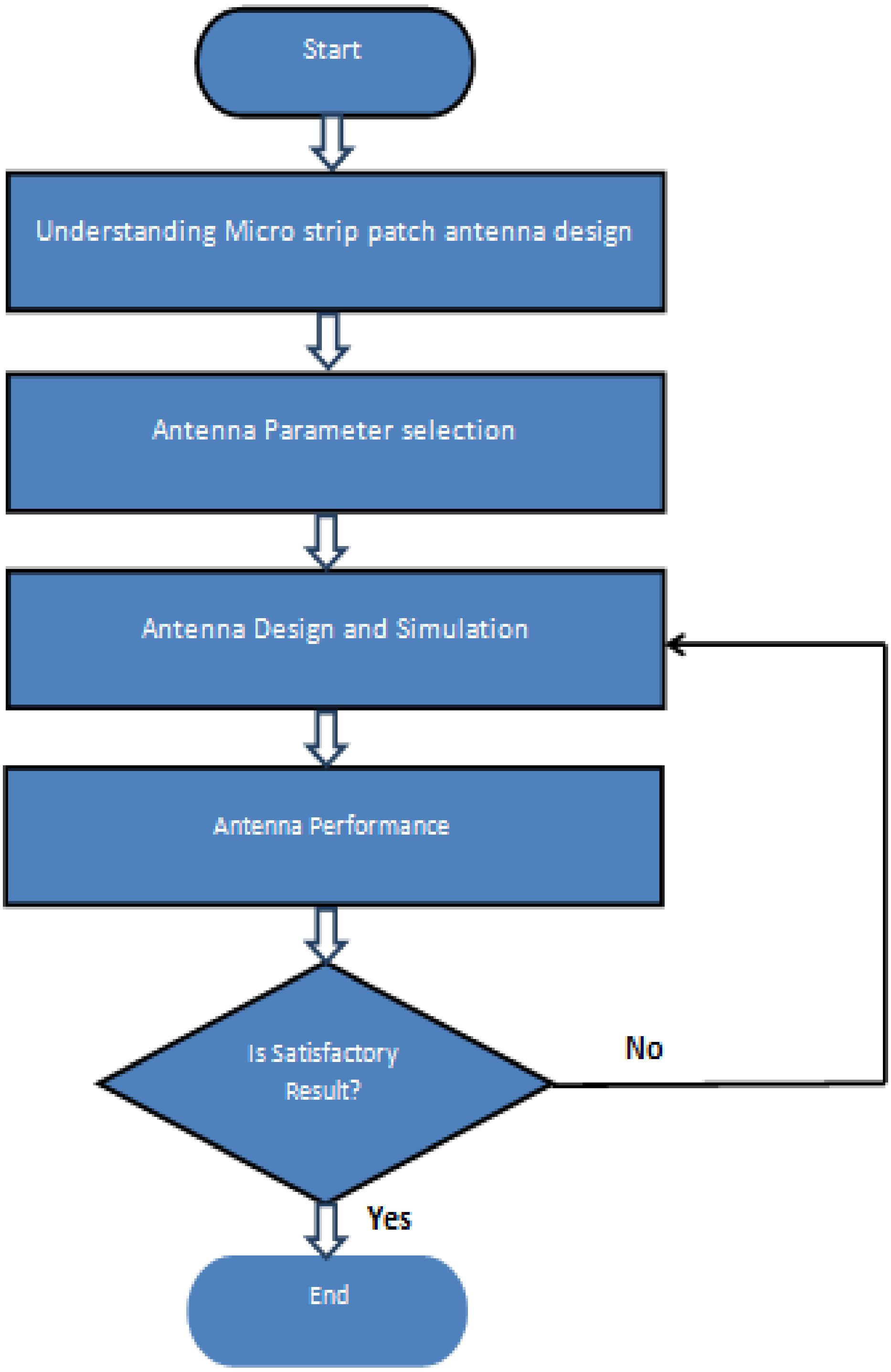


Fig. 4.1 Design flow chart of the microstrip patch antenna design.

4.3 Antenna Parameter Calculation

4.3.1 Patch Width Calculation (W):

The width (W) of the patch is calculation:

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

where,

C = speed of light in free space = 3×10^8 ms^{-1}

ϵ_r = dielectric constant of the substrate = 4.3.

f_r = desired resonant frequency = 10 GHz

we find, W = 9.214 mm.

4.3.2 Effective Dielectric Constant Calculation (ϵ_{reff}):

The effective dielectric constant calculation:

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}}$$

where,

ϵ_r = dielectric constant of the substrate = 4.3

w = width of the patch

h = height(thickness) of the Substrate = 1.6 mm

we find, ϵ_{reff} = 3.185.

4.3.3 Effective Length Calculation (L_{eff}):

The effective length is calculation,

$$L_{eff} = \frac{c}{2f_r\sqrt{\epsilon_{reff}}}$$

where,

C = speed of light in free space = 3×10^8 ms^{-1}

f_r = operating frequency = 10 GHz

ϵ_{reff} = effective dielectric constant = 3.185

we find, L_{eff} = 8.405 mm.

4.3.4 Length Extension Calculation (ΔL):

The extension of length is calculated by:

$$\Delta L = 0.412h \frac{(\epsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\epsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)}$$

where,

h = height of the substrate = 1.6 mm.

ϵ_{reff} = effective dielectric constant = 3.185.

W = width of the patch = 9.24 mm.

we find, ΔL = 0.721.

4.3.5 Actual Length of the Patch (L):

The actual length of patch is calculation:

$$L = L_{eff} - 2\Delta L$$

where,

L_{eff} = effective length = 8.405 mm.

ΔL = extension of length = 0.721.

we find, L = 6.96 mm.

4.3.6 Ground Plane Calculation (W_g, L_g):

Only for infinite ground planes, transmission line method is applicable, but for practical considerations finite ground pane is required. Same results for finite and infinite ground plane obtained if in case of infinite ground plane, the size of the ground plne around the periphery is greater than the patch dimensions by six times thickness of the substrate. Hence, for proposed design, the dimensions of ground plane would be given as:

$$W_g = 6h + W$$

where,

W = width of the patch = 9.214 mm.

h = height of the Substrate = 1.6 mm.

we find, W_g = 18.814 mm.

And,

$$L_g = 6h + L$$

L = length of the patch = 6.96 mm

h = height of the substrate = 1.6 mm

we find, L_g = 16.56 mm.

Here, W_g = Ground width and L_g = Ground length.

4.4 Antenna Design & Simulation

To design the antenna, we use 3D co-ordinate system in CST microwave studio simulation tool.

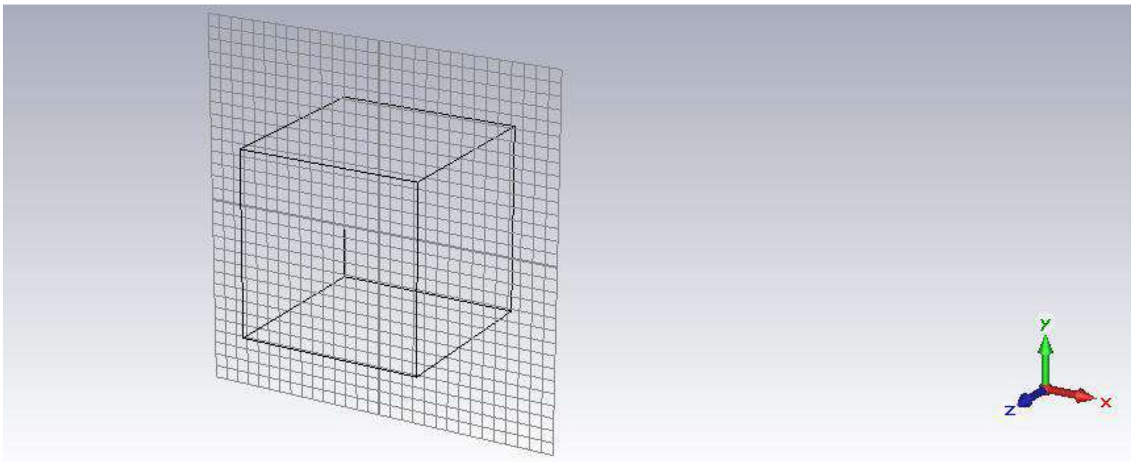
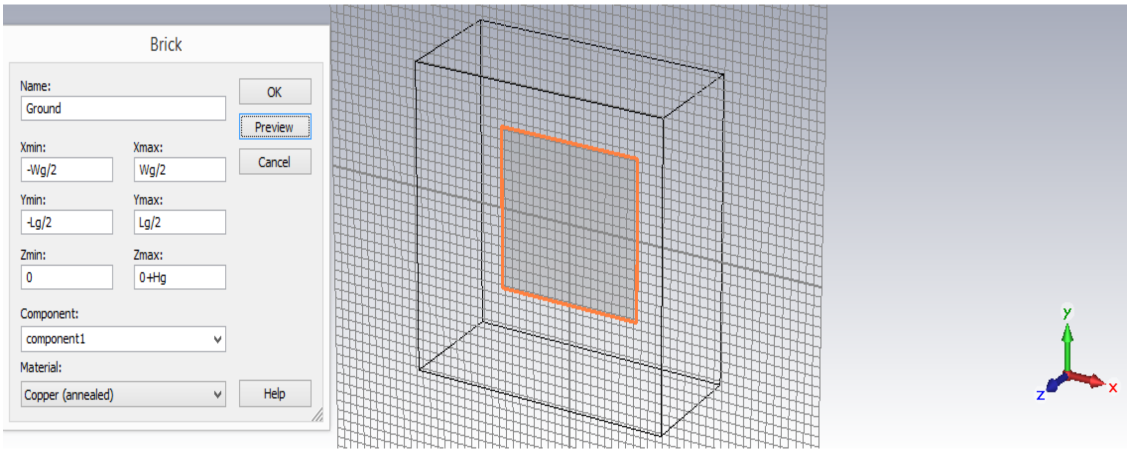


Fig.4.2 3D co-ordinate view in CST software.

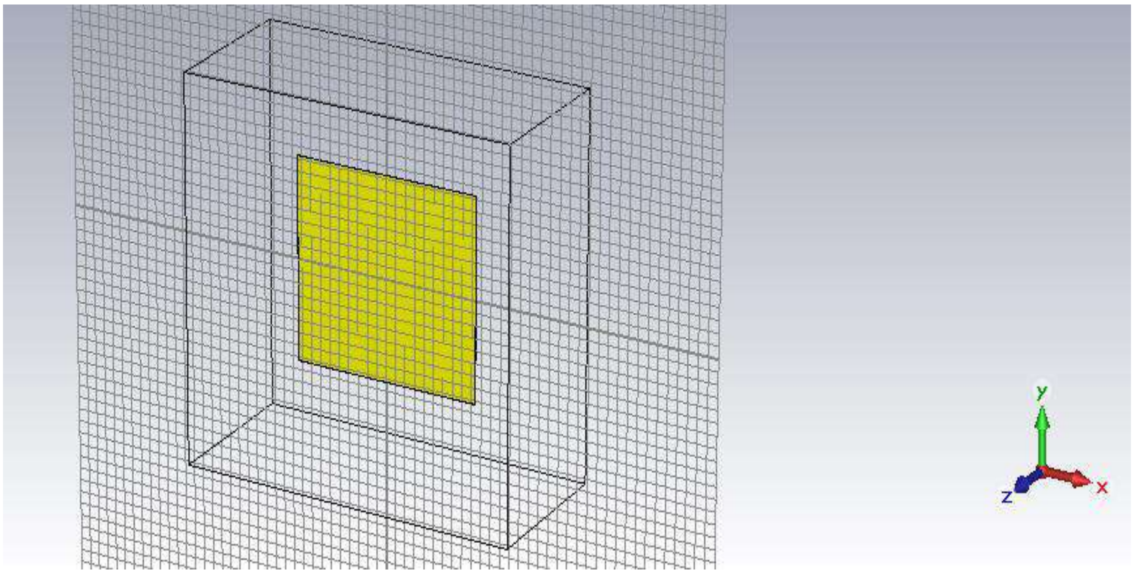
The step by step procedure of designing antenna is shown below:

4.4.1 Ground

The width of the ground is 18.814 mm and length of the ground is 16.56 mm. The thickness of the ground is 0.035 mm. The material used for ground is Copper(annealed). Width, length and thickness are taken along x, y, and z axis which are shown in the **Fig. 4.3**. The steps are presented by picture:



(a)

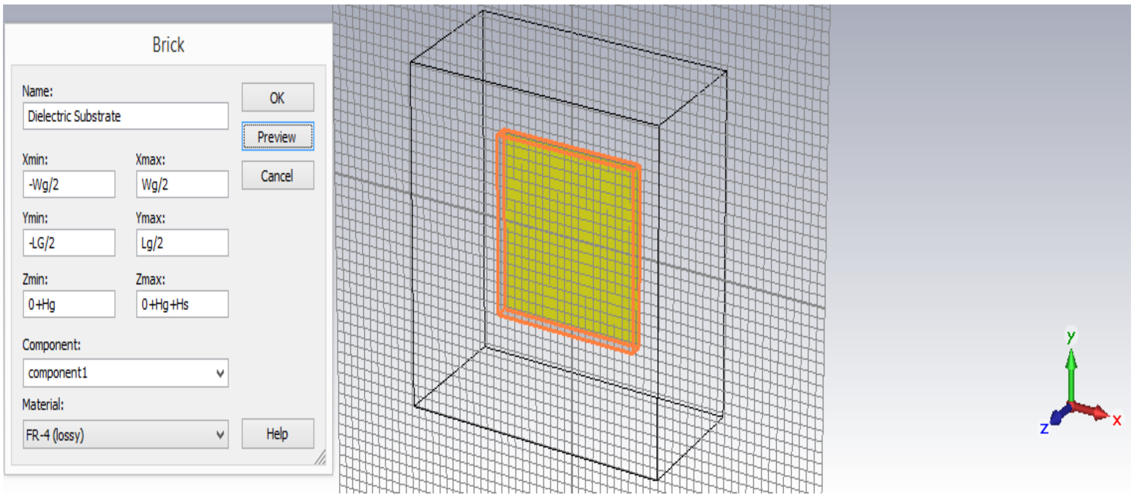


(b)

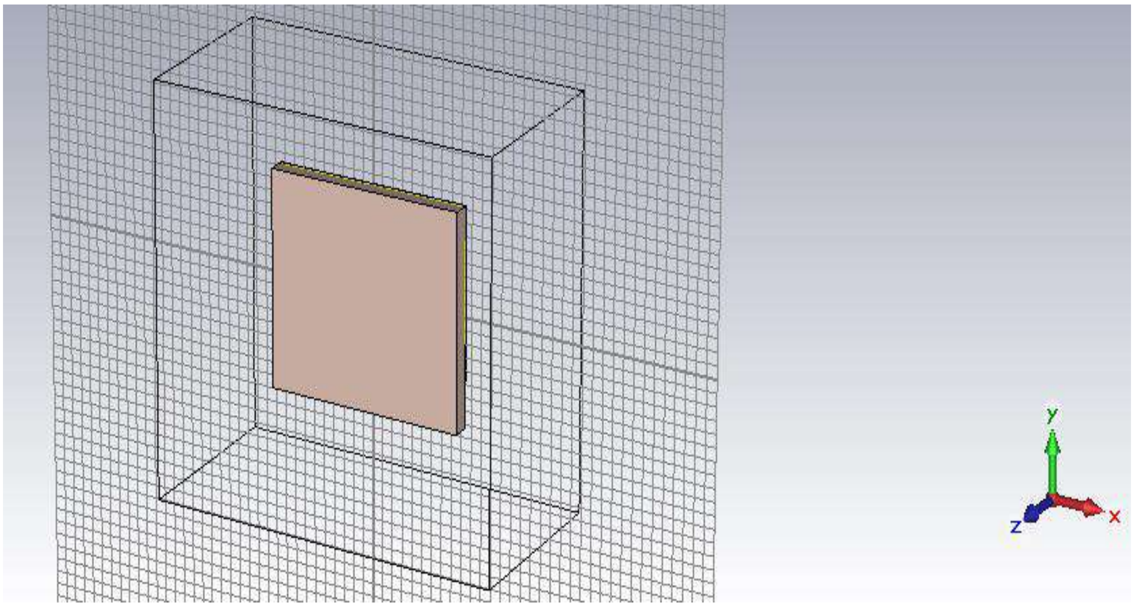
Fig. 4.3 Ground design (a) Before apply (b) After apply.

4.4.2 Dielectric substrate

The width and length of the dielectric substrate is exactly same as the ground substrate because the dielectric substrate will be etched on the up of ground. So the width is 18.814 mm and length is 16.56 mm. To attain a compact structure for MPA, so that it can be incorporate with satellite, the thickness of dielectric substrate is chosen as 1.6 mm. That ensures that the antenna will not be bulky. The material for dielectric substrate is chosen FR4(lossy). The steps are presented by picture:



(a)

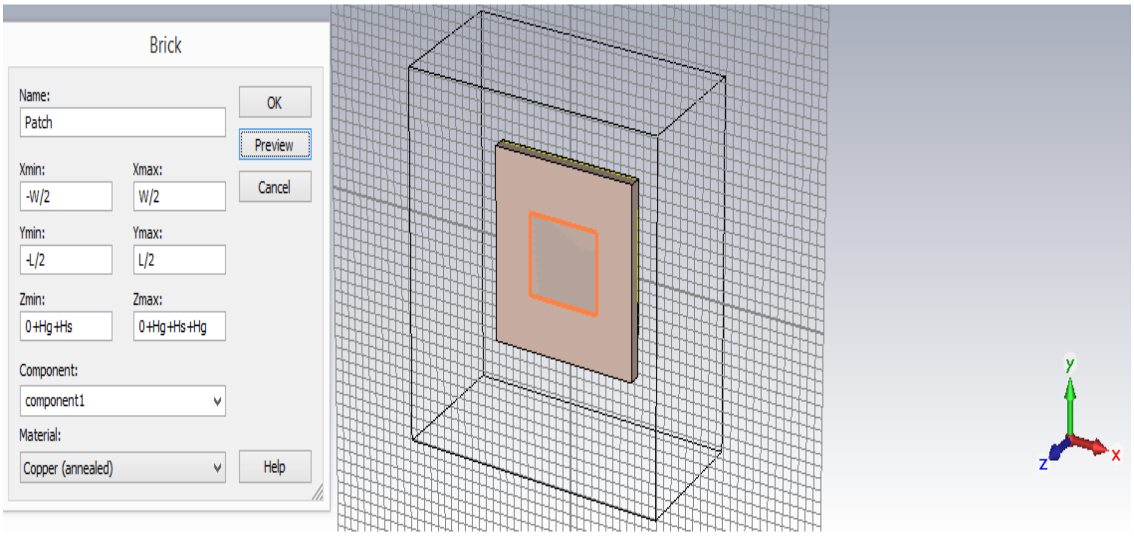


(b)

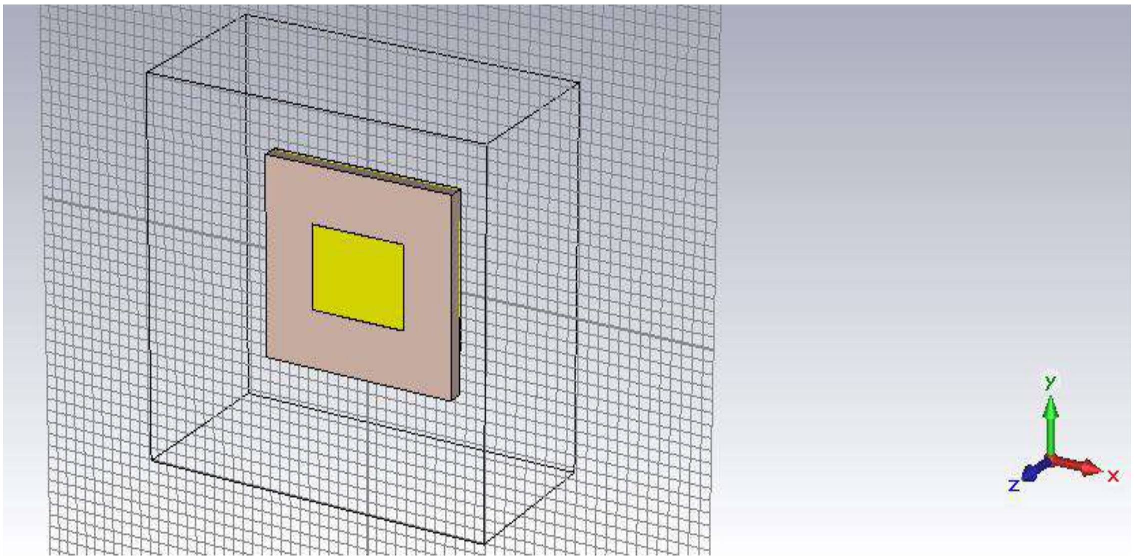
Fig.4.4 Dielectric Substrate design (a) Before apply (b) After apply.

4.4.3 Patch

Patch will be etched at the top of the dielectric substrate. Patch is a conductor, so the material for patch is Copper(annealed). The width of the patch is 9.214 mm and length of the patch is 6.96 mm. The thickness of the patch is 0.035 mm. The steps are presented by picture:



(a)

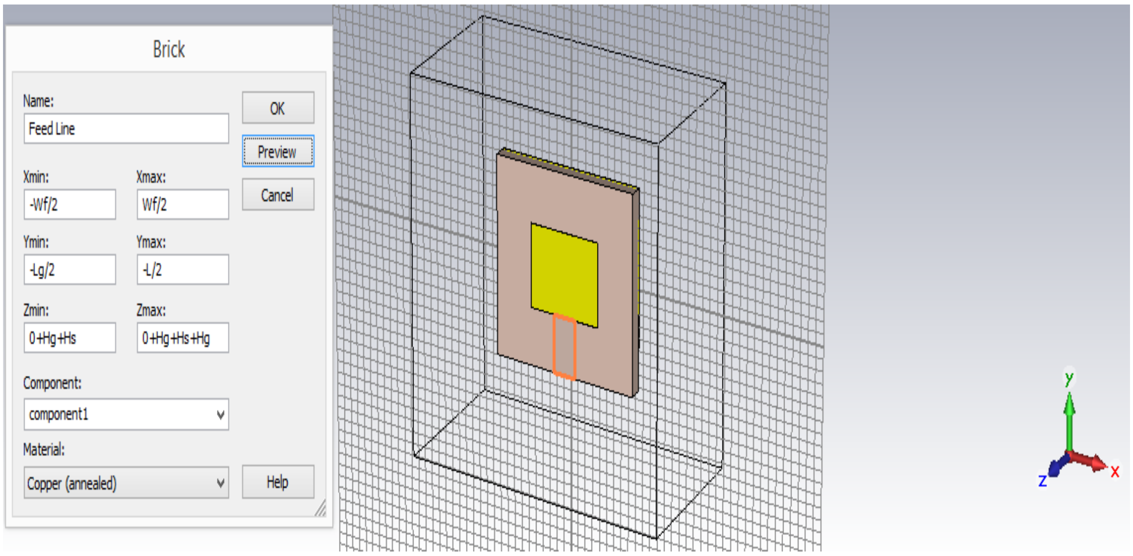


(b)

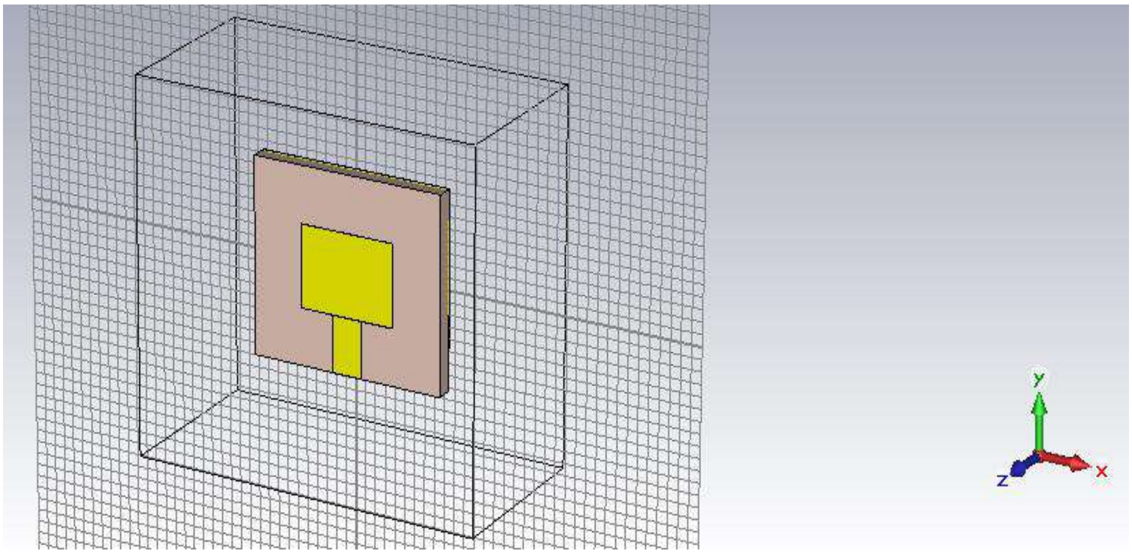
Fig. 4.5 Patch design (a) Before apply (b) After apply.

4.4.4 Feed Line

The feeding technique is used for the antenna is chosen as microstrip feed line technique. The width of the feed line is 2.932 mm which is obtained by impedance calculator, so that the impedance of the feed line is match with the 50Ω impedance of co-axial connector. The feed line will be also etched on the top of dielectric substrate. The thickness must be equal with the patch thickness. So the thickness of the patch is 0.035 mm. The steps are presented by picture:



(a)



(b)

Fig. 4.6 Feed Line design (a) Before apply (b) After apply.

4.4.5 Adding Patch and Feed Line

Patch and feed line are combined as only patch by Boolean add. The steps are presented by pictures:

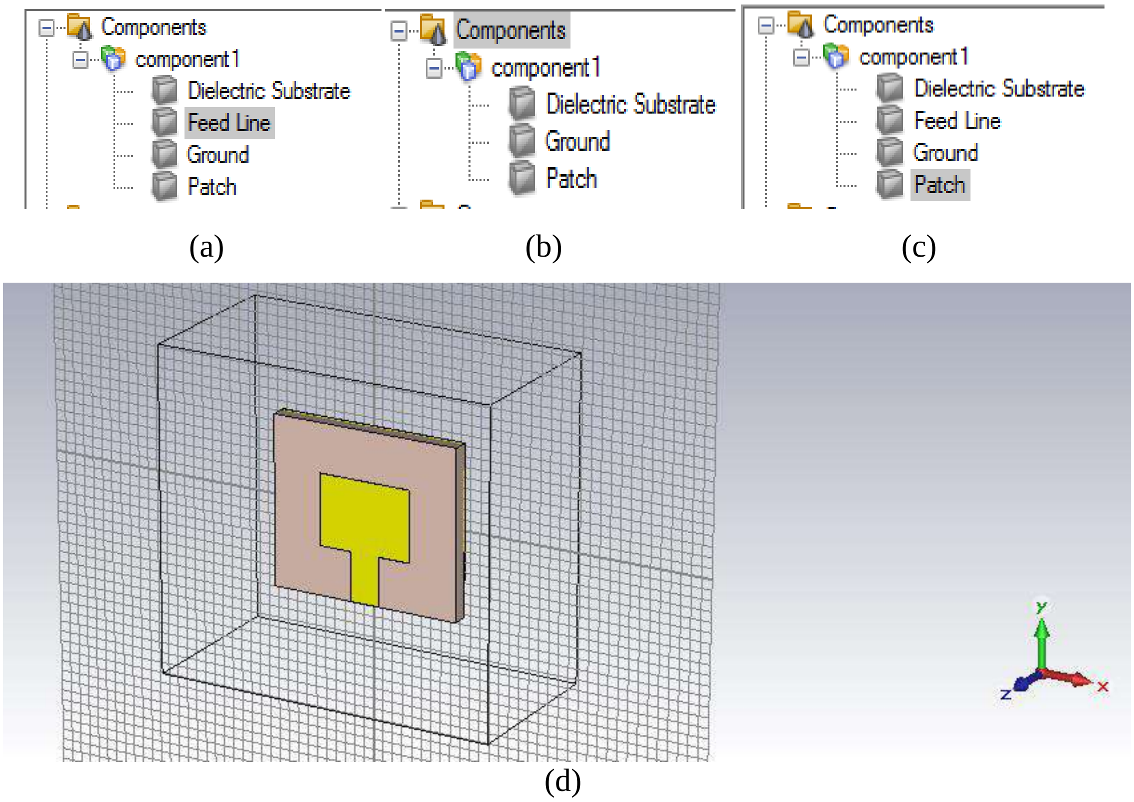


Fig. 4.7 Steps of adding patch and feed line.

4.4.6 Empty Space

Both the empty space1 and empty space2 is created in the patch. Basically the gap between patch and feed line is considered as 1mm. Thus Gpf = 1 mm. So the width of the empty sapce1 is 1mm and the length of the empty space1 is calculated by the equation 6*Hs/2 = 4.8mm which is denoted by Fi where Hs = Thickness of the dielectric substrate. Thus Fi = 4.8mm. As its intercept the patch, so the thickness will be same as patch i.e. 0.035mm. Empty space1 is created along -x axis direction. The material is chosen as Nickel(lossy metal), so that it intersects the patch and then by cutting the highlighted space from the patch, we find Empty space1. The steps are shown by picture:

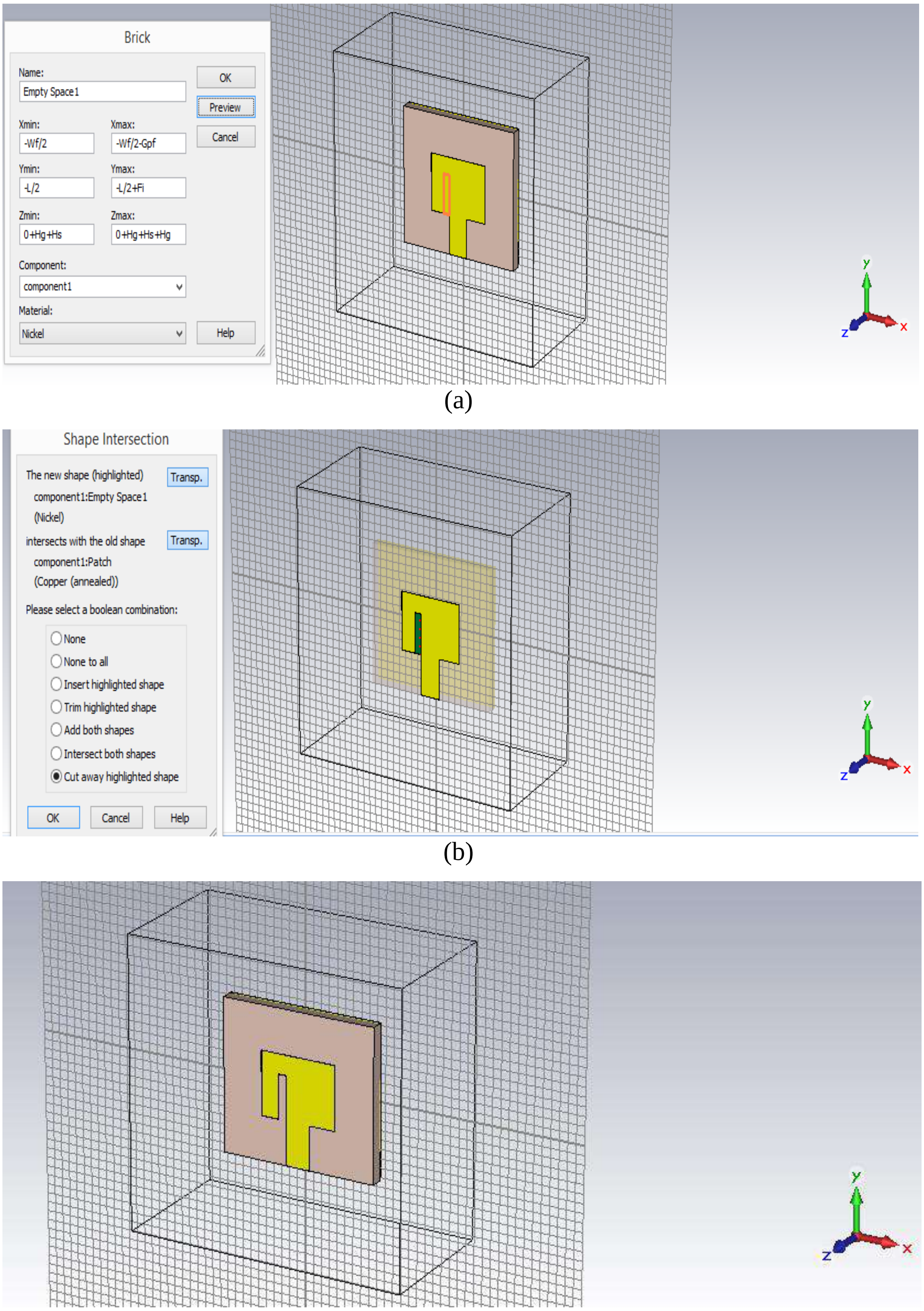
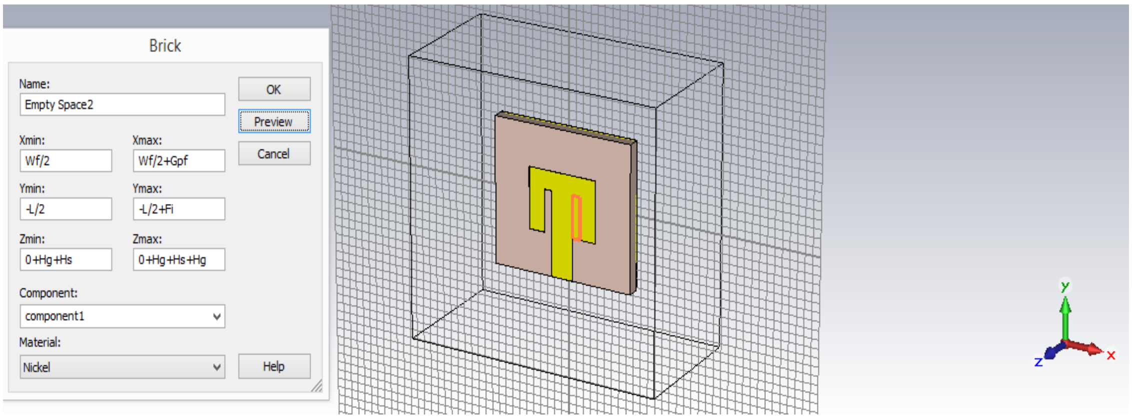
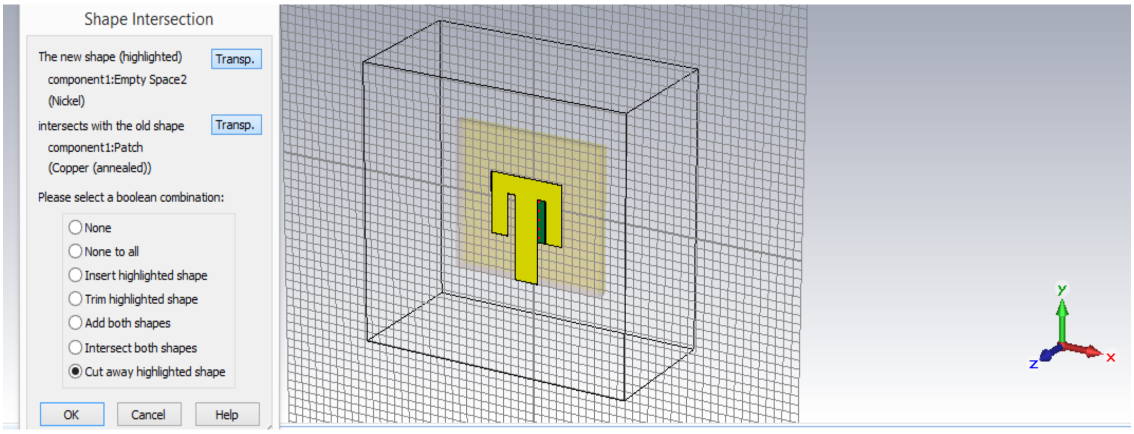


Fig. 4.8 Creation of Empty space1 (a) Before apply (b) Cut away highlighted shape (c) After apply.

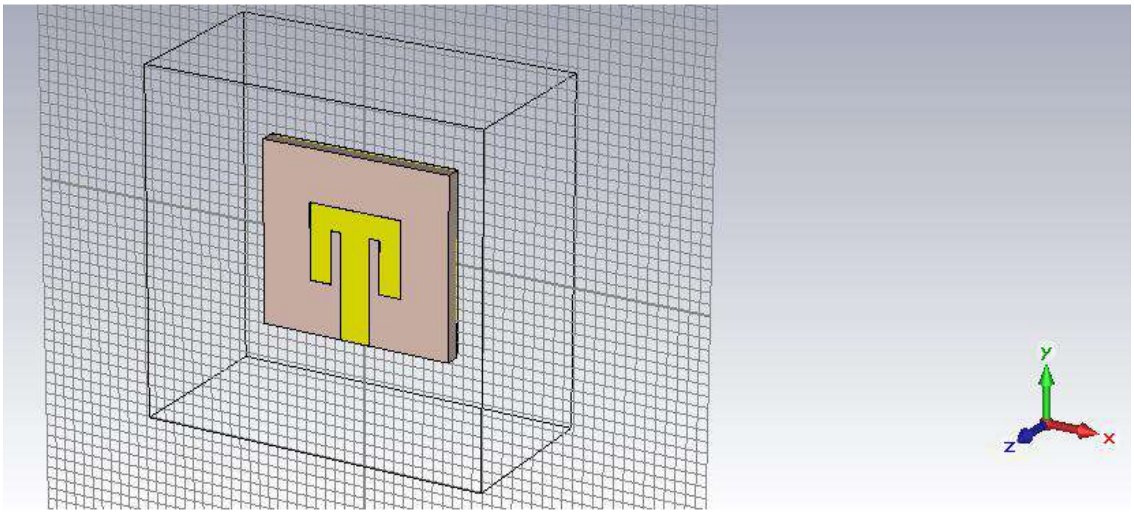
Empty space2 is created on the patch by exactly the same procedure as empty space1. The difference is that empty space2 is created along +x axis direction. The steps are shown by picture below:



(a)



(b)

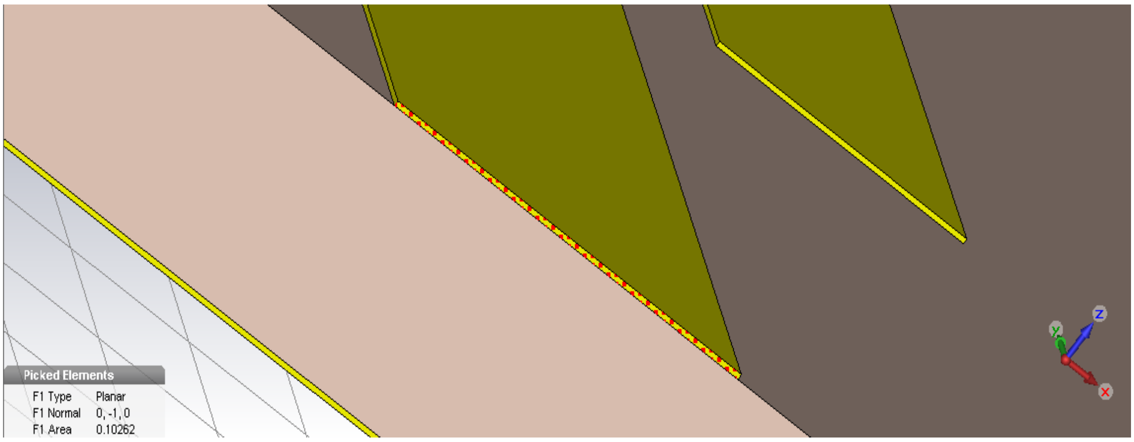


(c)

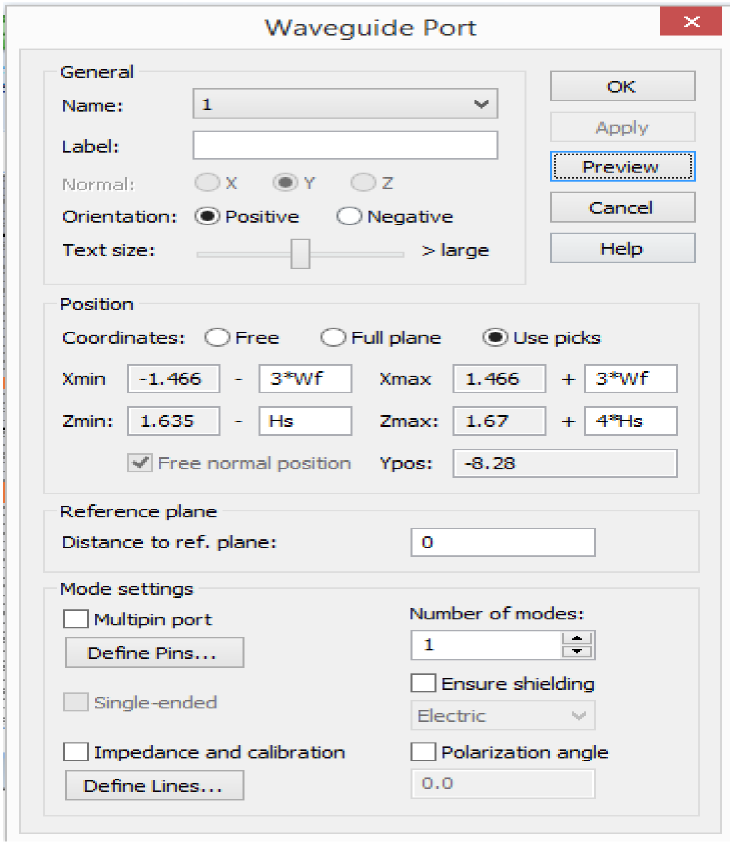
Fig. 4.9 Creation of Empty space2 (a) Before apply (b) Cut away highlighted shape (c) After apply.

4.4.7 Waveguide Port

There are two types of port: Discrete port and Waveguide port. In this design, Waveguide port is used. The port width should be six times of the feed line width(Wf) and the height of the port should be six times of substrate thickness(Hs). The width of the waveguide port is constructed along +x axis direction and the height is constructed along +z axis direction. The steps are shown by picture below:

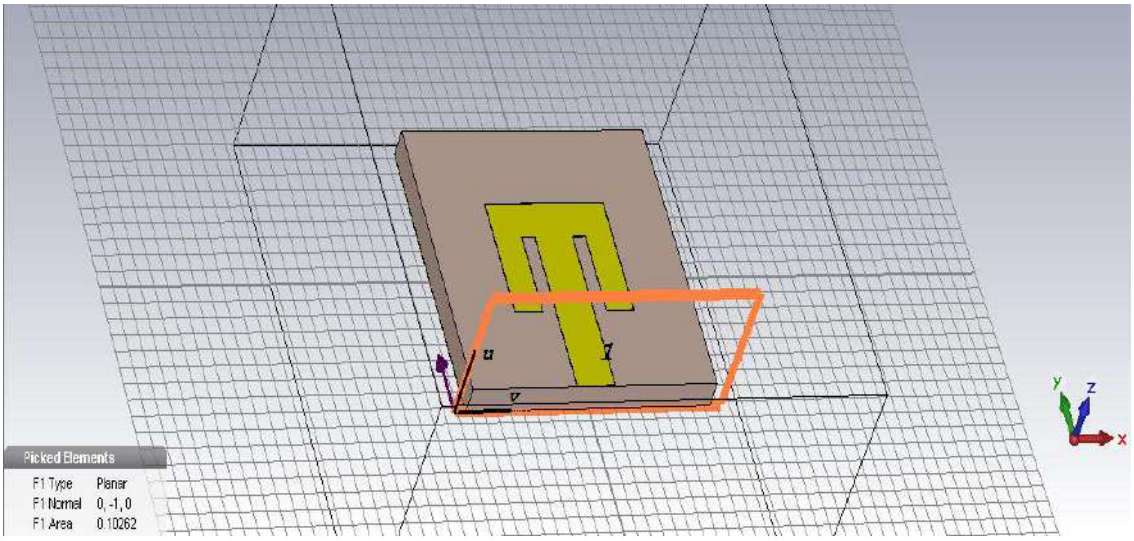


(a)

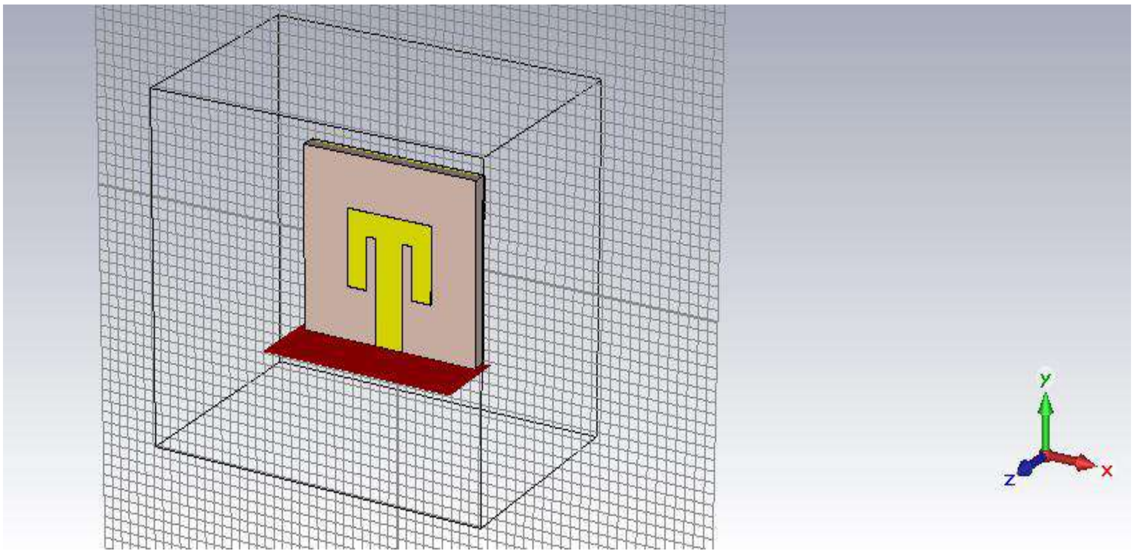


(b)

Fig. 4.10 Creation of waveguide port (a) Selection of face (b) Dimensions.



(c)

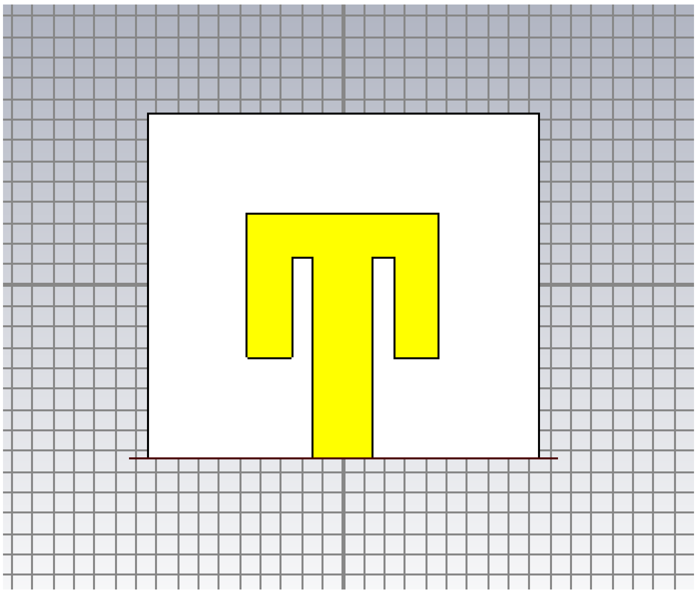


(d)

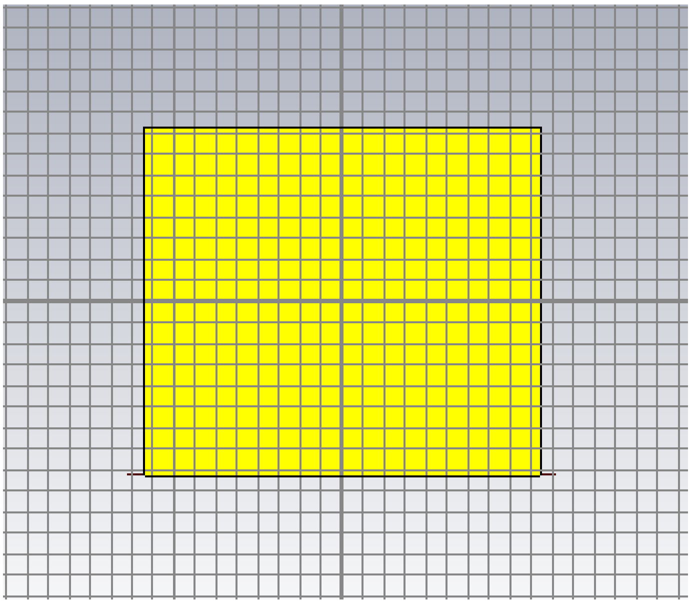
Fig. 4.11 Creation of waveguide port (a) Before apply (b) After apply.

4.4.8 Designed Microstrip Patch Antenna

After completing all the procedure, the designed antenna is shown below. **Fig. 4.12** shows the front view and the back view of the microstrip patch antenna. **Fig. 4.13** shows the 3D view of the designed microstrip patch antenna.



(a)



(b)

Fig. 4.12 2D view of the designed microstrip patch antenna (a) Front view (b) Back view.

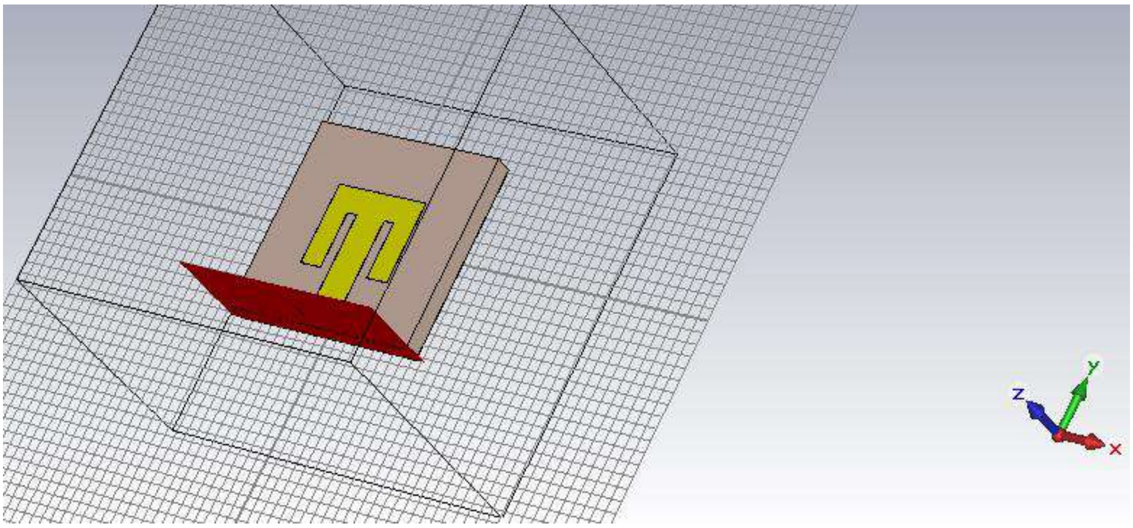


Fig. 4.13 3D view of the designed microstrip patch antenna.

4.4.9 Simulation

Simulation is done in between the frequency range of 8 GHz to 12GHz. The return loss i.e. S1,1 parameter is studied in dB. From the **Fig. 4.14**, we saw that the designed antenna resonates at 8.208 GHz which is far behind from our desired resonates frequency. The return loss for 8.208 GHz is -15.76 dB.

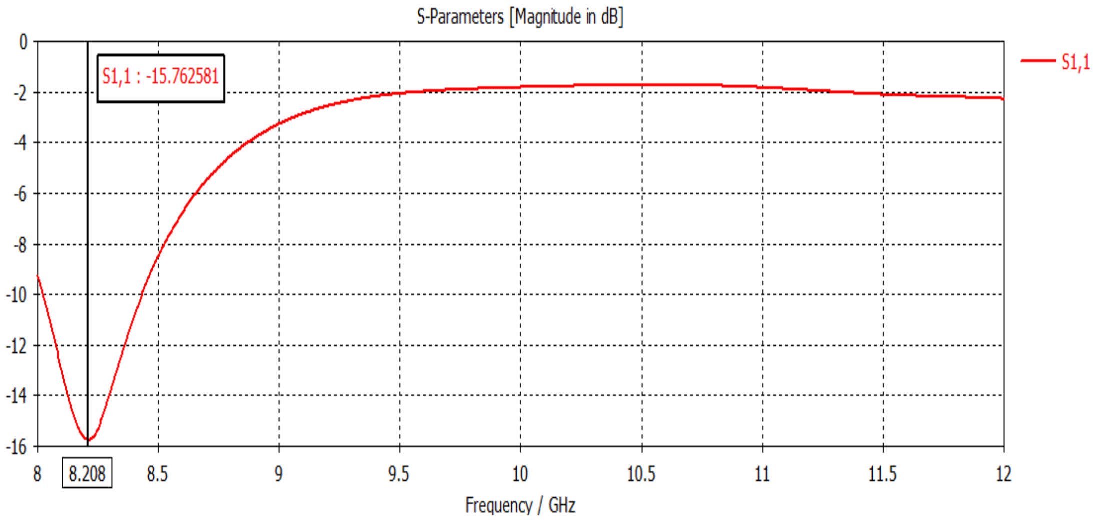


Fig. 4.14 Reflection co-efficient curve of designed microstrip patch antenna.

4.5 Redesigning of Microstrip Patch Antenna & Simulation

For our desired resonant frequency and characteristics, the antenna has been re-designed by optimizing the parameters and the port.

4.5.1 Optimized Parameters

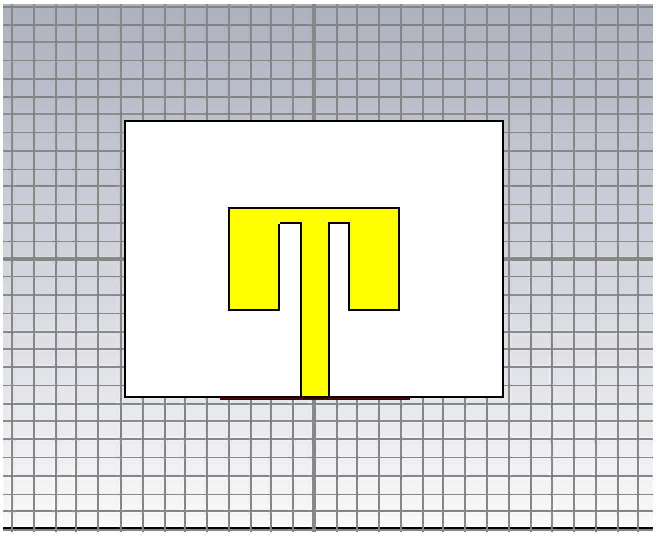
The optimized parameters are given below:

Table 4.1 Optimized dimensions of designed microstrip patch antenna.

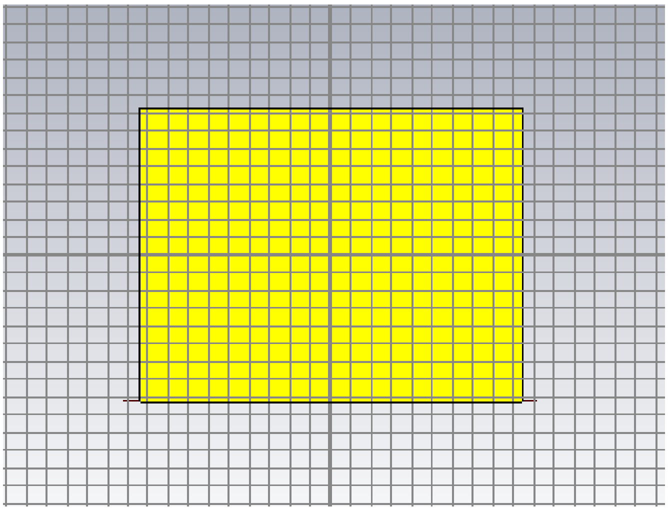
Parameters	**Calculated dimension (mm)**	**Optimized dimension (mm)**
Ground Width(Wg)	18.814	17.485
Ground Length(Lg)	16.56	15.297
Patch Width(W)	9.214	7.885
Patch Length(L)	6.96	5.697
Ground Thickness(Hg)	0.035	0.035
Dielectric Thickness(Hs)	1.6	1.6
Gap between patch and feed line(Gpf)	1	1
Fi(Length of empty slot)	4.8	4.8

4.5.2 Optimized Microstrip Patch Antenna

After optimizing the parameters, the new microstrip patch antenna is designed. **Fig. 4.15** shows the front view and the back view of the optimized microstrip patch antenna. **Fig. 4.16** shows the 3D view of the optimized microstrip patch antenna.



(a)



(b)

Fig. 4.15 2D view of the optimized microstrip patch antenna (a) Front view (b) Back view.

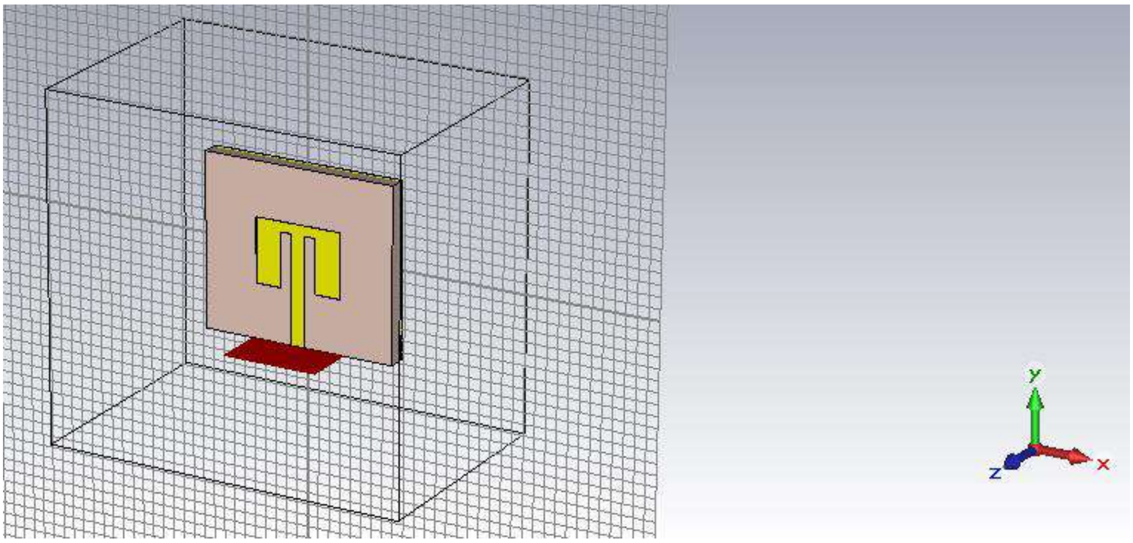


Fig. 4.16 3D view of the optimized microstrip patch antenna.

4.5.3 Simulation

The Simulation is done in between the frequency range of 8 GHz to 12 GHz. The return loss i.e. S-parameter is studied in dB. From the **Fig. 4.17**, we saw that the designed antenna resonates at frequency of 9.692 GHz.

The return loss for 9.692 GHz is -46.89 dB and the bandwidth it covers in the range of 9.35 GHz to 10.04 GHz (about 700 MHz).

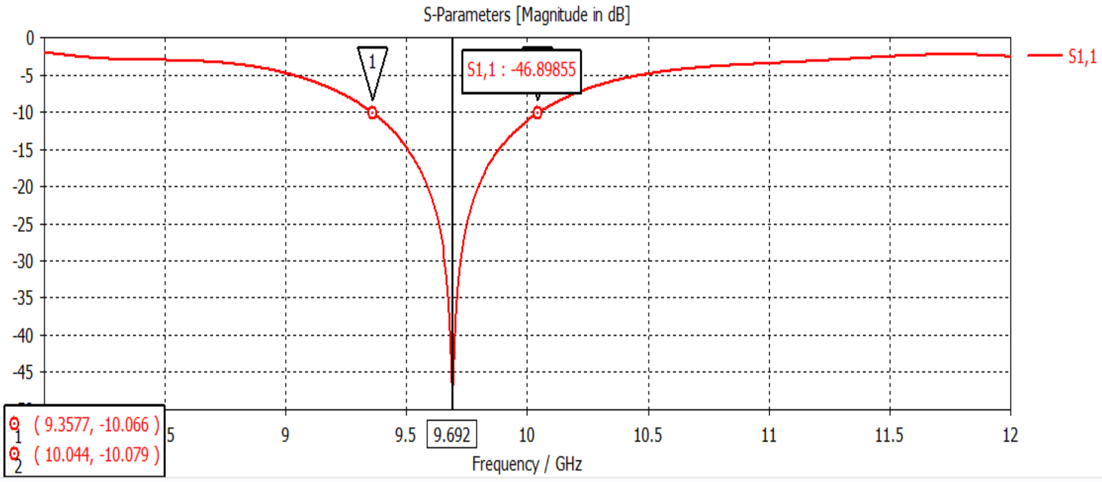


Fig. 4.17 Reflection co-efficient curve of optimized microstrip patch antenna.

4.6 Design for Enhanced Gain & Simulation

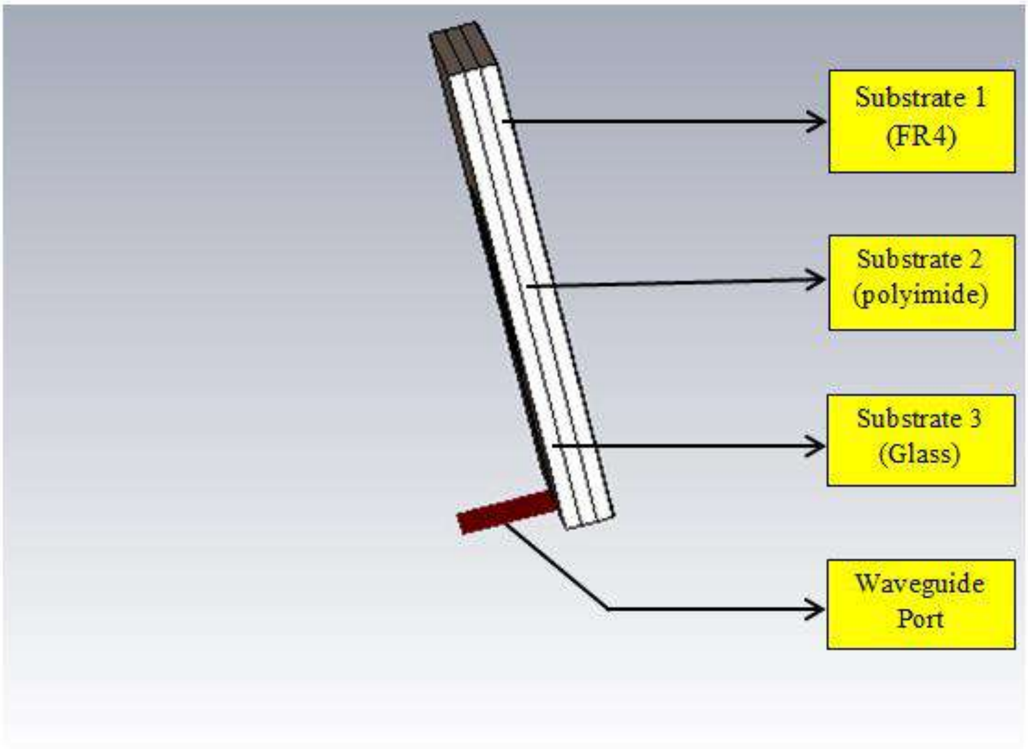
To enhance the gain of the optimized microstrip patch antenna, we use multiple dielectric substrate technique which is discussed below:

4.6.1 Selection of Different Dielectric

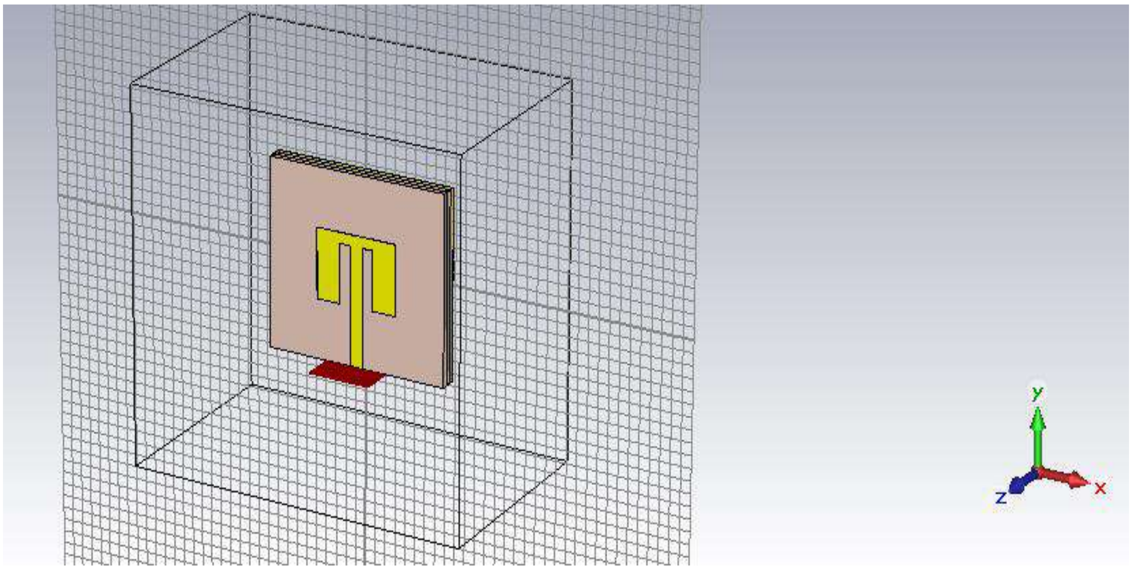
After applying and analyzing various dielectric substrate, finally the three dielectric substrate chosen are FR4 (lossy) as substrate 1, Polyimide (lossy) as substrate 2, and Glass (lossy) as substrate 3. The thickness of the total dielectric substrate is the same as single dielectric substrate i.e. 1.6 mm and dielectric constant of the dielectric substrates are 4.3, 3.5, and 4.82 respectively. Review of different dielectric substrates study are discussed in **Section 5.2** of **Chapter 5**.

4.6.2 Proposed Microstrip Patch Antenna Design

After applying three multiple dielectric layers, the new geometry of the microstrip patch antenna is shown:



(a)



(b)

Fig. 4.18 Proposed Microstrip patch antenna (a) Right side view (b) 3D view.

4.6.3 Simulation

The Simulation is done in between the frequency range of 8 GHz to 12 GHz. The return loss i.e. S-parameter is studied in dB. From the **Fig. 4.19**, we saw that the designed antenna resonates at frequency of 9.792 GHz which is closer to the desired resonant frequency 10 GHz than previous antennas. The return loss for 9.792 GHz is -18.44 dB and the bandwidth it covers in the range of 9.49 GHz to 10.1 GHz (about 610 MHz).

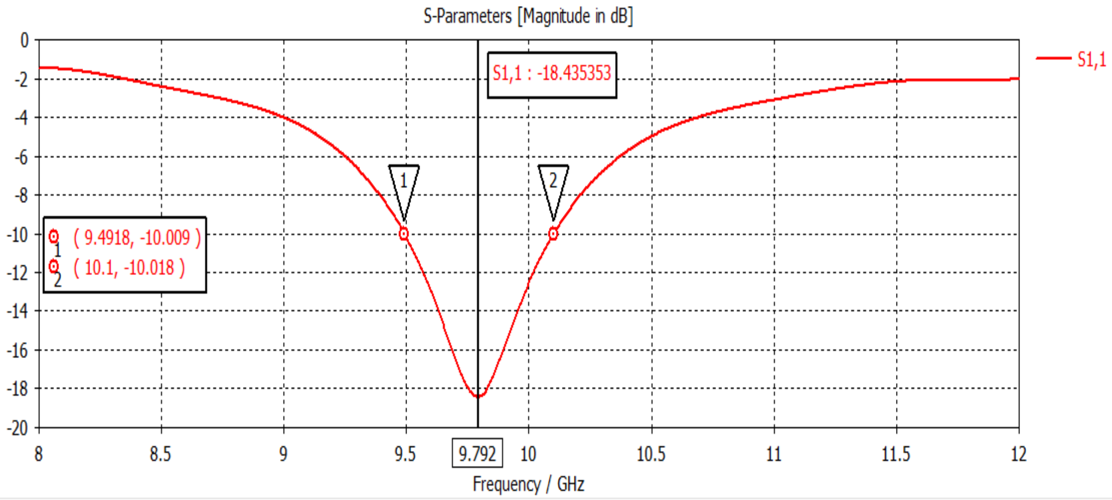


Fig. 4.19 Reflection co-efficient curve of proposed microstrip patch antenna.

All other results are shown and discussed in Chapter 5.

CHAPTER 5

SIMULATED RESULTS AND DISCUSSIONS

5.1 Introduction

In this chapter, we will discuss about the results that we obtained after performing simulation by using CST microwave studio software. The overall analysis is made on Reflection co-efficient(S1,1), VSWR, Gain, Radiation efficiency, Surface current density, Radiation pattern on co-polarization and cross-polarization. The simulation is done within the range of 8 GHz - 12 GHz, because it is the range of X band satellite applications specified by IEEE.

5.2 Review of Different Dielectric Substrates Study

We perform and analyze the microstrip patch antenna design with different multiple dielectric substrate layer. We perform that analysis to understand for which dielectric substrate, the microstrip patch antenna shows better performance and high gain. Table shows the reflection co-efficient and gain of different dielectric substrate.

Table 5.1 Results of using different dielectric substrates as layer.

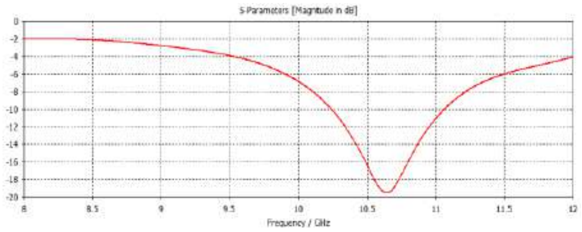
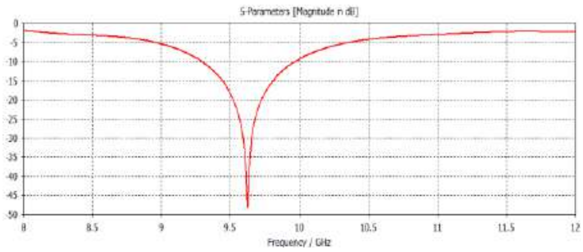
No.	**Substrates as** **1. Substrate 1** **2. Substrate 2** **3. Substrate 3**	**Reflection Co-efficient (S1,1)**	**Gain at Desired Resonant Frequency (10GHz)**
01	1. FR4(lossy) 2. RT5880(lossy) 3. FR4(lossy)		4.993 dB
02	1. FR4(lossy) 2. Glass(lossy) 3. FR4(lossy)		5.26 dB

Table 5.1 Continues

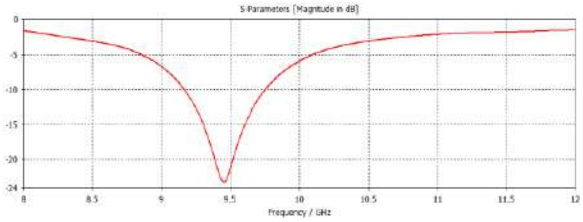
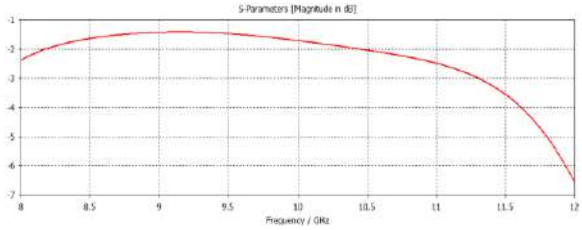
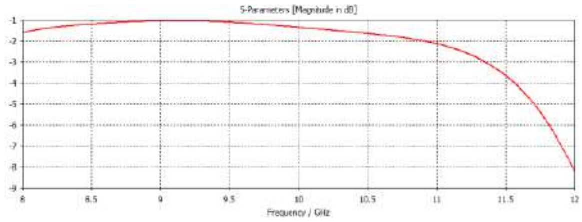
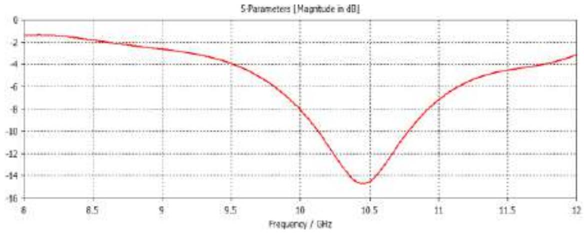
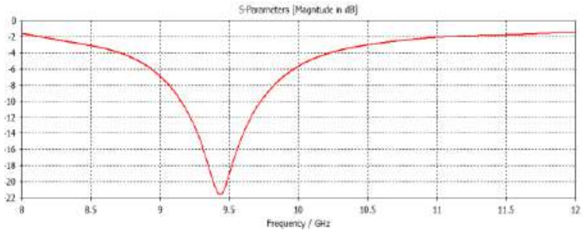
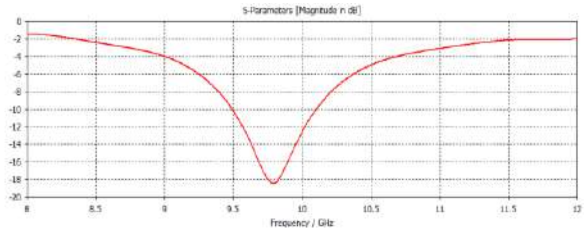
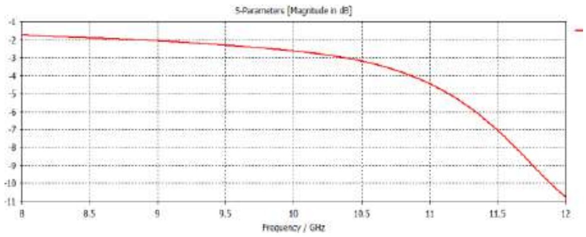
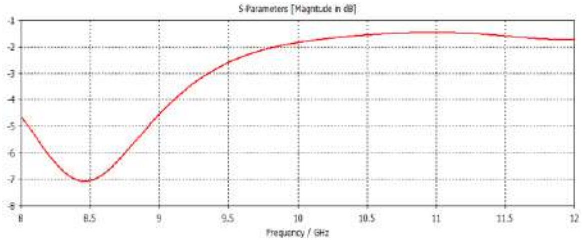
03	1. Glass(lossy) 2. FR4(lossy) 3. Glass(lossy)		5.82 dB
04	1. Silicon(lossy) 2. FR4(lossy) 3. Silicon(lossy)		2.19 dB
05	1. Silicon(lossy) 2. Glass(lossy) 3. Silicon(lossy)		3.01 dB
06	1. FR4(lossy) 2. RT5880(lossy) 3. Glass(lossy)		5.84 dB
07	1. FR4(lossy) 2. Glass(lossy) 3. Glass(lossy)		5.89 dB
08	1. FR4(lossy) 2.Polyimide(lossy) 3. Glass(lossy)		6.01 dB
09	1. FR4(lossy) 2. Air 3. Glass(lossy)		4.55 dB

Table 5.1 Continues

10	1. RT6010(lossy) 2. RT5880(lossy) 3. RT6010(lossy)		6.48 dB

From the above study, we have seen that, using RT6010(lossy), RT5880(lossy), RT6010(lossy) dielectric substrate, we found highest gain of 6.48 dB at resonant frequency 10 GHz but it has a poor reflection co-efficient. So we took FR4(lossy), Polyimide(lossy), Glass(lossy) dielectric substrate as the gain is 6.01 dB and it has a good reflection co-efficient having return loss of -18.44 dB at resonant frequency 9.792 GHz.

5.3 Reflection Coefficient

The proposed antenna resonates at 9.79 GHz. The return loss for 9.79 GHz is -18.43 dB. This antenna covers the bandwidth of 9.49 GHz to 10.1 GHz which means the bandwidth of this antenna is around 610 MHz. These frequency band find their application in satellite communication. Another three frequency taken from the frequency band are 9.69 GHz, 9.89 GHz and 10 GHz. The return losses are -16.09 dB, -16.19 dB and -12.53 dB which covers the minimum required value of return loss of -10 dB. The plots for return losses of the proposed antenna is shown in **Fig. 5.1**.

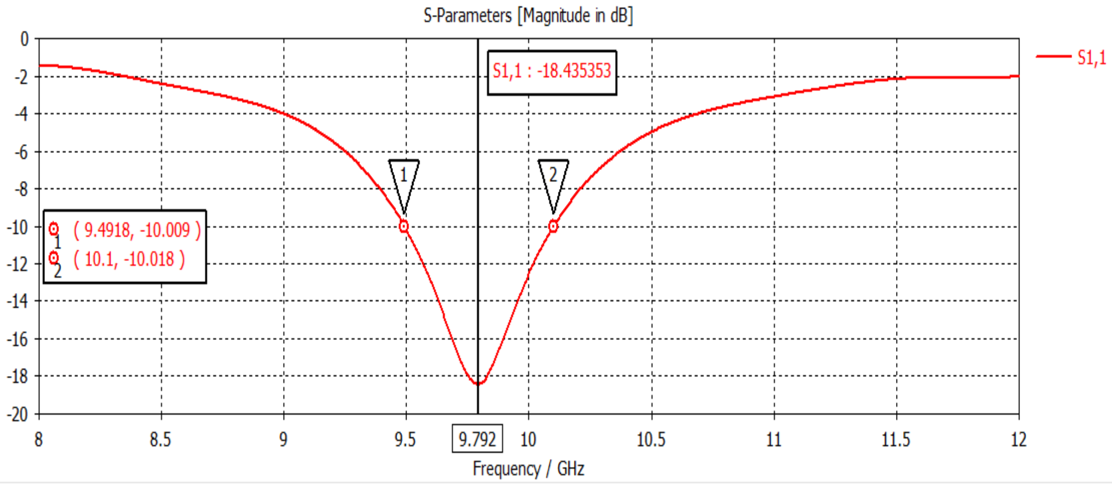


Fig. 5.1 Reflection co-efficient of the proposed antenna.

5.4 Radiation Patterns

Fig. 5.2 and **Fig. 5.3** illustrates the polar view of radiation pattern of the proposed microstrip patch antenna. Radiation pattern is a parameter that indicates the directionality of the radiated power to the antenna.

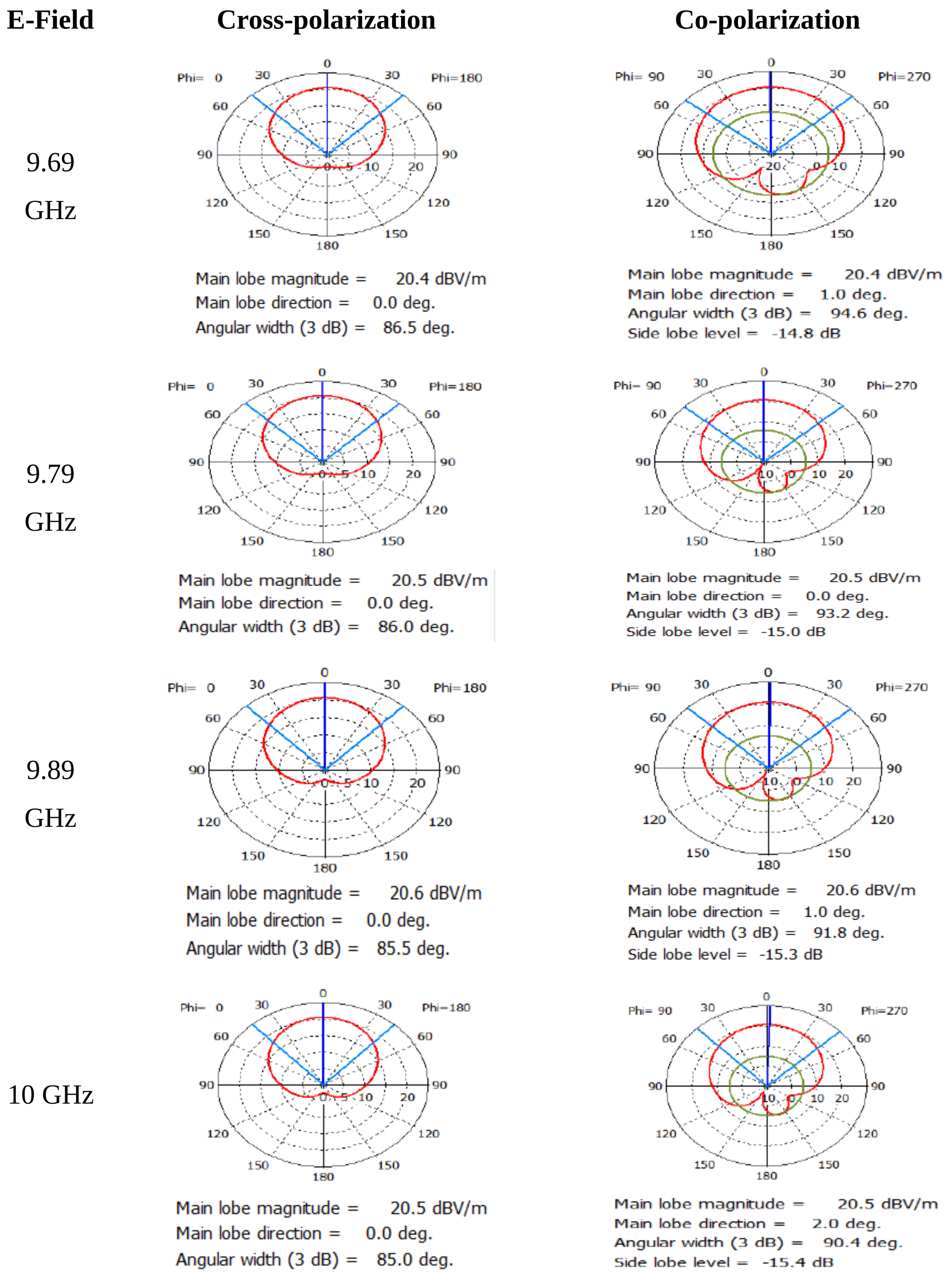
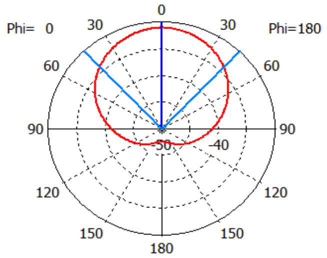


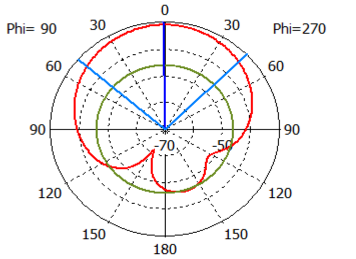
Fig. 5.2 Radiation pattern of E-field for frequency 9.69 GHz, 9.79 GHz, 9.89 GHz, 10 GHz.

H-Field | **Cross-polarization** | **Co-polarization**

9.69 GHz

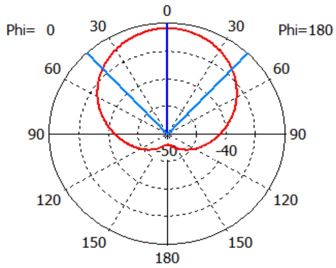


Main lobe magnitude = -31.1 dBA/m
Main lobe direction = 0.0 deg.
Angular width (3 dB) = 86.5 deg.

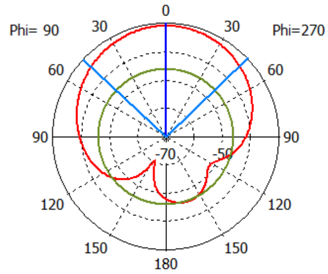


Main lobe magnitude = -31.1 dBA/m
Main lobe direction = 1.0 deg.
Angular width (3 dB) = 94.6 deg.
Side lobe level = -14.8 dB

9.79 GHz

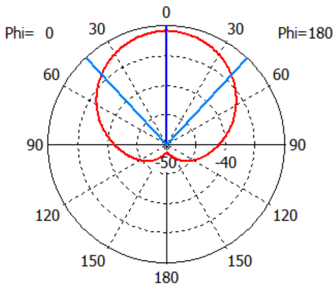


Main lobe magnitude = -31 dBA/m
Main lobe direction = 0.0 deg.
Angular width (3 dB) = 86.0 deg.

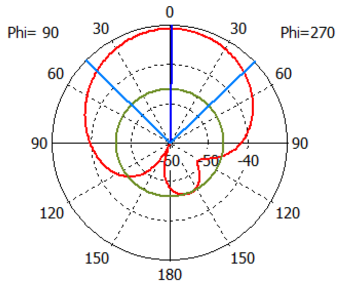


Main lobe magnitude = -31 dBA/m
Main lobe direction = 0.0 deg.
Angular width (3 dB) = 93.2 deg.
Side lobe level = -15.0 dB

9.89 GHz

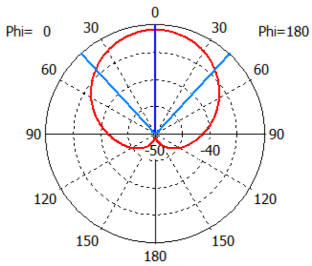


Main lobe magnitude = -30.9 dBA/m
Main lobe direction = 0.0 deg.
Angular width (3 dB) = 85.5 deg.

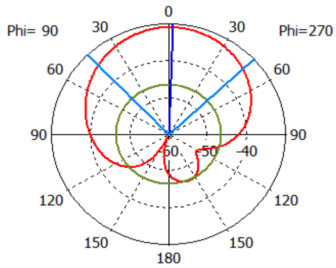


Main lobe magnitude = -30.9 dBA/m
Main lobe direction = 1.0 deg.
Angular width (3 dB) = 91.8 deg.
Side lobe level = -15.3 dB

10 GHz



Main lobe magnitude = -31 dBA/m
Main lobe direction = 0.0 deg.
Angular width (3 dB) = 85.0 deg.

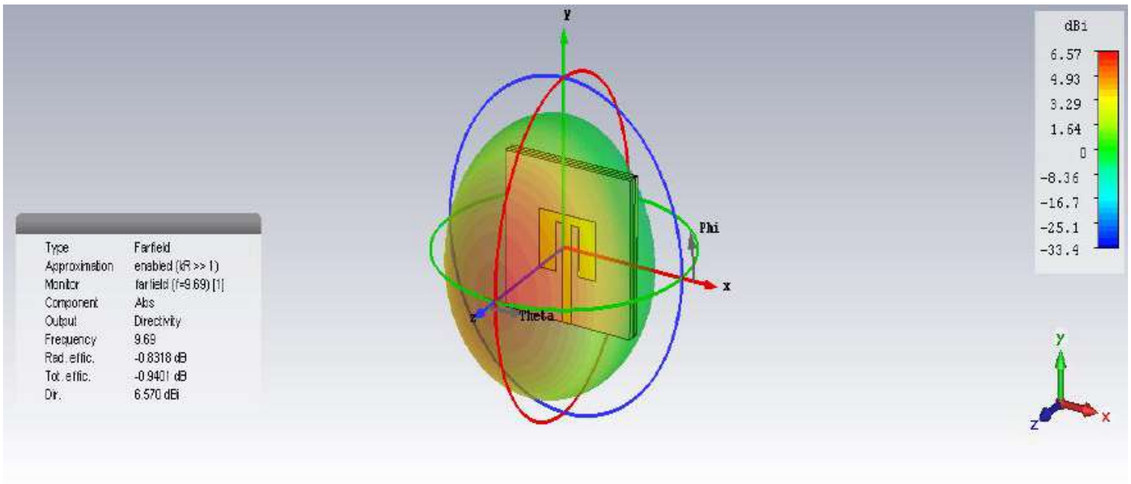


Main lobe magnitude = -31 dBA/m
Main lobe direction = 2.0 deg.
Angular width (3 dB) = 90.4 deg.
Side lobe level = -15.4 dB

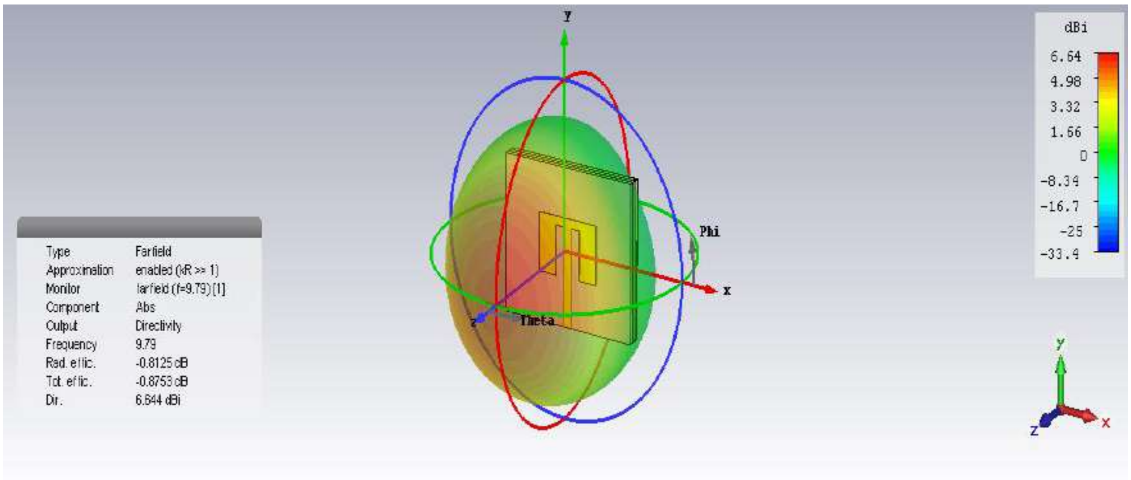
Fig. 5.3 Radiation pattern of H-field for frequency 9.69 GHz, 9.79 GHz, 9.89 GHz, 10 GHz.

5.5 Radiation Patterns in 3D View

Fig. 5.4 & **Fig. 5.5** shows the 3D radiation pattern in terms of directivity with the antenna structure inside.

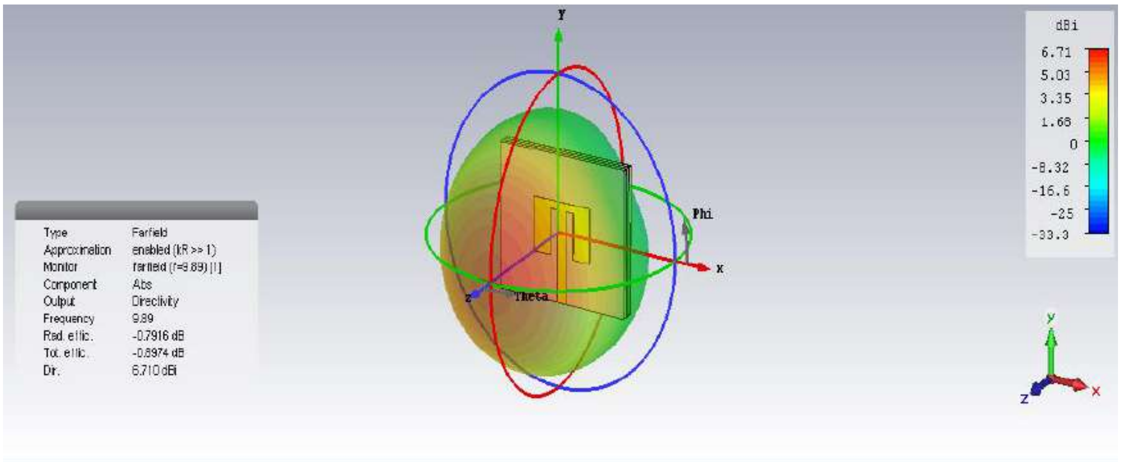


(a)

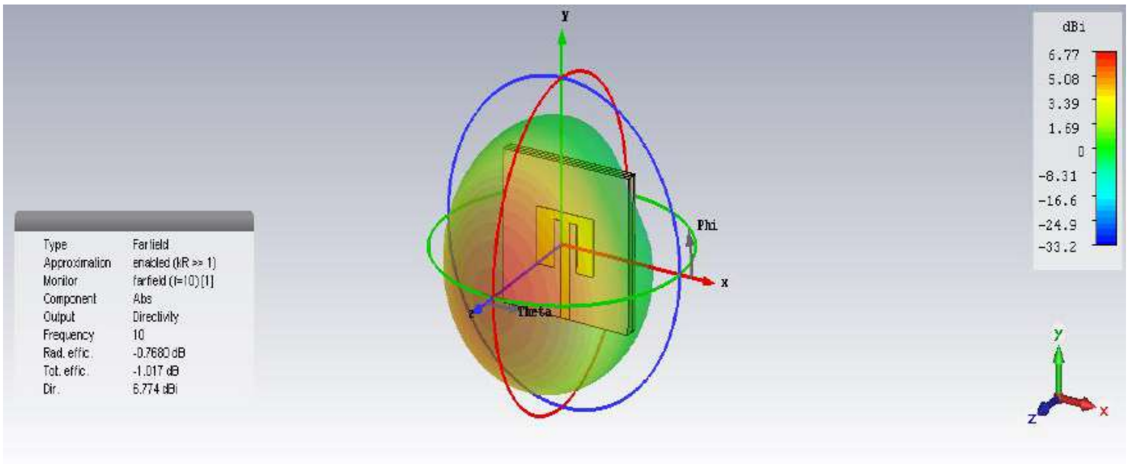


(b)

Fig. 5.4 3D view of directivity radiation pattern with structure inside (a) 9.69 GHz (b) 9.79 GHz



(a)



(b)

Fig. 5.5 3D view of directivity radiation pattern with structure inside (a) 9.89 GHz (b) 10 GHz.

5.6 Total Radiation Efficiency

The radiation efficiency is also measured and shown in **Fig. 5.6**. The highest radiation efficiency is 83.8% which is recorded at 10 GHz. The average radiation efficiency is 83.2% which is quite good to radiate.

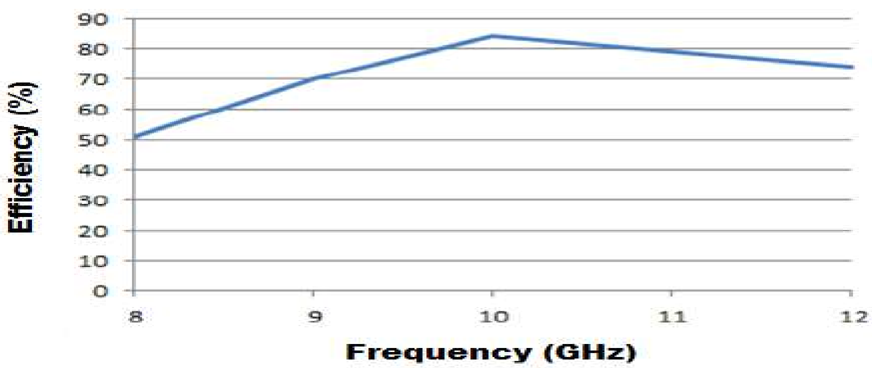
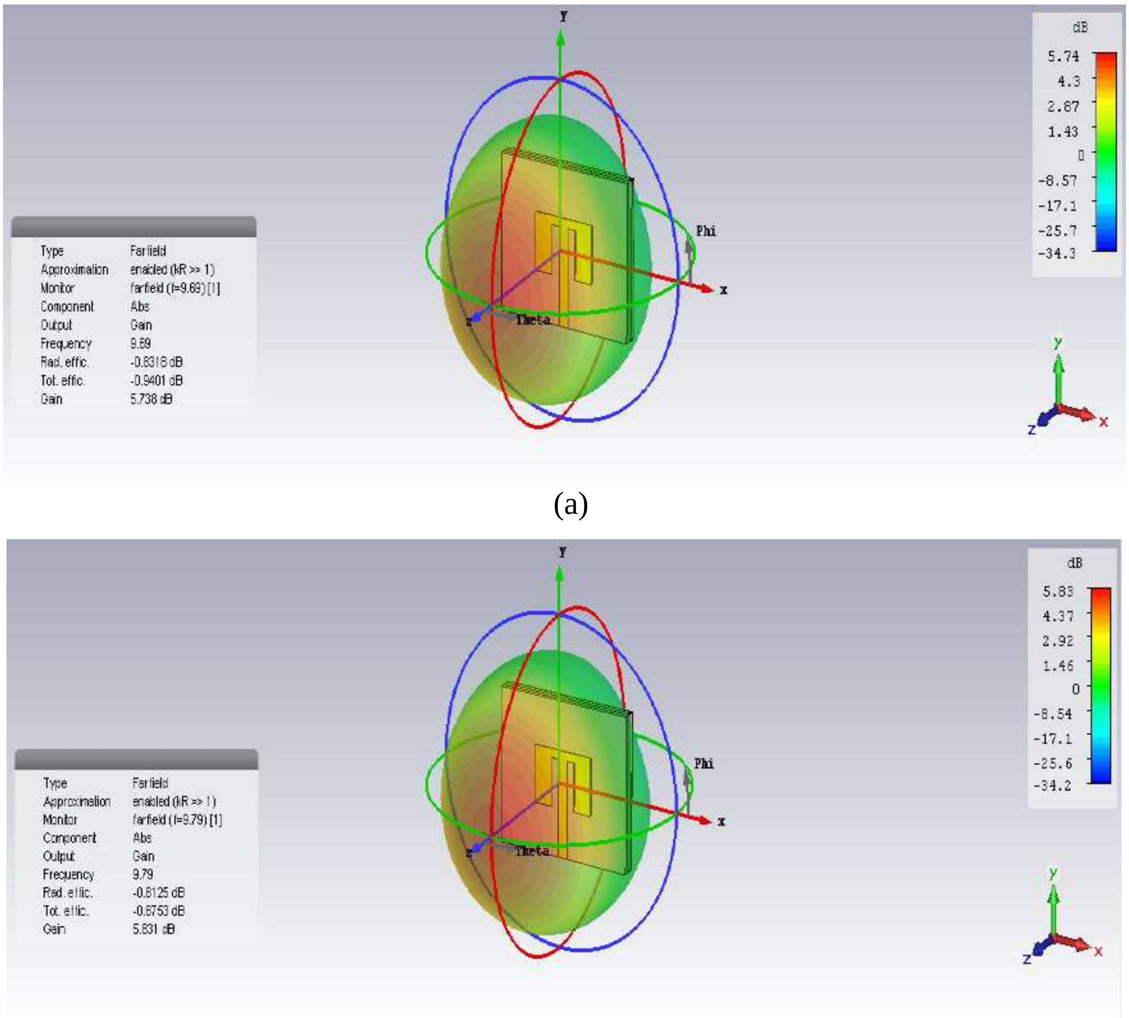


Fig. 5.6 Radiation efficiency curve of the proposed microstrip patch antenna.

5.7 Gain

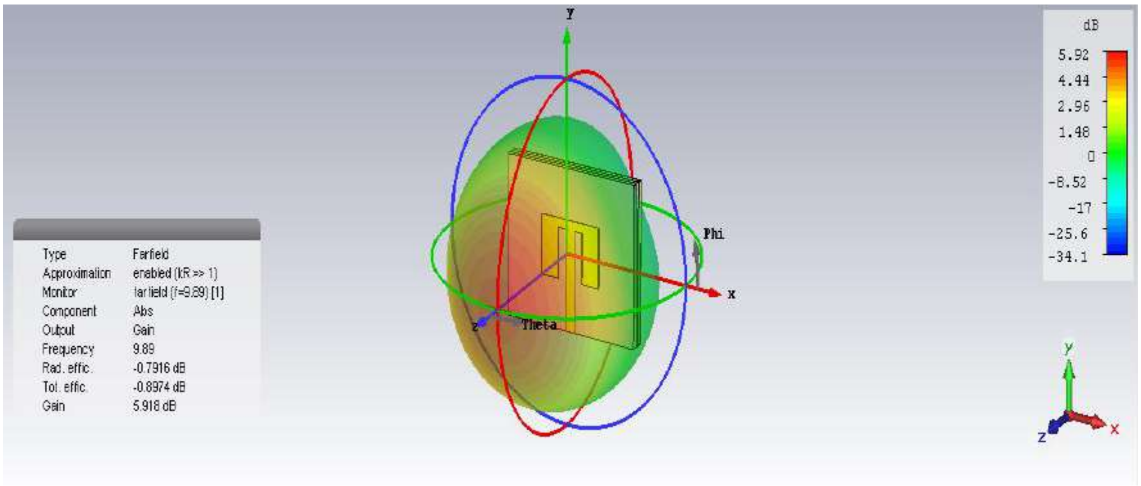
The gain of the antenna in a particular direction is more as compared to isotropic antenna radiating in all directions for providing a better performance. For frequency 9.69 GHz, 9.79 GHz, 9.89 GHz and 10 GHz among the frequency band of 9.49 GHz to 10.1 GHz, the gain of the antenna is 5.738 dB, 5.831 dB, 5.918 dB and 6.066 dB respectively. The maximum gain is achieved at 10 GHz which is 6.066 dB. Moreover, the average gain for the frequency band is 5.87 dB which is quite good for satellite applications. **Fig. 5.7** & **Fig. 5.8** shows the 3D gain plot for the proposed microstrip patch antenna with structure inside for better understanding.



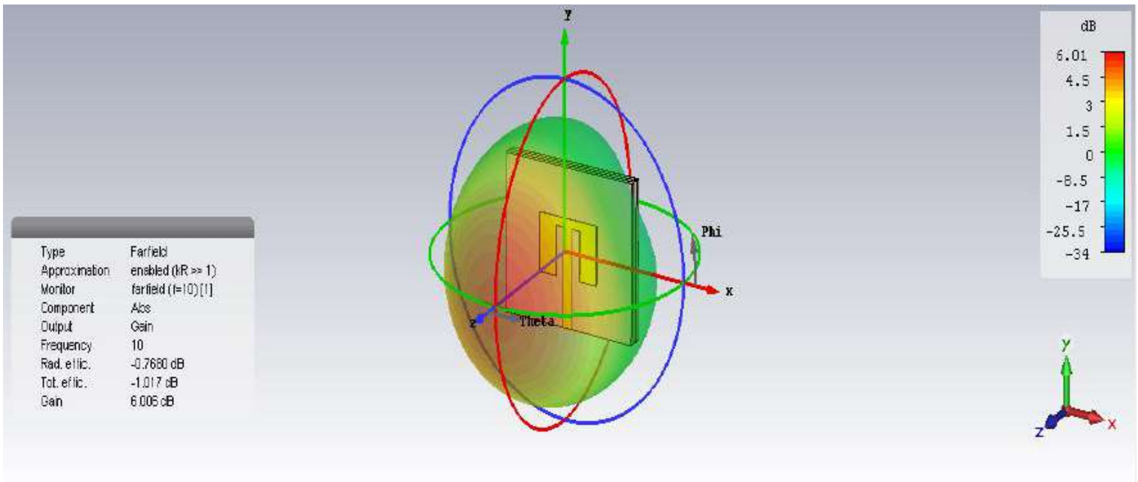
(a)

(b)

Fig. 5.7 3D view of gain radiation pattern with structure inside (a) 9.69 GHz (b) 9.79 GHz



(a)



(b)

Fig. 5.8 3D view of gain radiation pattern with structure inside (a) 9.89 GHz (b) 10 GHz.

The gain curve is shown in **Fig. 5.9**.

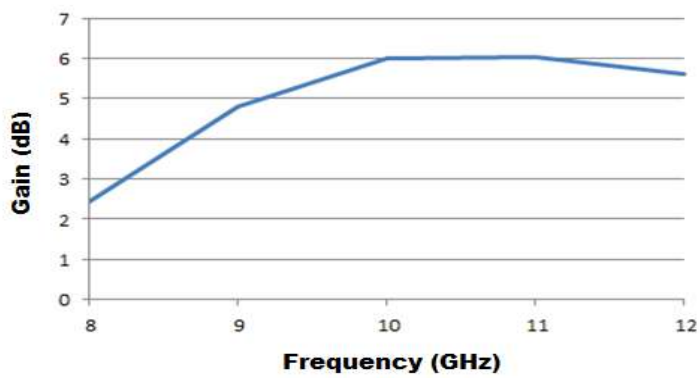
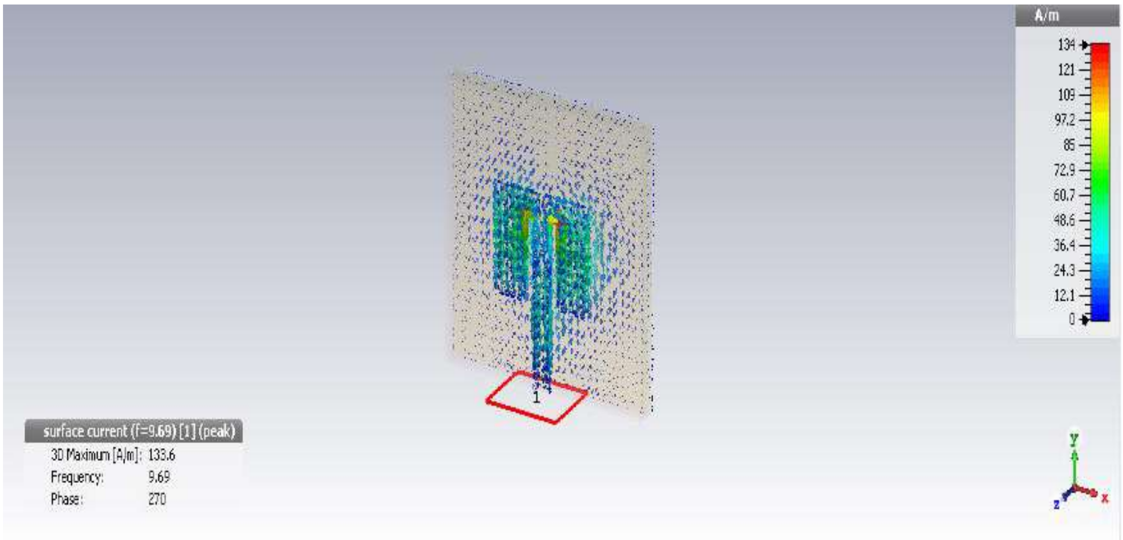


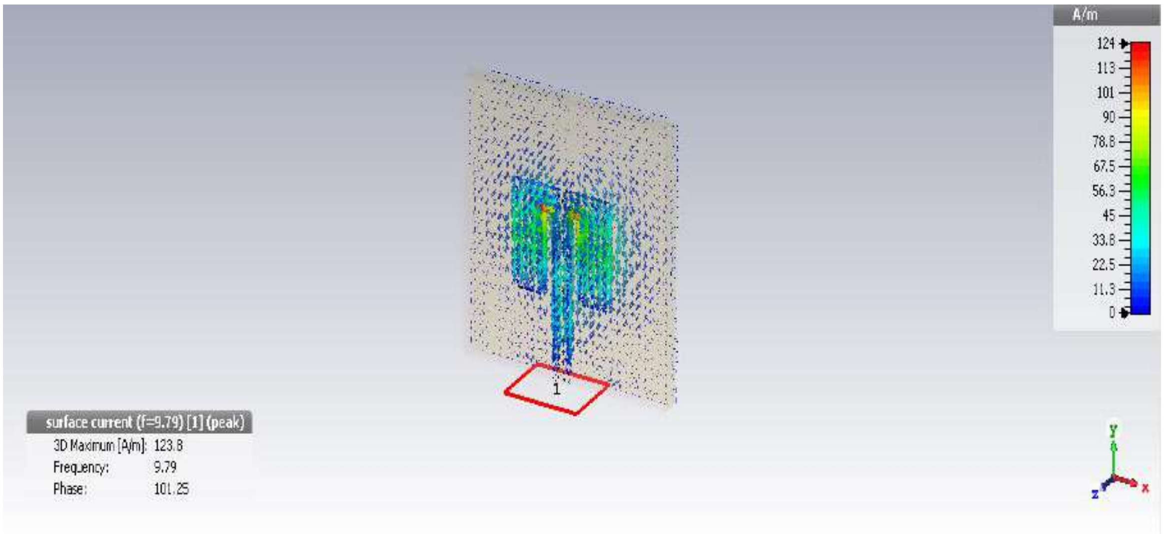
Fig. 5.9 Gain curve of proposed microstrip patch antenna.

5.8 Surface Current Distribution

Fig. 5.10 & **Fig. 5.11** shows the 3D view of the surface current distribution of the proposed microstrip patch antenna.

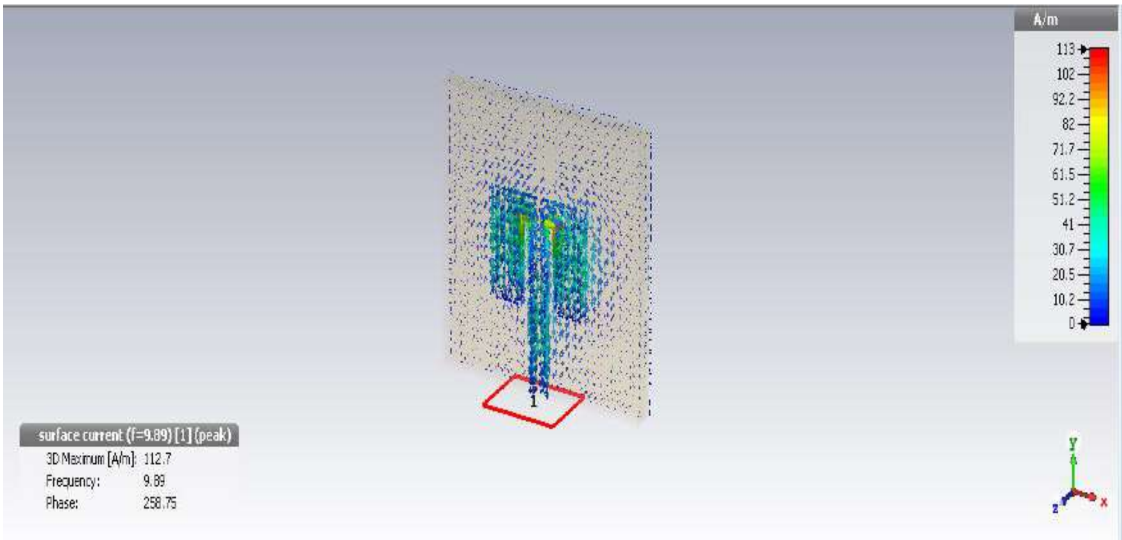


(a)

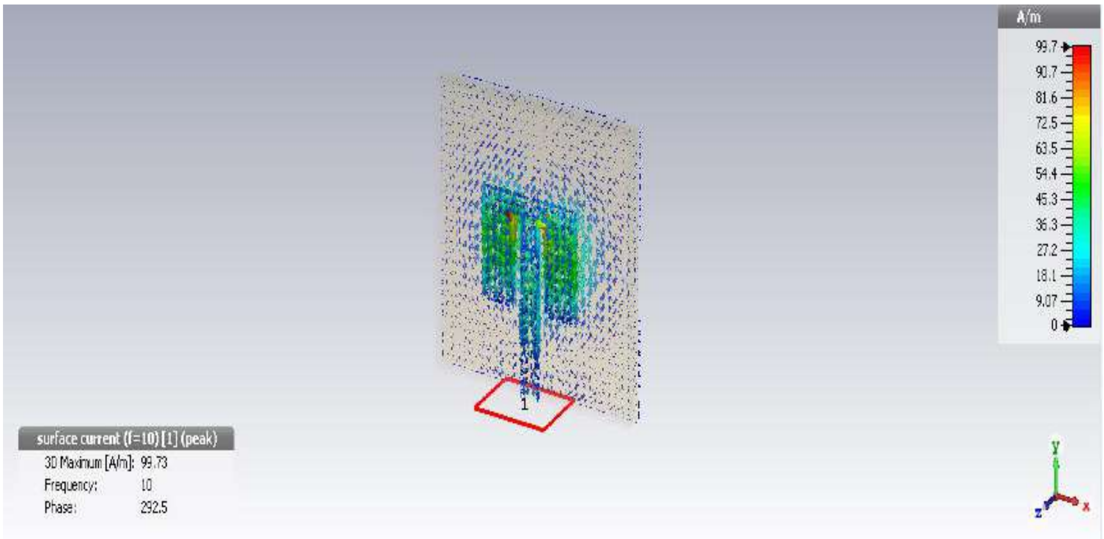


(b)

Fig. 5.10 3D view of the surface current density for frequency (a) 9.69 GHz (b) 9.79 GHz



(a)



(b)

Fig. 5.11 3D view of the surface current density for frequency (a) 9.89 GHz (b) 10 GHz.

It has been revealed through observation that surface current distribution at resonant frequency is much stronger than other frequency in the bandwidth range.

5.9 Comparison between Proposed Antenna and Existing Antenna

Table 5.2 Comparison between proposed antenna and existing antenna.

Reference	**Bandwidth (GHz)**	**Maximum Gain (dB)**	**Size (mm^3)**
Habib et al. [26]	16.7 - 17.9	4.89	5.55×3.5×1.5
M. Islam et al. [29]	9.75 - 11.85	2.1	40×40×1.6
A. Dastanraj et al. [31]	2.85 - 15.12	6.5	80×80×1
K. Aggarwal et al. [53]	9.6 - 10.3	5.6	45.9×30×1.4
Proposed MPA	9.49 - 10.1	6.01	17.49×15.29×1.67

Based on above comparison, we can say that our proposed microstrip patch antenna is good to be used in X band satellite applications for its moderate bandwidth, high gain and its compact size which makes it easy to incorporate with satellite.

In the next Chapter 6, conclusion of this study and future work is described.

CHAPTER 6

CONCLUSION

6.1 Conclusion

In this study, A compact MPA has been presented and demonstrated for X band satellite applications with high gain. Simulated results shows that using multiple dielectric layers can increase the gain than using single dielectric layer. Despite of using multi layer dielectric substrate layers, the size of antenna remains compact and small which makes it easy to incorporate with satellite. The proposed MPA resonates at 9.792 GHz with return loss of -18.44 dB having bandwidth of 9.49 GHz to 10.1 GHz (around 610 MHz). The average gain is 5.87 dB and the highest gain is 6.01 dB. Average directivity of 6.68 dBi. The average radiation efficiency is 83.1%.

Since the radiation pattern is omni-directional, so it can be used for satellite applications. Thus the proposed MPA is easy to fabricate and can be used for X band satellite applications.

Finally, all our objectives are obtained in this study.

6.2 Future Work

Based on our study, this work can be done in future:

1. Bandwidth can be enhanced by different techniques.
2. Gain can be increased by other dielectric material or by other techniques.
3. Fabrication can be done for satellite applications.
4. Verification of simulated results with the experimental results can be carried out.

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Appendix

Radar IEEE Band Designations

HF (High Frequency)	3 - 30	MHz
VHF (Very High Frequency)	30 - 300	MHz
UHF (Ultra High Frequency)	300 - 1000	MHz
L-band	1 - 2	GHz
S-band	2 - 4	GHz
C-band	4 - 8	GHz
X-band	8 - 12	GHz
Ku-band	12 - 18	GHz
K-band	18 - 27	GHz
Ka-band	27 - 40	GHz
Millimeter wave band	40 - 300	GHz