“STACKED DUAL FREQUENCY PATCH ANTENNA FOR WiMAX”

A Dissertation Submitted towards the Partial Fulfillment of

the Award of Degree of

MASTER OF TECHNOLOGY

IN

MICROWAVE AND OPTICAL COMMUNICATION ENGINEERING

BY

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ROLL NO. 05/MOC/2010

UNDER THE GUIDANCE OF

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DEPARTMENT OF
ELECTRONICS & COMMUNICATION ENGINEERING
&
APPLIED PHYSICS

DELHI TECHNOLOGICAL UNIVERSITY

SESSION 2010- 12

ACKNOWLEDGEMENT

With deep sense of admiration, I express my sincere thanks to my respected project guide, **Ms. N. Jayanthi**, Asst. Professor, ECE Department, Delhi Technological University, Delhi, for her valuable advice, guidance, timely help and the attitude with which she solved all of my queries in making this thesis possible. It has been a great honour for me to work under her.

I would also like to thank the Microwave Lab in charge, Mr. Nagesh for providing us all the things required for completing this project. His assistance was invaluable.

I also express my sincere thanks to all my M.Tech friends who have patiently extended all kind of help for accomplishing this undertaking. Finally I extend my gratitude to my family and all who are directly or indirectly involved in the successful completion of this project work.

JIMMY GAUTAM

M.Tech (MOCE)

CERTIFICATE

This is to certify that the thesis entitled **"STACKED DUAL FREQUENCY PATCH ANTENNA FOR WiMAX"** is the bonafide work carried out by me, towards partial fulfillment of the requirements for the award of the Degree of Master of Technology in Microwave and optical communication engineering jointly under Department of Electronics & Communication Engineering and Department of Applied physics of Delhi Technological University during the session 2010-12.Also, I hereby state that I have not submitted the matter embodied in this thesis for award of any other degree or diploma.

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This is to certify that the above made statements by the candidate are correct to the best of my knowledge.

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ABSTRACT

The aim of this project is to design a dual frequency microstrip patch antenna with stacked configuration in IE3D software. RT-DUROID 5880 is used as a substrate for this microstrip design. These rectangular stacked patches are excited using coaxial probe feed. The technology of mobile and wireless communication is rising at very rapid rate covering many technical areas. Worldwide Interoperability for Microwave Access (WiMax) technology is one of the most rapidly growing areas in the modern wireless communication. This provided users the mobility to shift around within a wide coverage area and even then to be connected to the network. It provides greatly increased independence and elasticity. Among wireless devices antenna is fairly a significant component. So, there is endlessly increasing necessities of capable and high performance antenna. The features of antenna which every technology requires are light weight, small in size and low cost etc. Other important desired properties of antenna are bandwidth and return loss. Next Generation devices have also more than one application embedded in single device so antenna supporting more than one band is required and multiband operation of antenna is another challenge.

The designed antennas resonate at two frequencies. 3.4 GHz and 5.6 GHz. The Bandwidth is also good enough to a sufficient level by introducing slots in the patches along with better return loss. The thesis provides a detailed study of how to design a probe-fed dual frequency microstrip patch antenna using IE3D software. Various parameters, for example the S Parameters, two dimensional and three dimensional

radiation patterns, gain, directivity and efficiency of the designed antenna are obtained from IE3D Momentum.

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LIST OF SYMBOLS

CAD	Computer Aided Design
CPW	Coplanar Waveguide
GSM	Global system for mobile communication
IEEE	institute of electrical and electronics engineering
IMT	International mobile telecommunication

ISM	International standard for mobile communication
MHz	Mega Hertz
GHz	Giga Hertz
MMIC	Microwave and millimeter wave integrated circuits
MoM	Method of moments
MSA	Microstrip Antenna
RFID	Radio frequency Identification
UWB	Ultra Wideband Antenna
VSWR	voltage standing wave ratio
WiFi	Wireless Fidelity
WiMAX	Worldwide interoperability for Microwave access
WLAN	wireless local area network

Chapter 1

Introduction

In This chapter, a concise introduction about importance of a microstrip patch antennas and different wireless standards is presented. This will explain the objective of the thesis and the summary of the complete thesis. Outline of the main topics of all chapters will be given in this chapter in brief manner

1.1 Introduction

For any communication system, antenna is one of the most important components. An antenna should be tuned to the frequency of the system, to which it is connected or operated. Antenna emits radiation after signal is fed to it and radiation is further distributed in the space in some manner. Radiation pattern is the name given to the graphical representation of the power radiated by the antenna. Due to the light weight, low cost and other advantageous characteristics, microstrip antenna has made scope and place in the wireless applications. Since mid 1950's, the radiation properties of microstrip structures are known and their application started in 1970's in missiles. Electronic circuit miniaturization has also become the main reason for the applications of patch antenna because the conventional antennas are bulky and also costly. Microstrip antennas are based on photolithography techniques. The only drawback of the conventional patch antenna is that it does not have good bandwidth characteristics. but some approaches can be applied to improve the microstrip antenna bandwidth. These include increasing the substrate thickness, introducing parasitic element either in coplanar or stack configuration, and modifying the shape of a common radiator patch by incorporating slots. The successful examples include E-shaped patch antennas, U-slot patch antennas, and V-slot patch antennas etc.

New technologies are emerging in the field of wireless communication day by day in which main point to think about the design are low cost, light weight, good performance, ease of installation of the components like in the field of mobile communication, satellite communication etc.. The multimedia communication is growing and working to connect people with technology to utilize the resources in better way. Information exchange with high speed and in less time with accuracy is the demand everywhere.

WiMAX (Worldwide Interoperability for Microwave Access)

WiMAX (Worldwide Interoperability for Microwave Access) is one of the new technologies in the information and communication field. In the current time, Worldwide Interoperability for Microwave Access (WiMAX) technology is fastest growing area in the modern wireless communication. The name WiMAX was created by the WiMAX forum which was formed in June 2001 to promote conformity and interoperability of the standard. The current WiMAX revision provides up to 40

Mbit/s with the IEEE 802.16m update expected to offer up to 1 Gbit/s fixed speeds. The IEEE 802.16 standard forms the basis of 'WiMAX' and is sometimes referred to colloquially as "WiMAX", "Fixed WiMAX", "Mobile WiMAX", "802.16d" and "802.16e". This provides users the mobility to move around within a wide coverage area and still be connected to the network. This also gives greatly increased freedom and flexibility. For the home user, wireless has become well-liked technology due to simplicity of installation, and location freedom. For success of all these wireless applications we require efficient and small antenna. In such a situation, portable antenna technology has developed along with mobile and cellular technologies. It is essential to have the best performance antenna for a device. The best performance antenna will get better transmission and reception, decrease power consumption, and increase marketability of the communication device.

Microstrip antennas can provide linear as well as circular polarisation. They can be printed using printed circuit board technology which is not so expensive and also they are compatible with MMIC. Due to these benefits, Microstrip antennas (MSA) are well suited for WLAN/WiMax application systems. Also, the technological demands of antennas which can function on various wireless bands and which also exhibits properties like low cost, less weight, low profile and have tendency of maintaining brilliant performance over a large spectrum of frequencies. In a single device, more than one application is embedded in next generation devices in which an antenna with the capability to operate in more than one band is required which has become the challenge. The systems having multi-band operation need antennas that resonate at the specified frequencies. On the other side, MSA have some drawbacks like narrow bandwidth, low gain etc. but these problems can be solved by some techniques which can make antennas to work properly for wider range of frequencies, i.e. Wider Bandwidth.

Different standards referred by IEEE are given in Table 1.1 shown below; table describes the different wireless bands and corresponding bandwidth suggested for different standards.

Table 1.1 Different types of wireless applications

Wireless Applications		Frequency Band (MHz)	Bandwidth (MHz)
GSM	GSM 900	890-960	70
	GSM 1800	1710-1805	95
	GSM 1900	1850-1990	140
IMT		2300-2400	100
		2700-2900	200
		3400-4200	800
		4400-4900	500
WLAN		2400-2484	84
		5150-5350	200
		5725-5825	100
Bluetooth		2400-2500	100
WiMAX		2500-2690	190
		3400-3690	290
		5250-5850	600

1.2 Purpose of the Thesis

a) Study of rectangular microstrip patch antenna
b) Design and simulation of Coaxial fed dual frequency stacked microstrip patch antenna for WiMAX applications.

1.3 Outline of the Thesis

Chapter1: The need of microstrip antennas in wireless application is presented with their benefits. Also different frequency bands for wireless applications are also shown and a brief introduction of WiMAX is given.

Chapter2: Fundamentals of antenna are discussed in these terms with the help of various important antenna terminologies which are necessary to be known before everything to proceed further in this project.

Chapter2: Microstrip antennas and their advantages and limitations are discussed. Various feeding methods and models are explained. It also gives explanation o f different problems and challenges which comes in design of Microstrip Patch antenna. The work that is already been published by the authors in context of Microstrip patch antenna design is given.

Chapter4: Dual frequency antenna and their types are discussed. Stacked patch antenna is focused more and circular polarisation is given in brief.

Chapter5: Geometry and simulated results of the designed antenna are shown in this chapter. Various parameters like return loss, smith chart, bandwidth, radiation pattern of the designed antenna are shown which verify that this antenna operates on dual frequency and resonates at 3.4GHz and 5.6GHz The effects of feed point location, is also shown graphically with smith chart and return loss.

Chapter6: The conclusion and future scope is given in this chapter.

CHAPTER 2

Antenna Basics and Literature Survey

2.1 Antenna terminology

First of all, we need to have knowledge of main antenna terms which are used in the designing of antenna to understand the concept of antenna. Some most important terms are given below.

2.1.1 Radiation pattern

The radiation from antenna in any direction is measured in terms of field strength at a point located at a particular distance from antenna. Radiation pattern of an antenna indicates the distribution of energy radiated by the antenna in the free space. The antenna radiation pattern, or antenna pattern, is defined as ``a mathematical function or a graphical representation of the radiation properties of antenna as a function of space coordinates" [1]. Radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization. The radiation pattern can be presented in two forms:

- Azimuth Pattern- The top view of the energy radiated by an antenna is known as Azimuth Pattern
- Elevation Pattern- the graphical side view is called an Elevation

Basically three types of patterns are studied which are as following

- **Field pattern** (in linear scale) typically represents a plot of the magnitude of the electric or magnetic field as a function of the angular space.
- **Power pattern** (in linear scale) typically represents a plot of the square of the magnitude of the electric or magnetic field as a function of the angular space.
- **Power pattern** (in dB) represents the magnitude of the electric or magnetic field, in decibels, as a function of the angular space.

Lobes in radiation pattern

Different parts of a radiation pattern are referred to as lobes, which may be subclassified into major or main, minor, side, and back lobes [1].

- A major lobe is defined as "the radiation lobe containing the direction of maximum radiation."A minor lobe is any lobe except a major lobe all the lobes with the exception of the major can be classified as minor lobes.
- A side lobe is "a radiation lobe in any direction other than the intended lobe.
- A back lobe is "a radiation lobe whose axis makes an angle of approximately 180◦ with respect to the beam of an antenna."

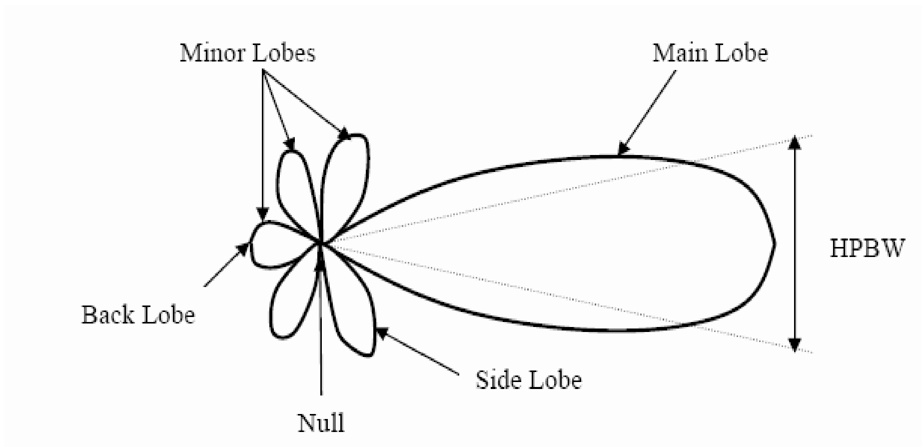

Figure 2.1: Radiation pattern of antenna

Types of patterns

- Directional antenna is one "having the property of radiating or receiving electromagnetic waves more effectively in some directions than in others. This term is usually applied to an antenna whose maximum directivity is significantly greater than that of a half-wave dipole."
- Omni-directional (radiates equally in all directions), such as a vertical rod (in the horizontal plane)
- Isotropic Radiators is one which radiates its energy equally in all directions. Even though such elements are not physically realizable, they are often used as references to compare to them the radiation characteristics of actual antennas

Microstrip antenna is an Omni-directional antenna which radiates normal to the patch surface into the upper hemisphere (180° in elevation plane) and 360° in azimuth plane. The rectangular patch excited in its fundamental mode has a maximum directivity in the direction perpendicular to the patch. The directivity decreases when moving away from broadside towards lower elevations. The 3 dB beamwidth (or angular width) is twice the angle with respect to the angle of the maximum directivity, where this directivity has rolled off 3 dB with respect to the maximum directivity.

2.1.2 Radiation intensity

Radiation intensity in given direction is defined as "the power radiated from an antenna per unit solid angle" [1]. The radiation intensity is a far-field parameter, and it can be obtained by simply multiplying the radiation density by the square of the distance. In mathematical form it is expressed as

$$U = r^2 W_{rad} \tag{2.1}$$

Where U = radiation intensity (W/unit solid angle)

W_{rad} = radiated energy

2.1.3 Directivity

Directivity of an antenna defined as "the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions [1]. The average radiation intensity is equal to the total power radiated by the antenna divided by 4π. If the direction is not specified, the direction of maximum radiation intensity is implied." Stated more simply, the directivity of a nonisotropic source is equal to the ratio of its radiation intensity in a given direction over that of an isotropic source. In mathematical form, using (2-15), it can be written as

$$D_{max} = D_0 = \frac{U_{max}}{U_o} = \frac{4\pi U_{max}}{P_{rad}} \tag{2.2}$$

D= directivity (dimensionless)

D_0= maximum directivity (dimensionless)

U = radiation intensity (W/unit solid angle)

U_{max} = maximum radiation intensity (W/unit solid angle)

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

2.1.4 Antenna efficiency

In antenna theory, radiation efficiency, which is often abbreviated to just efficiency is a figure of merit for an antenna [1]. It is a measure of the electrical losses that occur in the antenna. Radiation efficiency is defined by IEEE Std. 145-1983 "Definitions of Terms for Antennas" as "The ratio of the total power radiated by an antenna to the net power accepted by the antenna from the connected transmitter." It is sometimes expressed as a percentage. It will be frequency dependent.

2.1.5 Antenna gain

Gain is a measure of the ability of the antenna to direct the input power into radiation in a particular direction and is measured at the peak radiation intensity [1]. Consider the power density radiated by an isotropic antenna with input power P_0 at a distance R which is given by $S = P_0/4\pi R^2$. An isotropic antenna radiates equally in all directions, and it's radiated power density S is found by dividing the radiated power by the area of the sphere $4\pi R^2$. An isotropic radiator is considered to be 100% efficient. The expression for the maximum gain of an antenna is as follows

$$G = \eta \times D \tag{2.2a}$$

Where G is gain of antenna, η is efficiency and D is directivity.

Gain is achieved by directing the radiation away from other parts of the radiation sphere. In general, gain is defined as the gain-biased pattern of the antenna.

2.1.6 Beamwidth

The beamwidth of a pattern is defined as the angular separation between two identical points on opposite side of the pattern maximum [1]. In an antenna pattern, there are a number of beamwidths. One of the most widely used beamwidths is the Half-Power Beamwidth (HPBW), which is defined by IEEE as: “In a plane containing the direction of the maximum of a beam, the angle between the two directions in which the radiation intensity is one-half value of the beam.”

Antenna beamwidth is defined as the angle between half power points on the main beam. In case that we have a logarithm radiation power pattern in [dB] units, it means that we measure the angle between two 3dB points. The beamwidth of an antenna is defined as the angular separation between two identical points on opposite sides of the pattern maximum as seen in figure 2.1. There are a number of beamwidths in the antenna pattern. One of the most widely used beamwidths is the Half-Power Beamwidth (HPBW) [1].

2.1.7 Polarization

Polarization is the orientation of the electromagnetic waves far from the source. There are several types of polarization that apply to antennas [1].

- Linear (which comprises vertical and horizontal), oblique,
- Elliptical (left hand and right hand polarizations),
- Circular (left hand and right hand) polarizations.

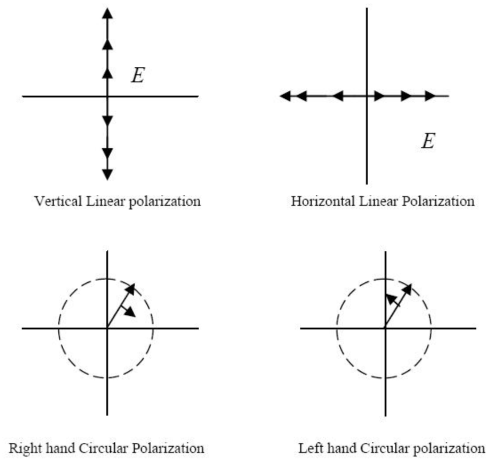

Figure 2.2: Different types of polarization

Polarization of a radiated wave is defined as "that property of an electromagnetic wave describing the time-varying direction and relative magnitude of the electric-field vector; specifically, the figure traced as a function of time by the extremity of the vector at a fixed location in space, and the sense in which it is traced, as observed along the direction of propagation [1]".

a) **Linear Polarization** A time-harmonic wave is linearly polarized at a given point in space if the electric-field (or magnetic-field) vector at that point is always oriented along the same straight line at every instant of time
b) **Circular Polarization** A time-harmonic wave is circularly polarized at a given point in space if the electric (or magnetic) field vector at that point traces a circle as a function of time. A circular polarized antenna can either be right-hand circular polarized (RHCP) or left-hand circular polarized (LHCP). The antenna is RHCP when the phases are 0° and 90° for the antenna in the figure below when it radiates towards the reader, and it is LHCP when the phases are 0° and 90°.

c) **Elliptical Polarization** A time-harmonic wave is elliptically polarized if the tip of the field vector (electric or magnetic) traces an elliptical locus in space. A wave is elliptically polarized if it is not linearly or circularly polarized. Although linear and circular polarizations are special cases of elliptical, usually in practice elliptical polarization refers to other than linear or circular.

2.1.8 Input impedance

Input impedance is defined as "the impedance presented by an antenna at its terminals or the ratio of the voltage to current at a pair of terminals or the ratio of the appropriate components of the electric to magnetic fields at a point"[1]. In this section we are primarily interested in the input impedance at a pair of terminals which are the input terminals of the antenna. In Figure 2.27(a) these terminals are designated as a − b. The ratio of the voltage to current at these terminals, with no load attached, defines the impedance of the antenna as

$$Z_A = R_A + jX_A \tag{2.3}$$

Where R_A – the real part, representing the power dissipated though heat or through radiation losses

X_A = imaginary part, representing the reactance of the antenna & the power stored in the near field of the antenna.

2.1.9 Reflection Coefficient and Return Loss

Reflection coefficient shows what fraction of an incident signal is reflected when a source drives a load. A **reflection coefficient** magnitude of zero is a perfect match; a value of one is perfect reflection. The symbol for reflection coefficient is uppercase Greek letter gamma (Γ). A short circuit has a value of -1 (1 at an angle of 180 degrees), while an open circuit is one at an angle of 0 degrees. Quite often we refer to only the magnitude of the reflection coefficient [1].

Return Loss shows the level of the reflected signal with respect to the incident signal in dB. The negative sign is dropped from the return loss value, so a large value for return loss indicates a small reflected signal. The return loss of a load is merely the magnitude of the reflection coefficient expressed in decibels. The correct equation for return loss is:

(2.4)

$$\text{Return loss} = -20 \times \log [\text{mag}(\Gamma)]$$

Where Γ is reflection coefficient

Thus in its correct form, return loss will usually be a positive number. If it's not, you can usually blame measurement error. The exception to the rule is something with negative resistance, which implies that it is an active device (external DC power is converted to RF) and it is potentially unstable (it could oscillate)

2.1.10 Bandwidth

The bandwidth of an antenna is defined as "the range of frequencies within which the performance of the antenna, with respect to some characteristics, conforms to a specified standard". The bandwidth can be considered to be the range of frequencies on either side of the center frequency where the antenna characteristics are close to those at the center frequency [1].

The bandwidth of an antenna is defined as the range of frequencies within which the performance of the antenna, with respect to specific characteristics, conforms to a specified standard. The desired bandwidth for this application was specified as 20% based on the return loss values below -10 dB. (Return loss is a measure of the reflection coefficient at the antenna terminals.) The bandwidth is the ratio of the upper and lower frequencies of an operation, expressed as

$$BW_{broadband} = \frac{f_H}{f_L} \tag{2.5}$$

$$BW_{narrowband} = \frac{(fH - fL)}{f_c} \times 100 \tag{2.6}$$

2.2 Literature

Before starting my project, it was compulsory to accumulate data and go through it for better knowledge and information. Information for the thesis was mainly gathered from books, journal, papers and the internet. Few papers which are published in the regard of my project are given below:

Dual-Band Circularly Polarized Antennas Using Stacked Patches with Asymmetric U-Slots [9]

In this paper, a new design for single-feed dual-band circularly polarized microstrip antennas is presented. A stacked patch configuration is used for the antenna, and circular polarization is achieved by designing asymmetrical U-slots on the patches. The dimensions of the U-slots are optimized to achieve circular polarization in both bands. A prototype has been designed to operate at two frequencies with a ratio of 1.66. Both experimental and theoretical results are presented and discussed. The circularly polarized bandwidth of the antenna is 1.0% at 3.5 GHz (WiMax) and 3.1% at 5.8 GHz (HiperLAN).

Dual frequency broadband microstrip antenna with a reactive loading and stacked elements [11]

A dual-band enhanced-bandwidth microstrip antenna is presented with a frequency separation of f2/f1 = 1:33. In order to achieve the dual-frequency operation, a rectangular patch is loaded with a stub at one of its radiating edges. To improve bandwidth at each band, two parasitic patches are coupled to the driven element. Bandwidths from a dual-band narrow-band antenna have been presented. The enhancement factors have been proved to be 9 in the first band and 5 in the second one, achieving bandwidths of 14.9% and 2.36% respectively. With regard to the gain, it is 8.4 dB in the first band and 7.7 dB in the second one; radiation patterns are both broadside which is of particular interest of base station antennas.

On the Dual-Frequency Behavior of Stacked microstrip Patches [12]

The dual-frequency behavior of stacked rectangular microstrip patches fabricated on a two-layered substrate is investigated. In the case where the top patch is longer than the bottom one, computations show that the lower resonance is very close to the resonant frequency of the isolated top patch and the upper resonance is determined primarily by the size of the bottom patch. In the opposite case, the investigation shows also that the lower resonance is very close to the resonant frequency of the isolated bottom patch and the upper resonance is highly dependent on the top patch size. Other results also indicate that substrate dielectric anisotropy has a more pronounced effect on the lower resonance than on the upper resonance.

Bandwidth Enhancement for Microstrip Patch Antenna Using Stacked Patch and Slot [13]

Small size wideband microstrip patch antenna with slot in ground plane and stacked patch fed through microstrip line is presented. By inserting slot on ground plane and stacked patch supported by wall, the bandwidth can improve up to 25% without significant change in the frequency. The bandwidth before adding the slot and the stacked patch was 3.72%, whereas after adding the slot and the stacked patch the bandwidth increased up to 25% ranging from 2.45 to 3.3 GHz. The radiation pattern has acceptable response at both E-plane and H-plane. The ground plane size is 30x90 mm; the antenna designed is based on Roger RT/duroid 5880 with dielectric constant 2.2.

H-shaped stacked patch antenna for dual band operation [14]

Analysis of U-slot loaded patch stacked with H-shaped parasitic elements is given in this paper. It is found that the antenna exhibits dual resonance and both the resonance frequency (upper and lower) depends directly on slot width and inversely on slot length. Both upper and lower resonance frequency increase with increasing the value of h2. Typically the bandwidth at lower and upper resonance is found 3.66% and 10.25% respectively. The radiated power at higher frequency is 0.73 dB as compared to lower resonance frequency. The theoretical results are compared with the simulated data obtained from IE3D. From the analysis it is found that U-slot loaded patch when stacked with H-shaped patch exhibits dual resonance and the radiated power and directivity improves.

A practical miniaturized u-slot patch antenna with enhanced bandwidth [15]

In this paper, an asymmetric U-slot patch antenna with low probe diameter is presented. It will be shown that reduction in probe diameter causes in reduction in bandwidth. One of the characteristics of this antenna is keeping the bandwidth in 30% in spite of reduction in antenna size and use of low probe diameter. The presented antenna in this paper has been fabricated by PCB technique and tested. The far-field results have also been presented based on simulation and measurement. Although the antenna has high cross polarisation level, in the case of using circular polarisation, the use of this antenna can be recommended because of its reduced size, high impedance bandwidth, high total gain in spite of having low size, and ease of fabrication.

Simulation and Design of Wide-Band Patch Antennas for Wireless Technology [16]

This paper presents the design of a dual band microstrip antenna for wireless communication. This antenna has a bandwidth of 24% with center frequency 5.57 GHz. The antenna is designed as a patch with two slots. The outer dimensions of the patch are designed so that the antenna resonates at the upper resonant frequency. The dimensions of the slots are designed to control the lower resonant frequency and the bandwidth. The paper presents how to choose the dimensions of the patch and the slots to control the resonant frequencies and the bandwidth of the antenna. A design and simulation of a patch antenna based on this geometry for WiMax technology is also presented.

Broadband Stacked Patch Antenna with Low VSWR and Low Cross-Polarization [18]

Low cross-polarization broadband stacked patch antenna is proposed. By means of the stacked patch configuration and probe-fed strip feed technique, the VSWR 1.2:1 bandwidth of the patch antenna is enhanced to 22% from 804 MHz to 1,002 MHz, which outperforms the other available patch antennas (<10%). Furthermore, the antenna has a cross polarization level of less than –20 dB and a gain level of about 9 dBi across the operating bandwidth. Simulation results are compared with the measurements, and a good agreement is observed A low cross-polarization broadband stacked patch antenna is presented. The proposed antenna has a wide VSWR 1.2:1 bandwidth (22%) and a low cross-polarization level (< –20 dB). The VSWR of the antenna is much lower than other available broadband patch antennas.

Design of Single-Feed Dual-Frequency Patch Antenna for GPS and WLAN Applications [19]

A design of single-feed dual-frequency patch antennas with different polarizations and radiation patterns is proposed. The antenna structure is composed of two stacked patches, in which the top is a square patch and the bottom is a corner-truncated square-ring patch, and the two patches are connected together with four conducting strips. Two operating frequencies can be found in the antenna structure. The radiations at the lower and higher frequencies are a broadside pattern with circular polarization and a conical pattern with linear polarization, respectively. A prototype operating at 1575 and 2400 MHz bands is constructed. Both experimental and simulated results show that the prototype has good performances and is suitable for GPS and WLAN applications.

Broadband Stacked H-shaped Patch Antenna [20]

A broadband U-slot loaded rectangular patch stacked with H-shaped patch antenna is presented in this paper. The resonating behavior of antenna depends on Slot width, slot length of side arm and base arm of U-slot. Similarly, it depends on notch length and width of H shaped parasitic patch and separation between the two patches. Optimization of these parameters gives impedance Bandwidth of 44.5%. The theoretical results are in good agreement with simulated results. From the analysis it is found that U-slot loaded patch when stacked with H-shaped patch exhibits broadband resonance with similar radiation pattern for entire range.

Compact double U-Slots Patch Antenna for Mobile WiMAX Applications [21]

A small triple-band 2.7 GHz, 3.2 GHz and 5.3 GHz compact microstrip patch antenna with two U shaped slots and a small ground plane is presented. It has been developed to be used in future WiMAX technology. The required bandwidths are fulfilled the WiMAX technology 4.8 %, 3 % and 2.5 % respectively. The return loss for the triple band are -18.5 dB, -14.5 dB and -19 respectively. The triple-band behaviour at 2.7, 3.2 and 5.3 GHZ has been achieved as well as the bandwidth requirements for WiMAX standards 4.8 %, 3 % and 2.5 % respectively. The return loss for the triple band is -18.5 dB, -14.5 dB and -19 dB respectively. Very broad radiation patterns have been obtained which seems to be adequate for the envisaged applications

A New I Slotted Compact Microstrip Antenna for L1 & L2 Bands [22]

A new high gain dual-band circularly polarized with a small frequency ratio is proposed for Global Positioning System (GPS) applications covering L1 and L2 frequencies of 1.575GHz and 1.227GHz. The antenna is consists of I slotted compact microstrip antenna with two truncated corners square patches that overlapped without an air-gap. The design achieved an impedance bandwidth of 20 MHz from 1.22 GHz to 1.24 GHz for the lower band, while upper band covers 97.88 MHz (from 1.562 to 1.66 GHz) with maximum gain of 7.27dBi and 6.87dBi in the lower and upper frequency band respectively. The bandwidth (VSWR ≤ 2) is 1.57% (1.222 GHz to 1.2414 GHz) for L2 and 6.27% (1.5617 GHz to 1.6626 GHz) for L1. The details of the antenna design are shown, and the results with low-profile characteristics make the antenna suitable for GPS applications.

L – Slotted rectangular microstrip patch antenna [24]

The microstrip patch is one of the most preferred antenna structures for low cost and compact design for wireless system and RF application. Dual-Band antennas are of a relative interest since they can support multiple communication systems. In this paper we present design of a novel compact small size microstrip antenna suitable for dual-band operations. By loading properly arranged slots on a rectangular microstrip patch, dual frequency and broadband operations of a single feed rectangular patch is achieved. Dual frequency operation is achieved by loading two pair of narrow slots in rectangular patch, parallel to the non radiating edge and better impedance bandwidth is achieved by using two dielectric materials Rohacell RO3003 in combination with foam. The impedance bandwidth of 130MHz and 1.45GHz band is obtained in the proposed design.

CHAPTER 3

Microstrip Antennas

3.1 MICROSTRIP ANTENNAS [2]

Microstrip antennas are planar resonant cavities that seep out from their edges and radiate. We can use printed circuit techniques to engrave the antennas on soft substrates to create low-cost and repeatable antennas in a small profile. The antennas fabricated on compliant substrates withstand tremendous shock and vibration environments. Manufacturers for mobile communication base stations often fabricate these antennas directly in sheet metal and mount them on dielectric posts or foam in a variety of ways to eliminate the cost of substrates and etching. This also eliminates the problem of radiation from surface waves excited in a thick dielectric substrate used to increase bandwidth. The dielectric substrate retains most of the power because the shielding ground plane is spaced a few substrate thicknesses away. Removing the shield in antenna applications allows radiation from resonant cavities. We also discover feeding circuits etched on the substrate radiate to some extent, but their radiation is comparatively small.

Microstrip patch antennas consist of metal patches large with respect to normal transmission-line widths. A patch radiates from fringing fields around its edges. Impedance match occurs when a patch resonates as a resonant cavity. When matched, the antenna achieves peak efficiency. A normal transmission line radiates little power because the fringing fields are matched by nearby counteracting fields. Power radiates from open circuits and from discontinuities such as corners, but the amount depends on the radiation conductance load to the line relative to the patches. Without proper matching, little power radiates. The edges of a patch appear as slots whose excitations depend on the internal fields of the cavity. The radiating edges and fringing fields present loads along the edges.

3.2 MICROSTRIP ANTENNA PATTERNS [2]

Patches consist of metal plates suspended over large ground planes. Electric currents flow on the plate and on the ground plane around the antenna, and these radiate. If we use vertical probes to excite the antenna from coaxial lines, the currents flowing on these radiate and add to the pattern.. Figure 3.1 illustrates the fringing electric fields around the edges of square and circular patch antennas excited in the lowest-order cavity modes. The arrow sizes indicate the magnitude of the fields. The fields vanish along a virtual electrically short-circuited plane halfway across the patches. On either side of the short-circuit plane, the fields are directed in opposite directions. Looking from above the fields along the width, both edges are in the same direction

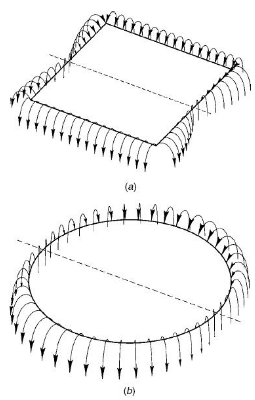

Figure 3.1: Fringing electric fields around microstrip patches: (*a*) Square (*b*) Circular

Magnetic currents found from the fringing electric fields can replace the electric currents located on the patch and the surrounding ground plane for pattern analysis. Figure 3.2 shows the distribution of magnetic currents around the edges, with the size of the arrowhead indicating magnitude.

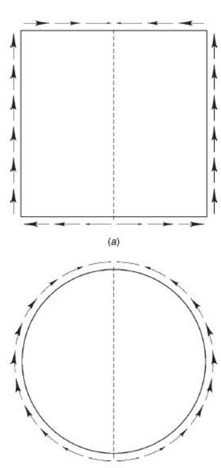

Figure 3.2 Equivalent magnetic currents: (a) Square (b) Circular

3.3 RECTANGULAR MICROSTRIP PATCH ANTENNA [2]

Rectangular patch antennas can be designed by using a transmission-line model [9] suitable for moderate bandwidth antennas. Patches with bandwidths of less than 1% or greater than 4% require a cavity analysis for accurate results, but the transmission line model covers most designs. The lowest-order mode, TM10, resonates when the effective length across the patch is a half-wavelength.

In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, and elliptical or some other common shape as shown in Figure 2.2. For a rectangular patch, the length L of the patch is usually $0.3333\lambda_o < L < 0.5\ \lambda_o$, where λ_o is the free-space wavelength. The patch is selected to be very thin such that $t << \lambda_o$ (where t is the patch thickness). The height h of the dielectric substrate is usually $0.003\ \lambda_o \leq h \leq 0.05\ \lambda_o$. The dielectric constant of the substrate (ε_r) is typically in the range $2.2 \leq \varepsilon_r \leq 12$. 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 reduced by increasing the thickness of the dielectric substrate. But as the thickness increases, an increasing fraction of the 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. Other problems such as lower gain and lower power handling capacity can be overcome by using an array configuration for the elements.

3.4 Properties of Microstrip Patch Antennas

Microstrip Antennas have many advantages in comparison with the conventional microwave antenna and hence many applications cover the broad frequency range from 100 MHz to 100 GHz. Some of the main characteristics of Microstrip antennas compared to conventional Microwave antennas are: [1]

- It has light weight and low volume.
- It has small profile planar configuration which can be easily created conformal to host surface.
- It has less fabrication cost, so it can be manufactured in large quantities.

- In patch antennas, Linear as well as circular polarizations are possible with simple feed.
- It can be easily incorporated with microwave integrated circuits (MICs).
- It has tendency of multiple frequency operations.
- It is mechanically strong when mounted on rigid surfaces
- It is Easy to make because fabrication can be done in PCB lab.

On the other side Microstrip Antennas also have some disadvantages and limits in comparison with the conventional microwave antennas which are given as following:

- It has Narrow bandwidth and associated tolerance problems.
- Patch antenna has Low efficiency.
- It has low gain (6 dB).
- It suffers large ohmic loss in the feed structure of arrays.
- It suffers from extraneous radiation from feeds and junctions.
- It is bad end fire radiator except tapered slot antennas.
- It has Low power handling capacity.
- It has Surface wave excitation.

A simple microstrip patch antenna is consisted of following

- A radiating patch (perfect electric conductor)
- Substrate
- Ground (perfect electric conductor)

Limitations can be addressed by using the following techniques [Kraus antenna]

1. Using thick substrates
2. Cutting slots
3. Introducing parasitic patch in the same plane or above top patch
4. Using aperture coupled stacked patches

Important parameters in designing Microstrip patch antennas are:

- Shape of the Metallic Patch
- Thickness of the Substrate

- dielectric constant of substrate and its tangent loss
- Type of feed used

3.5 Techniques to feed the patch antenna

One of the significant aspects of microstrip patch antenna is the range of feeding method appropriate for them. Microstrip patch antennas have radiating elements on one side of a dielectric substrate and can be fed by different methods. Between the feed line and the antenna input impedances, matching is mainly required. A fine impedance matching condition between the line and the patch without an extra matching elements is dependent heavily on feeding technique used. These techniques can be classified into two categories; one is Contacting and other is Non-contacting. In the former type, the RF power is given directly to the radiating patch using a connecting element such as a microstrip line. In the latter scheme, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch.

Following are the various feeding techniques depending upon the above categories:

- The microstrip line feed (contacting method) [1]
- Coaxial probe (contacting method) [5]
- Aperture coupling (non-contacting method) [3]
- Proximity coupling (non-contacting method) [3]
- Coplanar waveguide feed (contacting method) [3]

3.5.1 Microstrip line feed

In this technique, a conducting strip is linked in a straight line to the edge of the microstrip patch as shown in Figure 3.3. The conducting strip is smaller in width as compared to the patch and microstrip line patches have a number of advantages over other feeding technique. Because the feed layout and patches can be on one panel, it eases fabrication. The level of input impedance is simply controllable. The reason of the inset cut in the patch is to match the impedance of the feed line to the patch with no need for any extra matching element. This is obtained by correctly controlling the inset location. The equivalent diagram is shown in figure 3.4 which has two inductors, one resistance and one capacitor.

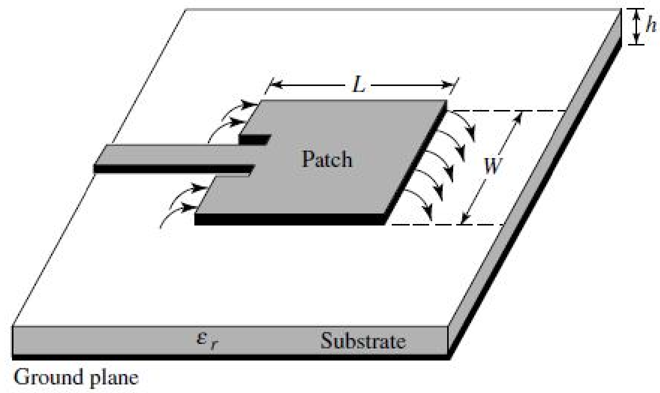

Figure 3.3: Microstrip line feed with inset cut [1]

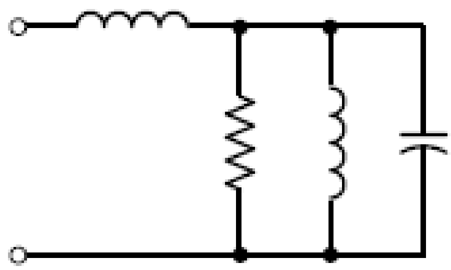

Figure 3.4: Equivalent circuit for Microstrip line feed [1]

3.5.2 Coaxial feed

The Coaxial feed or probe feed is a extremely common method used for feeding Microstrip patch antennas. As seen from figure 3.5, the inner conductor of the coaxial connector extends throughout the dielectric and is soldered to the radiating patch, even as the outer conductor is joined to the ground plane. Its equivalent circuit is shown in figure 3.6. The coaxial feed, by means of Huygens's principal, can be modeled by a cylindrical band of electric current curving on the center conductor from the bottom to top all along with the annular ribbon of magnetic current in the ground plane. An adulation that simplifies the calculation is to substitute the electric current by a uniform line current ribbon. To find out the probe impedance for a microstrip antenna, the problem of a parallel plate waveguide fed by a coaxial line has been analyzed using the integral formulation

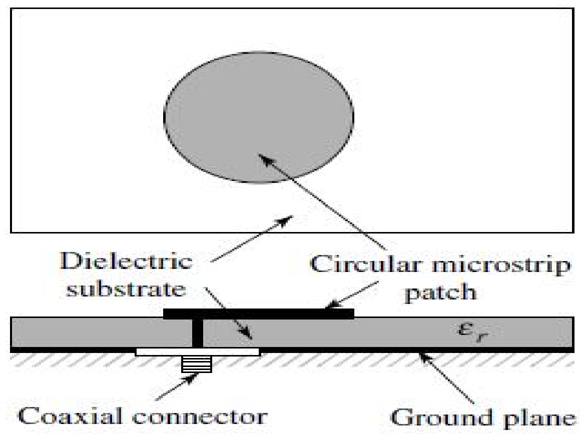

Figure 3.5: Probe fed rectangular microstrip patch antenna [1]

The main benefit of this type of feeding method is that the feed can be placed at any desired position inside the patch in order to match with its input impedance. This feed method is simple to manufacture and has small spurious radiation

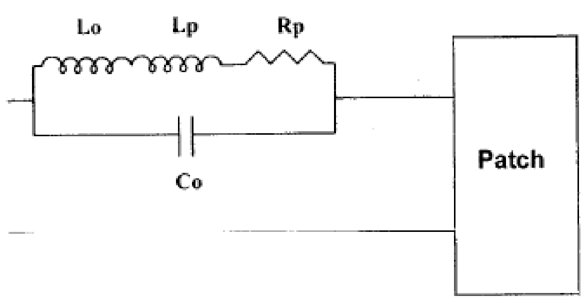

Figure 3.6: Equivalent circuit for coaxial feed or Probe feed [5]

on the other hand, its major disadvantage is that it provides narrow bandwidth and is difficult to form since a hole has to be drilled in the substrate and the connector protrudes exterior to the ground plane, thus not making it totally planar for thick substrates ($h > 0.02\lambda_o$). Also, for thicker substrates, the enlarged probe length makes the input impedance extra inductive, leading to matching problems. It is seen above that for a bulky dielectric substrate, which provides broad bandwidth, the microstrip line feed and the coaxial feed suffer from several disadvantages. The non-contacting feed techniques which have been discussed below, answer these problems.

3.5.3 Aperture coupled feed

In this type of feeding method, the radiating patch and the microstrip feed line are separated by the ground plane as shown in Figure 3.7. Coupling between the patch and the feed line is completed through a slot or an aperture in the ground plane. The coupling aperture is generally centered below the patch, leading to lesser cross polarization due to evenness of the configuration. The quantity of coupling from the feed line to the patch is resolute by the shape, size and position of the aperture. An extra cleared plan of aperture coupled microstrip patch is shown in figure 3.8. The feed line is along the resonant aspect of the patch. The slot, hence, has its length at a 90 degree angle to the resonant dimension.

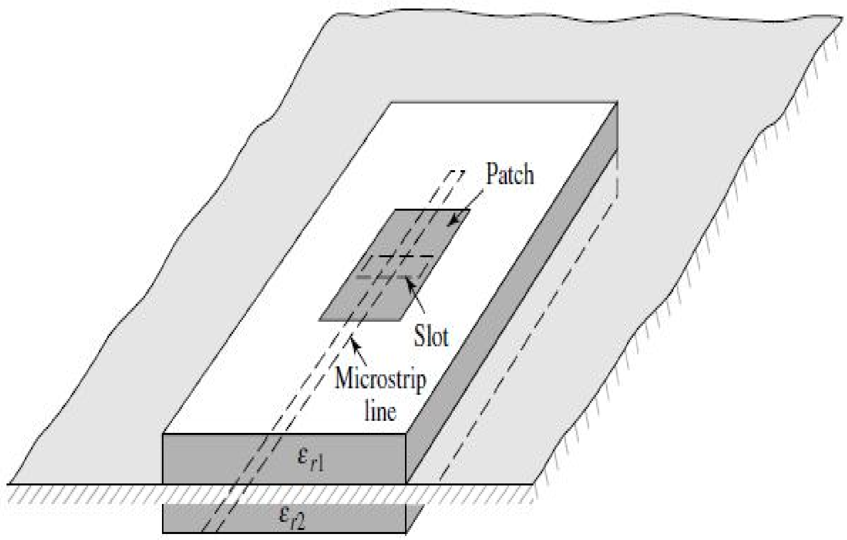

Figure 3.7: Aperture-coupled feed [1]

The slot, consequently, has its length perpendicular to the resonant length. The feed line is narrower than the slot. In aperture coupling, the patch is in series with the feed line. The aperture is also minute to be resonant, so it contributes only a reactance to the impedance. The stub away from the slot also presents a series reactance. An equivalent circuit for the antenna is shown in figure 3.9. L` represents the inductance linked with the below resonance slot. The patch is a parallel RLC circuit. The stub is an open circuited transmission line with the identical characteristic impedance as the feed line. The stub compensates for the inductance of the slot and the patch to facilitate to create real input impedance for the antenna.

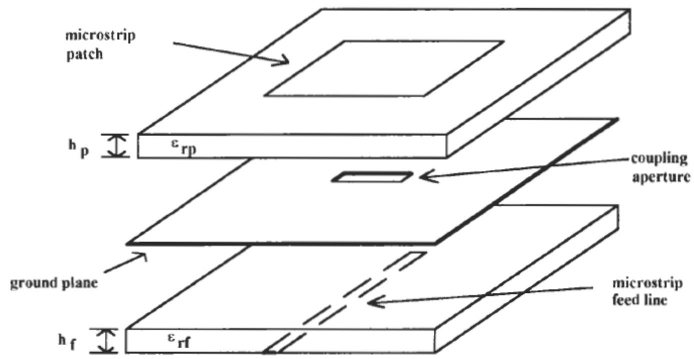

Figure 3.8: Aperture-coupled microstrip patch [3]

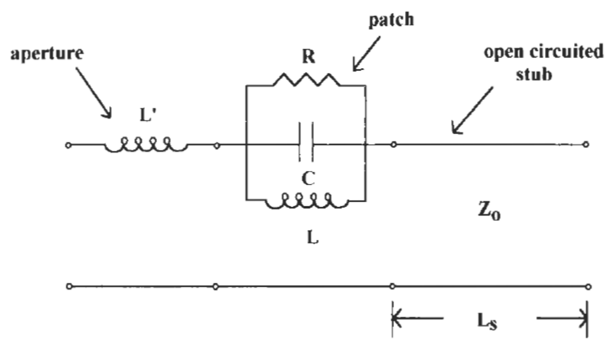

Figure 3.9: Equivalent circuits for Aperture-coupled feed [3]

Since the ground plane separates the patch and the feed line, spurious radiation is reduced. The position of the slot in ground plane can be changed to obtain the maximum coupling between patch and the feed line. The aperture coupling method gives the maximum bandwidth i.e.
21%. The major drawback of this feed method is that it is hard to manufacture due to multiple layers, which also increases the antenna thickness.

3.5.4 Proximity coupled feed

This type of feeding method comes in the category of non contacting method as there is no physical contact between patch and feed line. This method is also called as the electromagnetic coupling scheme. As shown in Figure 3.10, two dielectric substrates are used so that the feed line is present between the two substrates and the radiating patch is on top of the upper substrate. The main benefit of this feed method is that it deletes spurious feed radiation and gives very high bandwidth (as high as 13%), due to total increase in the thickness of the microstrip patch antenna. This method also gives choices between two unlike dielectric media, one for the patch and one for the feed line to optimize the individual performances. The line impedance can be maintained by changing the length and width of the feed line.

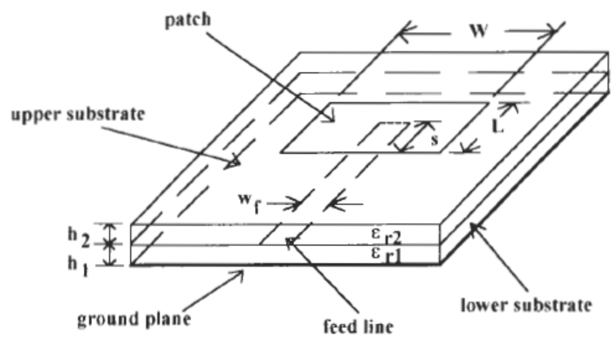

Figure 3.10: Proximity-coupled feed [3]

Coupling from the feed to the patch is represented by Cc. The coupling is controlled by two factors, the inset distance of the feed and the patch width. The coupling is increased with feed inset reaching a maximum when s=L/2. The coupling is symmetrical with respect to the center of the patch. Reducing the patch width increases the coupling.

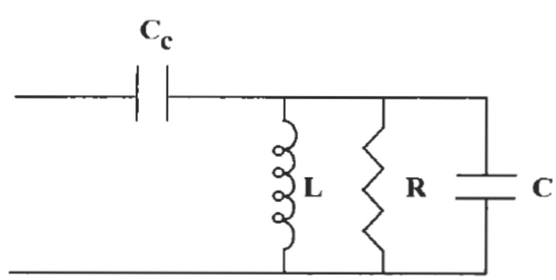

Figure 3.11: Equivalent circuit for Proximity-coupled feed [3]

Matching can be obtained by controlling the length of the feed line and the width-to-line proportion of the patch. The major shortcoming of this feed method is that it is hard to manufacture Microstrip Line Patch because of the two dielectric layers which need correct alignment. Also, overall thickness of the antenna is increased.

3.5.5 Coplanar Waveguide Feeding

Coplanar waveguide is a transmission line arrangement which consists of a central current-carrying trace on the top of a substrate, coplanar with side grounds extending beyond a symmetric gap to either side of trace. A coplanar waveguide (CPW) is the favored transmission line for microwave monolithic integrated circuits (MMIC). Both CPW and microstrip antennas belong to the planar geometry. Hence, for integrating microstrip antennas with CPW, it is advantageous to feed the microstrip antenna with a CPW. The coplanar waveguide (CPW) fed antenna have been widely used for wireless communications because of their features such as wide bandwidth, easiest structure of a single metallic layer, no soldering points, easy integration with MMICs etc.

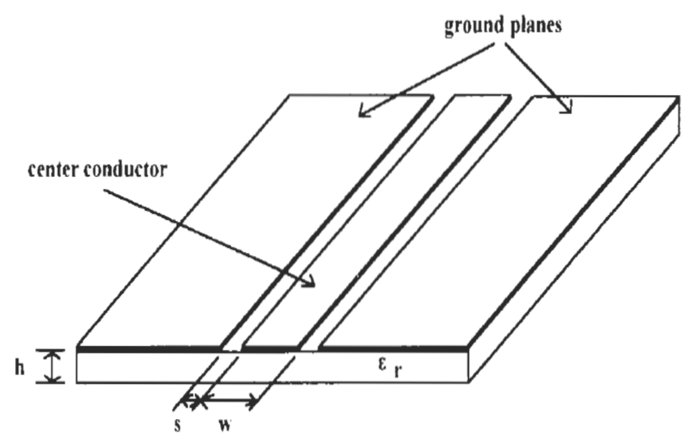

Figure 3.12: Coplanar Waveguide feed [3]

3.6 Microstrip antenna mechanical properties [2]

A microstrip patch antenna has very desirable mechanical properties.

- It can withstand tremendous shock and vibration. Because the antenna is on a solid substrate, the patch cannot flex, and small changes in the substrate thickness have only a minor effect on the resonant frequency. The commonly used soft substrate (Teflon and fiberglass) has a good damped resilience.

- Microstrip patch antennas have been used to telemeter data from artillery shells and high-velocity rockets, which have high shock and vibration levels. The repeatability of the dimensions of the patches depends only on the etcher's art.
- Complicated shapes and feed networks are produced as cheaply as simple ones.
- The antennas can withstand exposure to high temperatures when covered by a radome made of the same soft dielectric as the substrate. The cover protects the metal patches but has only a minor effect on the resonant frequency. High temperatures on the surface of the radome or ablation fail to change the resonance significantly because the radome itself has only a minor effect.
- Variation in the dielectric constant of the substrate causes problems with repeatability.
- Temperature variations can be a problem with thin substrates when the bandwidth is narrow. The patch and substrate size grow when the temperature rises, but they are overshadowed by the change in dielectric constant of soft substrates.
- Instead of decreasing the resonant frequency because of the increased patch size, a lowered dielectric constant raises the center frequency.
- Whenever we need more bandwidth than a microstrip patch can provide, we must turn to cavity antennas. We increase the antenna volume by penetrating the vehicle for the cavity, but we gain a design parameter.

3.7 Microstrip antenna applications [5]

The microstrip antenna, because of its small size, lightweight, low profile, and low manufacturing cost, is getting high level of interest in both commercial and military applications. With nonstop research and development and greater than before usage, microstrip antennas are eventually expected to swap conventional antennas for most applications. Some distinguished applications for which microstrip antenna have been developed include:

- Satellite communications Doppler and other radars radio altimeters
- Command and control systems
- Missiles and telemetry
- Remote sensing
- Feed elements in complex antennas

- Mobile communications

3.8 Analytical Models of Analysis [1]

There are different methods of analysis for microstrip antennas. The most accepted models are the transmission line model, cavity model, and full wave model (which include primarily integral equations/Moment Method). The transmission line model is the easiest of all and it gives excellent physical insight but it is less accurate and it is trickier to model coupling. The cavity model is more correct and gives good quality physical insight but is difficult in nature. The full wave models are tremendously accurate, flexible and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements and coupling. These give fewer insight as compared to the two models mentioned above and are far more difficult in nature. The mainly three models are explained below:

a) Transmission line model
b) Cavity model
c) Full wave model

Transmission Line Model

This representation represents the microstrip antenna by two slots of width W and height h, separated by a transmission line of length L. The microstrip is essentially a non- homogeneous line of two dielectrics, typically the substrate and air. therefore, as seen from Figure 3.14, most of the electric field lines reside in the substrate and parts of some lines in air. 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. For this reason, an effective dielectric constant (ε_{reff}) must be obtained in order to account for the fringing and the wave propagation in the line.

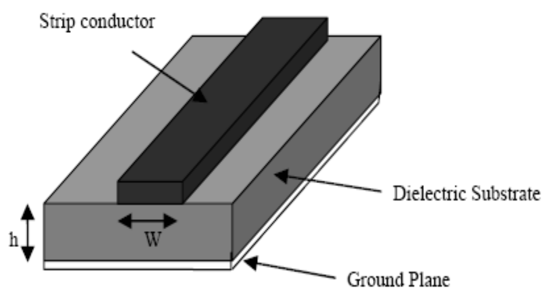

Figure 3.13: Microstrip Line

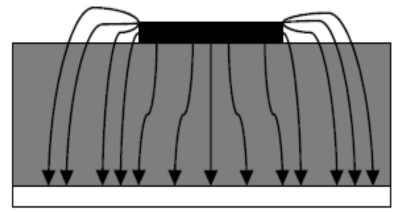

Figure 3.14: Electric Field Lines

The Value of ε_{reff} is slightly less than ε_r because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also spread in the air as shown in Figure 3.13 above. The expression for ε_{reff} is given by Balanis as:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{1/2} \tag{3.1}$$

Where ε_{reff} = Effective dielectric constant

ε_r = Dielectric constant of substrate

h = Height of dielectric substrate

W = Width of the patch

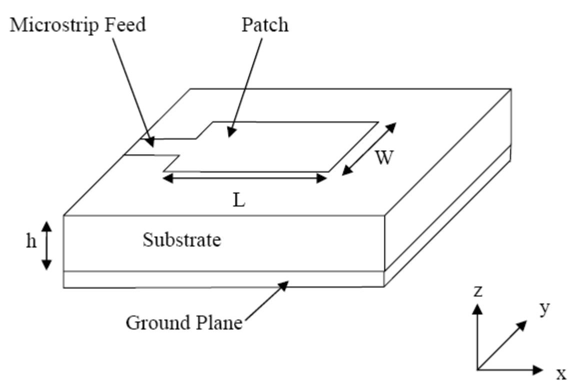

Figure 3.15: Microstrip Patch Antennas

Consider Figure 3.15 above, which shows a rectangular microstrip patch antenna of length L, width W resting on a substrate of height h. The co-ordinate axis is selected such that the length is along the x direction, width is along the y direction and the height is along the z direction.

In order to operate in the 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 $\lambda_o/\sqrt{\varepsilon_{reff}}$ where λ_o *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 Figure 3.16 shown below, the microstrip patch antenna is represented by 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 the open ends. The fields at the edges can be resolved into normal and tangential components with respect to the ground plane.

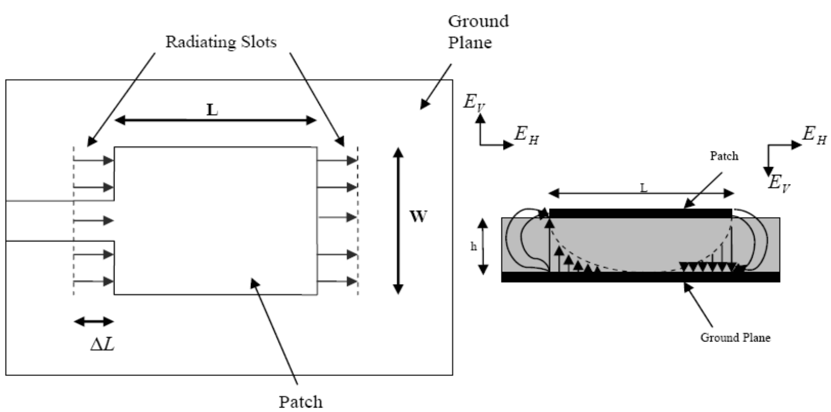

Figure 3.16: a) Top View of Antenna, b) Side View of Antenna

It is observed from Figure 3.16 that the normal components of the electric field at the two edges along the width are in opposite directions and thus out of phase since the patch is λ/2 long and hence they cancel each other in the broadside direction. The tangential components, which are in phase means that the resulting fields combine to give maximum radiated field normal to the surface of the structure. Hence the edges 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 the patch of the microstrip antenna looks greater than its physical dimensions. The dimensions of the patch along its length have now been extended on each end by a distance ΔL, which is given empirically by Hammerstad as:

$$\Delta L = 0.412h \frac{(\varepsilon_{reff} + 3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)} \tag{3.2}$$

The effective length of patch L_{eff} now becomes:

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

For given resonance frequency f_0 , the effective length is given by:

$$L_{eff} = \frac{c}{2 f_0 \sqrt{\varepsilon_{reff}}} \tag{3.4}$$

This formula includes a first order correction for the edge extension due to the fringing fields,

with:

L_{eff} = resonant length

λ_0 = wavelength in free space

ε_r = dielectric constant of the PC board material

Other parameters that will influence the resonant frequency:

- Ground plane size
- Metal thickness
- Patch width

For a rectangular microstrip patch antenna, the resonance frequency for any TM_{10} is given by:

$$f_0 = \frac{c}{2\sqrt{\varepsilon_{reff}}} \left[\left(\frac{m}{L}\right)^2 + \left(\frac{n}{W}\right)^2 \right]^{1/2} \tag{3.5}$$

Where m and n are modes along L and W respectively.

$$W = \frac{c}{2 f_0 \sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{3.6}$$

For efficient radiation, the width W is given by:

3.9 Substrate selection [5]

The substrate is composed of a dielectric material that affects the electrical performance of the antenna, circuits and transmission line. As a result, the substrate permittivity and thickness are critical parameters in microstrip patch antenna design. It can be assumed that good selections of both parameters will yield superior performance as well as reduce the number of optimization cycles required

Considerations in substrate selection include:

1. Variations of dielectric constant and loss tangent with temperature.
2. Temperature range of homogeneity and isotropicity.
3. Variations of dimensional stability with temperature, humidity and aging.
4. Impact Resistance
5. Resistance to chemicals.
6. Tensile and structural strength.
7. Flexibility.

CHAPTER 4

Dual frequency patch antennas

4.1 Dual-frequency techniques for patch antennas [6]

In theory, dual-frequency planar antennas should function with similar features, in terms of radiation and impedance matching, at two different frequencies. Getting these features by using planar technologies is not **a** simple matter, particularly when the built-in structural and technological ease typical of patch antennas is to be conserved

Types of dual-frequency patch antennas

1) Orthogonal mode dual-frequency patch antennas
2) Multi-patch dual frequency antennas
3) Reactively-loaded dual-frequency patch antennas

4.1.1 Orthogonal-mode dual-frequency patch antennas

These antennas are categorized by two resonances with orthogonal polarizations. These may be obtained by a rectangular patch which is the easiest way. An attractive quality of these antennas is their potential of synchronized matching of the input impedance at the two frequencies with a single feed arrangement. This may be achieved with a probe-fed configuration, which is displaced from the two principal axes of the patch. The performance of this way in terms of matching level and bandwidth is round about equal to that of the same patch fed individually on the two orthogonal principal axes.

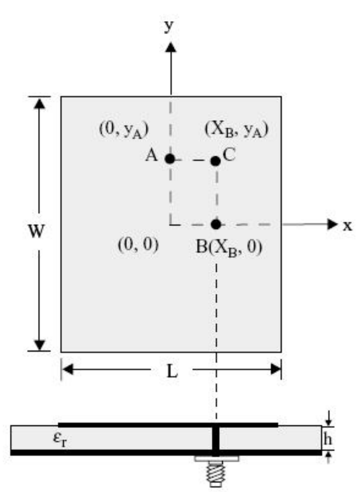

Figure 4.1: Dual-Frequency Operation with Orthogonal Polarization [7]

This provides the possibility of using the illustrious design formula for standard feeds. It is also worth noting that the simultaneous matching level for structures that provide the same polarizations at the two frequencies is, in general, worse with respect to the case relevant to orthogonal polarization

4.1.2 Multi-patch dual-frequency antennas

In these types of structures, the dual-frequency behaviour is achieved by using multiple radiating elements, each of them supporting strong currents and radiation at the resonance. This type includes multi-layer stacked patches that can use circular, annular, rectangular, and triangular patches. These antennas function with the same polarization at the two frequencies, as well as with a dual polarization. The same multilayer structures can also be used to widen the bandwidth of a single-frequency antenna, when the two frequencies are forced to be closely spaced. In this latter case, the lower patch can be fed by a usual arrangement and the upper patch by proximity coupling with the lower patch. In order to stay away from vanishing of the upper resonance, the sizes of the two patches should be close, so that only a frequency ratio close to unity may be obtained. **A** direct probe feed for the upper patch can also be used.

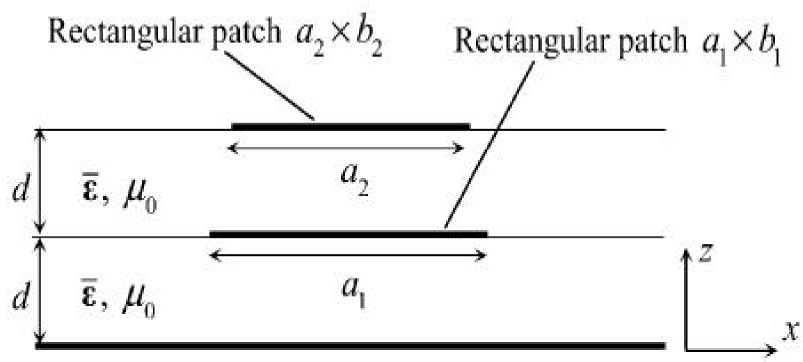

Figure 4.2: Stacked microstrip antenna structure [12]

4.1.3 Reactively-loaded patch antennas

The most well-liked method for achieving dual-frequency performance is to introduce a reactive loading to a single patch. The easiest way is to attach a stub to one radiating edge, in such a way as to establish a further resonant length that is responsible for the second operating frequency. Other types of loading can be used, including notches, pins and capacitors, and slots.

Loading the radiating edge with an inset is a substitute way to establish a dual frequency behaviour that creates the same effect as the microstrip loading effect, with the improvement of reduced size.

4.2 Stacked antenna [8]

Each microstrip patch antenna consists at least of one feed line and one radiating element. To increase the bandwidth of a microstrip antenna, additional parasitic radiators, placed in the same or in different layers, are used. In the case of different layers, the radiators as well as feed lines are etched on different dielectric substrates with a relative permittivity larger than one. Some additional dielectric layers are usually needed to support the etched patches and a quarter-wavelength reflector. This makes such antennas expensive and therefore unsuitable for mass production, for example, as a base station antenna for cellular communication systems. Stacked configurations are achievable with aperture coupled feeding, proximity feeding and co-axial feeding. Probe feeding technique is re-emerging in diversity of antenna system due to its robust nature. It provides good separation between feed network and radiating elements and due to direct contact with the radiator reduces dielectric layer misalignment difficulties. It also yields good front to back ratio which is very important where multiple arrays are located back-to-back in close proximity. Hence stacked configurations with probe -fed have been considered.

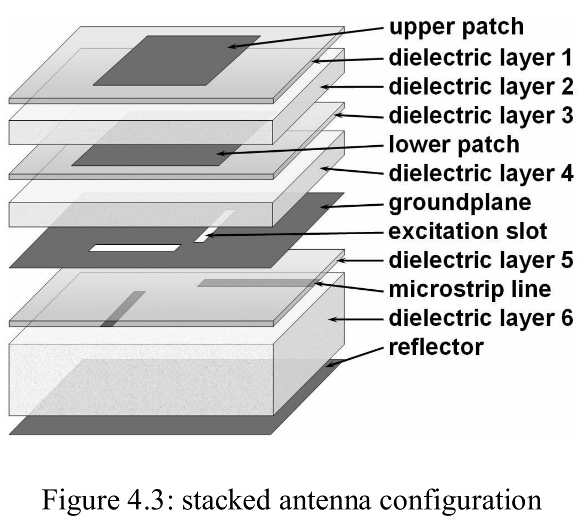

Figure 4.3: stacked antenna configuration

Significant quantity of literature is obtainable which provides strategy to design a probe fed stacked patch. It has been reported, that the combination of low dielectric constant and high dielectric constant can yield good impedance behavior. The broadest bandwidth can be achieved when the first-order mode on the lower patch is considerably greater in magnitude than corresponding mode on the top patch or in other words the top patch is loosely coupled. For this the substrate of lower patch should have higher dielectric constant than the upper substrate.

The thickness of each layer also plays a significant role in achieving the overall bandwidth. The thicker the lower layer, the greater the bandwidth will be. It has been suggested that the lower patch must be designed such that it is powerfully capacitive over the desired range of frequency instead of designing it for the minimum return loss. But the overall impedance will become inductive when parasitic patch is placed onto the configuration, if lower layer is too thick. Therefore a tradeoff has to be prepared between the bandwidth and the impedance control. The thickness of upper substrate (h2) depends upon the thickness of lower substrate (h1). The greater h1 leaves less freedom for the h2. For lower return loss h2 must be increased

4.3 Bandwidth optimisation [8]

Bandwidth is optimized by watchfully choosing the resonant frequencies of the parasitic elements and the coupling between them and the driven patch. To fine-tune the parasitic patch size, the distance between the driven and the parasitic elements and the position of the feeding point, the iterative process presented in to design stacked antennas is followed. Such process is applied for both parasitic elements.

4.4 Bandwidth extension [8]

A general realistic assumption is that the input-impedance characteristic of a resonant patch antenna behaves as a simple tuned circuit, in which case the 3 dB bandwidth *B* is approximately (100/Q) percent, where Q is the Q-factor of the equivalent tuned circuit. If the antenna is matched at the resonant frequency of the tuned circuit, then away from resonance the input impedance will be mismatched, creating a VSWR(> 1) of ***S,*** where Use of a thicker and/or lower-permittivity substrate reduces Q and hence increases B. An examination of numerous examples shows that, irrespective of whether the permittivity or substrate thickness is changed, the main effect (Table 1.7) is that *B*

increases with the volume of the antenna, i.e. the volume of substrate between the patch and ground plane. Some examples are shown in Fig.1.1, which also includes curves of radiation efficiency with and without allowance for the power lost to surface waves.
Stacked elements have the benefit of providing two or more metallic patches within the same aperture area. This allows the antenna designer to obtain multiple frequencies with or without dual polarisation. The dielectric substrates may differ in thickness or to control the bandwidths and sizes of the metallic radiator. Before presenting details of these stacked antennas, it is desirable to list some of their general advantages and disadvantages.

4.5 Circularly Polarized Patch [2]

A microstrip patch is one of the most widely used radiators for circular polarization. Figure 3.1shows some patches, including square, circular, pentagonal, equilateral triangular, ring, and elliptical shapes which are capable of circular polarization operation. However square and circular patches are widely utilized in practice. Circularly polarized (CP) antennas can decrease the loss caused by the misalignment between the signal and the receiving antenna. It has been widely used for satellite communication systems, such as MSAT and GPS.
A single patch antenna can be made to radiate circular polarization if two orthogonal patch modes are simultaneously excited with equal amplitude and $\pm 90^{\circ}$ out of phase with sign determining the sense of rotation. Two types of feeding schemes can accomplish the task as given in figure 4.4. The first type is a dual-orthogonal feed, which employs an external power divider network. The other is a single point for which an external power divider is not required.

4.5.1 Dual-Orthogonal Fed circularly Polarized Patch [2]

The fundamental configurations of a dual-orthogonal fed circularly polarized patch using an external power divider is shown in figure 4.5. The patch is usually square or circular. The dual-orthogonal feeds excite two orthogonal modes with equal amplitude but in- phase quadrature. Several power divider circuits that have been successfully employed for CP generation include the quadrature hybrid, the ring hybrid, the Wilkinson power divider, and the T-junction power splitter. The quadrature hybrid splits the input into two outputs with equal magnitude but 90^{0} out of phase. Other types of dividers, however, need a quarter-wavelength line in one of the output arms to produce a 90^0 phase shift at the two feeds. Consequently, the quadrature hybrid provides a broader axial ratio bandwidth. These splitters can be easily constructed from various planar transmission lines.

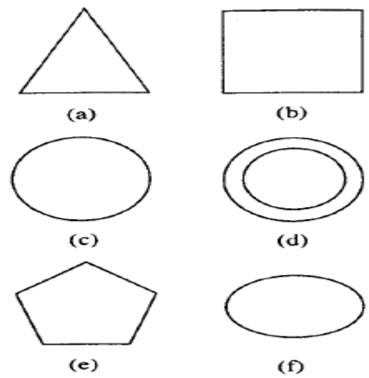

Figure 4.4: Various types of circularly polarized microstrip patch antennas

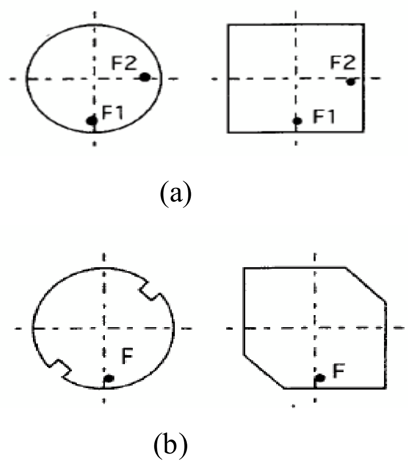

Figure 4.5: Two types of excitations for circularly polarized microstrip antennas: (a) dual-fed patch and (b) singly fed patch.

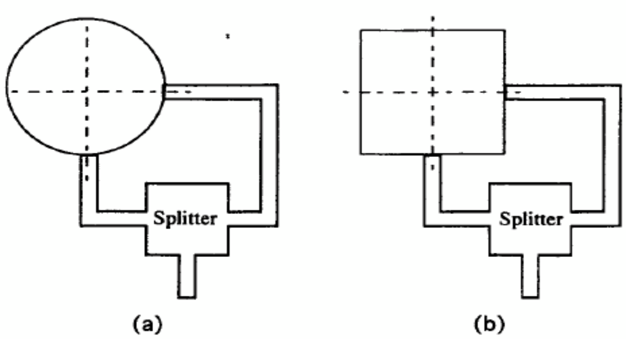

Figure 4.6: Typical configurations of dual-fed circularly Polarized microstrip antennas: (a) circular patch and (b) square patch

4.5.2 Singly Fed Circularly Polarized Patch [2]

Distinct configurations for singly fed CP microstrip antennas are shown in figure 4.7. A single point feed patch proficient of producing CP radiation is very desirable is situations where it is not easy to accommodate dual-orthogonal feeds with a power divider network.

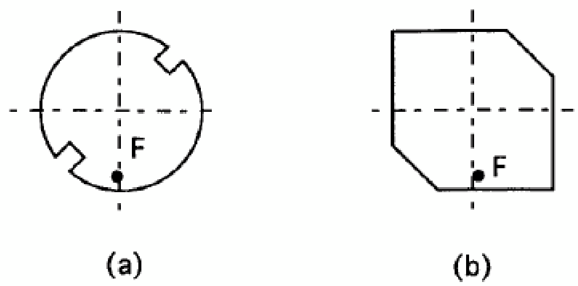

Figure 4.7: Typical configurations of singly fed circularly polarized microstrip antennas: (a) Circular patch and (b) square patch

Because a patch with single-point feed generally radiates linear polarization, in order to radiate CP, it is necessary for two orthogonal patch modes with equal amplitude an in phase quadrature to be induced. This can be accomplished by slightly perturbing a patch at appropriate locations with respect to the feed. Perturbation configurations for generating CP operate on the principle of detuning degenerate modes of a symmetrical patch by perturbation segments. The fields of a singly fed patch can be resolved into two orthogonal degenerates' modes 1 and 2. Proper Purturbation segments will detune the frequency response of mode 2 such that, at the operating frequency f_0, the axial ratio rapidly degrades while the input match remains acceptable. The actual detuning occurs either for one or both modes depending on the placement of perturbation segments.

A circular polarization can also be obtained from a single-point-fed square or circular patch on a normally biased ferrite substrate, as shown in figure 4.8. Pozar demonstrated that a singly fed patch radiates both left hand circularly polarized (LHCP) and right hand circularly polarized(RHCP) at the same level and polarity of bias magnetic field; however LHCP and RHCP have different resonant frequencies. The axial ratio bandwidth is found to be larger than the impedance bandwidth. The radiation efficiency is on the order of 70%.

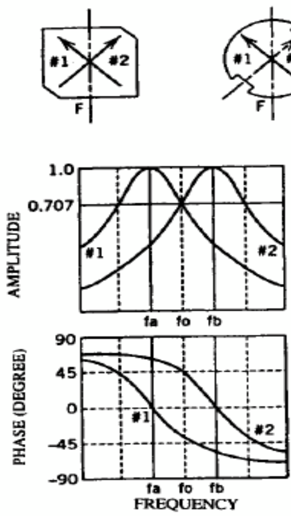

Figure 4.8: Amplitude and phase of orthogonal modes for singly fed circularly polarized microstrip antennas.

Dual circular polarization has also been achieved using a singly fed triangular or pentagonal microstrip antenna.

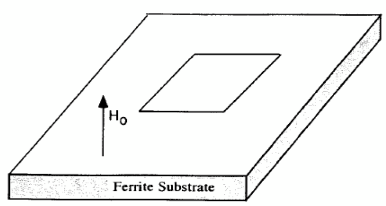

Figure 4.9: Geometry of a rectangular patch antenna on a normally biased ferrite substrate.

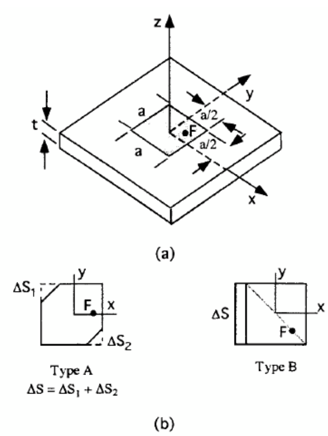

Figure 4.10: Configuration of singly fed microstrip patch antennas: (a) patch diagram and (b) type A and type B microstrip patch perturbations.

4.6 Circular polarisation using asymmetric slots

For example in paper [9], the asymmetry in the arrangement refers to the arms of the U-slot, which are of unlike lengths. For each layer, the U-slot is situated on the square patch that sits on top of the substrate of that layer. The probe feed is directly connected to the top patch, while the lower patch is fed with an indirect contact by a small clearance hole between the probe and the patch. This simple feed method reduces the fabrication errors in the stacked configuration.. It is significant to point out that with this initial starting point, two different values will be determined for the probe position on the two patches. Since a single feed is used in this stacked design, the initial probe position was approximated by the average position of probe along the -axis in the top and lower patches. For the U-slot patch shown in Fig. 4.11, when (Lul>L_{ur}), the antenna is left-hand circularly polarized (LHCP). Similarly, when (L_{ul}<L_{ur}), the antenna is right-hand circularly polarized (RHCP). As a result, since the relative length of arms in the U-slot determines the sense of polarization, in order to obtain the required polarization for the design, it is necessary to define linear constraints for the dimensions of the U-slot arms in the optimization. To demonstrate that different polarizations can be achieved for the two bands with this approach, two dual-band CP antennas with asymmetric U-slots are designed

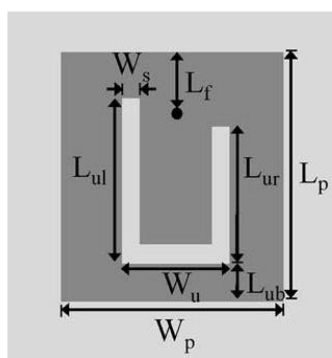

Figure 4.11: asymmetric u slot in patch antenna for circular polarisation [9]

U slot in patch antenna [25]

U slot functions as a series capacitor thus the inductive nature of the probe feed can be compensated and impedance matching can be achieved. The main benefit of u slot patch antenna is that it creates broad band characteristics with a single and simple topology.

The variation of u slot dimensions such as width of slot, slot length, probe location etc. dramatically change the antenna performance. Mathematical procedures have not been developed to design u – slot patch antenna. The techniques are useful for initial designs and desired antenna behaviour can be achieved by tuning process. The strength of dimensional invariance method is that it converges optimized design rapidly, if required frequency lies in the range in which design equation are reliable. The drawback of this method is that the design equations were developed for particular values of substrate permittivity and thickness.

U slot stacked patch antenna structures joins two broadbanding methods where wider bandwidths can be achieved by using stacked configuration, bandwidth problem can be overcome. Various experiments are done with U-slot like in [9],[15],[21],[27] etc.

Effect of Slot on Microstrip Patch Antenna

Current distribution on surface of conventional microstrip patch antenna flows longitudinally, but in loaded slot microstrip patch antenna, current distribution perturb by loading slots on microstrip antenna. Loading specific slot on the conducting patch element of antenna, decreased size with enhancement in bandwidth, gain can be achieved. The loading of slots on the conducting patch element can create meandering of the excited patch surface current paths and results in lowering of the resonant frequency, which refers to the reduced antenna size compared to the conventional microstrip patch antenna at designed frequency[30]

CHAPTER 5

Simulation and Results

5.1 IE3D Software

IE3D is an integral equation and method of moment based EM simulator.IE3D mainly focuses on general planar and 3D metallic structures in layered dielectric environments. It is extremely efficient, accurate and flexible for such structures. It can also model full 3D dielectric structures such as patch antennas with finite substrates and dielectric resonator antennas. It is not just a simulation tool but also a design tool. It can do real-time EM tuning and optimization

Some of IE3D's characteristics are

- It can model true 3D metallic structures in multiple dielectric layers in open, closed or periodic boundary
- It has High efficiency, high accuracy and low cost electromagnetic simulation tool on PCs with windows based graphic interface
- Facility of Automatic generation of non-uniform mesh with rectangular and triangular cells
- It can model structures with finite ground planes and differential feed structures
- Accurate modeling of true 3D metallic structures and metal thickness
- It has efficient matrix solvers
- It has ability of both 3D and 2D display of current distribution, radiation patterns and near field.

For our project IE3D was very helpful because it provided simplicity of patch design and good simulation results. This was the main cause for the slowness of IE3D compared to other software like Sonnet. We mostly took 100-150 frequency points for generation of all curves smoothly and accurately. It takes time for simulation depending on the patch dimensions, frequency range, degree of meshing etc.

Essential parameters for designing a simple rectangular patch

- Frequency of operation (f_0): The resonant frequency of the antenna should be chosen appropriately.

- Dielectric constant of the substrate (ε_r): A substrate with a high dielectric constant reduces the dimensions of the antenna.
- Height of dielectric substrate (h): For the microstrip patch antenna to be used in certain applications (such as cell phones) it is essential for the antenna to be light weighted and to ensure this the height of the dielectric substrate should be few mm.

5.2 Effect of substrate thickness

There is no exact analytical models developed for the U-slot microstrip patch antenna, but at some extent, its behavior can be understood by simple rectangular microstrip patch antenna, increasing the substrate thickness, *T,* and using substrates with lower values of dielectric constant, εr, can increase the bandwidth of rectangular microstrip patch antennas. This approach, however, is only useful up to $T < 0.02\lambda$. On the other side, there are several drawbacks of using thick substrates with high dielectric constants, namely

There are some drawbacks of using thicker substrates and high permittivity material which are as following: [2]

1. Substrates thicker than 0 0.11λ (for $\varepsilon_r = 2.2$ and where λ_0 is the wavelength in air) make the impedance locus of the probe-fed antenna patch increasingly inductive, resulting in difficulties in impedance matching.
2. Thick substrate with microstrip edge feed will give rise to increased spurious radiation from the microstrip step-in width and other discontinuities
3. Higher order modes may develop with thick substrates, resulting in distortions of the radiation pattern.
4. Surface wave power increases with substrate thickness, resulting in poor radiation efficiency.

5.3 Geometry of proposed antenna

Initial parameters are calculated using the design formulas of rectangular patch antenna and initially it was designed to be square and then optimized to get the better results. The dimensions of the u slot are calculated by using [9] and then their width and length are optimized for enhanced performance. Rectangular slot parameters of the upper patch are also calculated by the help of published papers on the concept already [7]. The length of the left arm of U- slot is larger than right arm therefore it is left hand circularly polarized. Dimension of the proposed antenna using rectangular patch are given in the table below

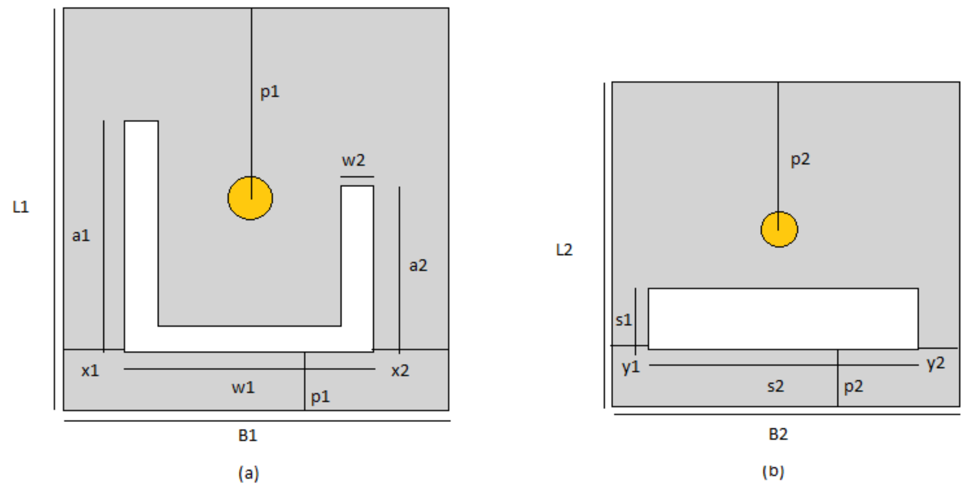

Figure 5.1: a) lower patch b) upper patch with probe feed

5.4 3D view of patch antenna

With the help of IE3D tool for three dimensional view of the geometry, the following design is made of the proposed antenna

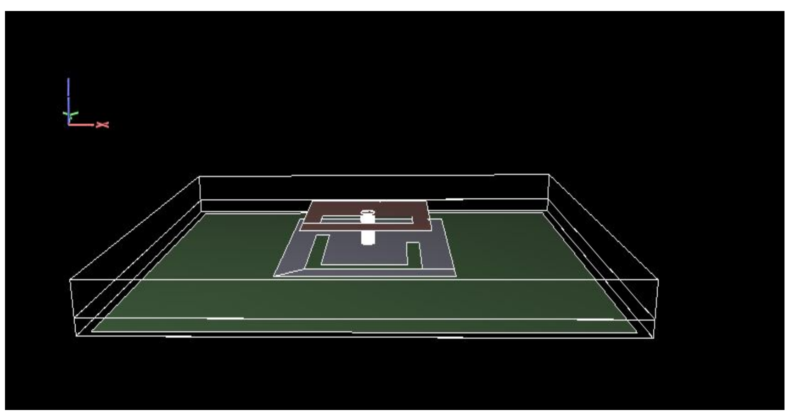

Figure 5.2: 3D view of patch antenna

Table 5.1: Optimized dimensions of the antenna

Ground size	50x40 mm^2
Lower Substrate thickness	1.534 mm

Upper Substrate thickness	3.175 mm
Lower Patch size(L1 x B1)	19.1x21.2 mm^2
Upper Patch size (L2 x B2)	14.5x12.7 mm^2
Slot Arms(a1,a2)	11.9mm, 8.93mm
Slot gap between arms(w1)	12.7mm
Slot width(w2)	1.6mm
Slit dimensions(s1 x s2)	10.5 mm
x1,x2,p1	2mm,2mm,2.65 mm
y1,y2,p2	3.01mm,3.01mm,2.23mm
Feed point location(x,y)	(0,1.1)
Ɛr (Lower)	2.22
Ɛr(upper)	2.2
Loss tangent	0.009
Probe Diameter	1.6mm

5.5 Results and simulations

Simulation was carried out in 150 frequency steps for good results and following are the results which were obtained after series of optimization steps

5.5.1 Return loss and bandwidth

It is clear from the figure that the patch resonates at 3.4GHz and 5.6GHz.Results of the proposed antenna show that it is having return loss of -31 dB at 3.4GHz frequency and the impedance bandwidth achieved is 146 MHz and return loss of -41 dB at 5.6GHz frequency and the bandwidth achieved is 355 MHz with respect to S11<-10dB .

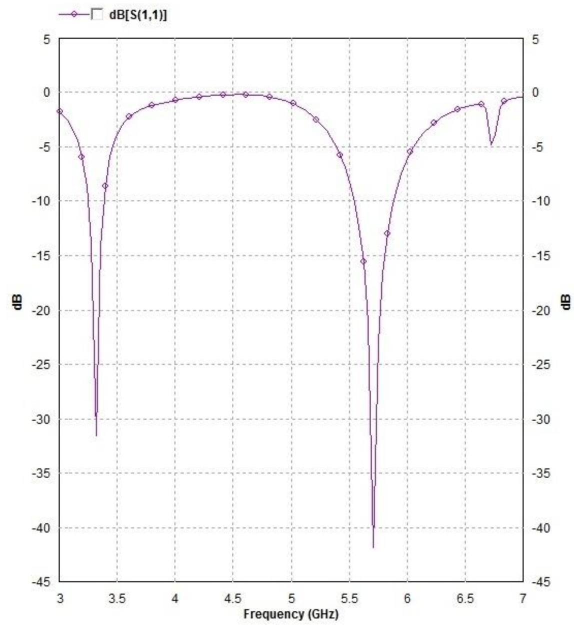

Figure 5.3: shows the return loss of the proposed antenna

5.5.2 VSWR

The VSWR is a way to measure impedance mismatch between the feeding system and the antenna. The higher the VSWR, the more is the mismatch. The minimum possible value of VSWR is unity and this refers to a perfect match. The following graph is showing VSWR ≤ 2 which is further used to calculate the bandwidth which comes to be 4.29% and 6.32% for 3.4 GHz and 5.6GHz respectively

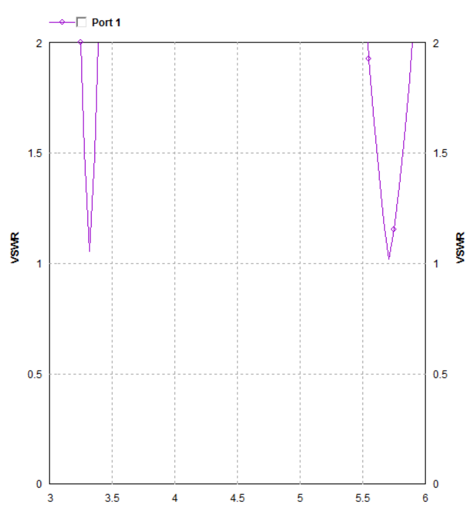

Figure 5.4: Graph showing bandwidth of the antenna

5.5.3 Smith chart

Here the smith chart corresponding to the obtained return loss with the probe feed at (0, 1.1) is given which shows good impedance matching near the center of the smith chart

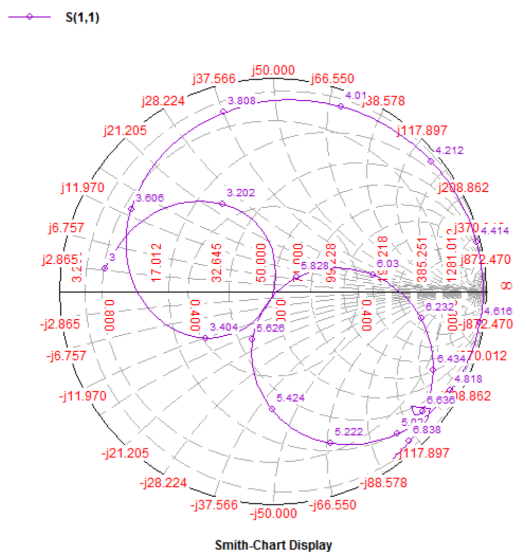

Figure 5.5: shows the smith chart representation of the proposed antenna

5.5.4 Antenna efficiency

In the following graph we can clearly see that antenna efficiency is about 83% for 3.4 GHz and 98% for 5.6 GHz. Antenna efficiency is also depicted in the same graph

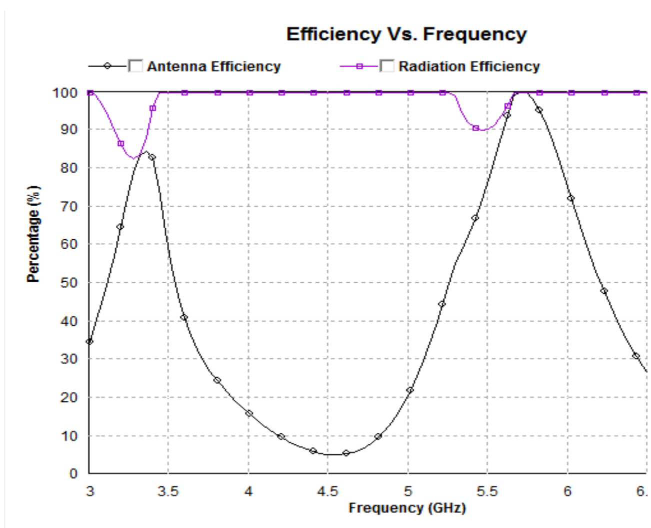

Figure 5.6: Antenna efficiency

5.5.5 Effect of Probe Location (x, y)

It is seen that if the location of the feed point is changed, the resonant frequency and the return loss will change accordingly. The feed point should be positioned at that point on the patch, where the input impedance matches 50 ohms for the resonant frequency. Therefore, a trial and error technique is used to find the feed point. For different positions of the feed point, the return loss (R.L) is noted and then comparison is done with other points and finally feed point is selected where the R.L is most negative.

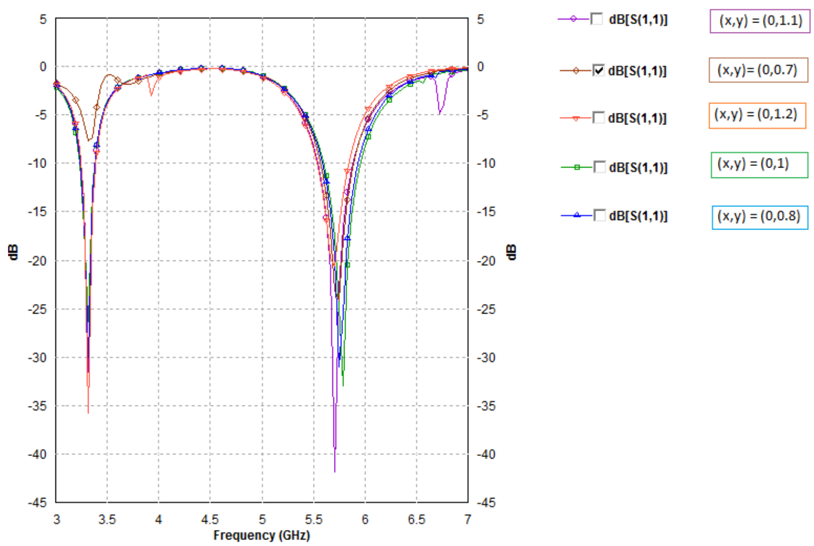

Figure 5.7: variation in return loss with location of probe

The effect of change in location of probe can also be seen from the smith chart variation as in following figure

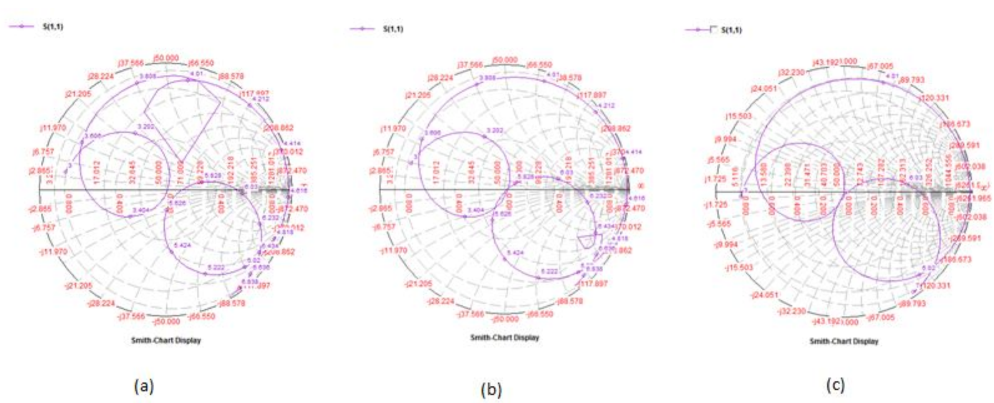

Figure 5.8: Change in probe location a) (x,y)=(0,0.8), b) (x,y)=(0,1.2) c) (x,y)=(0,1.1)

5.5.6 Radiation patterns at the resonant frequencies

Azimuth as well as Elevation radiation pattern of electric field is shown below using polar plots.

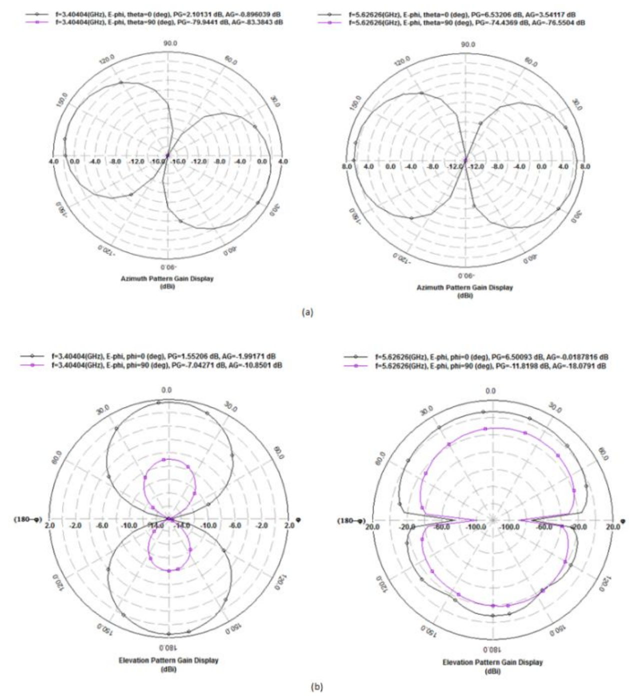

Figure 5.9: 2D radiation patterns

5.5.7 Antenna gain

The total antenna gain obtained at 3.4 GHz and 5.6 GHz is 3.43dBi and 7.25 dBi respectively. This is shown in the following graphs below:

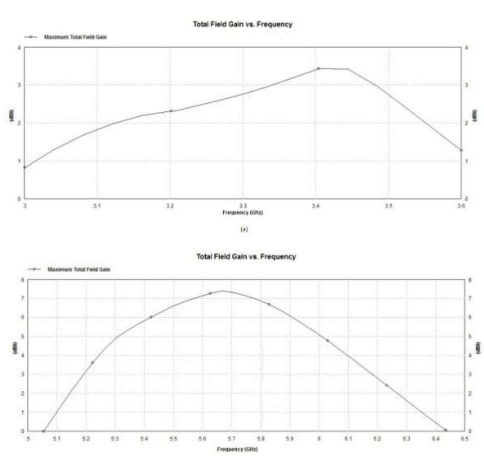

Figure 5.10: graph showing gain for a) 3.4 GHz b) 5.6 GHz

CHAPTER 6

Conclusion and Future Scope

The design of dual frequency stacked patch antenna with single Probe Feed for circular polarization has been done using IE3D software. The main parameters (such as return Loss curves, Radiation Patterns, gain etc.) that affect design and applications were studied. All the simulation results show that the proposed stacked antenna performs very well with the two frequencies. The parameters of the U-slot are optimized to provide different current paths for the two orthogonal modes required for circular polarization. In the design of the antenna, impedance matching is very important. Best results are obtained when the impedance of the system was perfectly matched to 50 Ω. It was done by varying the probe position in number of trials. It may be concluded that Microstrip Patch antenna beneficial than wire antennas for wireless devices as requirement of antenna to be small sized.

It is concluded from the results that return loss of the stacked rectangular patch antenna at both the frequencies 3.4GHz and 5.6 GHz are much better. At 3.4GHz the return losses, bandwidth and gain obtained are -31 dB, 4.29% and 3.43dBi respectively .At 5.6 GHz return losses, bandwidth and gain are -42dB, 6.32% and 7.25 dBi respectively. The proposed antenna is well suited for WiMAX applications.

Scope for Future

There were some areas in which improvements can be made and new results can be achieved by applying some more methods. They are:

- An absolute study of various field solvers and simulators (such as Sonnet, HFSS etc.) can be made and further comparison in results can be done.
- Design of the microstrip patch antenna can be configured to obtain more than two bands with a sufficient bandwidth with the available techniques for optimization.

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