DESIGN, FABRICATION AND PERFORMANCE EVALUATION OF MICRO-STRIP PATCH ANTENNAS FOR WIRELESS APPLICATIONS USING APERTURE COUPLED FEED.

A Thesis submitted in partial fulfillment of the requirements for the award of Degree of

MASTER OF ENGINEERING
In
ELECTRONICS AND COMMUNICATION

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CERTIFICATE

I hereby declare that the work which is being presented in the thesis entitled, **"Design, Fabrication and Performance Evaluation of Micro-Strip Patch Antennas for Wireless Applications using Aperture Coupled Feed"** in partial fulfillment of the requirement for the award of degree of Master of Engineering in Electronics and communication submitted in Electronics and Communication Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of Ms. Amanpreet Kaur, Assistant Professor, ECED.

The matter presented in this thesis has not been submitted in any other University/Institute for the award of degree.

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ABSTRACT

Wireless communications have been developed widely and rapidly in the modern world especially during the last two decades. The future development of the personal communication devices will aim to provide image, speech and data communications at any time, and anywhere around the world. This indicates that the future communication terminal antennas must meet the requirements of multi-band or wideband to sufficiently cover the possible operating bands. However, the difficulty of antenna design increases when the number of operating frequency bands increases. In addition, for miniaturizing the wireless communication system, the antenna must also be small enough to be placed inside the system. However, in order to transmit and receive more information large bandwidths are required, and bandwidth enhancement is currently a popular research area.

In this work presented, Transmission line model is used to simulate rectangular Microstrip Patch Antenna using aperture coupled feed. The aim is to study the effect of antenna dimensions Length (L), Width (W) and substrate parameters relative Dielectric constant (ε_r). Low dielectric constant substrates are generally preferred for maximum radiation. The conducting patch can take any shape rectangular, circular and there are many other configurations but rectangular is preferred.

The length of the antenna is nearly half wavelength in the dielectric; it is a very critical parameter, which governs the resonant frequency of the antenna. In view of design, selection of the patch width and length are the major parameter s along with the feed line depth.

So in this thesis, an aperture coupled antenna resonating at 10GHz, providing 234 MHz bandwidth for WLAN application (X Band) is designed in CST MICROWAVE STUDIO 9. The parametric study of the designed antenna is studied and the physical parameters examined in this study include the substrates and their dielectric constants, stub length and ground plane coupling slot length.

Also an aperture coupled antenna resonating at 5.8GHz, providing 309 MHz bandwidth for WLAN application is designed. Loading slots at the non-resonating sides of the patch of single band aperture coupled antenna making it dual band for WLAN covering the bands 5.15MHz to 5.25MHz and 5.75MHz to 5.85MHz. and its fabrication has been attempted in this thesis. The antenna parameters like operating frequency, input impedance, VSWR, Bandwidth, Return loss, directivity and gain are determined for each antenna configuration.

The operating frequency, input impedance, VSWR, Bandwidth, Return loss, directivity and gain of the single band antenna designed are 10GHz, 77.98ohm, 1.05, 234MHz, - 26.50988, 7.35 dBi and 9.153 dB respectively.

The operating frequency, input impedance, VSWR, Bandwidth, Return loss, directivity and gain of the single band antenna designed are 5.8GHz, 50ohm, 1.0325, 309MHz, - 34.827, 5.652 dBi and 5.756 dB respectively. The dual band antenna having two slots on the non-resonating sides of patch resonates at 5.2 GHz and 5.8 GHz and provides a wide bandwidth of 771.51MHz. The directivity of the antenna at 5.20GHz and 5.8 GHz are 5.226dBi and 5.308dBi, and gain is 5.304 dB and 5.754dB respectively.

The fabrication of the dual band is also done as well as the testing is done using VNA model no: E5071C. The testing results along with the comparison between testing results and simulated results are also shown. The operating frequency of single band at 5.8GHz is obtained at 5.83GHz, also the range of frequencies covered by dual band has shifted to 4.740 GHz to 5.632GHz. The reason for shifting has also been explained.

ACKNOWLEDGEMENT

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(Tanveer Kour Raina)

INDEX

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

MPA	Microstrip Patch Antenna
RMPA	Rectangular Microstrip Patch Antenna
WLAN	Wireless Local Area Network
Q	Quality Factor
CST	Computer Simulation Technology
VNA	Vector Network Analyzer

CHAPTER 1
AN OVERVIEW OF WIRELESS COMMUNICATION

Communication between humans was first by the sound through voice. With the desire for slightly more distance communication, there came devices like drums, some visual methods like, smoke signals and signal flags were used. The optical communication devices, utilized the light portion of the electromagnetic spectrum. With the advancement of the technology, now the electromagnetic spectrum, outside the visible region, has been employed for communication, through the use of radio. One of the humankind's greatest natural resource is the electromagnetic spectrum and antenna is key factor for utilizing this resource.

1.1 Wireless Communication

The transfer of the information between two or more points which are not directly connected is basically called Wireless communication. The term "Wireless" came into public use to refer to a radio receiver or transceiver (can be used both as transmitter and receiver) establishing its use in wireless communication such as in cellular network and wireless broadband internet. It is also used to refer to any type of operation that is implemented without use of wires. It encompasses various types of fixed, mobile and portable two way radios, cellular telephones. Other examples are satellite television, wireless computer mice, keyboards and headsets, broadcast television [1].

Wireless operation permits services, such as long range communications, that are impossible or impractical to implement with the use of wires. The most common use of wireless networks is to connect the laptop/mobile data communication users who travel from location to location. Another important use is for mobile networks that connect through antennas, via satellite communications.

Different modes of Wireless communication are:

1. Radio frequency communication
2. Microwave communication like long range line-of-sight high directional antennas and short range communications.
3. Infrared short range communication like remote controls etc.

Up to now, mobile wireless communication has gone through two generations in the past twenty years. And currently it is heading for the third generation and beyond the third generation. In the following, the features of each generation are presented.

1.1.1 The first generation [2]

1st Generation was tuned to transmit voice signals by the analog frequency modulation technology. And all the users within the system shared the available frequency spectrum (or the wireless channel) by frequency division multiple access (FDMA) technology eg AMPS. The first generation of mobile wireless communication system was a voice-oriented communication system.

1.1.2 The second generation [2]

In the early 1990s, the concept of the second generation was proposed and digital technology as well as the cellular network was accepted in the mobile communication. The second generation system can transmit voices as well as low speed data streams by the digital technology. And the data transmission rate of the second generation is about 64,000 bits per second. The multiple access technology of the second generation systems is CDMA or TDMA. It is a technology that different users can send/receive information in the same frequency bandwidth at the same time by means of using a unique code division channels assigned to each of them.

The second generation system has overcome many shortcomings of the first generation, such as the limited capacity, lack of security protection. The primary data service in the second generation is the short message eg GSM, TDMA. Because both the second generation and the first generation of mobile wireless communication system are the voice optimized systems and their bandwidths are limited, they are not suitable to provide high speed data services. Therefore, need for more advanced system, that is, the third generation of mobile wireless communication system came into picture.

1.1.3 The third generation [2]

In the late 20th century, the third generation of mobile wireless communication system was developed. On the basis of the second generation of mobile wireless communication system, the third generation system can provide the multi-media service and reach the data transmission rate at 2,000,000 bits per second eg CDMA.

To further improve the data transmission rate and capacity of mobile wireless communication system, researchers and manufactures have begun the research of the fourth generation of mobile wireless communication system—Beyond 3G.

1.1.4 The fourth generation of mobile wireless communication system [2]

On the basis of the 3^{rd} generation, the 4^{th} generation system is expected to accomplish the data transmission at the rate of 20,000,000 bits per second by means of a series of technologies, such as OFDM (orthogonal frequency division multiplexing), multiple carriers, self-adaptive modulation and so on. As a result, the capacity of the fourth generation of mobile wireless communication systems may be three or five times larger than the third generation of mobile wireless communication system by means of some special air interface, which supports larger variation of data transmission rate, packet switching and different required QOS (quality of service).one of the most promising technologies is WLAN , offering wireless data services to the users; it uses OFDM as the method of multiplexing.

1.2 WLAN Standards

One of the promising technology of future for data transmission i.e. WLAN and WiMAX. Wireless local area network (WLAN) links two or more devices using some wireless Distribution method and usually providing a connection through an access point to the wider internet. The IEEE standards for wireless local area i.e 802.11 which supported a maximum network bandwidth of 2Mbps- too slow for most applications, were developed by IEEE and to have improve the above standard, four subsets of Ethernet based protocol standards were included[4]:

Table 1.1 Different WLAN Standards

Parameters	**802.11a**	**802.11b**	**802.11g**	**802.11n**
Frequency	5-6 GHz	2.4 GHz	2.4 GHz	2.4/5 GHz
Data rate	54Mbps	11 Mbps	54 Mbps	248Mbps

Range	120m	140m	140m	250m
Type	LAN	LAN	LAN	LAN

1.3 Need for Antennas

In each and every case, the transmitters and receivers involved require antennas, even if some are hidden like inside laptop computers equipped with wi-fi, or inside radio. According to the IEEE standards definition of terms for antennas, antenna is basically defined as the means of transmitting and receiving radio waves. It can also be defined as the transitional structure between the free space and the guiding space.[3] Antenna are required by any radio receiver or transmitter to couple its electrical connection to the electromagnetic field. Radio waves are electromagnetic waves which carry signals through the air or through space, at the speed of light. Radio transmitters and receivers are used to convey signals/ information in the systems including broadcast radio, Wi-fi, point to point communication links and many remote controlled devices

1.3.1 Types of Antennas

Antennas are classified into many types which are described below:

1.3.1.1 On the basis of radiation:

- **Omni-directional antenna**: also called as weakly directional antennas which radiate and receive more or less in all directions.
- **Directional antenna**: also called as beam antennas which radiate and receive in a particular direction. A directional antenna is intended to maximize its coupling to the electromagnetic field in the direction of the other station or to cover a particular sector.

1.3.1.2 On the basis of Aperture

- **Wire Antennas:** these types of antennas are familiar to layman as these antennas are seen every-where like on automobiles, buildings. Ships, aircrafts, spacecrafts etc.
- **Aperture Antennas:** these antennas are more familiar to the layman today than in the past because of the increasing demand for more sophisticated form of antennas and also for utilization of higher frequencies. These are more useful in spacecraft and aircraft applications as they can be easily mounted on them.

- **Microstrip Antennas:** these antennas have use in space applications, government and commercial applications. They consist of metallic patch on grounded substrate. These antennas are mounted on the surface of high performance aircraft, spacecraft, satellites, missiles.
- **Array Antennas:** to get the required radiation characteristics, which is not possible with single antenna, then an aggregate of radiating elements called array are used. The arrangement of the arrays should be such that the radiations adds up to give maximum radiation in a particular direction or directions and minimum in other directions.

1.3.1.3 On the basis of polarization:

- **Linearly polarized antenna:** if the antenna is transmitting /receiving in the vertical E direction then it is called vertically polarized antenna. If the antenna is transmitting/ receiving in the horizontal E direction then it is called horizontally polarized antenna.
- **Circularly polarized antenna:** if the antenna is able to transmit/receive E field vectors of any orientation, then antenna is said to be circularly polarized antenna.

The major requirement in the present wireless world is to have the size of antenna as small as possible , so out the available structures when application in terms of WLAN is considered ; the microstrip antennas serve as the most optimum choice .

1.4 Introduction of Microstrip Patch Antenna

The applications in present-day mobile communication systems usually require smaller antenna size in order to meet the miniaturization requirements of mobile units. Thus, size reduction and bandwidth enhancement are becoming major design considerations for practical applications of microstrip antennas. For this reason, studies to achieve compact and broadband operations of microstrip antennas have greatly increased. Much significant progress in the design of compact microstrip antennas with broadband, dual-frequency, dual- polarized, circularly polarized, and gain-enhanced operations have been reported over the past several years[3].

Conventional microstrip antennas in general have a conducting patch printed on a grounded microwave substrate, and have the attractive features of low profile, light weight, easy fabrication, and conformability to mounting hosts. However, microstrip antennas inherently have a narrow bandwidth, and bandwidth enhancement is usually demanded for practical applications.

In its most basic form, a Microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in Figure 2.1. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo-etched on the dielectric substrate.

For a rectangular patch, the length L of the patch is usually $0.3333\,\lambda_0 < L < 0.5\,\lambda_0$, where λ_0 is the free-space wavelength. The patch is selected to be very thin such that (where t is the patch thickness). The height 'h' of the dielectric substrate is usually $0.003\,\lambda_0 \leq h \leq 0.05\,\lambda_0$. The dielectric constant of the substrate (ε_r) is typically in the range $2.2 \leq \varepsilon_r \leq 12$.

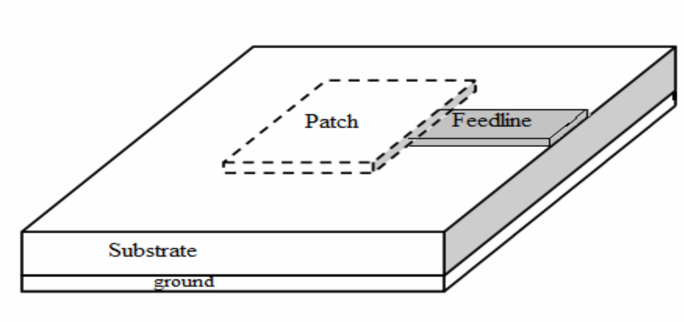

Fig 1.1 Structure of Micro-Strip Patch Antenna[3]

Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. This behavior can be explained on the basis of Transmission line model.

1.4.1 Basic theory of Microstrip Antenna Operation

The preferred models for the analysis of Microstrip patch antennas are the transmission line model, cavity model, and full wave model (which include primarily integral equations/Moment Method). Basically **the transmission-line model** represents the microstrip antenna by two slots, separated by a low-impedance Z_c transmission line of length L**.**

A Fringing Effects

Because the dimensions of the patch are finite along the length and width, the fields at the edges of the patch undergo fringing. This is illustrated along the length in Figures 2.6 (a,b) for the two radiating slots of the microstrip antenna. The same applies along the width. The amount of fringing is a function of the dimensions of the patch and the height of the substrate. For the principal E-plane (xy-plane) fringing is a function of the ratio of the length of the patch L to the height h of the substrate (L/h) and the dielectric constant of the substrate. Since for microstrip antennas L/ h >>1, fringing is reduced; however, it must be taken into account because it influences the resonant frequency of the antenna. The same applies for the width. Fringing makes the microstrip line look wider electrically compared to its physical dimensions. Since some of the waves travel in the substrate and some in air, an effective dielectric constant ε_{reff} is introduced to account for fringing and the wave propagation in the line.

For a line with air above the substrate, the effective dielectric constant has values in the range of $1<<\varepsilon_{reff}<\varepsilon_{r}$. For most applications where the dielectric constant of the substrate is much greater than unity ($\varepsilon_r >>1$), the value of will be closer to the value of the actual dielectric constant of the substrate. The effective dielectric constant is also a function of frequency.

According to it, as the frequency of operation increases, most of the electric field lines concentrate in the substrate. Therefore the microstrip line behaves more like a homogeneous line of one dielectric (only the substrate), and the effective dielectric constant approaches the value of the dielectric constant of the substrate[5]

The effective dielectric value of the substrate is given by:

$$W/h > 1$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{\frac{-1}{2}} \qquad 1.1$$

B Effective Length, Resonant Frequency, and Effective Width

Because of the fringing effects, electrically the patch of the microstrip antenna looks greater than its physical dimensions. For the principal E-plane (xy-plane), this is demonstrated in Figure 2.7 where the dimensions of the patch along its length have been extended on each end by a distance ΔL, which is a function of the effective dielectric constant and the width-to-height ratio (W/h).

A very popular and practical approximate relation for the normalized extension of the length is

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \quad 1.2$$

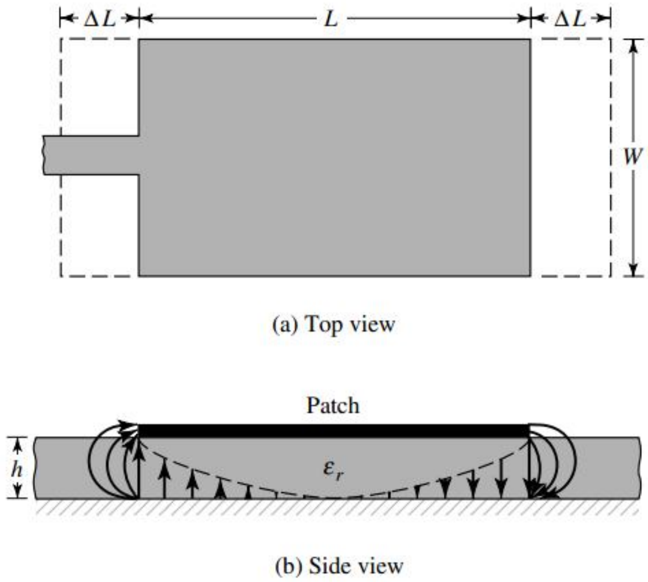

Fig 1.2 Physical and effective length of microstrip patch antenna[3]

Since the length of the patch has been extended by ΔL on each side, the effective length of the patch is now (L=λ/2 for dominant TM_{010} mode with no fringing)

$$L_{eff} = L + 2\Delta l \quad 1.3$$

For the dominant TM_{010} mode, the resonant frequency of the microstrip antenna is the function of length. Usually it is given by:

$$(f_r)_{010} = \frac{1}{2L\sqrt{(\varepsilon_r)}\sqrt{\varepsilon_0\mu_0}} - \frac{v_0}{2L\sqrt{(\varepsilon_r)}} \quad 1.4$$

Where v_0 is the speed of the light in free space[20]

C Design Procedure

In the typical design procedure of rectangular Microstrip patch antenna, three essential parameters are:

Frequency of operation (F_r): The resonant frequency of the antenna must be selected appropriately. The antenna designed should be useful for the X band communication system. The frequency range of X band is approximately 7.0 to 11.2 GHz. The resonant frequency selected for my design is 10 GHz.[16]

Dielectric constant of the substrate (ε_r): The dielectric constant of substrate (ε_r) material plays an important role in the patch antenna design. A substrate with a high dielectric constant reduces the dimensions of the antenna but it also affects the antenna performance. So, there is a trade-off between size and performance of patch antenna.

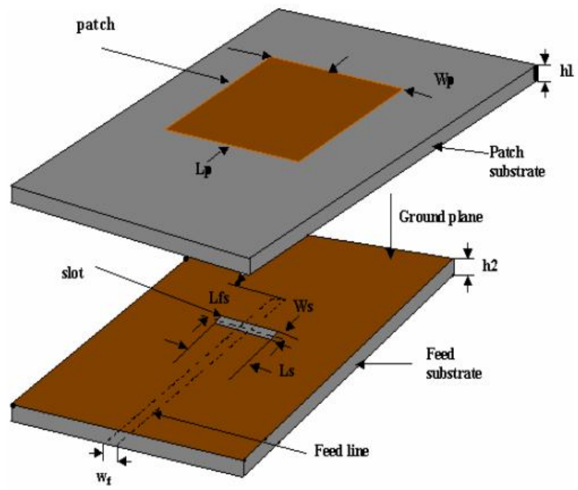

Fig 1.3 Aperture Coupled Microstrip Patch Antenna (Exploded View) [16]

Height of dielectric substrate (h): For the Microstrip patch antenna to be used in communication systems, it is essential that the antenna is not bulky. Hence, the height of the dielectric substrate should be less.

After the proper selection of above three parameters, the next step is to calculate the radiating patch width and length.

Step 1: Calculation of Width (W)

For an efficient radiator, practical width that leads to good radiation efficiencies is [20]

$$W = \frac{1}{2fr\sqrt{(\mu o \varepsilon o)}}\sqrt{\frac{2}{\varepsilon r+1}} \qquad 1.5$$

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

The effective dielectric constant can be bettered from equation (1.1)

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

The effective length is

$$L_{eff} = \frac{c}{2fo\sqrt{(\varepsilon reff)}} \quad 1.6$$

Step 4: Calculation of Length Extension (L)

$$\frac{\Delta L}{h} = 0.412 \frac{(\varepsilon reff+0.3)(\frac{W}{h}+0.264)}{(\varepsilon reff-0.258)(\frac{W}{h}+0.8)} \quad 1.7$$

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

The actual length of radiating patch is obtained by

$$L = L_{eff} - 2\Delta L \quad 1.8$$

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

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.[18] Hence, for this design, the ground plane dimensions would be given as:

$$L_g = 6h + L \quad 1.9$$

$$W_g = 6h + W \quad 1.10$$

1.4.2 Advantages and Disadvantages

Some of their principal advantages are given below [5]:

- Light weight and low volume.
- Low fabrication cost, hence can be manufactured in large quantities.
- Can be easily integrated with microwave integrated circuits (MI Cs).
- Capable of dual and triple frequency operations.

Micro-strip patch antennas suffer from a number of disadvantages as compared to conventional antennas. Their major disadvantages are [5]

- Narrow bandwidth.
- Low efficiency.
- Low Gain.

- Low power handling capacity.

Micro strip patch antennas have a very high antenna quality factor (Q). Q represents the losses associated with the antenna and 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. However, surface waves can be minimized by use of photonic band gap structures [6]. Other problems such as lower gain and lower power handling capacity can be overcome by using an array configuration for the elements.

1.4.3 Antenna Parameters

Before discussing the simulation of the microstrip patch antenna, it is important to discuss the parameters in details that are to be analyzed in simulation.

- **Return Loss:** It is the difference between forward and reflected power, in dB, generally measured at the input to the coaxial cable connected to the antenna.

  If the power transmitted by the source is P_t and the power reflected back is P_r , then the return loss is given by P_r.

  For maximum power transfer the return loss should be as small as possible. This means that the ratio P_r/P_t should be as small as possible, or expressed in dB, the return loss should be as large a negative number as possible. Return Loss is determined in dB as follows: [3]

  $$R_L = -20 \log |\Gamma| \text{ (dB)}, \text{ Here } |\Gamma| = V_O^-/V_0^+ = (Z_L - Z_0)/(Z_L + Z_0) \qquad 1.11$$

  Where | Γ | = is the reflection coefficient,

  V_O^- = is the reflected voltage

  V_0^+ = is the incident voltage,

  Z_L and Z_0 are the load and characteristic impedance.

- **Smith Chart:** It was invented by Phillip H. Smith (1905-1987), is a graphical aid or nomogram specializing in radio frequency (RF) engineering to assist in solving problems with transmission lines and matching circuits. Normalized scaling allows the Smith Chart to be used for problems involving any characteristic impedance or system impedance, although by far the most commonly used is 50 ohms.[5]

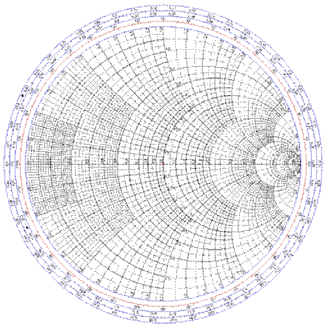

Fig 1.4 Smith Chart[5]

- **Directivity:** It is defined as the ratio of radiation intensity in a given direction from the antenna to the radiation intensity averaged over all the directions. The average radiation intensity is equal to the total power radiated by the antenna divided 4π. If the direction is not specified, the direction of maximum radiation intensity is implied. The directivity of the non-isotropic source is equal to the ratio of its radiation intensity in a given direction over that of an isotropic source. In numerical form, directivity is given by:[3]

$$\mathbf{D = U/U_0 = 4\pi U_{max}/ P_{rad}} \qquad 1.12$$

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

  U_o = radiation intensity of an isotropic antenna (W/unit solid angle)

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

  P_{rad} = total power radiated (W)

- **Gain:** It is defined as the ratio of the intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna is radiated isotropic ally. The radiation intensity corresponding to the isotropically radiated power is equal to power accepted (input) by the antenna divided by 4π.when the direction is not stated, the power gain is usually taken in the direction of maximum radiation.[3]

  It is given as:

$$\mathbf{Gain} = 4\pi\frac{\textit{radiation intensity}}{\textit{total input (accepted) power}} \qquad 1.13$$

- **Bandwidth:** It is defined as "the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard." The bandwidth can be considered to be the range of frequencies, on either side of a center frequency (usually the resonance frequency for a dipole), where the antenna characteristics (such as input impedance, pattern, beam-width, polarization, side lobe level, gain, beam direction, radiation efficiency) are within an acceptable value of those at the center frequency.[3]

- **Beam width:** It is defined as the angular separation between two identical points on opposite side of the pattern maximum.[3]
- **Efficiency:** It is used to take into account losses at the input terminals and within the structure of the antenna. Such losses may be due, to

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

In general, the overall efficiency can be written as

$$\mathbf{e_0 = e_r \times e_c \times e_d} \qquad 1.14$$

Where e_0 = total efficiency (dimensionless)

e_r = reflection(mismatch) efficiency = (1 - |?|2) (dimensionless)

e_c = conduction efficiency (dimensionless)

e_d = dielectric efficiency (dimensionless)[3]

1.4.4 Feeding Techniques

Micro strip patch antennas can be fed by a variety of methods. These methods can be classified into two categories- contacting and non-contacting. In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such as a microstrip line. In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch. The four most popular feed techniques used are the microstrip line, co axial probe (both contacting schemes), aperture coupling and proximity coupling (both non-contacting schemes) [6].

A **microstrip feed** uses a transmission line to connect the radiating patch to receive or transmit circuitry. Electromagnetic field lines are focused between the microstrip line and ground plane to excite only guided waves as opposed to radiated or surface waves. A microstrip line feed is generally used in two configurations namely Directly fed and Inset feed as shown in the figure 1.2 .

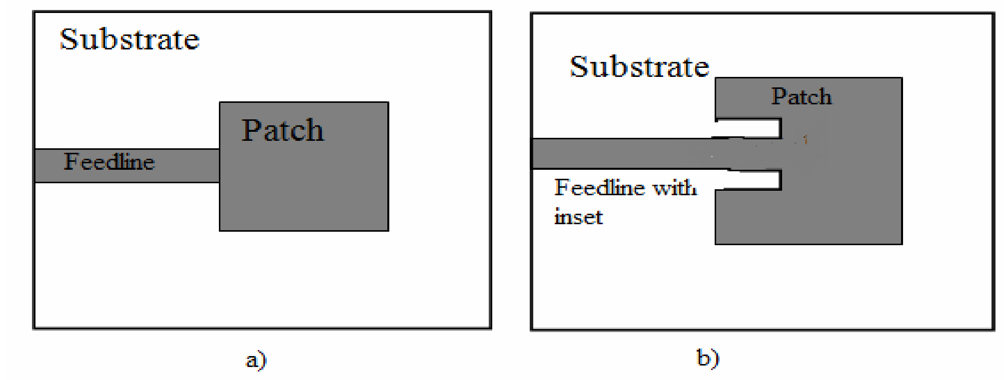

Fig 1.5 Geometry of Micro-Strip Feed line (a) directly feed (b) Inset feed[3]

A **probe fed** antenna consists of a microstrip patch fed by the center conductor of a co axial line (see Figure 1.3). The outer coax conductor is electrically connected to the ground plane. Due to the absence of a microstrip feed line, the substrate thickness and permittivity can be designed to maximize antenna radiation. However, the probe center conductor underneath the patch causes undesired distortion in the electric field between the patch and ground plane and produces undesired reactive loading effects at the antenna input port. The undesired reactance can be compensated by adjusting the probe location on the patch.

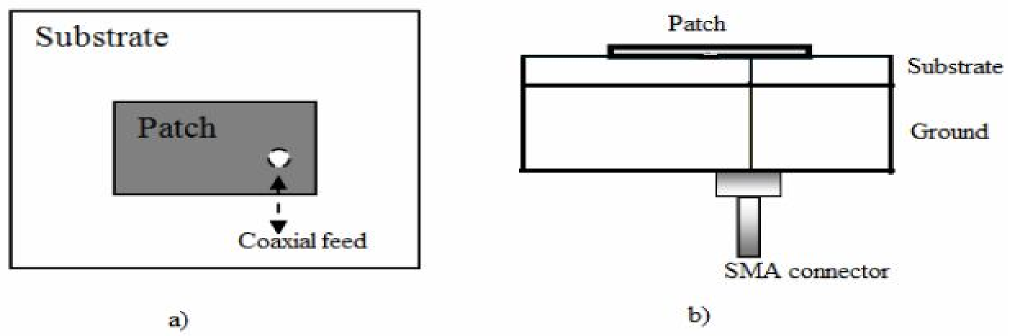

Fig 1.6 Geometry of Coaxial Probe Feed microstrip patch antenna (a) Top view (b) Side view[5]

In **Aperture Coupled** feeding technique, the radiating patch and the microstrip feed line are separated by the ground plane thereby eliminating the direct electrical connection between the conducting feed and radiating patch (see figure 1.4). Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane.

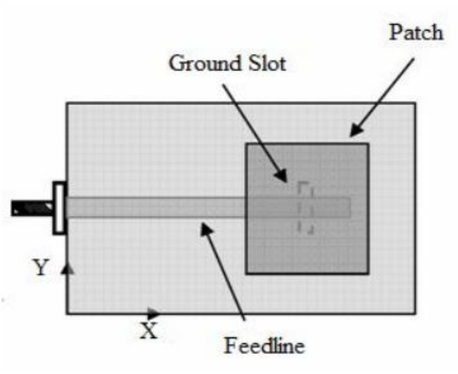

Fig 1.7 Geometry of an Aperture Coupled Feed Microstrip Antenna (Top View)[5]

The coupling aperture is usually centered under the patch, leading to lower cross-polarization due to symmetry of the configuration. The amount of coupling from the feed line to the patch is determined by the shape, size and location of the aperture.

The **Proximity Coupled** Feed technique is also called as the electromagnetic coupling scheme. As shown in Figure 1.5, two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate.

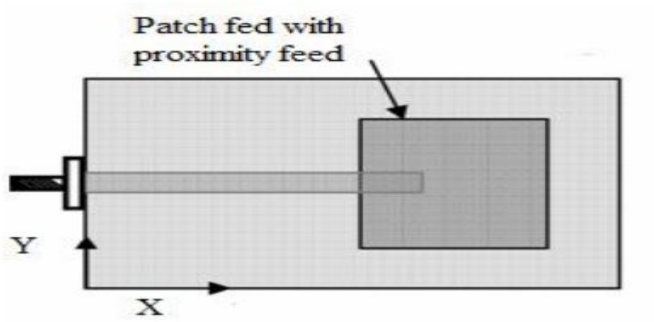

Fig 1.8 Geometry of proximity coupled feed microstrip patch antenna (Top view)[5]

1.4.4 Comparison between different feeding techniques

Table1.2 The comparisons between the feeding methods for MPA

Characteristics	Microstrip Feed line	Coaxial Feed	Aperture Coupled Feed	Proximity Coupled Feed
Spurious feed radiation	More	More	More	More
Reliability	Better	Poor due to soldering	Good	Good

Impedance Matching	Easy	Easy	Easy	Easy
Bandwidth	2-5%	2-5%	13%	21%

Due to more spurious radiation, more reliability and easy impedance matching, aperture coupled feeding techniques is used. Also, it provides better bandwidth as compared to Microstrip feed line and Coaxial coupled techniques.[6]

1.5 Objective of the thesis

- The basic principles of the Aperture coupled single band microstrip rectangular patch antenna and parameters variation are studied.
- Design and simulation of dual wideband aperture coupled MPA from the single band aperture coupled MPA is done and Fabrication and testing of the designed antennas is done.
- Design and simulation of triple band aperture coupled MPA with defective ground structure and wide band microstrip antenna using stacking and the parameters variations are also studied.

1.6 Thesis Organization

The thesis is divided into seven chapters.

Chapter 1 is dedicated to the Overview of wireless Communication and Microstrip antenna.

Chapter 2 includes the literature survey on the aperture coupled antenna. The brief idea about the researches done for bandwidth enhancement, defected ground structure and stacked aperture coupled antenna is given.

In Chapter 3, a single band antenna is designed and the effect of various physical parameters on the resonating frequency is studied.

*In Chapter 4***,** the single band antenna is loaded with slots such that a dual frequency antenna is obtained.

In Chapter 5, triple band antenna with defected ground structure as well as a wide band antenna using stacking is obtained and various parameters are also studied.

In Chapter 6, The antenna studied in Chapter 4 are fabricated and tested.

Chapter 7 is dedicated to the conclusion and the future work.

CHAPTER 2

LITERATURE SURVEY

This chapter gives us an idea about the evolution of Aperture Coupled Microstrip Antenna and various developments in the past.

2.1 Aperture Coupled Microstrip Antennas

The first aperture coupled microstrip antenna was fabricated and tested by a graduate student, Allen Buck, on August 1, 1984, in the University of Massachusetts Antenna Lab. This antenna used Duroid substrates with a circular coupling aperture, and operated at 2 GHz [19]. It was found that this antenna worked perfectly – it was impedance matched, and the radiation patterns were good. Most importantly, the required coupling aperture was small enough so that the back radiation from the coupling aperture was much smaller than the forward radiation level [7].

A new feed configuration for the microstrip antenna has been proposed by Pozar. It is preferable to mount the antenna elements on the low dielectric constant substrate in order to increase the bandwidth, efficiency. With the two layer design, the antennas are located on different substrate, which yields optimal array performance. The ground plane shields the antenna half space from the spurious radiation emitted by feed line. So, aperture coupling overcomes the problems related to probe feeds. [8]

D. M Pozar and R.Pous in the year 1990 found that the frequency response can be controlled by adjusting the size of the coupling aperture. Also, by the proper arrangement of size of coupling aperture, frequency selective surface can be made to pass linear or dual polarized wave.[9]

Slot aperture coupled microstrip antenna are attractive antenna elements because of their light weight, thin structure and ease of fabrication and compatibility with multi-layered feed networks. For mobile-satellite communication use, they at same time are required to fulfill other specifications like wide frequency bandwidth.[10]

Compared to probe-fed or microstrip line fed microstrip antennas, the microstrip antenna has the advantage of twice the available substrate area, individual optimization of antenna and feed substrates.[11]

2.2 Developments in the field of Aperture Coupled Microstrip Patch Antenna

With the help of references, various developments in Microstrip Patch Antenna are discussed.

2.2.1 Bandwidth enhancement of Aperture Coupled Microstrip Patch Antenna

An approach to increase the bandwidth and to increase the gain, an antenna with two parasitic elements has been designed. One parasitic element increases the bandwidth and other is used to increase the gain.[12]

In the year 1997, Shashi, Paul and Harokopus concluded that Smart antennas are required to increase the coverage of the base station for personnal communication systems. Although they provide high gain and coverage over the whole cell but still microstrip antennas are preferred as they provide high gain and coverage but are also flat in appearance and provide dual polarization. It reduces weight, while yielding excellent electrical performance. The dual polarization provides the required bandwidth to cover the entire transmit and receive bands.[13]

For many wireless applications, bandwidths of 10-15% are required and can be easily achieved by using large aperture with fairly thick antenna substrate. By using stacked antenna bandwidth in excess of 50% has been realized.[14]

For maximum coupling, the patch should be centered over the slot, moving the patch relative to the slot in H-plane direction has low effect, while moving it in the direction of E-plane decreases the coupling level, so for maximum coupling, the feed line should be at right angle to center of the slot.[15]

In the year 2006, Manoj, S.K.Koul showed the effect of the slot length, stub length and dielectric constant, and the variations that occur in return loss and resonant frequency and also studied that As the aperture length is reduced the input resistance of the antenna is decreases. This might be thought of as decreasing the coupling factor between the feed line and the antenna. [16]

Due to the current trend, one way of improving and making maximum use of wireless communication is by using array antennas. As the number of arrays in the antenna increases, there is an increase in gain, return loss, bandwidth.[17]

Use of the long microstrip line can effectively couples the energy first from the aperture cut from the ground plane and then to the patch. Also larger the ground plane, lesser will be the back radiation. As the ground plane size at low frequency is relatively smaller in terms of wavelength than at higher frequency, larger back radiation are expected at low frequency band.[18]

2.2.2 Antennas with Defected Ground Structure

In the year 2003, Y.J.Sung, M.Kin, Y.S.Kin gave a method to reduce the higher order harmonics with the help of Defected Ground Structure. A H-shaped defect on the ground plane helped to reduce the harmonics. Then its comparison with a conventional antenna is made and it was found that radiated power was drastically reduced which is based on the stop band characteristics of defected ground structure cell.[19]

A Novel structure called Defected Ground Structure & Defected Microstrip Structure, which has widely used in several applications such as reducing the size of patch antennas without degrading the performance of the antenna as better efficiency, better bandwidth etc. DGS/DMS has other application is suppression of harmonics without introducing a big attenuation in the fundamental frequency. This concept is given by Himanshu Singh, Y.K.Awasthi and A.K.Verma in the paper titled Microstrip Patch Antenna with the Defected Ground Structure and Defected Microstrip Structure.[20]

For multiband applications, a series of curved Microstrip Antenna with Defected Ground Structure, which are more smaller, with wider radiation beam and are suitable for WLAN applications in different environments, have been proposed by J.P.Geng, J.J.Li, R.H.Jin, S.Ye, X.L.Liang and M.Z.Li. The DGS in the ground plane of the Microstrip antenna are used to achieve useful multiband, small size and gain enhancement.[21]

A microstrip slot antenna with novel E-shaped coupling aperture is presented in the paper titled "A Compact Microstrip Slot Antenna With Novel E-shaped Coupling Aperture" given by Omid Hoseini Izadi and Mandana Mehrparvar. Different parameters of the antenna are explored. It's shown that by varying the dimensions of E-shaped slot and length of Ls (matching stub), the antenna can be designed for high gain, dual band or quad band characteristic.[22]

The effect of inserting a rectangular shape defected ground structure (DGS) into the ground plane of the conventional rectangular microstrip patch antenna (CRMPA) has been proposed by Mouloud Challal, Arab Azrar and Mokrane Dehmas in the year 2011.The performances of the CRMPA are characterized by varying the dimensions of the rectangular slot (RS-DGS) and also by locating the RS-DGS at specific position.[23]

In the year 2011, Halappa R. Gajera, Anoop C.N, M M Naik.G, Archana S. P, Nandini R Pushpitha B.K, Ravi Kumar M.D proposed their design of rectangular microstrip patch antenna (RMPA). The glass epoxy substrate with height 1.6mm and the dielectric constant is 4.4 is used. The half circular slot etched on the patch at the top right as DMS, two circular slots etched on the ground plane as DGS. The DGS helps in shifting the resonant frequency to desired frequency. DGS was used to improve the bandwidth and reduce the size of patch to make antenna, thereby achieving the gain of 4.65dBi.[24]

In the year 2012, Rajeshwar Lal Dua, Himanshu Singh, Neha Gambhir proposed the rectangular patch antenna designed with swastik structure DGS in the year 2012. Here, the radiating patch area is smaller as compared to the conventional antenna without DGS. So, this antenna design with DGS not only improve the parameters of the antenna without DGS but also can provide a smaller size of radiating patches, which will cause an overall reduction in antenna size.[25]

Introducing slots at the edges of the patch a size reduction of about 57% has been achieved with increased frequency ratio and multi- frequency operation. The multi resonant frequency antenna has been presented in the year 2012 with DGS structure, given by Sudipta das, Dr.P.P.Sarkar, Dr.S.K.Chowdhury, P.Chowdhury.[26]

2.2.3 Stacked Aperture Coupled Microstrip Patch Antenna

A paper titled "A novel low mutual coupling microstrip antenna array design using defected ground structure" by Mohsen Salehi, Ahad Tavakoli in year 2005 proposed a low mutual coupling design for a two element microstrip antenna array. A dumbbell shaped defect on the ground plane of the antenna is inserted between the patches creating a band gap in the operation frequency band of the antenna. Also keeping all physical parameters identical to the DGS case. In the EBG structure, three columns of mushroom-like EBG patches designed to have a bandgap centered at 6 GHz are inserted between the 0.5λ0 spaced elements and patches are connected to the ground plane using very thin vias. The By suppressing the surface waves, it provides a very low mutual coupling between array elements.[27]

The air gap can also be used in the microstrip patch antenna for dual band operation. The dual band can be achieved by varying the air gap between the single patch and aperture coupled patch microstrip antenna. The main advantage is that it has increase in the bandwidth of antenna, that also at two resonant frequencies and can vary over the wide range. The input impedance is easily matched at the two frequencies.[28]

A paper titled "A High Gain Dual Stacked Aperture Coupled Microstrip Antenna for Wideband Applications" given by N. Ghassemi, J. Rashed-Mohassel, M. H. Neshati and S. Tavakoli and M. Ghassemi had given a method to increase the gain bandwidth and decrease the thickness of a structure with the help of two rectangular stacked patches. To achieve this purpose, a numerical study is presented on the effects of, dielectric position on top layer, changing the positions of patches horizontally, length and position of the slot, and the length of the top patch.[29]

A parasitically coupled broadband patch antenna for the broadband wireless LAN application systems is presented in the paper titled "Broadband Stacked Patch Antenna for Bluetooth Applications” given by Anil B. Nandgaonkar and Shankar B. Deosarkar. It was observed that Stacked multi-resonators which are electromagnetically coupled microstrip antennas are used to widen the bandwidth and the performance of the antenna can be further improved by using substrates with low insertion losses.[30]

An active antenna enhanced with photonic band-gap and defected ground structures. Defected ground structure is employed to shrink down the size of the balanced power amplifier to 20% and suppress the higher mode up to 25 dB. A rectangular patch antenna is used as the radiating element. In this paper a stack of two dumbbell-shaped DGS cells are exploited on the ground plane of the output matching network of the reference amplifier , where the amplified high power signals are delivered to the antenna unit, to reduce the second harmonic of the amplifier unit. [31]

The effects of stacking Koch fractal antenna aperture coupled fed are investigated. It is shown that by stacking the antennas. The bandwidth can be increased up to 32% at the resonance frequency of 980 MHz which is much larger than the 3% bandwidth offered by a conventional Koch fractal antenna as well as having some 14% less surface area. This antenna has an 8dBi flat gain over the bandwidth. [32]

An inverted stacked microstrip patch antenna with single-fed for GPS applications is designed at L band. The radiation patterns of microstrip antennas depend upon parameters like width, length, resonant frequency and dielectric constant. In view of this, by varying the height of the air gap, feed position and dielectric constant of the patch, corresponding radiation pattern, near field and return loss are observed and The optimum feed position, dielectric constant and height of the air gap (h) are found to be (-4, 25), _r2 = 2.55 and h=8mm respectively. The return loss of -50.45 dB is observed at designed frequency 1.30GHz. in the paper titled “Parametric Study of a Novel Stacked Patch Antenna” given by V.Rajya Lakshmi, M. Sravani , G.S.M Raju.[33]

2.3 Research Gaps

- The use of parasitic elements, stacked patches, using thick substrates of low permittivity etc have proved to improve the bandwidth of the antenna [20] However, the broad banding design in microstrip antenna results in high volume in spite of its efficient results. The work regarding the reduction of the profile can be done.

- As the variations in antenna thickness yield improved results in terms of return loss [23], but we can use dielectric substrates with different permittivities. Since the upper substrate in aperture coupled antenna prefers low permittivity and lower substrate prefers high permittivity for appropriate functionality, the asymmetric variations in dielectric constant of the whole antenna body need to be worked up on to bring out more distinctive and improved results.
- Two different slot configurations proposed are transverse slot and longitudinal slot. Although the first configuration is simpler and does not need impedance matching as compared to the second one, the longitudinal slot antenna provides wider bandwidth [26]. The defected ground structures can be used in the longitudinal slot configurations to improve the bandwidth and increase the gain .
- A novel structure called DGS & Defected microstrip structure are used to reduce the size of patch antennas without degrading the performance of antenna.
- The use of different shaped patch antenna geometry has brought good performance in the VSWR and in response at low dielectric constant. Work can be done to analyze the antenna by taking the slot shape exactly as the patch shape.
- Different shaped slots on ground can help in achieving multiband applications. As different parameters of the slots are varied to get single, dual and quad band antennas.
- The air gap in microstrip patch antenna also plays an important role. With the variation in the air gap, multiple bands can be achieved.
- With the defected ground structure having different shapes can be used to reduce the higher order modes obtained also increase the bandwidth and increase the gain.
- The effects of dielectric position on top layer, changing the positions of patches horizontally, length and position of the slot, and the length of the top patch can provide high coupling and also increase the gain and bandwidth.

2.4 Thesis Problem definition

- Design of single band antenna for WLAN application (2.4GHz, 3.6GHz, 5.2GHz and 5.8GHz).
- Design of dual band antenna for WLAN application (2.4GHz, 3.6GHz, 5.2GHz and 5.8GHz).

- Design of triple band antenna for microwave applications (2.88GHz, 3.06GHZ) and WLAN applications (2.4GHz, 3.6GHz, 5.2GHz and 5.8GHz) using Defective Ground Structure.
- Bandwidth enhancement using Stacking for Direct Broadcast satellite applications (11.565GHz to 12.886GHz).
- Fabrication of single band and dual band antennas
- Testing of the fabricated antennas using Vector Network Analyzer.
- Comparison of Simulated and measured results.

CHAPTER 3
SINGLE BAND APERTURE COUPLED ANTENNA DESIGN AND ITS PARAMETRIC STUDY

This chapter covers the designing of aperture coupling using the transmission line model. Firstly a single band antenna is designed for Wireless Communication applications at a frequency of 10GHz. The effect of varying the various parameters of antenna geometry like stub length, dimensions of aperture and the effect of the various dielectric constant on the designed antenna are analyzed.

3.1 Design of Rectangular Microstrip Patch Antenna

The rectangular patch antenna is approximately a one-half wavelength long section of rectangular Microstrip transmission line. When air is the antenna substrate, the length of the rectangular Microstrip antenna is approximately one-half of a free-space wavelength. The length of the antenna decreases as the relative dielectric constant of the substrate increases. The resonant length of the antenna is slightly shorter because of the extended electric "fringing fields" which increases the electrical length of the antenna slightly. [3] A single element of rectangular patch antenna, as shown in figure 3.1, can be designed for 10 GHz resonant frequency using transmission line model explained in chapter 1.

3.1.1 Designing of Single Band Rectangular Microstrip Antenna:

This section describes the design of rectangular Micro strip patch antenna satisfying the given specifications

Table 3.1 Design Specifications of Single Band

Frequency (f_r)	10GHz
Dielectric Constant (ε_r)	3.2
Patch Substrate Thickness	0.762mm
Feed Substrate Thickness	0.508mm

Patch Dimension: The dimensions of the patch can be calculated applying in the formula given in the equation 1.8 (chapter 1). So the dimensions are: Length (L) = 7.5mm and Width (W) = 7.5mm.

Ground Dimension: The dimensions of the ground can be calculated referring to the equation1.9 (chapter 1). Length (L_g) = 35.4mm and Width (W_g) = 25.4mm

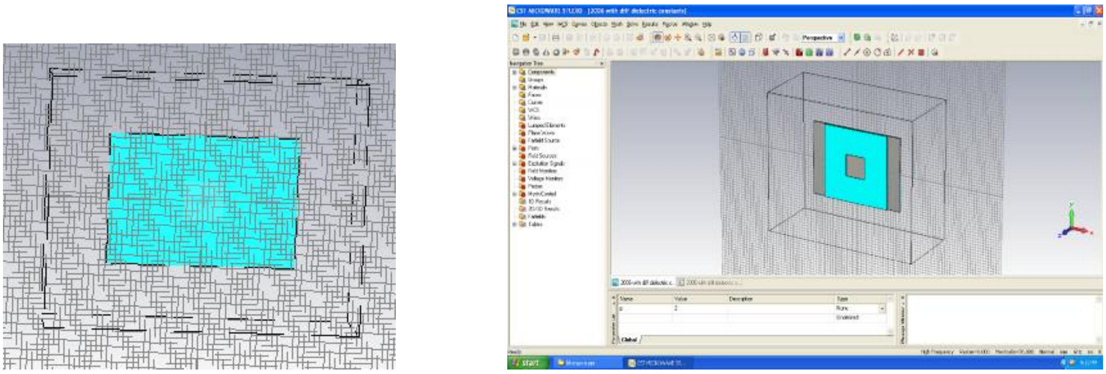

Fig 3.1 (a) Geometry of proposed Antenna (b) Designed structure on CST Microwave Studio

3.2 Simulation Setup and Result of Single Band Antenna at X-Band

The software used to model and simulate the Micro strip patch antenna is CST Micro wave Studio version 9. It analyzes 3D and multilayer structures of general shapes. It has been widely used in the design of MICs, RFICs, patch antenna, wire antenna and other RF/wireless antennas. It can be used to calculate return loss plot, current distributions, radiation patterns, smith chart etc.

The simulated results of the proposed antenna are presented in the below figures:

3.2.1 Return Loss and Antenna Bandwidth: Figure 3.2 shows the S_{11} parameters (return loss) for the proposed antenna resonates at 9.55GHz having value of -40dB. The bandwidth of the antenna can be said to be those range of frequencies over which the return loss is greater than -10 dB (corresponds to a VSWR of 2). Thus, the bandwidth of antenna can be calculated from return loss versus frequency plot. The bandwidth of the proposed patch antenna is 143 GHz and resonant frequency is 9.55GHz . More is the return loss means more of the coupling. If coupling is more than the antenna will have more directivity, thereby increasing the gain of the antenna.

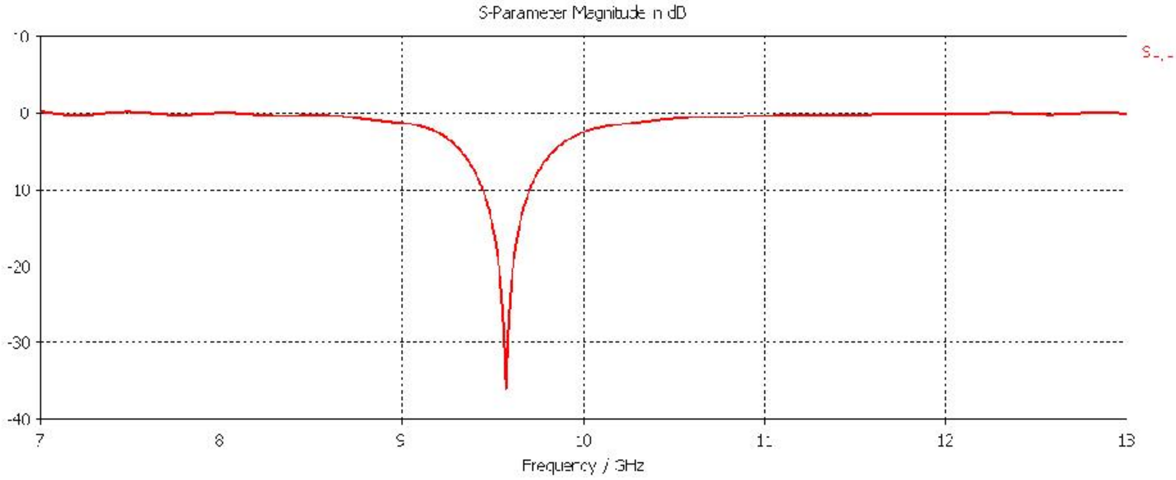

Fig 3.2 Return Loss S_{11} (in dB) at 9.55GHz

3.2.2 Smith Chart: The Smith Chart plot (figure3.3) represents that how the antenna impedance varies with frequency and gives impedance of 77.98 ohms. The size of the locus of the smith chart is controlled by the slot length. As the slot length increases, the size of the locus increases. For proper matching the locus must be large enough that it passes through the center of the smith chart.

As, it can be seen from the figure 3.3 that the circle cuts the resistive part at 0.77, thus matching at 77.98 ohm.

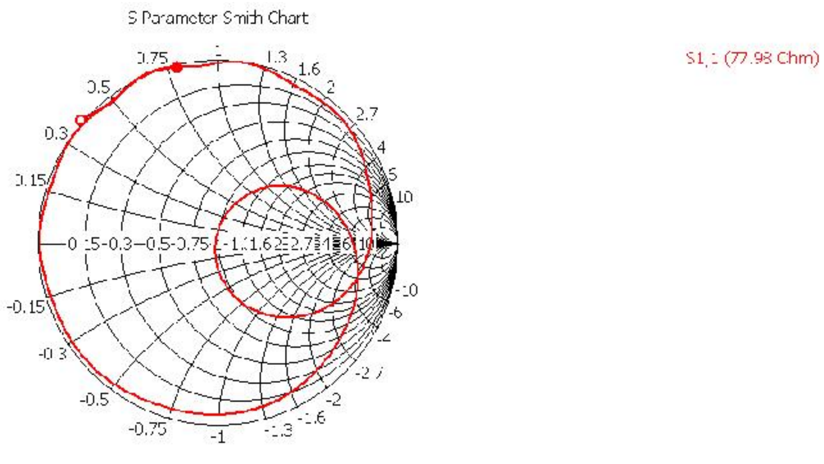

Fig 3.3 Smith Chart at 9.55GHz

3.2.3 Directivity: The Directivity plot (figure 3.4) represents amount of radiation intensity i.e is equal to 7.35 dBi. The simulated antenna radiates more in a particular direction as compared to the isotropic antenna which radiates equally in all directions, by an amount of 7.35 dBi

From polar plot view of the directivity, it can be seen that at a frequency of 10GHz,directivity is 7.354dBi, radiation pattern obtained is omnidirectional with main lobe directed at an angle of 5.0 degree, having angular beam-width of 81.4 degree. The magnitude of the main lobe is 7.4dBi.

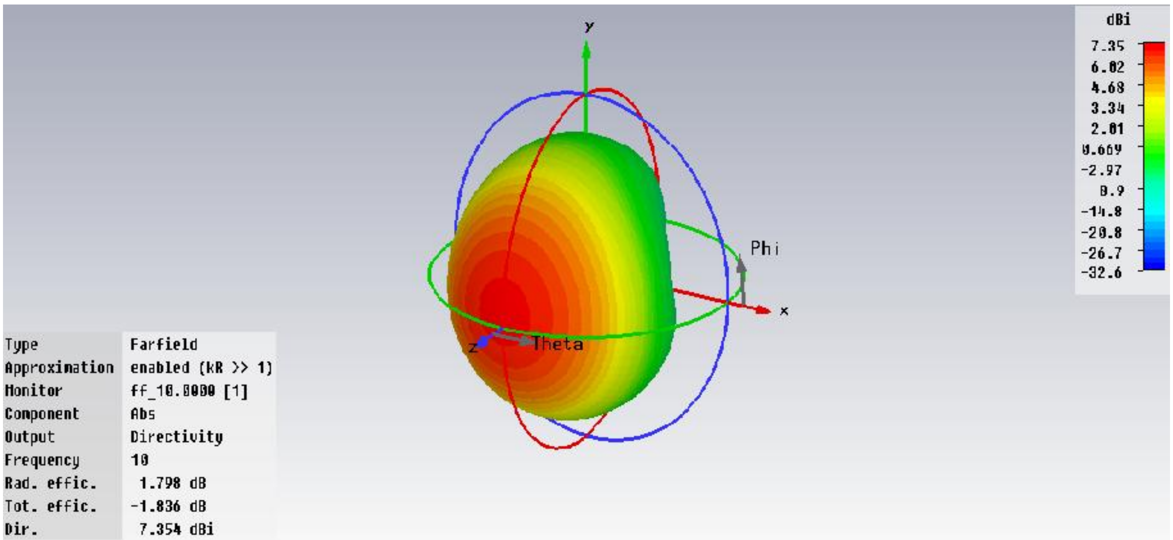

Fig 3.4 (a) Directivity (3D view) at 9.55GHz

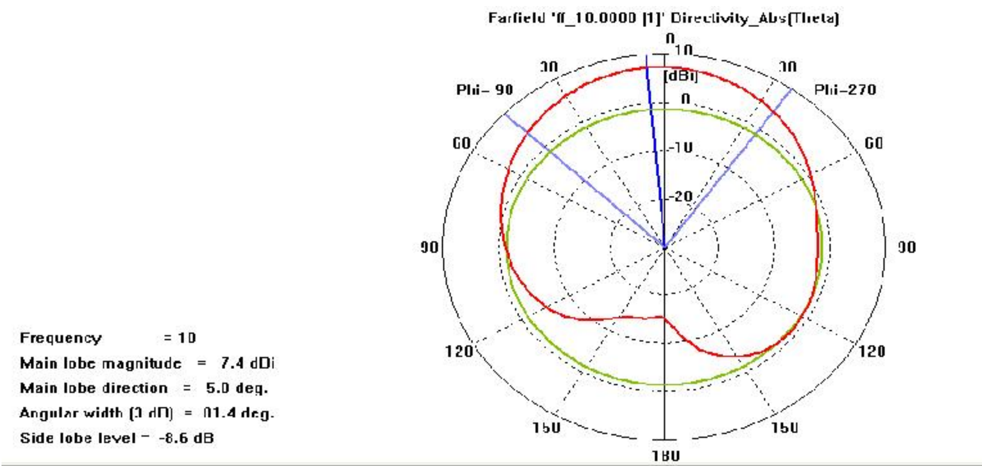

Fig 3.4 (b) Directivity (polar plot) at 9.55GHz

3.2.4 Gain: The Gain plot (figure3.5) gives the gain = 9.152 dB. The gain of the antenna in a particular direction is more as compared to isotropic antenna radiating in all directions which is very useful for WLAN applications in X-Band providing a better performance.

From polar plot view of the gain, it can be seen that at a frequency of 10GHz, gain is 9.152dB, radiation pattern obtained is omnidirectional with main lobe directed at an angle of 5.0 degree, having angular beam width of 81.4 degree. The magnitude of the main lobe is 9.2dB.

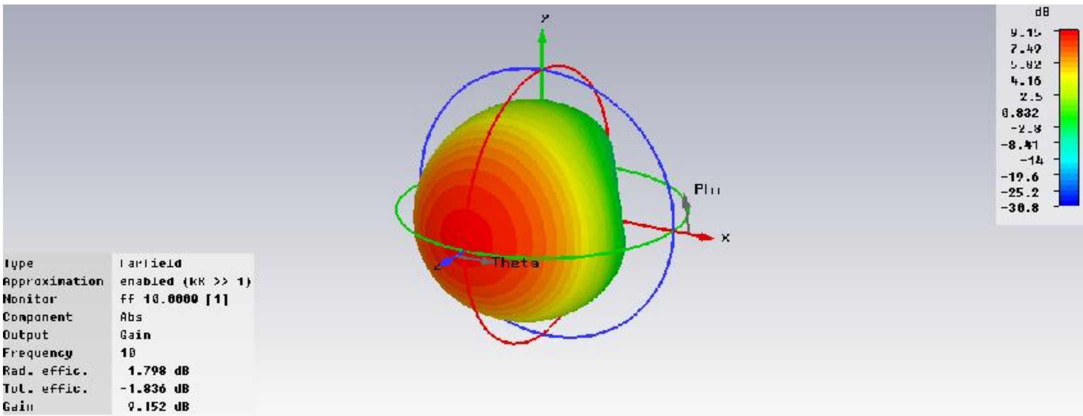

Fig 3.5 (a) Gain of the designed Antenna (3D view) at 9.55GHz

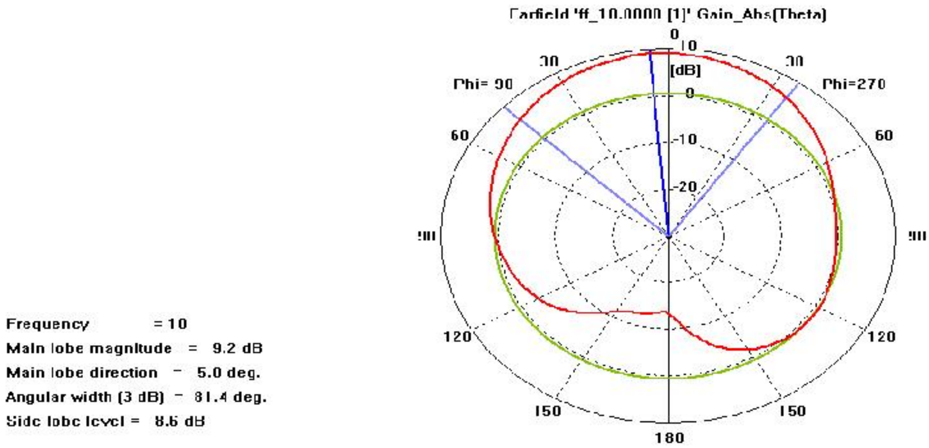

Fig 3.5 (b) Gain of the designed Antenna (polar plot) at 9.55GHz

3.2.5 Effect of Stub Length Variation: Feed point should be chosen in such a way so that there is a good impedance match between the generator impedance and the input impedance of the patch element. For maximum coupling, It should be placed perpendicular to the slot. [6] As from the figure 3.6, it can be seen that as a feed length is increased from 5.3mm to 8.3mm, the return loss is decreased from -6.5dB to -32dB till 6.3mm and then again increased to -16dB. So for proper matching, the stub length chosen is 6.3mm with return loss of -32dB and Stub length = 1.85mm is considered for design of this antenna

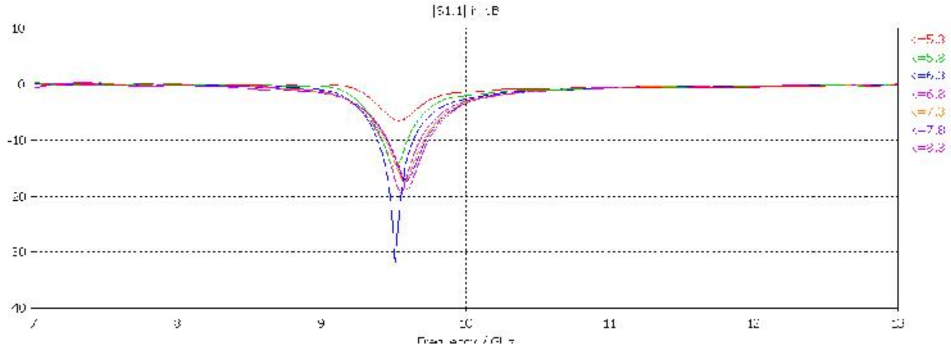

Fig 3.6 Effect of Feed Length Variation

3.2.6 Effect of Slot Length Variation: Coupling level is primarily decided by the slot length. There are two types of slots i.e. resonant and non-resonant type based on the length of the slot. If the slot length is comparable to the half of the wavelength of the antenna, it is called resonant slot. If the smaller length slots are used, it is non-resonant slot. As the slot length is decreased, input resistance also decreases. But there can also be decrease in the coupling between patch and feed line.[6] . When the aperture length (slot length) is increased from 3 mm to 6.3 mm keeping the slot width to slot length ratio to 1/10, there is a decrease in the coupling level. So, the slot length equal to 3.7 (1.85 x2 = 3.7 mm) is selected as depicted in figure 3.7.The slot length also affects the input impedance of the antenna.

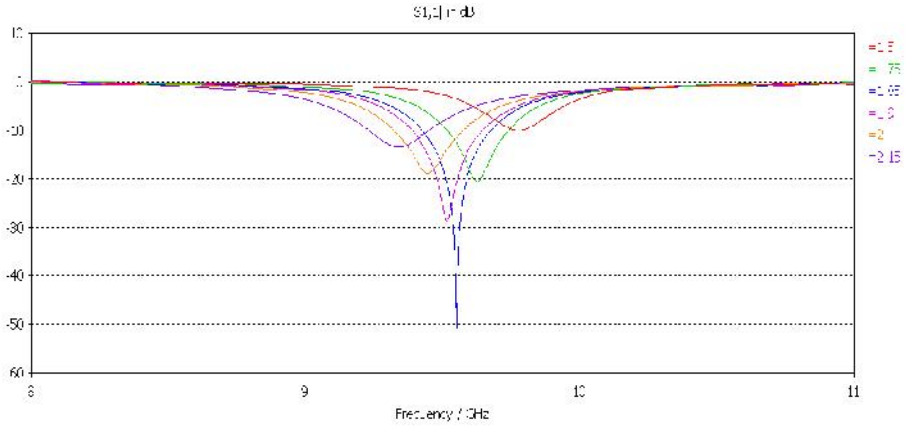

Fig 3.7 Effect of Slot Length Variation

3.2.7 Effect of the dielectric constant value of the substrate: It affects the bandwidth of the antenna directly. Also low permittivity of the dielectric substrate, wider the bandwidth and lesser surface wave excitation. High permittivity of the substrate is used for feed network and lower permittivity is used for antenna substrate. As the dielectric constant and thickness are varied in these analysis the feed line width and stub length are modified

to maintain a characterstic impedance of 50Ω and s atub length of $\lambda_g/4$ [6][18]. Larger the dielectric constant, smaller the antenna size and smaller the impedance bandwidth.
From the figure 3.8, it can be shown that As, the dielectric constant of antenna increases, the resonating frequency of the antenna decreases. Dielectric constant with value 3.2, resonating at 9.8GHz frequency, close to the frequency required. Also the return loss observed at this value of dilectric constant is more. So, the antenna having feed and the patch substrate of dilectric constant = 3.2 has been choosen

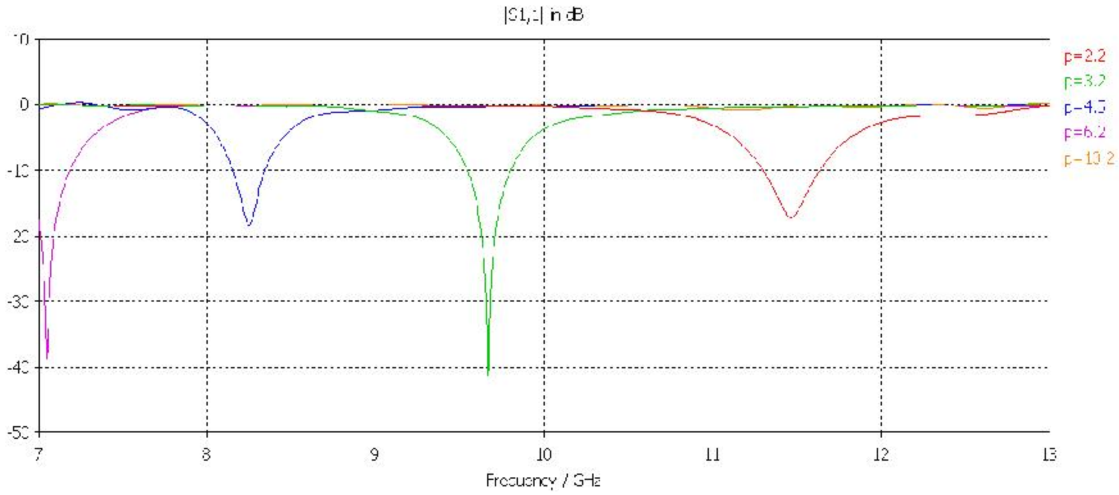

Fig 3.8 Effect of different Dielectric Constant of the substrate

In this chapter, the proposed antenna is simulated at X- band and the various parameters are also analyzed so as to get the desired results and also effect of the various physical parameters like patch length, patch width, aperture dimensions, antenna and feed substrates, feed line dimensions etc…are studied, by varying one parameter at a time and keeping all other parameters constant so that one can get an optimized antenna for the desired applications.

CHAPTER 4
WIDE DUAL BAND APERTURE COUPLED ANTENNA DESIGN FOR WLAN APPLICATIONS

This chapter covers the simulation and fabrication of the dual band aperture coupled antenna. Firstly a single band antenna is designed for Wireless Communication applications at a frequency of 5.8GHz. From the single band antenna, wide dual band with defected patch, covering the frequency bands of 5.2GHz and 5.8GHz is designed.

4.1 Design of Single Band Aperture Coupled Microstrip Antenna at 5.8GHz

A single element of rectangular patch antenna is designed for 5.8 GHz resonant frequency using transmission line model [6]. This section describes the design of rectangular Micro strip patch antenna satisfying the given specifications

Table 4.1 Design Specifications of Single Band Antenna

Frequency (f_r)	5.8GHz
Dielectric Constant (ε_r)	4.4
Patch Substrate Thickness	1.57mm
Feed Substrate Thickness	1.57mm

Patch Dimension: The dimensions of the patch can be calculated applying the formula given in the equation 1.8 (chapter 1). So the dimensions are: Length (L) = 14.8 mm and Width (W) = 9.53 mm

Ground Dimension: The dimensions of the ground can be calculated referring to the equation 1.9 (chapter 1). Length (L_g) = 20 mm and Width (W_g) = 17 mm.

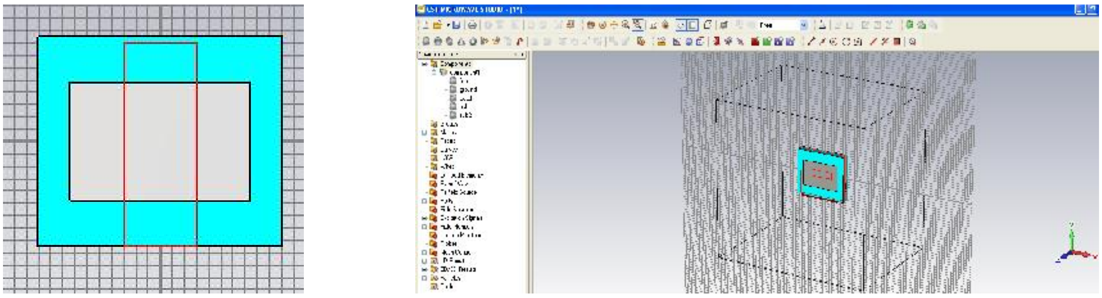

Fig 4.1 (a) Geometry of proposed Antenna (b) Designed structure on CST microwave studio

4.1.1 Simulation Setup and Result of Single Band Antenna

The simulated results of the proposed antenna are presented in the below figures:

4.1.1.1 Return Loss and Antenna Bandwidth: Figure 4.2 shows the S_{11} parameters (return loss = -30.680) for the proposed antenna. The designed antenna resonates at 5.83GHz. More negative is the return loss, more is the coupling and therefore more will be the directivity and gain of the proposed antenna in particular direction. The bandwidth of the simulated patch antenna is 308 MHz and resonant frequency is 5.83GHz (5.672 GHz – 5.980 GHz)

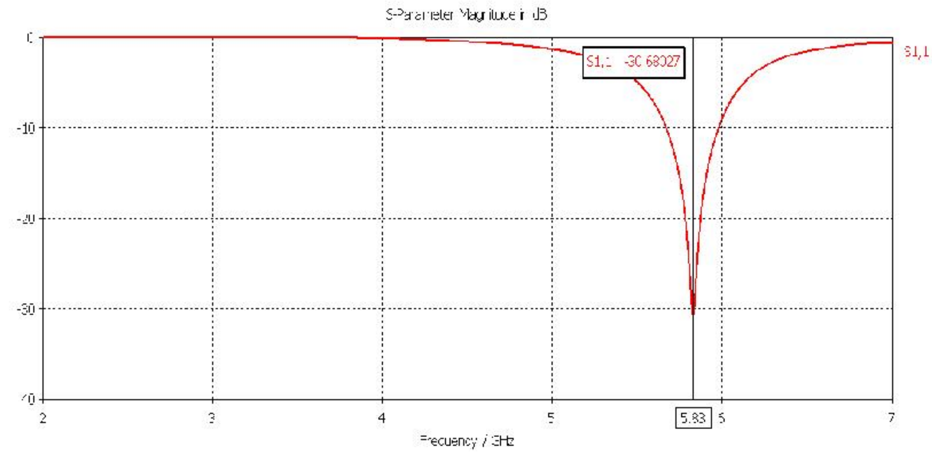

Fig 4.2 Return Loss S_{11} (in dB) of Simulated Antenna at 5.8GHz

4.1.1.2 Smith Chart: The Smith Chart plot (figure 4.3) represents that how the antenna impedance varies with frequency. The circle cuts the resistive part at 0.9, which is normalized at 50 ohm for perfect matching.

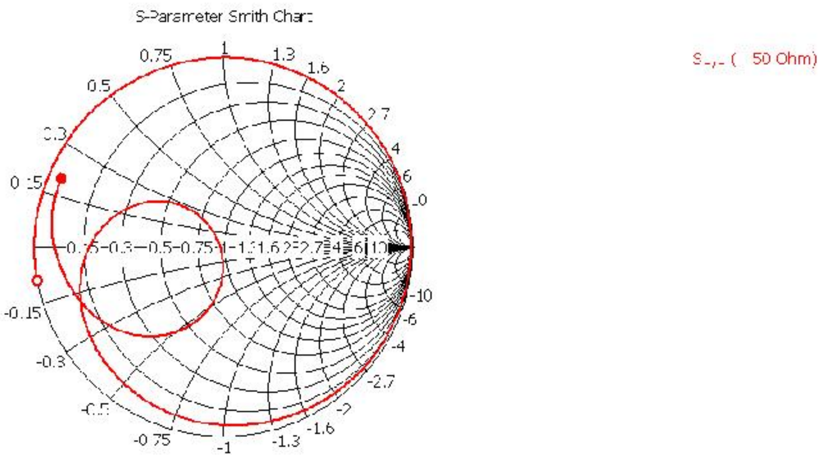

Fig 4.3 Smith Chart at 5.8GHz

4.1.1.3 Directivity: The Directivity plot (figure 4.4) represents amount of radiation intensity i.e is equal to 5.652 dBi. The simulated antenna radiates power more in the direction of main lobe maximum which is about 100 times as much as radiated by a non-directional isotropic antenna for same power input.

From polar plot view of the directivity, it can be seen that at a frequency of 5.8GHz,directivity is 5.652dBi, radiation pattern obtained is omnidirectional with main lobe directed at an angle of 7.0 degree, having angular beamwidth of 100 degree. The magnitude of the main lobe is 5.7dBi.

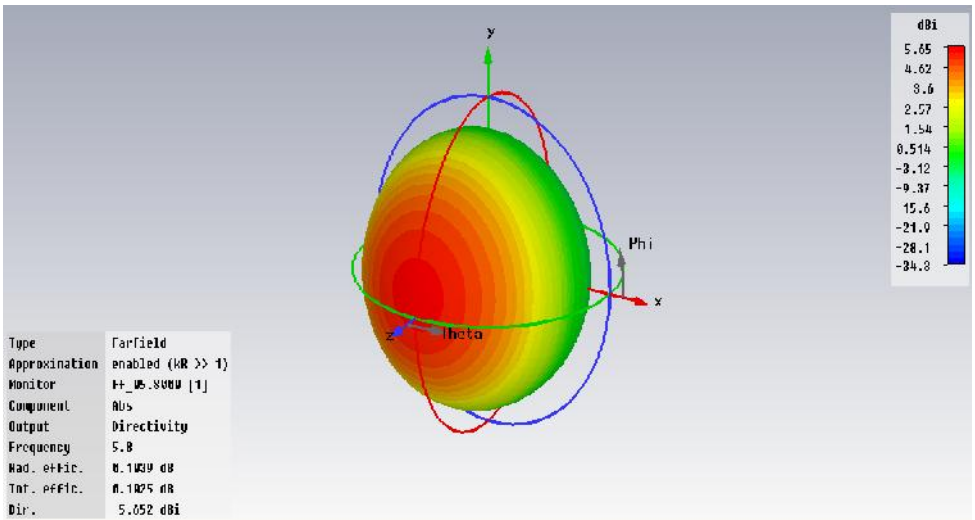

Fig 4.4 (a) Directivity (3D view) at 5.8GHz

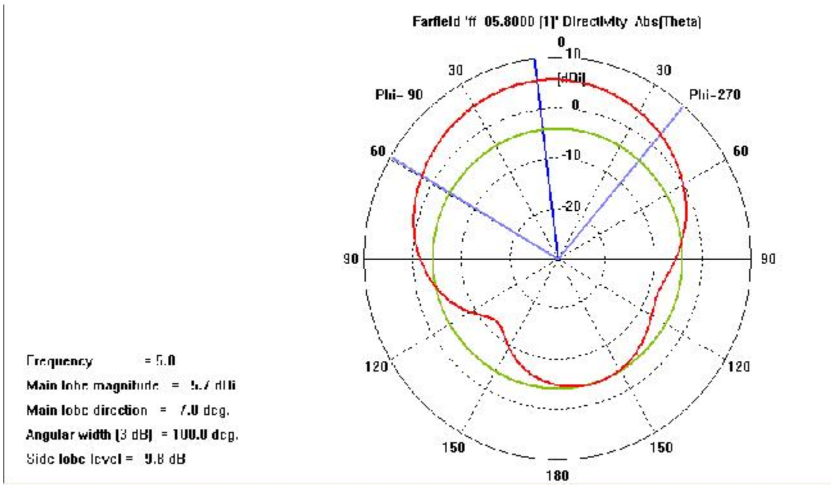

Fig 4.4 (b) Directivity (polar plot) at 5.8GHz

4.1.1.4 Gain: The Gain plot (figure 4.5) gives the gain = 5.756 dB. The gain of the proposed antenna is more as compared to isotropic antenna which means that more the gain, more directional is the antenna. Also, the bandwidth of the antenna proposed is good, so the proposed antenna is useful for the WLAN band (5.75 GHz to 5.85 GHz).

From polar plot view of the gain, it can be seen that at a frequency of 5.8GHz,gain is 5.756dB, radiation pattern obtained is omnidirectional with main lobe directed at an angle of 7.0 degree having angular beam width of 100 degree. The magnitude of the main lobe is 5.8dB.

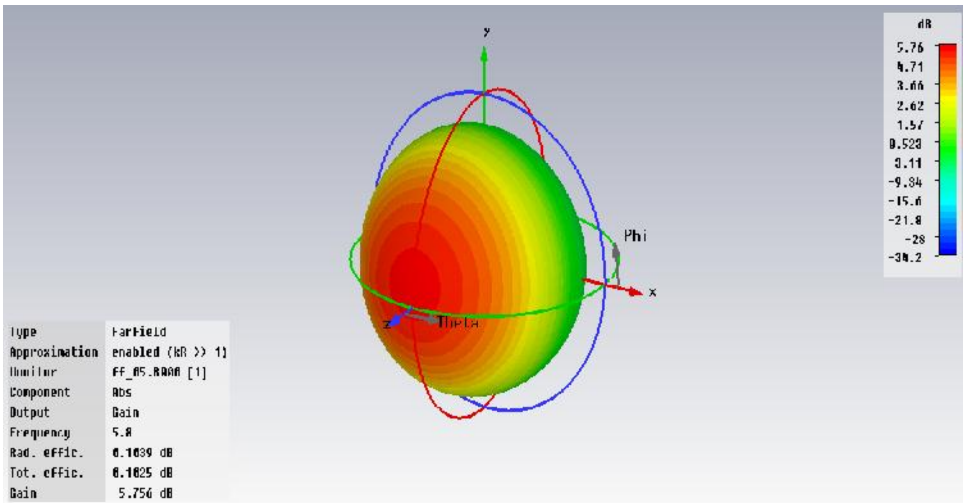

Fig 4.5 (a) Gain of the designed Antenna (3D view) at 5.8GHz

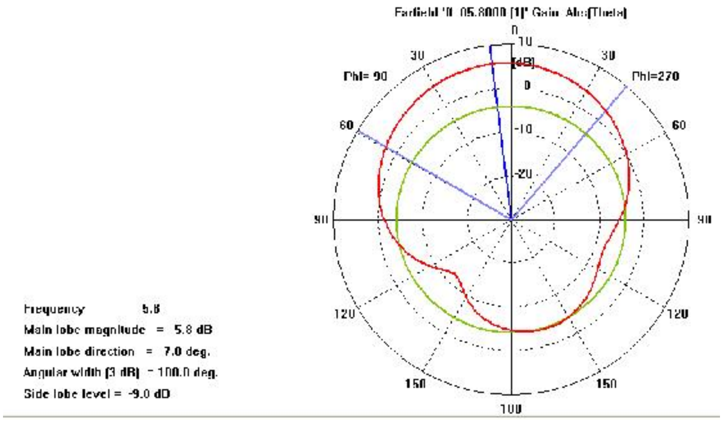

Fig 4.5 (b) Gain of the designed Antenna (polar plot) at 5.8GHz

4.2 Design of Dual Wide Band aperture Coupled Microstrip Antenna

This antenna is designed from the single band antenna discussed above, covering 5.2GHz and 5.8GHz bands of WLAN. The dual wide band antenna is designed with defected patch structure. Two slots are cut vertically parallel to the feed line, one at right side and other at left side, both having different dimensions. The slots on patch are adjusted by looking at the current distribution at both the frequencies.

Table 4.2 Design Specifications of the Slots on the Patch

Length of Slot 1 (on the left)	4.765mm
Width of Slot 1 (on the left)	0.5mm
Length of Slot 2 (on the right)	8.765
Width of Slot 2 (on the right)	0.5mm

The design structure of the proposed antenna is given below also the various parameters of the antenna are discussed below at both the frequencies.

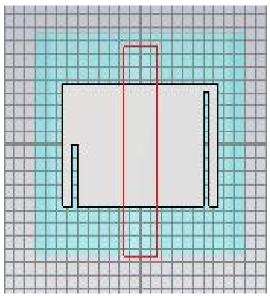

Figure 4.6 (a) Geometry of proposed Antenna

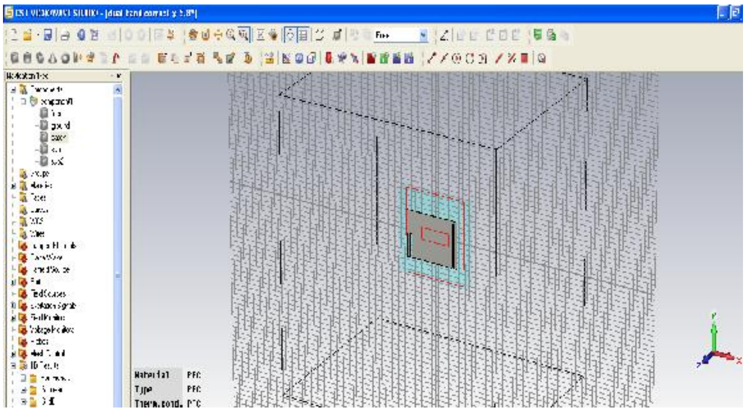

Figure 4.6 (b) Designed structure on CST microwave studio

4.2.1 Simulation Setup and Result of Dual Band Antenna

The software used to model and simulate the Micro strip patch antenna is CST Micro wave Studio version 9.

The simulated results of the proposed antenna are presented in the below figures:

4.2.1.1 Return Loss and Antenna Bandwidth: Figure 4.7 shows the wide dual band covering the frequency bands of WLAN (5.2GHz and 5.8GHz.) having a bandwidth of 771.51 MHz, are the results of simulated antenna. The bandwidth is measured below 10dB, As from figure, it is visible that two dips are formed, so the proposed antenna is called dual band antenna but also the center point of both the dips is below 10dB so it is called wide dual band antenna, covering a large range of frequencies, thereby useful for WLAN applications.

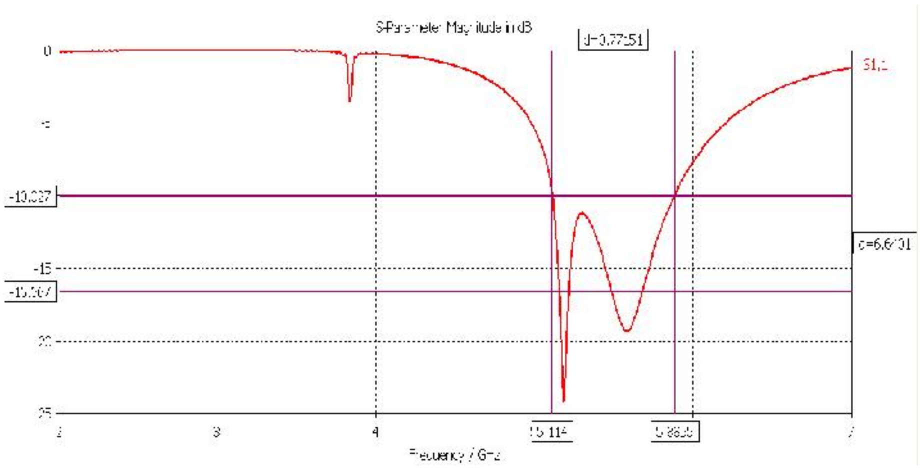

Fig 4.7 Return Loss S_{11} (in dB) of Simulated Dual Band Antenna

4.1.1.2 Smith Chart: The Smith Chart plot (figure 4.8) represents that how the antenna impedance varies with frequency. As, it is visible from the figure 4.8 that the circle cuts the resistive part of smith chart at two ends i.e 0.5 and 1.6. Also, the loop between the two ends gives us an idea about the bandwidth which means that the proposed antenna is a wide dual band antenna resonating at frequencies 5.18GHz and 5.58 GHz.

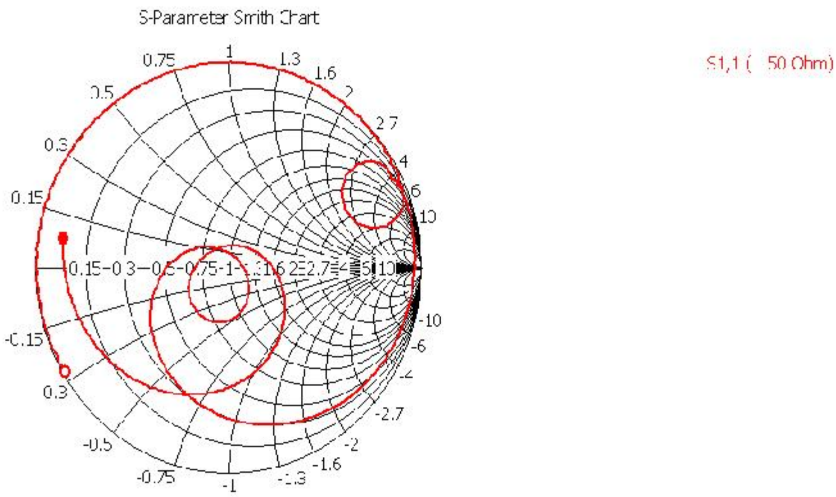

Fig 4.8 Smith Chart Dual Band Antenna

4.1.1.3 Directivity: The Directivity plot (figure 4.9) represents amount of radiation intensity i.e is equal to 5.226 dBi at a frequency of 5.2GHz. The red portion in the figure defines the maximum radiation and also it can be noticed that the directivity of dual band antenna at 5.2GHz has decreased as compared to the single band antenna at 5.8GHz.

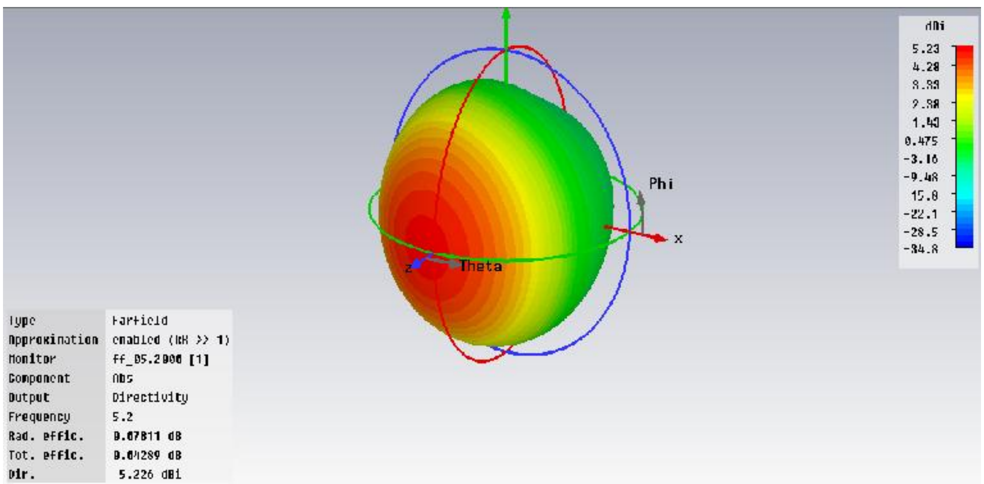

Fig 4.9 (a) Directivity (3D view) at 5.2GHz

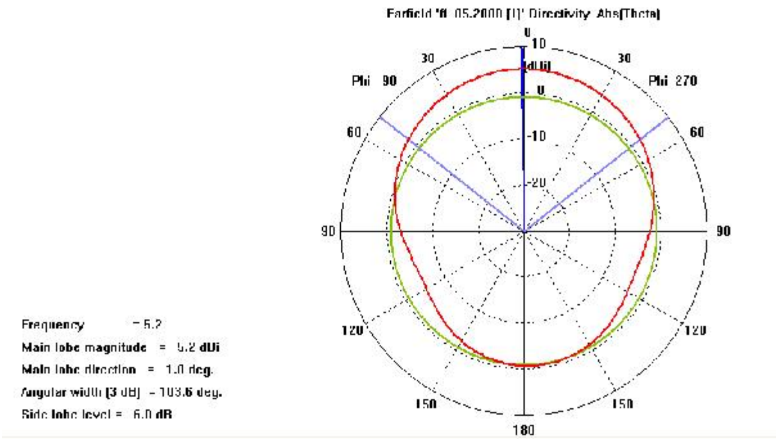

Fig 4.9(b) Directivity (polar plot) at 5.2GHz

From polar plot view of the directivity, it can be seen that at a frequency of 5.2GHz,directivity is 5.226dBi, radiation pattern obtained is omnidirectional with main lobe directed at an angle of 1.0 degree, having angular beam width of 103.6 degree. The magnitude of the main lobe is 5.2dBi.

The Directivity plot (figure 4.10) represents amount of radiation intensity i.e is equal to 5.308 dBi at a frequency of 5.8GHz. Also from polar plot view of the directivity, it can be seen that at a frequency of 5.8GHz,directivity is 5.308dBi, radiation pattern obtained is omnidirectional with main lobe directed at an angle of 6.0 degree, having angular beam width of 97degree. The magnitude of the main lobe is 5.3dBi.

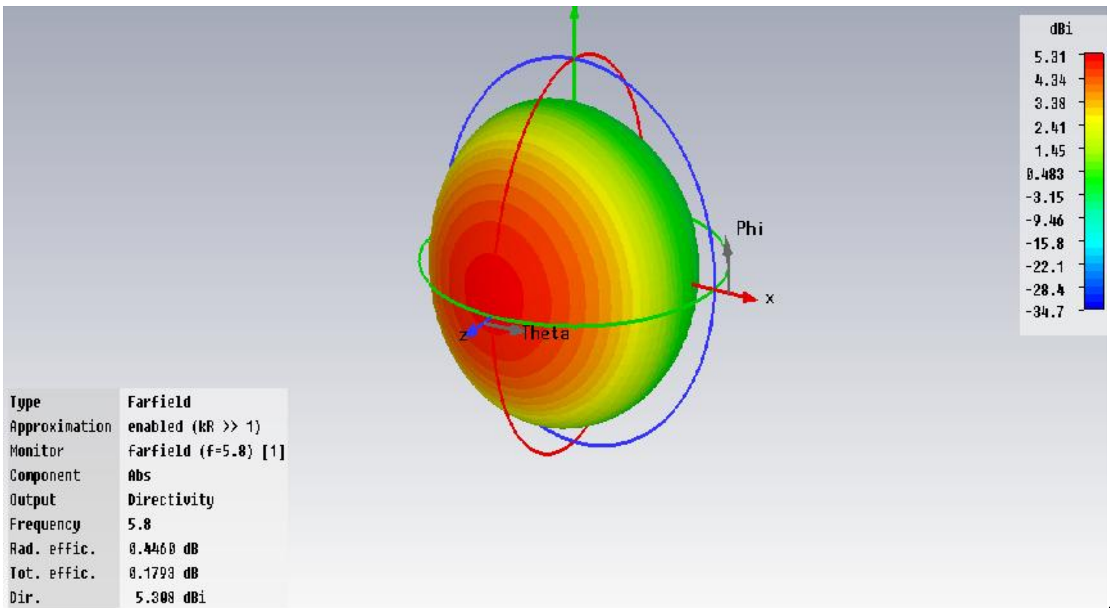

Fig 4.10 (a) Directivity (3D view) at 5.8GHz

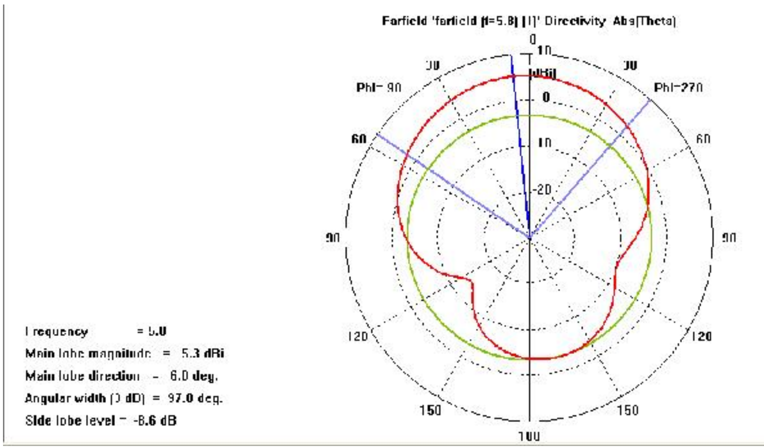

Fig 4.10 (b) Directivity (polar plot) at 5.8GHz

4.2.1.4 Gain: The Gain plot (figure 4.11) gives the gain = 5.304 dB at a frequency of 5.2GHz. Also from polar plot view of the gain, it can be seen that at a frequency of 5.2GHz,gain is 5.304 dB, radiation pattern obtained is omnidirectional with main lobe directed at an angle of 1.0 degree, having angular beam width of 103.6 degree. The magnitude of the main lobe is 5.3dB.

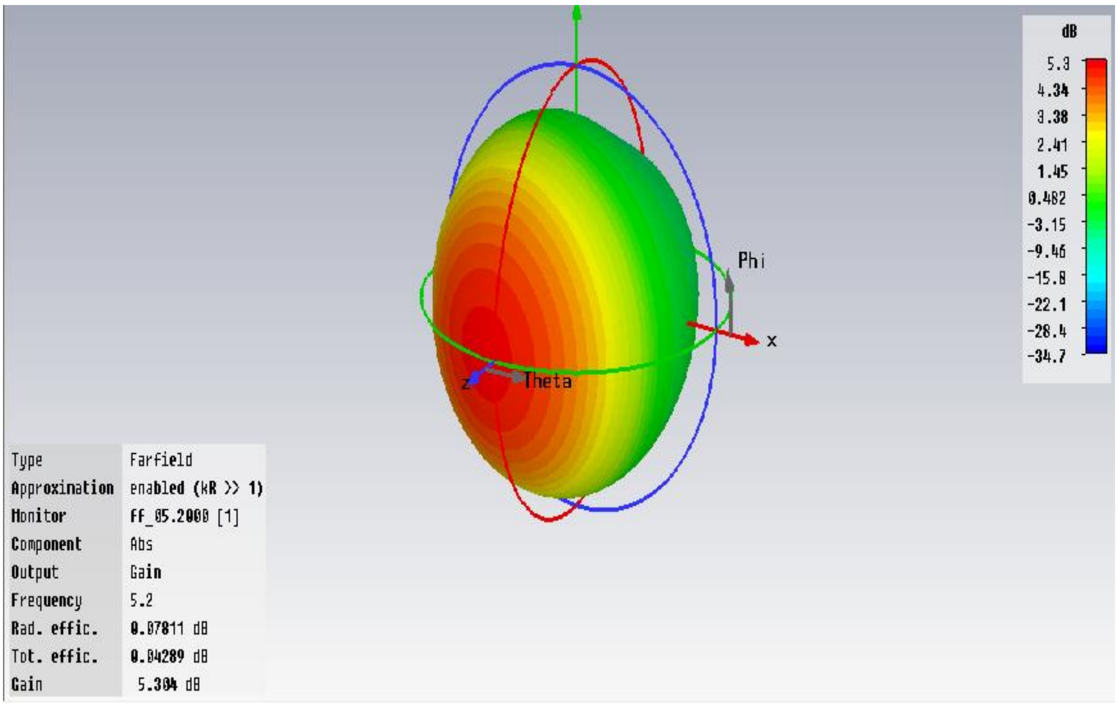

Fig 4.11 (a) Gain of the designed Antenna (3D view) at 5.2GHz

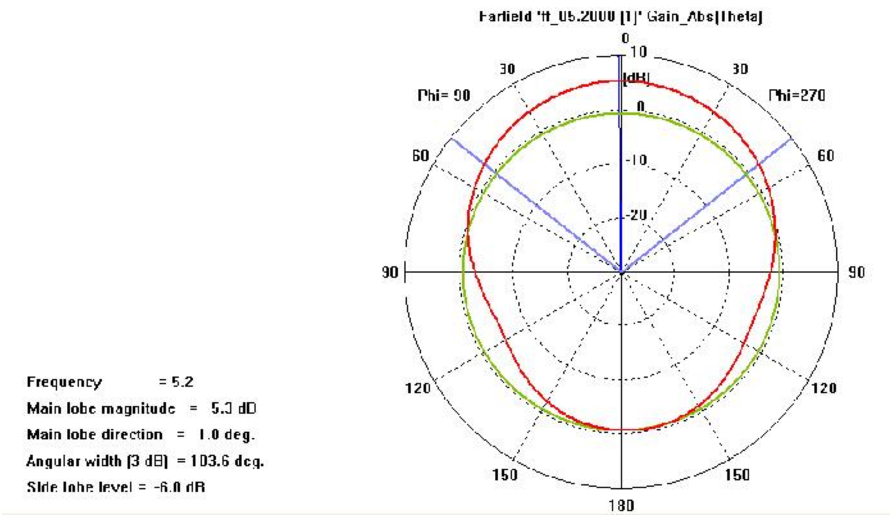

Fig 4.11 (b) Gain of the designed Antenna (polar plot) at 5.2GHz

The Gain plot (figure 4.12) gives the gain = 5.754 dB at a frequency of 5.8GHz.Also from polar plot view radiation pattern obtained is omnidirectional with main lobe directed at an angle of 7.0 degree, having angular beam width of 100 degree. The magnitude of the main lobe is 5.8dB. The red portion on the figure 4.12 (a) describes the maximum gain in the particular direction at an angle of 7.0 degree.

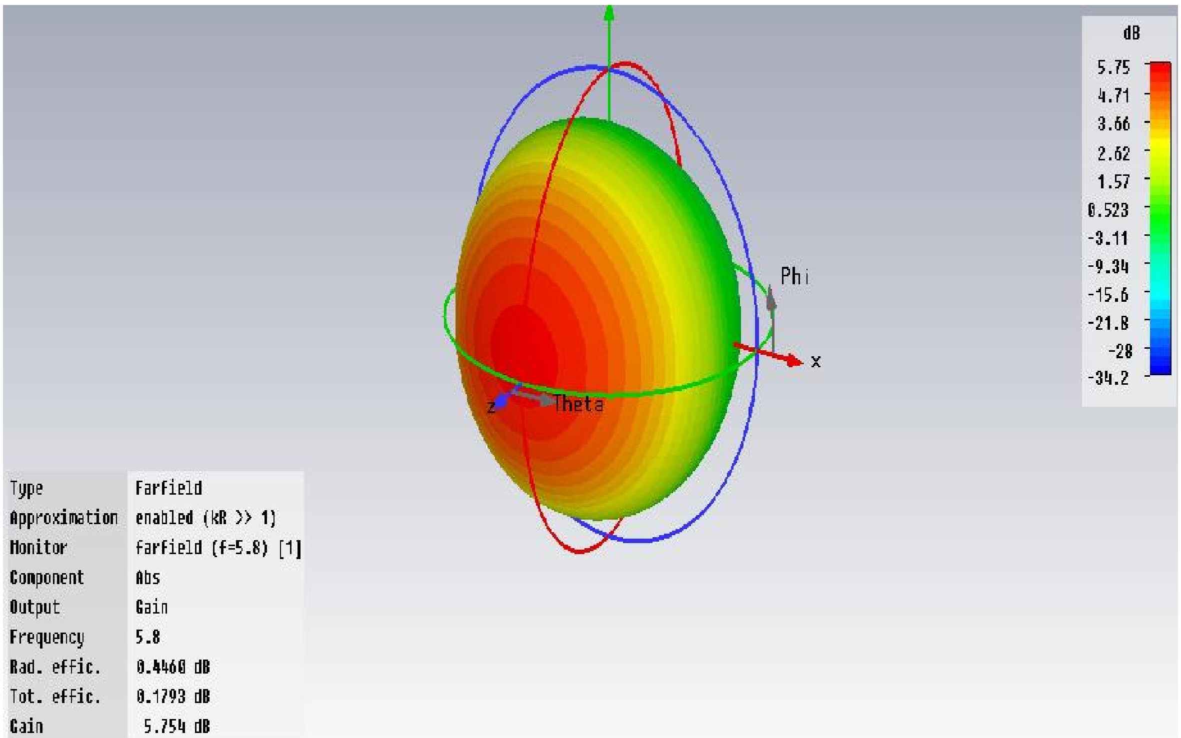

Fig 4.12 (a) Gain of the designed Antenna (3D view) at 5.8GHz

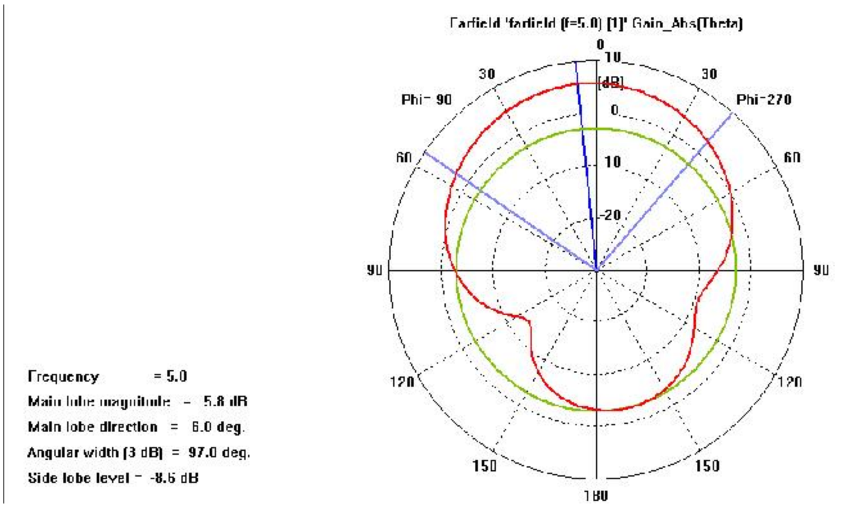

Fig 4.12 (b) Gain of the designed Antenna (polar plot) at 5.8GHz

4.2.1.5 Current Distribution at resonant frequencies of operation: According to the current distributions, the slots of different dimensions were cut in the patch so as to get wide dual band antenna for WLAN applications. The current distribution at both of the frequencies is given, with the help of which the slots on the patch were positioned.

Figure 4.13 reveals that surface current at 5.2GHz is highest near slot 2 proving that slot 2 is responsible for resonating at lower frequency band i.e. covering band from 5.15GHz to 5.25GHz. Also there is some amount of surface current at slot 1. The maximum value of surface current at slot 2 is 253.426 A/m.

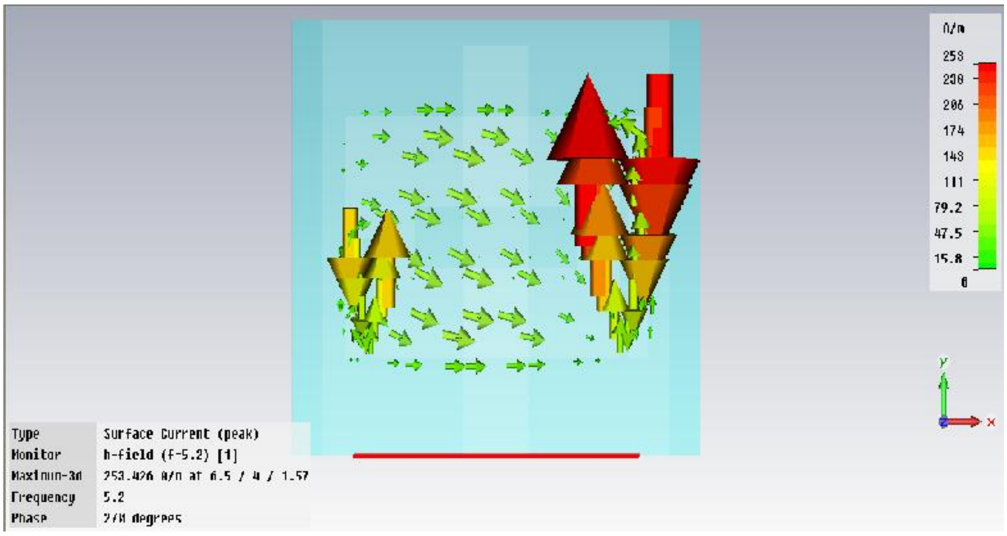

Fig 4.13 Current distribution at frequency 5.2GHz

Figure 4.14 reveals that surface current at 5.8GHz is highest near slot 1 proving that slot 1 is responsible for resonating at lower frequency band i.e. covering band from 5.75GHz to 5.85GHz. The maximum value of surface current is 47.0881 A/m.

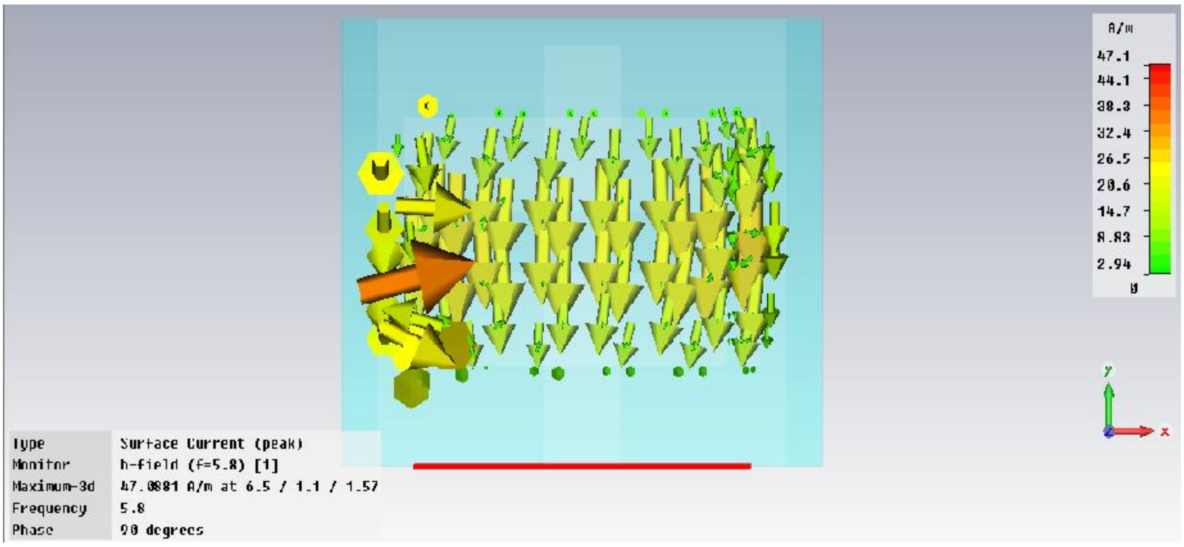

Fig. 4.14 Current distribution at frequency 5.8GHz

In this chapter, a single band antenna at frequency 5.8 GHz is simulated for WLAN application. The desired results are obtained with the reduced ground structure. Further, with the two vertical slots at non-resonating ends, wide dual band antenna is obtained with the reduced ground structure.

CHAPTER 5

TRIPLE BAND APERTURE COUPLED MICROSTRIP ANTENNA WITH THE DEFECTED GROUND STRUCTURE AND WIDE BAND ANTENNA DESIGN USING STACKING

This chapter basically deals with the two different antennas proposed using two different techniques. In one case, a simple aperture coupled antenna with defected ground structure giving triple band is simulated and in the other case, a wide band antenna is proposed with the help of stacking.

5.1 Design of Triple Band Microstrip Antenna with DGS

A novel E-shaped aperture coupled microstrip antenna is simulated. An E-shaped slot is etched on ground plane located between two substrates. In order to match the antenna input impedance to the feed line (50 ohm), an open ended stub is used at the end of the feed line.[22] By choosing the geometry of E shape and length of stub Ls appropriately, one can design the antenna for desired performance.

The triple band antenna simulated operated at the frequency 3GHz covering the bands 2.88GHz, 3.08GHz and 6.06GHz and covers the various applications. This section describes the design of rectangular Micro strip patch antenna satisfying the given specifications: it consists of two Rogers RT/duroid 5880 substrate layers with thickness of 1.57mm and relative permittivity of 2.2. A rectangular patch is located on the upper substrate and a 50 ohm feed line is placed on the lower one and the feed line width would be 4.9mm.[22]

The dimensions of the "E" to be etched on the ground plane are given below:

Table 5.1 Design Specifications of E-slot on ground

A	b	c	d	E	F	G	h	I	L_s
25	20	17.5	12.5	5	5	2.5	5	3.5	3.8

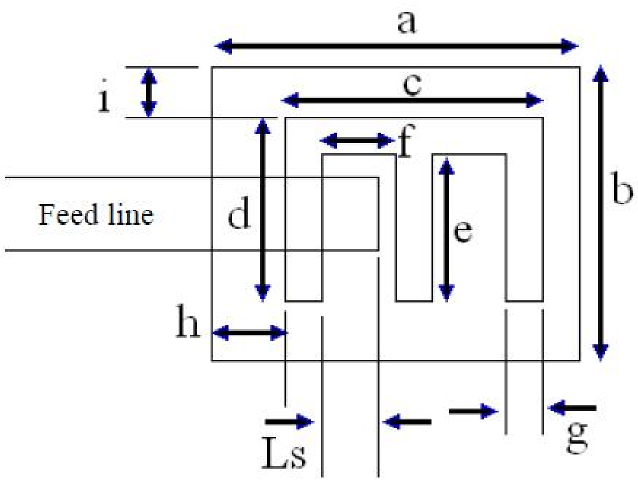

Fig 5.1 Dimensions of E-shaped slot on ground[22]

E-shaped aperture is placed exactly under the patch. Its dimensions are close to the patch dimensions. The design structure of the proposed antenna is given below also the various parameters of the antenna are discussed below at all three frequencies.

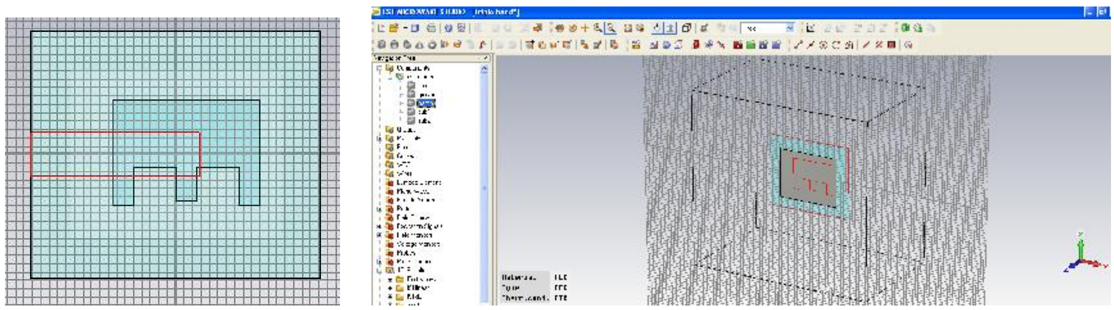

Figure 5.2(a) Geometry of proposed Antenna (b) Designed structure on CST Microwave Studio

5.1.1 Simulation Setup and Results of Triple Band Antenna with DGS

The software used to model and simulate the Micro strip patch antenna is CST Micro wave Studio version 9.

The simulated results of the proposed antenna are presented in the below figures:

5.1.1.1 Return Loss and Antenna Bandwidth: Figure 5.3 shows the wide dual band covering the frequency bands (2.88GHz and 3.07GHz.) having a bandwidth of 329 MHz. and a single band covering the band of 6.06GHz having bandwidth of 202MHz, covering the various application used for fastest communication and also for microwave communication.[34]

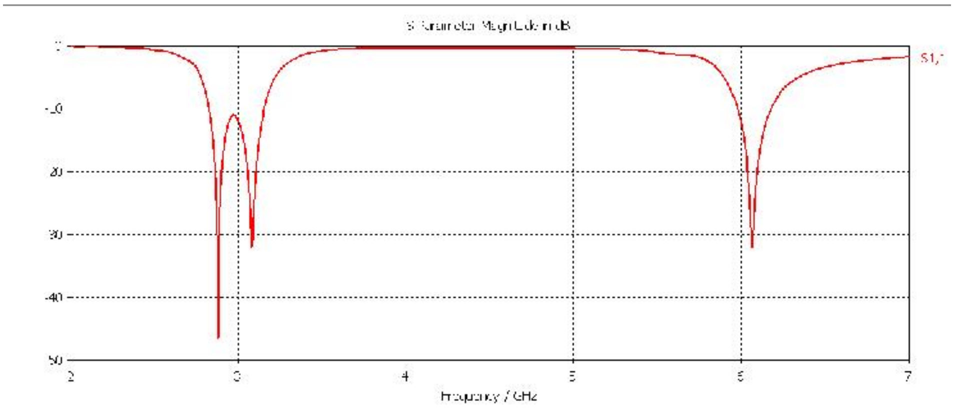

Fig 5.3 Return Loss S_{11} (in dB) of Triple Band Antenna

5.1.1.2 Smith Chart: The Smith Chart plot (figure 5.4) represents that how the antenna impedance varies with frequency. The circle cuts the resistive part at three different values 0.3, 0.75 and 1 and it is normalized to 50 ohm for perfect matching. Multiple circles describes that the proposed antenna is a triple band antenna. Also, from these circles, large bandwidth of the antenna is given, the distance between the points gives a wide dual band antenna and a single band with large bandwidth

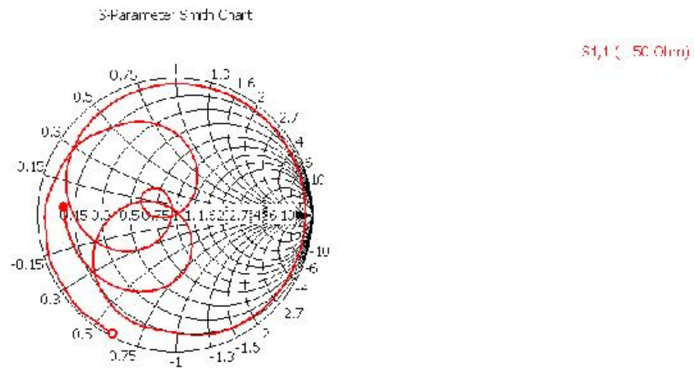

Fig 5.4 Smith Chart Triple Band Antenna

5.1.1.3 Directivity: The Directivity plot (figure 5.5) represents amount of radiation intensity i.e is equal to 4.368 dBi at a frequency of 2.88GHz. The radiation intensity in a particular direction can be described by the red color in the figure 5.5(a) and is directed in a particular direction at an angle of 2.0 degree.

From Polar Plot view of the directivity, it can be seen that at a frequency of 2.88GHz,directivity is 4.368dBi, radiation pattern obtained is omnidirectional with main lobe directed at an angle of 2.0 degree, having angular beam width of 89.5 degree. The magnitude of the main lobe is 4.4dBi.

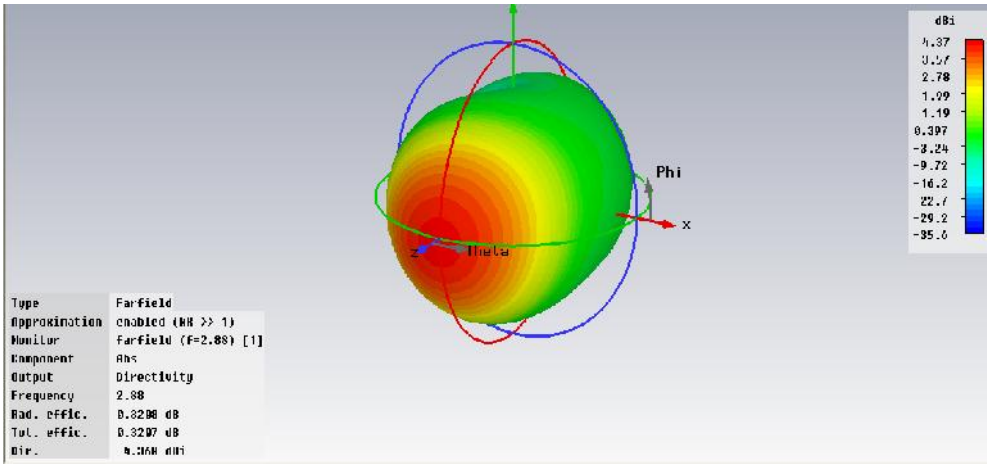

Fig 5.5 (a) Directivity (3D view) at 2.88GHz

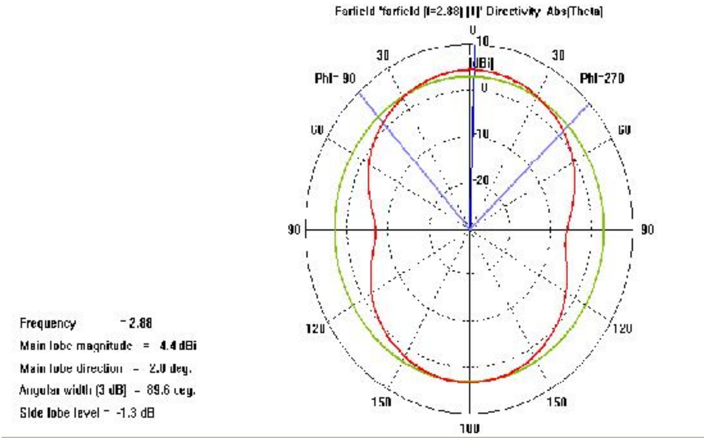

Fig 5.5 (b) Directivity (polar plot) at 2.88GHz

The Directivity plot (figure 5.6) represents amount of radiation intensity i.e is equal to 4.688 dBi at a frequency of 3.07GHz. Also from Polar Plot view of the directivity, it can be seen that at a frequency of 3.07GHz,directivity is 4.688dBi, radiation pattern obtained is omnidirectional with main lobe directed at an angle of 2.0 degree, having angular beam width of 89.6degree. The magnitude of the main lobe is 4.7dBi.

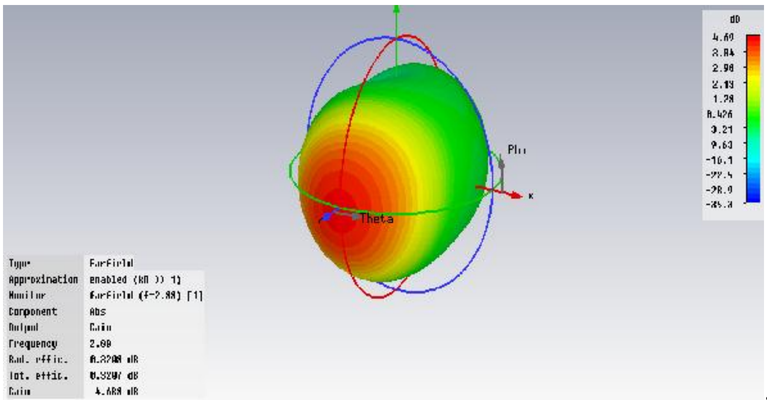

Fig 5.6 (a) Directivity (3D view) at 3.07GHz

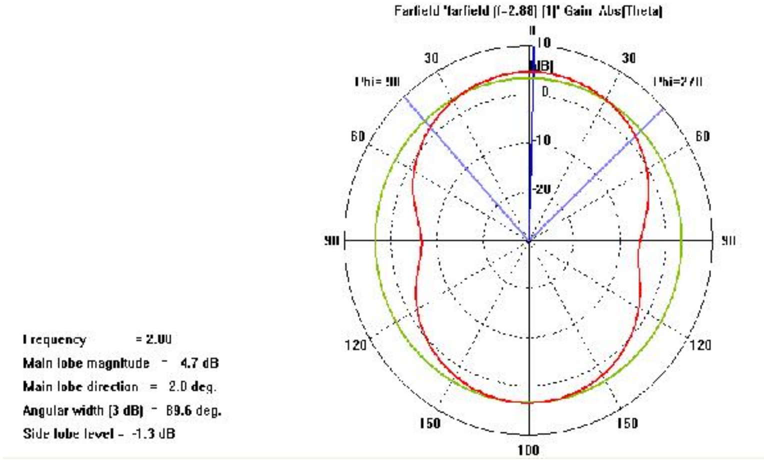

Fig 5.6 (b) Directivity (polar plot) at 3.07GHz

The Directivity plot (figure 5.7) represents amount of radiation intensity i.e is equal to 5.745 dBi at a frequency of 6.07GHz. Also from Polar Plot view of the directivity, it can be seen that at a frequency of 6.07GHz,directivity is 5.745dBi, radiation pattern obtained is omnidirectional with main lobe directed at an angle of 2.0 degree, having angular beam width of 89.6degree. The magnitude of the main lobe is 4.7dBi.

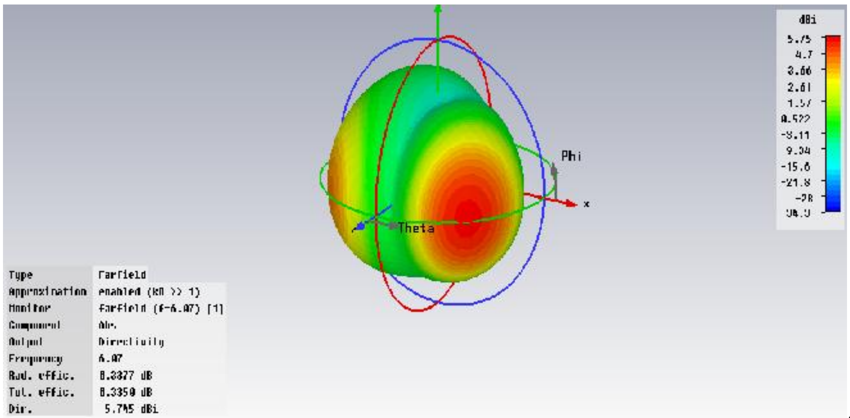

Fig 5.7 (a) Directivity (3D view) at 6.07GHz

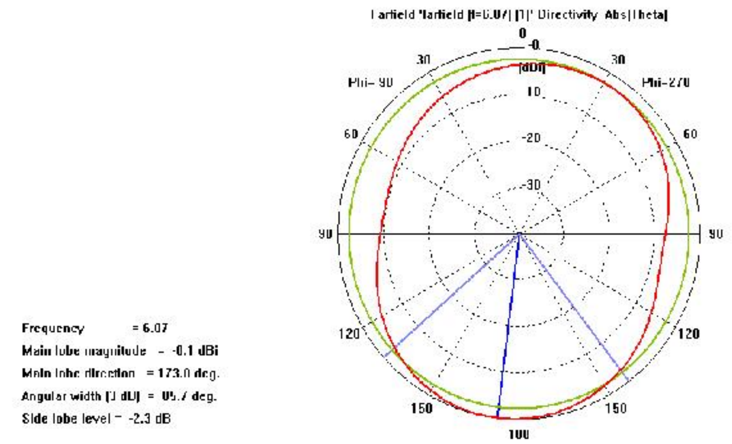

Fig 5.7 (b) Directivity (polar plot) at 6.07GHz

5.1.1.4 Gain: The Gain plot (figure 5.8) gives the gain = 4.688 dB at a frequency of 2.88GHz. Also from Polar Plot view of the gain, it can be seen that radiation pattern obtained is omnidirectional with main lobe directed at an angle of 2.0 degree, having angular beam width of 89.6 degree. The magnitude of the main lobe is 4.7dB.

More is the gain, more directional is the antenna, and the proposed antenna is directional at an angle of 2.0 degree, can be visible with the red color. The red color describes more gain and blue color describes least gain and in between the two colors defines the different range of gain.

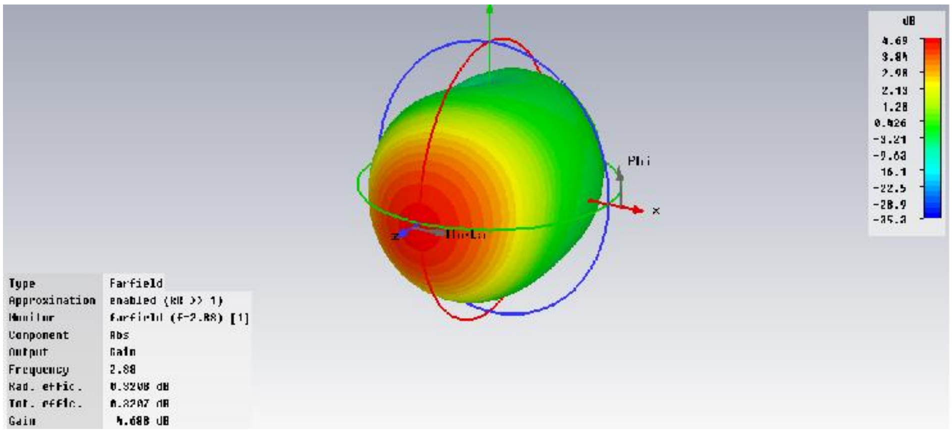

Fig 5.8 (a) Gain of the designed Antenna (3D view) at 2.88GHz

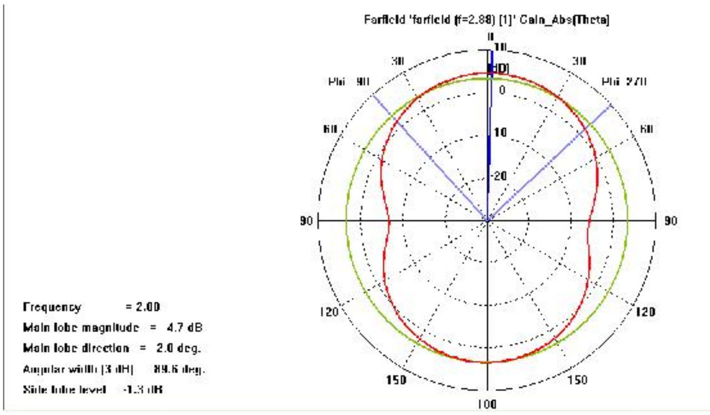

Fig 5.8 (b) Gain of the designed Antenna (polar plot) at 2.88GHz

The Gain plot (figure 5.9) gives the gain = 4.933 dB at a frequency of 3.07GHz.Also from Polar Plot view radiation pattern obtained is omnidirectional with main lobe directed at an angle of 2.0 degree, having angular beam width of 117.1 degree. The magnitude of the main lobe is 4.3dB.

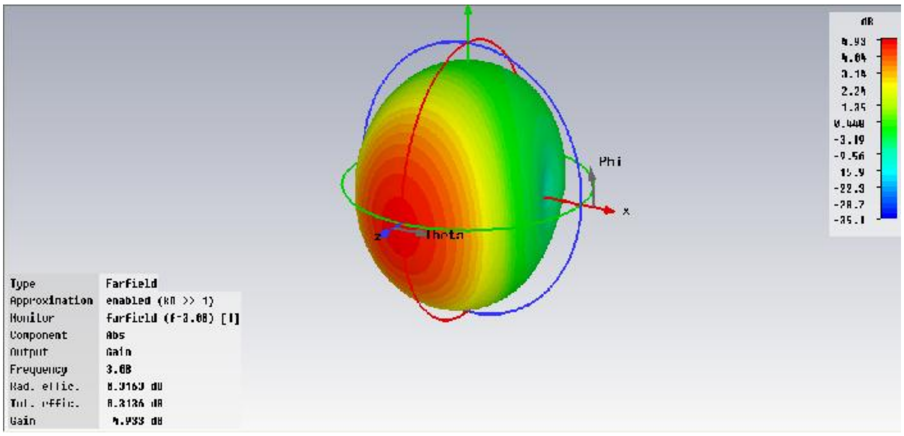

Fig 5.9 (a) Gain of the designed Antenna (3D view) at 3.07GHz

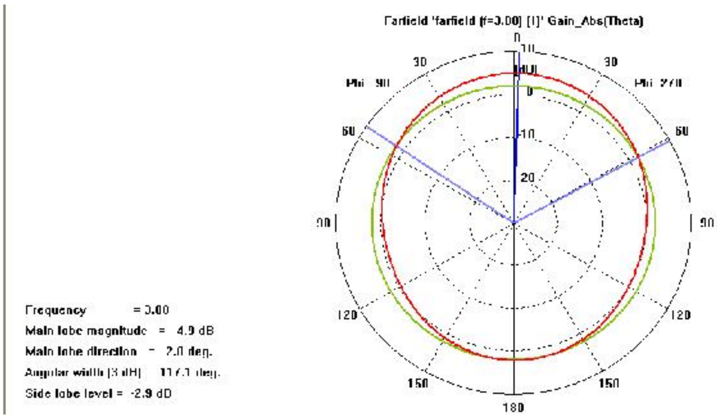

Fig 5.9 (b) Gain of the designed Antenna (polar plot) at 3.07GHz

The Gain plot (figure 5.10) gives the gain = 6.083 dB at a frequency of 6.07GHz.Also from Polar Plot view radiation pattern obtained is omnidirectional with main lobe directed at an angle of 173 degree, having angular beam width of 85.7 degree. The magnitude of the main lobe is 0.2dB.

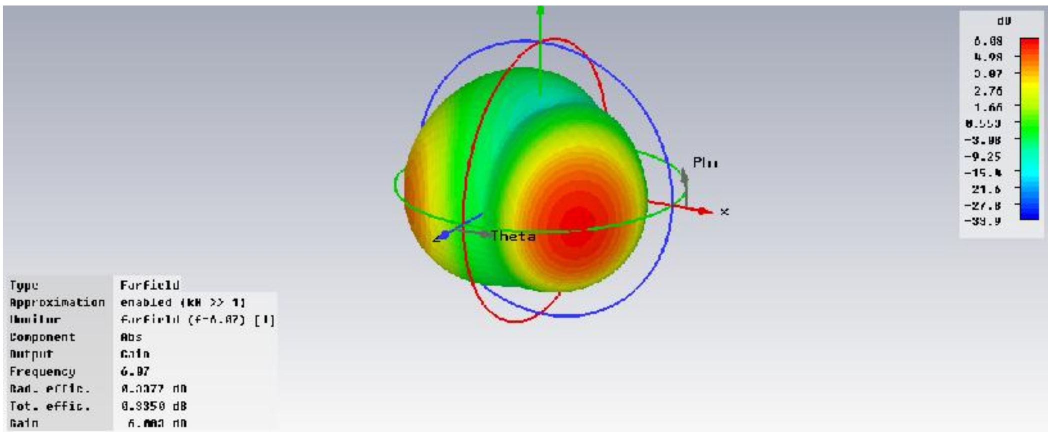

Fig 5.10 (a) Gain of the designed Antenna (3D view) at 6.07GHz

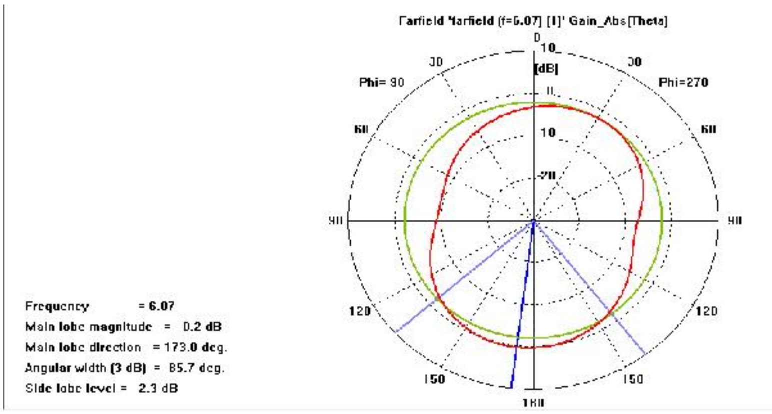

Fig 5.10 (b) Gain of the designed Antenna (polar plot) at 6.07GHz

5.2 Design of Wide Band Aperture Coupled Antenna with Stacking

Increasing impedance and gain bandwidth and decreasing dimensions of microstrip antennas are primary goals of researchers. Methods such as using parasitic patches, multilayer structures, materials with low dielectric constants and air gap between layers have been reported for increasing impedance and gain bandwidth. A structure with two rectangular patches placed in different layers above a rectangular slot, on the ground plane is presented in proposed design. Although using two patches instead of one patch will increase impedance bandwidth and gain of aperture coupled microstrip antennas, it will also increase the thickness of this type of antenna. Decreasing the thickness of dielectric layers in microstrip antennas results in less impedance bandwidth.

In the antenna structure shown in Figs. 5.11(a) and (b) two rectangular patches are placed on top of the slot and are separated by materials with low dielectric constants and air gaps. In this structure there are two air gaps (*D*2, *D*4) and three substrates (*D*1, *D*3, *D*5) made of the same material with equal relative permittivity of 2.2 and thicknesses of 0.38 mm. There is a 50Ω feed line under the first dielectric layer (*D*1) while a 0.38mm thickness slot is located above it. The parameters of the stub length and the slot length are also varied for the correct specifications of the proposed antenna.[28]

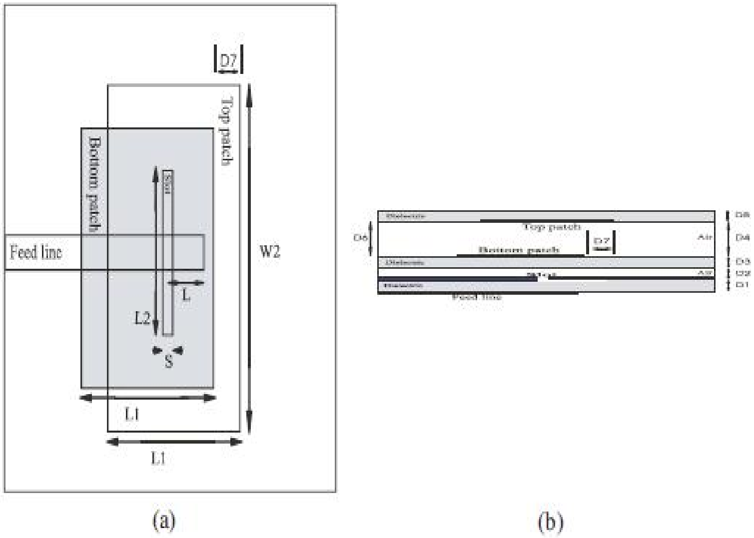

Fig 5.11 (a) Top view of proposed Antenna (b) Side view of proposed Antenna

Table 5.2 Dimensions of proposed Antenna (in mm)

D_1	D_2	D_3	D_5	D_6	D_7	S	W_1	W_2	L	L_1	L_2
0.38	0.5	0.38	0.38	1.6	2.5	0.4	10	14	2	8	7

The design structure of the proposed antenna is given below also the various parameters of the antenna are discussed below at all three frequencies.

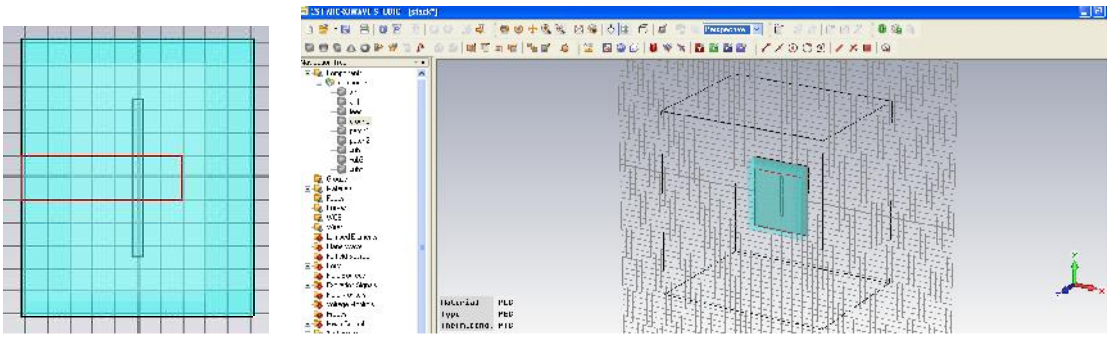

Figure 5.12(a) Geometry of proposed Antenna (b) Designed structure on CST microwave studio

5.2.1 Simulation Setup and Results of Wide Dual Band Antenna

The software used to model and simulate the Micro strip patch antenna is CST Micro wave Studio version 9.

The simulated results of the proposed antenna are presented in the below figures:

5.2.1.1 Return Loss and Antenna Bandwidth:

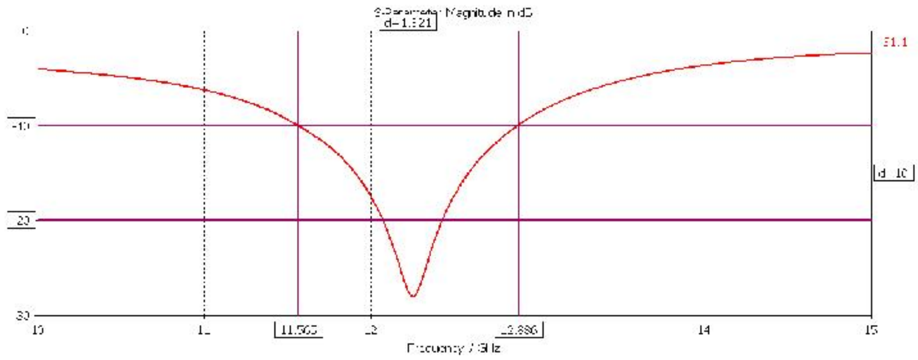

Fig 5.13 Return Loss S_{11} (in dB) at 12.255GHz

Figure 5.13 shows the wide band covering the frequency bands from 11.565GHz to 12.886GHz having a bandwidth of 1.321 GHz. and having return loss of -27.998 at frequency 12.255, also covering the various application used for Direct Broadcast Satellite Communication.

5.2.1.2 Smith Chart: The characteristic impedance of the proposed antenna is 39.3 ohms which is very less. The size of the locus of the smith chart is controlled by the slot length. As the slot length increases, the size of the locus increases. For proper matching the locus must be large enough that it passes through the center of the smith chart and it passes through 0.3 and 0.9 points through resistive part of smith chart, thus giving a large wide bandwidth.

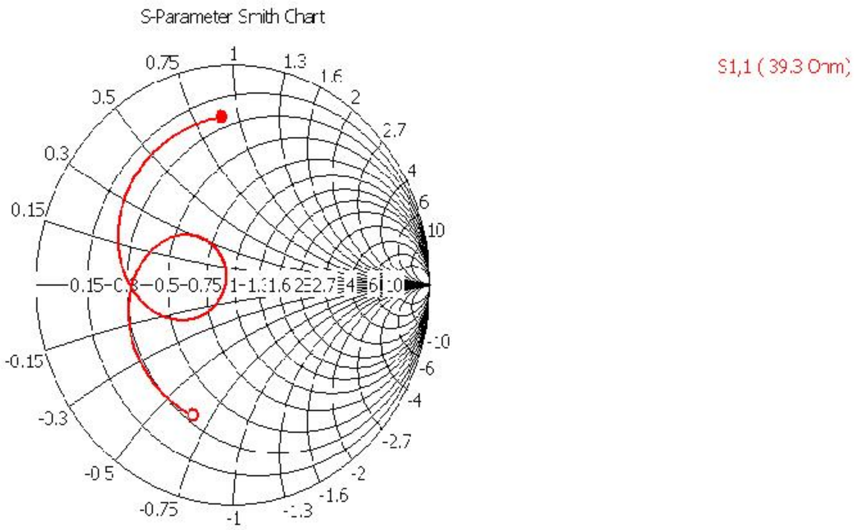

Fig 5.14 Smith Chart at 12.255GHz

5.2.1.3 Directivity: The Directivity plot (figure 5.15) represents amount of radiation intensity i.e is equal to 7.122 dBi at a frequency of 12.255GHz.

Also from Polar Plot view of the directivity, it can be seen that radiation pattern obtained is omnidirectional with main lobe directed at an angle of 0.0 degree, having angular beam width of 78.8degree. The magnitude of the main lobe is 6.7dBi.

The red color shows the maximum radiation in a direction which is angled at 0.0 degree but it is not an isotropic antenna, because it has a major lobe and a minor lobe too present in 2D view.

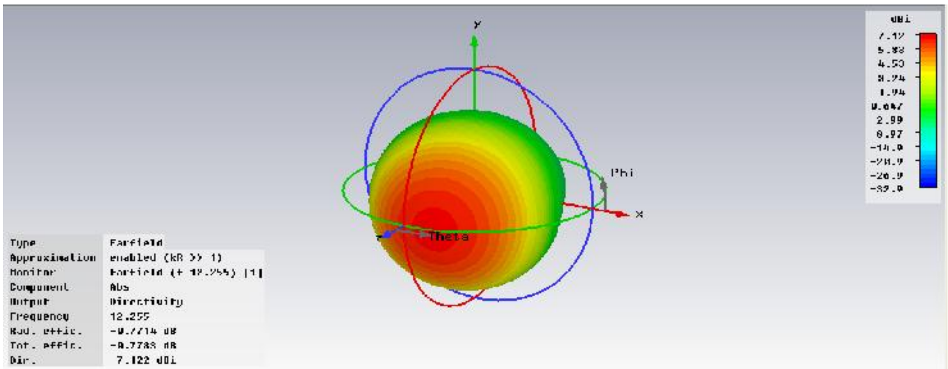

Fig 5.15 (a) Directivity (3D view) at 12.255GHz

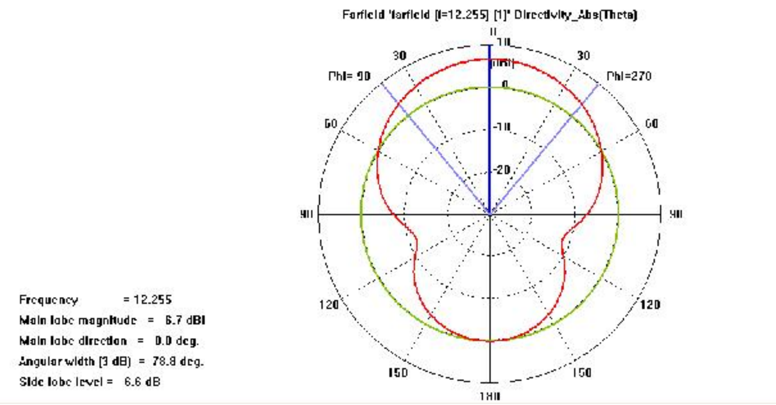

Fig 5.15 (b) Directivity (polar plot) at 12.255GHz

5.2.1.4 Gain: The Gain plot (figure 5.16) gives the gain = 4.688 dB at a frequency of 12.255GHz. Also from Polar Plot view of the gain, it can be seen that radiation pattern obtained is omnidirectional with main lobe directed at an angle of 2.0 degree, having angular beam width of 89.6 degree. The magnitude of the main lobe is 4.7dB.

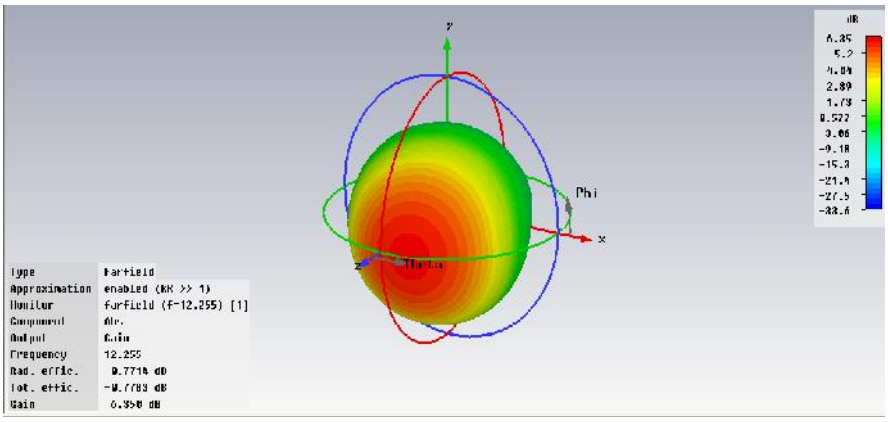

Fig 5.16 (a) Gain of the designed Antenna (3D view) at 12.255GHz

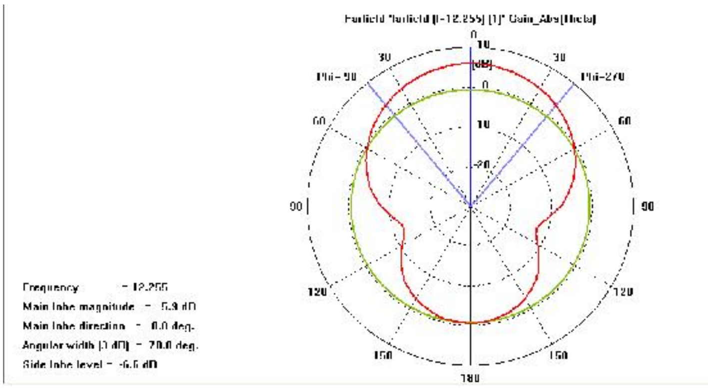

Fig 5.16 (b) Gain of the designed Antenna (polar plot) at 12.255GHz

5.2.1.5 Effect of Feed Length Variation: Feed point should be chosen in such a way so that there is a good impedance match between the generator impedance and the input impedance of the patch element.

Figure 5.17 shows that how the return loss varies as the stub length changes. As the stub length is increased, return loss decreased and also the resonating frequency is shifting to the left. So for stub length of 2mm, return loss is maximum i.e. -26.197dB[4]

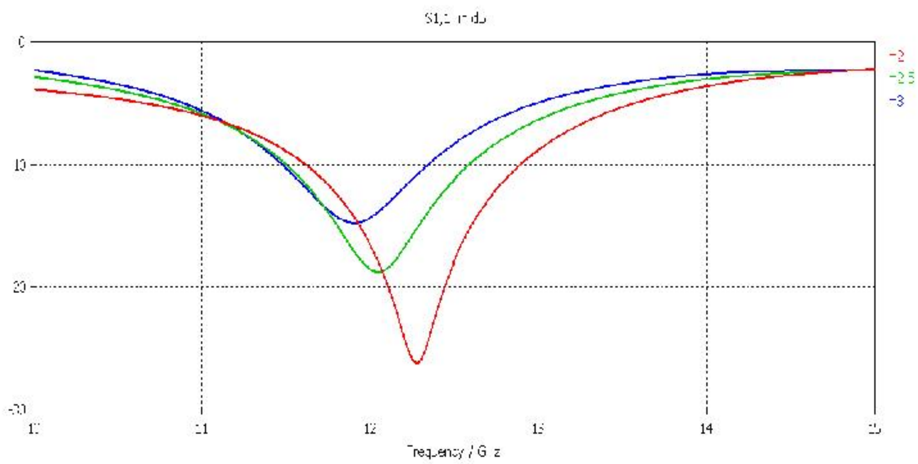

Fig 5.17 Effect of Stub Length Variation

5.2.1.6 Effect of Slot Length Variation: Coupling level is primarily decided by the slot length. There are two types of slots i.e. resonant and non-resonant type based on the length of the slot. If the slot length is comparable to the half of the wavelength of the antenna, it is called resonant slot. If the smaller length slots are used, it is non-resonant slot. As the slot length is decreased, input resistance also decreases. But there can also be decrease in the coupling between patch and feed line.[4]

The plot of resturn loss against frequency for various slot lengths has been plotted and is shown in Fig 5.18. As, it can be that at slot length of 7mm, return loss is maximum (-26.197). Slot length = 7mm is considered for design of this antenna seen from table given below. As the slot length is increasing, better impedance bandwidth is obtained at the middle of the bandwidth.

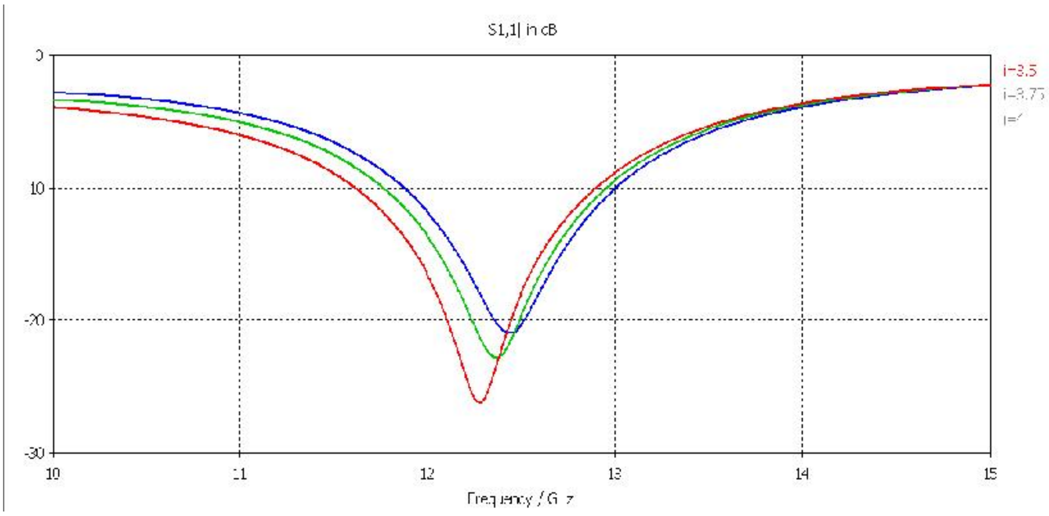

Fig 5.18 Effect of Slot Length Variation

In this chapter, the triple band antenna with defected ground structure is simulated. The E-shaped slot is made on the ground for the better coupling. The effect on the slot and the stub length gives triple band, in which one wide dual band and one single band antenna with large bandwidth is obtained.

A wide dual band antenna with the help of stacking is simulated; the patches with two low dielectric values and air gaps have been separated. Also the position of patch has been different. Both the patches were at two opposite ends.

Chapter 6

FABRICATION AND TESTING OF SINGLE AND DUAL BAND MSA

This chapter describes the entire procedure for fabrication of a microstrip patch antenna. Some fabricated antennas are also presented that are designed and simulated in chapter 5.

6.1 Simulated Results of the Antennas at 5.8 GHz

The simulated results of the antennas discussed in chapter 4 have been discussed below:

- **Single Band Antenna at 5.8 GHz**: The dimensions of the antenna are given below in the table 6.1

Table 6.1 Dimension of the designed antenna with aperture feed

Frequency (f_r)	5.8GHz
Dielectric Constant (ε_r)	4.4
Patch Substrate Thickness	1.57mm
Feed Substrate Thickness	1.57mm

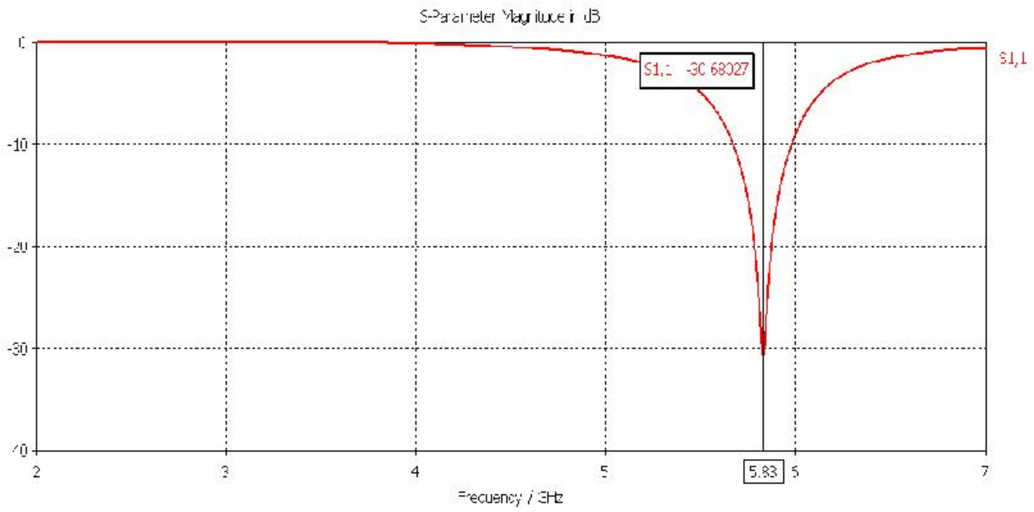

Fig 6.1 Return Loss S_{11} (in dB) of Simulated Antenna at 5.3GHz

- **Dual Band Antenna for WLAN Application:** In the single band antenna simulated above, two vertical slots on the non- resonating side of the patch are made to obtain the wide dual band. The dimensions of the slots are given below in the table 6.2

Table 6.2 Dimension of the slots for dual band

Length of Slot 1 (on the left)	4.765mm
Width of Slot 1 (on the left)	0.5mm
Length of Slot 2 (on the right)	8.765
Width of Slot 2 (on the right)	0.5mm

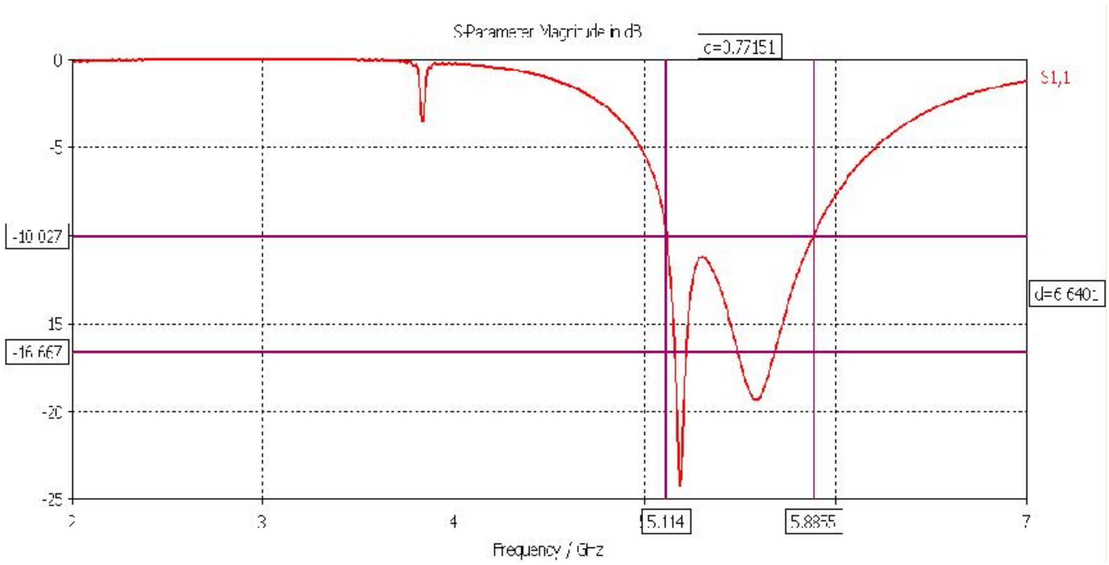

Fig 6.2 Return Loss S_{11} (in dB) of Simulated Antenna of Dual Band

6.2 Fabrication process:

There are various steps followed when we fabricate an antenna. This can be shown via a flow chart:

Draft the layers of antenna on a transparent sheet.

↓

Take photo of the layers on the negative by using a camera.

Brush the PCB

↓

Cut PCB into the required size.

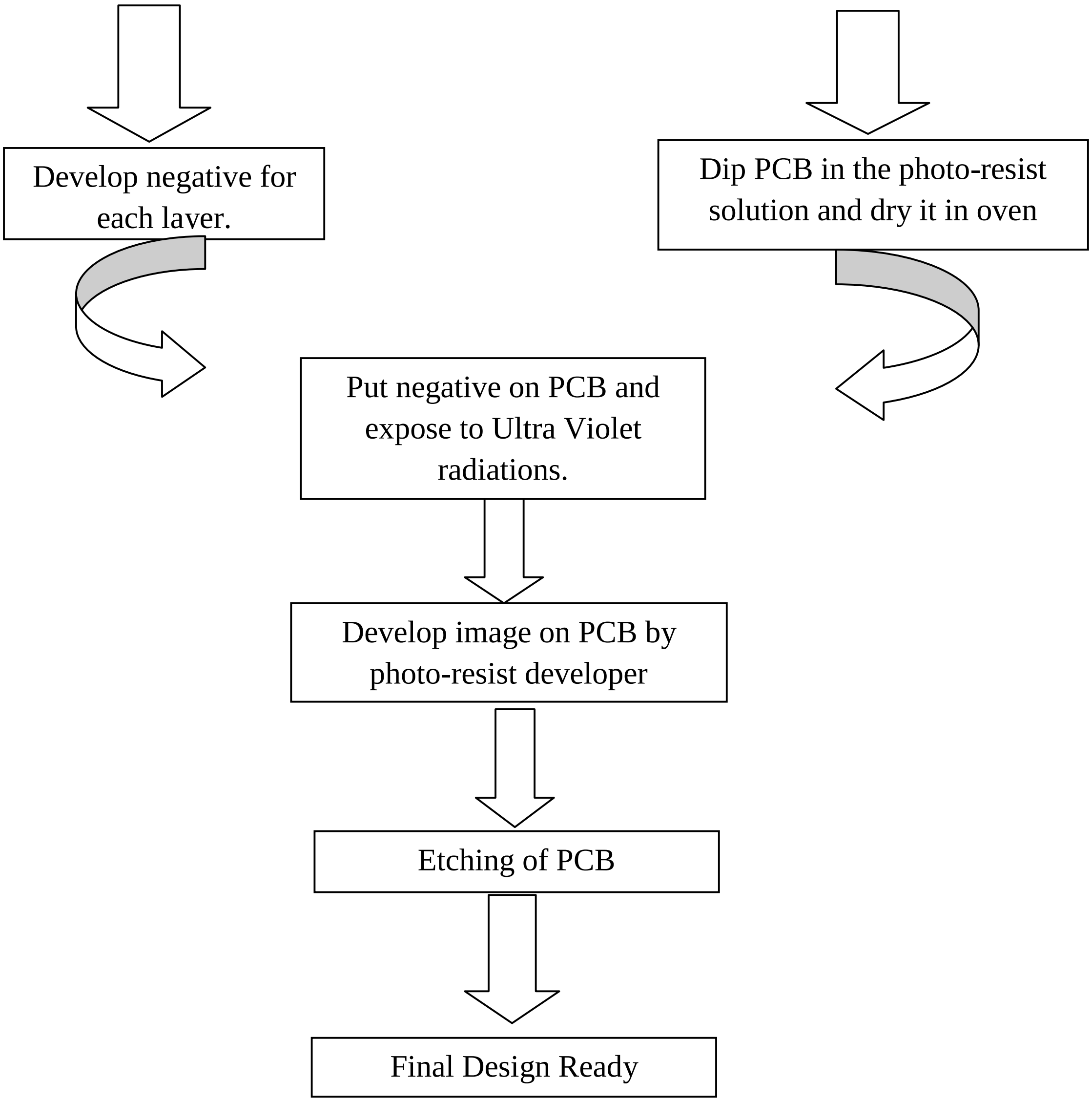

Fig 6.3: Fabricate Flow of PCB Design

6.3 Instruments used while fabricating a microstrip Patch antenna:

The hardware used to design of the antenna includes two processes namely PCB (Printed circuit board) design and testing of the antenna. The various steps for the PCB design are explained as:

- Negative developing: The negative development is done by software. The whole design in designed in this software and then print out of that design is taken.
- The PCB cutter is used to PCB's as per desired size. The actual size of antenna i.e. Substrate size of material, like FR4 ($\varepsilon r = 4.4$) is used here. Figure 6.4 shows the PCB cutter.

Fig 6.4 PCB cutter

- Operations on PCB: - Now the PCB is dipped once in the photo resist developer placed in yellow light. It dried in an oven for 3-5 minutes.

Fig 6.5 PCB Coating Unit

The oven unit is used to dry the final design on antenna, which contain the paint on the layer that protects the copper to clean up. Thus, the oven dries the PCB at 140-150 degree temperature properly. Figure 6.6 shows the picture of the Oven Unit.

Fig 6.6 Oven Unit

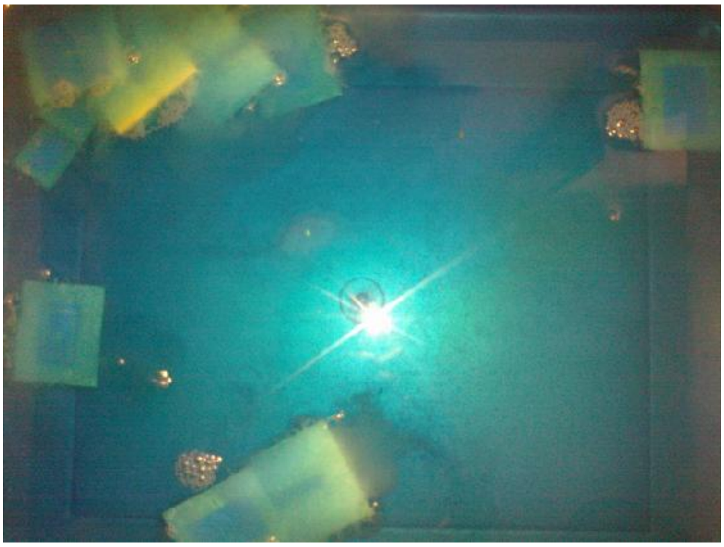

Fig 6.7Etching Unit

6.4 Fabricated antennas at frequency 5.83 GHz & 5.18 GHz

Below are the some fabricated antennas. Figure 6.2 shows the simple single band antenna at 5.8GHz with reduced ground structure to increase the bandwidth. Figure 6.3 shows the wide dual band antenna with reduced ground structure and having two vertical slots on the patch to increase the bandwidth and to get wide dual band covering the frequency bands from 5.14 GHz to 5.88 GHz. And both are the fabricated microstrip antennas with aperture coupled feed. The simulated results for both the antennas are discussed in chapter 4.

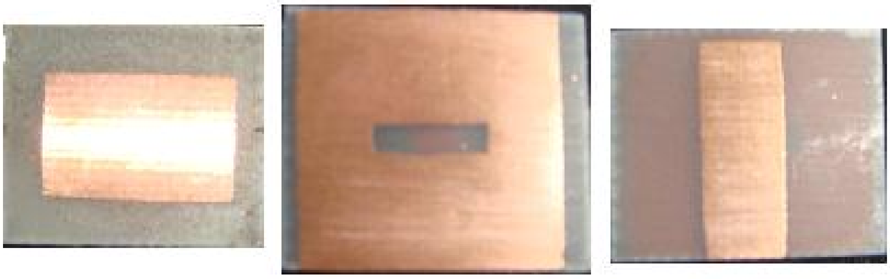

Fig 6.8 (a) Patch (b) Aperture on ground (c) Feed line of Single Band ACMA

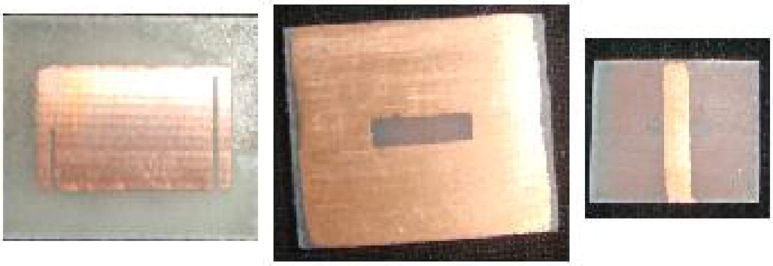

Fig 6.9 (a) Patch (b) Aperture on ground (c) Feed line of Dual Band ACMA

As from these figures, the material used for fabrication antenna is PEC (Copper) of height 0.035mm with 1.6mm (Substrate).

6.5 Testing of Antennas on VNA:

An aperture coupled single band microstrip patch antenna at 5.8 GHz for WLAN application was designed using CST2009 studio (software). But practically, antenna has been tested using VNA model no: E5071C, frequency range is 9KHz-8.5GHz and is shown below:

Fig 6.10 Instrument used for testing

Antenna resonates at 5.83 GHz frequency and covers the range from 5.656GHz to 6.001GHz. Thus bandwidth formed is 345M Hz i.e. wide band covered by antenna, useful for WLAN application. Figure 6.10 shows the graph at 5.83GHz. The material detail is given below in table6.1.

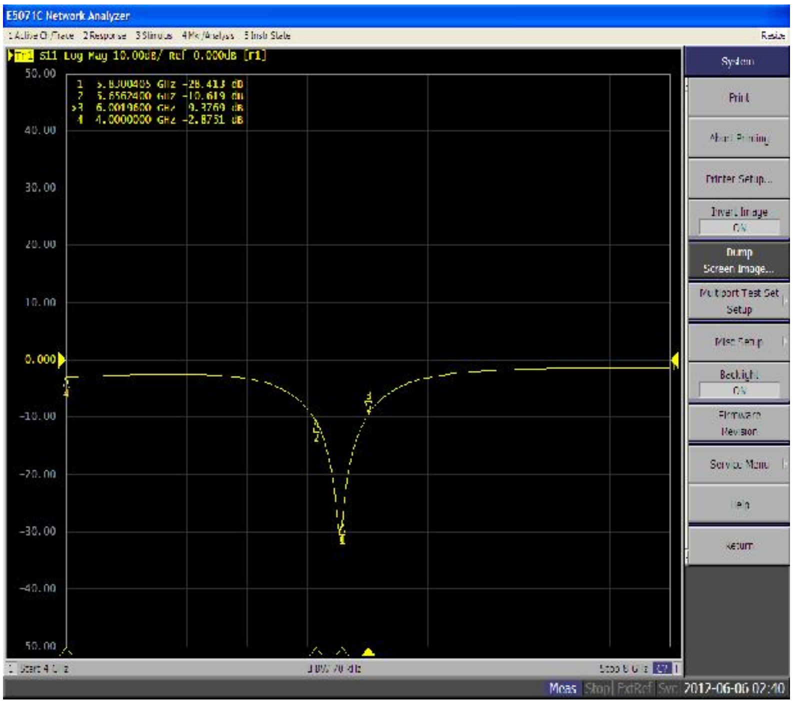

Figure 6.11 Tested results at 5.83GHz.

Now, the single band antenna is loaded with two slots at non-resonating side of the patch and thus covers a wide range of frequencies ranging from 4.740GHz to 5.632GHz, having a band width of 891.5MHz. the slots dimensions are given in table 6.2.

Fig 6.12 Tested results of wide dual band antenna

It was found that the results have some variations given below:

- In the single band, the simulated and the fabricated results resonated at 5.83 GHz, antenna's response in terms of return loss is same but the bandwidth of the fabricated results is more
- In the dual band, the simulated results covers the frequency bands 5.14 GHz to 5.89 GHz and in the fabricated results, antenna shifts to the left and covers the frequency bands 4.740 GHz to 5.632 GHz.

The return loss graphs show that the resonant frequencies have shifted in the magnitude from the designed frequency for all the designs. The root cause of the shift is could be due to the FR-4 board, which has that varies from 4.0 to 4.9. In practical world, a material which has varying along a length, width, and height, will affect resonant frequency to shift, during simulation it is assume a constant. The other factors affecting etching accuracy such as chemical used, surface finish and metallization thickness also could be the reason for shifting the resonant frequency.

Also for the variation on the return loss, resonant frequency and bandwidth, from the simulation software is a constraint which means that, the conductor is not easy to draw under the substrate. Since the aperture coupled antenna needs the feed to be on the same layer with the ground plane or the aperture, thus one more substrate is defined so that the feed can be drawn on the substrate. In simulation, the design is ideal and no air gap exists between the patch and the ground plane. Practically, with the use of adhesive to glue the patch to the ground plane, the variation is more visible as the adhesive will affect the effective dielectric constant value and contribute some height to the gap.[35] Other than that, electromagnetic coupling is also one of the important mechanisms in aperture coupled microstrip antenna. But the. in the simulation, the electromagnetic coupling to the environment is not modeled.

6.6 Comparison of Simulated and fabricated results:

The comparison between simulated and tested results is given below as for single band and dual band antennas referring to the figures 6.1, 6.2, 6.10, 6.11:

Table 6.3 Comparison between Simulated results and Fabricated results

Parameters	Simulated Results	Fabricated Results
Frequencies Covered in Single band	5.83GHz	5.83GHz
Frequencies Covered in wide Dual band	5.11GHZ to 5.88GHz	4.740 GHz to 5.632 GHz
Return Loss of single band	-30.680dB	-30 dB
Return Loss of wide dual band	-12 dB (at 5.499 GHz)	-11 dB (at 5.4753 GHz)
Bandwidth of single band	309 MHz	345 MHz
Bandwidth of Dual band	771.51MHz	891.5MHz
Applications covered by single band	WLAN	WLAN
Applications covered by Dual band	Covers a large range of frequencies, almost covering all applications of WLAN at 5.2GHz and 5.8GHz	Covers a large range of frequencies, covering applications of WLAN at 5.2GHZ and also used in military applications covering the bands from 4.74 GHz to 5GHz

The fabrication and the testing of the single band antenna and dual band antenna are done and it is observed that there occur some shifts in the results of simulated and fabricated antennas.

7.1 Conclusion

- In this report, firstly an aperture coupled, rectangular patch single band antenna was designed which resonates at 10 GHz and provides a bandwidth of 143 MHz, hence, this antenna can be used for the WLAN applications(X band). The physical parameters examined in this study include the substrates and their dielectric constants, feed line and ground plane coupling slot. The antenna parameters like operating frequency, input impedance, VSWR, Bandwidth, Return loss, directivity and gain are determined for each antenna configuration. Also, the effect of the physical parameters is studied on the antenna parameters.

Table 7.1 Parameters Variation and their effects

Parameters Varied	Different values of varied parameters	Effect of the parameters varied
Feed Line Length	K= 5.3 K=5.8 K=6.3 K=6.8 K=7.3 K=7.8 K=8.3	For maximum coupling, it plays an important role. It should be placed perpendicular to the center of the slot. As from Fig 4.7, it can be seen that as feed line length is increased, the return loss increases till feed line length=6.3mm, after that again with the increase of length, return loss decreases. Also the bandwidth increases till 6.3mm and then decreases. So for the best

		results, Feed length =6.3mm is considered.
Slot Length	I= 1.5 I= 1.55 I= 1.6 I= 1.65 I= 1.7 I= 1.75 I= 1.8 I= 1.85 I= 1.9 I= 1.95 I= 2.0 I= 2.05 I= 2.15	Slot length mostly affects return loss but it decreases the resonant frequency of antenna as well. As from Fig 4.8, it can see that as the slot length is increased, the return loss increases till i=1.85mm is reached and then the return loss decreases. Also the graph shifts towards the left as the slot length increases. So for good results i=1.85mm and slot length = 3,7mm is considered

- Also, an aperture coupled, rectangular patch single band antenna was designed which resonates at 5.8 GHz and provides a bandwidth of 309 MHz, hence, this antenna can be used for the WLAN applications .The designed antenna is loaded with two appropriately positioned and one dimensioned and one long slots at the non-resonating sides of the patch making it to dual band resonating at 5.2 GHz and 5.8 GHz. The wide dual band antenna is having bandwidth of 771.51. The directivity and gain of the antenna are fair enough to be used for the WLAN applications.

- A triple band antenna using defected ground structure was designed which resonates at frequency 2.88GHz, 3.07GHz and 6.07GHz and provides a wide dual band having bandwidth of 329MHz covering bands 2.88GHz and 3.07GHz and a single band having bandwidth of 202MHz covering band at 6.07GHz. The directivity and gain of the proposed antenna are fair enough to be used for providing reliable high-speed connectivity between notebook computers, PCs, personal organizers and other wireless digital appliances[36]. at the 6.07GHz frequency and are also used in microwave applications in neural networks at the frequency bands of 2.88GHz and 3.07GHz

- A wide band stacked antenna was designed which resonates at frequency of 12.255GHz and provides a wide bandwidth of 1.321GHz. The directivity and gain of the proposed antenna are fair enough to be used for Direct Broadcast satellite Communications. The slot length and stub length are varied and are studied below:

Table 7.2 Parameters variation

Parameters Varied	Different values of varied parameters	Effect of the parameters varied
Stub Length	I = 2 I = 2.5 I = 3	For maximum coupling, it plays an important role. It should be placed perpendicular to the center of the slot. It was observed that as slot length was increased, return loss increased (less negative) and also the resonating frequency was shifting to left.
Slot Length	I = 3.5 I = 3.75 I = 4	Although increasing the slot's length results in better impedance matching at the middle of the bandwidth, the impedance bandwidth will decrease. As, for I = 3.5, better results are obtained. So slot length = 7mm is considered.

- The simulated antenna in chapter4 were fabricated and tested. The fabricated results were bit different from the simulated results. In the single band antenna, the resonating frequency shifted from 5.8 GHz to 5.83 GHz, also the bandwidth of the fabricated antenna is more than that of simulated antenna. In the wide dual band antenna, the frequency range covered by simulated results, which was used for WLAN applications, shifted to left and fabricated results covers a wide range of frequencies but have different application i.e. used for Military application and also for WLAN applications. The bandwidth of the fabricated antenna is also increased as compared to simulated antenna.

7.2 Future Scope

The designed antennas in this thesis report is used in various applications like X-Band, WLAN, Microwave applications, Direct Broadcast satellite communications etc.

Various techniques can also be used in future to design antenna which are as follows:

- **Split-ring resonator structure (SRS):** A split-ring resonator (SRR) is a component of a Negative index metamaterial (NIM), also known as Double negative metamaterials (DNG) or Left-handed medium (LHM). SRRs are also used for research in Terahertz metamaterials, Acoustic metamaterials, and Metamaterial antennas. A single cell SRS has a pair of enclosed loops with splits in them at opposite ends. The loops are made of nonmagnetic metal like copper and have a small gap between them. The loops can be concentric, or square, and gapped as needed.
- **Electromagnetic band gap structure (EBG):** Electromagnetic Band Gap (EBG) substrates for patch antennas significantly reduce the effect of surface waves as a function of frequency and are able to provide relatively broadband frequency performance. EBG structures are 3-D periodic objectives that prevent the propagation of the EM waves in the specified band frequency for all angles and for all polarization states. In EBG only one out of ϵ_r and μ_r is negative.
- **Metamaterials:** A metamaterial is a metallic or semiconductor substance whose properties depend on its inter-atomic structure rather than on the composition of the atoms themselves. Certain metamaterials bend visible light rays in the opposite sense from traditional refractive media. Some metamaterials also exhibit such behavior at infrared (IR) wavelengths. Possible applications of transparent metamaterials with

negative indices of refraction include red and IR lasers, optical communications systems, spectrometry, monitoring systems to detect trace gases in the atmosphere, medical diagnostic equipment and optical cloaking devices. In metamaterials both ϵr and μr are negative.

- **Other feeding techniques:** the other feeding techniques of microstrip patch antenna like microstrip line, coaxial feeding, aperture coupling and CPW can also b used in future to design microstrip patch antenna.

List of Publications

- Tanveer Kour Raina, Amanpreet Kaur, Rajesh Khanna, “Design of Aperture Coupled Micro-Strip patch Antenna for Wireless Communication applications at 10Ghz (X BAND)”, IJEE, Vol 4, N0.1, June 2012.

- Tanveer Kour Raina, Amanpreet Kaur, Rajesh Khanna, “Study, Design And Simulation of Aperture Coupled Microstrip Patch Antenna for WLAN Applications at 5.2Ghz” , PEIE, 3rd – 4th, August, 2012

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