DESIGN, FABRICATION AND PERFORMANCE EVALUATION OF MULTIBAND APERTURE COUPLED MICROSTRIP ANTENNA

Thesis submitted towards the partial fulfillment of the

Requirement for the award of the Degree of

MASTER OF ENGINEERING

IN

ELECTRONICS AND COMMUNICATION ENGINEERING

Submitted By

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CERTIFICATE

I hereby declare that the work which is being presented in this thesis entitled, "**Design, Fabrication and Performance Evaluation of Multiband Microstrip Antenna using Aperture Coupled Feed**" in partial fulfillment of the requirement for the reward of degree of Master of Engineering in Electronics and Communication submitted in Engineering 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

The field of mobile and wireless communication is growing at very fast rate covering many technical areas. Wireless local area network (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX) technology is most rapidly growing area in the modern wireless communication. This gives users the mobility to move around within a broad coverage area and still be connected to the network.

The main aim of the thesis work would be to increase the number of frequencies using single patch antenna and to increase the bandwidth. This can be done by cutting different shapes of slot in patch and by using different shapes of patch using aperture coupling feed used for wireless applications. The analysis of aperture coupled microstrip antenna is done using transmission line model. A simple rectangular microstrip patch antenna is designed using aperture coupling at 5.2 GHz used for WLAN frequencies and its parametric study is done to get the best results.

Next, single U- slot is cut in the patch of simple aperture coupled antenna resonating at two WLAN frequencies 3.6 GHz, 5.2 GHz. Two U- slots in patch of simple aperture coupled antenna resonating at three WLAN frequencies 3.6 GHz, 5.2 GHz and 5.8 GHz. This will result in reducing the number of antennas as single antenna is resonating at two or three resonant frequencies.

Also a triple and multiband S- shaped slotted patch antenna is designed using aperture coupling feed used for L- band applications like GPS, satellite communication etc. These antenna cover the L1 (1.575 GHz), L2 (1.227 GHz) and L5 (1.176 GHz) frequencies, which are required for differential GPS system in order to provide maximum position accuracy. The antenna also covers LQ (1.48 GHz) frequency for satellite broadcast. The broadband and dual band E- shaped patch antenna is designed using aperture coupled feeding technique. These antennas fulfil requirement of both broad bandwidth and increased number of frequencies using single patch aperture coupled microstrip antenna.

The fabrication of the single band antenna resonating at 5.2 GHz is done using VNA model no: E5071C. The testing results along with the comparison between testing results and simulated results is also shown.

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(Garima)

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ABBREVIATIONS

WLAN	Wireless Local Area Network
ACMA	Aperture Coupled Microstrip Antenna
CST	Computer Simulation Technology
VNA	Vector Network Analyzer
SAR	Specific Absorption Rate

CHAPTER 1
INTRODUCTION

This chapter gives the brief introduction about different wireless standards and importance of microstrip patch antenna. After defining the objectives of thesis, chapter 1 closes with an outline of the thesis, listing the brief summary of the topics discussed in each chapter of the thesis.

1.1 Wireless Communication

The transfer of 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 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, headsets and broadcast television [1].

Wireless communication 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 the through antennas, via satellite communication.

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.

1.2WLAN and its standards

A 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 users.

The IEEE standards for wireless local area network were developed by IEEE and include four subsets of Ethernet based protocol standards [2]:

- 802.11
- 802.11a
- 802.11b
- 802.11g
- 802.11n

In 1997, the institute of Electrical and Electronics Engineers (IEEE) created the first WLAN standard. They called it 802.11 after the name of the group formed to oversee its development. Unfortunately, 802.11 only supported a maximum network data rate of 2 Mbps that is too slow for most applications.

802.11a operates in 5-6 GHz range with data rates commonly in the 6 Mbps, 12 Mbps, or s24 Mbps range. Because 802.11a uses the orthogonal frequency division multiplexing (OFDM) standard, data rates can be as high as 54 Mbps. The 802.11b standard (also known as Wi-Fi) operates in the 2.4 GHz range with up to 11 Mbps data rates and is backward compatible the 802.11 standard. 802.11b uses technology known as complementary code keying (CCK) modulation, which allows higher data rates.

In 2002 and 2003, WLAN products supporting a new standard called 802.11g emerged in the market. 802.11g attempts to combine the best of both 802.11a and 802.11b. 802.11g supporting bandwidth up to 54 Mbps, and it uses the 2.4 GHz frequency for greater range. The newest IEEE standard in the Wi-Fi category is 802.11n. It is designed to improve on 802.11g in terms of bandwidth supported by utilizing multiple wireless signals and antennas (called MIMO technology) instead of one.

1.3WiMAX and its standards:

WiMAX (Worldwide Interoperability for Microwave Access) is the next generation of wireless technology designed to enable pervasive, high speed mobile Internet access to the much higher array of devices including notebook PCs , handsets, smart phones, and consumer electronics such as gaming devices, cameras, camcorders, music players, and more. WiMAX is a telecommunications protocol that provides fixed and mobile Internet access. The name WiMAX was created by the WiMAX forum which was formed in June

2001 to promote conformity and interoperability of the standard. The current WiMAX revision provides up to 40 Mbit/s with the IEEE 802.16m update expected to offer up to 1 Gbit/s fixed speeds. The IEEE 802.16 standard forms the basis of WiMAX and is sometimes referred to colloquially as WiMAX, Fixed WiMAX, Mobile WiMAX, 802.16d and 802.16e clarification of the formal names are as follow [3]:

- 802.16-2004 is also known as 802.16d, which refers to the working party that has developed the standard. It is sometimes referred to as Fixed WiMAX, since it has no support for mobility.
- 802.16e-2005, often abbreviated to 802.16e, is an amendment to 802.16-2004. It introduced support for mobility and is therefore also known as Mobile WiMAX.

Table 1.1 shows the different wireless bands and corresponding bandwidth for different standards.

Wireless Applications		Frequency Band (MHz)	Bandwidth (MHz)
GSM	GSM 900	890-960	70
	GSM 1800	1710-1805	95
	GSM 1900	1850-1990	140
IMT		2300-2400	100
		2700-2900	200
		3400-4200	800
		4400-4900	500
WLAN Standard		2400-2485	84
		5150-5350	200
		5725-5825	100
Bluetooth		2400-2500	100
WiMAX Standard		2500-2690	190
		3400-3690	290
		5250-5850	600

Table 1.1: Various types of wireless applications and their frequency bands [4]

Microstrip antennas because of its various advantages are well suited for WLAN/WiMAX application systems. Microstrip antennas also have disadvantages like narrow bandwidth, low gain etc. Broad banding is main problem, for solving this problem there are many broad banding techniques available.

- Bandwidth can be enhanced by using parasitic patches [5]
- By using stacking [6]
- By using U-slot within the patch [7]
- Microstrip patch, with inserted slits at one of the radiating edges [8] etc.

1.4 Role of an Antenna

Antennas transfer energy from a cable into the air waves efficiently. Any transmit antenna can also be a receive antenna and vice versa. If you wish to transmit high power from an antenna, usually heat generation or high voltage is a concern that can destroy the antenna. To prevent problems, high power antennas require thicker wires and sometimes insulators to prevent overheating/burning and arcing. Many antennas can simply be made of wire of simple length and they will be very efficient. The length of an antenna changes its efficiency to the cable impedance. Receiver antennas are often made smaller than either transmit and transceiver antennas. Thus for wireless communication an antenna plays main role for communication at larger distances. Also microstrip patch antenna mostly required for large coverage and wireless applications.

1.5 Introduction to Microstrip Antennas:

The microstrip antenna, because of its small size, light weight, low profile and low manufacturing cost, is finding increasing applications in the commercial sector of the industry. Several important examples of the antenna's commercial applications are mobile satellite communications, direct broadcast satellite services, global positioning system, medical hyperthermia usage, etc [2]

Microstrip antennas are one of the most widely used types of antennas in the microwave frequency range, and they are often used in the millimeter-wave frequency range as well (Below approximately 1 GHz, the size of a microstrip antenna is usually too large to be practical, and other types of antennas such as wire antennas dominate).

In its most fundamental 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 Fig 1.1. 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.

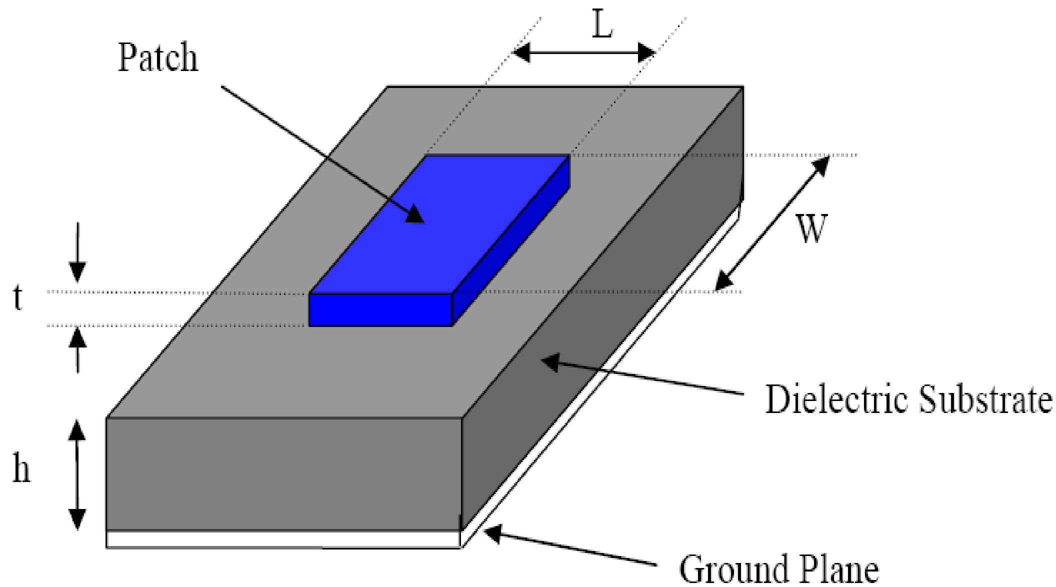


Fig 1.1 Geometry of Microstrip Antenna [9]

The metallic patch essentially creates a resonant cavity, where the patch is the top of the cavity, the ground plane is the bottom of the cavity, and the edges of the patch form the sides of the cavity. The edges of the patch act approximately as an open-circuit boundary condition. Hence, the patch acts approximately as a cavity with perfect electric conductor on the top and bottom surfaces, and a perfect "magnetic conductor" on the sides.

For a rectangular patch, the length L of the patch is usually $0.333\lambda o < 0.5\lambda o$, where λo is the free space wavelength. The patch is selected to be very thin such that $t << \lambda o$ (where t is the patch thickness). The height h of the dielectric substrate is usually $0.003\ \lambda o \leq h \leq 0.05\ \lambda o$. The dielectric constant of the substrate (ε_r) is typically in the range $2.2 \leq \varepsilon_r \leq 12$. Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. [2]

1.5.1 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 low impedance Zc transmission line of length L.

1.5.1.1 Radiation Mechanism of Microstrip Antenna

Because the dimensions of patch are finite along the length and width, the fields along edges of patch undergoes fringing. This is shown in Fig 1.2.The fringing fields around the antenna can help in explaining how the microstrip antenna radiates.

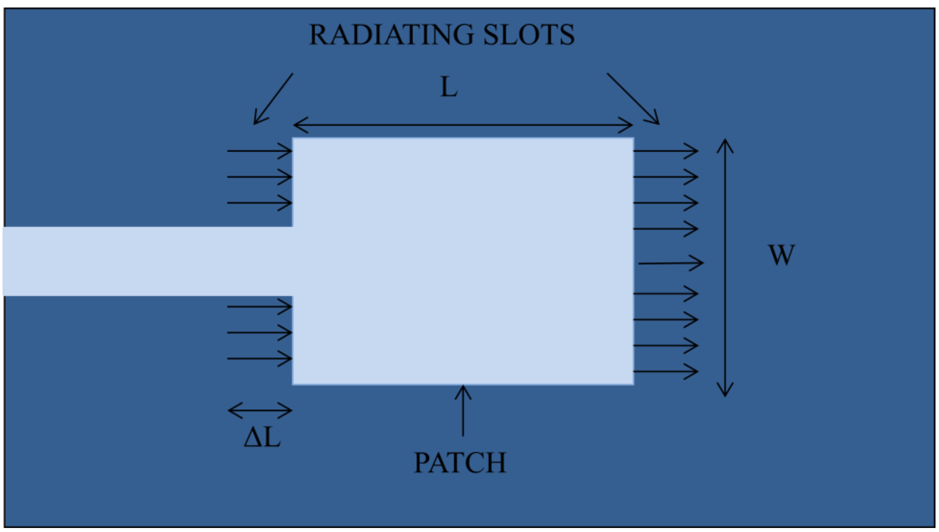


Fig 1.2 Top view of an antenna

The patch acts as open circuited transmission line. On exciting the radiating patch, the voltage and current distribution across patch is shown in Fig 1.3. On the open circuited end of patch (N), the current is minimum and at distance of λ/2 left of N i.e. at point M, the current becomes maximum and further left by distance λ/2 behind M i.e. at L, the current is minimum again. However since voltage is 90^0 out of phase with respect to current, the voltage is positive maximum at open circuited end of patch (point labeled N), zero at M and negative maximum at L. The electric field distribution between the radiating patch and ground is shown below in Fig 1.4. The electric field beneath the patch between L and N will cancel each other but the fringing fields at the ends L and N have tangential components in the same horizontal direction which adds up in phase and hence results in the strong radiation along horizontal direction. This is actually how a simple patch antenna radiates.

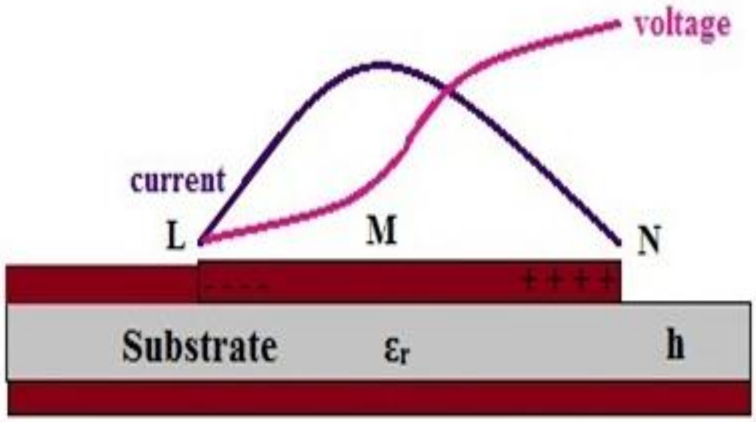


Fig 1.3 Voltage and current distribution across the radiating patch

The current adds up in phase on the patch antenna as well; however, an equal current but with opposite direction is on the ground plane, which cancels the radiation. This shows microstrip antenna radiates but the microstrip transmission line does not. The microstrip antenna's radiation arises from the fringing fields, which are due to the advantageous voltage distribution; hence the radiation arises due to the voltage and not the current. The patch antenna is therefore a "voltage radiator", as opposed to the wire antennas, which radiate because the currents add up in phased and are therefore "current radiators".

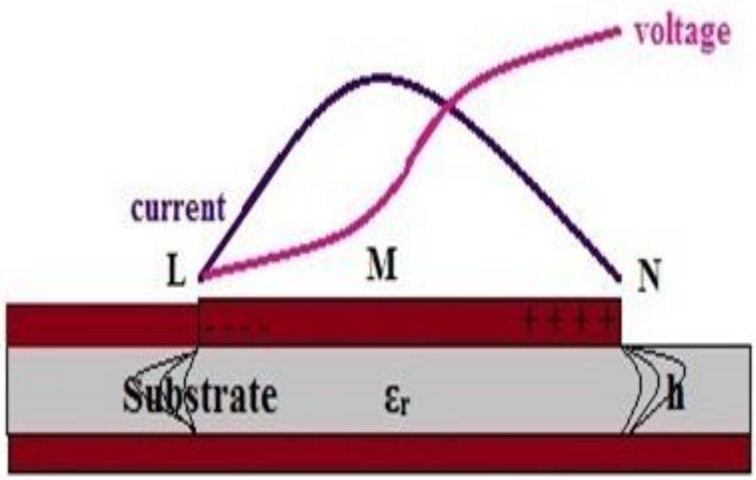


Fig 1.4 Electric field distribution in microstrip patch antenna

1.5.1.2 Effective Dielectric Constant, Length, Resonant Frequency and Effective Width:

Fringing makes the microstrip line look wider electrically 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 will be closer to the value of the actual dielectric constant of 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 the one dielectric (only the substrate), and the effective dielectric constant approaches the value of the dielectric constant of the substrate [10]. The effective dielectric constant is given by:

$$\frac{W}{h} > 1 \quad (1.1)$$

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \quad (1.2)$$

Because of fringing effects, electrically the patch of the microstrip antenna looks greater than its physical dimensions. For the principal E –plane (xy-plane), where the dimensions of the patch along its length are 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).This is shown in Fig 1.5. A very popular and practical approximate relation for the normalized extension of the length is:

$$\frac{\Delta L}{h} = 0.412\ \frac{(\epsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\epsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)} \quad (1.3)$$

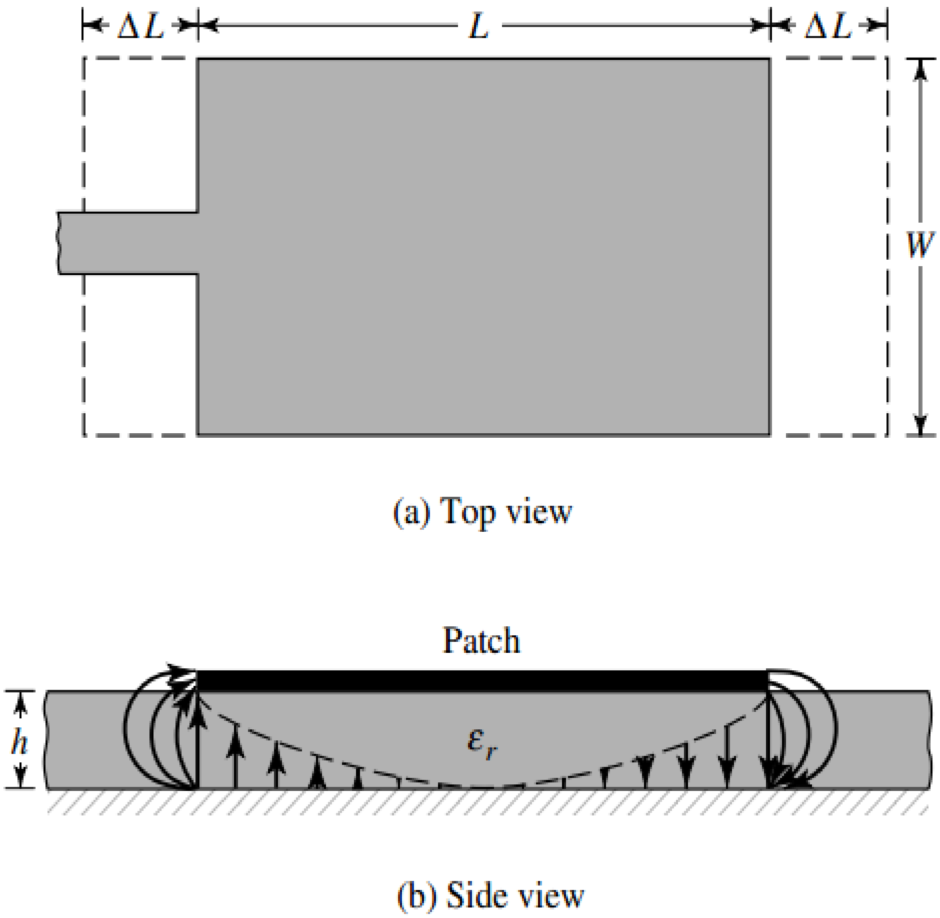


Fig 1.5 Physical and effective length of microstrip patch antenna [2]

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)

$$L_{eff} = L + 2\Delta L \qquad 1.4$$

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

$$(f_r)_{010} = \frac{1}{2L\sqrt{(\mathcal{E}r)}\sqrt{\mu o \varepsilon o}} = \frac{Vo}{2L\sqrt{\varepsilon r}} \qquad 1.5$$

Where Vo is the speed of the light in free space.

1.5.2 Challenges in design of microstrip antenna:

In design of a Microstrip Antenna, there are some parameters that should be taken care of, some of which are discussed below:

1.5.2.1 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 Pt and the power reflected back is Pr, then return loss should be as large a negative number as possible. Return Loss is determined in dB as follows [2]:

$$R_L = -20 \log |\Gamma| \, (dB) \tag{1.6}$$

Where $|\Gamma| = \frac{V_O^-}{V_O^+} = \frac{Z_L - Z_O}{Z_L + Z_O}$

$|\Gamma|$ = reflection coefficient

V_O^- = reflected voltage

V_O^+ = incident voltage

Z_L = load impedance

Z_O = characteristic impedance

1.5.2.2 Smith Chart: It was invented by Phillip H. Smith (1905-1987), is graphical aid or monogram 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 in 50 ohms. [10]

1.5.2.3 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 by 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:[2]

$$D = \frac{U}{U_O} = 4\pi \frac{U_{max}}{P_{rad}} \tag{1.7}$$

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

U_O = maximum radiation intensity (W/unit solid angle)

P_{rad} = total power radiated (W)

1.5.2.4 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 isotropically. 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 [2]. It is given by:

$$Gain = 4\pi \frac{radiation\ intensity}{total\ input\ power} \quad 1.8$$

1.5.2.5 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 center frequency [2].

1.5.2.6 Beam width: It is defined as the angular separation between two identical points on opposite side of the pattern maximum. [2]

1.5.2.7 Efficiency: It is used to take into account losses at the input terminals and within the structure of the antenna. Such losses are due to:

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

In general, the overall efficiency can be written as

$$e_o = e_r \times e_c \times e_d \quad 1.9$$

Where e_o = total efficiency (dimensionless)

e_r = reflection efficiency (dimensionless)

e_c = conduction efficiency (dimensionless)

e_d= dielectric efficiency (dimensionless) [3]

An antenna with significant bandwidth with return loss below -10 dB, VSWR of less than 2 (ideal VSWR = 1), feed point impedance of 50 ohms with uniform patch surface current distribution with high directivity, high gain and minimal side lobe level (> -20 dB) is generally required for efficient performance of an antenna.

1.6 Objectives of Thesis

- The basic principle and analysis of the aperture coupled microstrip antenna and effect of various parameters variation are studied.
- Design and simulation of single band microstrip antenna for WLAN application.
- Design and simulation of dual and triple band U- slot aperture coupled microstrip antenna used for WLAN applications.
- Design and simulation of triple and multi bans S- shaped slotted patch antenna used for GPS and satellite communication.
- Deign and simulation of broadband and dual band E- shaped patch antenna for L- band applications.
- Fabrication and testing of aperture coupled microstrip antenna at 5.2 GHz used for WLAN applications.

1.7 Thesis Organization

The thesis is divided into eight chapters listed below:

Chapter 1 is dedicated to overview of wireless communication and microstrip antenna. The various challenges have been discussed for an efficient antenna design.

Chapter 2 includes the literature survey of aperture coupled microstrip antenna. The brief idea about the researches done for bandwidth enhancement, defected ground structure, WLAN applications antenna stacked aperture coupled microstrip antenna.

Chapter 3 includes the analysis of aperture coupled microstrip antenna. It also includes the design of single band aperture coupled microstrip antenna used for WLAN applications and its parametric study.

Chapter 4 includes the design of dual and triple band U-slot aperture coupled microstrip antenna used for WLAN applications.

Chapter 5 includes the design of triple and multi band S- shaped slotted patch aperture coupled microstrip antenna with high gain and directivity values.

Chapter 6 is dedicated to versatility of E- shaped patch aperture coupled microstrip antenna and includes the design of broadband and dual band aperture coupled microstrip antenna.

Chapter 7 is dedicated to fabrication and testing of single band aperture coupled microstrip antenna at 5.2 GHz used for WLAN applications.

Chapter 8 is dedicated to conclusion and future work.

CHAPTER 2
LITERATURE SURVEY

This chapter concentrates on the literature review of the microstrip patch antenna.

2.1 History

The concept of microstrip antenna was first proposed by Deschamps in 1953. A patent was issued in France in 1955 in the names of Gutton and Baissinor. After the 1970s, research publications started to flow with the appearance of the first design equation. Since then, different authors started investigation on microstrip patch antennas like James hall, David M. Pozar and there are also some who contributed a lot. Throughout the years, authors have dedicated their investigations to create new designs or variations to the original antenna that, to some extent; produce either wider bandwidth or multiple frequency operation in a single element. However most of these innovations bear disadvantages related to size, height or overall volume of the single element and the improvement in bandwidth suffers usually from degradation the other characteristics.

2.2 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. The antenna used duroid substrates with a circular coupling aperture, and operated at 2 GHz. It was found that this antenna worked perfectly- it was impedance matched and the radiation pattern was 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. [11]
- 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. [12]

- 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. [13]

2.2.1 Bandwidth enhancement of Aperture Coupled Microstrip Antenna

- An approach to increase bandwidth and to increase the gain, an antenna with two parasitic elements has been designed. One parasitic element increases the bandwidth and other is to increase gain. [14]
- L. Giauffret, J.M. Laheurte and A. Papiernik in the year 1995 found that CPW fed aperture-coupled microstrip antenna has a large bandwidth with high gain and low cross polarization levels, and is also compact with only one substrate, and can be easily connected to both passive and active components. [15]
- Vivek Rathi, Girish Kumar, and K. P. Ray in the year 1996 shows a new “hour glass”-shaped aperture configuration which was capable for providing maximum coupling and increased bandwidth as compared to other aperture shapes. [16]
- In the year 1997, Shashi, Paul and Harokopus concluded that Smart antennas are required to increase the coverage of the base station for personal 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. [17]
- B.L. Ooi and C.L. Lee in the year 1999 shows a rectangular air- filled stacked patch antenna with an offset L-shaped probe. The top patch and lower U-slot patch are all supported by thin basswoods at the four corners and was capable of providing an impedance bandwidth of 44.4% and average gain of -15 dB. [18]
- Yoshiaki Kamiya, Wataru Chujo and Masayuki Fujise in the year 1991 found that aperture coupled microstrip antenna instead of fulfilling the requirements like light weight, thin structure and ease of fabrication and compatibility with multi-layered feed

networks also provide wide bandwidth for mobile-satellite communication use, as compared to inline and coaxial feeding technique. [19]

- 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 [20]
- 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.[21]
- In the year 2006, Manoj, S.K.Koul showed the effect of the slot length and dielectric constant, and the variations that occur in return loss and resonant frequency and also studied that with the reduction of antenna length. Input resistance of the antenna also decreases. [22]
- 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. [23]
- 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 is expected at low frequency band. [24]

2.2.2 Aperture Coupled Microstrip Antenna for WLAN Applications

- S.D Targonski and D.M.Pozar in the year 1998, proposed that 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% can be achieved. [25]
- In the year 2005, Rashid A. Saeed, S. Khatun, Borhanuddin, M. A. Khazani, Rania A. Mokhtar, Mahmoud Alshamary proposed the design of single fed aperture coupled microstrip antennas for WLAN applications. For maximum coupling the patch should be centered over the slot, moving the patch relative to the slot in the H-plane direction has

little effect, while moving the patch relative to the slot in the E-plane (resonant) direction will decrease the coupling level, also for maximum coupling, the feed line should be positioned at right angles to the center of the slot. [26]

- Chien-Yuan Pan, Tzyy-Sheng Horng, in the year 2007 proposed a novel printed monopole antenna with dual wideband which simultaneously satisfied wireless local area network (WLAN) and worldwide interoperability for microwave access (WiMAX) applications. The antenna structure consists of a rectangular monopole with a microstrip feed line for excitation and a trapezoid conductor-backed plane for band broadening. [27]
- Mehdi Ali, Abdennacer Kachouri and Mounir Samet, proposed a compact dual-band microstrip antenna for universal 2.4 /5.2GHz WLAN applications by loading two pairs of slits in the non-radiating edges. By increasing the length of the slits, the higher resonant frequencies are tuned. [28]
- In the year 2003, Y. L. Kuo, K. L Wong proposed a Printed Double T-Monopole antenna for 2.4/5.2 GHz dual band for WLAN applications, comprises two stacked T-shaped monopoles of different sizes, which generate two resonant modes for desired dual band operations, and covers 2.4 and 5.2 GHz bands. [29]
- In the year 2009, Mohammed Al-Husseini presents a low cost ultra wide band microstrip antenna for wireless communication used for 3G/WLAN/WiMAX and UWB applications. The ground plane is partial and comprises a rectangular part and a trapezoidal part. The patch is half ellipse, where the cut is made along the minor axis and several slots are incorporated in the patch. [30]
- In the year 2010, Kuang Fuqiang proposed a triple band microstrip antenna for WLAN applications. The proposed antenna is made up of two one quarter wavelength resonating components, fed by a 50Ω microstrip line. The lower and higher resonant frequencies can be easily tuned by adjusting a few parameters of presented antenna.[31]
- Recently, in the year 2012, Md. Nazmul Hasan, Syed Waqar Shah, M.I.Babar shows the by smartly introducing the U-slot in patch, a dual band antenna for WLAN applications can be obtained. It was also studied that by varying the U-slot broadness frequency can be shifted to desired frequency. [32]

- In the year 2012, Bharath Kelothu, K.P.Subhashini and G.Lalitha Manohar proposed a compact high gain microstrip antenna for dual band WLAN applications. The dual band operation is obtained by embedding a pair of L-shaped slots and the performance of the microstrip antenna depends heavily on dimensions of the slot, as the width and the length increases, the return loss and VSWR increases. [33]

2.2.3 Slotted Aperture Coupled Microstrip Antenna

- In the year 1995, Huynh and Lee proposed an antenna with a U-slot in the patch and shows that an antenna with U-slot can provide impedance bandwidth in excess of 30%for an air substrate thickness of about $0.08\lambda_O$, and in excess of 20% for the microwave substrates of similar thickness. [34]
- Shi Chang Gao, Le Wei Li in the year 2002 proposed a microstrip antenna with an H-shaped coupling aperture which can achieve a wide bandwidth, low cross polarization levels and low backward radiation levels. To achieve a wide bandwidth, stacked patches with an air layer in between is used and H- shaped aperture is used to reduce backward radiations levels. [35]
- A microstrip antenna with novel E- shaped coupling aperture is presented in this paper titled “A Compact Microstrip Slot Antenna with Novel E- shaped Coupling Aperture” given by Omid Hoseini Izadi and Mandana Mehrparvar. Different parameters of antenna are explored .It is shown that by varying the dimensions of E- shaped slot and length of matching stub, the antenna can be designed for high gain, dual band or quad band characteristics. [36]
- In the year 2010, Nasimuddin, Zhi Nig Chen, and X. Qing proposed a S-shaped slotted patch antenna with a small frequency ratio for GPS applications. It was concluded that frequency ratio can be controlled by adjusting the S-shaped slot arm lengths. [37]

2.2.4 Stacked Aperture Coupled Microstrip Antenna

- Since the gain of a single-patch antenna is only about 4-7 dBi, then to obtain higher gains Shigeru Egashira and Eisuke Nishiyama in the year 1996 proposed the stacked microstrip antenna with two parasitic elements, one of which increases the impedance bandwidth and the other to enhance the gain. [38]

- In the year 1999, Rod B. Waterhouse proposed the design strategy to achieve bandwidths in excess of 25% for probe-fed stacked patches and concluded that choice of appropriate dielectric materials for such bandwidths and the selection of the substrate below the lower patch play a major role in producing broad-band responses. [39]
- 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. [40]

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. 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, but we can use dielectric substrates with different permittivity. 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 upon to bring out distinctive and improved results.
- An aperture coupled microstrip stacked antenna is required to provide wide bandwidth but results in low cross polarization which leads to quite high back radiation level. This can be reduced by using the new aperture coupled microstrip antennas, in which the slot is fed by a microstrip line and coupled to several parasitic patch radiators etched on the opposite side from the slot. The patches are employed to reduce the radiation into the half-space that they occupy and increase the radiation in other half space.
- Novel structures called DGS and defected microstrip structures are used to reduce the size of patch antennas without degrading the performance of antenna.

- Stacked aperture coupled microstrip antenna was presented to increase the bandwidth of about one octave which will result in surface waves and increased antenna height. So work can be done regarding reducing antenna size by introducing slots in the patch cleverly which will result in increased bandwidth without increasing number of stages.

2.4 Thesis Problem Definition:

- Design of single band antenna at 3.6 GHz for WLAN application.
- Design of U- slot dual band antenna for WLAN applications (3.6 GHz and 5.2 GHz).
- Design of double U- slot triple band antenna for WLAN applications (3.6 GHz, 5.2 GHz and 5.8 GHz)
- Design of S- shaped slotted patch antenna for triple band characteristics, used for GPS and satellite communication.
- Design of stacked S- shaped slotted patch antenna for multiband characteristics, used for GPS and satellite communication.
- Design of broadband and dual band E- shaped Aperture Coupled Microstrip Antenna.
- Fabrication and testing of single band aperture coupled microstrip antenna at 5.2 GHz used for WLAN applications.

Conclusion

In this chapter, the literature survey of aperture coupling and microstrip line feeding techniques has been studied.

CHAPTER 3
ANALYSIS OF APERTURE COUPLED MICROSTRIP ANTENNA

There are several methods to analyze aperture coupled microstrip antenna such as integral equation approach, cavity model, transmission line model, model expansion method, and a hybrid approach. Here, analysis has been done using transmission line model because of its ability to arrive at the simpler design. It also includes the design and parametric study of single band antenna at 5.2 GHz.

3.1 Geometry of Aperture Coupled Microstrip Antenna

Aperture coupled microstrip antenna basically divided into two parts: radio patches and feed network. In this type of feeding technique, the radiating patch and the microstrip feed line are separated by the ground plane as shown in figure. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane. Generally, a high dielectric material is used for the bottom substrate and a thick, low dielectric constant material is used for the top substrate to optimize radiation from the patch. The amount of coupling from the feed line to the patch is determined by the shape, size and location of the aperture. [2]

Fig. 3.1 shows the assembly of an aperture coupled microstrip antenna in detail. The patch of length L and width W is placed on a substrate with height h_1 and relative permittivity is ϵ_{r1}. The lower substrate height is h_2 and its relative permittivity is ϵ_{r2}. Both substrates are separated by a metallic plane, having a rectangular cutout of edge length La and width Wa and its center at the position $(x_o y_0)$. This rectangular cutout is called coupling aperture. The lower edge of patch is chosen at the point of origin ($x_o = L/2\,, y_o = W/2$) describes a coupling aperture aligned with the center of the patch. The feeding is realized by an open ended microstrip line of width W_L, overlapping the point x_o by length ΔL.

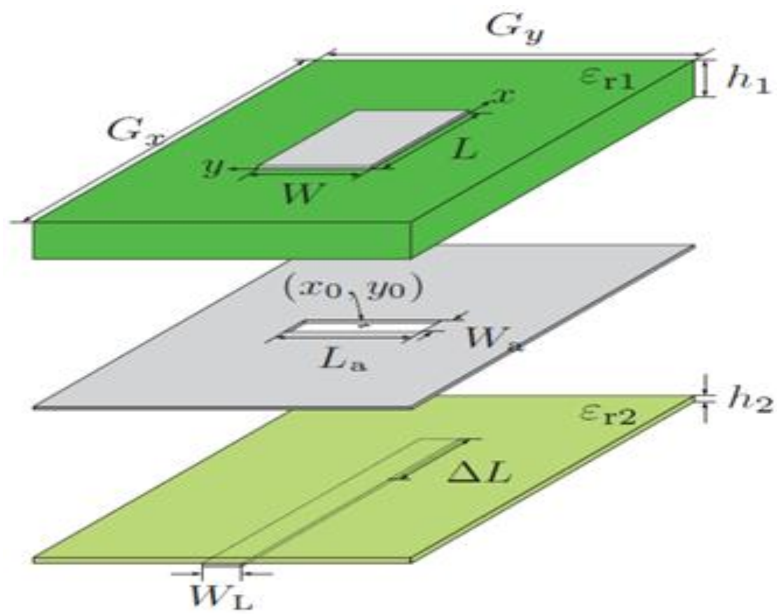


Fig 3.1 Schematic assembly of Aperture Coupled Microstrip Antenna [41]

3.2 Equivalent structure of Aperture Coupled Microstrip Antenna

A number of theoretical and experimental studies have been performed to analyze the aperture coupled microstrip patch antenna. Full-wave approaches based on the method of moments, spectral domain analysis, and the finite-difference time-domain method have been used to determine various antenna parameters. For providing the rapid and accurate design, it is effective to use the method of transmission line model, especially thin substrate.

A simplified equivalent circuit of an aperture coupled microstrip antenna is shown below in Fig 3.2. The microstrip patch is characterized by admittance Y_p and the aperture by admittance Y_a. Z_{in} characterizes the input impedance of the antenna, consisting of serial connection of a transformer and an open ended microstrip line. This line corresponds to the end of microstrip line of length ΔL. The slot (aperture) interrupts the longitudinal current flow in the feed line and the patch, resulting in a coupling between them. The coupling between the patch, aperture, and the feed line can be described by the two impedance transformers. The transformer, with a turn ratio of n_2 : 1, models the coupling between microstrip line and coupling aperture and patch is modeled by the transformer with transfer ratio of 1: n_1 and the admittance Y_p describes n_1 is the turn ratio of energy between aperture and patch, it can be calculated by corresponding current distribution equation.

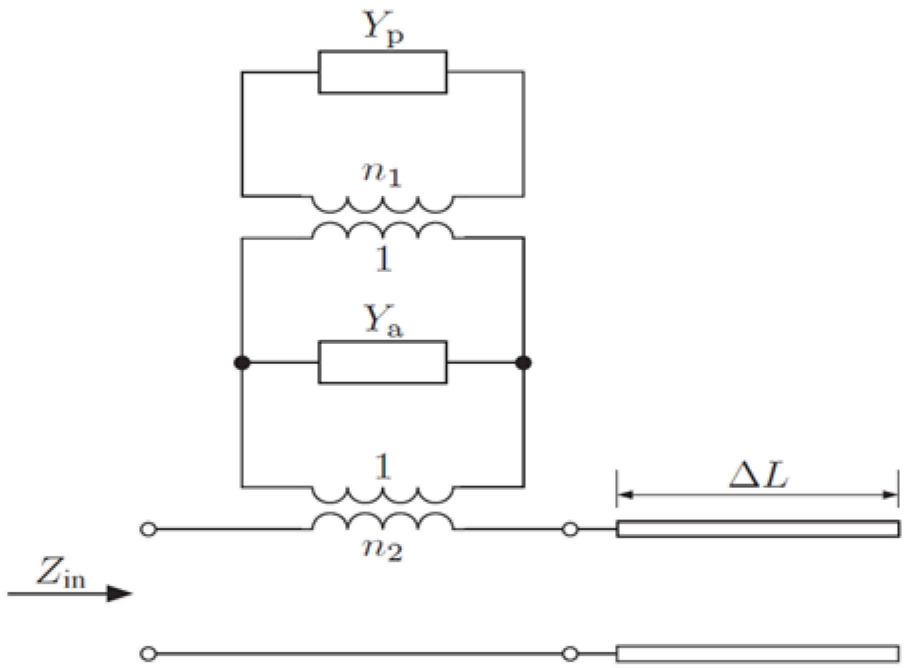


Fig 3.2 Equivalent circuit of ACMA based on transmission line model [41]

For the determination of n_1, [42] assumes that the ratio is approximately equal to the fraction of current intercepted by the aperture to the total patch current, so that:

$$n_1 = \frac{L_a}{W} \qquad 3.1$$

This corresponds to the consideration, that the coupling is reduced for smaller apertures. The turn ratio of energy between feed line and aperture is n_2, which can be expressed as:

$$n_2 = \frac{\Delta V}{V_o} \qquad 3.2$$

Where V_o is the voltage of aperture, ΔV defines the voltage discontinuity of the microstrip line due to the slot and is given by:

$$\Delta V = \iint e \times h \ \ ds \qquad 3.3$$

Where e is the electric field of aperture and h is normalized magnetic field. If D is the effective width of feed line and h is the height of substrate, then for a aperture of smaller size n_2 can be written as:

$n_2 = \frac{L_{ap}}{\sqrt{Dh}}$ 3.4

3.3 Patch Admittance

To get an approximation for the admittance Y_p, the patch is also modeled by electric lines in the transmission line model. Fig 3.3 shows the resulting equivalent circuit for the patch.

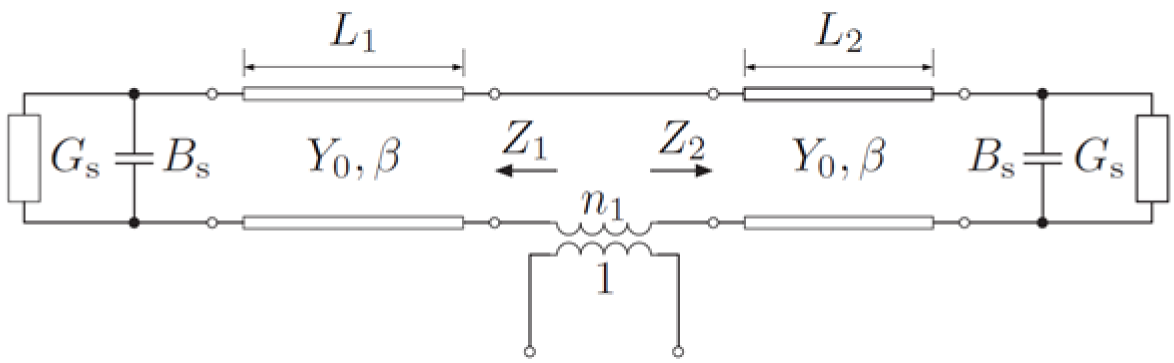


Fig. 3.3 Equivalent circuit of Patch [41]

Two lines are positioned behind the transformer, one with length $L_1 = x_o$ and the other with length $L_2 = L - L_1$. Together they have the total length (L) of the patch, which is split into two lines at the position x_o by the transformer. If input impedances, $Z_1$and Z_2 are the impedances looking into left and right side of the aperture, then total impedance of the patch is given by:

$Z_p = Z_1 + Z_2 = 1/Y_1 + 1/Y_2$ 3.5

The equivalent circuit allows the single input impedance to be determined to and is given by:

$Y_i = Y_o \frac{G_s + jB_s + jY_o \tan(\beta L_i)}{Y_o + j(G_s + B_s)\tan(\beta L_i)}, with\ i = 1, 2$ 3.6

Within the equivalent circuit, Y_o and β are the transmission line admittance and phase constant of transmission line with the width W on a substrate with a relative permittivity of ϵ_{r1}. The load admittances $Y_s = G_s + jB_s$ consider the two radiating sides of the patch. Here, G_s depicts the radiated power and B_s depicts the stored energy save in the field near the slot.

3.4 Aperture Admittance

The admittance of the coupling aperture Y_a is also determined by the transmission line theory, as the coupling aperture is modeled as a short ended slot line at both ends. Hence, the admittance of aperture is given by:

$$Y_a = -j2\, Y_{ao} Cot\, \left(\frac{\beta L_a}{2}\right) = jB_a \qquad 3.7$$

With Y_{ao} being the characteristic impedance of a slot line, placed on the substrate with the relative permittivity ϵ_{r2}.

3.5 Input Impedance

Based on these transmission line models, an expression for the input impedance Z_{in} of the aperture coupled patch antenna in the equivalent circuit of Figure 3.2 can be derived to

$$Z_{in} = \frac{n_2^2}{n_1^2 Y_p + Y_a} - jZ_{mo} Cot(\beta_m \Delta L) \qquad 3.8$$

Here, Z_{mo} is the transmission line impedance of the feeding line and β_m is the corresponding phase constant. Setting $n_1^2 B_p + B_a = 0$ results in:

$$B_p = \frac{-B_a}{n_1^2} \qquad 3.9$$

Substitute equation 1 and 5 in equation 6 and consider cot(x) = 1/x for smaller x, yields the following condition for resonance given by:

$$B_p \approx \frac{4 Y_{ao} W^2}{\beta_s L_a^3} \qquad 3.10$$

Here, β_s describes the phase constant of the slot line. Above equation shows that increasing length L_a results in a decreasing susceptance B_p, resulting in decreasing resonance frequency. [44] An increasing length L_a not only results in a decreasing resonance frequency f_{res}, but also in an increasing resonance R_{res} , due to the increasing coupling between the patch and microstrip line. Hence, the influence of the admittance Y_p is increased, too. In general, an increased coupling yields an increasing resonance resistance and a decreasing resonance frequency.

Due to the fact, both resonances – the one of the patch and other of the aperture – results in two loops different sides within the smith chart, a greater bandwidth can be achieved. An increased coupling can also be achieved by decreasing height, so the patch and the coupling aperture are closer together. [43]

3.6 Parametric Analysis of Rectangular ACMA at 5.2 GHz used for WLAN applications

Design, analysis and simulation results obtained for rectangular aperture coupled microstrip antenna at 5.2 GHz will be presented, with the evaluation of various parameters effect on the optimization of design. The parameters are analyzed one by one, with the particular effect on the antenna performance, with the next subsections.

3.6.1 Design of Rectangular Aperture Coupled Microstrip Antenna

The rectangular patch antenna is approximately a 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 free- space wavelength. The length of antenna is slightly shorter because of extended electric "fringing fields" which increase the electric length of antenna slightly. [2] A single element of rectangular patch antenna, as shown in Fig 1.6, can be designed for 5.2 GHz frequency using transmission line model explained in chapter 1.

3.6.1.1 Designing of Single Band Rectangular Microstrip Antenna:

Frequency (f_r)	5.2 GHz
Dielectric constant	4.4
Patch Substrate Thickness	1.57
Feed Substrate Thickness	1.57

Table 3.1 Design specifications of Single Band ACMA

Patch Dimension: The dimensions of patch can be calculated by applying the formula given in section 1.4.1.2 (chapter 1). So the dimensions are: Length (L) = 10.8 mm and Width (W) = 20mm.

Ground Dimension: The dimensions of the ground can be calculated referring to section 1.4.1.2 (chapter 1). Length (Lg) = 22.66mm and Width (Wg) = 20.12 mm.

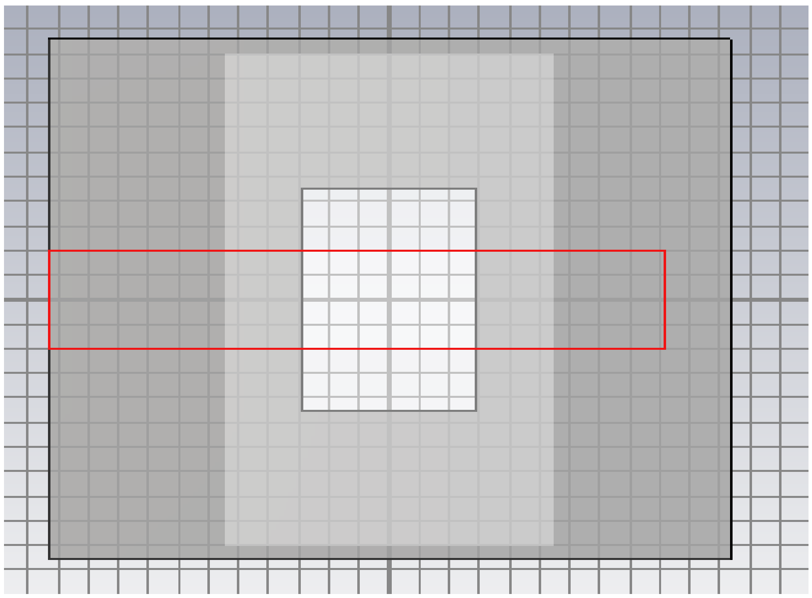


Fig 3.4 Designed structure on CST Microwave Studio

3.6.2 Simulation Setup and Result of Single Band Aperture Coupled Microstrip Antenna

The software used to model and simulate the Microstrip patch antenna is CST Microwave Studio 2010. 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. The simulated results of proposed antenna are presented in figures below:

3.6.2.1 Return Loss and Antenna Bandwidth

Figure 3.5 shows the S_{11} parameters (return loss) for proposed antenna resonates at 5.2 GHz with return loss of -36.85 dB. 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 can be calculated from return loss versus frequency response plot. The measured -10 dB bandwidth of the proposed antenna is 390 MHz and resonant frequency is 5.2 GHz. More is the return loss, means more of the coupling. If coupling is more, then the antenna will have more directivity, thereby increasing the gain of antenna.

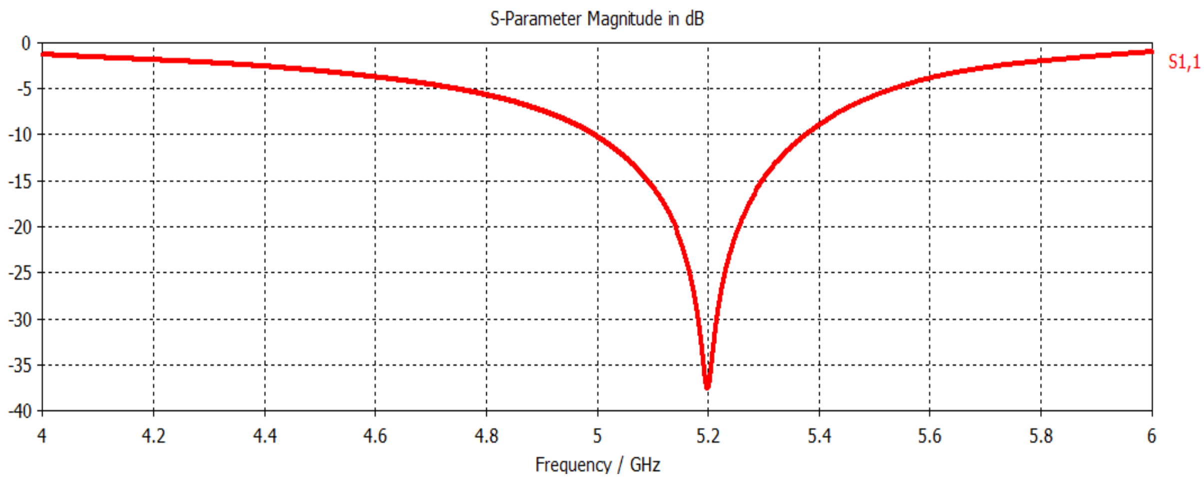


Fig 3.5 Return Loss S_{11} (in dB) of Single band antenna

3.6.2.2 Smith Chart

The smith chart shown in figure 3.6 represents that how the antenna impedance varies with frequency and gives impedance of 52.88 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 the center of the smith chart. It can be seen from the Fig 3.6 that the circle cuts the resistive part at 0.52, thus matching at 52.88 ohm.

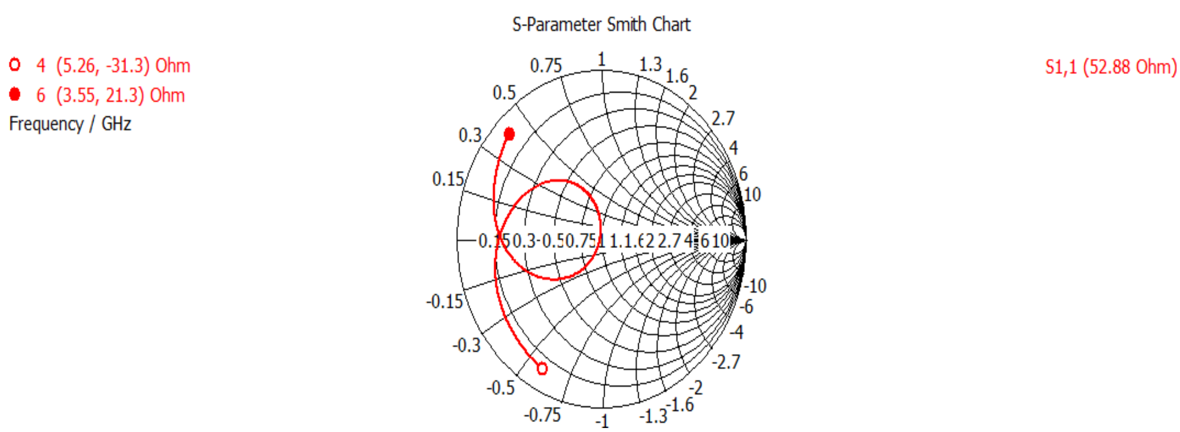


Fig 3.6 Smith Chart for single band antenna

3.6.2.3 Directivity

The directivity plot shown in Fig 3.7 represents the amount of radiation intensity of the antenna. The proposed antenna provides 5.838 dBi, directivity at 5.2 GHz. The simulated antenna radiates more in particular direction as compared to the isotropic antenna which radiates equally in all directions, by an amount of 5.838 dBi. From polar plot view of directivity, it can be seen that at a frequency of 5.2 GHz, directivity is 5.838 dBi, radiation pattern obtained is omni directional with main lobe at an angle of 0 degree, having angular width of 105.9 degree. The magnitude of main lobe is 5.8 dBi.

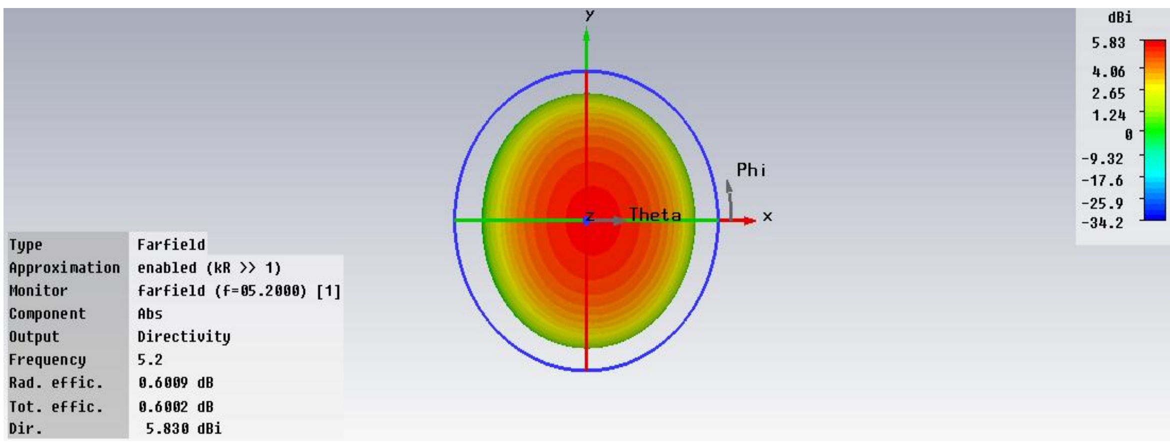


Fig 3.7 (a) Directivity (3D view) at 5.2 GHz

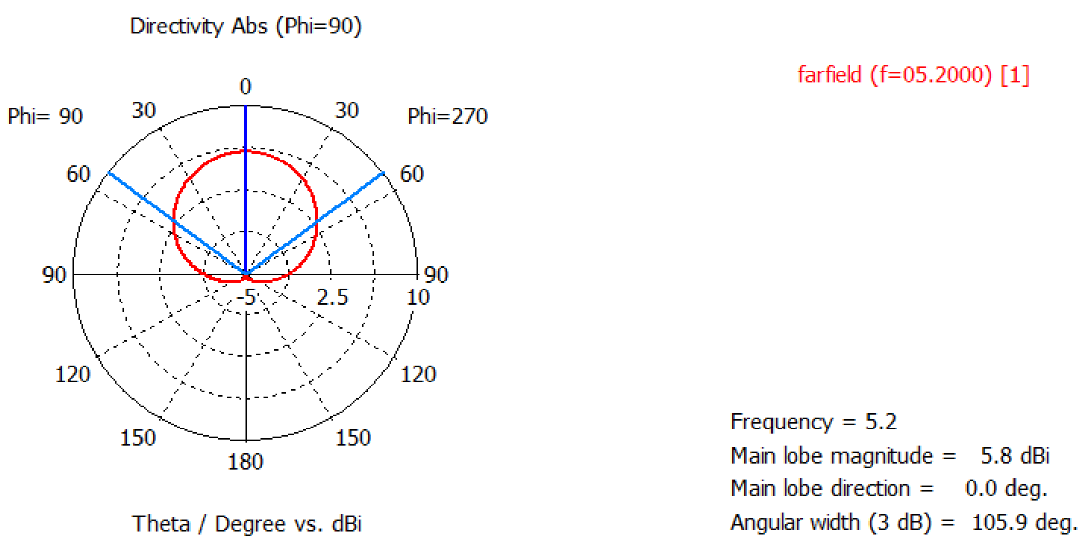


Fig 3.7 (b) Directivity (polar plot) at 5.2 GHz

3.6.2.4 Gain

The gain of a particular antenna in a particular direction is more as compared to isotropic antenna radiating in all directions which is very useful for WLAN applications providing a better performance. The proposed single band antenna provides the gain of 6.431 dB at 5.2 GHz.

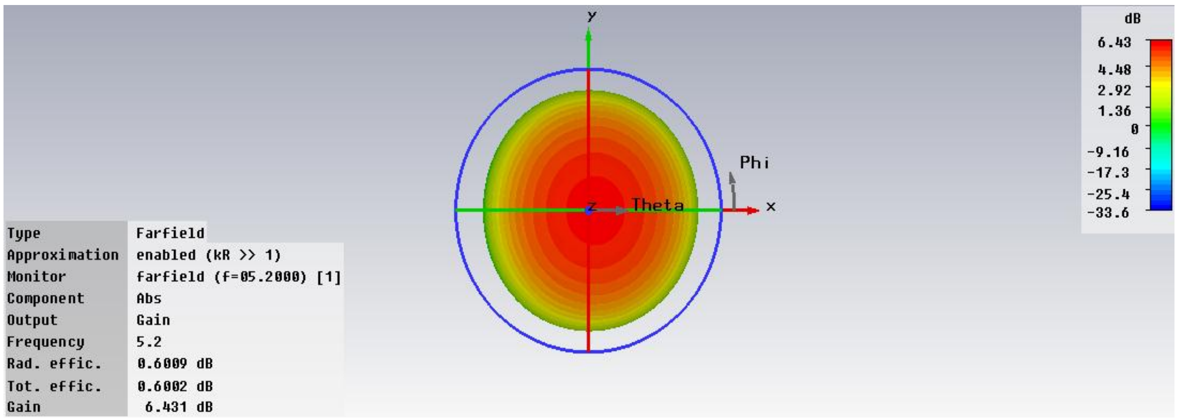


Fig 3.8 (a) Gain (3D view) at 5.2 GHz

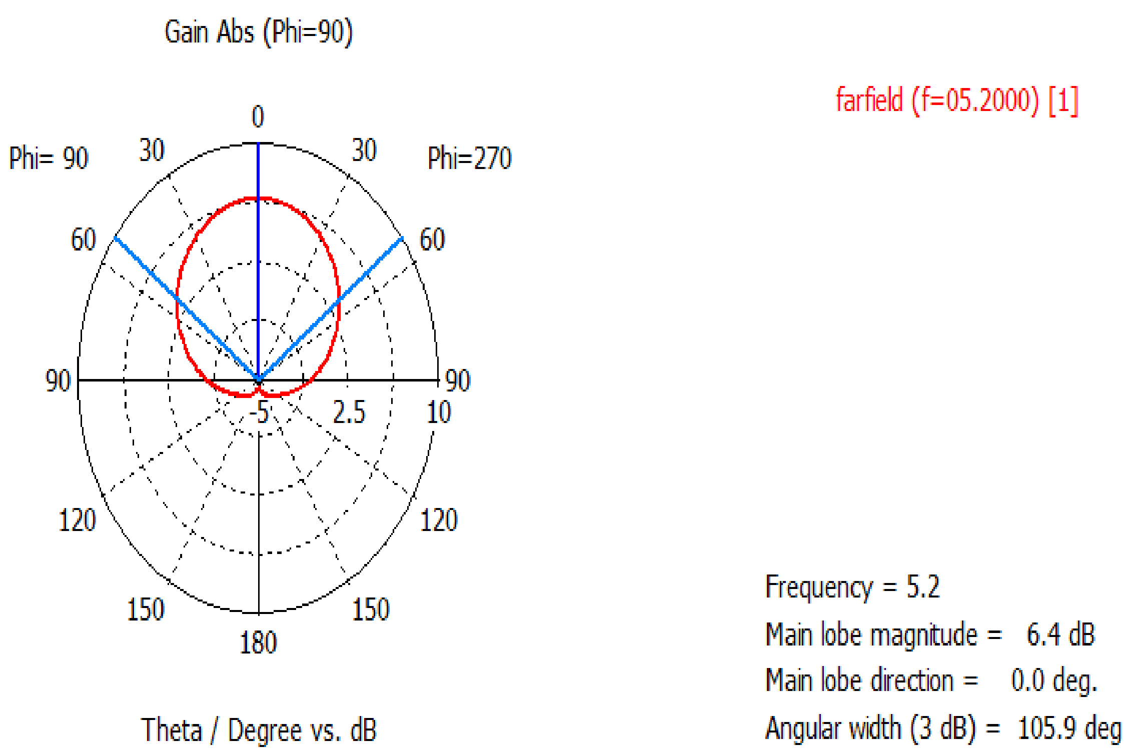


Fig 3.8 (b) Gain (polar plot) at 5.2 GHz

3.6.3 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 impendence of the patch element. For maximum coupling, it should be placed perpendicular to the slot. [9] As from the figure 3.9, it can be seen that as a feed stub length is increased from 8.4 mm to 10.2 mm, the return loss is increased from -17 dB to – 39 dB till 9.2 mm and then start decreasing till10.2 mm. So for proper matching, the sub length chosen is 9.2 mm with return loss of – 39 dB and Sub length = 9.2 mm is considered for design of this antenna.

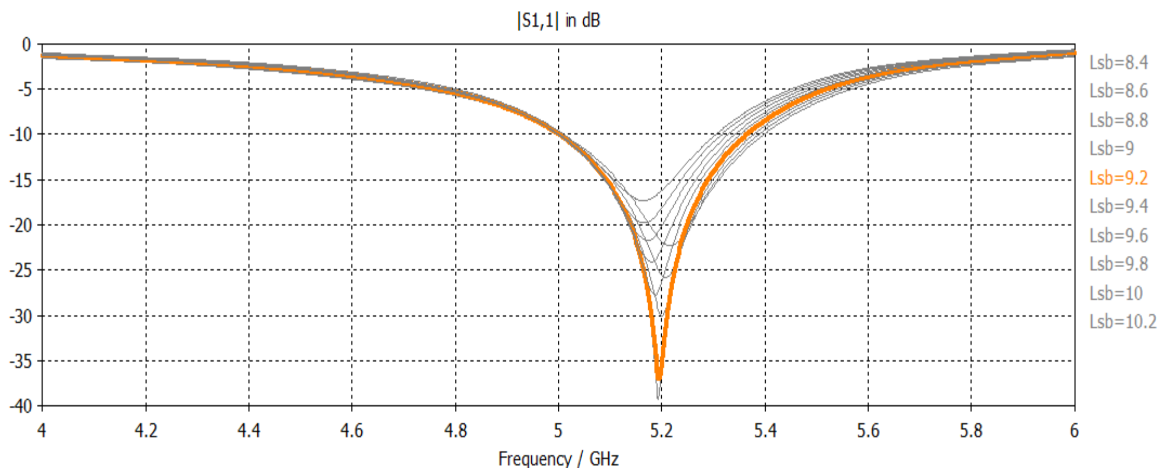


Fig 3.9 Effect of Stub Length Variation

3.6.4 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 slot. If the slot length is comparable to the half of wavelength of the antenna, it is called 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. [9] When the aperture length is increased from 4 mm to 5 mm, keeping the slot width to slot length ratio to 1/10, return loss increases till 4.6 mm and then start decreasing again. But taking into account both desired resonant frequency and slot length, the slot length equal to 4.5 mm is selected as shown in figure. The slot length also affects the input impedance of antenna.

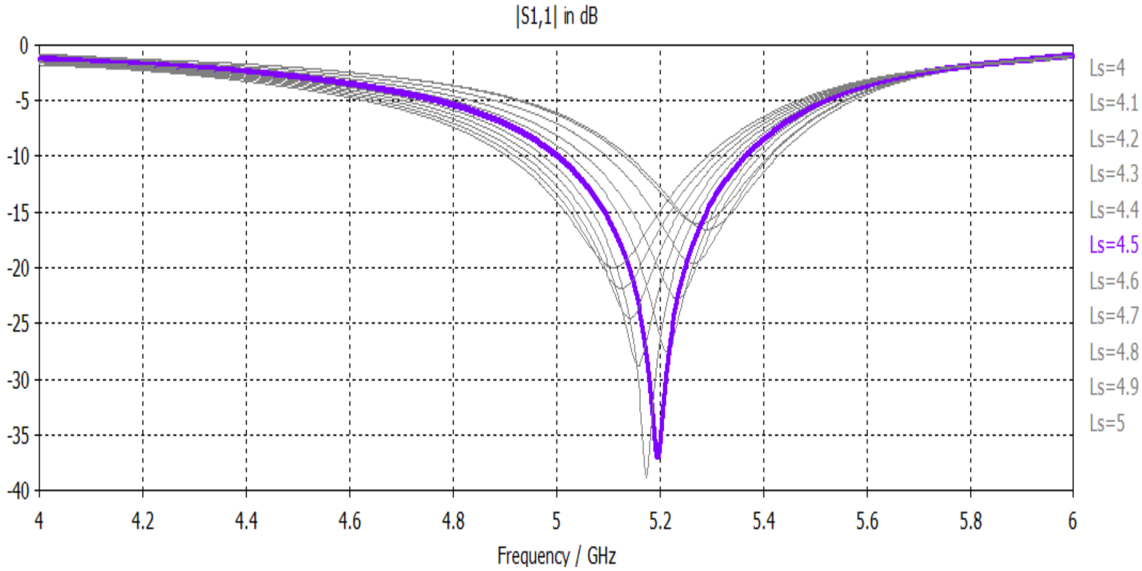


Fig 3.10 Effect of Slot Length Variation

3.6.5 Effect of dielectric constant value of substrate:

It affects the bandwidth of the antenna directly. Low permittivity of the dielectric substrate results in wider bandwidth and lesser surface wave excitation. Higher permittivity of the substrate is used for feed network and lower permittivity is used for antenna substrate. As the dielectric constant and thickness is varied, feed line width and stub length must be modified to maintain characteristic impedance of 50 ohm and stub length of λ_g /4 [2].

Larger the dielectric constant, smaller will be the antenna size and impedance bandwidth. From the Fig 3.11, it can be shown that as the dielectric constant increases, resonant frequency decreases. Dielectric constant with the value 4.4, resonating close to frequency required i.e. 5.2 GHz. Also return loss observed at this value of dielectric constant is highest. So, the antenna having feed and the patch substrate of dielectric constant 4.4 are chosen.

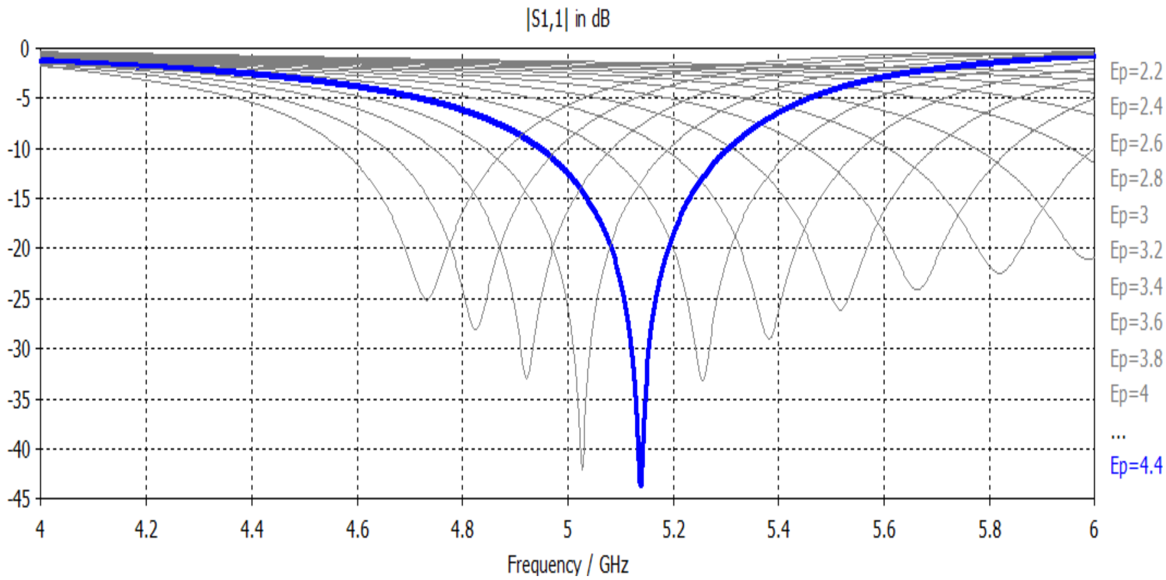


Fig 3.11 Effect of Dielectric Constant

Conclusion

In this chapter, aperture coupled microstrip antenna using transmission has been analyzed. Also designing of antenna along with its parametric study has been done using aperture coupled feeding technique.

CHAPTER 4

DUAL AND TRIPLE BAND U-SLOT ACMA

This chapter covers the designing of dual band and triple band U-slot aperture coupled microstrip antenna for WLAN applications. Initially microstrip patch antenna with U-slot in patch was mainly used for bandwidth enhancement. However subsequent researches revealed that wideband characteristic can be modified to multiband characteristic by intelligent placement of U-slot, thereby perturbing the surface current flow in the patch.

4.1 Dual band U- slot ACMA for WLAN Applications

4.1.1 Design of Dual band U- slot Aperture Coupled Microstrip Antenna

This section describes the design of dual band U-slot aperture coupled microstrip antenna satisfying the following specifications:

Frequency (f_r)	3.6 GHz and 5.2 GHz
Dielectric constant (ϵ_r)	4.4
Patch substrate thickness	1.57 mm
Feed substrate thickness	1.57 mm

Table 4.1 Design specifications of Dual band U-slot ACMA

Basically a simple aperture coupled microstrip antenna with rectangular patch, results in single- band antenna. For dual band operation a single U-slot is cut in the patch as shown in Fig 4.1. However, when a U-slot is cut in the rectangular patch, a notch is introduced within the matching band, results in dual- band antenna. For better coupling aperture in ground is also of U-shape having length (La) and width (Wa) is shown Fig 4.2. The resulting antenna will resonate at 3.6 GHz and 5.2 GHz, used for WLAN applications. The optimal parameters for U- slot dual band antenna are tabulated table 4.2 and complete designed view is shown in Fig 4.3.

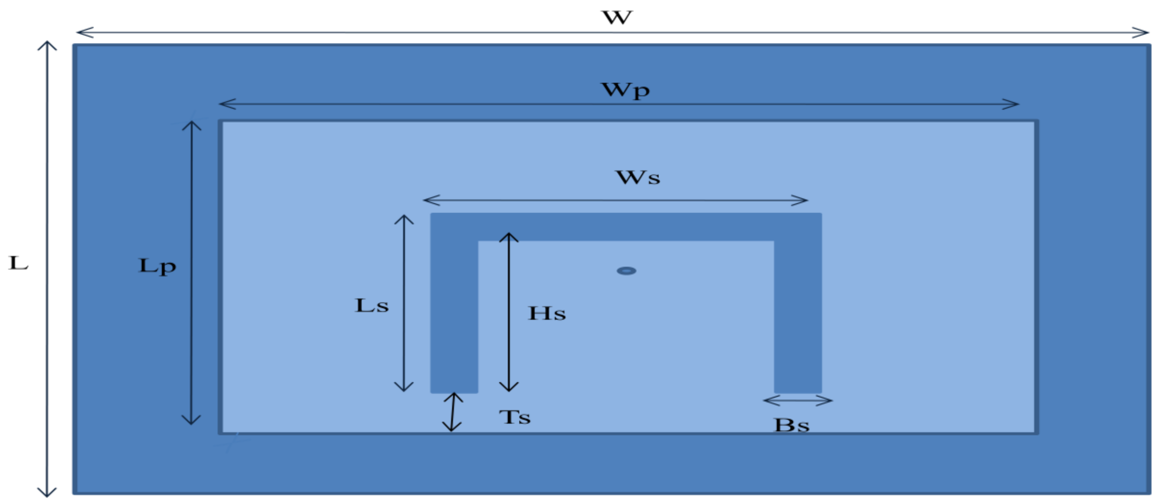


Fig 4.1 Geometry of U – Slot Dual Band ACMA

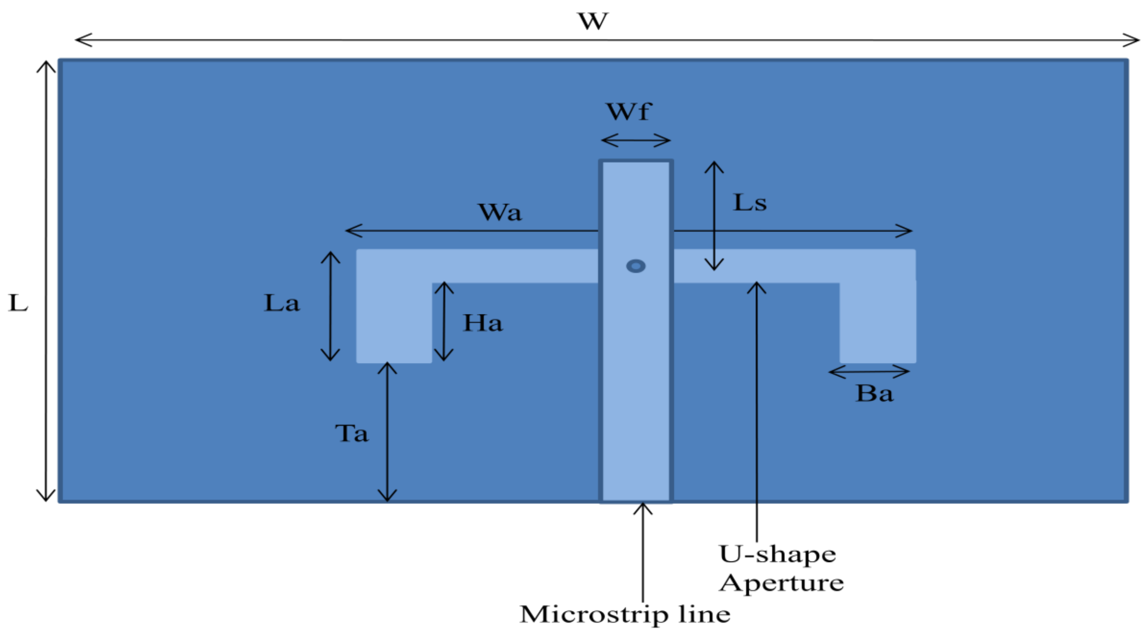


Fig 4.2 Geometry of U- Shaped Aperture

Parameters	L	W	L_p	W_p	L_S	W_S	B_S	H_S	T_S	L_a	W_a	B_a	H_a	T_a
Unit (mm)	32	40	20.98	27.8	11	10	1	10	3.6	3.04	7	0.5	2.6	13

Table 4.2 Proposed parameters of U- slot dual band ACMA

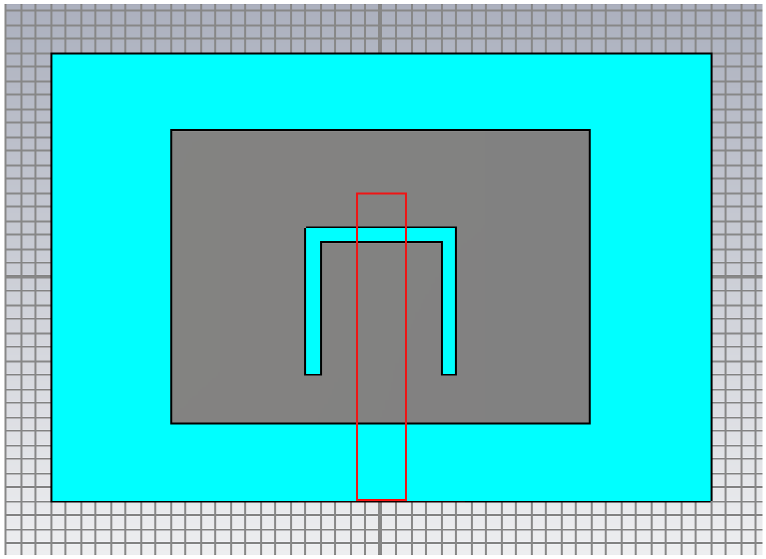


Fig 4.3 Designed structure on CST Microwave Studio

4.1.2 Simulation Setup and Result of U- slot Dual band Antenna

The software used to model and simulate the Microstrip patch antenna is CST Microwave Studio 2010. 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. The simulated results of proposed antenna are presented in figures below:

4.1.2.1 Return Loss and Antenna Bandwidth:

Figure 4.4 shows the S_{11} parameters (return loss) for proposed antenna. The lower band resonates at 3.6 GHz with return loss of -32.46 dB and upper band resonance occurs at 5.2 GHz with return loss -20.30 dB. 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 can be calculated from return loss versus frequency response plot. The measured -10 dB bandwidth of the proposed antenna is 59 MHz and 146 MHz at 3.6 GHz and 5.2 GHz respectively.

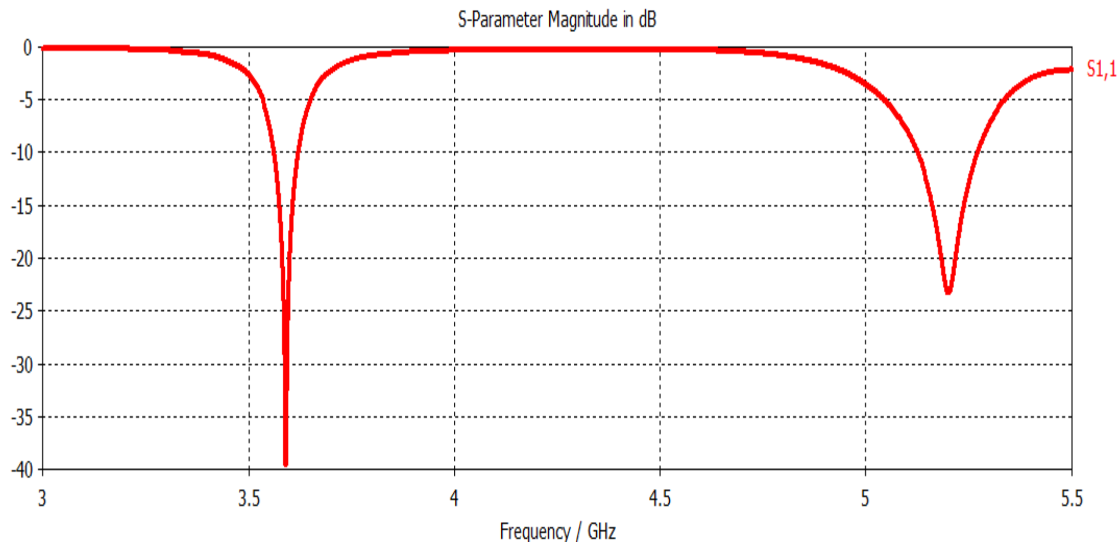


Fig 4.4 Return Loss S_{11} (in dB) of Dual band antenna

4.1.2.2 Smith Chart:

The smith chart shown in Fig 4.5 represents that how the antenna impedance varies with frequency and gives impedance of 50.08 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 the center of the smith chart. It can be seen from the figure 4.5 that the circle cuts the resistive part at 0.50, thus matching at 50.08 ohm.

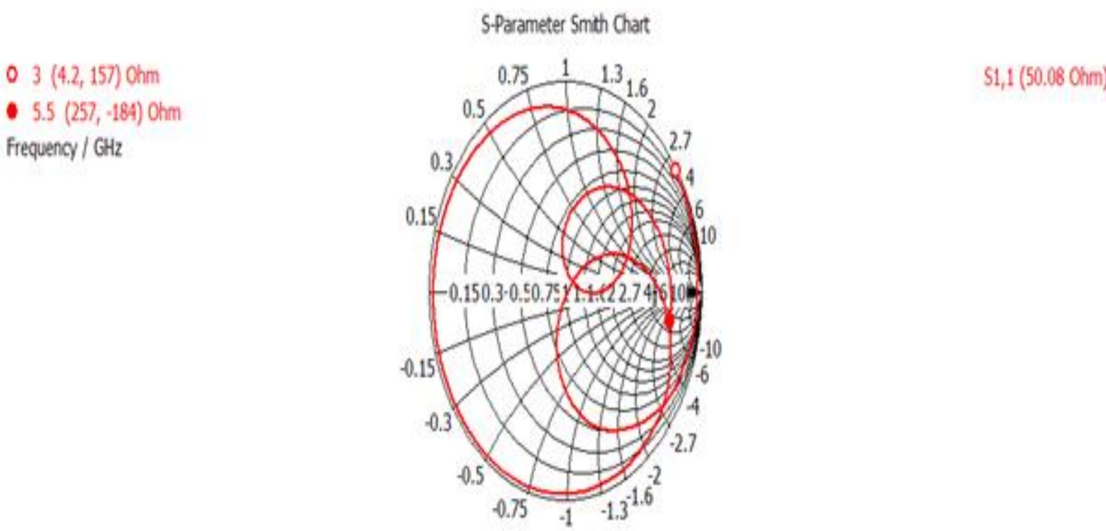


Fig 4.5 Smith Chart for dual band antenna

4.1.2.3 Directivity

The directivity plot shown in Fig 4.6 represents the amount of radiation intensity of the antenna.

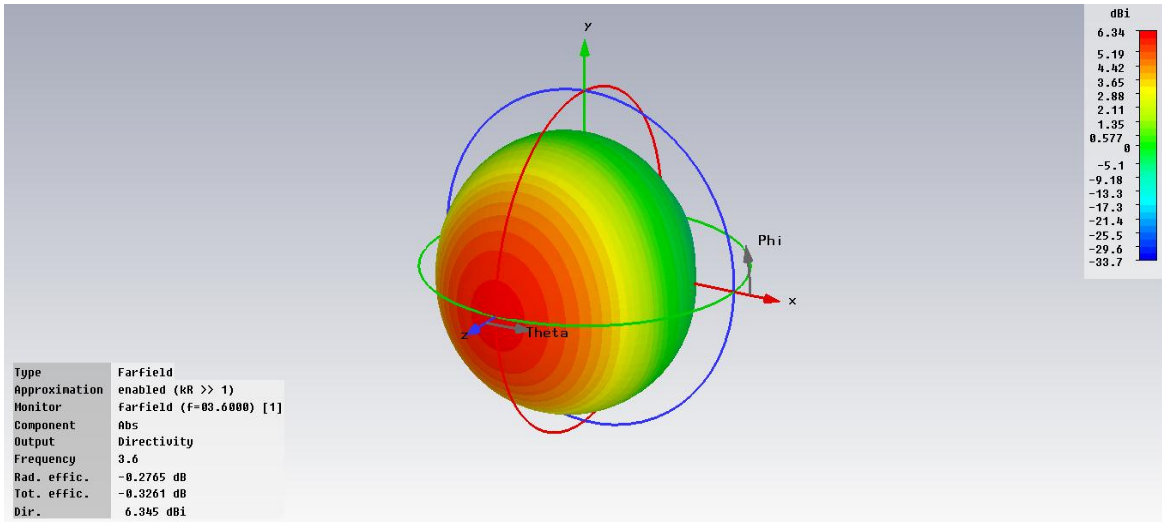


Fig 4.6 (a) Directivity (3D view) at 3.6 GHz

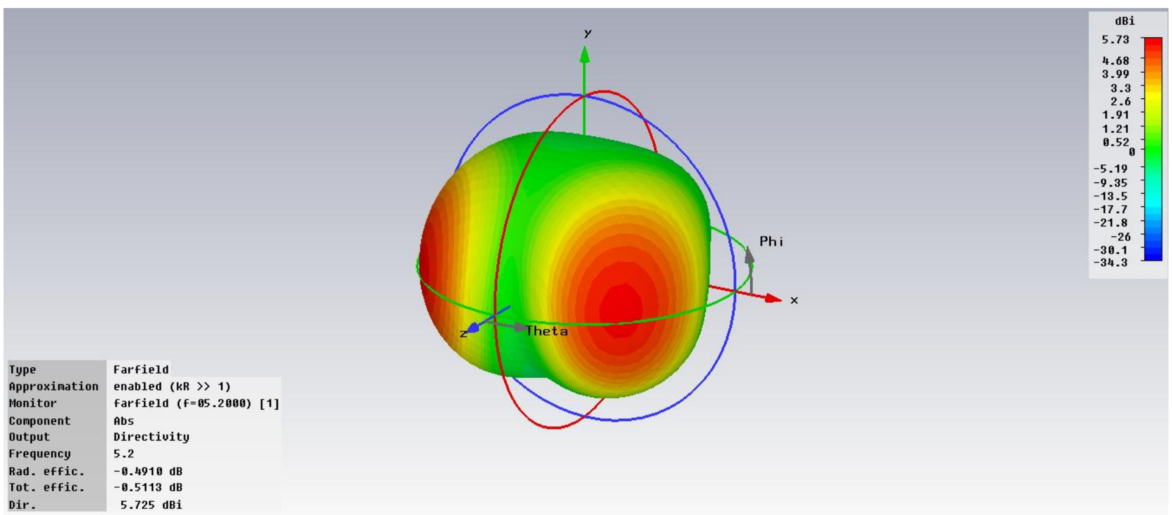


Fig 4.6 (b) Directivity (3D view) at 5.2 GHz

4.1.2.4 Gain

The gain of a particular antenna in a particular direction is more as compared to isotropic antenna radiating in all directions which is very useful for WLAN applications providing a better performance. The proposed antenna provides the gain of 6.068 dB and 5.234 dB at 3.6 GHz and 5.2 GHz frequency as shown in Fig 4.7.

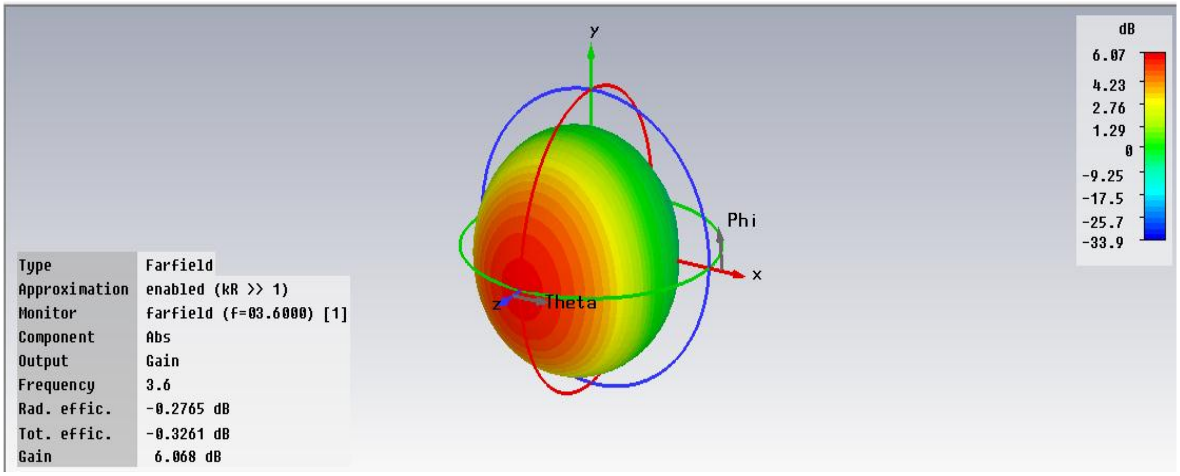


Fig 4.7 (a) Gain (3D view) at 3.6 GHz

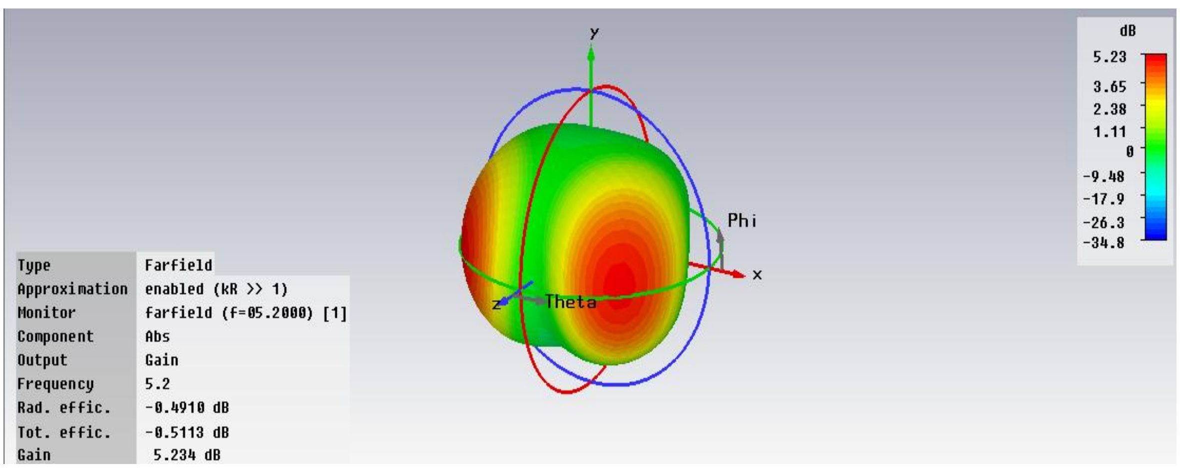


Fig 4.7 (b) Gain (3D view) at 5.2 GHz

4.1.2.5 Current Distribution at resonant frequencies of operation:

According to the current distributions, the slots of different dimensions were cut in the patch to provide wideband characteristics or multiband characteristics. Basically position of the slots in the patch describes current distribution at both of the frequencies.

Fig 4.7 (a) reveals the surface current at 3.6 GHz is highest in the middle of the patch and near the arms of U-slot providing that patch is responsible for resonating at lower frequency band from 3.56 GHz to 3.62 GHz. The maximum amount of surface current at slot at patch is 140 A/m

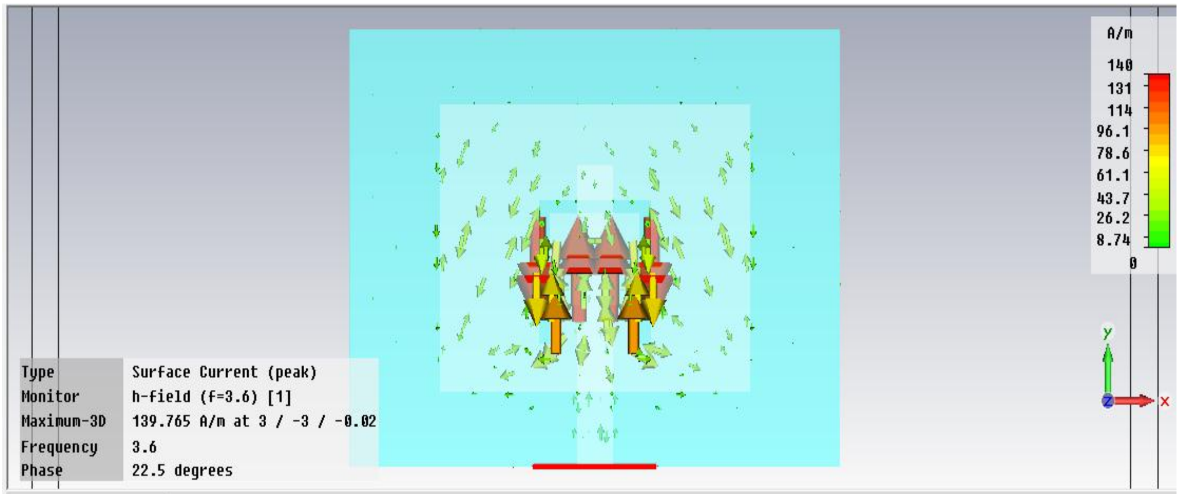


Fig 4.8 (a) Current distribution at 3.6 GHz frequency

Fig 4.7 (b) reveals the surface current at 5.2 GHz is highest in the arms of U- slot and some amount of current is present in whole patch, providing that U-slot is responsible for resonating at upper frequency band from 5.12 GHz to 5.27 GHz The maximum amount of surface current at slot at patch is 140 A/m.

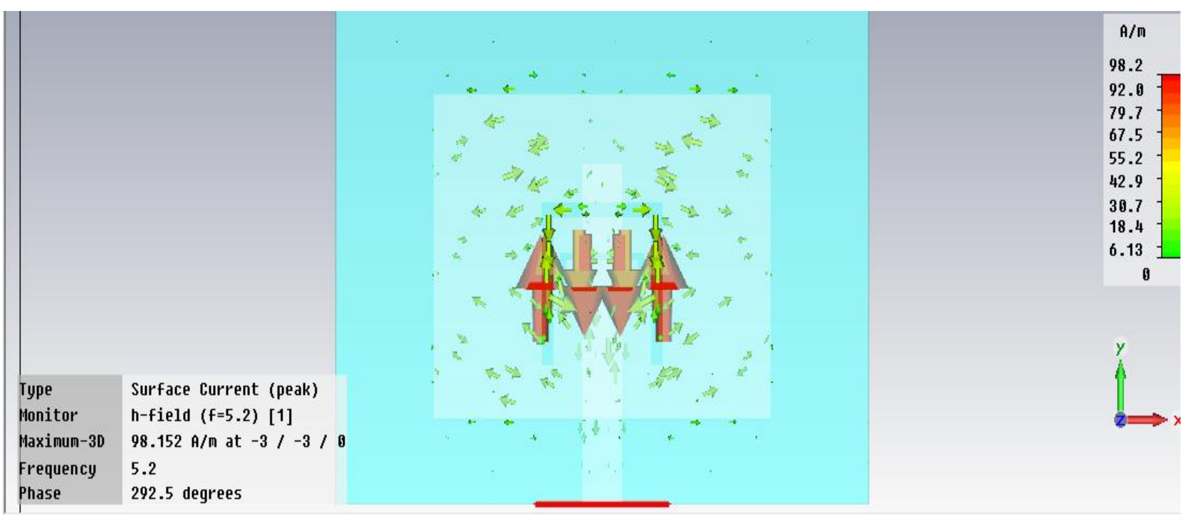


Fig 4.8 (b) Current distribution at 5.2 .GHz frequency

4.2 Triple band U- slot ACMA for WLAN Applications

4.2.1 Design of Triple band U- slot Aperture Coupled Microstrip Antenna

This section describes the design of dual band U-slot aperture coupled microstrip antenna satisfying the following specifications:

Frequency (f_r)	3.6 GHz, 5.2 GHz and 5.8 GHz
Dielectric constant (ϵ_r)	4.4
Patch substrate thickness	1.57 mm
Feed substrate thickness	1.57 mm

Table 4.3 Design Specifications of Triple Band U-slot ACMA

A simple aperture coupled microstrip antenna with rectangular patch, results in single- band antenna. When a single U-slot is cut in the patch is cut in the rectangular patch, a notch is introduced within the matching band, results in dual- band antenna. If another U-sot is cut in the same patch, two notches are introduced within the matching band (figure 4.8), results in triple band aperture coupled microstrip antenna. The resulting antenna will resonate at 3.6 GHz, 5.2 GHz, and 5.8 GHz, used for WLAN applications. The complete designed view is shown in figure 4.9 and the optimal parameters for U- slot triple band antenna are tabulated table 4.3.

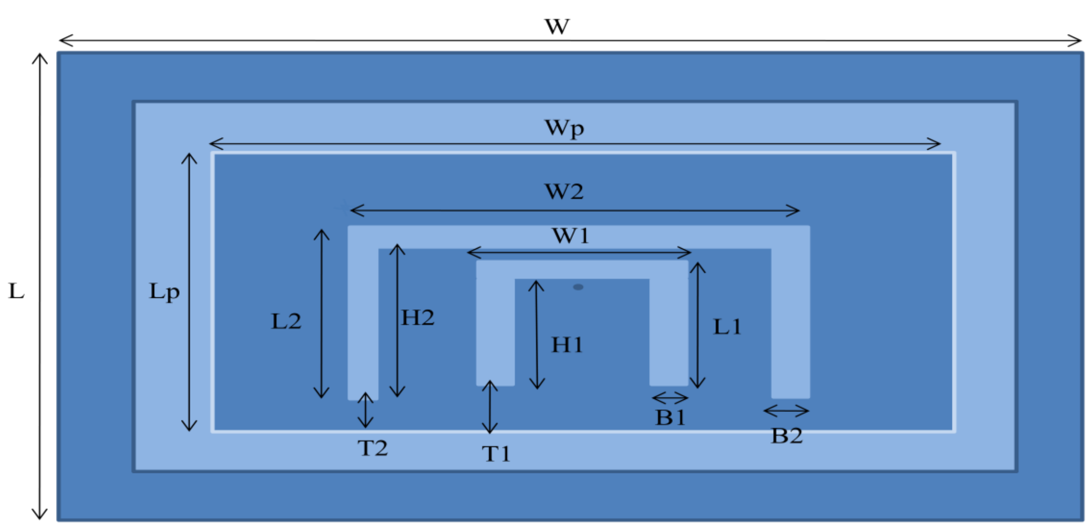


Fig 4.9 Geometry of U – slot Triple band ACMA

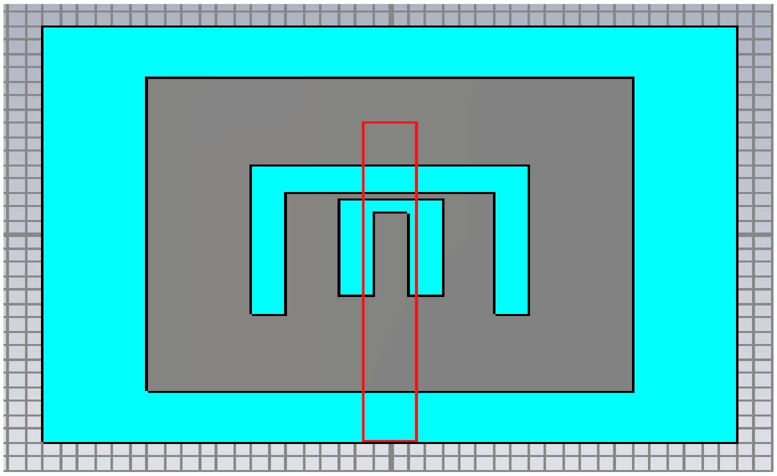


Fig 4.10 Designed structure on CST Microwave Studio

Parameters	L	W	L_p	W_p	L_1	W_1	B_1	H_1	T_1	L_2	W_2	B_2	H_2	T_2
Unit (mm)	30	36	22.62	28	7	6	1	6	4.31	11.8	16	2	9.8	4.51

Table 4.4 Proposed parameters of U- slot triple band ACMA

4.2.2 Simulation Setup and Result of U- slot Dual band Antenna

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

4.2.2.1 Return Loss and Antenna Bandwidth:

Figure 4.10 shows the S_{11} parameters (return loss) for proposed antenna. The lower band resonates at 3.6 GHz with return loss of -17.7 dB, middle band resonates at 5.2 GHz with return loss -26.85 dB and upper band resonance occurs at 5.8 GHz with return loss -23 dB. 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 can be calculated from return loss versus frequency response plot. The measured -10 dB bandwidth of the proposed antenna is 40 MHz, 31 MHz and 128 MHz at 3.6 GHz, 5.2 GHz, and 5.8 GHz respectively.

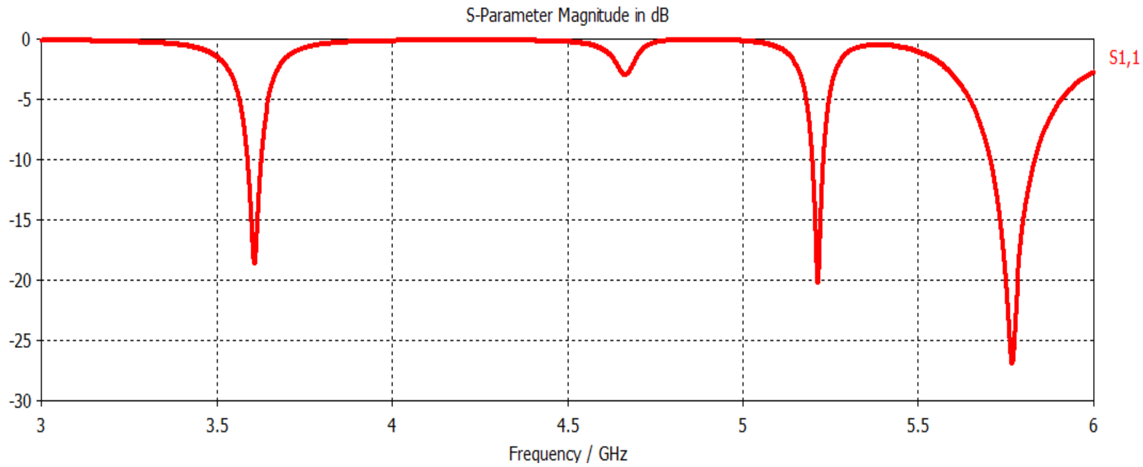


Fig 4.11 Return Loss S_{11} (in dB) of Triple band antenna

4.2.2.2 Smith Chart:

The smith chart shown in figure 4.11 represents that how the antenna impedance varies with frequency and gives impedance of 50.73 ohm. 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 the center of the smith chart. It can be seen from the figure 4.5 that the circle cuts the resistive part at 0.50, thus matching at 50.73 ohm.

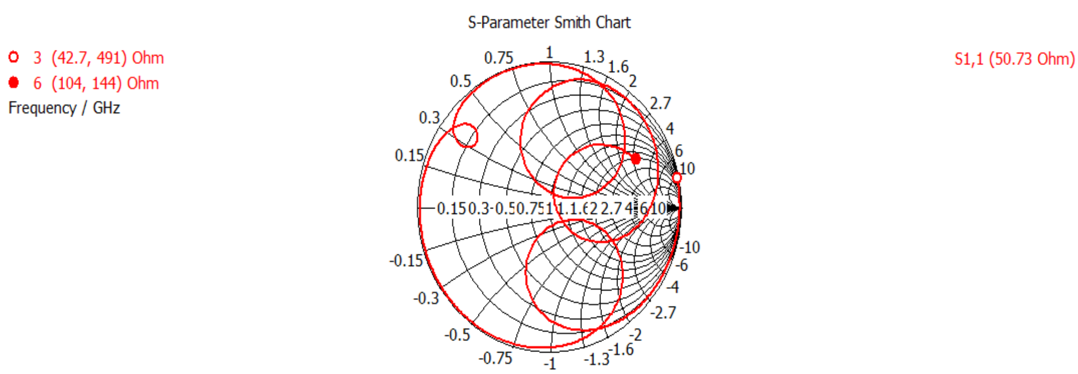


Fig 4.12 Smith Chart for triple band antenna

4.2.2.3 Directivity

The directivity plot shown in Fig 4.12 represents the amount of radiation intensity of the antenna. The proposed antenna provides 6.103 dBi, 6.371 dBi, and 3.77 dBi directivity at 3.6 GHz, 5.2 GHz, and 5.8 GHz frequency respectively. The simulated antenna radiates more in particular direction as compared to the isotropic antenna which radiates equally in all directions, by an amount of 6.103dBi, 6.371 dBi, and 3.77 dBi.

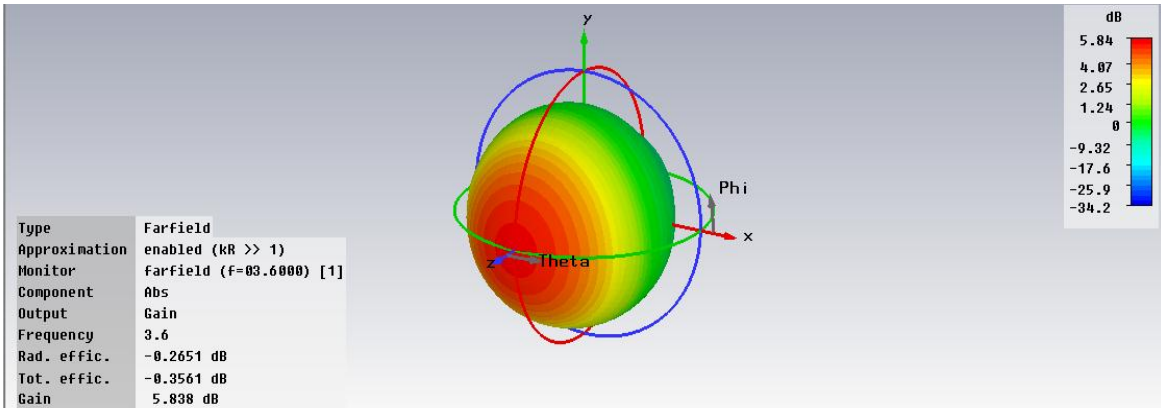


Fig 4.13 (a) Directivity (3D view) at 3.6 GHz

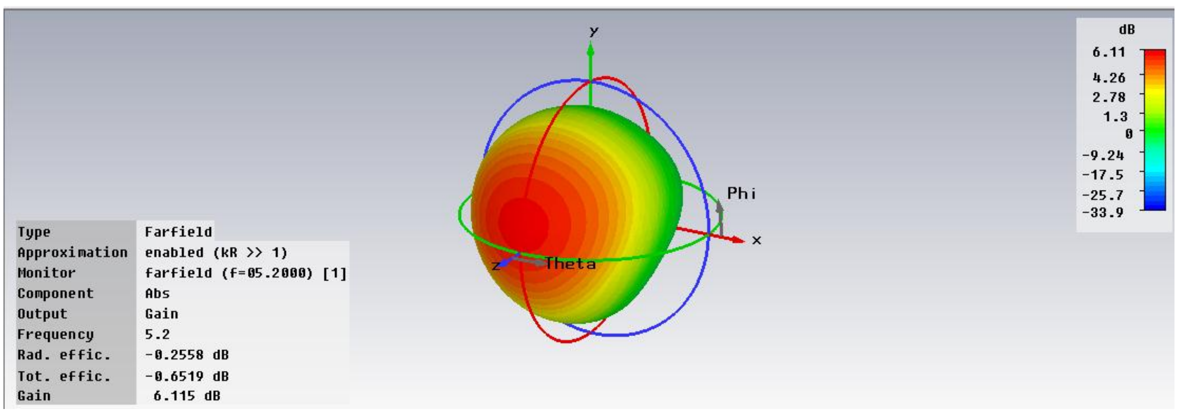


Fig 4.13(b) Directivity (3D view) at 5.2 GHz

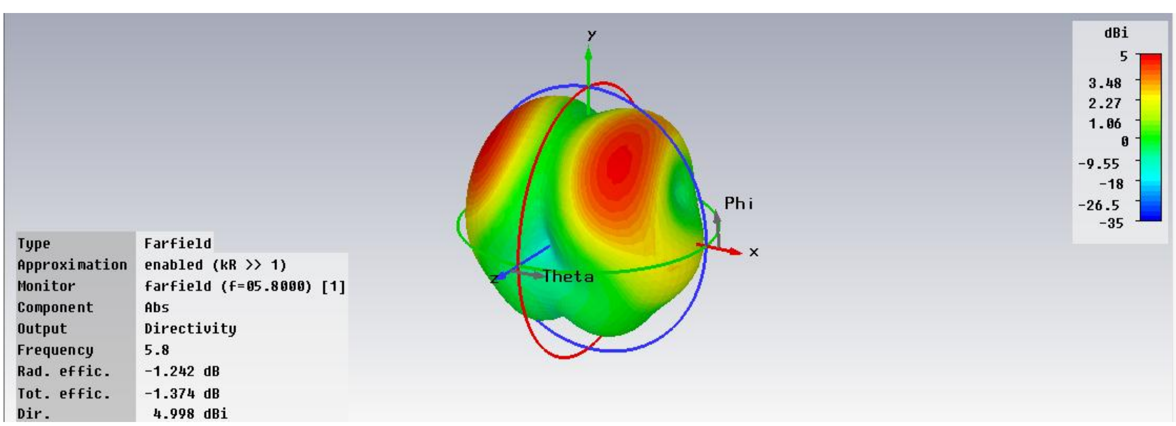


Fig 4.13 (c) Directivity (3D view) at 5.8 GHz

4.2.2.4 Gain

The gain of a particular antenna in a particular direction is more as compared to isotropic antenna radiating in all directions which is very useful for WLAN applications providing a better performance. The proposed antenna provides the gain of 5.838 dB, 6.115 dB and 3.775 dB at 3.6 GHz, 5.2 GHz and 5.8 GHz frequency as shown in figure 4.13

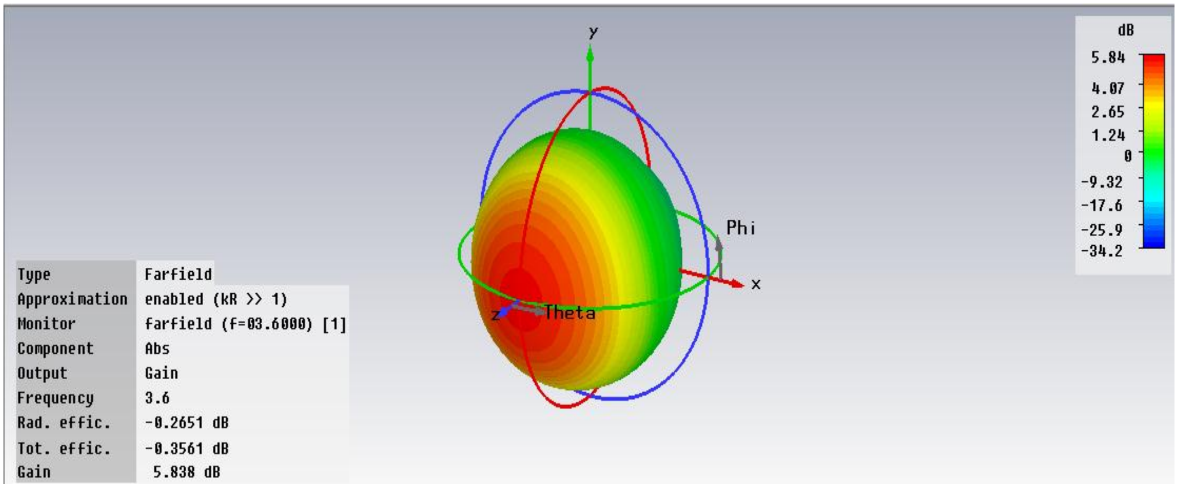


Fig 4.14 (a) Gain (3D view) at 3.6 GHz

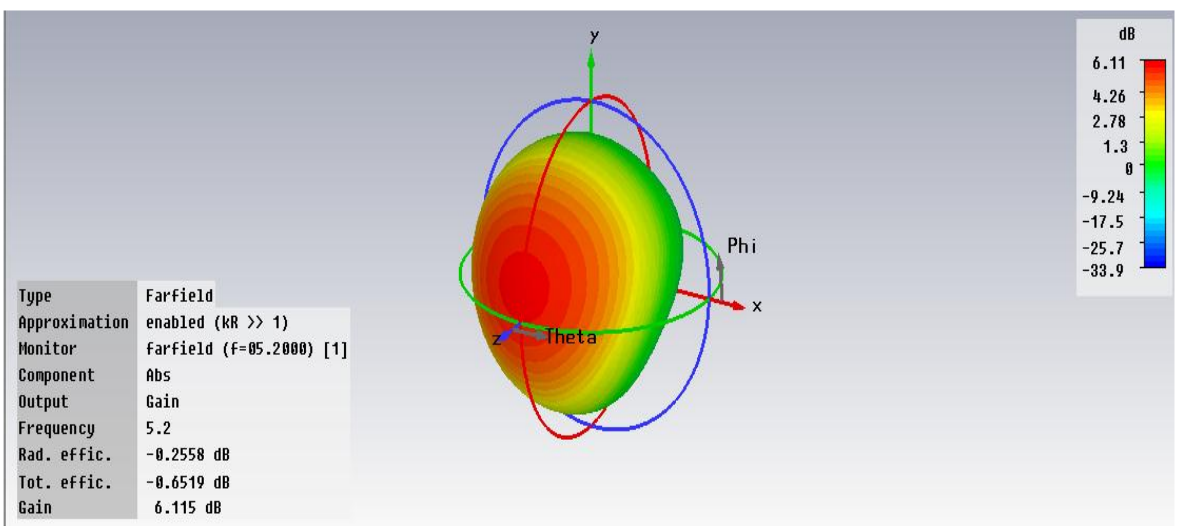


Fig 4.14 (b) Gain (3D view) at 5.2 GHz

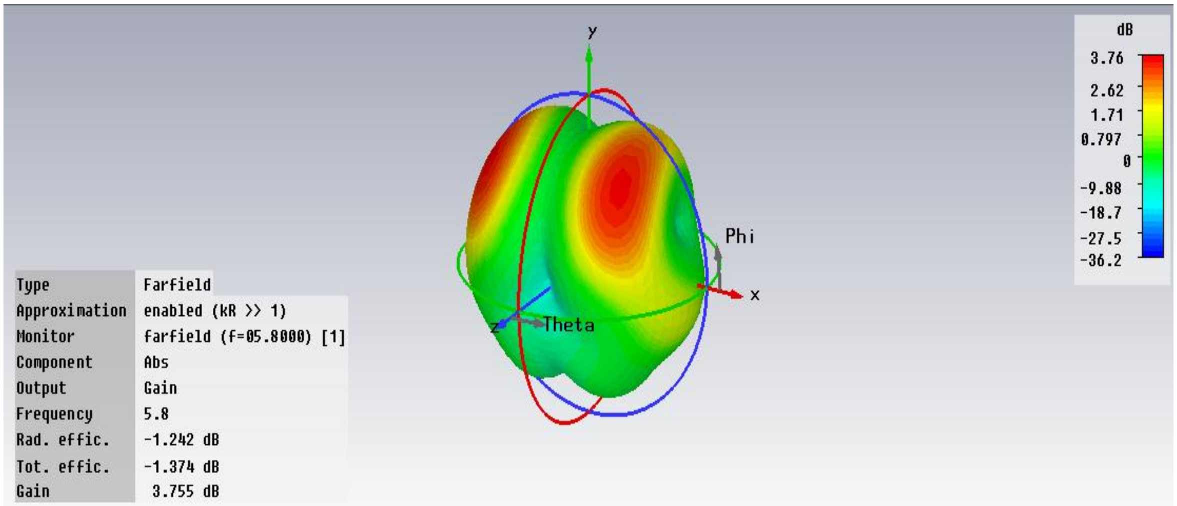


Fig 4.14 (c) Gain (3D view) at 5.8 GHz

Conclusion

In this chapter dual band and triple band U-slot antenna is designed. A single U- slot results in dual band antenna and inserting another U- slot in same patch results in triple band antenna. Both antennas provide satisfying values of gain and directivity.

CHAPTER 5

TRIPLE and MULTI BAND S- SHAPED SLOTTED PATCH ACMA FOR L- BAND APPLICATIONS

This chapter basically deals with two different antennas proposed using two different techniques. In one case, a simple aperture coupled antenna with S- shaped slotted patch is proposed to provide tri band aperture coupled microstrip antenna and in other case, a multiband antenna S- shaped microstrip antenna is proposed using stacking.

5.1 Design of Tri Band Asymmetrical S-Shaped Slotted Patch ACMA

A novel asymmetrical S- shaped slotted patch aperture coupled microstrip antenna is simulated. An S- shaped slot is cut at the center of a square patch radiator for triple band operation. A single microstrip feed line is underneath the center of the coupling aperture ground plane. The frequency ratio of the antenna can be controlled by adjusting the S- shaped slot arm length. [37]

This section describes the design of S- shaped slotted patch of Asymmetrical S- shaped slotted patch microstrip antenna satisfying the following specifications. The aperture size is $W_a \times L_a$ shown in Fig 5.1 and various parameters are tabulated in table 5.1.

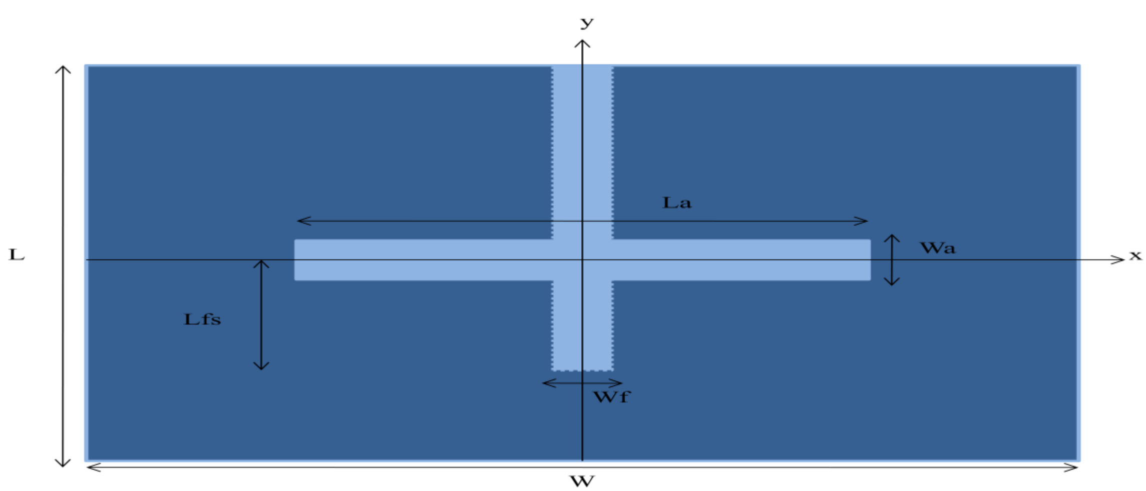


Fig 5.1 Aperture Coupled Feeding Structure of Triple Band Antenna

Parameter	L	W	L_a	W_a	W_f	L_{fs}
Unit (mm)	115	110	62.5	4.4	4	8

Table 5.1 Proposed Parameters of Aperture Coupled Feeding Structure

The 50 ohm microstrip feed line and the aperture are etched on the opposite sides of an RO4003 substrate with height (h_1) is 1.524 mm and dielectric constant ($\in_{r1}$) is 3.35. The patch substrate is of foam material with dielectric constant ($\in_{r2}$) = 1.06. The open end of microstrip feed line extends from the center of the aperture. The dimensions of S –shaped slotted patch are tabulated in table 5.2 and designed structure on CST Microwave Studio is shown in Fig 5.3

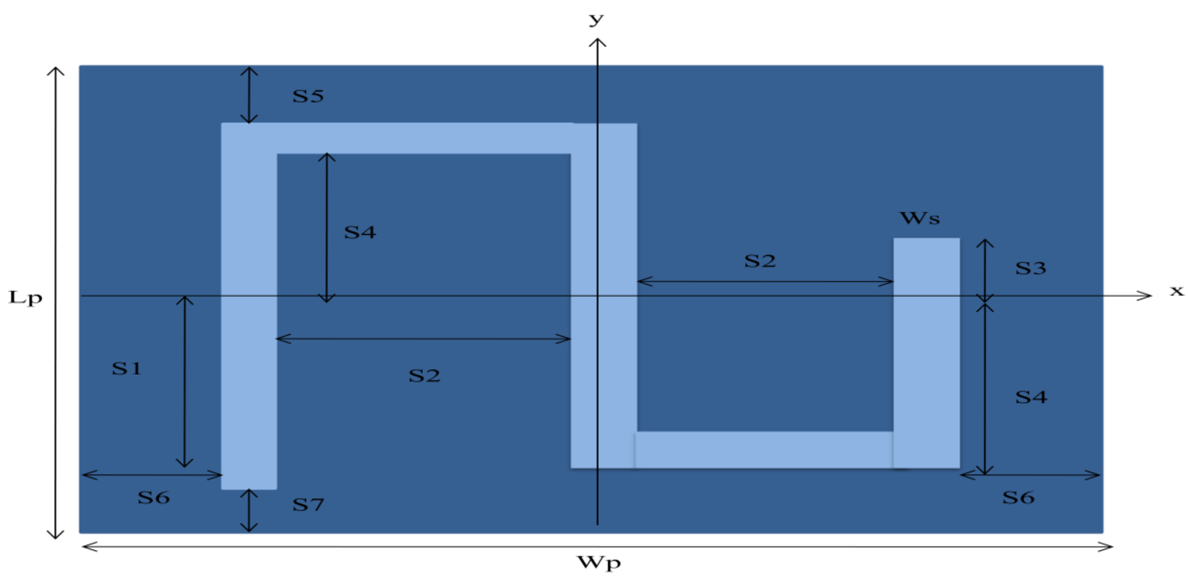


Fig 5.2 Geometry of S- shaped slotted patch

Parameter	L	W	L_p	W_p	S_1	S_2	S_3	S_4	S_5	S_6	S_7
Unit (mm)	115	110	88	80	21	25.5	10.0	20.0	17.75	10.0	23.0

Table 5.2 Proposed Parameters of S- shaped Slotted Patch

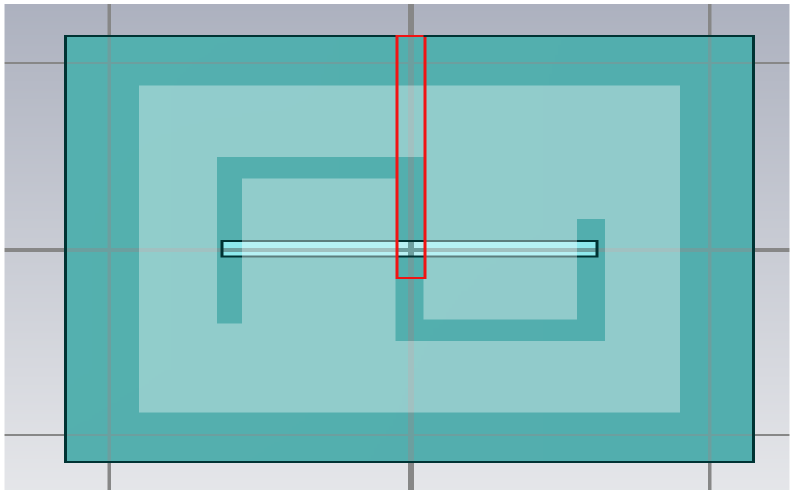


Fig 5.3 Designed Structure on CST Microwave Studio

5.1.1 Simulation Setup and Results of Triple Band Antenna

The software used to model and simulate the microstrip patch antenna CST Microwave Studio 2010. The simulated results of the proposed antenna are presented in the figures below:

5.1.1.1 Return Loss and Antenna Bandwidth

Figure 5.4 shows the S_{11} parameters (return loss) for proposed antenna. The graph shows the broadband covering two resonant frequencies (1.17 GHz and 1.227 GHz) and another band resonates at 1.48 GHz frequency. The measured -10 dB bandwidth of the broadband is 16.33 % (1.1047 - 1.2953 GHz) and for upper band it is 9.22 % (1.3931 – 1.5279)

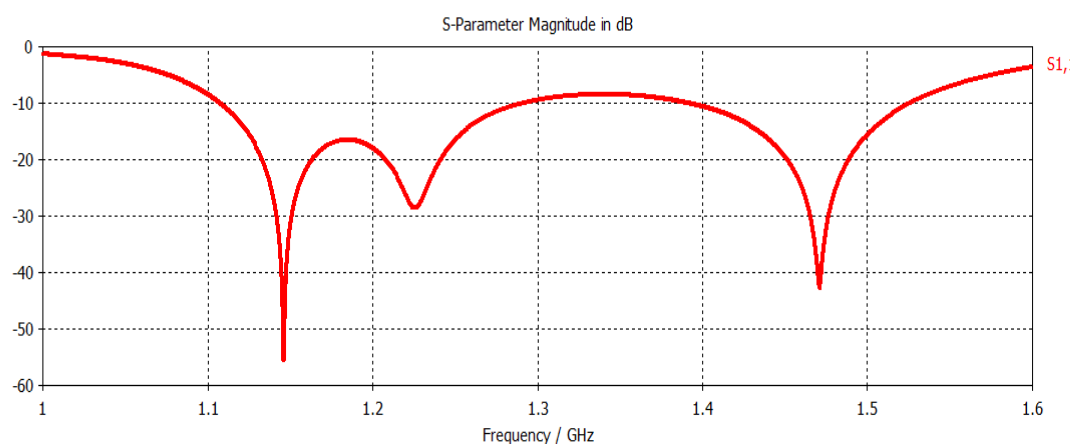


Fig 5.4 Return Loss S_{11} (in dB) of Triple band antenna

The proposed triple band antenna resonates at 1.17 GHz, 1.227 GHz and 1.48 GHz. The frequencies 1.17 GHz (L5) and 1.227 GHz (L2) are required for differential GPS system in order to provide maximum position accuracy. The antenna also resonates at 1.48 (LQ) GHz frequency used for satellite broadcast.

5.1.1.2 Smith Chart:

The smith chart shown in Fig 5.5 represents that how the antenna impedance varies with frequency and gives impedance of 52.31 ohm. Multiple circles describes that the proposed antenna is a triple band antenna.

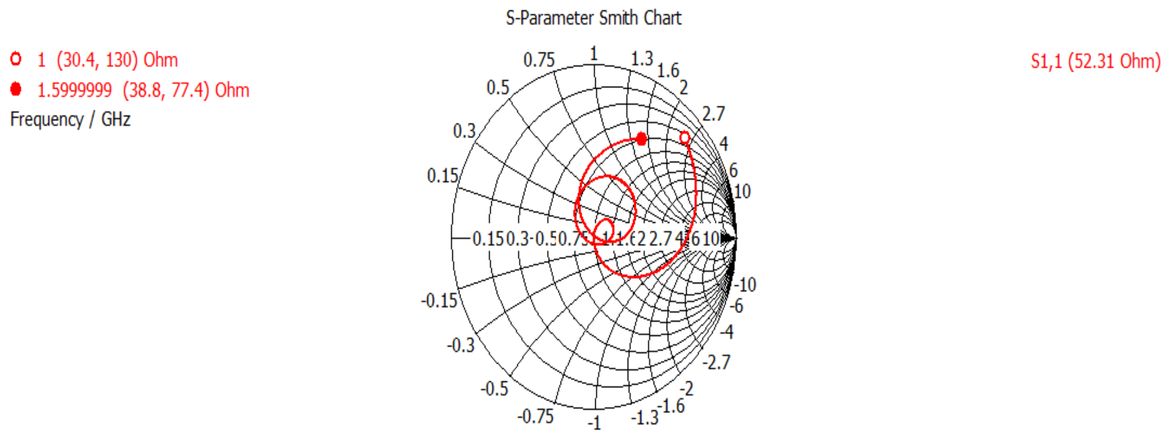


Fig 5.5 Smith Chart for triple band antenna

5.1.1.3 Directivity:

The directivity plot shown in Fig 5.6 represents the amount of radiation intensity of the antenna and shows the considerable high directivity values at different resonant frequencies. The proposed antenna provides 7.037 dBi, 7.403 dBi and 8.368 dBi directivity at 1.17 GHz, 1.227 GHz and 1.48 GHz frequency respectively. The simulated antenna radiates more in particular direction at different resonant frequencies as compared to the isotropic antenna which radiates equally in all directions, by an amount of 7.037 dBi, 7.403 dBi and 8.368 dBi.

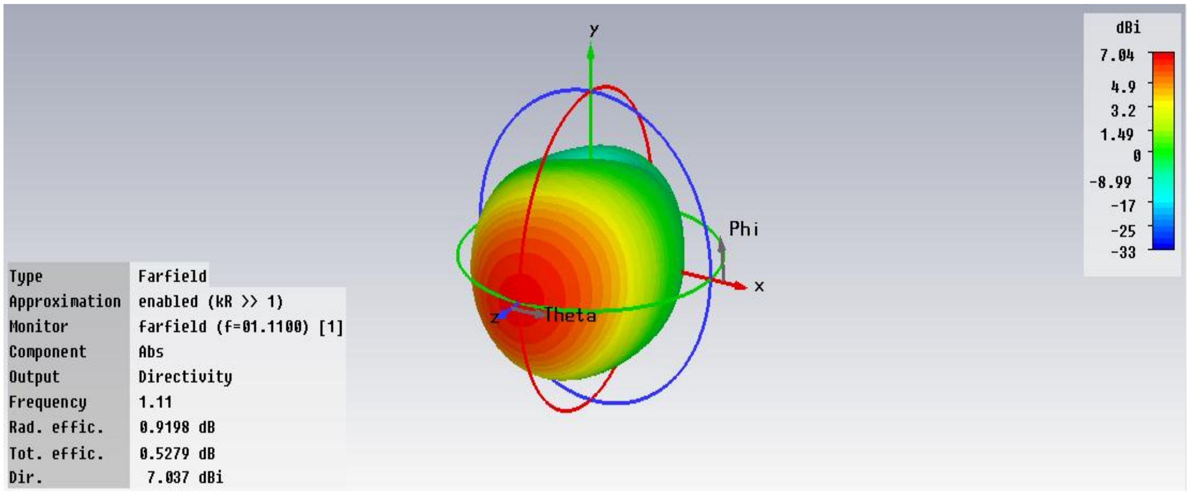


Fig 5.6 (a) Directivity (3D view) at 1.17 GHz

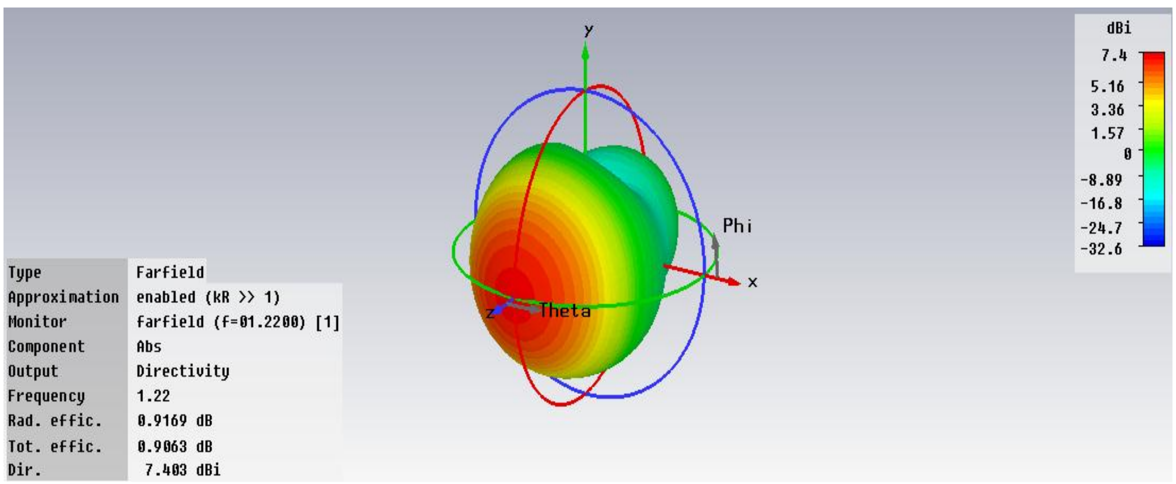


Fig 5.6 (b) Directivity (3D view) at 1.227 GHz

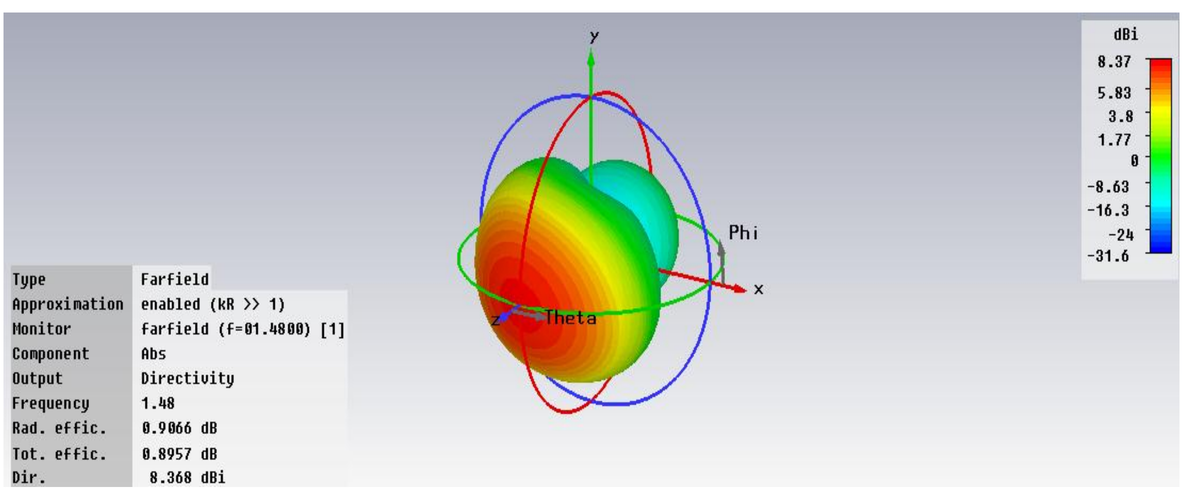


Fig 5.6 (c) Directivity (3D view) at 1.48 GHz

5.1.1.4 Gain:

The gain of a particular antenna in a particular direction is more as compared to isotropic antenna radiating in all directions which is very useful for WLAN applications providing a better performance. The proposed antenna provides the gain of 8.505 dB, 8.32 dB and 9.724 dB at 1.17 GHz, 1.227 GHz and 1.48 GHz frequency respectively as shown in figure 5.7.

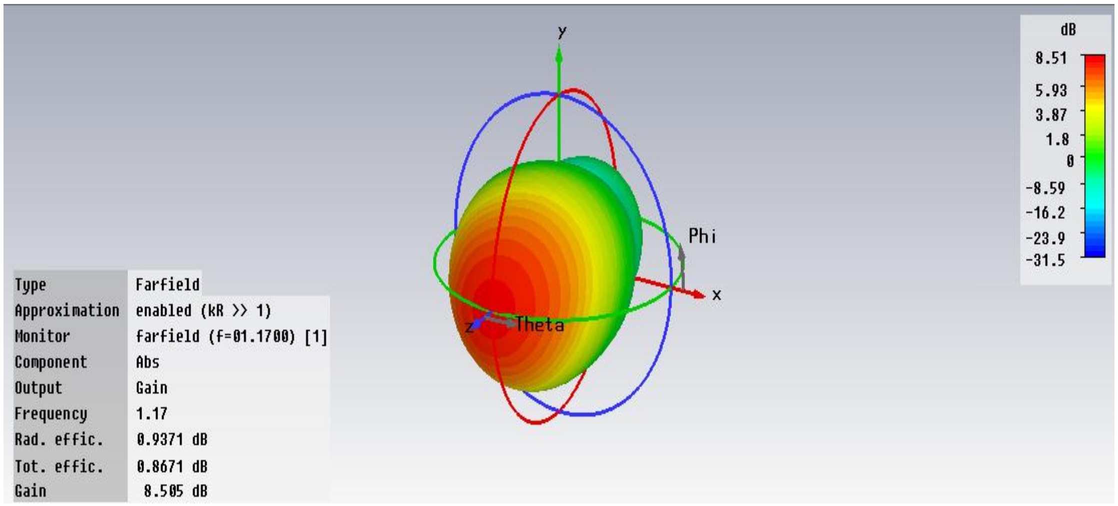


Fig 5.7 (a) Gain (3D view) at 1.17 GHz

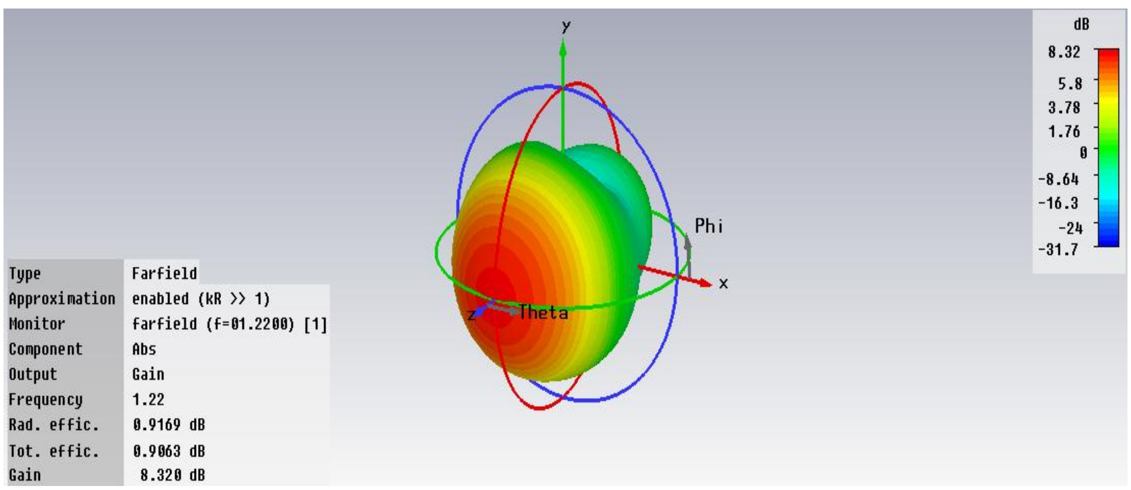


Fig 5.7 (b) Gain (3D view) at 1.227 GHz

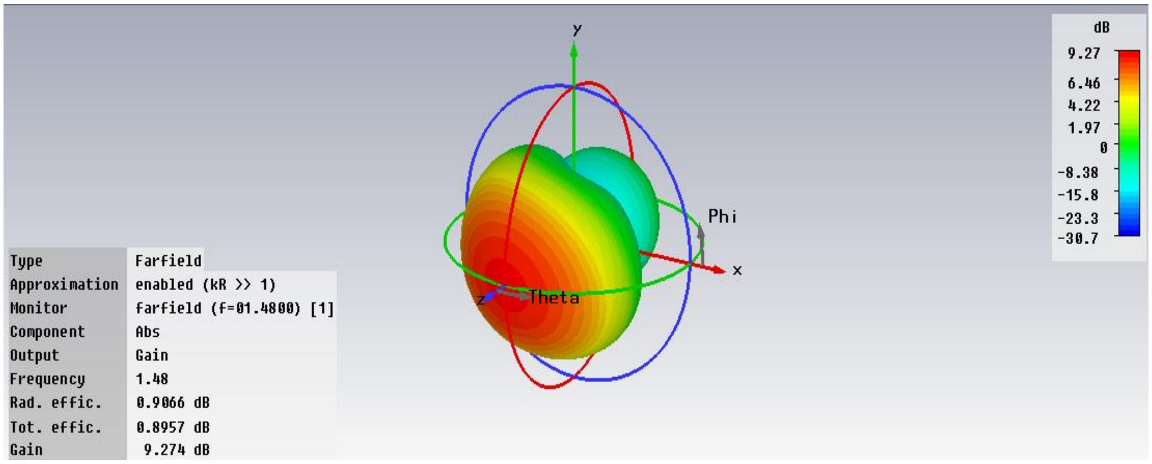


Fig 5.7 (c) Gain (3D view) at 1.48 GHz

5.1.1.5 Effect of varying slot length (S_1) on antenna performance Figure 5.8 shows the effect of variation of slot length (S_1) on the antenna performance. As we increase the slot length (S_1) from 18 mm to 25 mm, the return loss increases till 20 mm and then start decreasing, as we varies the length (S_1) from 22 mm to 25 mm. Slot length (S_1) also effects the -10dB bandwidth of frequency band at 1.48 GHz. As we vary stub length from 18 mm to 20 mm, bandwidth increases but after 20 mm, bandwidth starts decreasing. So slot length (S_1) largely effects the return loss and bandwidth of antenna. Hence, slot length (S_1) of 20 is chosen for proposed antenna as it provides the maximum return loss and bandwidth for the antenna.

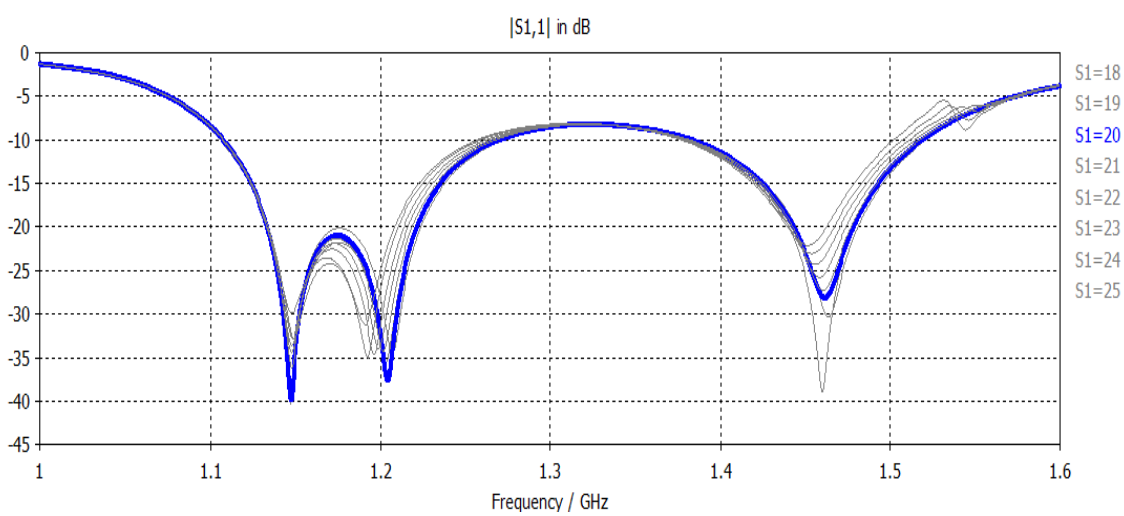


Fig 5.8 Effect of varying slot length (S_1)

5.1.1.6 Effect of varying slot length (S_3) on antenna performance

Figure 5.9 shows the effect of variation of slot length (S_3) on the antenna performance. For first wideband, increasing the slot length (S_3) from 8mm to 24 mm, will increase the return loss till 20 mm and then start decreasing it as length goes from 21 mm to 24 mm, but bandwidth continuously decreases as we vary the length (S_3) from 8 mm to 24 mm. Slot length (S_3) also effects the -10dB bandwidth and return loss of frequency band at 1.48 GHz. As we vary stub length from 8 mm to 24 mm, both bandwidth and return loss increases till 20 mm but after 20 mm, bandwidth starts decreasing. So slot length (S_3) also largely effects the return loss and bandwidth of antenna.

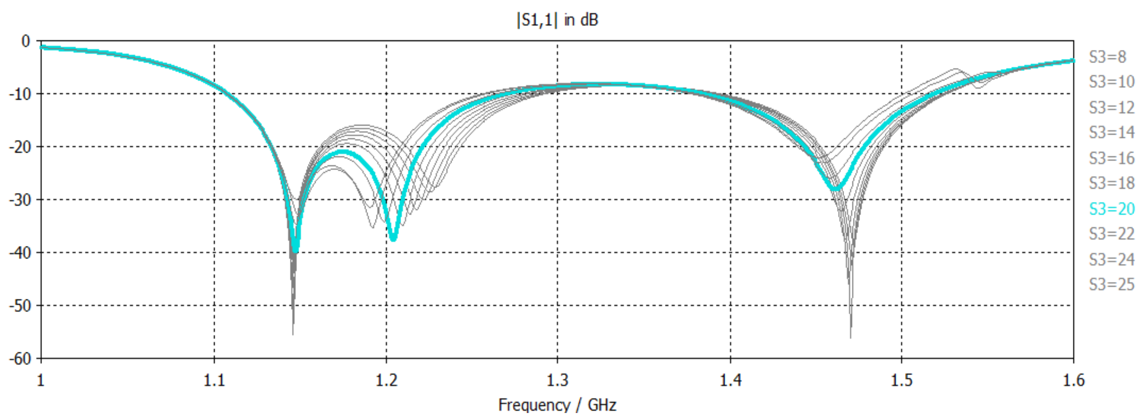


Fig 5.9 Effect of varying slot length (S_3)

5.2 Stacked Multiband S- Shaped Slotted Patch ACMA for L-Band Applications

Increasing impedance and gain bandwidth and decreasing dimensions of microstrip antenna as 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 bandwidth and gain bandwidth.

Here, a stacked multiband microstrip patch antenna fed through an aperture coupled 50Ω microstrip line is designed for L- band applications. An S- shaped slot in upper patch and a rectangular- slot in lower patch is cut at the centre for multi band operation. The patch antenna has been designed and simulated in CST Microwave Studio. The antenna covers the

L1 (1.575 GHz), L2 (1.227 GHz) and L5 (1.176 GHz) frequencies, which are required for differential GPS system in order to provide maximum position accuracy. The antenna also covers LQ (1.48 GHz) frequency for satellite broadcast.

5.2.1 Design of Stacked Multiband S- Shaped Slotted Patch ACMA

The basic stacked aperture coupled microstrip antenna is shown in Fig 5.10.The patch is fed through an aperture coupled 50Ω microstrip line under the feed substrate. Stub length (L_{fs}), the extension of feed line after the aperture is used to tune the excess reactance.

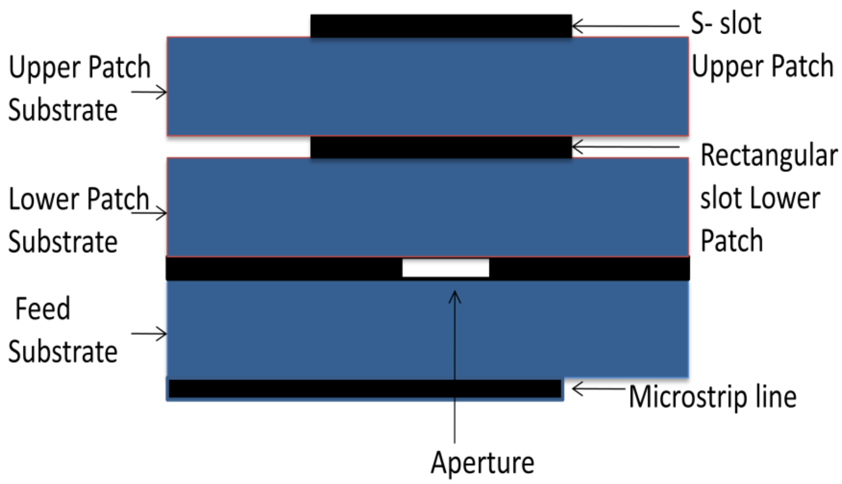


Fig 5.10 Geometry of Stacked Multiband ACMA

The patch antenna intended to operate at centre resonant frequency having length (Lu) and width (Wu) for upper patch having length (L_l) and width(W_l) for lower patch is formed on the dielectric substrate above the ground plane. The RO4003 substrate with dielectric constant ($\in_r$) = 3.38 and tan δ = 0.0027 is used for both upper patch and lower patch substrates. Thickness of lower patch substrate (h1) and upper patch substrate (h2) is 19mm and 16mm respectively. Foam material with dielectric constant($\in_r$) = 1.06 and thickness of 1.5 mm is used for feed substrate. The geometry of S-shaped and rectangular slot is shown in Fig 5.11 and 5.12 and proposed parameters of stacked multiband aperture coupled microstrip antenna are tabulated in table 5.3

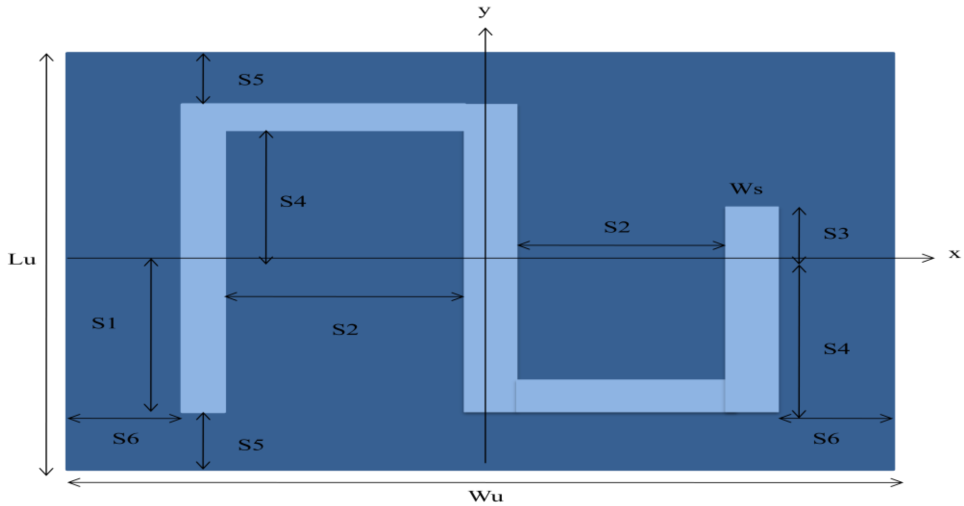


Fig 5.11 Geometry of S- Shaped Slotted Upper Patch

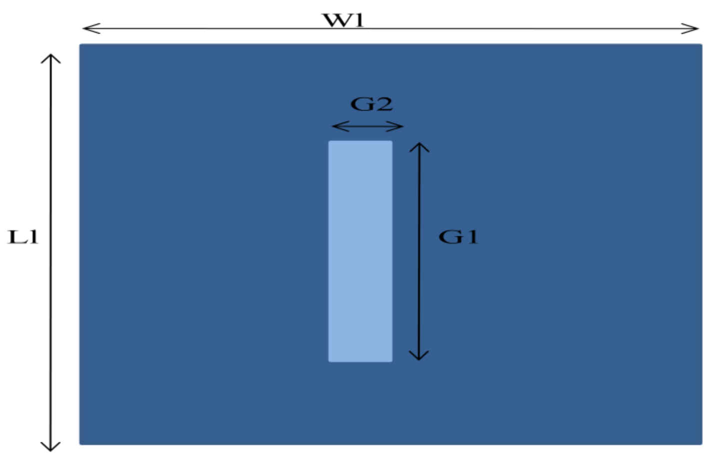


Fig 5.12 Geometry of Rectangular Shaped Slotted Lower Patch

Parameter	Lu	Wu	S1	S2	S3	S4	S5	S6	Ll	Wl	G1	G2
Unit (mm)	88	80	23.0	25.5	13.5	20.0	17.75	10.0	76	72	40	12

Table 5.3 Proposed Parameters of Multiband ACMA

5.2.1 Simulation Setup and Results of Triple Band Antenna

The software used to model and simulate the microstrip patch antenna CST Microwave Studio 2010. The simulated results of the proposed antenna are presented in the figures below:

5.2.1.1 Return Loss and Antenna Bandwidth

Figure 5.4 shows the S_{11} parameters (return loss) for proposed antenna. The graph shows the three bands, first wideband covering two resonant frequencies i.e. 1.175 (L5) GHz and 1.227 (L2) GHz, third band resonating at 1.48 GHz (LQ) and the fourth band resonating at 1.575 (L1) GHz. The measured -10 dB bandwidth of the wideband is 23.88 % (1.1631 - 1.3514 GHz). Third and fourth band provide 8 MHz and 13 MHz bandwidth.

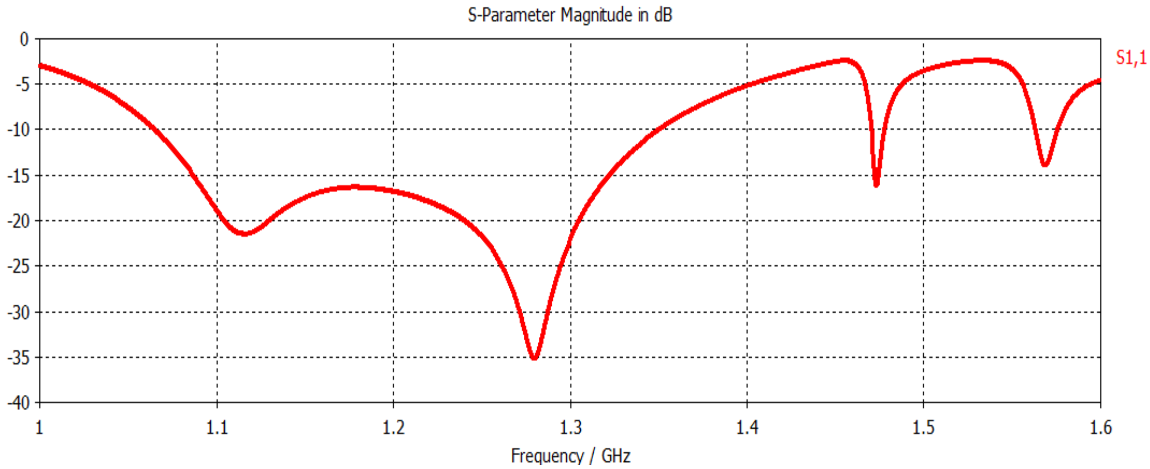


Fig 5.13 Return Loss S_{11} (in dB) of Multiband antenna

5.2.1.2 Smith Chart

The smith chart shown in Fig 5.12 represents that how the antenna impedance varies with frequency and gives impedance of 51.28 ohm. Multiple circles describes that the proposed antenna is a triple band antenna.

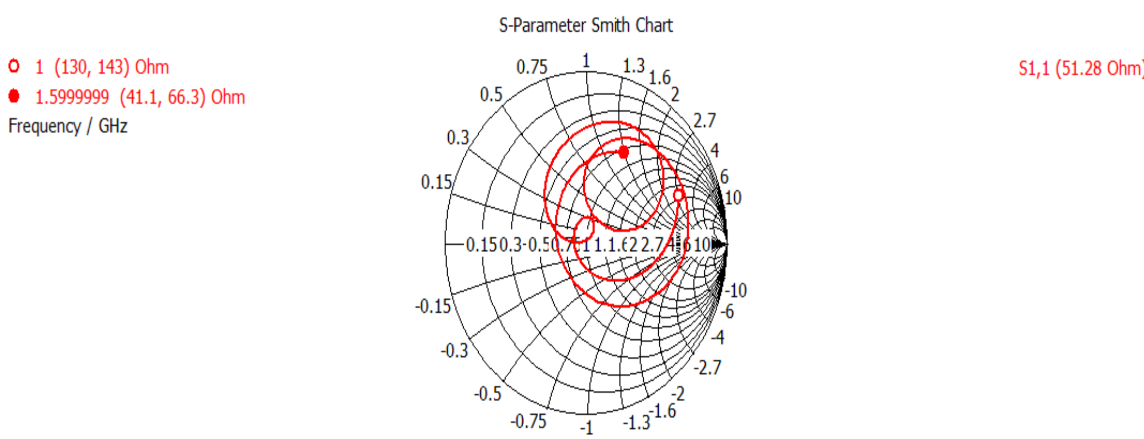


Fig 5.14 Smith Chart for multiband antenna

5.2.1.3 Directivity

The directivity plot shown in Fig 5.13 represents the amount of radiation intensity of the antenna shows the considerable high directivity values at different resonant frequencies. The proposed antenna provides 7.429 dBi, 7.453 dBi, 7.867 dBi and 7.218 dBi directivity at 1.17 GHz, 1.227 GHz, 1.48 GHz and 1.575 GHz frequency respectively. The simulated antenna radiates more in particular direction at different resonant frequencies as compared to the isotropic antenna which radiates equally in all directions, by an amount of 7.037 dBi, 7.403 dBi, 7.867 dBi and 7.218 dBi.

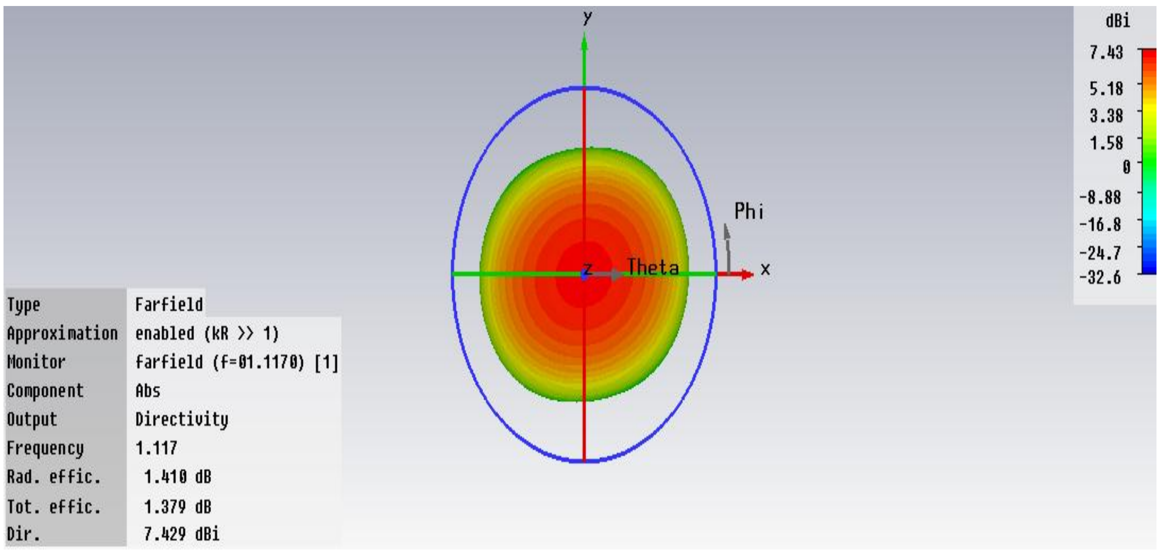


Fig 5.16 (a) Directivity (3D view) at 1.17 GHz

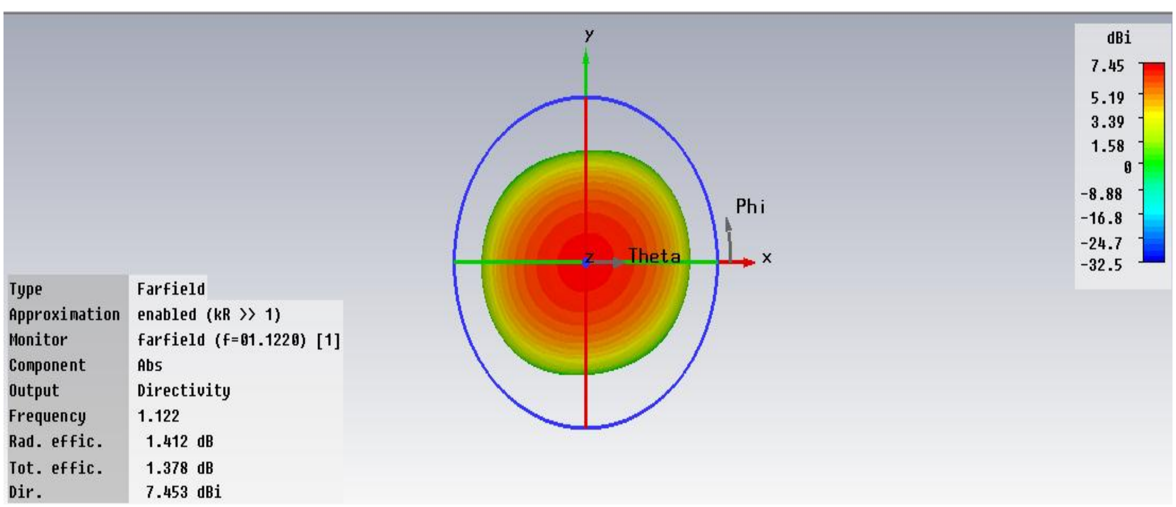


Fig 5.16 (b) Directivity (3D view) at 1.227 GHz

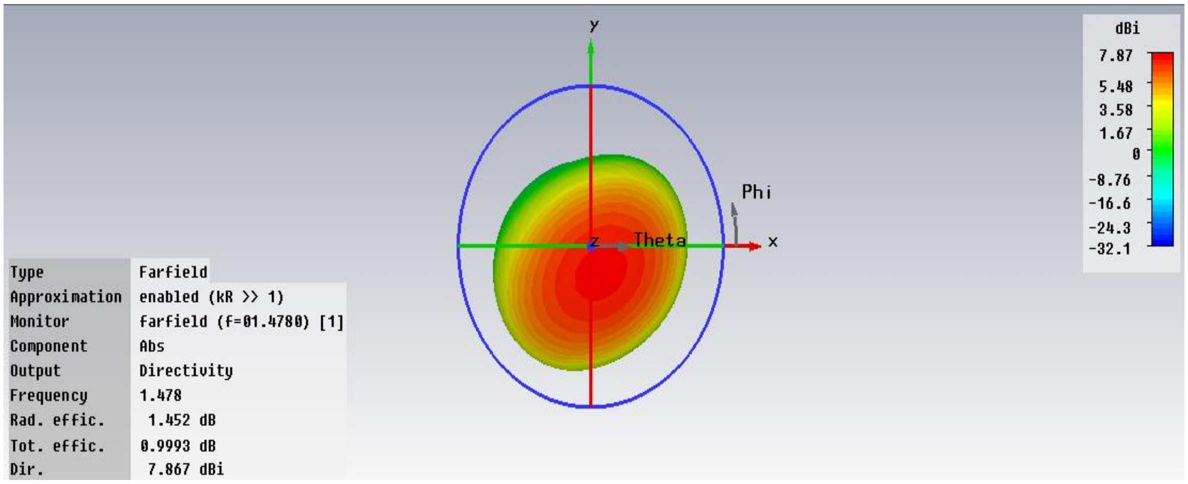


Fig 5.16 (c) Directivity (3D view) at 1.48 GHz

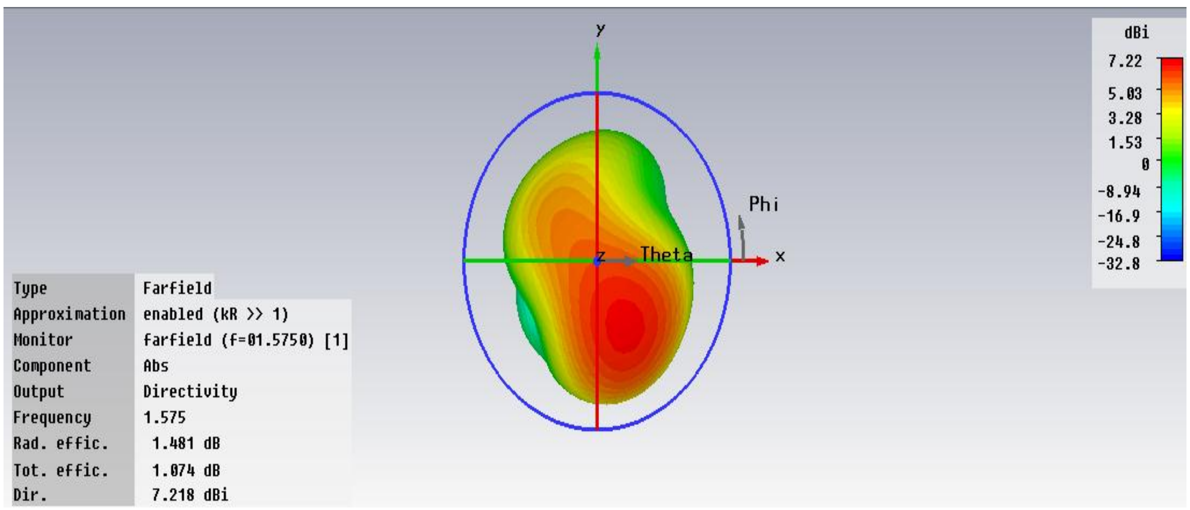


Fig 5.16 (d) Directivity (3D view) at 1.575 GHz

5.2.1.4 Gain

The gain of a particular antenna in a particular direction is more as compared to isotropic antenna radiating in all directions which is very useful for WLAN applications providing a better performance. The proposed antenna provides the gain of 8.838 dB, 9.136 dB, 9.296 dB and 8.699 dB at 1.17 GHz, 1.227 GHz, 1.48 GHz and 1.575 GHz frequency respectively as shown in Fig 5.14.

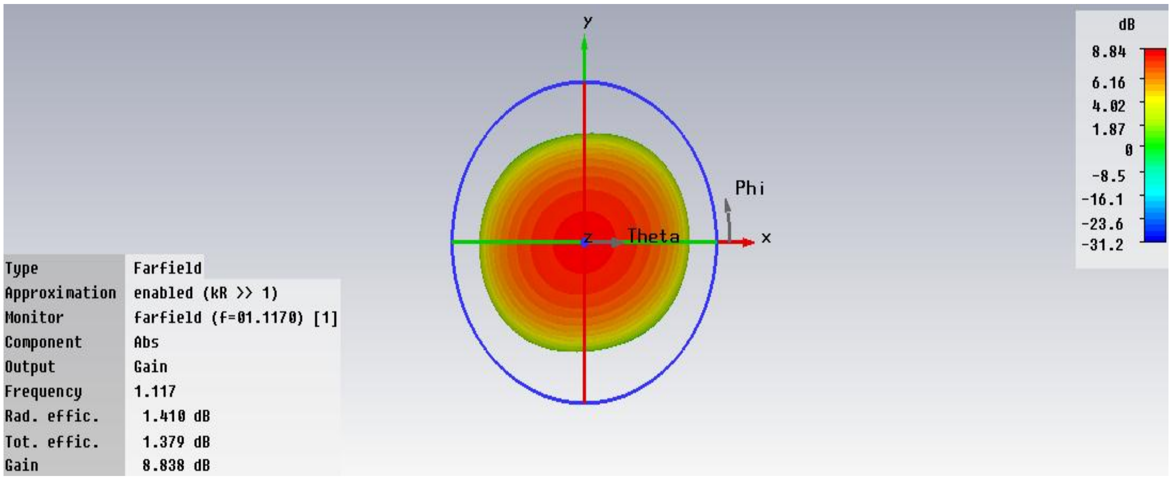


Fig 5.1 7 (a) Gain (3D view) at 1.17 GHz

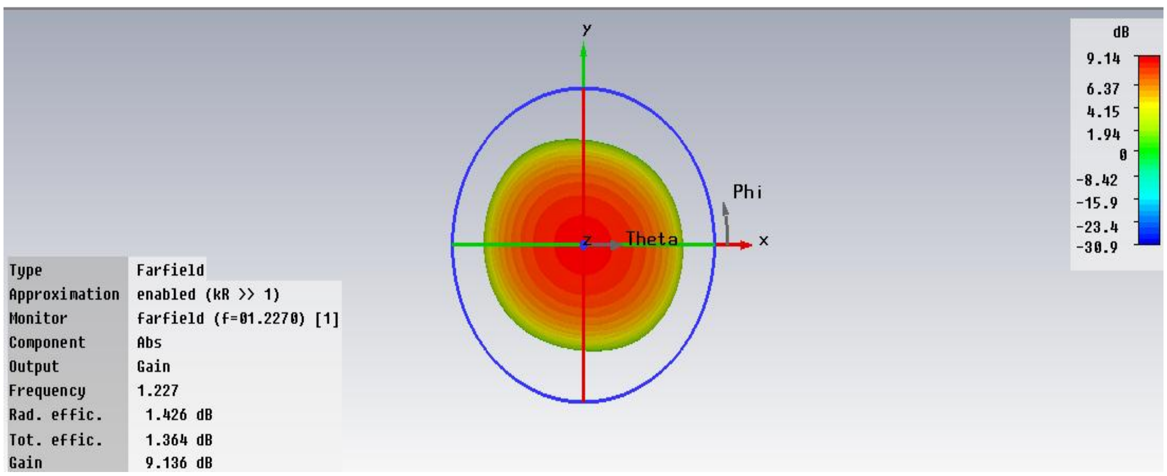


Fig 5.17 (b) Gain (3D view) at 1.227 GHz

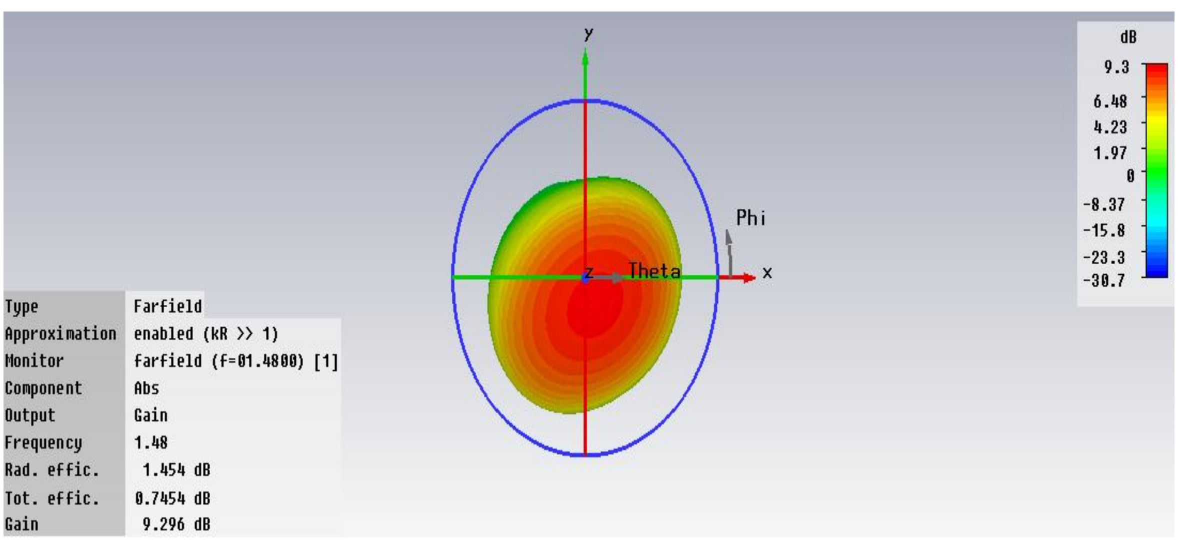


Fig 5.17 (c) Gain (3D view) at 1.48 GHz

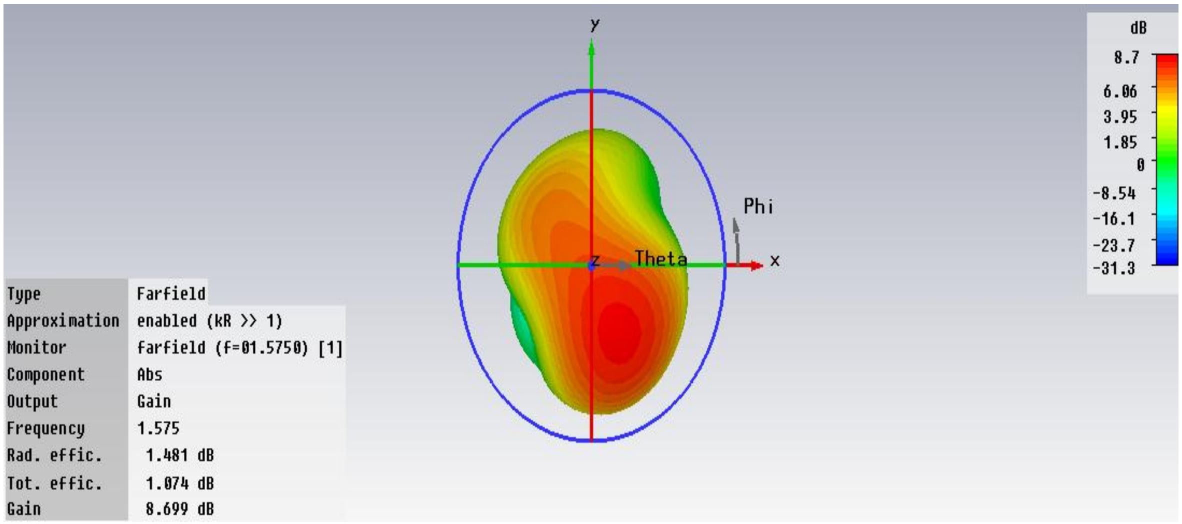


Fig 5.17 (d) Gain (3D view) at 1.575 GHz

Conclusion

In this chapter, dual band is designed by cutting S- slot in patch and triple band antenna is designed using stacking. Both antennas provide very high values of gain and directivity and also results in less frequency ratio.

CHAPTER 6

BROADBAND AND DUAL BAND E- SHAPED PATCH ACMA

This chapter basically deals with two antennas, one-broadband E- shaped patch antenna and other dual band E- shaped aperture coupled microstrip antenna. By making variation in geometry of E- shape patch and stub length both antennas are designed.

6.1 Broadband E- Shaped Patch ACMA for Bluetooth and WiMAX Applications

In this section an aperture coupled E- shaped patch is presented to provide broadband characteristics. 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. By choosing the geometry of E- shaped patch and stub length L_{sb} appropriately, one can design the antenna of desired performance.

The broadband antenna covers the frequency range from 2.40 GHz - 2.86 GHz and covers the various applications. The feed substrate and patch substrate are made up of dielectric substrate with dielectric constant (ε) = 2.2 and thickness of 6.7 mm. Fig 6.1 shows the geometry of wideband E- shaped microstrip antenna and the designed structure on CST is shown in Fig 6.2. The proposed parameters of antenna are tabulated in table 6.1.

As the antenna covers the frequency range from 2.40 GHz- 2.86 GHz, it can be used for Bluetooth (2.4 – 2.5 GHz) and WiMAX (2.50 GHz - 2.69 GHz) applications.

Parameters	L	W	Ws	SL 1	SL 2	D	H
Unit (mm)	42	28	5	14	6	16	6.7

Table 6.1 Proposed parameters of Broad band E- shaped patch ACMA

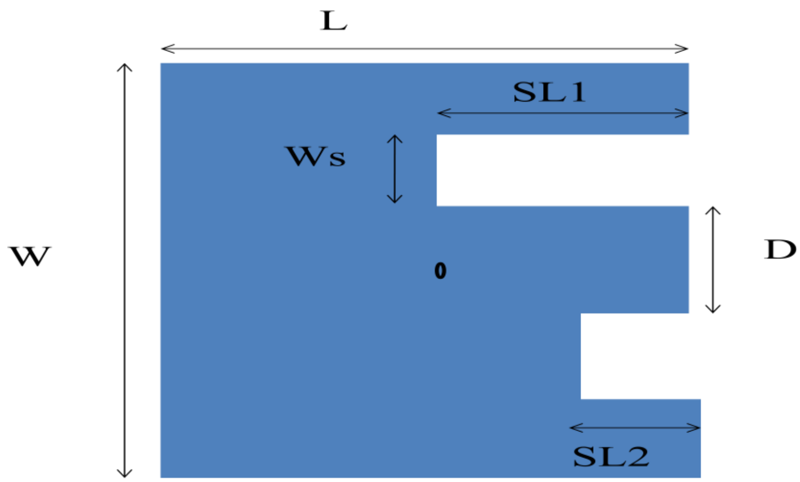


Fig 6.1 Geometry of E- shaped patch

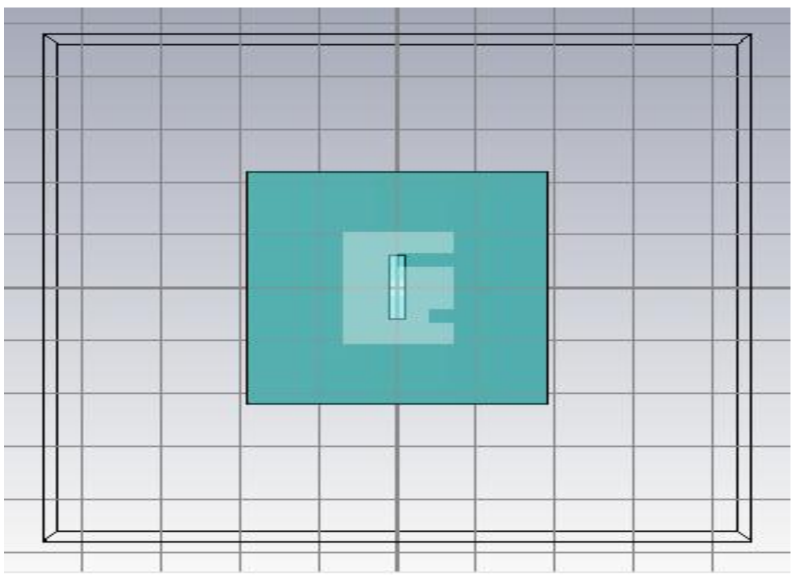


Fig 6.2 Designed structure on CST Microwave Studio

6.2 Simulation Setup and Results of Broadband E- Shaped Patch Antenna

The software used to model and simulate the microstrip antenna is CST Microwave Studio 2010. The simulated results of the proposed antenna are presented in the figures shown below:

6.2.1 Return Loss and Antenna Bandwidth:

Figure 6.3 shows the S_{11} parameters (return loss) for proposed antenna. It covers the frequency range from 2.40 GHz to 2.86 GHz and covers the various applications. The lower band resonates at 2.48 GHz with return loss of -26.38 dB and upper band resonance occurs at 2.78 GHz with return loss -24 dB. 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 can be calculated from return loss versus frequency response plot. The measured -10 dB bandwidth of the proposed antenna is 461 MHz.

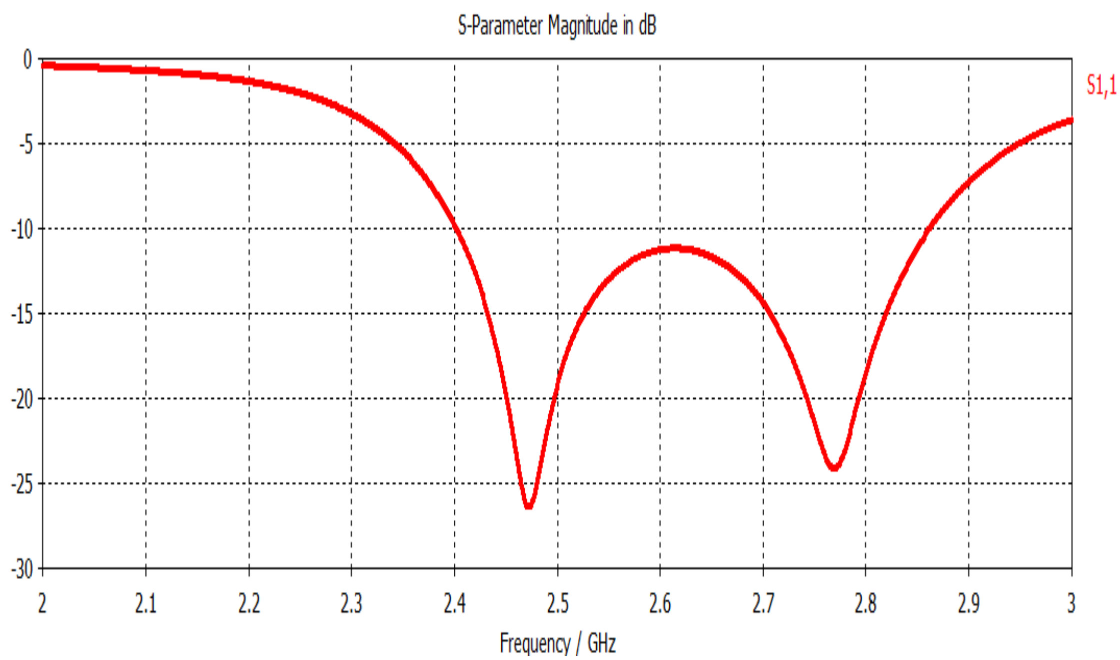


Fig 6.3 Return Loss S_{11} (in dB) of Broadband Antenna

6.2.2 Directivity

The directivity plot shown in figure 6.4 represents the amount of radiation intensity of the antenna. The proposed antenna provides 6.880 dBi and 6.586 dBi directivity at 2.48 GHz and 2.78 GHz frequency respectively. The simulated antenna radiates more in particular direction as compared to the isotropic antenna which radiates equally in all directions, by an amount of 6.880 dBi and 6.586 dBi.

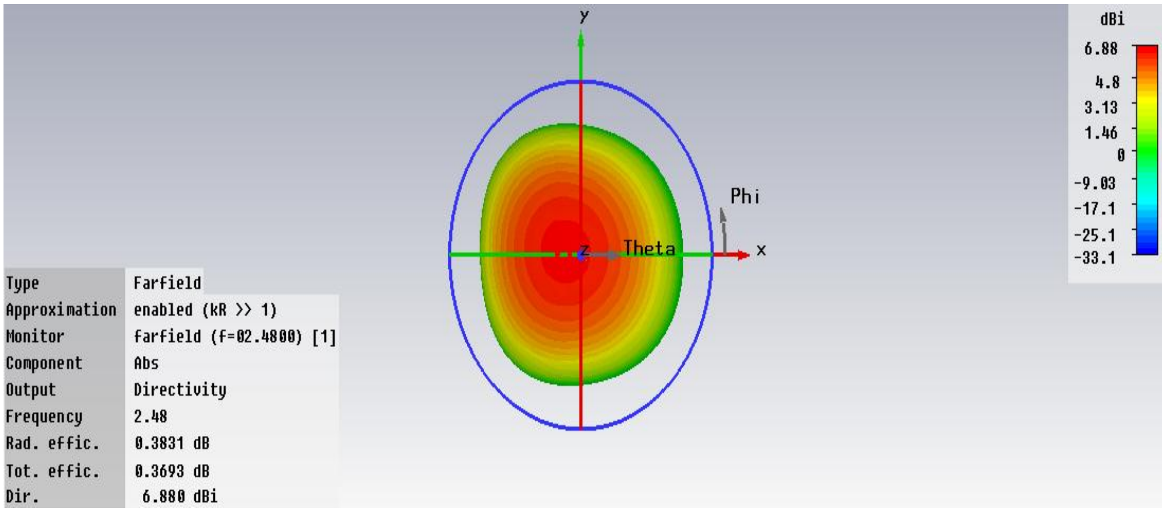


Fig 6.4 (a) Directivity (3D view) at 2.48 GHz

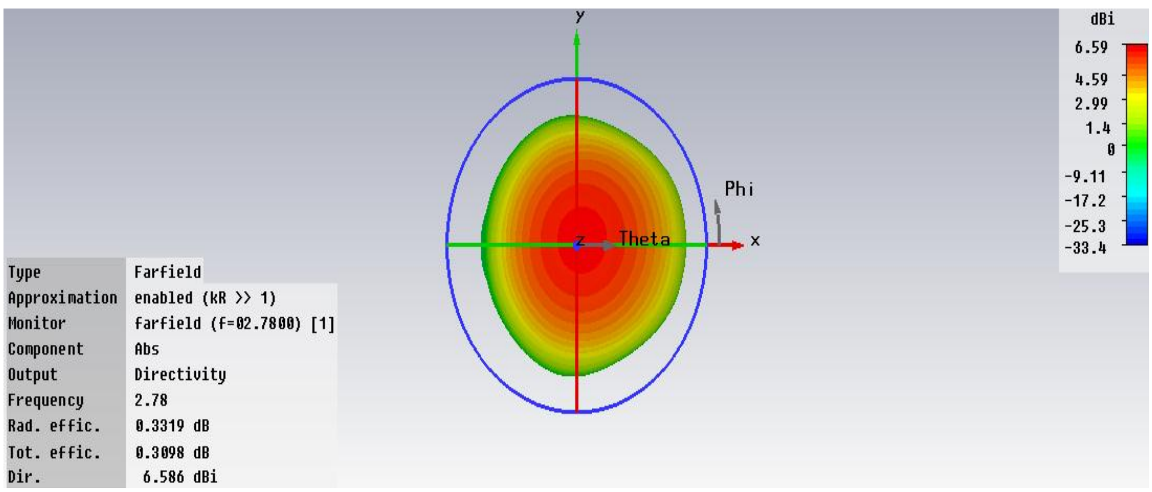


Fig 6.4 (b) Directivity (3D view) at 2.78 GHz

6.2.3 Gain

The gain of a particular antenna in a particular direction is more as compared to isotropic antenna radiating in all directions which is very useful for many applications providing a better performance. The proposed antenna provides the gain of 7.263 dB and 6.918 dB at 2.48 GHz and 2.78 GHz frequency as shown in Fig 6.5.

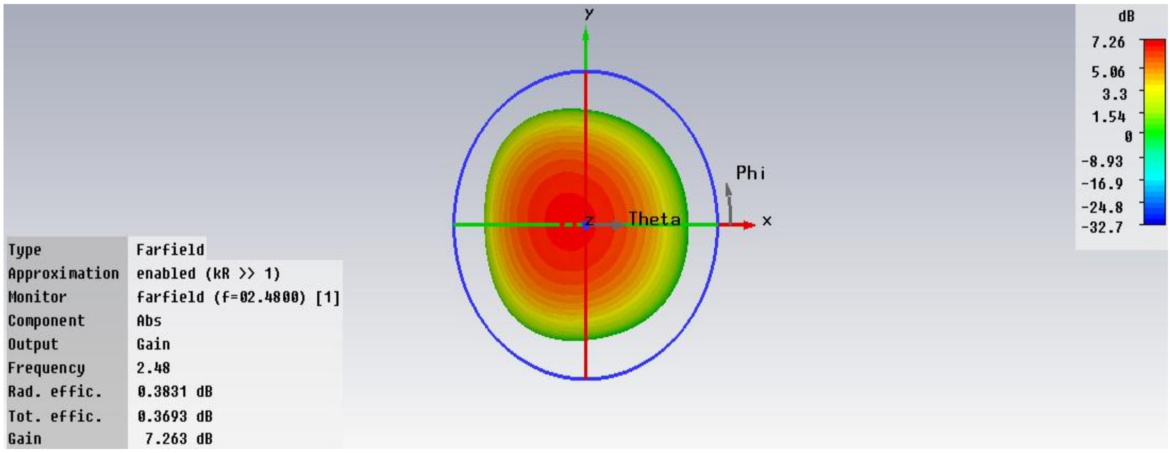


Fig 6.5 (a) Gain (3D view) at 2.48 GHz

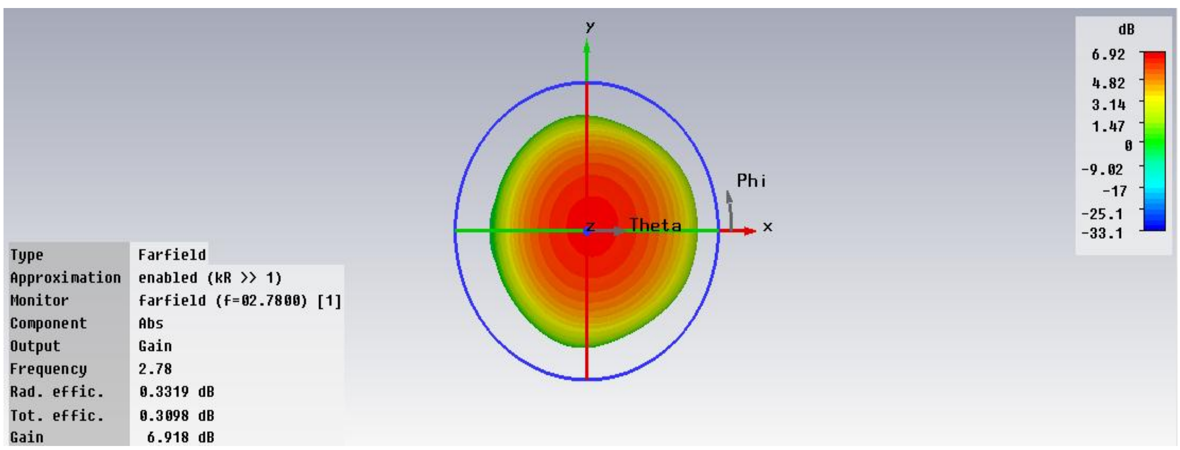


Fig 6.5 (b) Gain (3D view) at 2.78 GHz

6.3 Dual Band E- Shaped Patch ACMA

This section shows the dual band E- shaped patch aperture coupled microstrip antenna. By varying the slot lengths (SL1 AND SL2) cut in rectangular patch to make it E- shaped patch and stub length, dual band characteristics can be obtained.

The dual band antenna covers the frequency range from The upper band covers the frequency range from 2.47 GHz to 2.82 GHz and the lower band resonates at frequency 2.72 GHz with return loss -37.19 dB. The feed substrate and patch substrate are made up of dielectric substrate with dielectric constant (ε) = 2.2 and thickness of 6.7 mm. Figure 6.6 shows the geometry of wideband E- shaped microstrip antenna and the designed structure on CST is shown in Fig 6.7. The proposed parameters of antenna are tabulated in table 6.2.

Parameters	L	W	Ws	SL 1	SL 2	D	H
Unit (mm)	42	28	4	20.5	19	18	6.7

Table 6.2 Proposed parameters of Dual band E- shaped patch ACMA

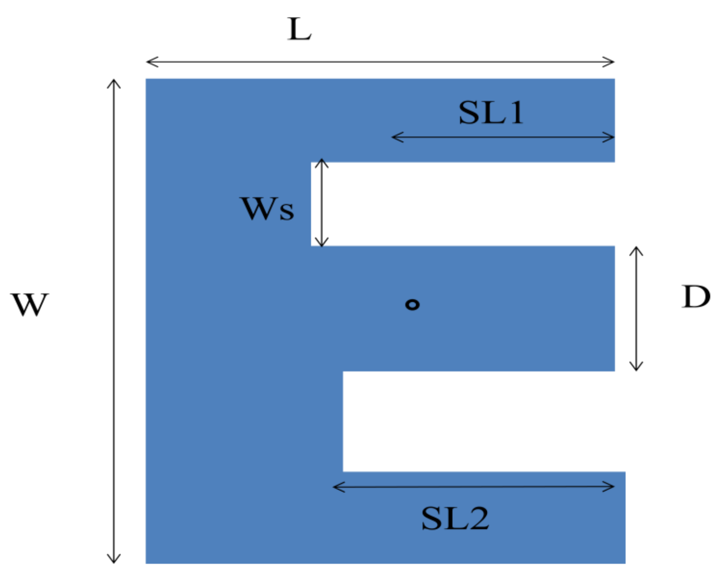


Fig 6.6 Geometry of E- shaped patch

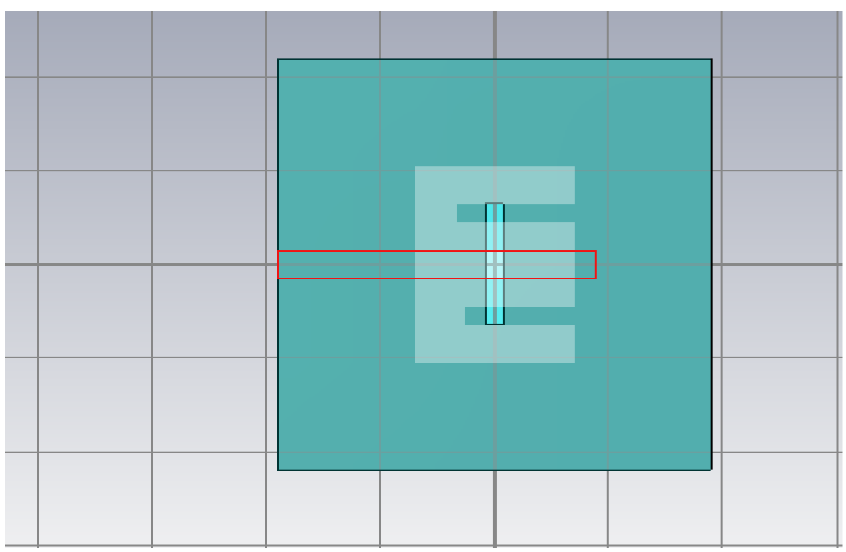


Fig 6.7 Designed structure on CST Microwave Studio

6.3.1 Return Loss and Antenna Bandwidth:

Figure 6.3 shows the S_{11} parameters (return loss) for proposed antenna. The upper band covers the frequency range from 2.47 GHz to 2.82 GHz and covers the various applications. It resonates at frequency 2.72 GHz with return loss -37.19 dB. The lower band resonates at 2.1 GHz with return loss of -21 dB and upper band resonance occurs at 2.72 GHz with return loss -24 dB. 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 can be calculated from return loss versus frequency response plot. The measured -10 dB bandwidth of the proposed antenna is 352 MHz and 24 MHz for upper band and lower band respectively.

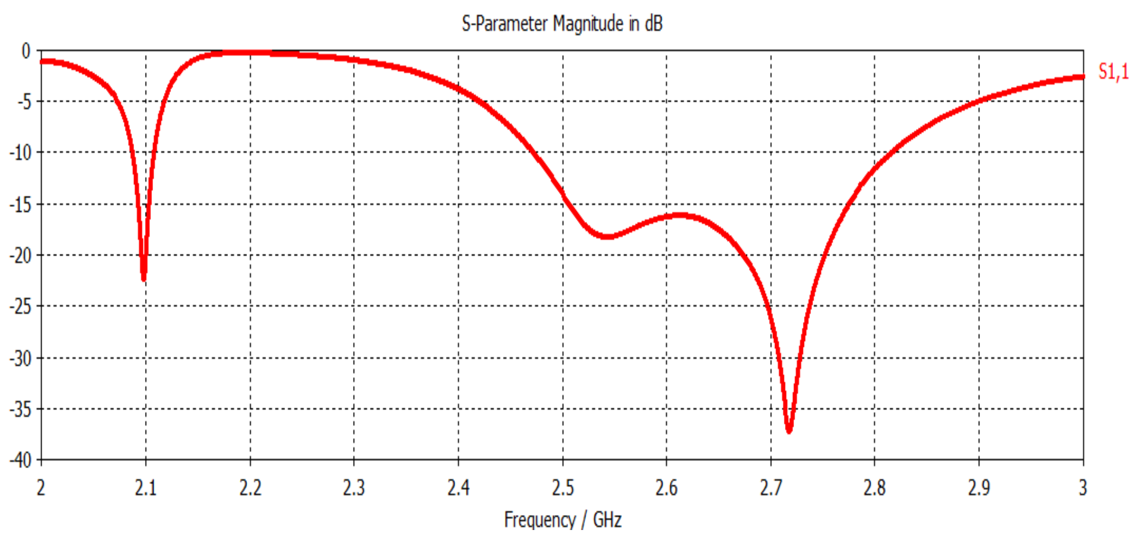


Fig 6.8 Return Loss S_{11} (in dB) of Dualband Antenna

6.3.2 Directivity

The directivity plot shown in Fig 6.4 represents the amount of radiation intensity of the antenna. The proposed antenna provides 6.169 dBi and 6.895 dBi directivity at 2.1 GHz and 2.72 GHz frequency respectively. The simulated antenna radiates more in particular direction as compared to the isotropic antenna which radiates equally in all directions, by an amount of 6.169 dBi and 6.895 dBi.

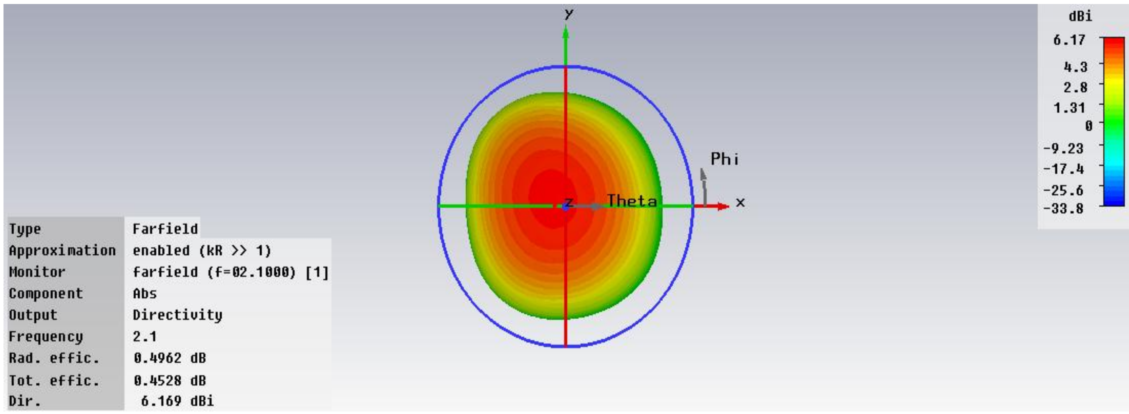


Fig 6.9 (a) Directivity (3D view) at 2.1 GHz

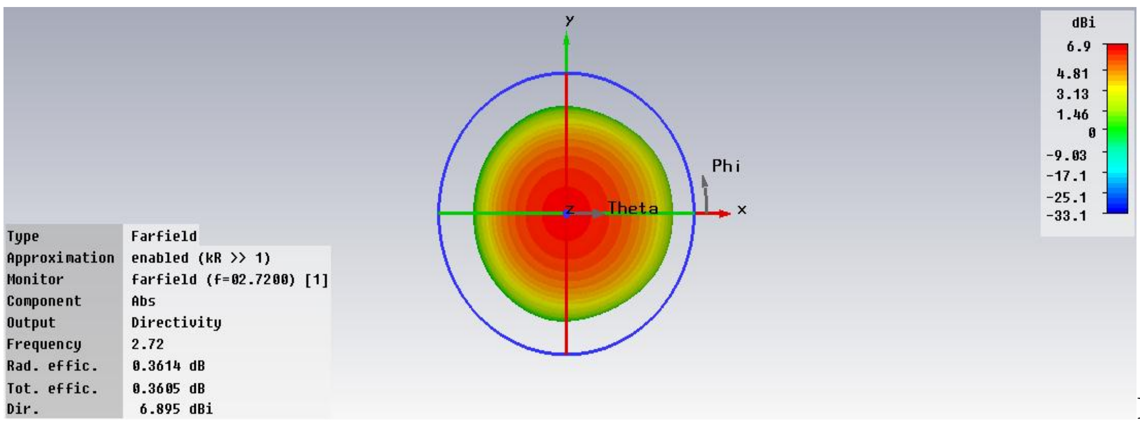


Fig 6.9 (b) Directivity (3D view) at 2.72 GHz

6.3.3 Gain

The gain of a particular antenna in a particular direction is more as compared to isotropic antenna radiating in all directions which is very useful for many applications providing a better performance. The proposed antenna provides the gain of 7.263 dB and 6.918 dB at 2.48 GHz and 2.78 GHz frequency as shown in Fig 6.5.

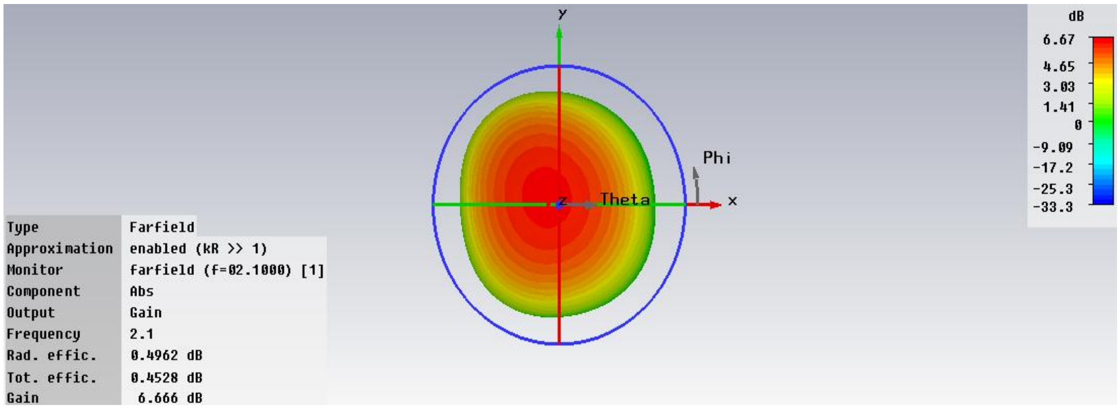


Fig 6.10 (a) Gain (3D view) at 2.1 GHz

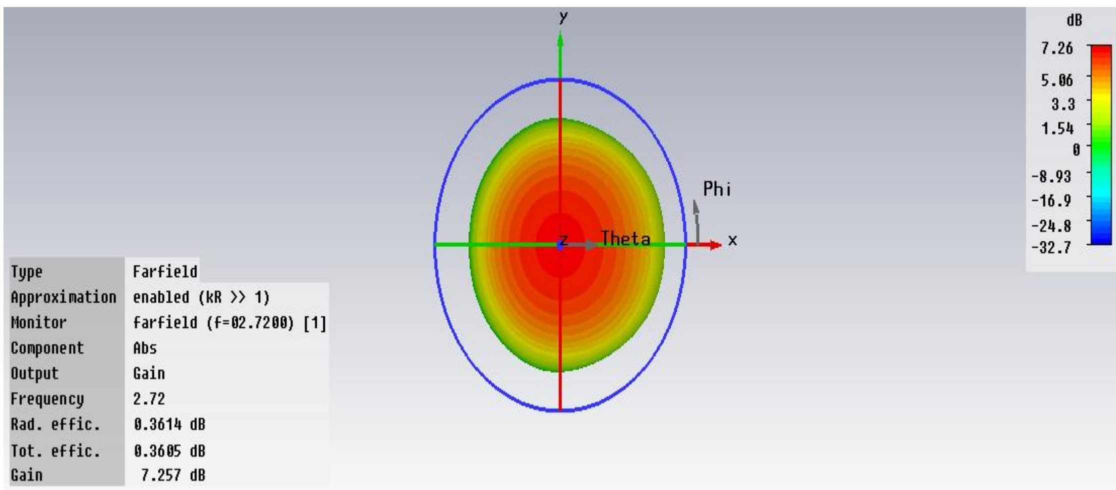


Fig 6.10 (b) Gain (3D view) at 2.72 GHz

Conclusion

In this chapter versatility of E- shaped patch is shown. Asymmetrical arms of E- shaped patch results in broadband antenna whereas symmetrical arms of E- shaped patch antenna results in dual band antenna. Both antennas provide very good values of gain and directivity.

CHAPTER 7
FABRICATION AND TESTING OF SINGLE BAND ACMA

This chapter describes the entire procedure for fabrication of aperture coupled microstrip patch antenna. Some fabricated antennas are also presented that are designed and simulated in chapter 3 and chapter 4.

7.1 Simulated Results of the Single Band ACMA at 5.2 GHz

The simulated results of the antenna discussed in chapter 3 have been discussed below:

Frequency (f_r)	5.2 GHz
Dielectric constant	4.4
Patch Substrate Thickness	1.6
Feed Substrate Thickness	1.6
Patch shape	Rectangular

Table 7.1 Dimensions of Designed Single Band ACMA

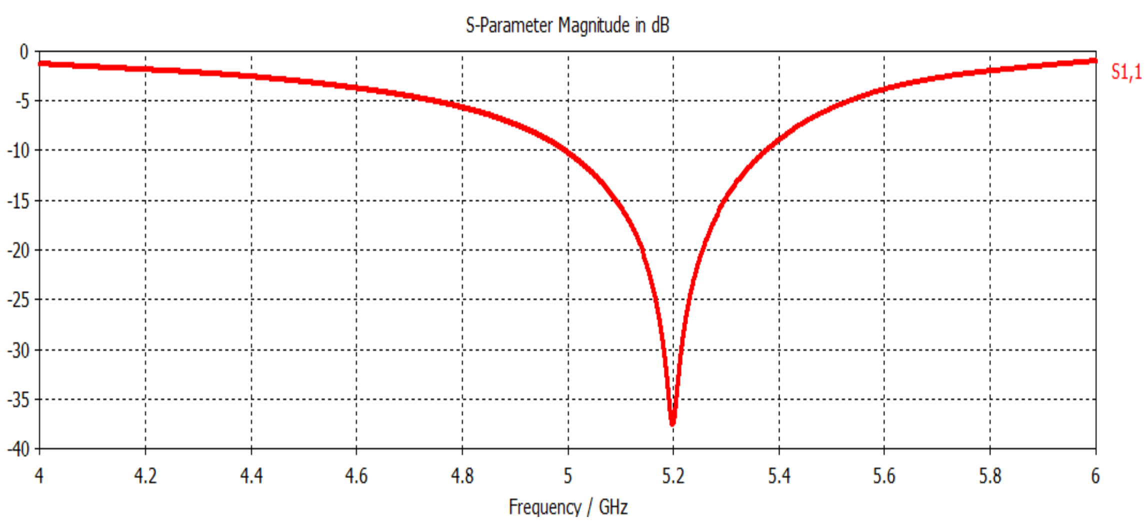


Fig 7.1 Return Loss S_{11} (in dB) of Single band antenna at 5.2 GHz

Figure 7.1 shows the return loss for the proposed antenna which resonates at 5.2 GHz with return loss of – 36.85 dB. The bandwidth can be calculated from the return loss versus frequency plot. The bandwidth of the proposed antenna is and resonant frequency is 5.2 GHz. More is the return loss means more of the coupling 390 MHz.

7.2 Fabrication Process

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

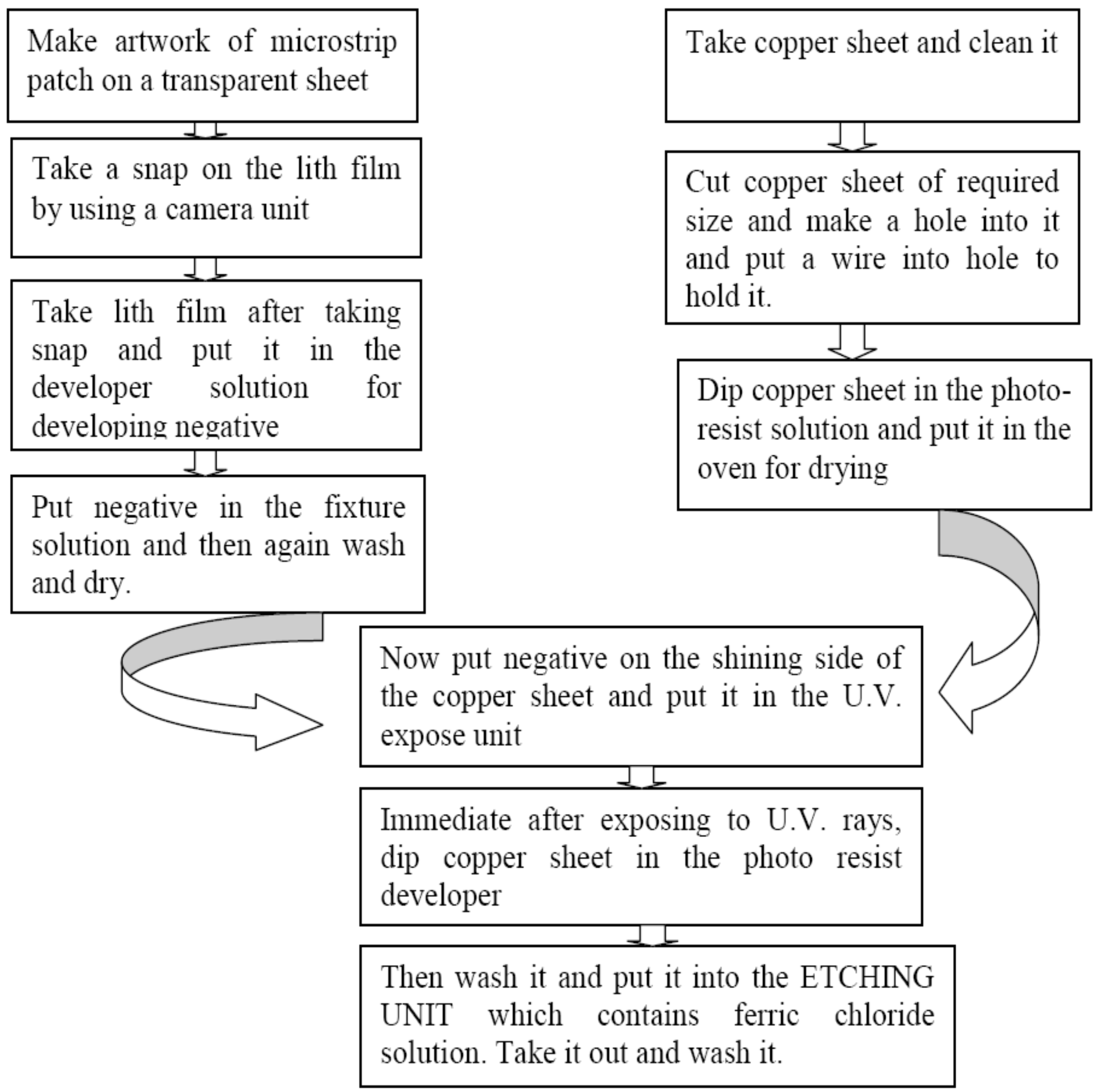


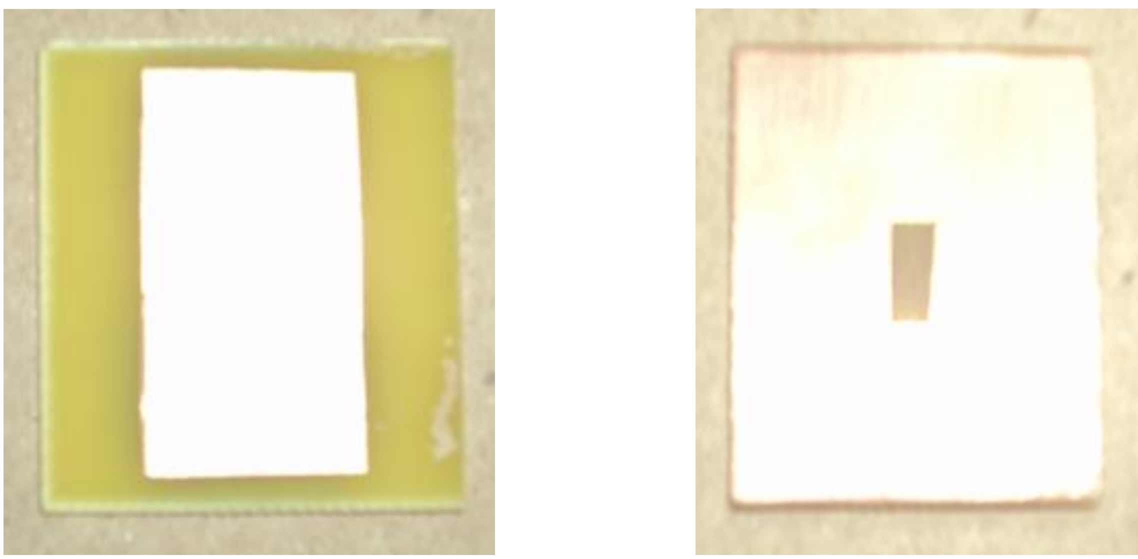
Fig 7.2 Fabrication Flow of PCB Design

7.3 Instruments used while fabricating a microstrip patch antenna

The hardware used for the design of the antenna includes two processes namely PCB (Printed circuit board) design and testing of the antenna. In the PCB designing, the negative developing of the design is done by using software and the layout is first printed out and it is further dipped in a photo resist developer. Then it is dried in an oven unit at 140-150 degree temperature properly. After drying the antenna design in the oven unit, it is dipped into the nitric acid solution for etching out the painted part out of the design. It is kept in the solution for about 15-20 minutes for the final design.

7.4 Fabricated Single Band Aperture Coupled Microstrip Antenna

Figures below show the fabricated structure of single band aperture coupled microstrip antenna resonating at 5.2 GHz.



(a) Top view of Antenna showing Patch (b) Aperture in Ground

Fig 7.3 Fabricated Structure of Single Band ACMA

7.5 Testing of Antenna on VNA

A vector network analyzer is a test system that enables the RF performance of radio frequency and microwave devices to be characterized in terms of network scattering parameters or S parameters. The information provided by the vector network analyzer is then used to ensure that the RF design of the circuit is optimized to provide the best performance. A single band aperture coupled microstrip antenna used for WLAN applications were designed using CST microwave studio 2010. But practically, antenna has been tested using VNA model no. E5071C Agilent, frequency range is 9 KHz – 8 GHz and is shown in Fig 7.10 below:

The tested antenna resonates at 5.25 GHz frequency with return loss -24.95 dB as compared to the -36.85 dB return loss of the CST simulated results. Fig 7.4 shows the graph at 5.25 GHz.

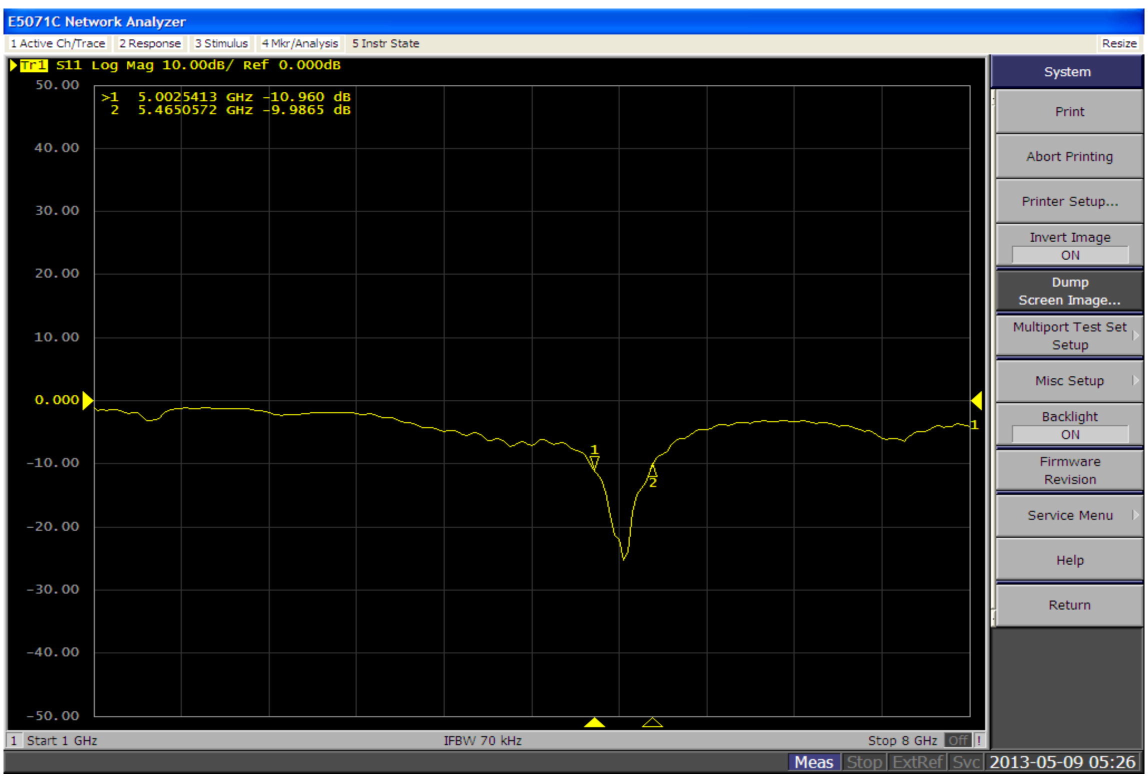


Fig 7.4 Tested Results on VNA

The return loss graph shows that the resonant frequencies have shifted in the magnitude by 0.05 GHz from the designed frequency. The root cause of the shift could be due to the FR-4 board, which varies from 4.0 to 4.9. In practical world, a material which is 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. 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. Other than that, electromagnetic coupling is also one of the important mechanisms in aperture coupled microstrip antenna. But, in the simulation, the electromagnetic coupling to the environment is not modeled.

7.5 Comparison of Fabricated and Simulated Results

The comparison between simulated and fabricated results for the single band slot antenna referring to fig. 7.1 and 7.4 is given below

Parameters	Simulated Results	Fabricated Results
Frequency Covered	5.2 GHz	5.25 GHz
Return Loss	-36.85 dB	-24.95 dB
Application Covered	WLAN	WLAN

Table 7.2 Comparison of Simulated and Tested Results

The fabrication and testing of single band aperture coupled microstrip antenna is done and it is observed that there occur some shifts in the results of simulated and fabricated antenna. As can be seen from the above table, a shift of 0.05 GHz is observed. Even though the radio frequency has been shifted, still it is covering the WLAN band from 5.14 GHz -5.24 GHz because during simulation ±10% margin has been considered.

Chapter 8

CONCLUSION AND FUTURE WORK

8.1 Conclusion

- In this report, firstly analysis of aperture coupled microstrip antenna using transmission line model is done. To understand aperture coupled microstrip antenna more deeply a single band antenna is designed which resonates at 5.2 GHz and provides the bandwidth of 390 MHz, hence, this antenna can be used for WLAN applications. The physical parameters examined in the study include the substrates and their dielectric constants, stub length, slot (aperture) length. The antenna parameters like operating frequency, input impedance, bandwidth, return loss, directivity and gain are determined.

Parameters Varied	Different values of varied parameters (mm)	Effect on antenna performance
Stub length	L_{sb} = 8.4 L_{sb} = 8.6 L_{sb} = 9 L_{sb} = 9.2 L_{sb} = 9.4 L_{sb} = 9.6 L_{sb} = 9.8 L_{sb} = 10 L_{sb} = 10.2	Stub length plays an important role for maximum coupling. It should be placed perpendicular to the center of the slot. Also from figure 3.9, increase in stub length results in increase in return loss and bandwidth till 6mm and then start decreasing. So for the best results, L_{sb} = 9.2 is considered.

Slot length	L_s = 4 L_s = 4.1 L_s = 4.2 L_s = 4.3 L_s = 4.4 L_s = 4.5 L_s = 4.6 L_s = 4.7 L_s = 4.8 L_s = 4.9 L_s = 5	Slot length affects the return loss and bandwidth. Also from figure 3.10, increase in slot length increases the return loss till 4.6 mm and then start decreasing.But considering both desired resonant frequency and return loss, L_s = 4.5 mm is considered.

- A dual- and triple- band U- slot aperture coupled antenna is designed. By cutting the single U- slot in patch, a dual band antenna is obtained which resonates at 3.6 GHz and 5.2 GHz frequency. When two U- slots are cut in the patch, it provides triple band antenna resonating at 3.6 GHz, 5.2 GHz and 5.8 GHz. Both antennas can be used for WLAN frequencies.

- A triple band S- shaped slotted patch antenna is designed used for L-band applications. The designed triple band antenna provides a broadband covering two resonant frequencies (1.17 GHz and 1.227 GHz) and another band resonates at 1.48 GHz frequency. The measured -10 dB bandwidth of the broadband is 16.33 % (1.1047 - 1.2953 GHz) and for upper band it is 9.22 % (1.3931 – 1.5279). The frequencies 1.17 GHz (L5) and 1.227 GHz (L2) are required for differential GPS system in order to provide maximum position accuracy. The antenna also resonates at 1.48 (LQ) GHz frequency used for satellite broadcast. It also provides considerable high values of gain and directivity.

- A stacked multiple band antenna is designed used for L- band applications. For multiband operation two slots are cut, one – S- slot is cut in upper patch and another rectangular slot is cut in lower patch. The designed antenna provide three bands, first wideband covering two resonant frequencies i.e. 1.175 (L5) GHz and 1.227 (L2) GHz, third band resonating at 1.48 GHz (LQ) and the fourth band resonating at 1.575 (L1) GHz. The measured -10 dB bandwidth of the wideband is 23.88 % (1.1631 - 1.3514 GHz). Third and fourth band provide 8 MHz and 13 MHz bandwidth.

- An aperture coupled antenna with E- shape patch is designed. By making variations E shape patch geometry and stub length, broadband and dual band antenna is designed. The broadband antenna covers the range from 2.40dB - 2.86dB and the dual band antenna resonates at 2.1 GHz and 2.72 Ghz.

8.2 Future Scope

Although an extreme research has been done for optimum antenna design used for wireless applications but still there is so much work to be done with microstrip antennas. In this thesis work, aperture coupled micrcostrip patch antennas up to multiband and broadband characteristics are proposed, used for WLAN, GPS and satellite communications. Next, one can work on various techniques listed below to improve antenna performance:

- **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 $\in_r$ 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 $\in_r$ and μ_r 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.

Publication

- Garima, Amanpreet Kaur, Rajesh Khanna, “Dual- and Triple- Band U- Slot Microstrip Patch Antenna for WLAN Applications”, IJARCCE, vol. 2, n0. 5, may 2013.

Acceptance

- Garima, Amanpreet Kaur, Rajesh Khanna, “A Triple- Band Aperture Coupled Microstrip Antenna for GPS Applications”, ICECIT, oct. 2013.

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