Design and Fabrication of Dual and Triple Band Microstrip Patch Antennas Using Proximity Coupling for Wireless Applications

Thesis submitted in partial fulfillment of the requirements for the award of degree of

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Submitted By

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CERTIFICATE

I hereby certify that the work which is being presented in the thesis entitled, "*Design and Fabrication of Dual and Triple Band Microstrip Patch Antenna Using Proximity Coupling for Wireless Applications*", in partial fulfillment of the requirements for the award of degree of Master of Engineering in *Electronics and Communication Engineering* submitted in Electronics and Communication Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of *Amanpreet kaur* and refers other researcher's work which are duly listed in the reference section.

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

Aditi

Signature:

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This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.

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ABSTRACT

The wireless revolution is transforming the existing global telecommunications networks into an integrated system that will provide a broad class of ubiquitous communications services to customers anywhere, anytime, in motion or fixed. Antenna is an important device in WLAN communication system because its performance will directly impact on the quality of wireless communications. The continuous shrinking size of electronic equipments demands similar size antenna elements in order to fit properly in wireless devices without compromising the other radiation properties of the antenna. In this respect microstrip patch antennas are quite an obvious choice.

This project started by identifying two main disadvantages of the typical microstrip antenna that are the low gain and narrow bandwidth. These two major drawbacks have limited its application despite of other advantages as compared to the conventional antenna. With the purpose of designing a wideband microstrip antenna, the two already proven bandwidth enhancement techniques; the patch stack configuration and coplanar parasitic patch was studied. Several antenna configurations were proposed and from the simulation result, the antenna bandwidth was improved from the typical 8 ~ 9 % up to 36 % by using these two techniques using a simple coaxial probe feeding without any matching network. A microstrip patch antenna consists of radiating patch placed on the dielectric material. The feed line is sandwiched between the two substrates in proximity feeding technique. The different types of slots on the patch and the stacking help in increasing the bandwidth and give the efficient results.

In this thesis report various antenna designs are given and then study the various effects of different parameters like patch length, patch width, substrate height, and dielectric constant for WLAN applications. The antennas are designed using CST 9 microwave studio. The antenna parameters like return loss, bandwidth, resonating frequency, directivity, gain and VSWR are calculated for each antenna design in order to get the best antenna.

ACKNOWLEDGEMENT

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Aditi Gupta

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List of Abbreviations

AIA	Active Integrated Antennas
BW	Band Width
CDMA	Code Division Multiple Access
CST	Computer Simulation Technology
DGS	Defected Ground Structure
DMS	Defected Microstrip Structures
EBG	Electromagnetic Band Gap
EDGE	Enhanced Data Rates for Global Evolution
FDTD	Finite Difference Time Domain
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HPLAN	High Performance Local Area Network
MPA	Microstrip Patch Antenna
OFDM	Orthogonal frequency-division multiplexing
PBG	Photonic Band Gap
PC	Proximity Coupled
Q	Quality Factor
RF	Radio Frequency
RL	Return Loss

SMS	Short Messaging Service
UHF	Ultra High Frequency
UWB	Ultra Wideband
VHF	Very High Frequency
VSWR	Voltage Standing Wave Ratio
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network

CHAPTER 1

INTRODUCTION

In this chapter the brief idea about the wireless communication and MSA is given.

Overview of Wireless Communication

Wireless communication is the fastest growing segment of the communication industry. It has captured the attention of the media and the imagination of the public. Cellular systems have experienced exponential growth over the last few decades and there are currently around two billion users worldwide. Indeed cellular phones have become a critical business tool and part of everyday life in most developed countries, and are rapidly supplanting antiquated wire line systems in many developing countries [1].

The table below shows the different wireless communication applications and their BW.

Wireless Applications		Frequency Band (MHz)	Bandwidth (MHz)
	GSM 900	890-960	70

GSM	GSM 1800	1710-1805	95
	GSM 1900	1850-1990	140
IMT		2300-2400	100
		2700-2900	200
		3400-4200	800
		4400-4900	500
WLAN		2400-2484	84
		5150-5350	200
		5725-5825	100
Bluetooth		2400-2500	100
WiMAX		2500-2690	190
		3400-3690	290
		5250-5850	600

Table 1.1 Various Types of Wireless Applications and its Frequency Band [2]

1.2 Wireless Communication Systems

Evolution of wireless access technologies is about to reach its Fourth Generation (4G). Looking past, wireless access technologies have followed different evolutionary paths aimed at unified target: performance and efficiency in high mobile environment. The First Generation (1G) has fulfilled the basic mobile voice, while the Second Generation (2G) has introduced capacity and coverage. This is followed by the Third Generation (3G), which has quest for data at higher speeds to open the gates for truly "Mobile broadband" experience, which will be further realized by the Fourth Generation (4G) [2].

First Generation (1G)

First Generation Technology (1G) and AMPS wireless technology is based on analog signals. Analog signals are radio transmissions sent in a wave-like form. A mobile device sends the waves to a base station where they are processed to determine the signal's next destination (i.e., another base station, mobile phone, land-line phone etc.). Once the destination is determined, the signal is reconstructed as accurately as possible into its original wave form by the base station. The analog signal received by the end user may closely resemble the original transmission but rarely duplicate it. Noticeable differences in quality and form occur due to recreation errors of the signal wave. Signal destruction (the signal is lost or damaged during transmission), translation and interference problems threaten analog transmission to a greater extent than their digital counterparts. In 1G, Narrow band analogue wireless network is used, with this we can have the voice calls and can send text messages. These services are provided with circuit switching. The speed of transfer is only at 9.6 Kbps.

Second Generation (2G)

2G is the second one, improved by introducing the concept of digital modulation , which means converting voice (only) in digital code in your phone and then into analog signals(imagine that it flies in the air). Being digital, they overcome some of the limitations of 1G, such as it omits the radio power from handsets making life healthier and it has enhanced privacy. In this case Narrow Band Wireless Digital Network is used. It brings more clarity to the conversation.

2.5G is the transition of 2G and 3G in 2.5 G, the most popular services like SMS (short messaging service), GPRS, EDGE, high speed circuit switched data and more had been introduced [2].

2G networks (GSM, CDMA, DAMPS) are the first digital cellular systems launched early 1990s. In 2G the roaming facility a semi-global facility is available.

Some of the advantages that 2G had over 1G are:

- The lower powered radio signals.
- The digital voice encoding increase sound quality and lowering the noise floor.
- The lower power emissions.
- Provides digital data services, such as SMS and email and enhanced privacy.

Third Generation (3G)

3G is the current generation of mobile telecommunication standards. It had been introduced to overcome the limitations of 2G and 2.5G. In this 3G Wide Brand Wireless Network is used with which the clarity increases and gives the perfection as like that of a real conversation. The data are sent through the technology called Packet Switching. Voice calls are interpreted through Circuit Switching. It is a highly sophisticated form of communication that has come up in the last decade. It allows simultaneous use of speech and data services and offers data rate up to 2Mbps , which provides services like video call, mobile TV, mobile internet and downloading, categorizing it into triple play service [2]. There are a bunch of technologies that fall under 3G like WCDMA, EV-DO, and HSPA and others. 3G operates at a range of 2100MHz and has a bandwidth of 15-20MHz. High speed internet service, video chatting are the assets of 3G.

The features and services of 3G are as follows:

- 3G provides global roaming and gives clarity of voice.
- 3G also have entertainments such as Fast Communication, Internet, Mobile T.V, Video Conferencing, Video Calls, Multi Media Messaging Service (MMS), 3D gaming, Multi-Gaming etc are also available with 3G phones.
- 3G networks have data rates 384 KB/s and more.

Some of the applications are Mobile TV, Video on demand, Video conferencing, Tele-medicine, Location-based services.

Fourth Generation (4G)

A successor of 2G and 3G, 4G promises a high downloading speed and is yet to shower its wonders on, then with the case of Fourth Generation that is 4G in addition to that of the services of 3G some additional features such as Multi-Media Newspapers, also to watch T.V programs with the clarity as to that of an ordinary T.V. In addition, we can send Data much faster than that of the previous generations, scalable bandwidths up to at least 40 MHz should be provided.

In telecommunications 4G is the fourth generation of cellular wireless standards. In 2008 the ITU-R organization specified the IMT –Advanced (international mobile telecommunication advanced) requirements for 4G standards, setting peek speed requirement for 4G services at 100 Mbit/s for high mobility communications (such as from trains and cars) and 1Gbit/s for low mobility communications (such as pedestrians and stationary users). A 4G system is expected to provide a comprehensive and secure all-IP based mobile broadband solution to laptop computer wireless modems, smart phones and other mobile devices. Facilities such as ultra broadband internet access, IP telephony, gaming services and HDTV streamed multimedia may b provided to users. Although legacy systems are in place to adopt existing users, the infrastructure for 4G will be only packet-based (all-IP). Some proposals suggest having an open Internet platform. Technologies considered to be early 4G include: Flash-OFDM, the 802.16e mobile version of WiMax (also known as WiBro in South Korea), and HC-SDMA.

The Forth Generation could be ready for implementation around 2012.

1.3 Antenna is a Vital Part of the Wireless Communication System

Wireless networking devices consists of different components and that are essential components because without them we cannot do the access to the network from the wireless networking device.

An antenna can be defined as any wire, or conductor, that carries a pulsing or alternating current. Antennas transmit or receive electromagnetic waves by converting electromagnetic radiation into electric current or vice versa. Such a current will generate an electromagnetic field around the wire and that field will pulse and vary as the electric current does. If another wire is placed nearby, the electromagnetic field lines that cross this wire will induce an electric current that is a copy of the original current, only weaker. If the wire is relatively long, in terms of wavelength, it will radiate much of that field over long distances. They transmit and receive radio waves and are widely used for radios and televisions as also for point-to-point communication, wireless LAN, cell phones, radar, and spacecraft communication [3].

Different types of antennas are used for different applications – for radios, televisions, and radar systems. Antennas are build for transmission of different frequencies and so they can be categorized by different frequency types. For instance radio antennas could be for frequency modulation (FM) or amplitude modulation (AM) broadcasting.

Television antennas could work for Ultra High Frequency (UHF), Very High Frequency (VHF), or both. Antenna types are also categorized in terms of customers' needs varying with range like short, medium, or long range. Location is another way of looking at antenna types that include indoor, outdoor and attic installation.

1.4 Antenna Parameters

There are various parameters of antenna which are used to calculate in order to check the efficient working of antenna. The following are the few antenna parameters:

- **Return Loss**

  The return loss (RL) is the parameter which indicates the amount of power that is lost to the load and does not return as a reflection. As already known, waves are reflected leading to the formation of standing waves when the transmitter and antenna impedance do not match [4].

Hence the RL is the parameter similar to VSWR to indicate how well the matching between the transmitter and the antenna has taken place.

The RL is defined as

$$RL = -20 \log10|\acute{\Gamma}| \qquad \text{(i)}$$

In practical applications, the applicable VSWR of 2 is acceptable corresponds to an RL of -9.5 dB or 11% power reflection [3].

- **Smith Chart**

The Smith Chart, invented by Phillip H. Smith (1905-1987), is a graphical aid or monogram specializing in radio frequency (RF) engineering to assist in solving problems with transmission lines and matching circuits. The Smith Chart is plotted on the complex reflection coefficient plane in two dimensions and is scaled in normalized impedance (the most common), normalized admittance or both, using different colors to distinguish between them. These are often known as the Z, Y and YZ Smith Charts respectively. Normalized scaling allows the Smith Chart to be used for problems involving any characteristic impedance or system impedance, although by far the most commonly used is 50 ohms.

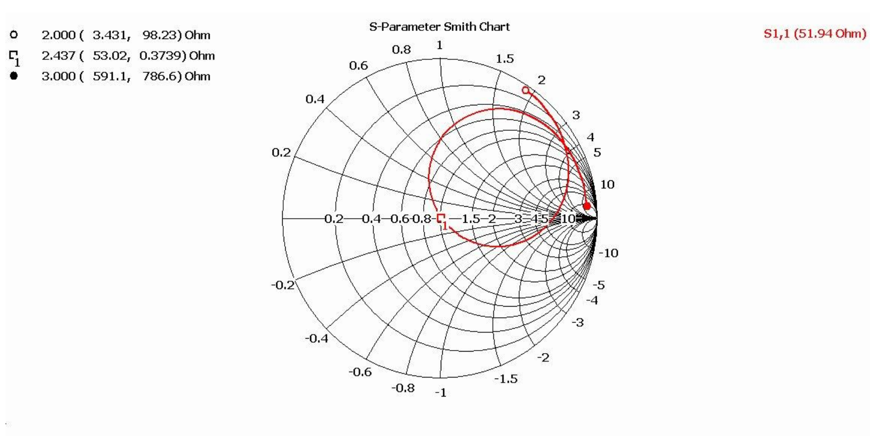


Figure 1.1 Smith Chart

- **Voltage Standing Wave Ratio (VSWR)**

The most common case for measuring and examining VSWR is when installing and tuning transmitting antennas. When a transmitter is connected to an antenna by a feed line, the impedance of the antenna and feed line must match exactly for maximum energy transfer from the feed line to the antenna to be possible. When an antenna and feed line do not have matching impedances, some of the electrical energy cannot be transferred from the feed line to the antenna. Energy not transferred to the antenna is reflected back towards the transmitter. It is the interaction of these reflected waves with forward waves which causes standing wave patterns.

Matching the impedance of the antenna to the impedance of the feed line is typically done using an antenna tuner. The tuner can be installed between the transmitter and the feed line, or between the feed line and the antenna. Both installation methods will allow the transmitter to operate at a low VSWR. Ideally, VSWR must lie in the range of 1-2

- **Directivity**

Directivity of an antenna defined as the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions [3].

In mathematical form, it can be written as

$$D = U / U_o = 4\Pi U / P_{rad} \qquad \text{(ii)}$$

If the direction is not specified, it implies the direction of maximum radiation intensity. Directivity is dimensionless.

U=radiation intensity (W/unit solid angle)

U0 = radiation intensity of isotropic source (W/unit solid angle)

Prad = total radiated power (W)

- **Gain**

The gain of the antenna is closely related to the directivity, it is a measure that takes into account the efficiency of the antenna as well as its directional capabilities. Gain of an antenna (in a given direction) 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 were radiated isotropically [3].

$$\text{Gain} = 4\Pi \text{ radiation intensity / total input (accepted) power} \qquad \text{(iii)}$$
$$= 4\Pi\, U(\Theta,\varphi) / P_{in}$$

- **Radiation Pattern**

  An antenna radiation pattern or antenna pattern is defined as "a mathematical function or graphical representation properties of the antenna as a function of space coordinates.

  The radiation pattern is a graphical depiction of the relative field strength transmitted from or received by the antenna. Antenna radiation patterns are taken at one frequency, one polarization, and one plane cut. The patterns are usually presented in polar or rectilinear form with a dB strength scale.

  Since a Microstrip patch antenna radiates normal to its patch surface, the elevation pattern for $\varphi = 0$ and $\varphi = 90$ degrees would be important. Figure 3.7 below shows the gain of the antenna at 2.438 GHz for $\varphi = 0$ and $\varphi = 90$ degrees.

  The maximum gain is obtained in the broadside direction and this is measured to be 6.8dBi for both, $\varphi = 0$ and $\varphi = 90$ degrees.

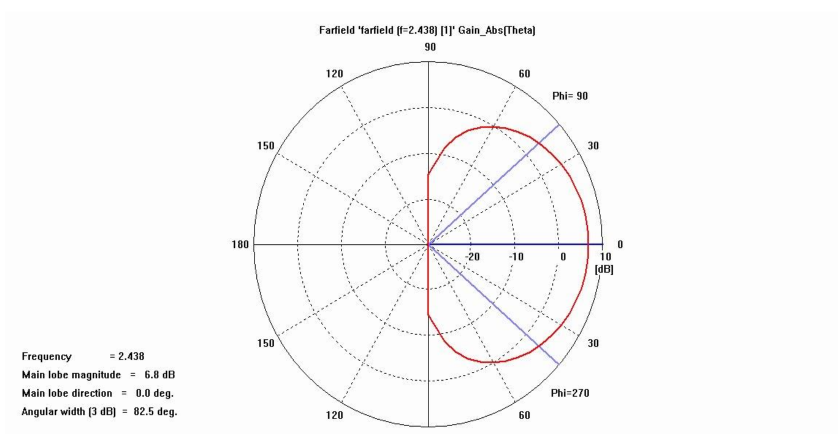


Figure 1.2 Radiation pattern for ϕ = 90 degree (E plane)

Out of all the antennas the most suited ones for the wireless applications is MSA because of its small size, comfort ability and inexpensive.

1.5 Microstrip Antenna

The idea of the microstrip antenna was introduced in 1950's but it became popular and took place in various applications in 1970's.

A microstrip patch antenna consists of a radiating conducting strip placed on a grounded dielectric layer. Design of the radiating patch (length, width, feed type etc.) and characteristic of the dielectric substrate (dielectric constant, height of the substrate etc.) determines the behavior of the antenna. The center conductor of a coaxial cable serves as the feed probe to couple electromagnetic energy in and/or out of the patch [4]. The electric field distribution of a rectangular patch excited in its fundamental mode is also indicated. Microstrip patch can be of different shapes such as rectangular, square or disk patches. They can provide linear, dual or circular polarization by appropriate feeding. Patch antennas are low cost, have a low profile and are easily fabricated.

Consider the microstrip antenna shown in Figure 1.3, fed by a microstrip transmission line. The patch antenna, microstrip transmission line and ground plane are made of high conductivity metal (typically copper). The patch is of length L, width W, and sitting on top of a substrate of thickness h with permittivity ε_r. The thickness of the ground plane or of the microstrip is not critically important. Typically the height h is much smaller than the wavelength of operation, but not much smaller than 0.05 of a wavelength.

The frequency of operation of the patch antenna of Figure 1.1 is determined by the length L. The center frequency will be approximately given by:

$$f_c = C / 2L\sqrt{\mathcal{E}_r} = 1 / 2L\sqrt{\mathcal{E}_o \mathcal{E}_r \mu_o} \qquad \text{(iv)}$$

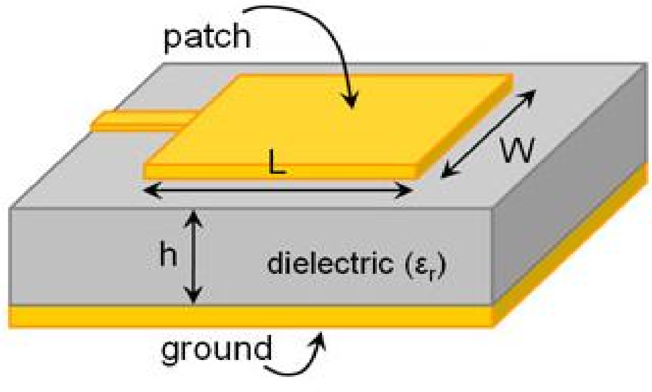


Figure1.3 Typical Microstrip Patch Antenna

The electric field is zero at the center of the patch, maximum (positive) at one side, and minimum (negative) on the opposite side. The minimum and maximum electric fields continuously change side according to the instantaneous phase of the applied signal. The electric field shown above does not stop abruptly at the patch's periphery as in cavity, but the fields extend the outer periphery to some degree. These fields extension are known as fringing fields and cause the patch to radiate.

The dielectric substrate act as an electrical insulator is a substance that is highly resistant to the flow of electric current. Ideally, the dielectric constant $\mathcal{E}_r$ of the substrate should be low ($\mathcal{E}_r <$ 2.5) to enhance the fringing field that account for the radiation. However in some cases, other performance requirements may dictate the use of dielectric material whose dielectric constants can be greater for $\mathcal{E}_r > 4$ [3].

1.5.1 The Advantages & Disadvantages of Microstrip Antenna

Microstrip antennas have several advantages compared to the conventional microwave antennas, and many applications cover the broad frequency range from ~100 MHz to ~100 GHz. Below are some advantages of them compared to the conventional antennas.

- Light weight, low volume, thin profile configurations
- Low fabrication cost, readily amenable to mass production
- Both linear and circular polarization are possible with simple feed
- Dual frequency and dual polarization antennas can be easily made
- No cavity backing is required
- Easily can be integrated with microwave integrated circuits
- Feed lines and matching networks can be fabricated simultaneously with the antenna structure

On the other side, there are also some limitations compared to the conventional antennas as follow.

- Narrow bandwidth and associated tolerance problems
- lower gain (~6 dB)
- Large ohmic loss in the feed structure of arrays
- Most microstrip antennas radiate into half-space
- Complex feed structures required for high performance arrays
- Polarization purity is difficult to achieve
- Poor end-fire radiator, except tapered slot antenna
- Extraneous radiation from feed and junctions
- Lower power handling capability
- Excitation of surface waves

Microstrip antenna fabricated on a substrate with high dielectric constant is strongly preferred for easy integration with MMIC RF front-end circuitry. However, use of high dielectric constant substrate leads to poor efficiency and narrow bandwidth.

1.5.2 Applications of Microstrip Antenna

The wide range of application from transportation, communication to biomedical can be seen [4].

- Aircraft and ship antennas - Communication and navigation, altimeters, blind landing systems

- Missiles - Radar, proximity fuses and telemetry
- Satellite communications - Domestic direct broadcast TV, vehicle-based antennas, communication
- Mobile - radio Pagers and hand phones, man pack systems, mobile vehicle
- Remote sensing - Large, lightweight apertures
- Biomedical Applicators - in microwave hyperthermia
- Others - Intruder alarms, personal communication etc

1.5.3 Basic Theory of Operation of MSA

The basic operation for the microstrip antenna can basically be divided into two groups; methods that are based on the equivalent magnetic current distribution around the patch edges and also methods that are based on the electric current distribution on the patch conductor and the ground plane. For this kind of analysis methods, the radiation from the microstrip antenna is calculated from the equivalent magnetic current distribution around the periphery of the radiating patch, which is obtained from the corresponding voltage distribution. Means the analysis problem is concentrated on finding the edge voltage distribution for a given excitation and for a specified mode. Two main methods based on this kind of analysis are transmission line model and the cavity model.

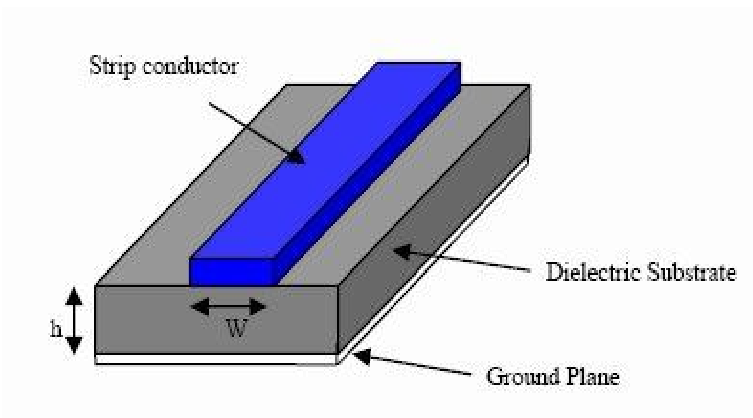
For the electric current distribution based method, the Method of Moments (MoM) is the most common. This method is considered as a full wave model which includes primarily integral equations or Moment Method.

In overall, the transmission line model is the simplest of all and it gives good physical insight but it is less accurate. The cavity model is more accurate and gives good physical insight but is complex in nature. The full wave models such as the Method of Moments is extremely accurate, versatile and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements and coupling. These characters give less insight as compared to the two models mentioned previously and it is far more complex in nature. In the next sections, the three methods mentioned above are discussed briefly [3].

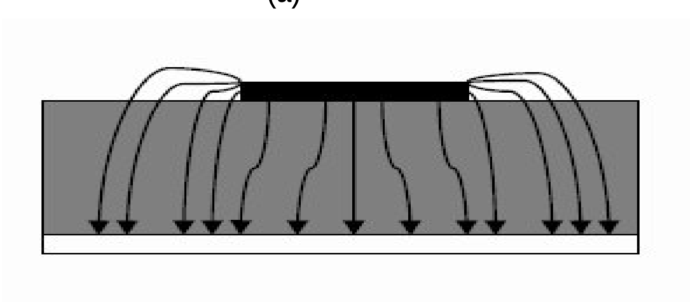
Transmission Line Model

This model is considered as the simplest and normally used in understanding the basic performance of the microstrip antenna. Originally this model was developed for rectangular patch but has been extended for generalized patch shapes. In this modeling the microstrip antenna is represented by two slots of width W and height h, separated by a transmission line with length L. The microstrip is a non-homogeneous line of two dielectrics, typically the substrate and air [3].

Looking at the Figure 1.4 shown below, most of the electric field lines reside in the substrate and parts of some lines are in the air. For that, this transmission line cannot support the pure transverse-electric-magnetic (TEM) mode of transmission due to the fact that the phase velocities would be different in the air and the substrate.



(a)



(b)

Figure 1.4 (a) Microstrip Line (b) Electric Field Line

Instead, the dominant mode of the propagation would be the quasi-TEM mode, means that the effective dielectric constant $\mathcal{E}_{reff}$ must be obtained in order to account for the fringing and the wave propagation in the line.

The value of $\mathcal{E}_{reff}$ is slightly smaller than $\mathcal{E}_r$ since the fringing fields around the periphery of the patch are not confined in the dielectric substrate, but also spreading the as shown in Figure 1.4 (b). Based on Balanis [3], the expression for $\mathcal{E}_{reff}$ is given by

$$\mathcal{E}_{reff} = (\mathcal{E}_r +1) / 2 + (\mathcal{E}_r -1) / 2 \, [1 + 12 \, W / h]^{½} \qquad (v)$$

where $\mathcal{E}_{reff}$ - effective dielectric constant

$\mathcal{E}_r$ - dielectric constant of substrate

h - height of dielectric substrate

W - width of the patch

Below Figure 1.5 shows a rectangular microstrip patch antenna of length L, width W layered on a substrate with height of h. The coordinate axis is selected such that the length is along x direction, width is along the y direction and the height is along the z direction.

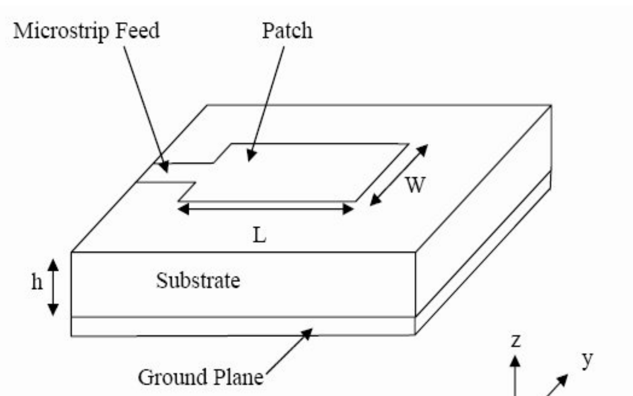
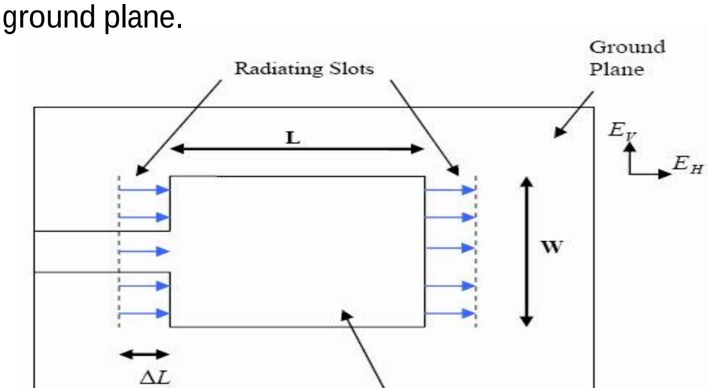


Figure 1.5 Microstrip Patch Antenna

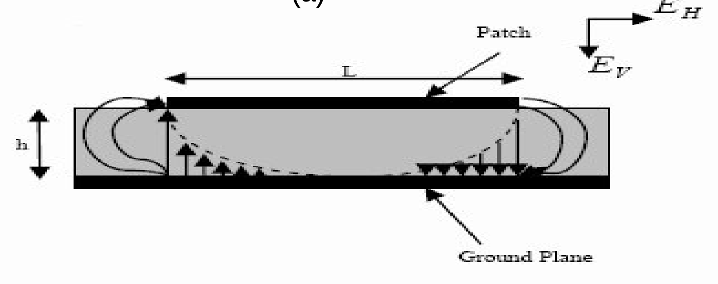
In order to operate in the fundamental TM_{10} mode, the length of the patch must be slightly less than λ/2 where λ is the wavelength in the dielectric medium and is equal to λ / $\mathcal{E}_{reff}$ where λ is the free space wavelength. The TM_{10} implies that the field varies one λ / 2 cycle along the length and there is no variation along the width of the patch.

In Figure 1.4(a) shown below, the microstrip patch antenna is represented by two slots, separated by a transmission line of length L and open circuited at both the ends. Along the width of the patch, the voltage is maximum and the current is minimum due to the open ends. The fields at edges can be resolved into normal and tangential components with respect to the ground plane.

It is seen from Figure 1.6(b), the normal components of the electric field at the two edges along the width are in opposite directions and thus out of phase since the patch is λ / 2 long and hence they cancel each other in the broadside direction. The tangential components in Figure 1.6 (b) which are in phase, means that the resulting field combines to give maximum radiated field normal to the surface of the structure. Hence the edges along the width can be represented as two radiating slots, which are λ / 2 apart and excited in phase and radiating in the half space above the ground plane.



(a)



(b)

Figure 1.6 (a) Top View of Patch Antenna (B) Side View of Patch Antenna

The fringing fields along the width can be modeled as radiating slots and electrically the patch of the microstrip antenna looks greater than its physical dimensions. The dimension of the patch along its length have now been extended on each end by a distance ΔL, which is given empirically by [3] as,

$$\Delta L = 0.412h\,(\mathcal{E}_{reff} + 0.3)\,[W/h + 0.264]\;/\;(\mathcal{E}_{reff} - 0.258)\,[W/h + 0.8] \qquad \text{(vi)}$$

The effective length of the patch L_{eff} now becomes,

$$L_{eff} = L + 2\Delta L \qquad \text{(vii)}$$

For a given resonance frequency fo, the effective length is given by [3] as,

$$L_{eff} = c \,/\, 2f_o\sqrt{\varepsilon_{reff}} \qquad \text{(viii)}$$

For a rectangular microstrip patch antenna, the resonance frequency for any TM_{mn} mode is given by [3] as,

$$f_o = c \,/\, 2\sqrt{\varepsilon_{eff}}\,[(m/l)^2 + (n/W)^2]^{1/2} \qquad \text{(ix)}$$

where m and n are modes along L and W respectively. For efficient radiation, the width W is given by [3] as,

$$W = c/\, 2f_o\sqrt{(\varepsilon r + 1)/2} \qquad \text{(x)}$$

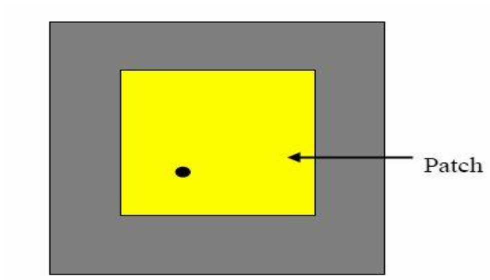
1.5.4 Feeding Techniques

Selection of the feeding technique is based on some factors. The most important consideration is the efficient transfer of power between the radiating structure and the feed structure that is the impedance matching between them. Basically they can be classified into two categories; the contacting and non-contacting method.

In the contacting method, the RF source is fed directly to the radiating patch using a connecting element such as a microstrip line. In the non-contacting method, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch. Below is some most popular feeding technique.

Coaxial Probe Feeding

Coaxial probe feeding is the most common feeding technique for the microstrip antenna. As shown below in Figure, the inner conductor of the coaxial connector is extended through the dielectric substrate and directly attached to the patch while the outer conductor is connected to the ground plane. Coaxial feeding has several advantages such as easiness in term of fabrication process, flexibility to be located at any desired location at the patch in or order to get matched input impedance and low spurious radiation [3]. However in case of application for the thicker dielectric substrate, longer probe length makes the input impedance more inductive that leads to the matching problem.



top view

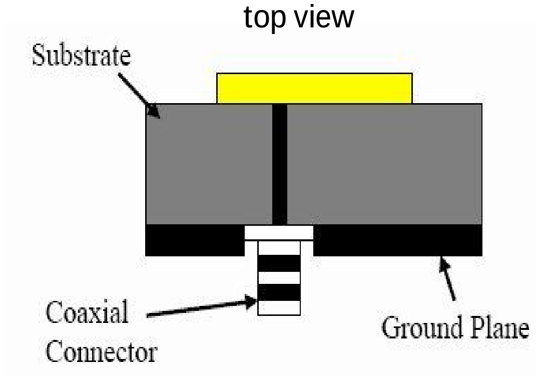


Figure 1.7 Coaxial Probe Feeding

Microstrip Feed Line

In this kind of feeding technique, a conducting strip line is directly connected to the edge of the patch to create a planar structure. The width and the inset position of the strip line can be optimized to match the input impedance without the need for any additional matching element. This provides an ease in term of fabrication, modeling and the impedance matching. However as the thickness of the dielectric substrate is increased, surface waves and spurious feed radiation also increases, creating a limit to the bandwidth of the antenna [3].

Figure 1.8 Microstrip Coplanar Feeding

Aperture Coupled Feeding

The radiating patch and the microstrip feed line are separated by the ground plane as show below in Figure. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane. The coupling aperture is normally centered under the patch, leading to lower cross-polarization due to symmetry of the configuration. The shape, size, and the location of the aperture determine the amount of coupling from the feed line to the patch. Spurious radiation is minimized due to separation between the patch and the feed line by the ground plane. Generally, a high dielectric material is used for the bottom substrate and a thick, low dielectric material is used for the top substrate to optimize the radiation from the patch [3]. Difficulty in fabrication due to multiple layers which also increase the antenna thickness is the major advantage of this feeding technique.

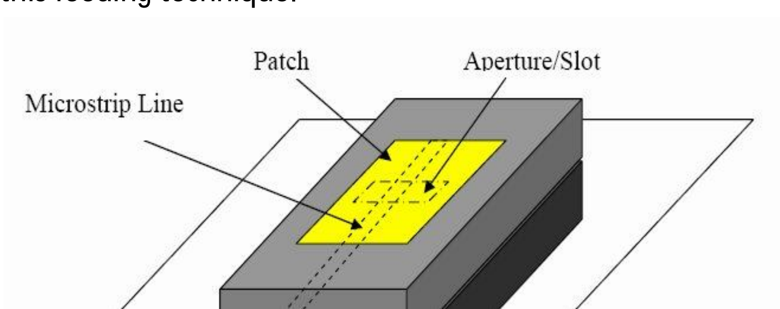


Figure 1.9 Aperture Coupled Feeding

Proximity Coupled Feeding

As shown in below Figure, the feed line is sandwiched between two dielectric substrates and the radiating patch is on top of the upper substrate. The advantages of this kind of feeding technique are elimination of spurious feed radiation and high bandwidth due to overall increase in the thickness of the microstrip patch antenna. Impedance matching is achieved by controlling the length of the feed line and the width-to-line ratio of the patch. Difficulty in fabrication due to the need of proper alignment between the two substrates is the main disadvantage of this technique [3].

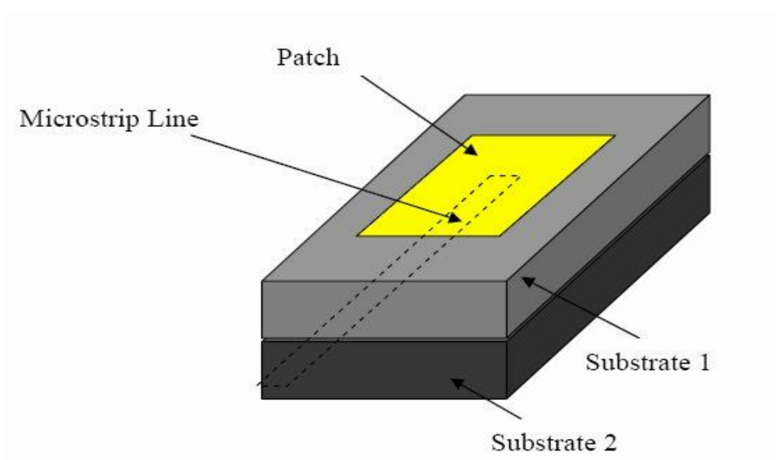


Figure 1.10 Proximity Coupled Feeding

Comparison between Different Feeding Techniques Used for Microstrip Antenna

The table below shows the comparison of all the feeding techniques used in microstrip patch antenna.

Characteristics	**Microstrip Line Feed**	**Coaxial Feed**	**Aperture coupled Feed**	**Proximity coupled Feed**
Spurious feed Radiation	More	More	More	Less
Reliability	Better	Poor due to Soldering	Good	Good
Impedance Matching	Easy	Easy	Easy	Easy

Bandwidth (achieved with impedance matching)	2-5%	2-5%	13%	21%

Table 1.2

Comparison of the Characteristics for Different Feed Techniques [4]

1.5.5 Selection of Proximity Coupled Feeding Technique for Research Work

The following few advantages of proximity feeding technique over the other feeding techniques results in the selection of this particular technique for the research work.

- Higher bandwidth as compared to other feeding techniques
- Proximity feeding technique has less spurious radiations
- There is no direct contact between the feed line and the radiating patch
- Highly reliable feeding technique
- It has good suppression of higher order modes
- Impedance matching is easy

1.6 Thesis Motivation

In recent years, the demand for broadband antennas has increased for use in high frequency and high-speed data communication systems. Printed antennas are economical and easily hidden inside packages, making them well suited for consumer applications. Unfortunately, a "classical" Microstrip patch antenna has a very narrow frequency bandwidth that precludes its use in typical communication systems. However, if the frequency bandwidth could be widened, a broad-band Microstrip antenna would prove very useful in commercial applications such as 2.5 G and 3 G wireless systems, wireless local area networks (WLAN), and Bluetooth personal networks. The microstrip antenna has many advantages like light weight, low profile, easy fabrication and conformability to mounting post etc as compared to the conventional microwave antennas. Narrow bandwidth and low gain are two major disadvantages that limit its applications. The size reduction together with gain and bandwidth enhancement has become a major consideration in the microstrip antenna design. Many studies have been carried out and several proposed techniques are proven to be able to improve the bandwidth performance and gain of the microstrip antenna.

This thesis describes the theory, implementation and discusses the performance of the proximity coupled microstrip patch antenna using the bandwidth enhancement techniques, the proximity coupled stack configuration of microstrip patch antenna in order to improve the bandwidth performance and gain for the WLAN applications. It is hoped that this work will add more information to the growing research literature in the area of antenna designing.

1.7 Thesis Objective

The main objective of this thesis is to design, fabrication and testing of the rectangular microstrip patch antenna using proximity feeding technique covering all the bands of WLAN. The other job is to improve the bandwidth of the microstrip antenna upto the wide band level by using stacking phenomenon and improve the gain of the antenna using Defected Ground Structure DGS.

To design a Microstrip patch antennas for a specific resonating frequency, accurate dimensions of patch, the substrate with efficient dielectric constant and height is required. Therefore, it becomes necessary to use simulation programs to test the performance of the antenna before fabrication. For the modeling and simulation of patch antennas, here we are using Computer Simulation Technology (CST) Microwave Studio version 9.

1.8 Thesis Outline

The outline of this thesis is as follows.

Chapter 1: It presents the background information about the wireless communication and the typical Microstrip patch antenna. It also introduces about various wireless frequency bands.

Chapter 2: A brief literature study of the microstrip antenna in order to get its basic fundamental. the main aspects of the microstrip antenna such as its structure configuration, radiation mechanism, polarization, feeding techniques, method of analysis etc are covered. Several techniques used in the enhancement of the bandwidth, broad-banding and multi-banding is presented in this chapter.

Chapter 3: This chapter describes the design procedure of single band, dual band, triple band Rectangular Microstrip patch antenna using proximity feeding technique. The designing and simulation using CST 9 Microwave Studio of rectangular Microstrip patch antenna is done and simulation results are presented. The snap shots of the fabricated antenna are also given in this chapter.

This chapter also describes some techniques to improve the bandwidth of the microstrip patch antenna using proximity feeding technique. The bandwidth can be improved by the following techniques:

• By using slots on the radiating patch.

• By using stacking in which more number of patches and substrates are used.

• By using impedance matching

Chapter 4: This chapter describes the fabrication procedure of the antenna and the various instruments used for antenna fabrication. It also covers the testing of antenna.

Chapter5: This chapter gives the conclusion to this thesis and the future work continued antenna design by using a different structure configuration, the use of different dielectric substrate material as well as combination of different substrate in one structure.

1.9 Conclusion

The table 1.1 indicates that for different wireless application, there is different band of frequencies, for these wireless applications it is desired to design an antenna which covers multiple frequency bands so that the requirement of multiple antennas for different applications is covered by a single antenna. Also the designed antenna should be low profile, simple and inexpensive and should show the desired performance measures as explained above in the chapter.

CHAPTER 2

Literature Survey on Proximity Coupled Microstrip Patch Antenna

2.1 Progress of Proximity Coupled Microstrip Patch Antenna

The bandwidth of the patch antenna depends on the resonant frequency, the dielectric permittivity of the substrate and its thickness. In 1995 David Sinchez-Hemindez and Ian D. Robertson found that wider bandwidth can be accomplished by employing a thick substrate with low dielectric constant; yet, there is a limit on the maximum usable thickness of the substrate so that surface waves will not be radiated. Dual frequency operation can be obtained by using multilayer structures. An adjustable air gap between the substrate and the ground plane in order to tune the resonant frequency of a microstrip patch antenna has also been carried out [10].

Microstrip antennas with a proximity-coupled feed enjoy a greater bandwidth as well as easier impedance matching than those with an edge feed. Slots have been introduced on the microstrip patches to improve the performance of the antennas. A cross slot with unequal slot lengths on the circular patch provides the circular polarization [11].

In 1998 C. H. Chan, Y. X. Yu and K. M. Luk Department of Electronic Engineering City University of Hong Kong Hong Kong found that for improving the inherently narrow bandwidth of a microstrip antenna, it is very effective to use an electrically thick substrate. Proximity coupling offers the advantage of low cross polarization (typically 25dB) because of no spurious radiation from a perpendicular probe. The microstrip-line feed above a slotted ground plane has been found to be excellent for exciting the electrically thick microstrip antenna [12].

The capacity issue for wireless communication applications is not easily solved, with the expansion in mobile communication systems and the number of people using their services. Much effort has been devoted to the bandwidth enhancement of microstrip antennas, and many techniques have been proposed. These techniques include the use of impedance matching network, multiple resonators arranged in stacked or co-planar structure, lossy materials, the reactive loading using U-shaped slot, the capacitively probe-fed structure, and L-probe feeding. A circular patch is used as the main radiator, and an H-shaped shot is cut in the ground plane [13].

The advantages of Active Integrated Antennas (AIAs) for applications in microwave and millimeter wave integrated transceivers in wireless systems. Proximity coupled (PC) patch antennas, due to their multilayer architecture, provide a solution for developing a thin and compact feed network without compromising the antenna performance. This type of patch antennas is reported to have achieved higher bandwidths compared to other feeding techniques [14].

The need for wireless broadband communications has increased rapidly in recent years demanding quality of service, security, handover, and increased throughput for the Wireless Local Area Networks (WLANs). The main aim of future wireless communication is high speed networking services for multimedia communication. The most important high data rate wireless broadband networking systems for future wireless communications are High Performance Local Area Network, HPLAN uses omnidirectional antennas. But for short distance indoor LAN communication, directive antenna can be used. The design of dual frequency shorted stacked patch antenna and shorted E-shaped patch antenna are also developed for the application in wireless communication. Single layer microstrip antennas have very narrow bandwidth, but using multi-layered configurations like proximity coupled microstrip antennas or aperture coupled microstrip antennas, higher bandwidth can be achieved. A thin wideband microstrip patch using two parallel slots is designed for WLAN. In a triple band omnidirectional antenna, consisting of three pairs of back-to-back printed dipoles, for the operation at 2.4 GHz, 5.2 GHz and 5.8 GHz bands. The input impedance of a proximity coupled microstrip antenna is a sensitive function of length and width of the microstrip feed line [15].

In 2008 T. Archevapanich, J. Nakasuwan, B. Purahong, N. Anantrasirichai, O. Sangaroon designed a slot antenna having a rectangular U-strip slot to achieve desirable two frequency bands. The three configurations of slot antenna fed by microstrip line which have the same size are presented for desirable frequency and bandwidth. The slot antenna fed by microstrip line is design for dual band by using U-strip and improvement by etching dual U-slot in the U-strip. Finally, the slot antenna with dual U-strip and dual U-slot is introduced for dual band coverage standard of IEEE 802.11b/g, IEEE 802.11j ,IEEE 802.11a and WiMAX of IEEE802.16d. WLAN provides wireless communication between the client devices with an access point in a local network. According to the standard of IEEE for WLAN, the network works at 2.4 GHz band (2.4-2.483 GHz for IEEE 802.11 b/g) and 5 GHz band (5.15-5.35 GHz and 5.725-5.825 GHz for IEEE 802.11a). Antenna is an important device in WLAN communication system because its performance will directly impact on the quality of wireless communications [16].

In 2009 R.J. Lin, M. Ye design an antenna composed of U-slot and T-slot on the patch and a rectangular window for ground plate that can be used for dual band [17].

The design of multiband antenna, which covers 2.4GHz, 5.2GHz and 5.8GHz WLAN bands, becomes the main topic in the antenna field. Monopole microstrip antennas easily realize dual-band and multiband by constructing different resonant lengths of radiator [18].

The microstrip antenna (MSA) has several advantages like low profile planar conFigureuration, however its applications gets restricted because of lower operating bandwidth (BW). In 2011 Amit A. Deshmukh, M. Parulekar, S. Kadam and Ameya Kadam found that the commonly used technique to realize broadband microstrip antenna is by cutting the slots at an appropriate position inside the patch. The bandwidth of an E-shaped microstrip antenna is further increased by cutting the pair of rectangular slots on one of its edge. This increase in bandwidth is due to another mode introduced by additional pair of slots. The slot affects the resonance frequency of higher order mode, which along with modes of E-shaped patch, realize higher bandwidth. This antenna gives a larger BW of 47% with broadside radiation pattern with a peak gain of approximately 10 dBi. The Ψ-shaped MSA realized by cutting the additional pair of slots inside the E-shaped MSA and gives larger BW [19].

2.2 Bandwidth Enhancement in Proximity Coupled Microstrip Patch Antenna

In 2000 a new stacked microstrip antenna structure that enhances the bandwidth without changing the resonance frequency is proposed. The effect of the various antenna parameters on the bandwidth is investigated. The region under the stacked antennas is kept the same as for the conventional structure within a radius R from the center of the structure. This is necessary to keep the resonance frequency without any significant change after introducing the surrounding medium. The proposed structure adds another two degrees of freedom to the design, which are: R and we will see that these parameters can be optimized to give a maximum bandwidth, and it is 35% for the structure studied here as compared to 21.8% for the original structure and for the same center resonance frequency of 4.5 GHz [20].

Impedance matching at the feed point of microstrip antennas as a possibility to improve the bandwidth has shown to improve the bandwidth without disturbing the radiating element's pattern. The simplified real frequency technique (SWT) has shown to work very effectively to design an impedance matching circuit consisting of a LC ladder network, with bandwidth improvements of approximately 100% being achieved with the addition of the matching circuit. Recently another matching technique consisting of coupled lines in the feed transmission line has been proposed. This matching structure exhibits resonant behavior, but takes up a substantial amount of space [21]

The bandwidth of the antenna is defined as the range of frequencies, over which the performance of the antenna with respect to some characteristic conforms to a specific standard. The bandwidth of the antenna depends on the patch shape, resonant frequency, dielectric constant, and the thickness of the substrate. Impedance bandwidth is usually specified in terms of a return loss or maximum SWR typically less than 2.0 or 1.5 over a frequency range. Conversion of bandwidth from one SWR level to another can be accomplished by using the relation between bandwidth (BW) and quality factor (Q) [22].

The greatest disadvantage of MPA is its low bandwidth which can be as low as 1%. The most straightforward way to improve the MPA bandwidth is to increase the patch-ground plane separation by using a thicker substrate. Unfortunately, the thick substrate will support surface wave modes that will increase mutual coupling in antenna arrays. Mutual coupling will result in serious degradations in impedance mismatch, large radiation loss, polarization distortion and scan blindness in phased array antennas. Another way to improve the bandwidth of an MPA is to create several resonant structures into one antenna by adding more layers, more patches or more extra components. The other technique for Multi-band antennas is the multiple layers which consisting of two or more metallic patches supported by one or more dielectric layers. There are two techniques for multi-band MPA using multiple layers. Firstly the diachronic technique with frequency band separation of 10:1. Secondly the stacking technique which uses two or three substrates providing two or more metallic patches within the same aperture area with frequency bandwidth of 5.6% for the stacked circular disc or up to 13% with four rectangular patches or up to 33% with strip-slot-foam-inverted patch antenna. Size, weight, feed fabrication, and high coupling between stacked patches are the main disadvantages of the stacked antennas [23].

In 2006 Indra Surjati and Eko Tjipto Rahardjo and Djoko Hartanto defines that although rectangular and circular geometries are most commonly used, other geometries having greater size reduction find wide applications in modern communication systems, where the prime concern is compactness. The equilateral triangle patch configuration is chosen because it has the advantage of occupying less metalized area on substrate than other existing configurations. Dual frequency operation of triangular microstrip antenna has been studied by many researchers using probe feed and direct coupling. A new design of coplanar waveguide feed line for dual frequency operation of triangular microstrip antenna using a pair of slit to increasing the bandwidth. By controlling the gap between the two slits, the antenna can resonate at two frequencies with wider impedance bandwidth [24].

The designing of the antennas on multilayer laminates is challenging, especially to ultra-wideband (UWB) antenna design, where the operating bandwidth from 3.1 to 4.8 or 6 to 10.6 or 3.1 to 10.6 GHz. This challenge is due to the difficulty of obtaining the directional radiation over a wide impedance bandwidth of the microstrip antenna. For high data rate transmission system, we need the directional wideband microstrip antennas with constant gain over the wide frequency range. Design of the low-profile directional microstrip antenna for UWB applications is very challenging. The printed multilayered antenna can be integrated into the circuit, and the ground plane can also be used to isolate the antenna from the other components in the circuit. the design and optimization of a wideband multilayered microstrip antenna with sandwich substrate without any air/foam layer is proposed for UWB applications. The sandwich substrate is used for enhanced impedance bandwidth in addition to keep the driven patch compact and thus the overall antenna size is reduced. The thickness and overall size of the antenna are reduced and compared with the conventional broadband antenna with an air or foam layer [25].

In 2010 Murli Manohar, S K Behera, & P K Sahu states that previous techniques of increasing the bandwidth of antenna have limitations like, excitation of surface waves and increase in antenna size. A rectangular patch with a U slot embedded in it has been found to be a broadband antenna. Printed antenna's are economical and can be accommodated in the device package. The design of multi polarized and multi frequency with a dual line feed rectangular microstrip E-shape patch antenna is given. Two parallel slots are incorporated to perturb the surface current path, introducing local inductive effect that is responsible for the excitation of the second resonant mode with rectangular slots. Dual frequency operations can be realized by exciting the microstrip patch antenna using a single feed or dual feed [26].

2.3 Antennas with Defected Ground Structure

Defected Ground Structures (DGS) are implemented by etching slots of different shapes in the ground planes. They have been employed to improve the performance in multiple applications such as filters, couplers or dividers, as well as to reduce the mutual coupling between elements of antenna arrays [27].

The surface wave restricts the wide use of microstrip antenna, electromagnetic band gap (EBG) or photonic band gap (PBG) structure is a method to reduce the surface waves, which exhibit band-gap feature too. EBG has been applied in the field of antenna to improve the performance of antenna, such as suppression of surface wave propagation, increasing the gain of antenna and improving the radiation pattern by inserting the EBG structure into the substrate. DGS is realized by etching the ground plane of microstrip antenna, this disturbs the shield current distribution in the ground plane which influences the input impedance and current flow of the antenna [28].

A miniaturized proximity coupled antenna with DGS is developed for switchable polarization application. A new DGS is proposed, and compared with the conventional cross and dumbbell shaped ones, the proposed DGS has better SWF and higher unloaded Q-factor [29].

The back to back geometries have been reported by the various researchers but here a new coupling method i.e. proximity coupling with the defected ground structure is used for the consideration of the increased bandwidth. The application of DGS is given for size reduction of microstrip antennas. A dumbbell shaped DGS is used in the common ground plane of a back to back combined single feed proximity coupled microstrip antenna [30].

In 2010 S. Fallahzadeh, H. Bahrami, A. Akbarzadeh, and M. Tayarani gives a new approach to enhance the isolation between transmitting and receiving ports in a diplexer patch antenna is presented. Spiral defected microstrip structures (DMS) are added to the feeding lines to form a stop band behavior in the other frequency band and increasing the isolation [31].

2.4 Research Gaps

A simple feed network can be employed, because only a microstrip line, offset from the center of the rectangular patch antenna, is used to generate the good circularly polarized waves. The proposed antenna is suitable for a phased array antenna using a multilayered feed network integrated with microwave devices in mobile satellite communications [32].

S. Gao' and A. Sambell define a simple broadband antenna. A circular patch is used as the main radiator, and an H-shaped shot is cut in the ground plane. By using only one patch, the designed antenna achieves a bandwidth of 26 %. Good broadside radiation patterns are observed, and it can be designed as an end fire radiator also with the cross-polar levels is below -20 dB at both E- and H-panes using the other feeding techniques available. The antenna is simple in structure and easy to be fabricated, thus promising for applications in wireless communication systems [13].

The slot antenna fed by microstrip line is design for dual band by using U-strip and improvement by etching dual U-slot in the U-strip. Finally, the slot antenna with dual U-strip and dual U-slot is introduced for dual band coverage standard of IEEE 802.11b/g (2.4-2.4835 GHz), IEEE 802.11j (4.90-5.091), IEEE 802.11a (5.15-5.35 GHz) and WiMAX of IEEE802.16d (5.7-5.9 GHz). This can be extended to other wireless applications [16].

A novel dual-band microstrip patch antenna for Wireless Local Area Network (WLAN) application is proposed. Dual band characteristic for the 2.4 GHz band and the 5 GHz band is produced by using U-slot and T-slot. The rectangular window for ground plate is used to increase the impedance bandwidth. This design can completely cover the 2.4/5 GHz band for IEEE 802.11b/g and 802.11a standards. It can can be further extended to a triple band antenna [17].

Progress In Electromagnetic Research 2006 a novel microstrip antenna with wide bandwidth is presented. Two different radiating elements connected together through a matched section and are embedded on a single layer structure. This new structure offers a dual-band microstrip antenna. By controlling the two resonance frequencies of the two elements, a wide frequency bandwidth of approximately 9% has been achieved. A more bandwidth enhancement, up to 12%, has been achieved by adding two parasitic elements to one element of the proposed antenna. BW can b further enhanced by using DGS structure [23].

A broadband microstrip antenna with low–high–low (sandwich) dielectric constant substrate combination using a microstrip line-via feed is presented for ultra-wideband applications. The proposed antenna consists of three dielectric substrates; low dielectric constant substrates that contain the microstrip feed line as well as parasitic patches and a high dielectric constant substrate that contains the driven patch. The antenna has measured 10 dB return loss bandwidth of 46.9% and directive gain .5.2 dBi at boresight across the impedance bandwidth. The total height of antenna is 5.77 mm or 0.077lo at 4 GHz. Stacking could also be done here to get multiband behavior [25].

In 2009 Indra Surjati, Yuli KN and Yuliastuti defines a bandwidth enhancement using array technique and combined with transformator λ/4 for the feed line matching is proposed and experimentally studied. The maximum bandwidth can also be achieved by controlling the distance between the two patch antennas and by adjusting the length of the transmission feed line 50 Ohm [33].

The half circular slot etched on the patch at the top right as DMS, two circular slots etched on the ground plane as DGS. The DGS helps in shifting the resonant frequency to desired frequency. The bandwidth 230MHz with respect to center frequency 5.23GHz which High Performance Local Area Network type 1 (HIPERLAN/1) the frequency bands 5.150 GHz – 5.350 GHz. The percentage bandwidth of 4.39% and the average gain of 4.65dBi are achieved. The performance can be further improved by shifting the DGS depending on current distribution [34].

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.

The use of different shaped patch antenna geometry has brought good performance in the VSWR and in response at low dielectric constant. Work can be done to analyze the antenna by taking the slot shape exactly as the patch shape.

2.5 Problem Statement

- Design and simulation of the single band MSA covering the bands of WLAN using proximity feeding technique.
- Design and simulation of dual band MSA using slots on radiating patch for WLAN applications using proximity feeding technique.
- Design of stacked antennas to get multiband behavior in single antenna and to improve the overall bandwidth of the antenna.
- Design of Defected ground structures to improve the bandwidth and gain of the antenna.
- Fabrication and testing of designed antenna for single band behavior.
- Testing of the antenna parameters like return loss, smith chart, BW, VSWR etc using VNA.
- Comparison of simulated and tested results.

2.6 Conclusion

In the above chapter an extensive study is carried out regarding MSA with proximity feeding, enhancement in the BW of the available antennas using various techniques like cutting slots in the patch or in the ground which is also known as DGS.

Based upon the above literature, the research gaps are identified so that the target for the project work has been defined which will be covered in the next chapters.

Chapter 3

Design of MSA Using Proximity Feeding Technique for Wireless Applications

In this chapter, the procedure for designing a rectangular Microstrip patch antenna is explained. The design is simulated using Computer Simulation Technology (CST) Microwave Studio. Finally, the results obtained from the simulations are demonstrated.

3.1 Microstrip Patch Antenna Using Proximity Feeding Technique

This configuration uses two-layer substrate with the microstrip line on the lower layer and patch antenna on the upper layer. The feed line terminates in an open and underneath the patch. This feed is better known as an “electromagnetically coupled” microstrip feed. Coupling between the patch and the microstrip is capacitive in nature [5].

The substrate parameters of two layers can be selected to increase the bandwidth of the patch and to reduce the spurious radiations from the open end of the microstrip. For this the lower layer should be thin. The radiating patch being placed on the double layer gives a larger bandwidth. Fabrication of this feed is, however, slightly more difficult because of the requirement for accurate alignment between the patch and the feed line, but soldering is eliminated.

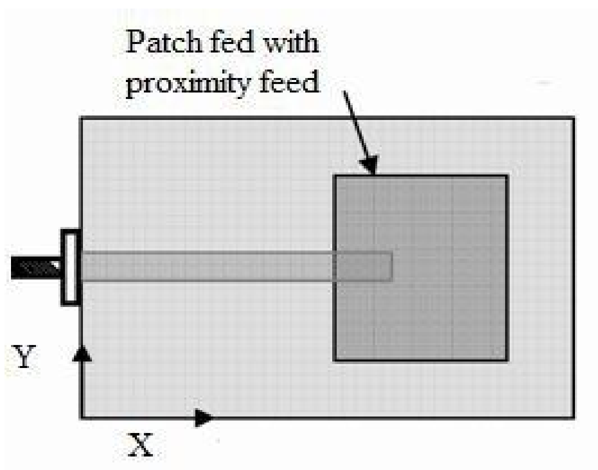


Figure 3.1 Geometry of a Proximity Coupled Microstrip Feed Patch Antenna (top view)

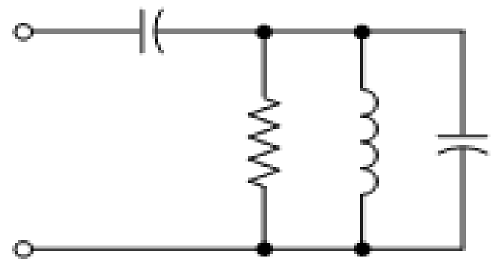


Figure 3.2 Equivalent Circuit of Proximity Coupled Microstrip Patch Antenna

3.2 Design Procedure of Single Band MSA Using Proximity Feeding

The design of the patch antenna requires three parameters:

- The dielectric constant of the substrate ($\mathcal{E}_r$)
- The resonant frequency (f_r)
- The height of the substrate (h)

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

Frequency of Operation (fr): The resonant frequency of the antenna must be selected appropriately. The Mobile Communication Systems uses the frequency range from 2100-5600 MHz. Hence the antenna designed for the mobile communication system must be able to operate in this frequency range. The resonant frequency selected for my design is 2.45 GHz.

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

After the proper selection of above three parameters, the next step is to calculate the radiating patch width and length. By using all these given parameters the length and width of patch is calculated using the microstrip antenna patch calculator.

Step 1: Calculation of Width (W)

For an efficient radiator, practical width that leads to good radiation efficiencies is calculated by transmission line model equation (ix) given in topic 1.5.3

Step 2: Calculation of Effective Dielectric Coefficient ($\mathcal{E}_{reff}$)

The effective dielectric constant is obtained by referring to equation (iv)

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

The effective length is calculated using equation (vii) of topic 1.5.3

Step 4: Calculation of Length Extension (ΔL)

The value of ΔL can be obtained by using equation (v) given in chapter 1.

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

The actual length of radiating patch is obtained by

$$L = L_{eff} - 2\Delta L \quad 3.5 \qquad \text{(xi)}$$

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

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

$$Lg = 6h + L \qquad \text{(xii)}$$

$$Wg = 6h + W \quad 3.6 \qquad \text{(xiii)}$$

3.3 Design of Single Band Microstrip Patch Antenna Using Proximity Feeding Operating at 5.2GHz for WLAN Applications

The single band microstrip patch antenna resonating at 5.2 GHz for WLAN applications can b designed using the following specification:

Variable	Value
Resonating frequency	5.2GHz
Dielectric constant of the substrate	4.4
Height of the substrate	1.570mm

Table 3.1: Single Band Patch Antenna Specifications Resonating at 5.2 GHz

A high dielectric constant will result in a smaller patch size but this will generally reduces bandwidth efficiency and might have difficulty in fabricating a very small patch size antenna.

3.3.1 Antenna Design

The radiating rectangular patch is printed on the upper side of the first substrate. The dimensions of the rectangular patch are width Wp is 15.42mm and length Lp is 11.58mm calculated using transmission line equation referring 1.5.3 topic. The two substrates used are of same material and have same height. The substrate is made up of material having dielectric constant 4.4 and height of the substrate is 1.57mm. The feed line is sandwiched between the two substrates. The width of the feed line is 3mm and the length from the center of the microstrip towards the patch axis along the positive y direction is 1.5mm.

The following parameters for antenna design are calculated by using the above steps of the antenna design using the transmission line model equations.

Variable	Value
Width of the patch (W_p)	15.42mm
Length of the patch (L_p)	11.58mm

Height of the patch (H_p)	0.035mm
Width of the ground (W_g)	28.97mm
Length of the ground (L_g)	22.638mm
Width of the feed line (W_f)	3mm

Table 3.2 Dimensions of the Patch Antenna Design for 5.2 GHz frequency

The simulated antenna design using CST 9 microwave studio is given in the Figure below:

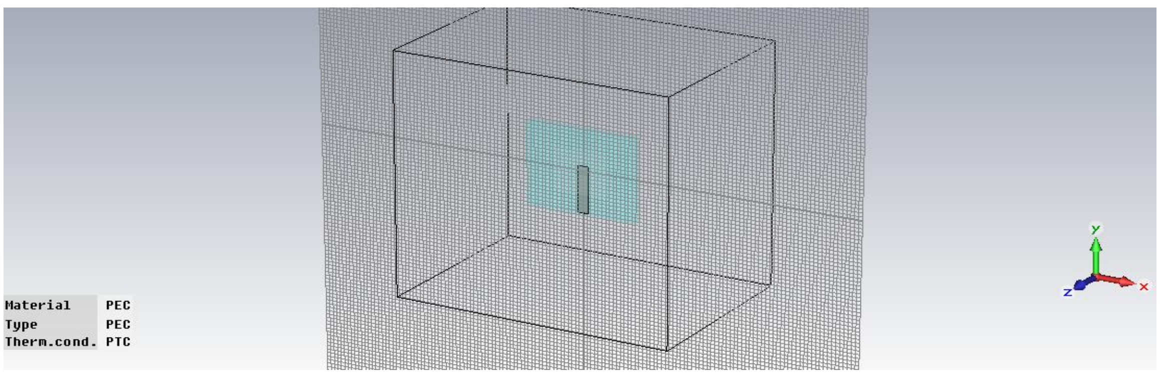


Figure 3.3 Designed Structure of MSA on CST Microwave Studio resonating at 5.2 GHz

3.3.2 Simulation Results

The simulation results of the above designed antenna of various parameters like return loss, impedance, gain, directivity and VSWR are given by using CST microwave studio 9.

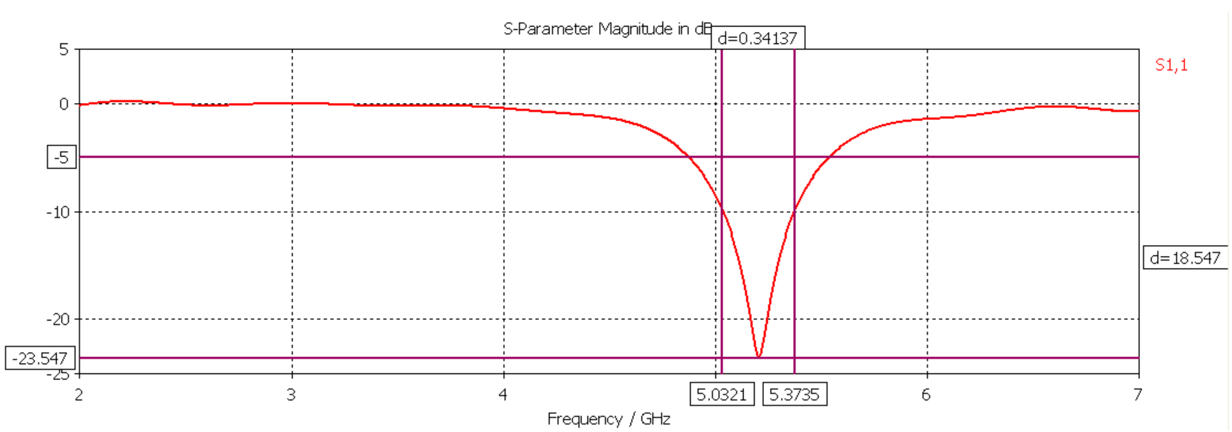


Figure 3.4 Simulated Return Loss of MSA Resonating at 5.2 GHz

The above designed antenna shows good return loss approximately -25dB which is an excellent result. This antenna resonates at 5.2 GHz frequencies which is applicable for Wireless Local Area Network (WLAN standards- 2.4-2.483 GHz for IEEE 802.11 b/g, 5.15-5.35 GHz and 5.725-5.825 GHz for IEEE 802.11a) applications and gives a bandwidth of approximately 340MHz. the bandwidth is calculated by subtracting lower frequency from the upper frequency at -10dB.

The proposed antenna design gives good impedance of approximately 48 ohms which shows that the antenna is perfectly matched and the power loss is minimum. The result of the designed antenna is given below:

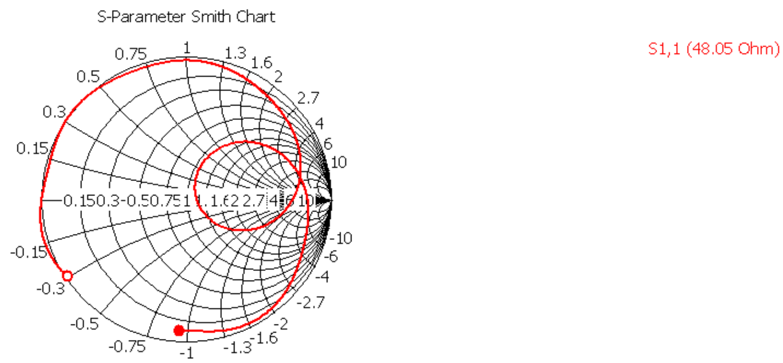


Figure 3.5 Smith Chart of MSA Resonating at 5.2 GHz

The designed antenna shows the VSWR of 1.14 at 5.2 GHz frequency.

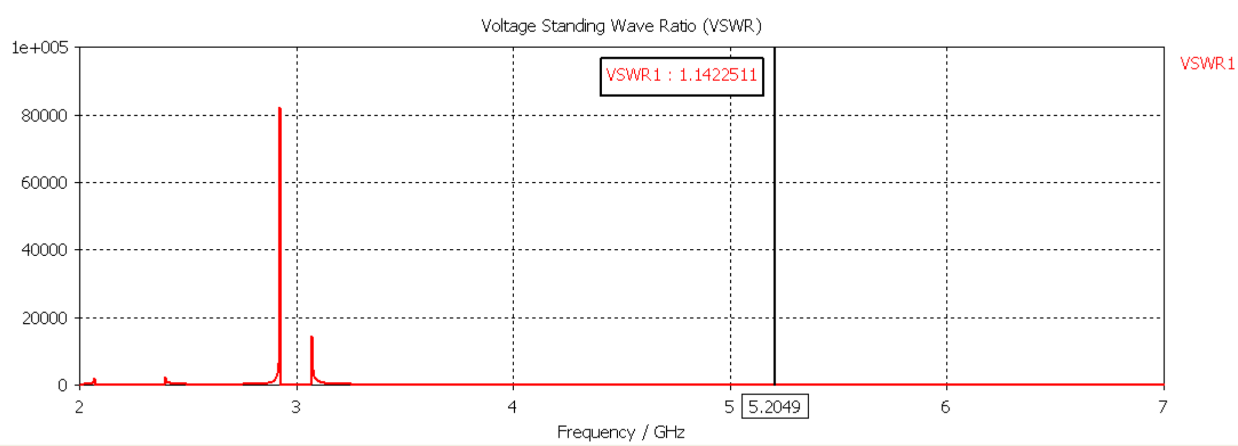


Figure 3.6 Simulated VSWR of MSA at 5.2 GHz

The simulation results of Directivity in 3D and 2D is given below, the value of Directivity is 6.4 dBi at 5.2 GHz frequency.

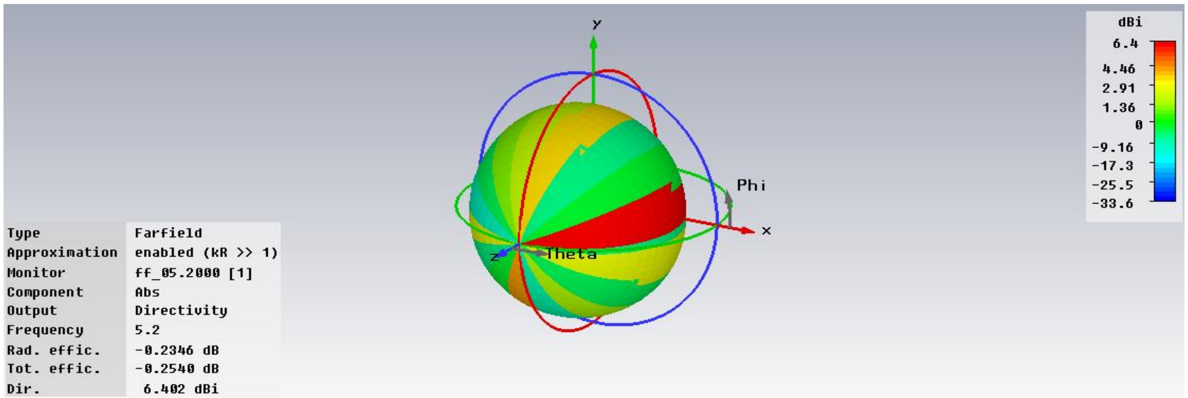


Figure 3.7 Simulated 3D Directivity at 5.2 GHz

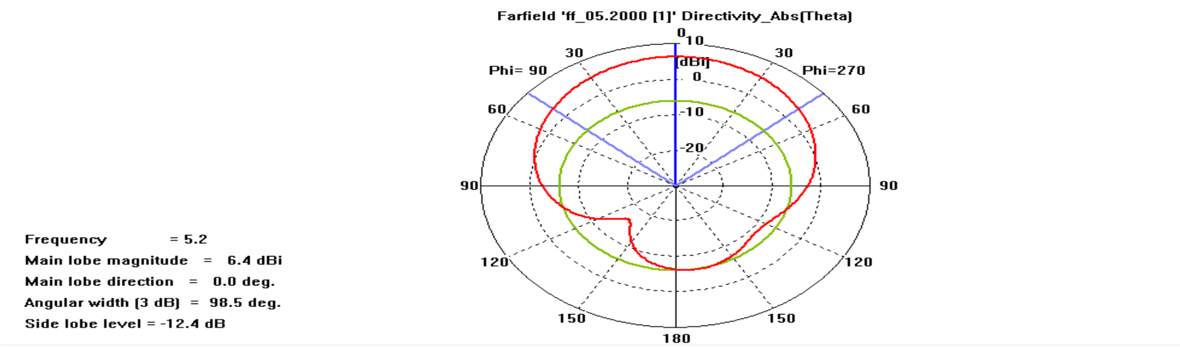


Figure 3.8 Simulated 2D Directivity at 5.2 GHz

The simulation result of the gain is given in Figure 3.10 and the gain obtained is 6.2 dB.

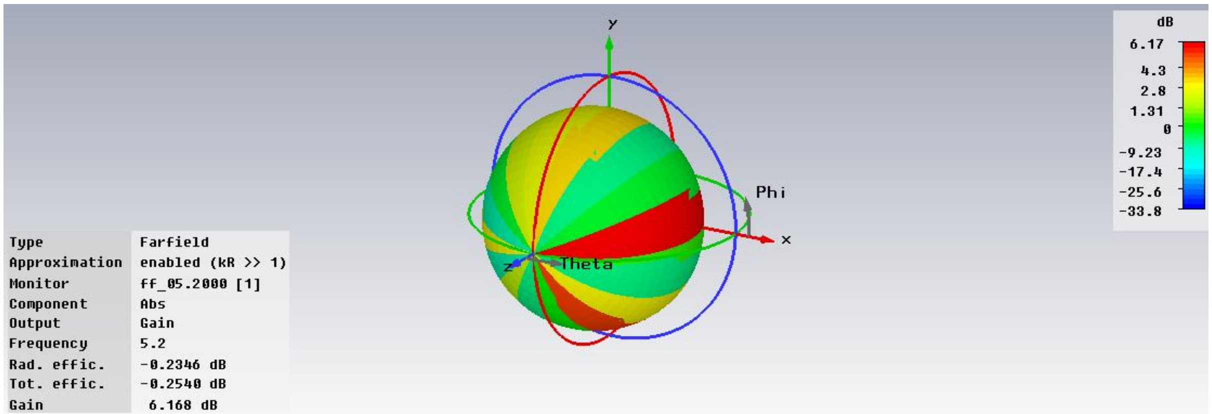


Figure 3.9 Simulated 3D Gain at 5.2 GHz

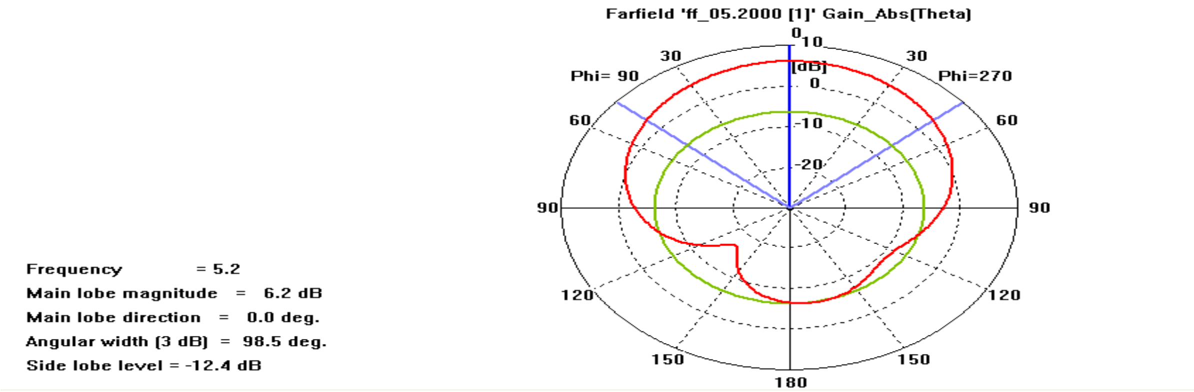


Figure 3.10 Simulated 2D Gain at 5.2 GHz

The results of the above designed antenna are summarized in the following table.

Parameters	**Values**
Operating frequency	5.2GHz
Return loss	-23.5dB
Impedance	48 ohms
VSWR	1.14
Bandwidth	340MHz
Directivity	6.4dBi
Gain	6.17dB

Table 3.3 Summary of Parameter Values of Designed Antenna at 5.2 GHz frequency

3.3.3 Physical Parametric Study of the Antenna

In this section, the effect of the various physical parameters like patch length, patch Width, aperture dimensions, antenna and feed substrates, feed line dimensions etc are studied, by varying one parameter at a time and keeping all other parameters Constant so that one can get an optimized antenna for the desired applications.

Effect of Patch Width

The Figure below shows the effect of patch width on the return loss. By decreasing the value of the patch width from 7mm to 3 mm the value of return loss decreases and the resonating frequency shifts towards right that is the resonating frequency increases.

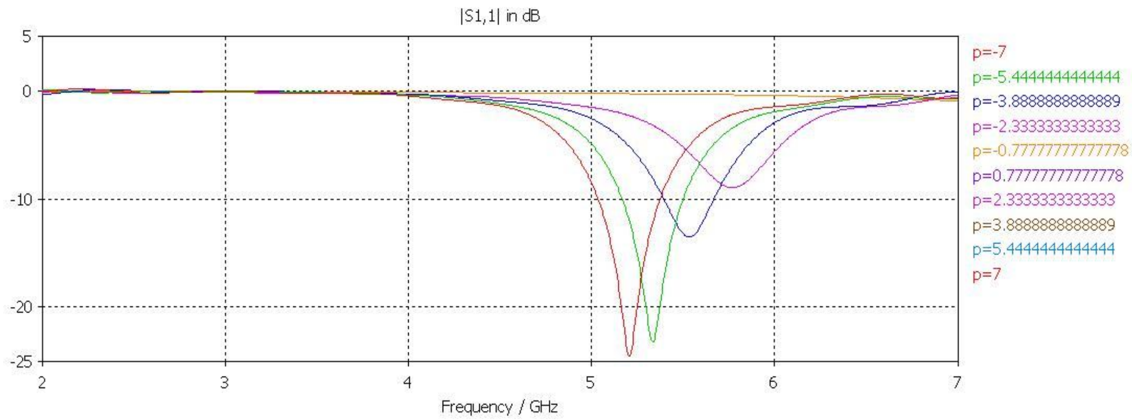


Figure 3.11 Variation of S Parameter with respect to Patch Width Resonating at 5.2 GHz

Effect of Slot Width

The Figure below shows the effect of slot width on the return loss, by decreasing the width of the slot there is small variation in the return loss and the resonating frequency.

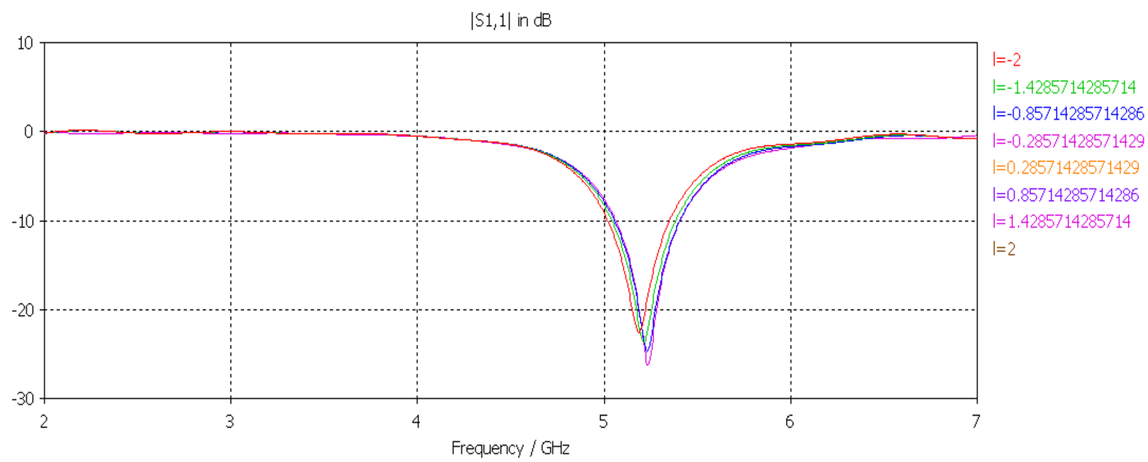


Figure 3.12 Variation of S parameter with respect to slot width resonating at 5.2 GHz

Effect of Feed Line Width

The Figure below shows the effect of width of feed line on the return loss, by decreasing the width of the feed line the return loss increases and the resonating frequency also increases but it affects the impedance of the antenna.

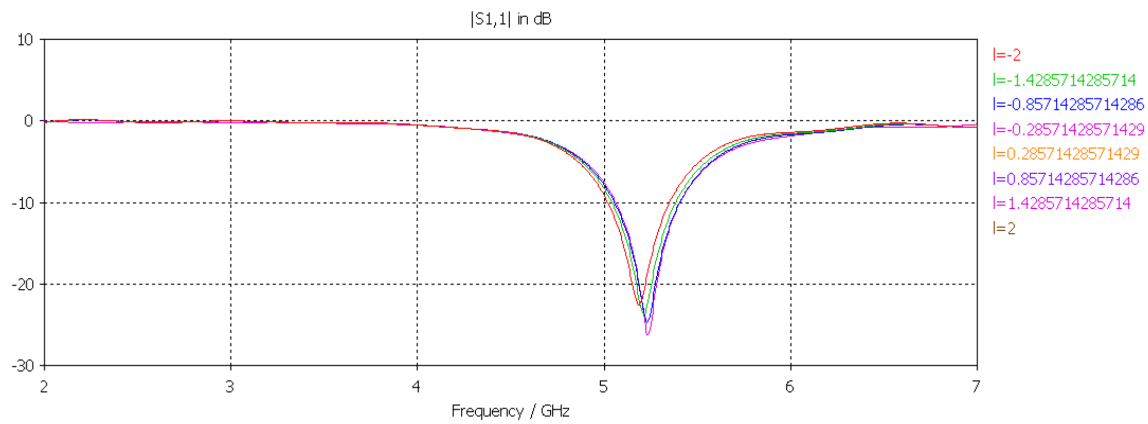


Figure 3.13 Variation of S Parameter with respect to Feed Line Width at 5.2 GHz

3.4 Design of Microstrip Patch Antenna for WLAN Applications Operating at 2.4GHz

The designed antenna has following specifications:

Variable	Value
Operating frequency (f_r)	2.4GHz
Dielectric constant ($\mathcal{E}_r$)	4.4
Substrate height (h)	1.57mm

Table 3.4 Single Band Antenna Specifications at 2.4 GHz

3.4.1 Antenna Design

The dimensions of the rectangular patch are width Wp is 31.916mm and length Lp is 27.134mm by using equation given in the topic 1.5.3. The radiating rectangular patch is printed on the upper side of the upper substrate. The two substrates used are of same material and have same height. The substrate is made up of material having dielectric constant 4.4 and height of the substrate is 1.57mm. The feed line is sandwiched between the two substrates. The width of the feed line is 2.74mm and the length from the center of the microstrip towards the patch axis along the positive y direction is 1.5mm. In this design the dimensions of the upper and the lower substrates are different. The following parameters for antenna design are calculated by using the above steps of the antenna design:

Variable	**Value**
Width of the patch (W_p)	31.916mm
Length of the patch (L_p)	27.134mm
Height of the patch (H_p)	0.035mm
Width of the ground (W_g)	51.456mm
Length of the ground (L_g)	42.874mm
Width of the feed line (W_f)	2.74mm
Width of the upper substrate	51.456mm
Length of the upper substrate	42.874mm
Width of the slot	6mm
Length of the slot	3mm

Table 3.5 Dimensions of Single Band Antenna Design for 2.4 GHz frequency

The Figure below shows the simulated antenna design using CST 9 microwave studio:

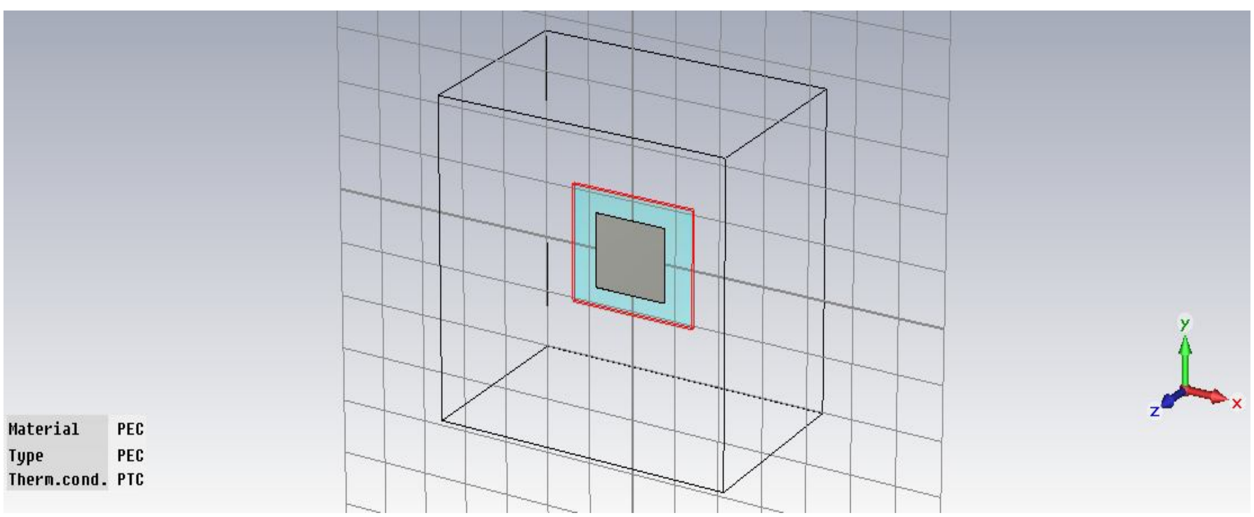


Figure 3.14 Antenna Design of MSA using CST 9 at 2.4 GHz

3.4.2 Simulation Results

The simulation results of antenna parameters like return loss, impedance, bandwidth, VSWR, gain and directivity are obtained using CST 9 microwave studio and given in the next section. The designed antenna gives a good return loss of -40dB which shows that matching of antenna is good and the losses are minimum. The bandwidth obtained is 92MHz where 84 MHZ is acceptable for WLAN applications at 2.4GHz. The simulated result of the antenna is given as follows:

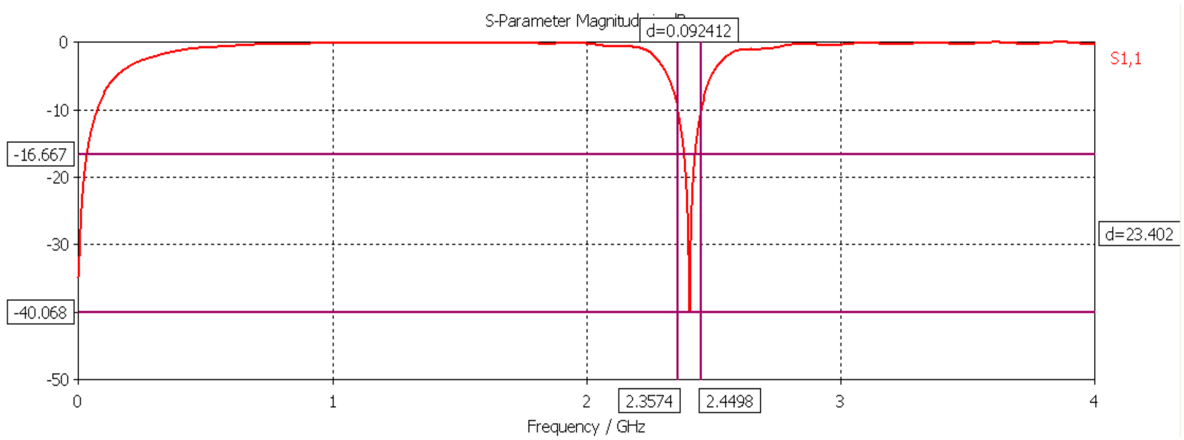


Figure 3.15 Simulated Return Loss of MSA Resonating at 2.4 GHz

The designed antenna gives an impedance of 50.75 ohms where as for practical applications impedance of 50 ohms is acceptable. The results show the best impedance thus antenna is perfectly matched.

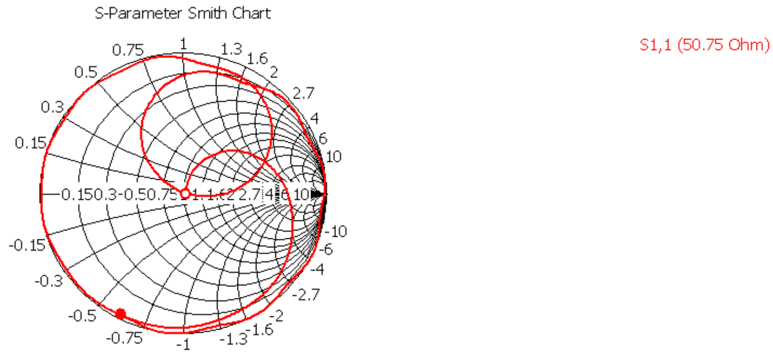


Figure 3.16 Smith Chart of MSA Resonating at 2.4 GHz

This VSWR parameter is used for matching and tuning of the transmitting antennas. For practical applications the value of VSWR lies between 1 and 2. The designed antenna gives a VSWR of 1.06 at 2.4GHz frequency. The simulation results of VSWR are given as follows:

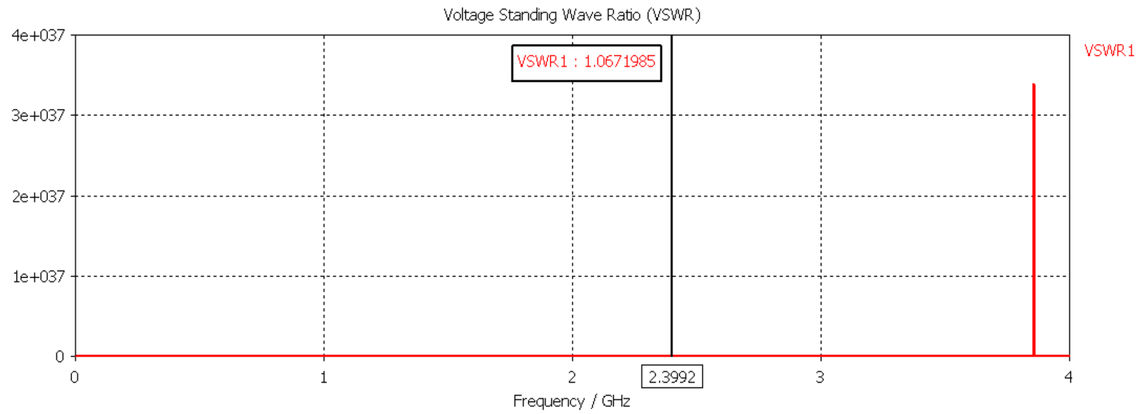


Figure 3.17 Simulated VSWR at 2.4 GHz

The above designed antenna gives a directivity of 5.96dBi at 2.4 GHz frequency. The simulated result of the proposed antenna is given below:

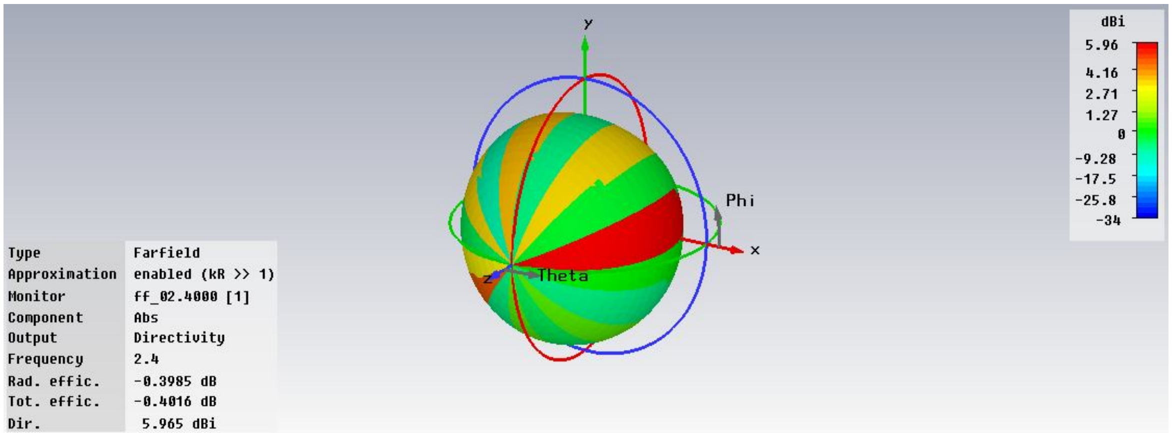


Figure 3.18 Simulated Directivity at 2.4 GHz

The designed antenna gives a gain of 5.57 dB at 2.4 GHz frequency. The simulated results are given as follows:

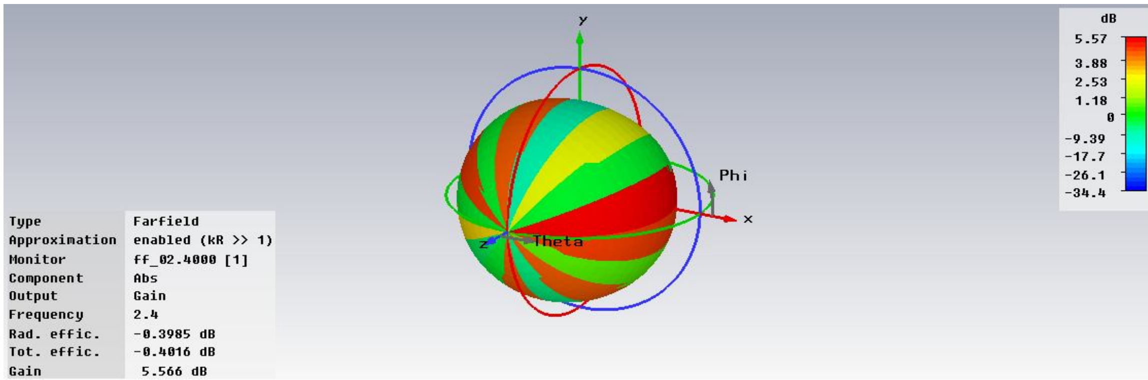


Figure 3.19 Simulated Gain of MSA at 2.4 GHz

The simulated results of various parameters of the above designed antenna are summarized in the following table. The simulated values of parameters show that antenna results are good for practical WLAN applications.

Parameters	**Values**
Operating frequency	2.4GHz
Return loss	-40dB
Impedance	50.75ohms
VSWR	1.06
Bandwidth	92 MHz
Directivity	5.96dBi
Gain	5.57dB

Table 3.6 Summary of the Antenna Parameters of Designed Antenna at 2.4 GHz frequency

3.4.3 Physical Parametric Study of the antenna

Effect of Slot Width

The results of the antenna varies if any parameter is varied with rest of the parameters are constant, by decreasing the width of the slot on the patch the return loss decreases and the resonating frequency shifts towards left that is the resonating frequency decreases.

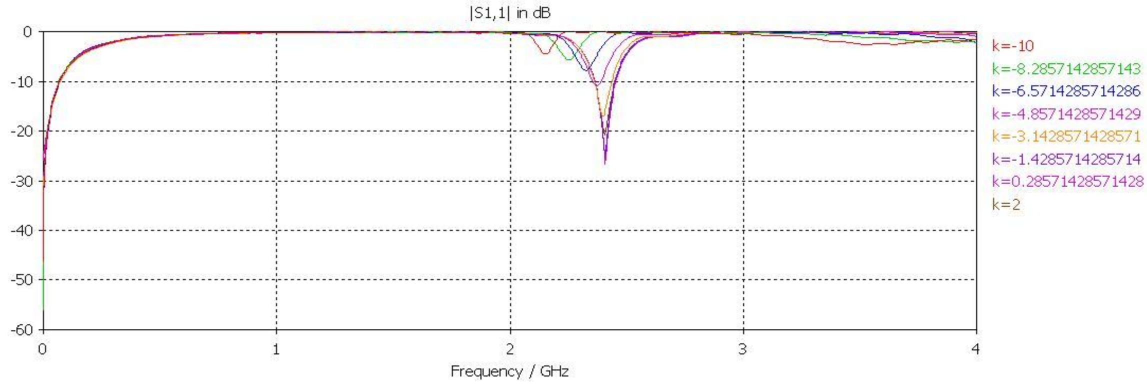


Figure 3.20 Variation of S Parameter with respect to Slot Width Resonating at 2.4 GHz

Effect of Feed Line Width

The Figure below shows the effect of width of the feed line on the return loss, by decreasing the value of the width of the feed line the return loss of the antenna decreases.

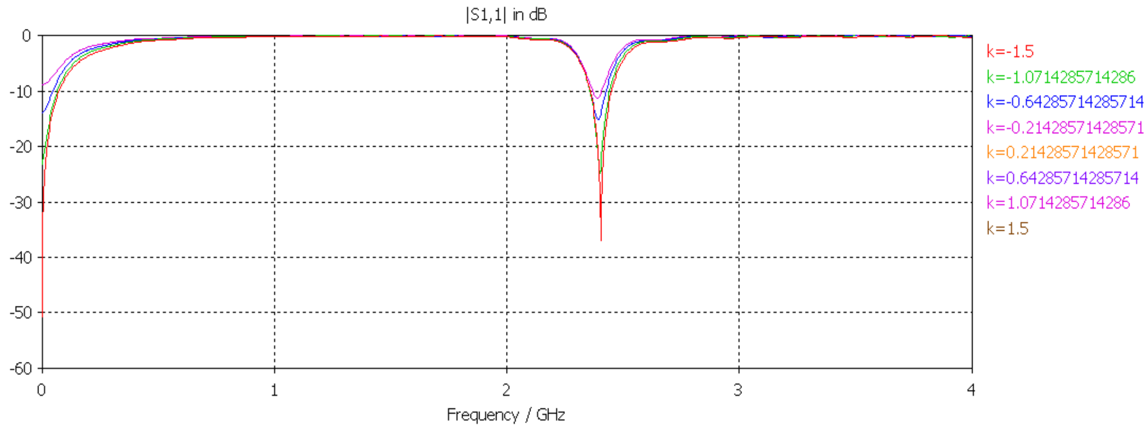


Figure 3.21 Variation of S Parameter with respect to Feed Line Width at 2.4 GHz

3.5 Design of Dual Band Proximity Coupled E-Shaped Stacked Microstrip Patch Antenna for Wireless Communication Applications at 2.4GHz and at 4.65GHz

The continuous shrinking size of electronic equipments demands similar size antenna elements in order to fit properly in wireless devices without compromising the other radiation properties of the antenna. But as far as size of these patches concerned, the patch length should be around half-a-wavelength for the structure to act as a good radiator. Different techniques have already been used for the antenna size reduction such as using the substrate with high dielectric constant, edge shorted patches with shorting plates or shorting walls, use of the shorting pin at the suitable position etc [40].

E shaped slot on the upper patch of the antenna gives better results and helps in improving the return loss and other parameters of antenna. A stacked antenna is designed which helps in increasing the bandwidth and also covers two bands but the size of the antenna also increases. The slots help in improving the gain and the coupling of the antenna which in short improves the efficiency of the designed antenna.

3.5.1 Stacking

The stacking is the advanced technique used to increase the bandwidth of the antenna. In order to further increase the bandwidth, a combination of two or more of these methods may be used which leads to an increase in bandwidth. In stacking the number of substrates and the number of patches are increased. In proximity the feed line is sand witched between two substrates but in stacking extra substrate and the patch fabricated on that substrate is attached on the radiating patch of simple proximity feed antenna without stacking. The air gap is defined between the radiating patch of the main antenna and the stacked substrate.

3.5.2 Antenna Design

In this section a Dual band antenna is defined which resonates efficiently at two frequencies 2.4GHz and 4.65GHz. In this design stacking is used, the size of the stacked substrate is different from the main substrates. The design of the antenna has patch width Wp of 39.43mm and the length of patch Lp is 31.16mm by using the above given steps of the antenna parameter calculation. The substrates used are of same material having dielectric constant of 3.38 and the height of the substrate is 1.524mm. The dimensions of the stacked patch are width Wp 22.72mm and the length Lp is 17.72mm. The dimensions of the E shaped slots are given as the width of the upper slot is 9.5mm and the length of the slot is 3.425, the upper and the lower slot are of same dimensions and the dimensions of the center slot is width 7.7mm and length 2.75mm. The simulated design of the antenna is given the Figure below.

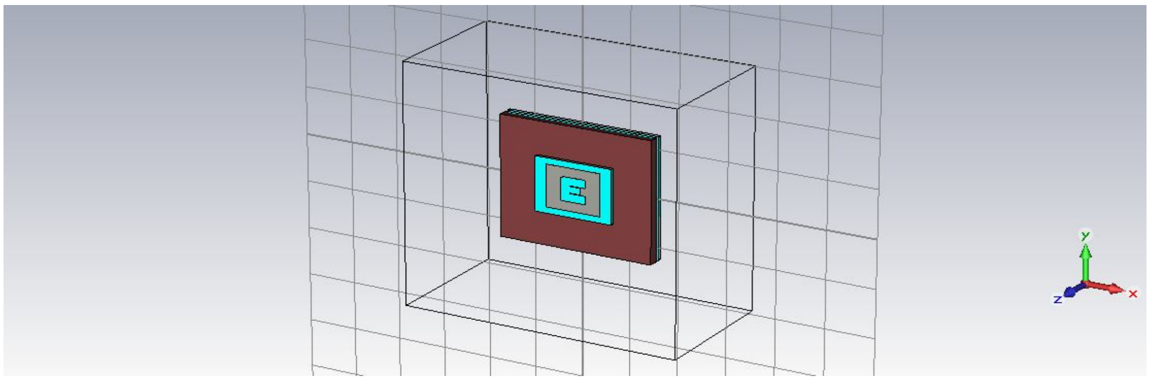


Figure 3.22 Simulated Design of the Dual Band MSA

The following table shows the various parameters of the designed antenna having E shaped slot:

Resonating frequency fr (GHz)	**Feeding technique**	**Patch width Wp(mm)**	**Patch length Lp(mm)**	**Height of the substrate h(mm)**	**Dielectric constant (Ɛr)**
2.4	Proximity	39.43	31.16	1.524	3.38
4.65	Proximity	22.72	17.72	1.524	3.38

Table 3.7 Parameters of Dual Band Antenna Design Resonating at 2.4 GHz and 4.65 GHz Frequencies

3.5.3 Simulation Results

The return loss (RL) is the parameter which indicates the amount of power that is lost to the load and does not return as a reflection. As already known, waves are reflected leading to the formation of standing waves when the transmitter and antenna impedance do not match. Hence the RL is the parameter similar to VSWR to indicate how well the matching between the transmitter and the antenna has taken place [4].

The designed antenna gives the excellent results of return loss that is at frequency 2.4GHz it gives the return loss of -26dB and at 4.65 GHz frequency it gives the return loss of -30dB where -10dB is acceptable for practical applications which shows that the above designed antenna is perfectly matched and the power lost is minimum. The simulated results of the return loss and given in the Figure below.

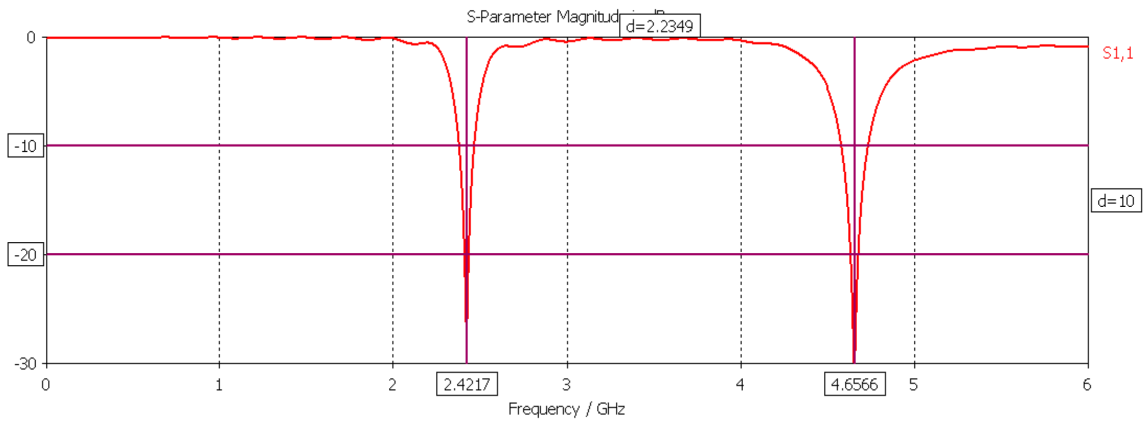


Figure 3.23 Simulated Return loss of Dual Band MSA at 2.4 GHz and 4.6 GHz

Bandwidth is defined as the difference the upper frequency and the lower frequency. At 2.4GHz frequency the bandwidth obtained is 90MHz where 84MHz is acceptable and at 4.65 GHz the bandwidth obtained is 115MHz which is efficient.

VSWR is another parameter defined for antenna which shows that how well the antenna is matched. The value of VSWR for a good antenna is less than or equal to 2 for practical antennas, the designed antenna gives a VSWR of 1.2 at 2.4GHz and 1.1 at 4.65GHz, which is below 2 so that value defines that the antenna is perfectly matched.

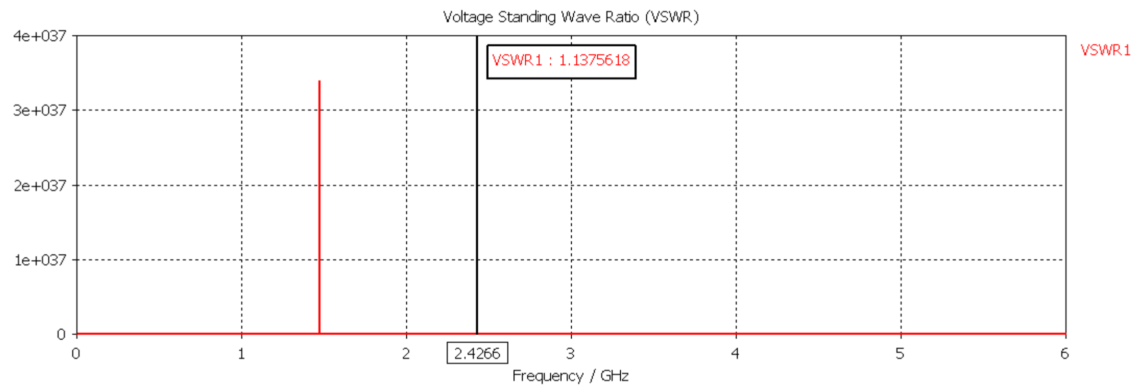


Figure 3.24 (a) VSWR at 2.4GHz

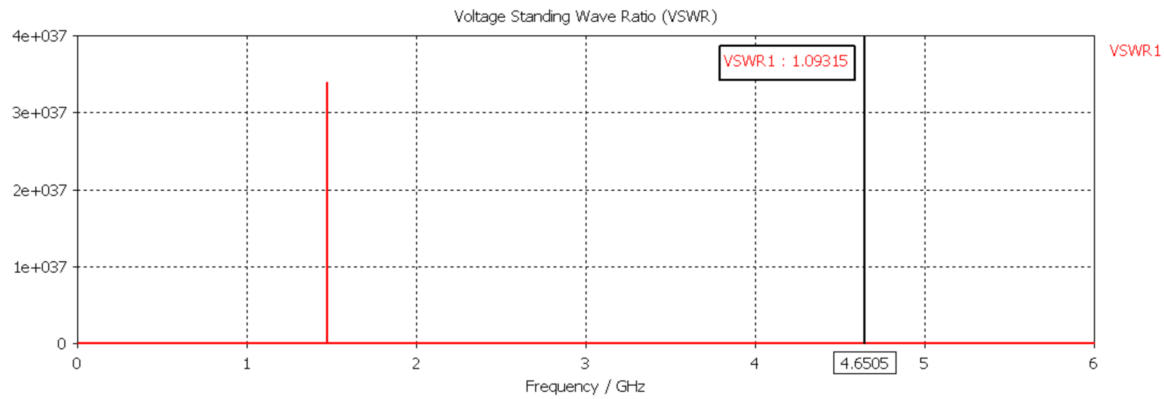


Figure 3.24 (b) VSWR at 4.65 GHz

The impedance of the above designed antenna is 47.47 ohms which is approximately equal to 50ohms which is acceptable. The smith chart below shows two circles for two resonating frequencies. The circles passes through resistance 1 circle which shows that the antenna is perfectly matched and thus losses are minimum.

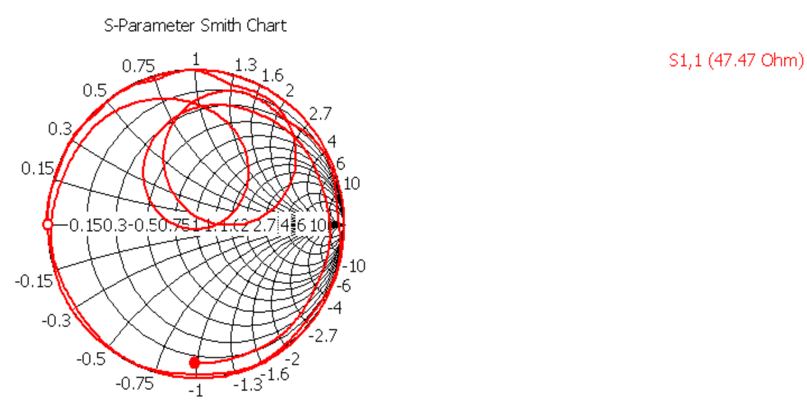


Figure 3.25 Smith Chart of Dual Band MSA at 2.4 GHz and 4.65 GHz

The current distribution graph shows the direction of the current flow and the intensity of the current. The surface current graph below shows that the current is distributed along the whole patch area but it is maximum at the center along the feed line, so if a slot is cut at that position and the length and width of the slot are varied accordingly the desired results can be obtained. The surface current distribution is shown in the figure below:

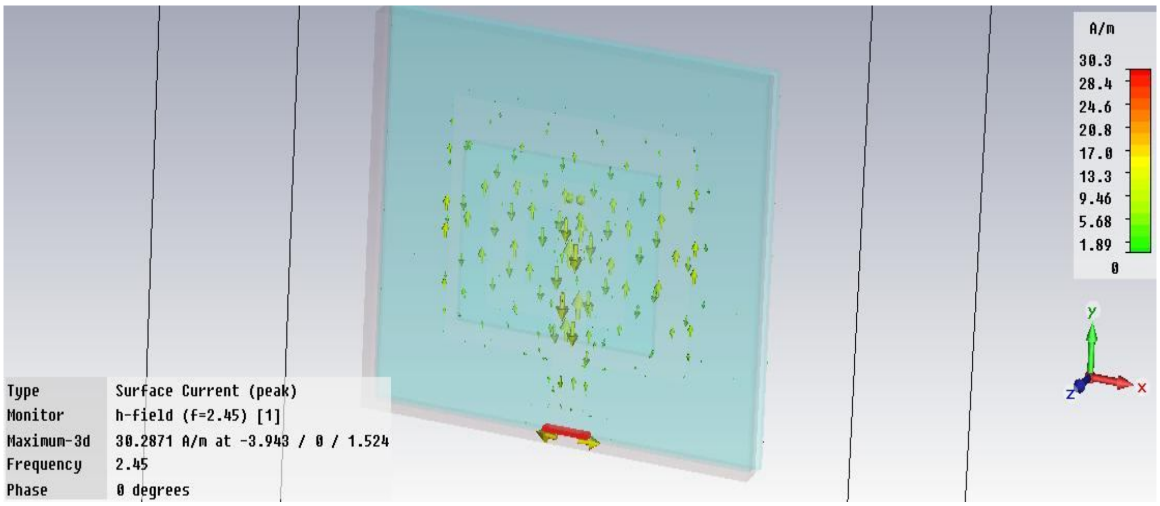


Figure 3.26 Surface Current at 2.4 GHz Frequency

The simulated antenna design gives the directivity of 6.8 dBi at 2.4 GHz and 5.4 dBi at 4.65GHz the simulated results of directivity are given in the Figure below.

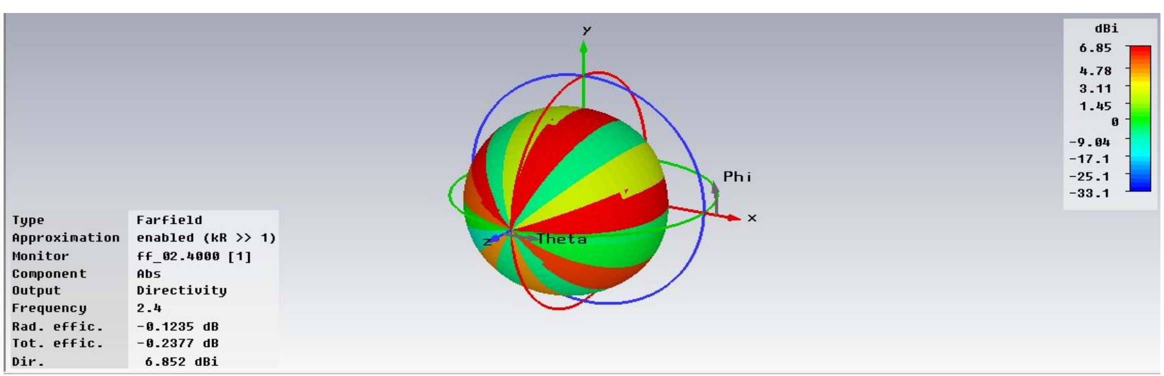


Figure 3.27 (a) Directivity at 2.4GHz

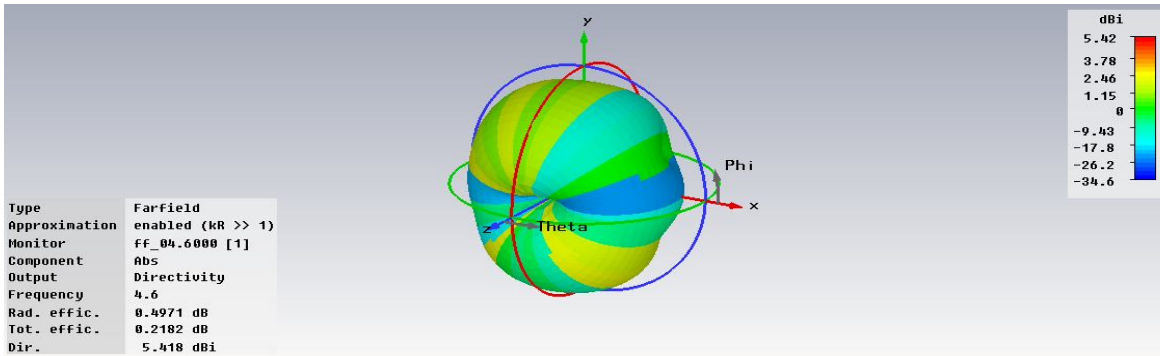


Figure 3.27 (b) Directivity at 4.65 GHz

Gain is a dimensionless quantity. The simulation results of the gain are given in the Figure below and the gain obtained is 6.7 dB at 2.4GHz and 5.9 dB at 4.65GHz.

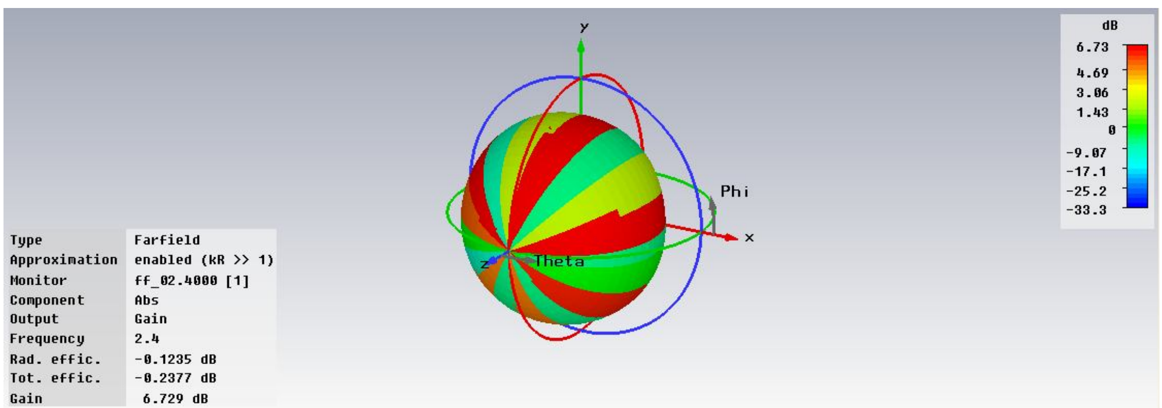


Figure 3.28 (a) Gain at 2.4GHz

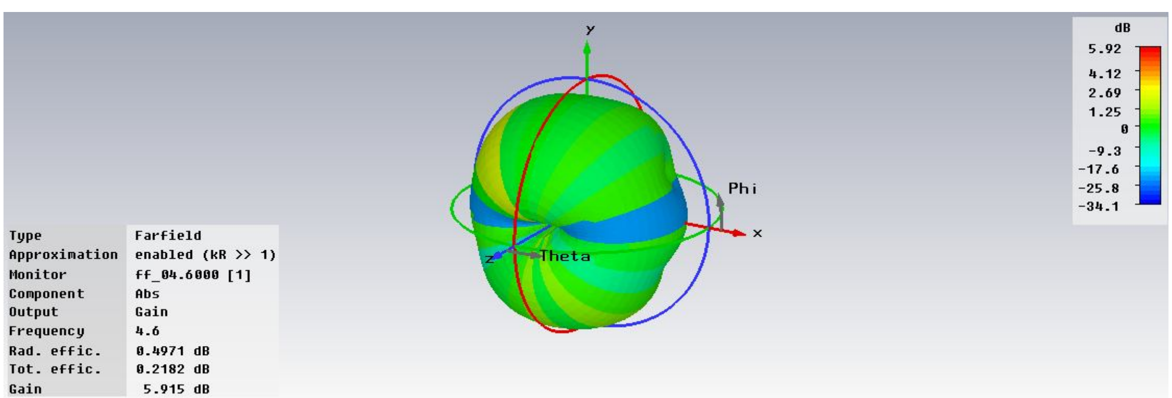


Figure 3.28 (b) Gain at 4.65GHz

The results of the dual band antenna operating at 2.4 GHz and 4.65GHz are summarized in the following table.

Resonating frequency fr (GHz)	**Return loss (dB)**	**Bandwidth (MHz)**	**VSWR**	**Directivity (dBi)**	**Gain (dB)**
2.4	-26	90	1.2	6.8	6.7
4.65	-30	155	1.2	5.4	5.9

Table 3.8 Comparison of Antenna Parameters Values of Dual Band Antenna Resonating at 2.4 GHz and 4.65 GHz Frequencies

The above designed antenna gives excellent results and covers two frequencies that 2.4GHz and 4,65GHz which efficient parameter values and can b used for various applications in military, RADAR and various wireless applications. By the use of stacking the bandwidth of the antenna is increased but it also increases the size of the antenna.

The Figure below shows the effect of the patch width on the return loss:

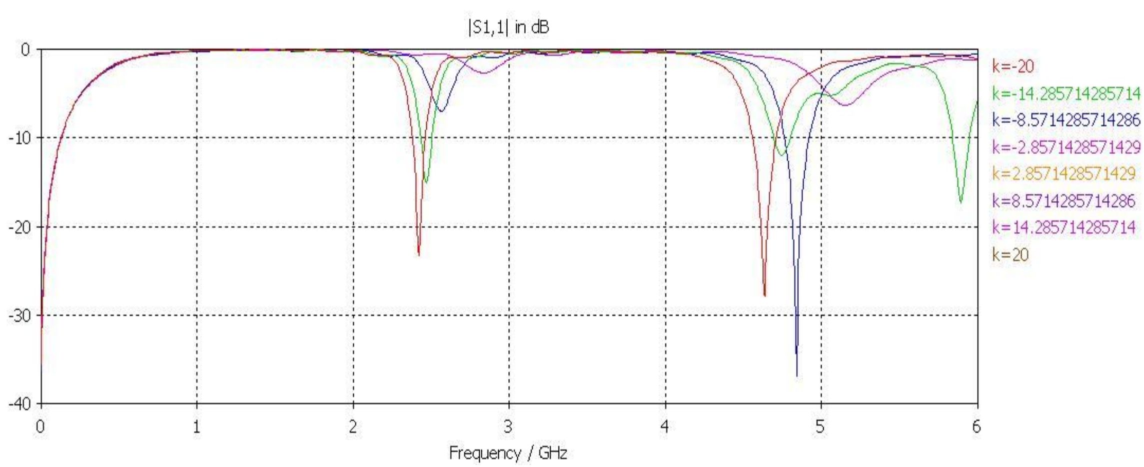


Figure 3.29 Variation of S Parameter with respect to of Patch Width

3.6 Design of Triple Band Microstrip Patch Antenna Using Proximity Feeding for WLAN Applications Using Defected Ground Structure and Stacking

In this section a microstrip patch antenna is discussed which operates at three different resonating frequencies which are 2.45GHz, 4.1 GHz and 5.8GHz. These frequencies cover the

WLAN applications. In this a defected ground structure of dumbbell shaped is used which helps in removing the higher harmonics and helps to in increase the gain and bandwidth. Stacking is used to increase the number of bands and to increase the overall bandwidth of the antenna. An inverted T shaped slot on the radiating patch gives the better response and a new resonating frequency.

Limited work is done in the field of usage of DGS for size reduction of microstrip antennas is there in literature, although its application have been reported for harmonic reduction, cross-polarization suppression and mutual coupling reduction in antenna arrays etc. Although the back to back geometries have been reported by the various researchers but here proximity coupling with the defected ground structure is used for the consideration of the increased bandwidth [34]. A dumbbell shaped DGS is used in the common ground plane of a back to back combined single feed proximity coupled microstrip antenna.

3.6.1 Defected Ground Structure

Since the late 1980‘s, defected ground structures (DGS) have attracted the interest of many researchers, due to their interesting properties in terms of size miniaturization, suppression of surface waves and arbitrary stop bands. Since then, they have been used in many applications like low pass filters, band pass filters, antennas, waveguides and others. A DGS unit cell is a defect in the ground plane of a physical transmission line be it microstrip, coplanar waveguide or whatever structure where a reference ground plane conductor exists, which is capable of producing a transmission zero in the response of the structure. The resonant frequency of this transmission zero depends on the physical dimensions of the defect. The main advantage of DGS, that it is easier to model and therefore to use in more complex structures. The first DGS structure is the well-known dumbbell shaped DGS, published in 1998.

3.6.2 Antenna Design

The antenna can b designed by using following specifications:

Variables	Values
Operating frequency (f_r)	2.45 Ghz, 4.1GHz, 5.8GHz
Dielectric constant ($\mathcal{E}_r$)	4.4

Height of the substrate (h)	1.57mm

Table 3.9 Triple Band Antenna Specifications

In this section a triple band antenna is defined which resonates efficiently at three frequencies 2.45GHz, 4.1GHz and 5.8GHz. In this design stacking and DGS is used. The size of the stacked substrate is different from the main substrates. The design of the antenna has patch width Wp of 29.036mm and the length of patch Lp is 25.054mm is calculated using transmission line model equations given in chapter 1. The substrates used are of same material having dielectric constant of 4.4 and the height of the substrate is 1.57mm. The dimensions of the stacked patch are width Wp 21.82mm and the length Lp is 17.218mm. The dimensions of the inverted T shaped slots are given as the width of the vertical slot is 3mm and the length is 20mm, the dimensions of horizontal slot are width 11mm and length 1.5 mm. The simulated design of MSA is given below.

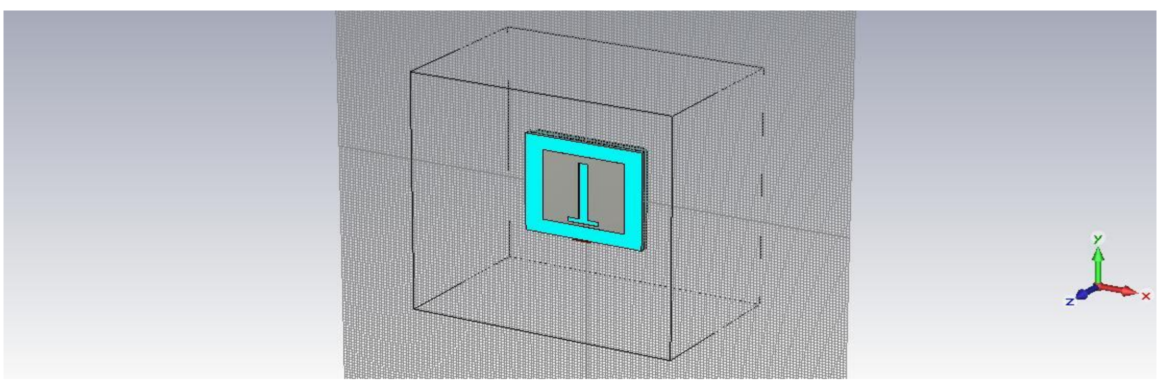


Figure 3.30 Simulated Design of Triple Band MSA

By using the given specifications the following parameters for antenna design are calculated by using the above steps of the antenna design:

Variable	Value
Width of the patch (W_p)	29.036mm
Length of the patch (L_p)	25.054mm
Height of the patch (H_p)	0.035mm
Width of the ground (W_g)	21.056mm
Length of the ground (L_g)	34.874mm
Width of the substrate	41.456mm
Length of the substrate	34.874mm
Width of the stacked patch	21.82mm
Length of the stacked patch	17.218mm
Width of the stacked substrate	24.774mm
Length of the stacked substrate	21.438mm
Height of the air gap	1.5mm
Dimensions of the T shaped slot on the patch (vertical slot)	3mm, 20mm
Dimensions of T shaped slot on the patch (horizontal slot)	11mm, 1.5mm
Dimensions of the slot on the stacked patch	10mm, 1.5mm
Width of the feed line	0.8mm
Dimensions of dumbbell shaped slot on the ground	3mm, 1.5mm and 7mm, 3mm

Table 3.10 Dimensions of the Triple Band Antenna Resonating at 2.4 GHz, 4.1 GHz and 5.8 GHz Frequencies

3.6.3 Simulation Results

The above designed antenna gives return loss of -16dB and bandwidth 88MHz of at 2.45GHz, -13.5dB and bandwidth of 75MHz at 4.1 GHz and -17.5dB and bandwidth of 67Mhz at 5.8GHz frequency. The simulated results of the proposed antenna are given below:

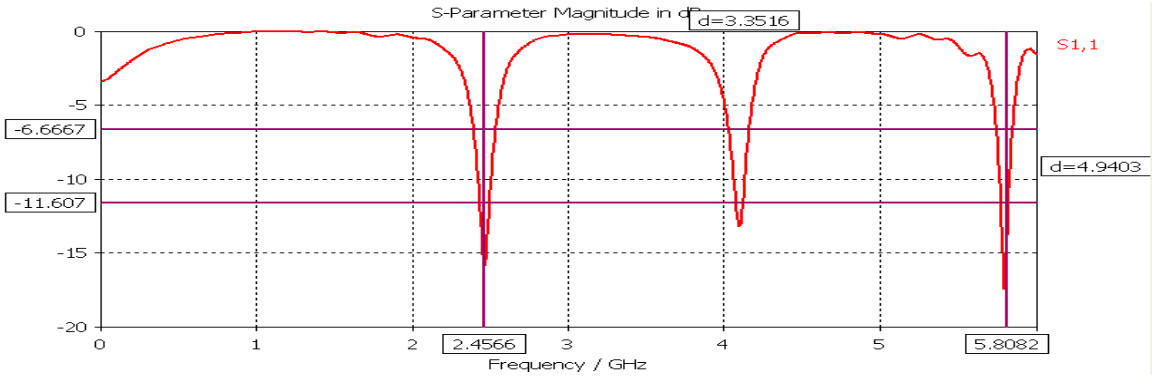


Figure 3.31 Simulated Return Loss of MSA Resonating at 2.45 GHz, 4.1GHz and 5.8 GHz

The designed antenna gives an impedance of around 52 ohms which is nearby 50ohms so it is acceptable. The simulated result of impedance is given below:

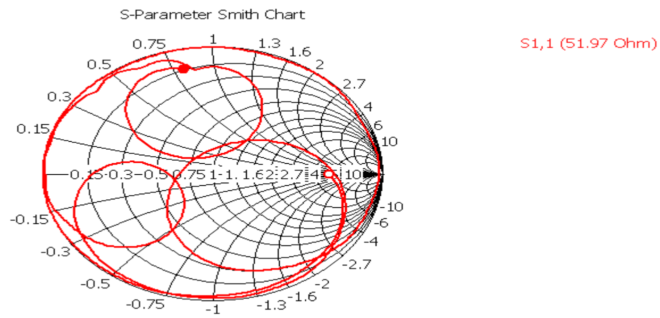


Figure 3.32 Smith Chart of MSA Resonating at 2.45 GHz

The simulated antenna gives VSWR of 1.4 at 2.45GHz, 1.5 at 4.1GHz and 1.3 at 5.8GHz. The simulation results of VSWR at three different resonating frequencies are given as follows:

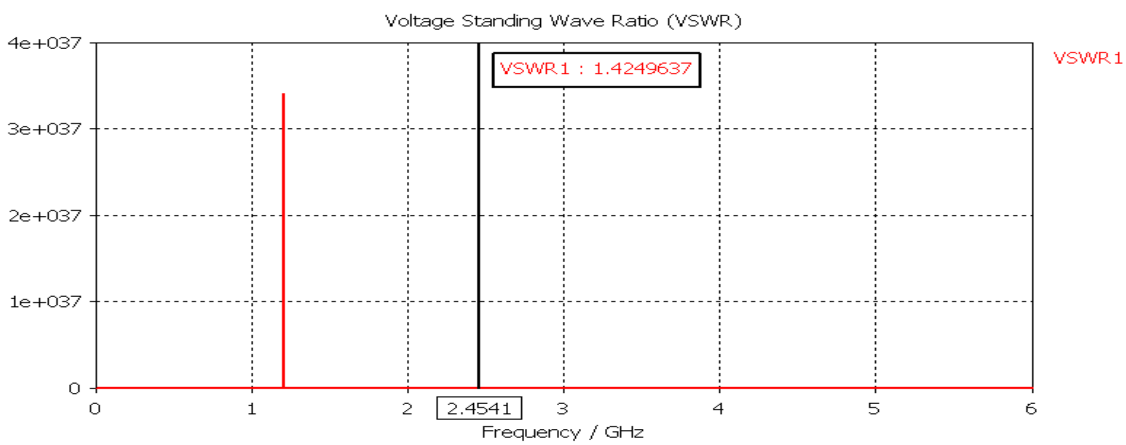


Figure 3.33 (a) Simulated VSWR at 2.45 GHz Frequency

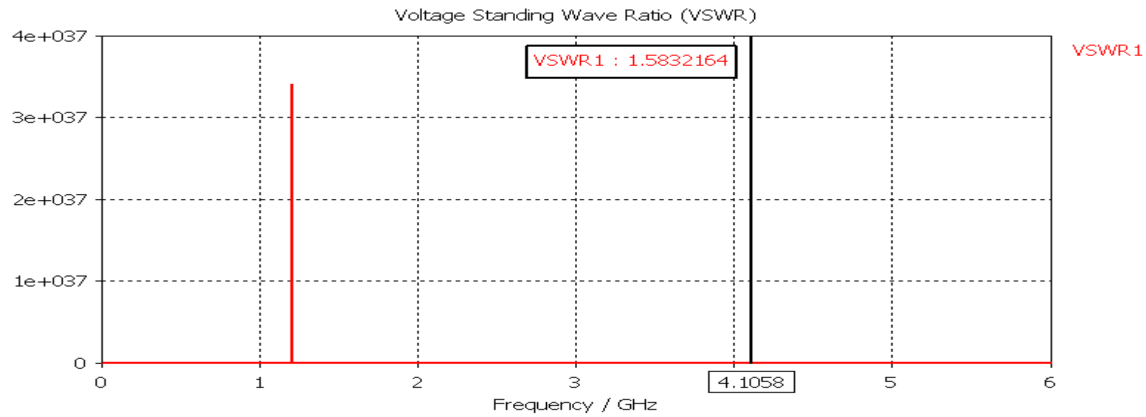


Figure 3.33 (b) Simulated VSWR at 4.1GHz Frequency

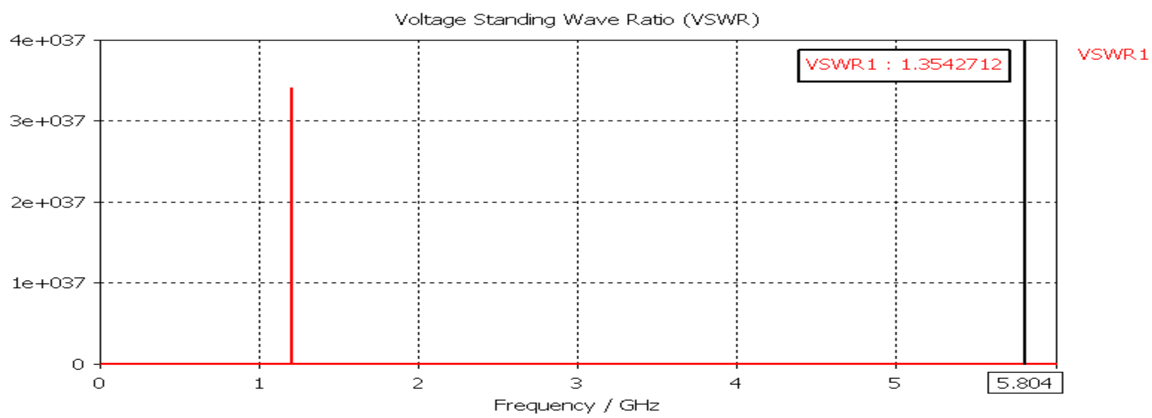


Figure 3.33 (c) Simulated VSWR at 5.8GHz Frequency

The designed antenna gives a directivity of 3.39 dBi at 2.45GHz, 6.24 dBi at 4.1 GHz and 4.6 dBi at 5.8 GHz. The results of directivity at three different frequencies are given below:

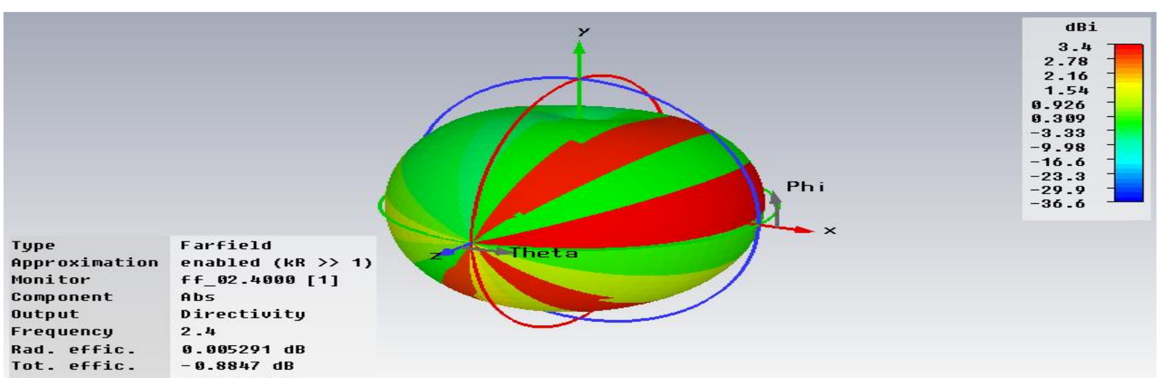


Figure 3.34 (a) Simulated Directivity at 2.45GHz

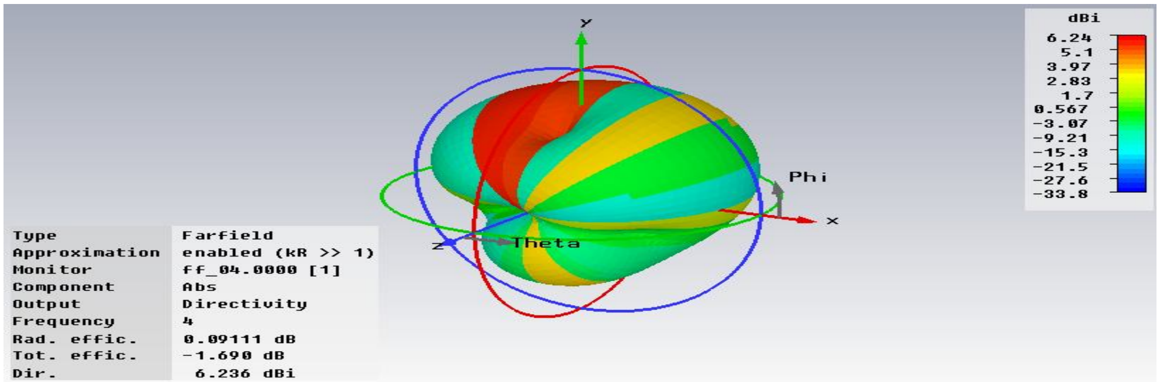


Figure 3.34 (b) Simulated Directivity at 4.1 GHz

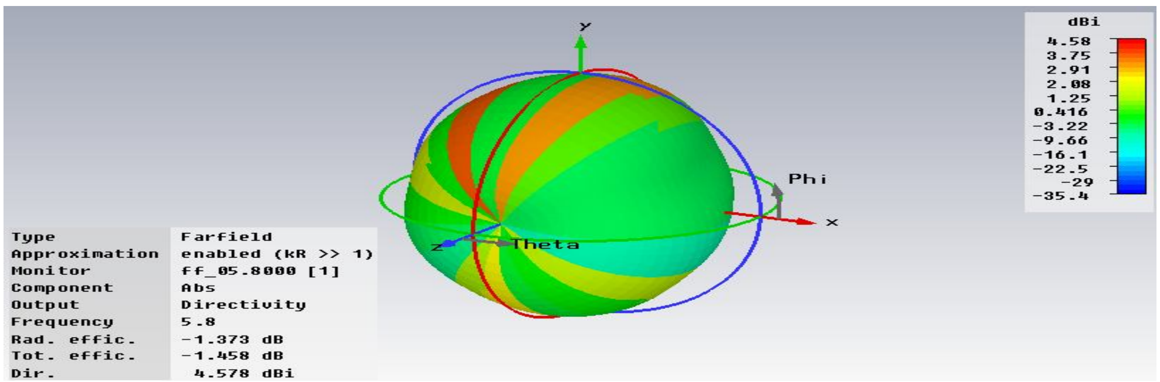


Figure 3.34 (c) Simulated Directivity at 5.8 GHz

In this design a reduced ground structure is used which decreases the gain of the antenna but the overall antenna parameters are efficient. The designed antenna gives a gain of 3.4dB at 2.45 GHz, 6.3 dB at 4.1 GHz and 3.2 dB at 5.8 GHz. The simulated results of gain at three different frequencies are given below:

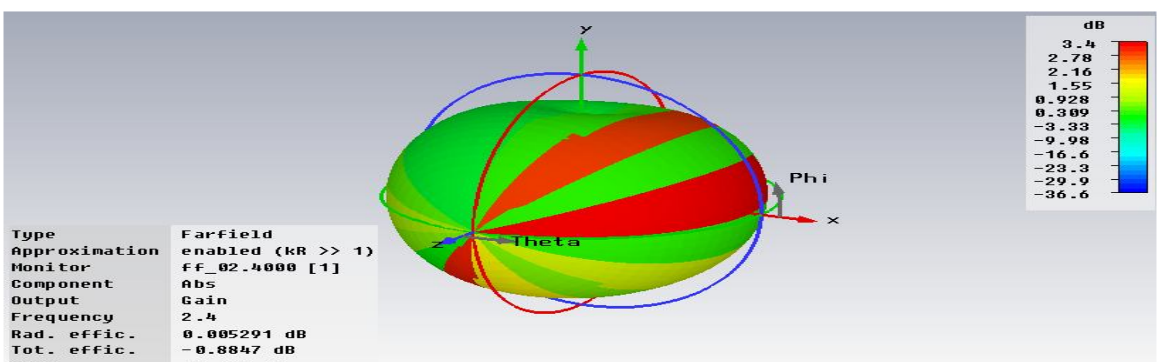


Figure 3.35 (a) Gain at 2.45 GHz Frequency

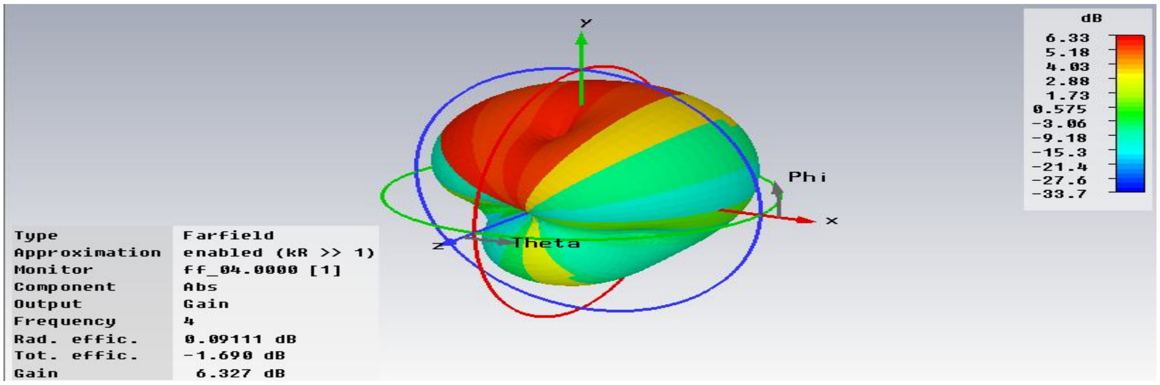


Figure 3.35 (b) Gain at 4.1 GHz Frequency

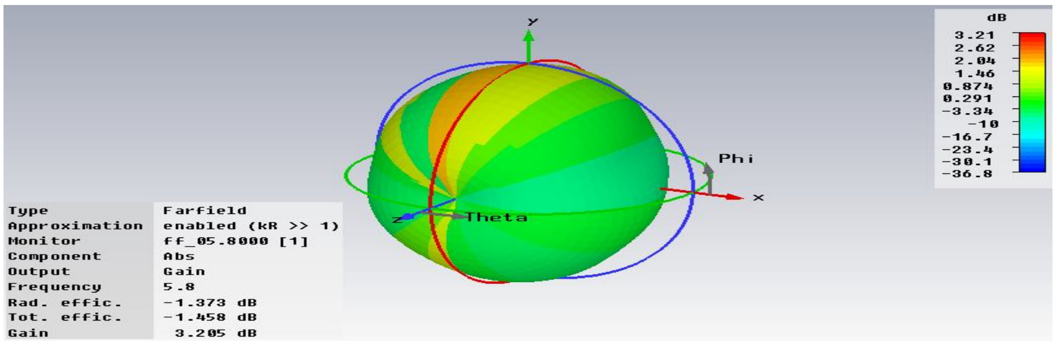


Figure 3.35 (c) Gain at 5.8 GHz Frequency

The comparison of the parameter values at three different resonating frequencies are given in the table below

Parameters	Operating frequency 2.45GHz	Operating frequency 4.1 GHz	Operating frequency 5.8GHz
Return loss	-16 dB	-13 dB	-17.5 dB
Impedance	52 ohms	52 ohms	52 ohms
VSWR	1.4	1.5	1.35
Bandwidth	88 MHz	75 MHz	67 MHz
Directivity	3.4 dBi	6.2 dBi	4.56 dBi
Gain	3.4 dB	6.3 dB	3.2 dB

Table 3.11 Comparison of the antenna parameters values of triple band antenna resonating at 2.4 GHz, 4.1 GHz and 5.8 GHz

The table above shows that the antenna is acceptable, for various applications. The return loss is maximum at 5.8 GHz frequency, the gain/directivity is maximum at 4.1 GHz frequency and bandwidth is maximum at 2.4 GHz frequency. Due to stacking the overall bandwidth is increased. The impedance obtained shows that the antenna is matched.

3.7 Conclusion

In the above chapter single, dual and triple band antennas are simulated using CST9 microwave studio, these antenna designs give efficient simulated results for return loss, BW, gain, directivity, impedance etc and can be used for various wireless applications like WLAN, WiMAX and radio altimeters.

Chapter 4

Fabrication of Antennas and Comparison of Their Results with the Simulation

In this chapter the simulation and fabrication of two single band antennas operating at WLAN frequency bands has been done. The simulation has been carried out using CST9 software and the fabrication is done using PCB fabrication process. The results are measured on VNA and compared with the simulated ones.

4.1 Simulated Antennas Resonating At 5.2 Ghz And 2.4 Ghz Respectively

By referring to section 3.3 and 3.4 for design of an antenna resonating at 5.2 GHz and 2.4GHz we obtain the following parameters for simulation using transmission line model(1.5.3) The simulated results of return loss and the smith chart of the antenna designs resonating at 5.2 GHz and 2.4 GHz for WLAN applications are given below:

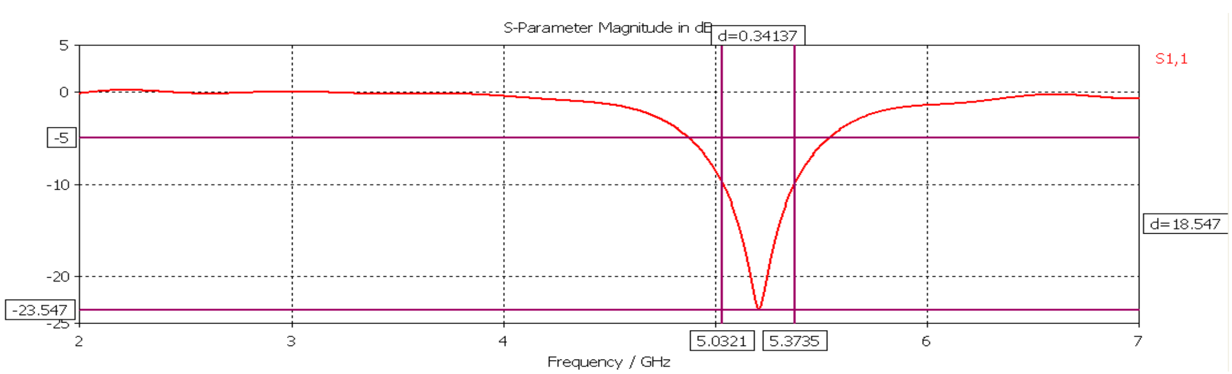


Figure 4.1 Simulated Return Loss at 5.2 GHz frequency

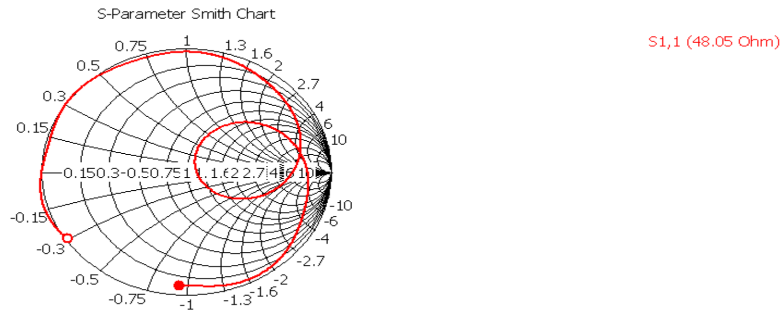


Figure 4.2 Smith chart at 5.2 GHz frequency

The following are the simulated results of antenna resonating at 2.4 GHz

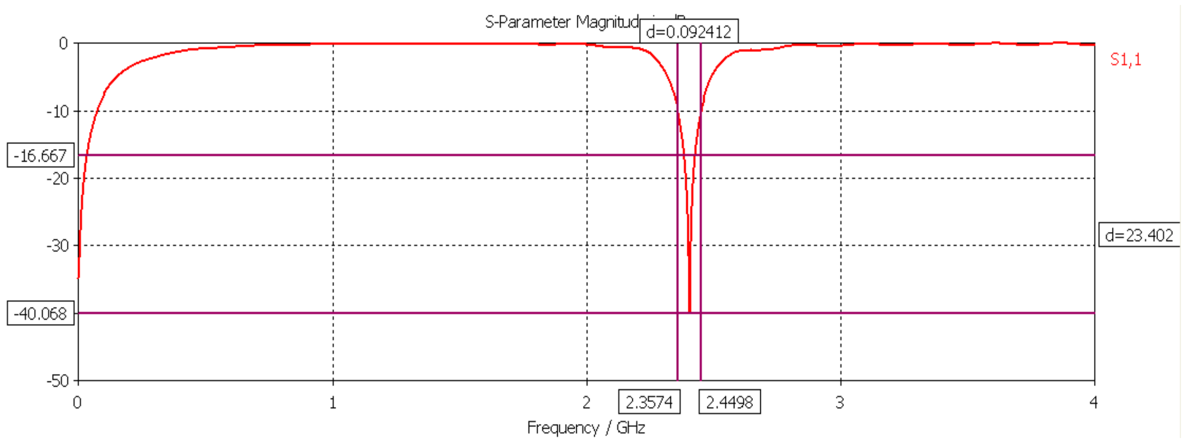


Figure 4.3 Simulated Return Loss at 2.4 GHz Frequency

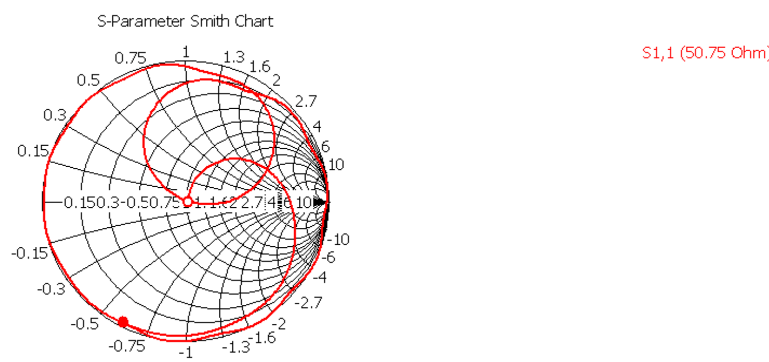


Figure 4.4 Smith chart at 2.4 GHz Frequency

The table below shows the simulated results of the designed antenna at 5.2 GHz and 2.4 GHz frequencies.

Parameters	Simulated results at 5.2 GHz frequency	Simulated results at 2.4 GHz frequency
Return loss	-23.5dB	-40dB
Impedance	48 ohms	50.75 ohms

Table 4.1 Simulated Results of Designed Antenna at 5.2 GHz and 2.4 GHz Frequencies

4.2 Flow Chart of Antenna Fabrication Process

In this topic whole fabrication procedure of the microstrip patch antenna using proximity feeding technique is covered. The fabrication of antenna is done in few steps which are given in the flow chart which makes easy to understand the fabrication procedure.

The flow chart of the antenna fabrication is given below:

Make the layout of the antenna design using layout plus software using 2007 version

↓

Develop the negative of the layout of the designed

↓

Take the copper sheet and clean it

Cut the copper sheet of required dimensions

Make the photo printing of patch, ground and feed line on the PCB

Dip the copper sheet in the photo resists solution and then after that put it in the oven for drying

Put that PCB in the UV exposure unit

Wash the PCB and put it into the etching solution which contains ferric chloride solution. Take it out and wash it

Figure 4.5 Flow Chart of Antenna Fabrication Process

4.3 Instruments Used for Fabrication Process

There are various instruments which are used in antenna fabrication process like camera unit, UV exposure, PCB cutter, oven and etching unit. The snap shots of these instruments are given below:

The camera is used to make the negatives of the antenna design.

Figure 4.6 Camera Used for Fabrication of Antenna

The oven is used for drying the antenna design on the PCB.

Figure 4.7 Oven Used for Fabrication of Antenna

The PCB cutter is used to cut the antenna according to the dimensions required for the antenna

Figure 4.8 PCB Cutter Used for Antenna Fabrication

The etching unit is used to remove the unwanted copper of the PCB.

Figure 4.9 Etching Unit Used for Antenna Fabrication

4.4 Fabricated Antenna Design

The negative of the designed antenna fabricated design of the microstrip patch antenna is given in the Figure below:

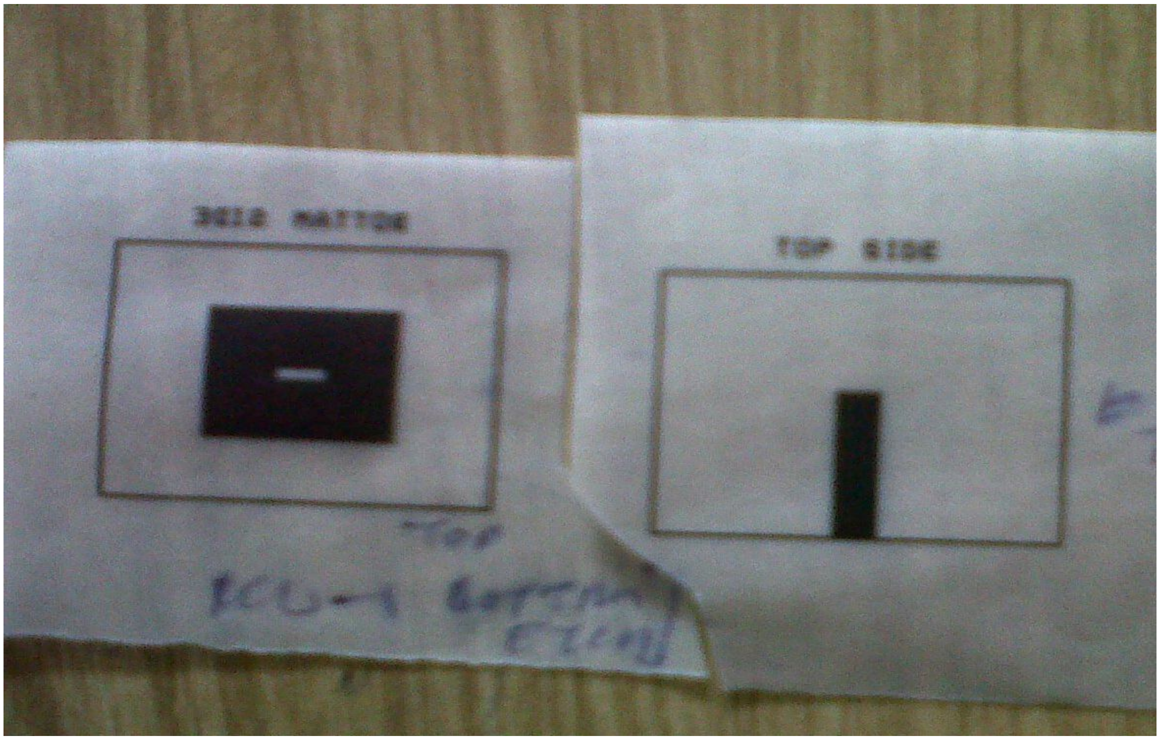


Figure 4.10 Negative of the Antenna Design Resonating at 5.2 GHz

Figure 4.11 Fabricated Antenna at 5.2 GHz Connected with SMA Connector

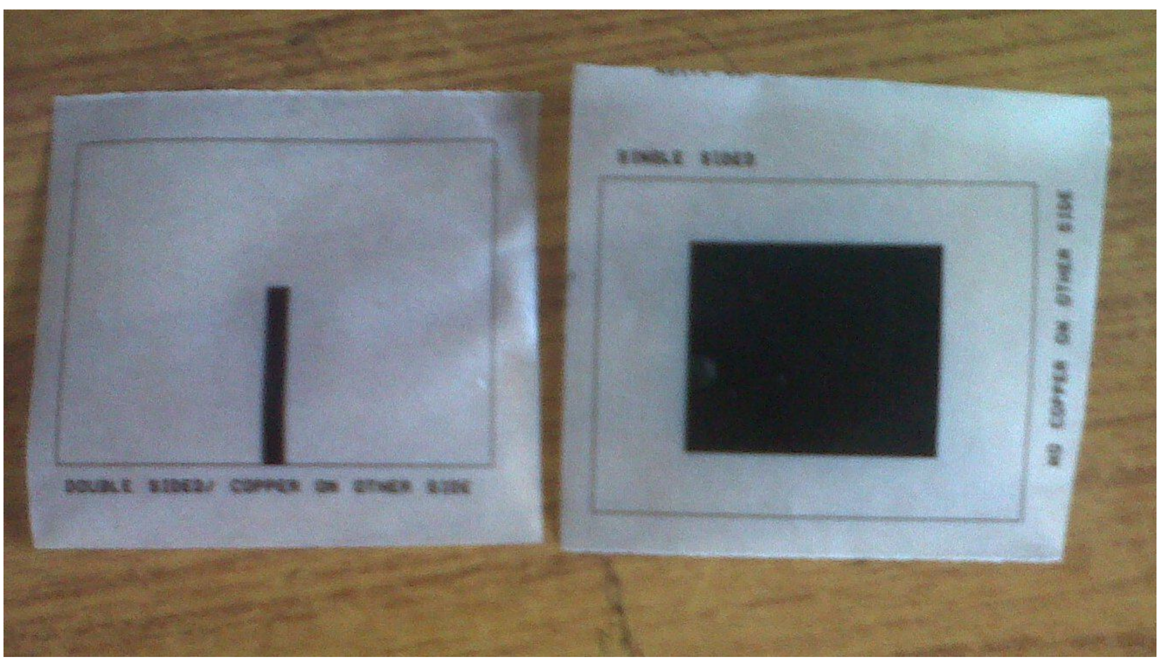


Figure 4.12 Negative of the Antenna Design Resonating at 2.4 GHz

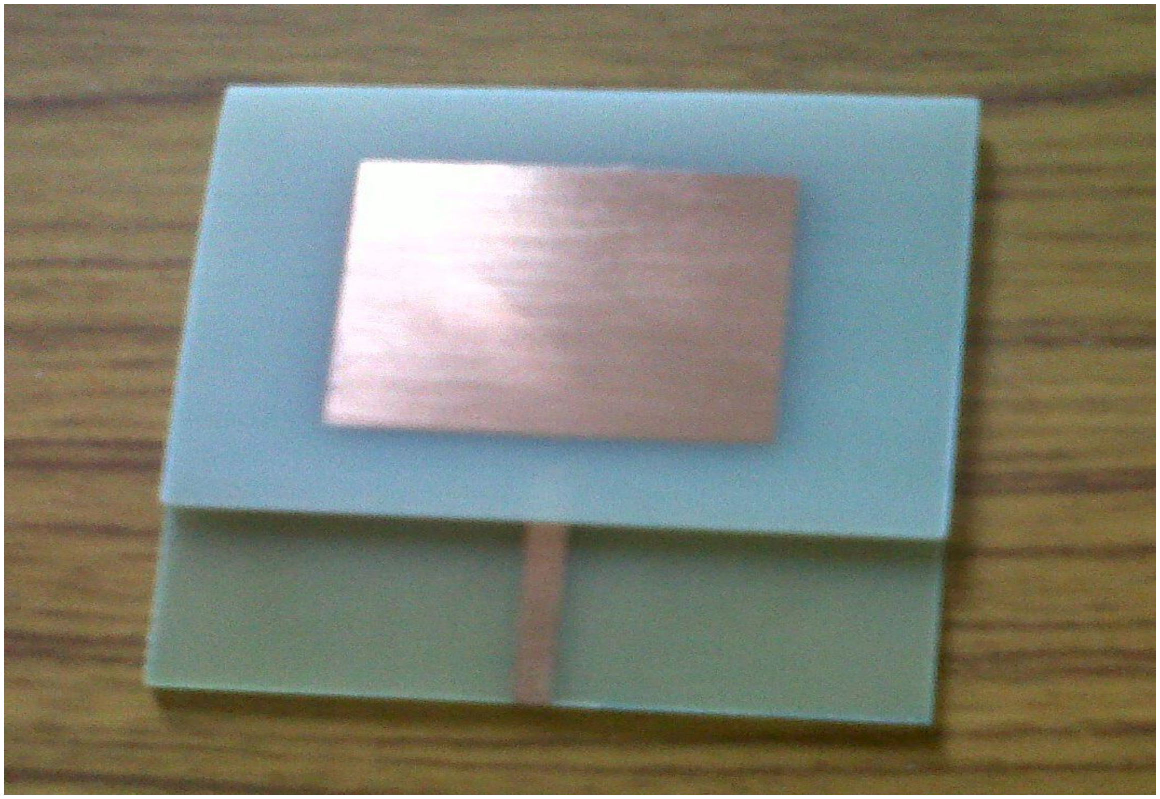


Figure 4.13 Fabricated Antenna at 2.4 GHz

4.5 Testing of Antenna

The testing of antenna can be done by using Network Analyzer (E5071C-ENA Series) which analyses one port and two port networks. The Figure below shows the network analyzer.

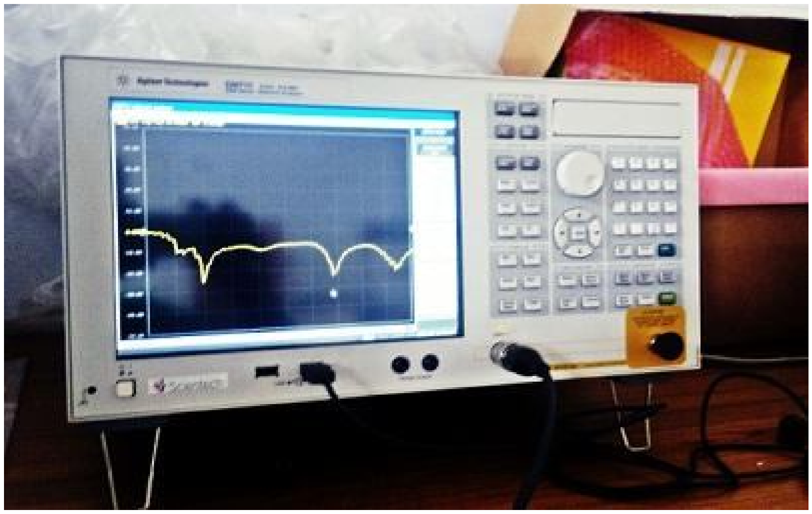


Figure 4.14 Network Analyzer for Testing

The antenna shows results that perfectly matched with the simulated results. The Figures below shows the tested results of designed antenna using network analyzer.

Figure 4.15 Measured Return Loss using Network Analyzer at 5.2 GHz

The Figure below shows the result of impedance.

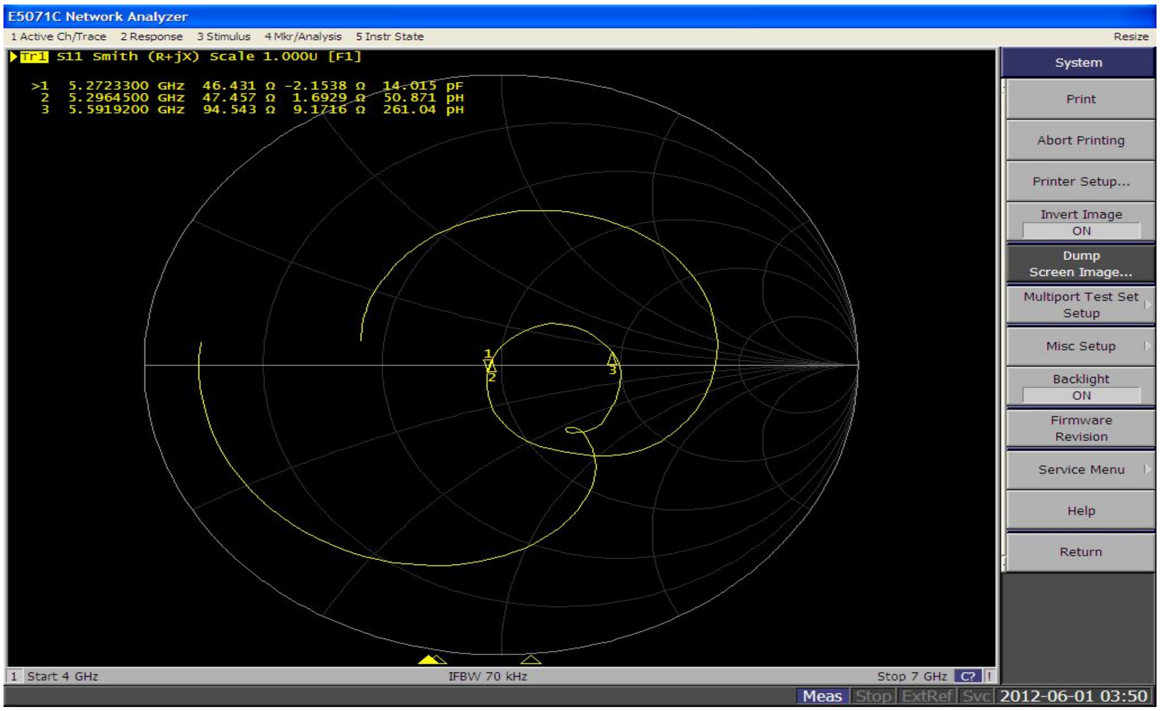


Figure 4.16 Smith Chart using Network Analyzer at 5.2 GHz

The figures below show the tested results of designed antenna resonating at 2.4 GHz.

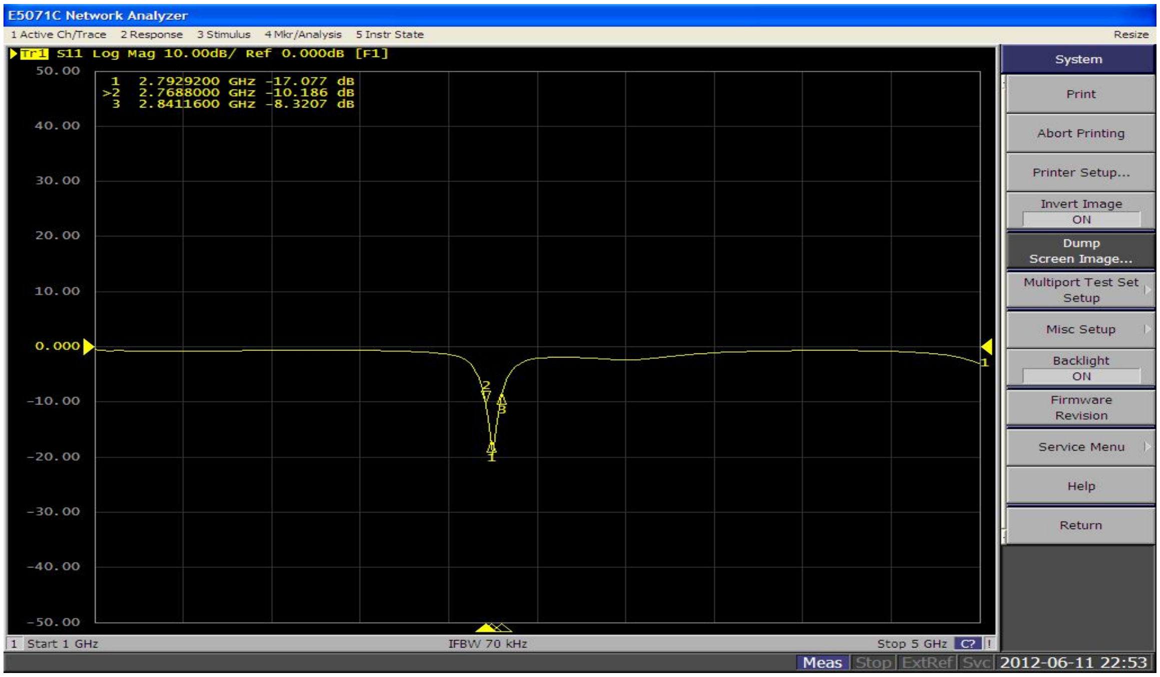


Figure 4.17 Measured Return Loss using Network Analyzer at 2.4 GHz

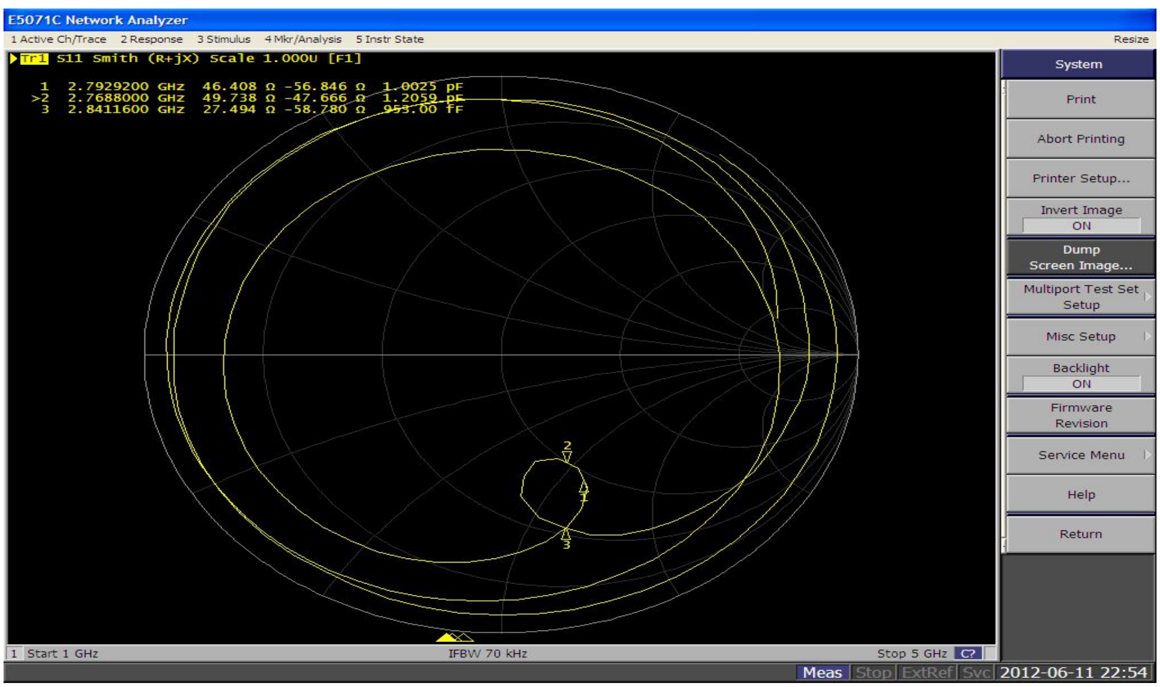


Figure 4.18 Smith Chart using Network Analyzer at 2.4 GHz

The table below shows the comparison of the simulated and the tested results of the designed antenna and the results are 90% matched by referring to topic 3.1.2.

Parameters	Tested results at 5.2 GHz frequency	Tested results at 2.4 GHz frequency
Return loss	-35dB	-21dB
Impedance	46.43 ohms	46.5ohms
Resonating frequency	5.1 GHz	2.7 GHz

Table 4.2 Tested Results of Antenna Design at 5.2 GHz and 2.4 GHz Frequency

4.6 Conclusion

The simulated and tested results are 90% matched, the 10% losses are due to lose soldering connections, due to presence of air or due to lose SMA connector connections. After these small variations in the results due to some reasons the results are still acceptable.

Chapter 5

Conclusion and Future Scope

5.1 Conclusion

In this thesis report three configurations of microstrip patch antenna using proximity feeding technique is given for WLAN applications. The first is the typical design of single band rectangular microstrip patch antenna, the second is the dual band rectangular microstrip patch antenna using stacking and the third is the triple band rectangular microstrip patch antenna using stacking and Defected Ground Structure (DGS). The various antenna parameters like return loss, impedance, VSWR, directivity, gain, bandwidth and operating frequency are studied for antenna designing. The effect of physical parameters on the antenna parameters are also studied in this thesis report.

Initially, the work starts with the designing of the single band rectangular microstrip patch antenna operating at 5.2 GHz and 2.4 GHz for WLAN applications. The designed single band antennas give efficient results. The results gives return loss of -24 dB and -40 dB and band width of 340 MHz and 92 MHz respectively. The antenna has various applications in mobile phones, electronic devices like microwave ovens, satellite communication etc.

It is also concluded that physical parameters like patch width, patch length, slot width, slot length, feed line width etc effects the results of the antenna. It can be observed that varying these parameters in the right manner gives optimized results for a desired resonant frequency operation of MSA.

The table below shows the variation of S parameters width respect to the patch width at a resonating frequency of 5.2 GHz for WLAN. By applying a sweep, as the patch width is increased from 1.556mm to 14mm the desired results obtained with patch width of 14mm that is return loss of -24.35dB and the resonating frequency of 5.2 GHz by referring to topic 3.3.3 and figure 3.11.

Patch width	14mm	10.8mm	7.78mm	4.66mm	1.556mm
Return loss	-24.357dB	-23.052dB	-13.53dB	-8.879dB	0
Resonating frequency	5.2GHz	5.33GHz	5.536GHz	5.784GHz	NA

Table 5.1 Variation of S Parameter with respect to the Patch Width

There is effect of slot width on the return loss and the resonating frequency which is shown in the following table. The graph shifts in resonating frequency towards right with the decrease in the slot width referring to figure 3.12. The table below shows the effect of slot width on the S parameter resonating at 5.2 GHz. By applying sweep on the slot width the optimized results obtained at 4mm width with resonating frequency of 5.18 GHz which is approximately equal to 5.2 GHz and a return loss of -22.5 dB.

Slot width	4mm	2.86mm	1.714mm	0.572mm
Return loss	5.186GHz	5.21GHz	5.23GHz	5.24GHz
Resonating freq	-22.5dB	-23.7dB	-24.7dB	-26.31dB

Table 5.2 Variation of S Parameter with respect to Slot Width

These physical parameters affect the results of the antenna resonating at 2.4 GHz frequency. The table below shows the effect on S parameters. By applying a sweep on the feed line width, as the feed line width is increased from 0.428mm to 3mm for 2.4 GHz antenna design the optimized results obtained at 3mm width with a return loss of -36.59 dB and a resonating frequency of 2.4 GHz by referring to topic 3.4.3.

Feed line width	3mm	2.14mm	1.286mm	0.428mm
Return loss	-36.59dB	-24.861dB	-15.346dB	-11.223dB
Resonating freq	2.404GHz	2.400GHz	2.393GHz	2.387GHz

Table 5.3 Variation of S Parameter with respect to Feedline Width resonating at 2.4GHz

The table below shows the variation of S parameter with respect to slot width resonating at 2.4 GHz frequency. As the width of the slot is decreased from 20mm to 2.86mm the efficient results obtained at 2.86mm slot width with a return loss of -25.5dB referring to figure 3.20.

Slot width	20mm	16.56mm	13.14mm	8.96mm	8mm	6.28mm	2.86mm
Return loss	-4.5dB	-5.67dB	-7.9dB	10.9dB	-21dB	-17.0dB	-25.5dB
Resonating freq.	2.15 GHz	2.25 GHz	2.235 GHz	2.37 GHz	2.41 GHz	2.49 GHz	2.41 GHz

Table 5.4 Variation of S Parameter with respect to Slot Width

In the second section a dual band microstrip patch antenna is designed using stacking that is using more number of substrates and more no of patches. The E shaped slot on the upper stacked patch helps in improving the results. The designed antenna gives efficient results resonating at 2.4 GHz and 4.65 GHz. The proposed antenna can be used for various applications like RADAR, mobile, biomedical instruments etc.

The third section covers the triple band antenna covering two bands of WLAN using stacking and DGS. The dumbbell shaped slot in the ground helps in improving the results and the stacking helps in improving the bandwidth and gives the multiple bands. The slots can be cut on the patch and on the ground plane by viewing the current distribution graph, the slots length, width and the position of the slots are varied in order to obtain the desired results of the antenna. The designed antenna efficiently resonates at 2.45 GHz, 4.1 GHz and 5.8 GHz and gives the improved results.

The results of the designed antennas are summarized in the following table.

Antenna configuration	**Return loss**	**Resonating frequency**	**Bandwidth**	**Impedance**
Single band antenna	-24 dB	5.2 GHz	340 MHz	48 ohms
Single band antenna	-40 dB	2.4 GHz	92 MHz	50.75 ohms
Dual band antenna	-26 dB, -30 dB	2.4GHz, 4.65 GHz	90MHz, 155 MHz	48 ohms
Triple band antenna	-16 dB, -13 dB, -17.5 dB	2.45 GHz, 4.1 GHz, 5.8 GHz	88 MHz, 75 MHz, 67 MHz	52 ohms

Table 5.5 Comparison of the Antenna Parameters Values of the Single Band, Dual Band and Triple Band Antenna Configurations

The above table shows that the return loss is maximum at 2.4GHz frequency which shows that the antenna is perfectly matched and losses are minimum. The bandwidth is maximum for 5.2

GHz frequency that is 340 MHz for which 100 MHz is acceptable. The VSWR of all the antenna designs is between 1 and 2 so all designs are acceptable.

5.2 Future Scope

The designed antennas in this thesis report is used in various applications like WLAN, IMT (International Mobile Telecommunications), WiMAX, microwave ovens, USB dongles, satellite communications etc.

The work on microstrip antenna design using proximity coupling can be extended to:

- Using different structure configuration, the use of different dielectric substrate material as well as combination of different substrate in one structure
- Using different slots on the patch and the ground, the use of different shape of patch with larger radiating area.
- Using impedance matching network to enhance the impedance bandwidth.

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

- **Split-Ring Resonator Structure (SRS):** A split-ring resonator (SRR) is acomponent of a Negative index metamaterial (NIM), also known as Double negative metamaterials (DNG) or Left-handed medium (LHM). SRRs are also used for research in Terahertz metamaterials, Acoustic metamaterials, and Metamaterial antennas. A single cell SRS has a pair of enclosed loops with splits in them at opposite ends. The loops are made of nonmagnetic metal like copper and have a small gap between them. The loops can be concentric, or square, and gapped as needed.
- **Electromagnetic Band Gap Structure (EBG):** Electromagnetic Band Gap (EBG) substrates for patch antennas significantly reduce the effect of surface waves as a function of frequency and are able to provide relatively broadband frequency performance. EBG structures are 3-D periodic objectives that prevent the propagation of

the EM waves in the specified band frequency for all angles and for all polarization states. In EBG only one out of $\mathcal{E}_r$ 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 $\mathcal{E}_r$ 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 the same microstrip patch antennas.

List of Publication

Published

Aditi Gupta and Mrs. Amanpreet kaur "*Study of proximity coupled micro-strip patch antenna for WLAN applications*", National Conference on Advances in Computing, Communication Networks & Electrical Systems, March 27-28, 2012.

Accepted

Aditi Gupta and Mrs. Amanpreet kaur "*Design of proximity coupled micro-strip patch antenna operating at 5.2 GHZ for WLAN applications*" Internation Conference on Electrical and Electronics Engineering, June 28th, 2012

Communicated

Aditi Gupta and Mrs. Amanpreet kaur, "*Design of Proximity Coupled Micro-strip Patch Antenna for Wireless Communication Applications at 1.575GHz and at 2.45GHz.*", International Journal of Multimedia Technologies.

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