

STUDY AND INVESTIGATIONS ON VARIOUS MICROSTRIP PATCH ANTENNAS FOR WIRELESS APPLICATIONS

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DECLARATION

I, Neha Ahuja, hereby certify that the work which is being presented in this thesis entitled **"STUDY AND INVESTIGATIONS ON VARIOUS MICROSTRIP PATCH ANTENNAS FOR WIRELESS APPLICATIONS"** by me in partial fulfillment of the requirements for the award of degree of Master of Engineering in Electronics and Communication Engineering from Thapar University (Deemed University), Patiala, is an authentic record of my own work carried out under the supervision of Dr. Rajesh Khanna & Ms. Jaswinder Kaur.

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

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ABSTRACT

Wireless communications has been developed widely and rapidly in the modern world especially during the last two decades. The future development of the personal communication devices will aim to provide image, speech and data communications at any time, and anywhere around the world. This indicates that the future communication terminal antennas must meet the requirements of multi-band or wideband operations to sufficiently cover the possible operating bands. However, the difficulty of antenna design increases when the number of operating frequency bands increases within a single antenna.

The aim is to study and design various rectangular microstrip patch antennas for wireless communication systems and study the effect of various antenna parameters like patch length (L), patch width (W), substrate relative dielectric constant, substrate thickness etc. Here, coaxial feed and microstrip line feed methods have been used to excite the patch antenna.

The single band rectangular patch antennas have been designed for the frequency 5.2 GHz using microstrip line feeding and coaxial feeding technique. The design is successfully simulated using CST Microwave Studio software. In microstrip line feed antenna, the return loss is -47dB & bandwidth is 196 GHz. In coaxial feed antenna the return loss is -35 dB & bandwidth is 160 GHz.

Three dual band antennas using DGS structure and one dual band antenna using dual patch has been designed. The designs have been successfully simulated using CST Microwave Studio Software.

Dual band defected ground microstrip patch antenna for WLAN/WiMax and satellite application, the return loss for 5.5 GHz band and 6-7 GHz band is -27.26 dB and -20.77 dB respectively, bandwidth for 5.5 GHz band and 6-7 GHz band is 1.24 GHz (4.6053 GHz – 5.8481 GHz) and 1.04 GHz (6.124GHz – 7.16 GHz) respectively.

Dual band microstrip patch antenna for GSM and WiMax application, the return loss for GSM band and WiMax band is -20.8 dB and -30.98 dB respectively, bandwidth for GSM band and WiMax band is 366 MHz (1600 MHz – 1900 MHz) and 583 MHz (3350 MHz – 3933 MHz) respectively.

Dual band microstrip patch antenna, using two slits and defected ground structure, the return loss for 3.5 GHz band and 5.8 GHz band is -41.71 dB and -20.67 dB respectively, bandwidth for 3.5 GHz band and 5.8 GHz band is 495 MHz (3.403 GHz – 3.901 GHz) and 260 MHz (5.569 GHz – 5.830 GHz) respectively.

Dual band antenna using dual patch, the return loss for 3.5 GHz band and 5.8 GHz band is -37.78 dB and -46.315 dB respectively, bandwidth for 3.5 GHz band and 5.8 GHz band is 65 MHz (3.4572 GHz – 3.5228 GHz) and 138 MHz (5.7087 GHz – 5.8474 GHz) respectively.

CHAPTER 1

INTRODUCTION

Communication between humans was first by sound through voice. With the desire for slightly more distance communication came, devices such as drums, then, visual methods such as signal flags and smoke signals were used. The optical communication devices, of course, utilized the light portion of the electromagnetic spectrum. It has been only very recent in human history that the electromagnetic spectrum, outside the visible region, has been employed for communication, through the use of radio. One of humankind's greatest natural resources is the electromagnetic spectrum and the antenna has been instrumental in harnessing this resource.

1.1 Aim and Objectives

Microstrip patch antenna used to send onboard parameters of article to the ground while under operating conditions. The aim is to design and fabricate a Microstrip Patch Antenna and study the effect of antenna dimensions Length (L), and substrate parameters relative Dielectric constant (ϵ_r), substrate thickness (t) on the Radiation parameters of Bandwidth and slots. The defected ground structure has also been implemented and the effect of that has been studied.

1.2 History of Microstrip Patch Antenna

The rapid development of microstrip antenna technology began in the late 1970's. The first aperture coupled microstrip antenna was fabricated and tested by a graduate student, Allen Buck, on August 1, 1984, in the University of Massachusetts Antenna Lab. This antenna used 0.062" Duroid substrates with a circular coupling aperture, and operated at 2 GHz. As is the case with most original antenna developments, the prototype element was designed without any rigorous analysis or CAD - only an intuitive view of how the fields might possibly couple through a small aperture. They were pleasantly surprised to find that this first prototype worked almost perfectly – it was impedance matched, and the radiation patterns were good. Most importantly, the required coupling aperture was small enough so that the back radiation from the coupling aperture was much smaller than the forward radiation level.

The geometry of the basic aperture coupled patch antenna is described. The radiating microstrip patch element is etched on the top of the antenna substrate, and the microstrip

feed line is etched on the bottom of the feed substrate. The thickness and dielectric constants of these two substrates may thus be chosen independently to optimize the distinct electrical functions of radiation and circuitry. Although the original prototype antenna used a circular coupling aperture, it was quickly realized that the use of a rectangular slot would improve the coupling, for a given aperture area, due to its increased magnetic polarizability. Most aperture coupled microstrip antennas now use rectangular slots, or variations thereof.

1.3 Overview of Microstrip Antenna

A microstrip antenna consists of conducting patch on a ground plane separated by dielectric substrate. This concept was undeveloped until the revolution in electronic circuit miniaturization and large-scale integration in 1970. After that many authors have described the radiation from the ground plane by a dielectric substrate for different configurations.

The first practical antenna was developed by Howell [37] and Munson [38]. The early work of Munson on micro strip antennas for use as a low profile flush mounted antennas on rockets and missiles showed that this was a practical concept for use in many antenna system problems. Various mathematical models were developed for this antenna and its applications were extended to many other fields. A microstrip antenna is characterized by its Length, Width, Input impedance, and Gain and radiation patterns.

Various parameters of the microstrip antenna and its design considerations were discussed in the subsequent chapters. The length of the antenna is nearly half wavelength in the dielectric; it is a very critical parameter, which governs the resonant frequency of the antenna. There are no hard and fast rules to find the width of the patch.

1.4 Waves on Microstrip

The mechanisms of transmission and radiation in a microstrip can be understood by considering a point current source (Hertz dipole) located on top of the grounded dielectric substrate (Figure 1.1) [40]. This source radiates electromagnetic waves. Depending on the direction toward which waves are transmitted, they fall within three distinct categories, each of which exhibits different behaviours.

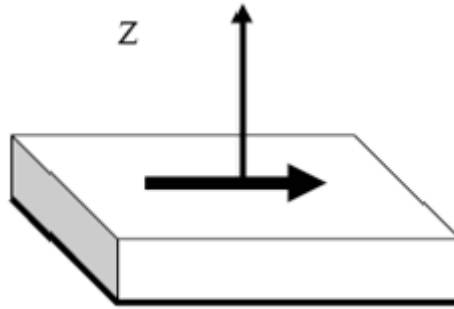


Figure 1.1 Hertz dipole on a microstrip substrate

1.4.1 Surface Waves

The waves transmitted slightly downward, having elevation angles θ between $\pi/2$ and $\pi - \arcsin(1/\sqrt{\epsilon_r})$, meet the ground plane, which reflects them, and then meet the dielectric-to-air boundary, which also reflects them (total reflection condition). The magnitude of the field amplitudes builds up for some particular incidence angles that leads to the excitation of a discrete set of surface wave modes; which are similar to the modes in metallic waveguide.

The fields remain mostly trapped within the dielectric, decaying exponentially above the interface (Figure 1.2) [40]. The vector α , pointing upward, indicates the direction of largest attenuation. The wave propagates horizontally along β , with little absorption in good quality dielectric. With two directions of α and β orthogonal to each other, the wave is a non-uniform plane wave. Surface waves spread out in cylindrical fashion around the excitation point, with field amplitudes decreasing with distance (r), say $1/r$, more slowly than space waves. The same guiding mechanism provides propagation within optical fibres.

Surface waves take up some part of the signal's energy, which does not reach the intended user. The signal's amplitude is thus reduced, contributing to an apparent attenuation or a decrease in antenna efficiency. Additionally, surface waves also introduce spurious coupling between different circuit or antenna elements. This effect severely degrades the performance of microstrip filters because the parasitic interaction reduces the isolation in the stop bands.

In large periodic phased arrays, the effect of surface wave coupling becomes particularly obnoxious, and the array can neither transmit nor receive when it is pointed at some particular directions (blind spots). This is due to a resonance phenomenon, when the

surface waves excite in synchronism the Floquet modes of the periodic structure. Surface waves reaching the outer boundaries of an open microstrip structure are reflected and diffracted by the edges. The diffracted waves provide an additional contribution to radiation, degrading the antenna pattern by raising the side lobe and the cross polarization levels. Surface wave effects are mostly negative, for circuits and for antennas, so their excitation should be suppressed if possible.

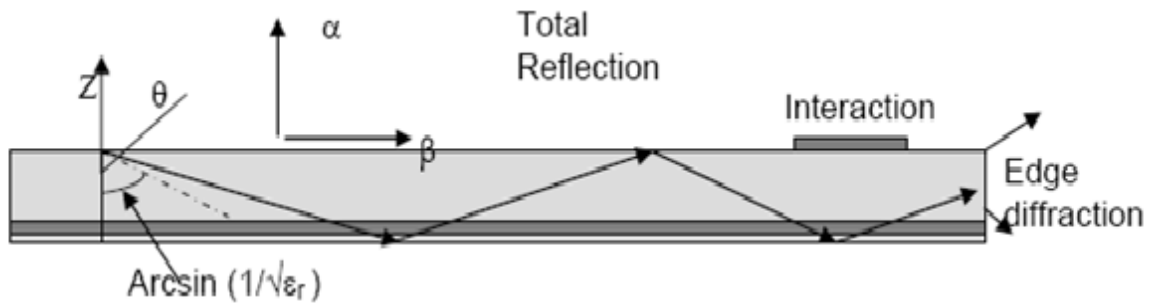


Figure 1.2 Surface waves

1.4.2 Leaky Waves

Waves directed more sharply downward, with θ angles between $\pi - \arcsin(1/\sqrt{\epsilon_r})$ and π , are also reflected by the ground plane but only partially by the dielectric-to-air boundary. They progressively leak from the substrate into the air (Figure 1.3) [40], hence their name leaky waves, and eventually contribute to radiation. The leaky waves are also non uniform plane waves for which the attenuation direction α points downward, which may appear to be rather odd; the amplitude of the waves increases as one moves away from the dielectric surface. This apparent paradox is easily understood by looking at the Figure 1.3 actually, the field amplitude increases as one move away from the substrate because the wave radiates from a point where the signal amplitude is larger. Since the structure is finite, this apparent divergent behaviour can only exist locally, and the wave vanishes abruptly as one crosses the trajectory of the first ray in the Figure.

In more complex structures made with several layers of different dielectrics, leaky waves can be used to increase the apparent antenna size and thus provide a larger gain. This occurs for favourable stacking arrangements and at a particular frequency. Conversely, leaky waves are not excited in some other multilayer structures.

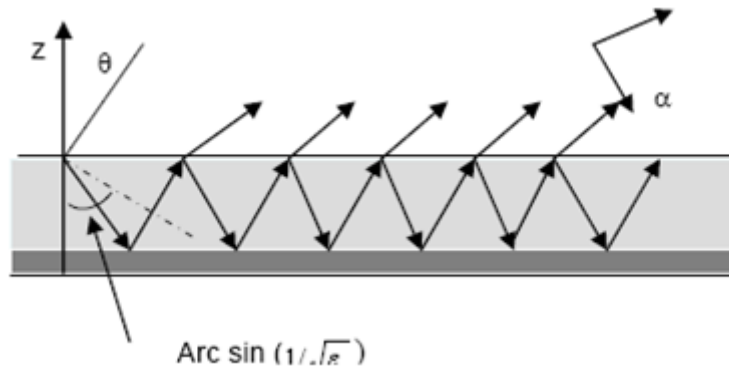


Figure 1.3 Leaky waves

1.4.3 Guided Waves

When realizing printed circuits, one locally adds a metal layer on top of the substrate, which modifies the geometry, introducing an additional reflecting boundary. Waves directed into the dielectric located under the upper conductor bounce back and forth on the metal boundaries, which form a parallel plate waveguide. The waves in the metallic guide can only exist for some Particular values of the angle of incidence, forming a discrete set of waveguide modes. The guided waves provide the normal operation of all transmission lines and circuits, in which the electromagnetic fields are mostly concentrated in the volume below the upper conductor. On the other hand, this build up of electromagnetic energy is not favourable for patch antennas, which behave like resonators with a limited frequency bandwidth.

1.5. IEEE Standards

1.5.1. IEEE standard for WLAN

The IEEE 802.11 standard was proposed in 1997 for WLANs application. After few year new standard was proposed, operating on the 2.4 GHz ISM band (2.4 - 2.484 GHz), is called 802.11b or 802.11 HR (High Rate), which provides a data rate up to 11 Mbps. The IEEE 802.11a standard was approved in 1999, operating on the 5 GHz ISM bands (5.15 - 5.35GHz and 5.725 -5.825GHz). The change of band shows that 802.11a and 802.11b products are not compatible. Therefore, the IEEE proposed 802.11g standard which is compatible with both 802.11b and 802.11a technology. The 802.11g standard was accepted in 2003.

Since 802.11b and 802.11g are using 2.4 GHz frequency band while 802.11a uses 5 GHz frequency band so a dual band antenna is requirement for WLAN applications. The

popularity of WLAN is increased due to high-speed transfer rate. This increased the development of broadband antennas [41].

1.5.2. IEEE standard for WiMax

WiMax technology is based on the IEEE 802.16 standard also called Broadband Wireless Access. The name WiMax was created by the WiMax forum which was formed in June 2001 to promote conformity and interoperability of the standard.

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

Table 1: Table of WIMAX and WLAN Standards

The forum describes WiMax as "a standards-based technology enabling the delivery of last mile wireless broadband access as an alternative to cable and DSL". There is no uniform global licensed spectrum for WiMax, although the WiMax Forum has published three licensed spectrum profiles: 2.5 GHz (2.5-2.69 GHz), 3.5 GHz (3.4-3.69 GHz) and 5.5 GHz (5.25-5.85 GHz). WiMax provide the data rate upto 70 Mbps over 50 Km.

IEEE 802.16-2004 is often called IEEE 802.16d, since that was the working party that developed the standard. It is also frequently referred to as "fixed WiMax" since it has no support for mobility. It replaced IEEE Standards 802.16-2001, 802.16c-2002, and 802.16a-2003. 802.16e-2005 is an amendment to 802.16-2004 and is often referred to in shortened form as 802.16e. It introduced support for mobility, amongst other things and is therefore also known as "mobile WiMax" [41].

1.6. Microstrip Patch Antenna Theory

In its most fundamental form, a microstrip patch antenna (MPA) consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in Figure 1.4. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate.

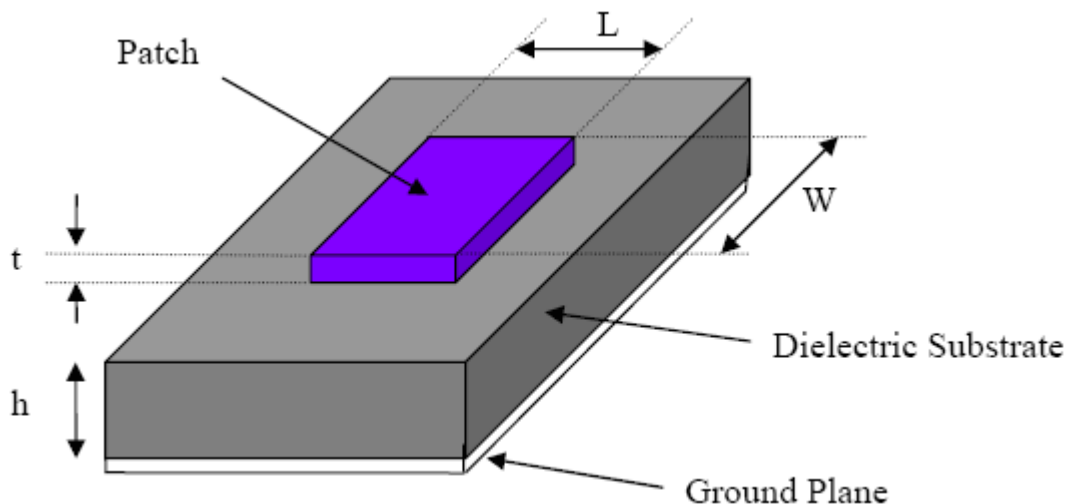


Figure 1.4: Structure of a Microstrip Patch Antenna

In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, and elliptical or some other common shape as shown in Figure 1.5 [40]. For a rectangular patch, the length L of the patch is usually $0.3333\lambda_0 < L < 0.5\lambda_0$, where λ_0 is the free-space wavelength. The patch is selected to be very thin such that $t \ll \lambda_0$ (where t is the patch thickness). The height h of the dielectric substrate is usually $0.003\lambda_0 \leq h \leq 0.05\lambda_0$. The dielectric constant of the substrate (ϵ_r) is typically in the range $2.2 \leq \epsilon_r \leq 12$.

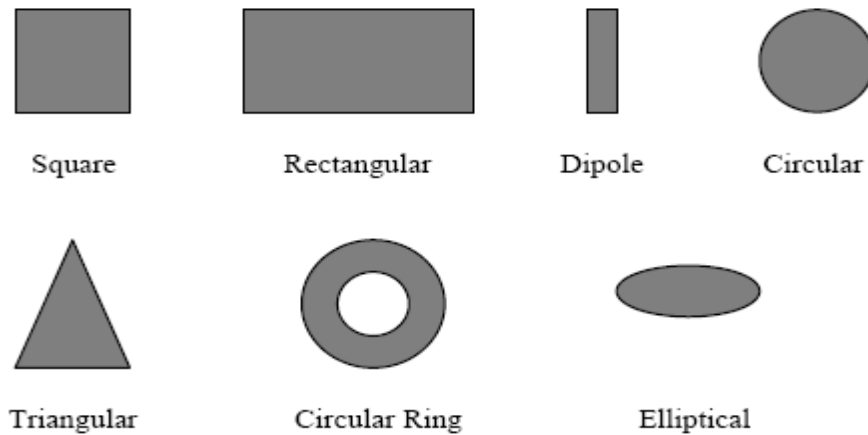


Figure 1.5: Common shapes of microstrip patch elements

Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. For good antenna performance, a thick dielectric substrate having a low dielectric constant is desirable since this provides better efficiency, larger bandwidth and better radiation [6]. However, such a configuration leads to a larger antenna size. In order to design a compact microstrip patch antenna, substrates with higher dielectric constants must be used which are less efficient and result in narrower bandwidth. Hence a trade-off must be realized between the antenna dimensions and antenna performance.

1.7 Advantages and Disadvantages

Microstrip patch antennas are increasing in popularity for use in wireless applications due to their low-profile structure. Therefore they are extremely compatible for embedded antennas in handheld wireless devices such as cellular phones, pagers etc. The telemetry and communication antennas on missiles need to be thin and conformal and are often in the form of microstrip patch antennas. Another area where they have been used successfully is in satellite communication. Some of their principal advantages discussed by Kumar and Ray [2] are given below:

- Light weight and low volume.
- Low profile planar configuration which can be easily made conformal to host surface.
- Low fabrication cost, hence can be manufactured in large quantities.
- Supports both, linear as well as circular polarization.
- Can be easily integrated with microwave integrated circuits (MICs).
- Capable of dual and triple frequency operations.

- Mechanically robust when mounted on rigid surfaces.

Microstrip patch antennas suffer from more drawbacks as compared to conventional antennas. Some of their major disadvantages are given below:

- Narrow bandwidth.
- Low efficiency.
- Low Gain.
- Extraneous radiation from feeds and junctions.
- Poor end fire radiator except tapered slot antennas.
- Low power handling capacity.
- Surface wave excitation.

Microstrip patch antennas have a very high antenna quality factor (Q). It represents the losses associated with the antenna where a large Q leads to narrow bandwidth and low efficiency. Q can be reduced by increasing the thickness of the dielectric substrate. But as the thickness increases, an increasing fraction of the total power delivered by the source goes into a surface wave. This surface wave contribution can be counted as an unwanted power loss since it is ultimately scattered at the dielectric bends and causes degradation of the antenna characteristics. Other problems such as lower gain and lower power handling capacity can be overcome by using an array configuration for the elements.

1.8 Feed Techniques

Microstrip patch antennas can be fed by a variety of methods. These methods can be classified into two categories- contacting and non-contacting. In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such as a microstrip line. In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch [1]. The four most popular feed techniques used are the microstrip line, coaxial probe (both contacting schemes), aperture coupling and proximity coupling (both non-contacting schemes).

1.8.1 Microstrip Line Feed

In this type of feed technique, a conducting strip is connected directly to the edge of the microstrip patch as shown in Figure 1.6. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure.

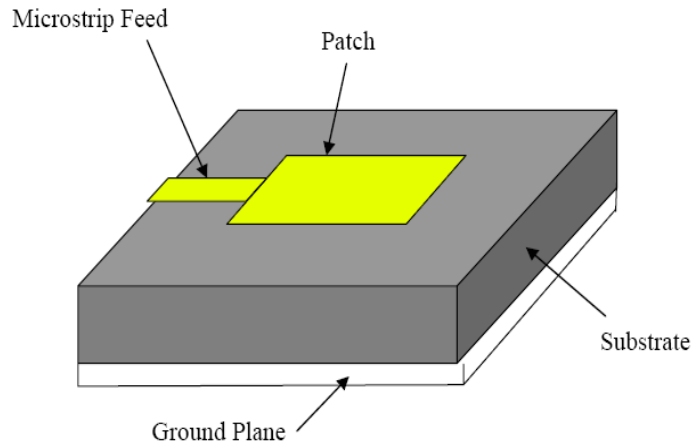


Figure 1.6: Microstrip Line Feed

The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without the need for any additional matching element. This is achieved by properly controlling the inset position. Hence this is an easy feeding scheme, since it provides ease of fabrication and simplicity in modelling as well as impedance matching. However as the thickness of the dielectric substrate being used, increases, surface waves and spurious feed radiation also increases, which hampers the bandwidth of the antenna [1]. The feed radiation also leads to undesired cross polarized radiation.

1.8.2 Coaxial Feed

The Coaxial feed or probe feed is a very common technique used for feeding microstrip patch antennas.

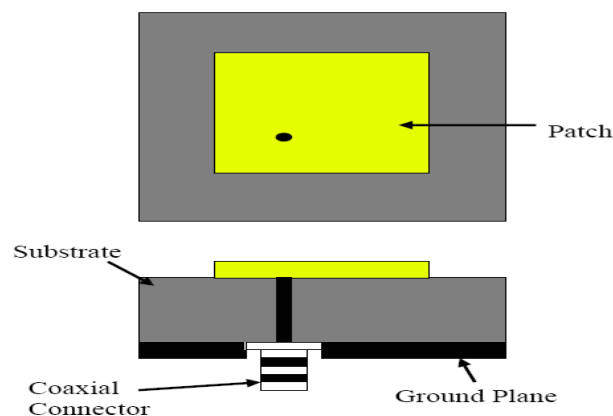


Figure 1.7: Probe fed Rectangular Microstrip Patch Antenna

The inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane. The main advantage of this type of feeding scheme is that the feed can be placed at any desired

location inside the patch in order to match with its input impedance. This feed method is easy to fabricate and has low spurious radiation. However, a major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, thus not making it completely planar for thick substrates ($h > 0.02\lambda_0$). Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems [2]. It is seen above that for a thick dielectric substrate, which provides broad bandwidth, the microstrip line feed and the coaxial feed suffer from numerous disadvantages. The non-contacting feed techniques which have been discussed below, solve these issues.

1.8.3 Aperture Coupled Feed

In this type of feed technique, the radiating patch and the microstrip feed line are separated by the ground plane as shown in Figure 1.8. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane.

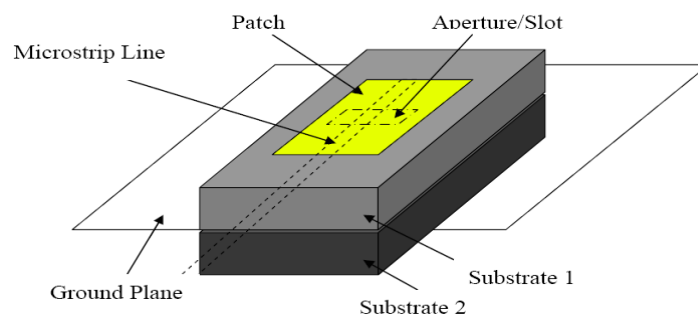


Figure 1.8: Aperture-coupled feed

The coupling aperture is usually centred under the patch, leading to lower cross polarization due to symmetry of the configuration. The amount of coupling from the feed line to the patch is determined by the shape, size and location of the aperture. Since the ground plane separates the patch and the feed line, spurious radiation is minimized. Generally, a high dielectric material is used for bottom substrate and a thick, low dielectric constant material is used for the top substrate to optimize radiation from the patch [1]. The major disadvantage of this feed technique is that it is difficult to fabricate due to multiple layers, which also increases the antenna thickness. This feeding scheme also provides narrow bandwidth.

1.8.4 Proximity Coupled Feed

This type of feed technique is also called as the electromagnetic coupling scheme. As shown in Figure 1.9, two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate. The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth (as high as 13%) [1], due to overall increase in the thickness of the microstrip patch antenna. This scheme also provides choices between two different dielectric media, one for the patch and one for the feed line to optimize the individual performances.

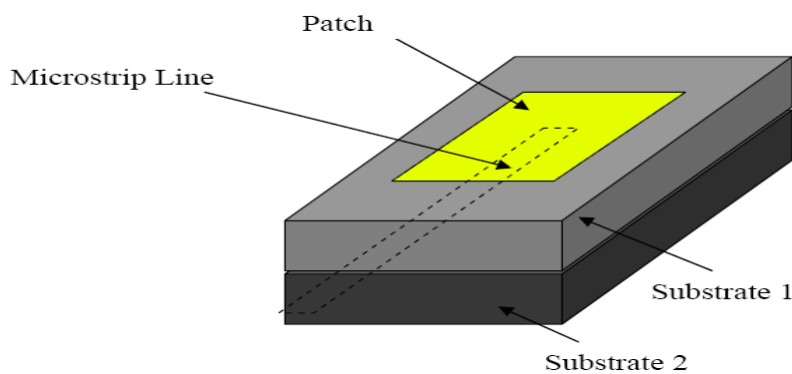


Figure 1.9: Proximity-coupled Feed

Matching can be achieved by controlling the length of the feed line and the width-to-length ratio of the patch. The major disadvantage of this feed scheme is that it is difficult to fabricate because of the two dielectric layers which need proper alignment. Also, there is an increase in the overall thickness of the antenna.

1.9 Methods of Analysis

There are many methods of analysis for microstrip antennas. The preferred models for the analysis of Microstrip patch antennas are the transmission line model, cavity model, and full wave model [1] (which include primarily integral equations/Moment Method). 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 are extremely accurate, versatile and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements and coupling. These give less insight as compared to the two models mentioned above and are far more complex in nature.

1.10 Transmission Line Model

This model [40] represents the microstrip antenna by two slots of width W and height h , separated by a transmission line of length L . It was indicated earlier that the transmission-line model is the easiest of all but it yields the least accurate results and it lacks the versatility. However, it does shed some physical insight. Rectangular microstrip antenna can be represented as an array of two *radiating* narrow apertures (slots), each of width W and height h , separated by a distance L . Basically the transmission-line model represents the microstrip antenna by two slots, separated by a low-impedance Z_c transmission line of length L .

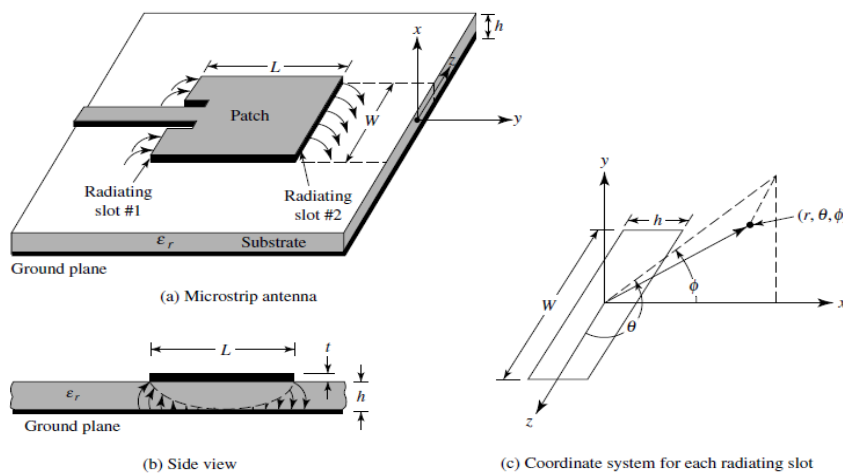


Figure 1.10: Microstrip antenna and coordinate system

1.10.1. Fringing Effects

Because the dimensions of the patch are finite along the length and width, the fields at the edges of the patch undergo fringing. This is illustrated along the length in Figure 1.10 [40] for the two radiating slots of the microstrip antenna. The same applies along the width. The amount of fringing is a function of the dimensions of the patch and the height of the substrate. For the principal E -plane (xy -plane) fringing is a function of the ratio of the length of the patch L to the height h of the substrate (L/h) and the dielectric constant ϵ_r of the substrate. Since for microstrip antennas $L/h \gg 1$, fringing is reduced; however it must be taken into account because it influences the resonant frequency of the antenna. The same applies for the width.

For a microstrip line shown in Figure 1.11, typical electric field lines are shown in Figure 1.11. This is a nonhomogeneous line of two dielectrics; typically the substrate and air. As can be seen, most of the electric field lines reside in the substrate and parts of some lines

exist in air. As $W/h \gg 1$ and $\epsilon_r \gg 1$, the electric field lines concentrate mostly in the substrate. Fringing in this case makes the microstrip line look wider electrically compared to its physical dimensions. Since some of the waves travel in the substrate and some in air, an *effective dielectric constant* ϵ_{reff} is introduced to account for fringing and the wave propagation in the line.

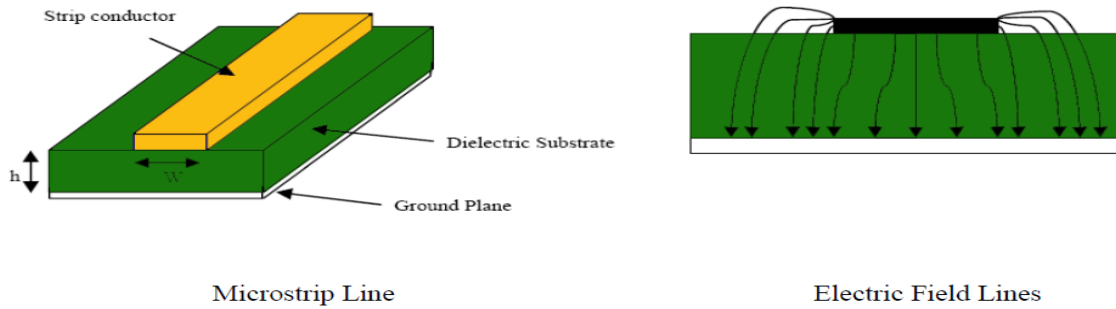


Figure 1.11: Microstrip line feed, its electric field lines, and effective dielectric constant geometry

To introduce the effective dielectric constant, let us assume that the centre conductor of the microstrip line with its original dimensions and height above the ground plane is embedded into one dielectric, as shown in Figure 1.11.

For a line with air above the substrate, the effective dielectric constant has values in the range of $1 < \epsilon_{reff} < \epsilon_r$. For most applications where the dielectric constant of the substrate is much greater than unity ($\epsilon_r \gg 1$), the value of ϵ_{reff} will be closer to the value of the actual dielectric constant ϵ_r . The effective dielectric constant is also a function of frequency. As the frequency of operation increases, most of the electric field lines concentrate in the substrate. Therefore the microstrip line behaves more like a homogeneous line of one dielectric (only the substrate), and the effective dielectric constant approaches the value of the dielectric constant of the substrate. Typical variations, as a function of frequency, of the effective dielectric constant for a microstrip line with three different substrates are shown in Figure 1.12.

For low frequencies the effective dielectric constant is essentially constant. At intermediate frequencies its values begin to monotonically increase and eventually approach the values of the dielectric constant of the substrate. The initial values (at low frequencies) of the effective dielectric constant are referred to as the *static values*, and they are given by [7].

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

Equation 1.1

1.10.2. Effective Length, Resonant Frequency, and Effective Width

Because of the fringing effects, electrically the patch of the microstrip antenna looks greater than its physical dimensions.

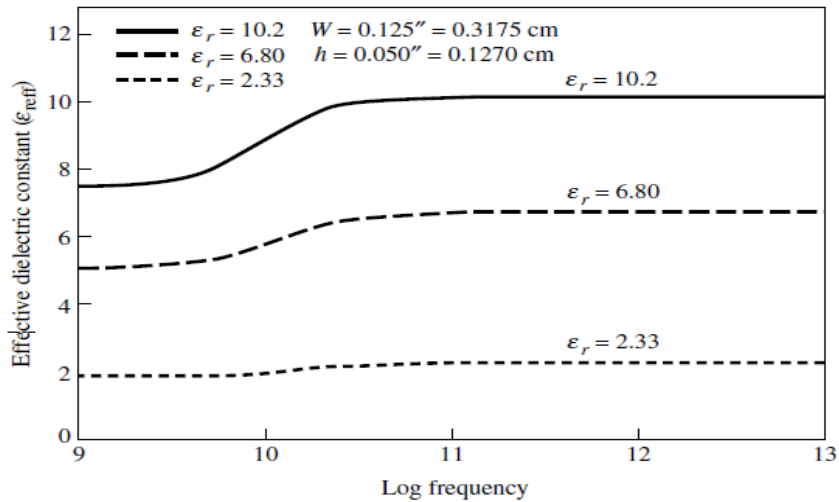


Figure 1.12: Graph of Dielectric constant versus frequency for typical substrate

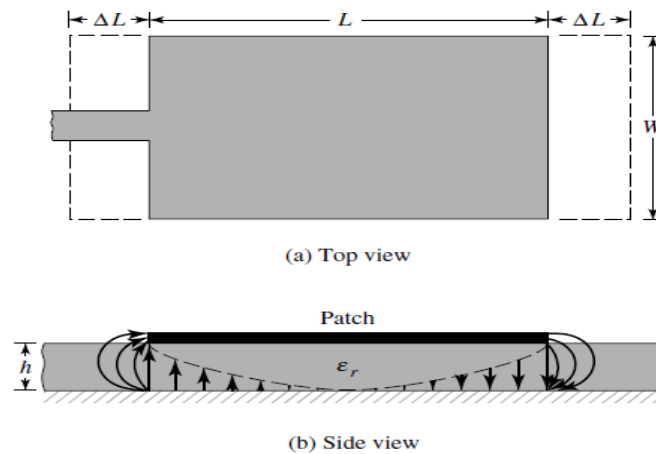


Figure 1.13: Physical and effective lengths of rectangular microstrip patch.

For the principal E -plane (xy -plane), this is demonstrated in Figure 1.13 where the dimensions of the patch along its length have been extended on each end by a distance ΔL , which is a function of the effective dielectric constant ϵ_{reff} and the width-to-height ratio (W/h). A very popular and practical approximate relation for the normalized extension of the length is [39]

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

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

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

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

$$(f_r)_{010} = \frac{1}{2L\sqrt{\epsilon_r}\sqrt{\mu_0}\epsilon_r} = \frac{g_0}{2L\sqrt{\epsilon_r}} \quad \text{Equation 1.4}$$

Where, g_0 is the speed of light in free space. Since does not account for fringing, it must be modified to include edge effects and should be computed using

$$\begin{aligned} (f_{rc})_{010} &= \frac{1}{2L_{eff}\sqrt{\epsilon_{reff}}\sqrt{\mu_0}\epsilon_0} = \frac{1}{2(L + 2\Delta L)\sqrt{\epsilon_{reff}}\sqrt{\mu_0}\epsilon_0} \\ &= q \frac{1}{2L\sqrt{\epsilon_r}\sqrt{\mu_0}\epsilon_0} = q \frac{g_0}{2L\sqrt{\epsilon_r}} \end{aligned} \quad \text{Equation 1.5}$$

Where

$$q = \frac{(f_{rc})_{010}}{(f_r)_{010}} \quad \text{Equation 1.6}$$

The q factor is referred to as the *fringe factor* (length reduction factor). As the substrate height increases, fringing also increases and leads to larger separations between the radiating edges and lower resonant frequencies.

CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

Prior to start my thesis, it is important to have a deep understanding on the existing pages of Microstrip antenna. The main sources of information for the dissertation are books, journal, theses and dissertations and the internet. There are three major areas of reading in the literature review, which are antenna design, methods for improving performance of microstrip patch antenna and related simulation software. The papers referred are mainly for wireless application employing various techniques like simple patch antennas, microstrip patch antennas using slots in patch, microstrip patch antennas using Defected Ground Structure (DGS) for size reduction.

2.2 Research Paper Literature Review

In order to start the thesis, the first step is to study the research papers that have been already published by other researchers. Papers related to this work are chosen and studied. With the help of literature review, it becomes easier to perform this work.

The concept of Microstrip radiator was first proposed by Deschamps in 1953. A patent was issued in France in 1955 in the name of Gutton and Baissinot. Development during the 1970s was accelerated by the availability of good substrates. The first practical antennas were developed by Howell and Munson. Since then extensive research and development on Microstrip antennas aimed at exploiting their advantages.

2.2.1 Design, simulation and fabrication of a microstrip patch antenna for dual band application [8]

This paper describes a coaxially-fed single-layer compact microstrip patch antenna for achieving dual-polarized radiation suitable for applications in the IEEE Radar Band C and X. Simultaneous use of both frequencies should dramatically improve data collection and knowledge of the targets in an airborne synthetic aperture radar system. The designed antenna consists of three rectangular patches which are overlapped along their diagonals. The design and simulation of the antenna were performed using 3D full wave electromagnetic simulator IE3D.

2.2.2 Design of circular polarized microstrip aperture coupled patch antenna for 5.8 GHz ISM band [9]

This paper presents the design of an aperture coupled modified cross-slot microstrip patch antenna with four new slots generating a circular polarization and using a microstrip substrate produced by plane type printing technology which meets such a demand. The antenna is characterized by small size, light weight, and multifunctional operation. As a result, a return loss of -40 dB at the centre frequency 5.84 GHz was obtained by simulation of the ISM band with an operation frequency 5.8 GHz and a return loss of -37 dB at 5.79 GHz by actual measurement, suggesting that the match between the feeding line and radiation patch is better than the existing aperture coupled cross slot microstrip antenna, and the axial ratio is also good.

2.2.3 Design of Ultra Wideband slotted microstrip patch antenna [10]

The author proposed the design of an Ultra Wideband slotted microstrip patch antenna is presented. The proposed antenna has good performance of UWB with impedance bandwidth between 1.78 GHz to 11.13 GHz. The antenna exhibits the return loss (S_{11}) below -10 dB for the frequency range mentioned. Effects of design antenna parameters such as the slot (size, position and dimension), patch shape and feed width have been investigated to obtain a better S_{11} value. Results are obtained using CST Microwave Studio.

2.2.4 Dual band microstrip antenna using U and S slots for WLAN application [11]

A dual band microstrip patch antenna for solution standard wireless local area network (WLAN) is presented. Dual band characteristic is produced by combining the 2.4 GHz band and the 5 GHz band by using slot U. Wideband characteristics is achieved at frequency 5 GHz by using slot S. This design can completely cover the IEEE standard (802.11 b/g and 802.11 a) for WLAN.

2.2.5 Slotted e-shape antenna design for dual frequency operation[12]

In this paper, the author proposed a slotted e-shape rectangular patch antenna with dual-frequency operation is introduced. The patch dimension of 34 times 23 mm was fabricated

using FR4 substrate having thickness of 1.6 mm and permittivity of 4.8. The measured results show that the designed antenna achieves a VSWR less than 2 with bandwidth of 3.02% (2.45-2.525 GHz) at lower frequency and 1.65% (6.125 - 6.025 GHz) at upper frequency. The measured gain of this antenna is 3 dB for both working frequencies.

2.2.6 Design of a broadband E-shaped microstrip antenna [13]

A broadband E-shaped microstrip antenna is proposed in this paper. Its bandwidth is further increased by inserting a pair of tapered slits into an appropriate radiating edge of the rectangular patch antenna. The Antenna is designed and simulated by three-dimensional electromagnetic field software HFSS. Results show that the designed antenna has an impedance bandwidth over 21% (from 12.7GHz to 15.7 GHz) for VSWR \leq 2, which is four times greater than the conventional rectangular patch antenna. Satisfactory radiation patterns have also been obtained through simulation. The maximum gain in frequency band is 8.52dB. The resulting size of the microstrip antenna is 15 mm \times 15mm, realizing miniaturization, high power gain, and wide band features of the microstrip antennas.

2.2.7 Design and development of wideband and dual-band microstrip antennas [14]

In this paper, a study of the wideband and dual-band characteristics of single- and double-notched rectangular patch antennas is presented. A comparative study of the experimental results employing coax, microstrip, aperture-coupled and electromagnetically coupled feed techniques has been made for increased bandwidth and improved cross polar level. Optimum coax-fed location input resonant resistance and notch parameters are estimated using the transmission-line model. The experimental radiation patterns were compared with simulated and theoretical patterns and found to be in good agreement. The maximum measured impedance bandwidths of 26.6% in band 1 and 31.7%, in band 2 have been achieved for coax-fed single-notched patches. A double-layered double-notched aperture coupled (composite) patch antenna was also designed, and further improvement in impedance bandwidth of 39% was achieved without significant degradation in radiation characteristics. From the measured and calculated results it can be seen that single- or double-notched composite patches can be designed to yield wide- and dual-band operations suitable for mobile communications.

2.2.8 The gain enhancement of Microstrip array antenna with dielectric lens -A comparative study [15]

In this paper, a four element and an eight element Microstrip array antenna with its printed feed network on a monolithic substrate is first analyzed for the predicted radiation patterns and compared with experimental results. The gain enhancement of the Microstrip array with dielectric lens is then studied. The advantage of using dielectric lens is observed to be 4dbi extra gain which translates to an effective larger size antenna. These types of array-lens are useful as low cost smart antenna. The experiment is carried out in S band range of frequencies.

2.2.9 Design of microstrip patch antenna using novel U-shaped feeding strip with unequal arm [16]

In this paper, a novel feeding technique for the microstrip patch antenna has been proposed. The U-shaped feeding strip with an unequal arm is proposed to feed a printed rectangular ring patch antenna to achieve high gain. Measured results of the prototype antenna agree very well with simulated results. According to the measured results, the antenna shows good impedance bandwidths satisfying ISM 2.45/5.8 GHz with good impedance matching. Stable radiation patterns are achieved with maximum gains of 9.56 and 10.17 dBi for both bands.

2.2.10 Novel inset feed design technique for microstrip patch antenna [17]

In this paper, a new design technique for the impedance matching of inset feed section that improves the performance of a conventional and grooved microstrip patch antenna is proposed. The purposed impedance matching technique for inset feed microstrip patch antenna is based on the concept of coplanar waveguide feed line and has been investigated for a printed antenna at X-Band antenna operating at a frequency of 10GHz. The proposed technique has been used in the design of Grooved Microstrip patch antenna array.

2.2.11 Design of double C-slot microstrip patch antenna for WiMax application [18]

A new standard known as WiMax (Worldwide Interoperability for Microwave access) has been established by the IEEE 802.16 working group. WiMax theoretically can have coverage of up to 50 km radius. WiMax antennas have aroused high interest in recent years. Researchers are focusing on how to design antennas for WiMax technology.

WiMax has three allocated frequency bands, the low band (2.5-2.69 GHz), the middle band (3.2-3.8 GHz) and the upper band (5.25-5.8 GHz). The microstrip patch antenna is a very good candidate for integrations in applications such as wireless communication systems, mobile phones and laptops. In this paper a double C-slot microstrip antenna is designed and simulated for the WiMax frequency range of 2.5-2.69 GHz. This antenna presents an extension to the single C slot antenna presented at LAPC 2009. The proposed antenna has a gain of 6.46 dBi and presents a size reduction of 37% when compared to a conventional square microstrip patch antenna. Extensive simulation results using Advanced Design Systems by Agilent (uses the MOM method) will be presented.

2.2.12 Design of high gain multiple U-slot microstrip patch antenna for wireless system [19]

In this paper, a novel multi-slotted microstrip patch antenna with high gain is presented and discussed. The design adopts contemporary techniques such as probe feeding and multi-slotted patch. These techniques can contribute to the enhanced performance of the antenna. The design also employs a novel shape patch. By integrating these techniques the proposed design offers low profile, high gain and compact antenna element. The maximum gain at the resonant frequency of 2.45GHz is 11.35dBi. The lowest return loss can be -34.49 dB at 2.45GHz. The proposed design has a simple structure and a compact dimension of 87mm*51mm. The proposed design is suitable for particular wireless communication application such as WiFi and WLAN.

2.2.13 Design of c-slot microstrip patch antenna for WiMax applications [20]

In this paper, a small compact Microstrip patch antenna with C-shaped slot is presented and simulated using Advanced Design Systems. It is developed to operate in the WiMax frequency range of 2.5-2.69 GHz. The antenna presents a size reduction of about 37% when compared to a conventional patch antenna. The return loss is -19.1 dB and the antenna presents a broad radiation pattern.

2.2.14 An overview on defected ground structure [21]

This paper focuses on overview of defected ground structure (DGS). The basic conceptions and transmission characteristics of DGS are introduced and the equivalent

circuit models of varieties of DGS units are also presented. Finally, the main applications of DGS in microwave technology field are summarized and the evolution trend of DGS is given.

2.2.15 Defected Ground Structure in the perspective of Microstrip Antennas: A Review [22]

Defected ground structures (DGS) have been developed to improve characteristics of many microwave devices. Although the DGS has advantages in the area of the microwave filter design, microwave oscillators, microwave couplers to increase the coupling, microwave amplifiers, etc., it is also used in the microstrip antenna design for different applications such as antenna size reduction, cross polarization reduction, mutual coupling reduction in antenna arrays, harmonic suppression etc., The DGS is motivated by a study of Photonic / Electromagnetic Band gap structures. The etching of one or more PBG element creates defect in the ground plane and used for the same purpose. The DGS is easy to be an equivalent L-C resonator circuit. The value of the inductance and capacitance depends on the area and size of the defect. By varying the various dimensions of the defect, the desired resonance frequency can be achieved. In this paper the effect of DGS, to the different antenna parameter enhancement is studied.

2.2.16 Microstrip patch antenna with skew-f shaped dgs for dual band operation [23]

The goal of this paper is to use defected ground structure (DGS) in microstrip antennas for dual band operation at microwave frequencies. The soft nature of the DGS facilitates improvement in the performance of microstrip antennas. A design study on microstrip patch antenna with specific DGS slot has been presented in the proposed work. In this paper, a stacked microstrip patch antenna (SMPA) has been designed for broadband behaviour, and then skew- F shaped DGS has been integrated with a detailed study of possible DGS slots in a small area for dual band operation. The design and optimization of both the SMPA and DGS structures along with the parametric study were carried out using CST Microwave Studio V.9. Further, the dual band antenna, i.e., the SMPA with skew-F shaped DGS, has been fabricated, and the experimental results have shown a good agreement with the simulation ones.

2.2.17 A new defected ground structure for different microstrip circuit applications [24]

In this paper, a microstrip transmission line combined with a new U-headed dumb-bell shaped defected ground structure (DGS) is investigated. The proposed DGS of two U-shape slots connected by a thin transverse slot is placed in the ground plane of a microstrip line. A finite cut-off frequency and attenuation pole is observed and thus, the equivalent circuit of the DGS unit can be represented by a parallel LC resonant circuit in series with the transmission line. A two-cell DGS microstrip line yields a better low-pass filtering characteristics. The simulation is carried out by the MoM based IE3D software and in the experimental measurements a vector network analyzer is used. The effects of the transverse slot width and the distance between arms of the U-slot on the filter response curve are studied.

This DGS is utilized for different microstrip circuit applications. The DGS is placed in the ground of a capacitive loaded microstrip line and a very low cutoff frequency is obtained. The DGS is adopted under the coupled lines of a parallel line coupler and an improvement in coupling coefficient is noticed. The proposed DGS is also incorporated in the ground plane under the feed lines and the coupled lines of a bandpass filter to improve separately the stopband and passband performances.

2.2.18 2.45 GHz microstrip patch antenna with defected ground structure for bluetooth [25]

In this paper, a rectangular microstrip patch antenna with DGS has been analyzed and simulated for the wireless applications. The proposed antenna has been simulated at 2.45 GHz frequency. This compact antenna fed by Quarter Transformer feeding. This type of feeding is mostly used for impedance matching purposes. The antenna is simulated by the software HFSS. HFSS, high frequency structure simulator is employed to analyze the proposed antenna and simulated results on return loss, the E and H plane radiation pattern and polar plot gain is presented. The resultant antenna with Defected Ground Structure has improved in parameters performance.

2.2.19 Compact defected ground structure in microstrip technology [26]

A meander microstrip line with defected ground structure is proposed. Its radiation loss and slow-wave effect are evaluated. The compact configuration presents broad stopband

and improved slow-wave characteristics. A good agreement between simulation and measurement verifies the designed circuit.

2.2.20 Design of Low-Pass Filters Using Defected Ground Structure [27]

A method to design low-pass filters (LPF) having a defected ground structure (DGS) and broadened transmission-line elements is proposed. The previously presented technique for obtaining a three-stage LPF using DGS by Lim *et al.* is generalized to propose a method that can be applied in design n -pole LPFs for $n \geq 5$. As an example, a five-pole LPF having a DGS is designed and measured. Accurate curve-fitting results and the successive design process to determine the required size of the DGS corresponding to the LPF prototype elements are described. The proposed LPF having a DGS, called a DGS-LPF, includes transmission-line elements with very low impedance instead of open stubs in realizing the required shunt capacitance. Therefore, open stubs, tee- or cross-junction elements, and high-impedance line sections are not required for the proposed LPF, while they all have been essential in conventional LPFs. Due to the widely broadened transmission-line elements, the size of the DGS-LPF is compact.

2.2.21 Compact multi frequency slotted microstrip patch antenna with enhanced bandwidth using defected ground structure for mobile communication [28]

In recent years, great interest was focused on microstrip antennas for their low profile, light weight, small volume and compability with microwave integrated circuit (MIC) and monolithic microwave integrated circuit (MMIC). With the continuous growth of wireless communication service and the constant miniaturization of communication equipment, there are higher and higher demands for the low volume of antennas, integration and working band. Operation in two or more discrete bands with an arbitrary separation of bands is desired in many applications, such as Global positioning system(GPS), Worldwide Interoperability for microwave access (Wi-MAX). In this paper we present the design of a novel compact small size, single feed, single layer, multi frequency microstrip antenna. Resonant frequency has been reduced drastically by cutting unequal slots at the edge of the patch. The size of the antenna is reduced to 57%. For the design and simulation purpose we have used method of moment based EM Simulation software I3ED.

2.2.22 Modified triangular patch microstrip antenna with enhanced radiation properties [29]

This research presents a hexagonal shape Defected Ground Structure (DGS) implemented on two element triangular patch microstrip antenna array. The radiation performance of the antenna is characterized by varying the geometry and dimension of the DGS and also by locating the DGS at specific position, which were simulated. Simulation and measurement results have verified that the antenna with DGS had improved the antenna without DGS. Measurement results of the hexagonal DGS have axial ratio bandwidth enhancement of 10 MHz, return loss improvement of 35%, mutual coupling reduction of 3 dB and gain enhancement of 1 dB.

2.2.23 Rectangular patch antenna performances improvement employing slotted rectangular shaped for wlan applications [30]

This paper describes the effect of inserting a rectangular shape defected ground structure (DGS) into the ground plane of the conventional rectangular microstrip patch antenna (CRMPA). The performances of the CRMPA are characterized by varying the dimensions of the rectangular slot (RS-DGS) and also by locating the RS-DGS at specific position. Simulation results have verified that the CRMPA including RS- DGS had improved the CRMPA without RS-DGS. The return loss (RL) enhances approximately of 100 %, and gain improvement of 0.8 dB.

2.2.24 Design, analysis and optimization of a slotted microstrip patch antenna array at frequency 5.25 ghz for wlan-sdma system [31]

The design of array antenna is vital study for today's Wireless communication system to achieve higher gain, highly directional beam and also to counteract the effect of fading while signal propagates through various corrupted environments. In this study, the design and analysis of a (2x2) microstrip patch antenna array is introduced. It is designed to function in the 5.25 GHz which corresponds to IEEE 802.11a (VSWR<2, data rate 54Mbps/ B.W 20 dB and S-parameters, $S_{ij} < -20\text{dB}$ where $i \neq j$) wireless LAN application. It achieves single band functionality through additional slots to rectangular patch of dimension 18.8 mm by 24.4mm. The proposed antenna array is a high gain, low-cost, low weight base station antenna. The characteristic analyses such as return loss (RL), bandwidth, VSWR and radiation pattern of the prototype antenna array have been investigated both numerically and experimentally. In this investigation, VSWR less than

1.45 and bandwidth of 180MHz (For $RL > -9.5\text{dB}$) and antenna gain of 13.88 dBi have been achieved. Both numerical and experimental studies have been carried out to optimize the distance between the antenna elements. The measured results have a good agreement with that of simulated results. The numerical study has been done by using Zeland make IE3D electromagnetic simulator and measurements have been done with the help of Agilent make N5230A, network analyzer.

2.2.25 Characteristics of a novel slow-wave defected ground structure for planar wideband filters [32]

This paper presents a new approach for designing compact band stop and band pass filter. This technique is based on defected ground structure. Despite other filters that use DGS just to improve the response of the filter, in this paper Defected Ground Structure is used as the building block of the filter. The center frequency of the filter can be easily controlled by changing the dimension of the DGS resonator. Two filters with center frequency of 1.17GHz and 3.2GHz has been designed and simulated. The structure of the filter has been improved for wideband and high Q applications. Current characteristics and slow wave factor of the filter have been analyzed.

2.2.26 Microstrip patch antenna with defected ground structure for cross polarization suppression [33]

In this, author explains defected ground structure (DGS) to reduce the cross-polarized (XP) radiation of a microstrip patch antenna. The DGS pattern here is simple and easy to etch on a commercial microstrip substrate. This will only reduce the XP radiation field without affecting the dominant mode input impedance and co-polarized radiation patterns of a conventional antenna. The new concept has been examined and verified experimentally for a particular DGS pattern employing a circular patch as the radiator. Both simulation and experimental results are presented.

2.2.27 A proposed defected microstrip structure (dms) behavior for reducing rectangular patch antenna size [34]

In this paper, the author illustrates a defected microstrip structure (DMS) to reduce the size of a rectangular patch antenna by increasing its electric length, without degrading its performance. To illustrate this advantage, one conventional and one proposed defected patch antenna were developed and measured at 1.77 GHz. The simulated and measured

results concerning the radiation patterns and bandwidth of both antennas are very closely related, but the proposed defected antenna achieves 22% of total-area reduction.

2.2.28 Microstrip patch antenna with defected ground structure defected microstrip structure [35]

In this paper, the author proposed the antenna geometry to design a very compact microstrip patch antenna using thin dielectric substrate having low dielectric constant. This antenna provides better efficiency, better band-width without any enhancement in the weight, volume or cost. He used HFSS (high frequency simulator) to analyze the proposed antenna and simulated results on return loss, the E-and H-plane radiation pattern is presented. The antenna parameter in frequency domain analysis has been investigated to show its capability as an effective radiating element. Due to low-profile structure it can be used in wireless application.

2.2.29 Size reduction of microstrip patch antenna using defected microstrip structures [36]

In this paper, the author illustrates about the use of discontinuities in ground planes or in microstrip lines to improve the performance of different passive circuits. It includes size reduction of amplifiers; enhancement of filter characteristics and applications to suppress harmonics in patch antennas. This paper presents an improved method of size reduction of a microstrip antenna using Defected Microstrip Structure. It does so by introducing imperfections in the microstrip antenna on the conducting layer using a DMS designed defect. The design was simulated using IE3D Electromagnetic Simulator. The results are very encouraging as it increases the number of components in a given constant area. On the other hand, a new proposal, called defected microstrip structure (DMS), has been successfully used in reducing the size of, and can be further used as tuning technique for, rectangular patch antennas.

INTRODUCTION TO MICROSTRIP PATCH ANTENNA

3.1 Introduction

In this chapter, the procedure for designing a rectangular Microstrip patch antenna is explained. The antenna parameters are studied and explained.

3.2 Rectangular Microstrip Patch Antenna

The rectangular patch antenna is approximately a one-half wavelength long section of rectangular microstrip transmission line. When air is the antenna substrate, the length of the rectangular microstrip antenna is approximately one-half of a free-space wavelength. The length of the antenna decreases as the relative dielectric constant of the substrate increases. The resonant length of the antenna is slightly shorter because of the extended electric "fringing fields" which increases the electrical length of the antenna slightly. [6]

3.3 Design Procedure of Single Band Rectangular Microstrip Patch antenna

A single element of rectangular patch antenna, as shown in Figure 3.1 and 3.2, can be designed for any resonant frequency using transmission line model equations [6].

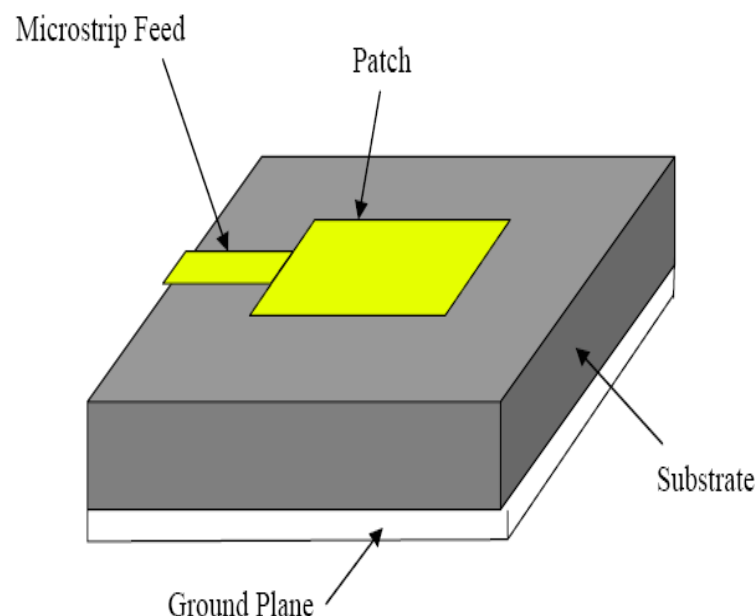


Figure 3.1: Rectangular Microstrip patch antenna using microstrip line feed

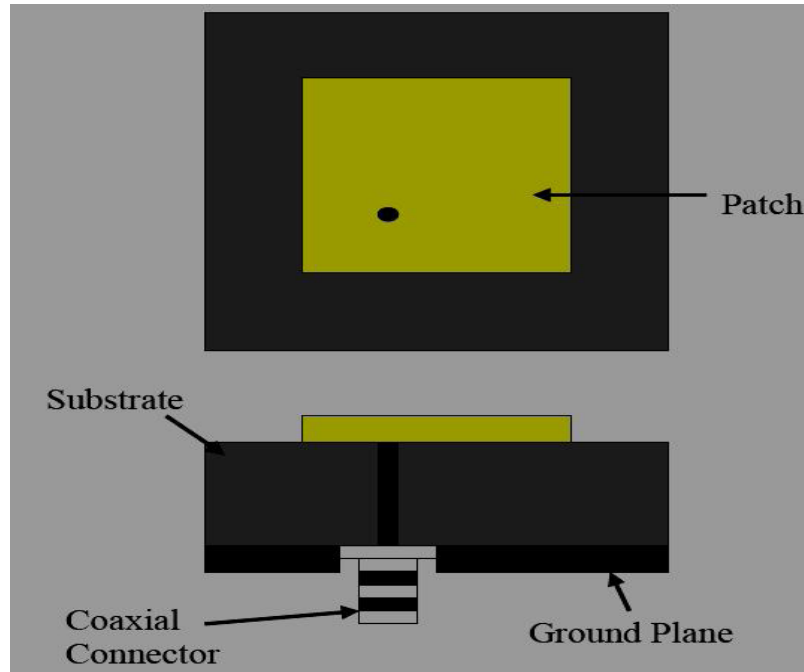


Figure 3.2: Rectangular Microstrip patch antenna using coaxial feed

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

Frequency of operation (f_r): The resonant frequency of the antenna must be selected appropriately. The 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 5.2 GHz.

Dielectric constant of the substrate (ϵ_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.

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

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

Step 1: Calculation of Width (W)

For an efficient radiator, practical width that leads to good radiation efficiencies is [4]

$$W = \frac{1}{2f_r \sqrt{\mu_0 \epsilon_0}} \sqrt{\frac{2}{\epsilon_r + 1}} \quad \text{Equation 3.1}$$

Where, v_0 is the free space velocity of light.

Step 2: Calculation of Effective Dielectric Coefficient (ϵ_{reff})

The effective dielectric constant is

$$\epsilon_{\text{reff}} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + 12 \frac{h}{W} \right]^{-\frac{1}{2}} \quad \text{Equation 3.2}$$

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

The effective length is

$$L_{\text{eff}} = \frac{c}{2f_0 \sqrt{\epsilon_{\text{reff}}}} \quad \text{Equation 3.3}$$

Step 4: Calculation of Length Extension (ΔL)

$$\frac{\Delta L}{h} = 0.412 \frac{(\epsilon_{\text{reff}} + 0.3) \left(\frac{W}{h} + 0.264 \right)}{(\epsilon_{\text{reff}} - 0.258) \left(\frac{W}{h} + 0.8 \right)} \quad \text{Equation 3.4}$$

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

The actual length of radiating patch is obtained by

$$L = L_{\text{eff}} - 2\Delta L \quad \text{Equation 3.5}$$

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

The transmission line model is applicable to infinite ground planes only. However, for practical considerations, it is essential to have a finite ground plane. It has been shown by [6] 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:

$$L_g = 6h + L \quad \text{Equation 3.6(a)}$$

$$W_g = 6h + W \quad \text{Equation 3.6(b)}$$

3.4 Antenna Parameters

3.4.1. S-parameters

S-parameters describe the input-output relationship between ports (or terminals) in an electrical system. For instance, if we have 2 ports (intelligently called Port 1 and Port 2), then S12 represents the power transferred from Port 1 to Port 2. S21 represents the power transferred from Port 2 to Port 1.

S_{21} represents the power received at antenna 2 relative to the power input to antenna 1. For instance, $S_{21}=0$ dB implies that all the power delivered to antenna 1 ends up at the terminals of antenna 2 (which isn't physically possible). If $S_{21}=-10$ dB, this implies that 1 Watt delivered to antenna 1 (or 0 dB), ends up as -10 dB at antenna 2, or 0.1 Watts.

S_{11} represents how much power is reflected from the antenna. If $S_{11}=0$ dB, then all the power is reflected from the antenna and nothing is radiated. If $S_{11}=-10$ dB, this implies that if 3 dB of power is delivered to the antenna, -7 dB is the reflected power. The rest was "accepted" by the antenna. This accepted power is either radiated or absorbed as losses within an antenna. Since antennas are typically designed to be low loss, the majority of the power delivered to the antenna is radiated. Return loss is the difference between forward and reflected power, in dB.

3.4.2. Smith Chart:

The Smith Chart is a fantastic tool for visualizing the impedance of a transmission line and antenna system as a function of frequency. The **Smith Chart**, invented by Phillip H. Smith (1905-1987), is a graphical aid 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 colours 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. Smith Charts can be used to increase understanding of transmission lines and how they behave from an impedance viewpoint. Smith Charts are also extremely helpful for impedance matching. The Smith Chart is used to display a real antenna's impedance when measured on a Vector Network Analyzer (VNA). Smith Charts is a useful tool for making the equations involved in transmission lines easier to manipulate.

The Smith Chart is shown in Figure 3.3.

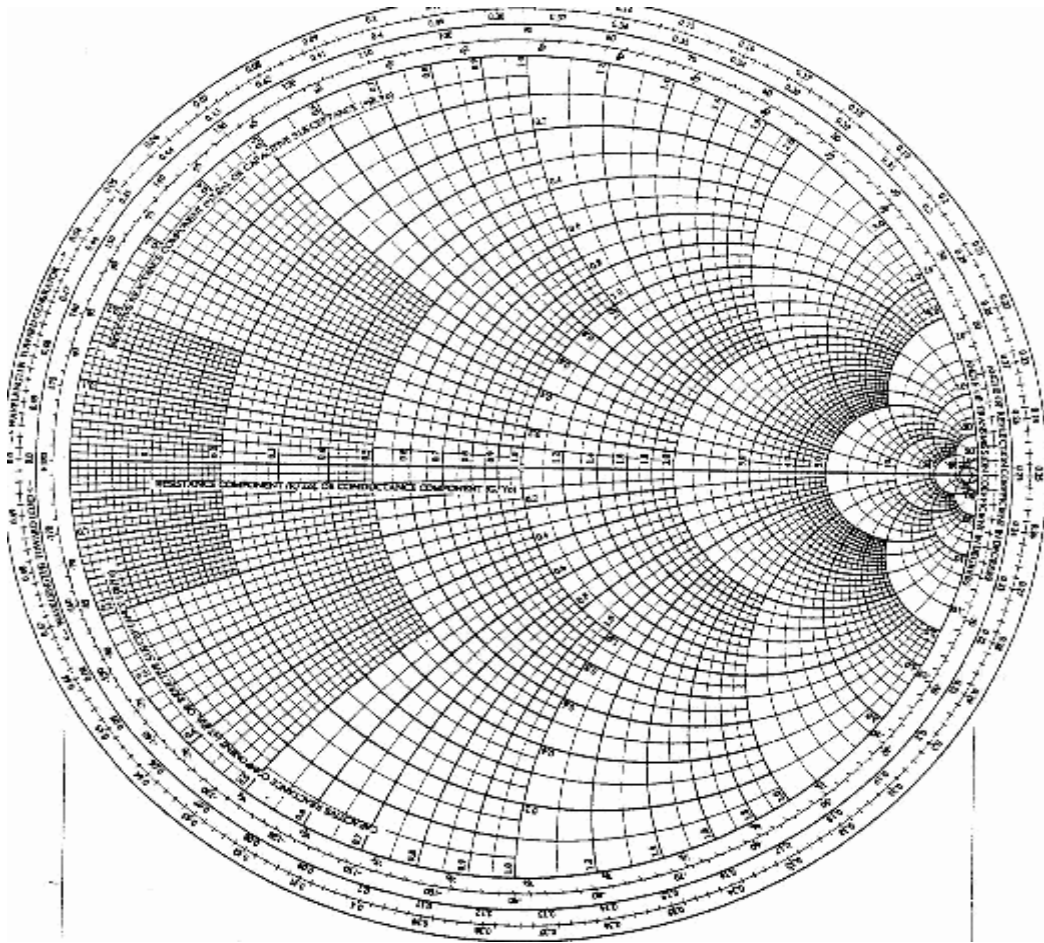


Figure 3.3: Smith chart

3.4.3. 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

3.4.4. Radiation Pattern

A radiation pattern defines the variation of the power radiated by an antenna as a function of the direction away from the antenna. This power variation as a function of the arrival angle is observed in the far field. As an example, consider the 3-dimensional radiation pattern in Figure 3.5 [48], plotted in decibels (dB).

This is an example of a donut shaped or toroidal pattern. In this case, along the z-axis, which would correspond to the radiation directly overhead the antenna, there is very little power transmitted. In the x-y plane (perpendicular to the z-axis), the radiation is maximum. These plots are useful for visualizing which directions the antenna radiates.

Typically, because it is simpler, the radiation patterns are plotted in 2-d. In this case, the patterns are given as "slices" through the 3d plane. Standard spherical coordinates are used, where θ is the angle measured off the z-axis, and ϕ is the angle measured counter clockwise off the x-axis.

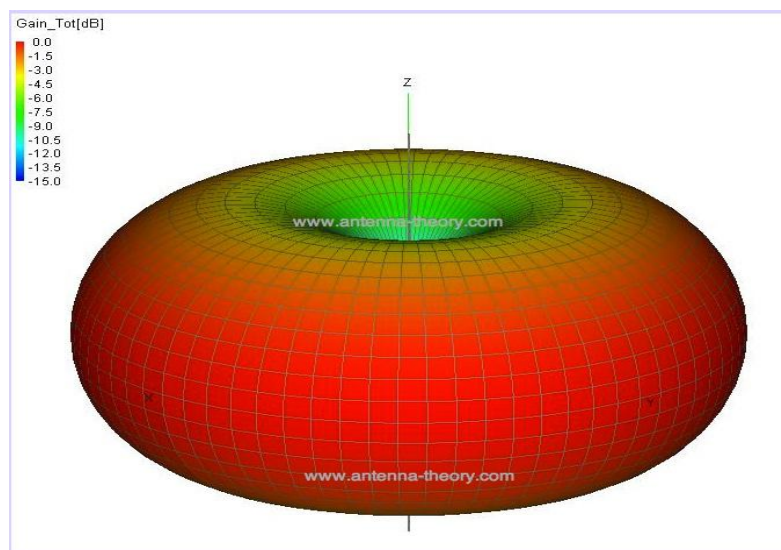


Figure 3.5: Example of radiation pattern

A pattern is "isotropic" if the radiation pattern is the same in all directions. These antennas don't exist in practice, but are sometimes discussed as a means of comparison with real antennas. Some antennas may also be described as "omnidirectional", which for an actual means that it is isotropic in a single plane (as in Figure 3.5 above for the x-y plane). The third category of antennas are "directional", which do not have a symmetry in the radiation pattern.

Directivity is a fundamental antenna parameter. It is a measure of how 'directional' an antenna's radiation pattern is. An antenna that radiates equally in all directions would have effectively zero directionality, and the directivity of this type of antenna would be 1 (or 0 dB).

Finally, we'll conclude with a list of antenna types and their directivities, to give you an idea of what is seen in practice.

Antenna Type	Typical Directivity	Typical Directivity (dB)
Short Dipole	1.5	1.76
Half Wave Dipole	1.64	2.15
Patch (Microstrip) Antenna	3.2-6.3	5-8
Horn Antenna	10-100	10-20
Dish Antenna	10-10,000	10-40

Table 2: Directivity for various types of antenna

SINGLE BAND MICROSTRIP PATCH ANTENNA DESIGN

4.1 Introduction

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

4.2 Designing of Single Band Rectangular Microstrip Antenna using coaxial feeding technique:

This section describes the design of a single band rectangular microstrip patch antenna using coaxial feeding technique satisfying the given specifications-

Frequency(f_r)	5.2 GHz
Dielectric constant(ϵ_r)	4.4
Substrate Height(h)	1.6 mm

As for the substrate selection, the major consideration will be the dielectric constant. A high dielectric constant will result in a smaller patch size but this will generally reduce bandwidth efficiency and might have difficulty in fabricating a very small patch size antenna.

4.2.1 PATCH DIMENSION:

Length (L) = 12.37 mm

Width (W) = 17.54 mm

GROUND DIMENSION:

Length (L_g) = 22.83 mm

Width (W_g) = 27.154 mm

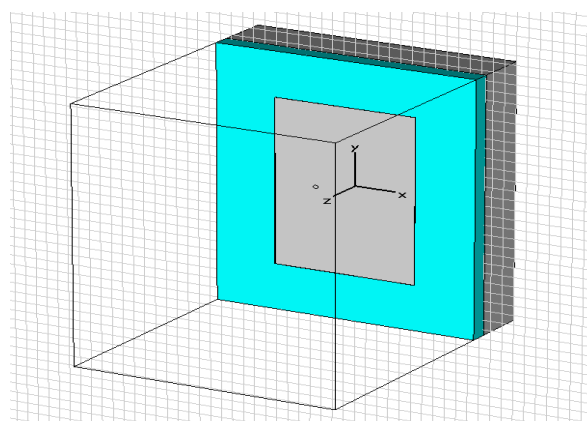


Figure 4.1: Geometry of Proposed Antenna using coaxial feed

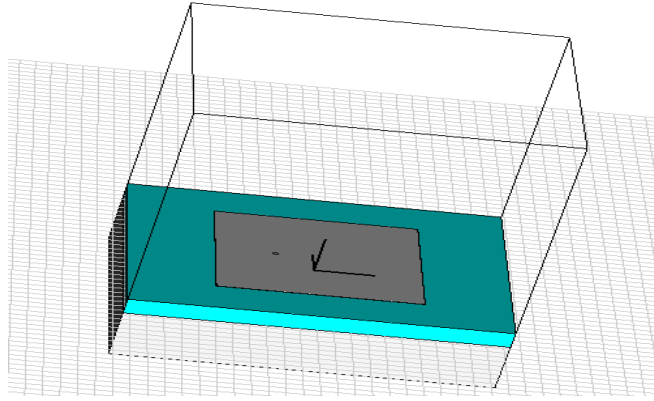


Figure 4.2: Designed structure on CST microwave studio

4.2.2 Return Loss of coaxial feed antenna

Figure 4.3 shows the S11 parameters (return loss) for the proposed antenna.

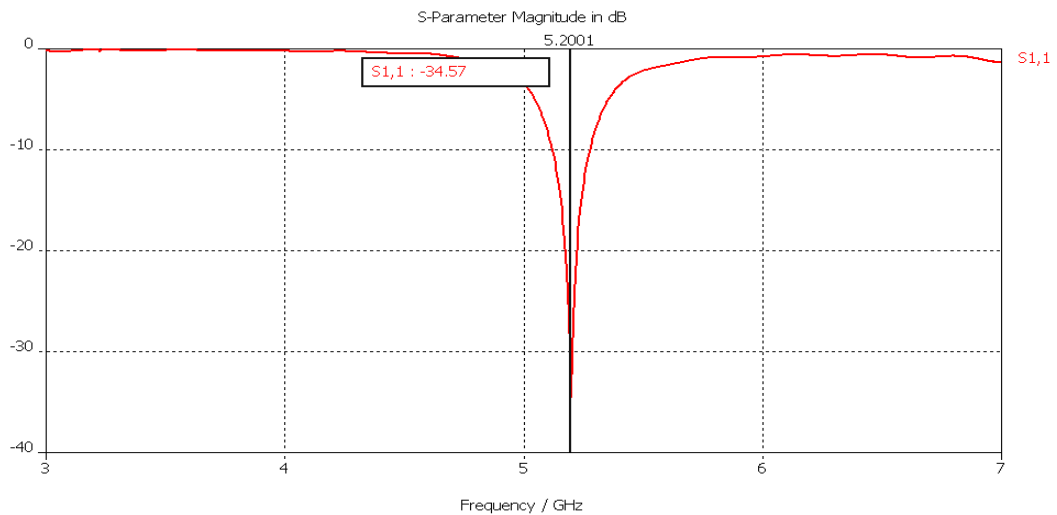


Figure 4.3 Return Loss of coaxial feed antenna (S_{11} in dB)

The designed antenna resonates at 5.2 GHz. The return loss at 5.2 GHz frequency is -34.57 dB as shown in Figure 4.3.

4.2.3 Bandwidth of coaxial feed antenna

The bandwidth of the antenna bandwidth of antenna can be calculated from return loss versus frequency plot. The bandwidth of the proposed patch antenna is 160 MHz is shown in Figure 4.4 and resonant frequency is 5.20 GHz which is very close to WLAN standard.

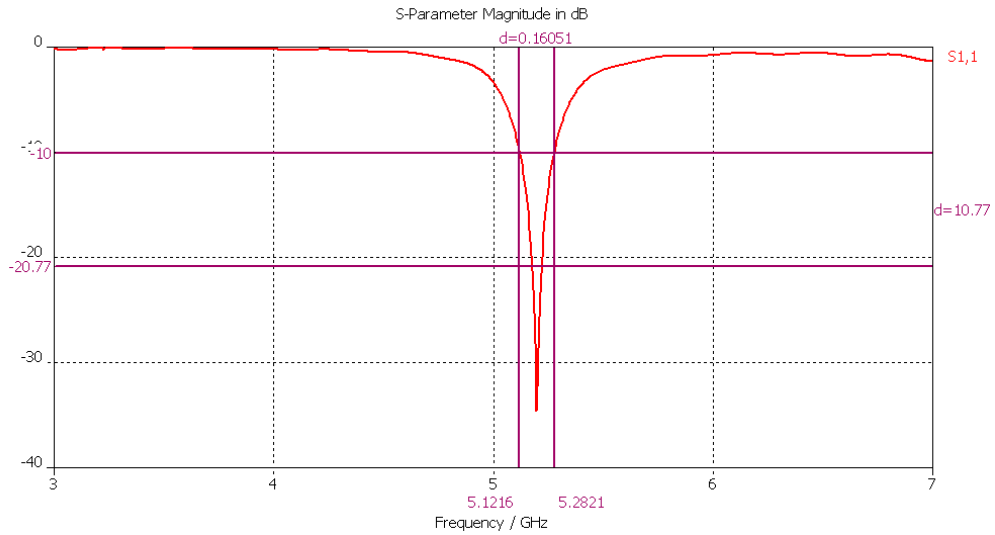


Figure 4.4 Bandwidth of coaxial feed antenna (S_{11} in dB)

4.2.4 Smith Chart of coaxial feed antenna

The Smith Chart plot represents that how the antenna impedance varies with frequency. The value of impedance should lie near 50 ohms in order to perfectly match the port with the antenna, as shown in Figure 4.5. The antenna impedance for this antenna is 50.43 Ω .

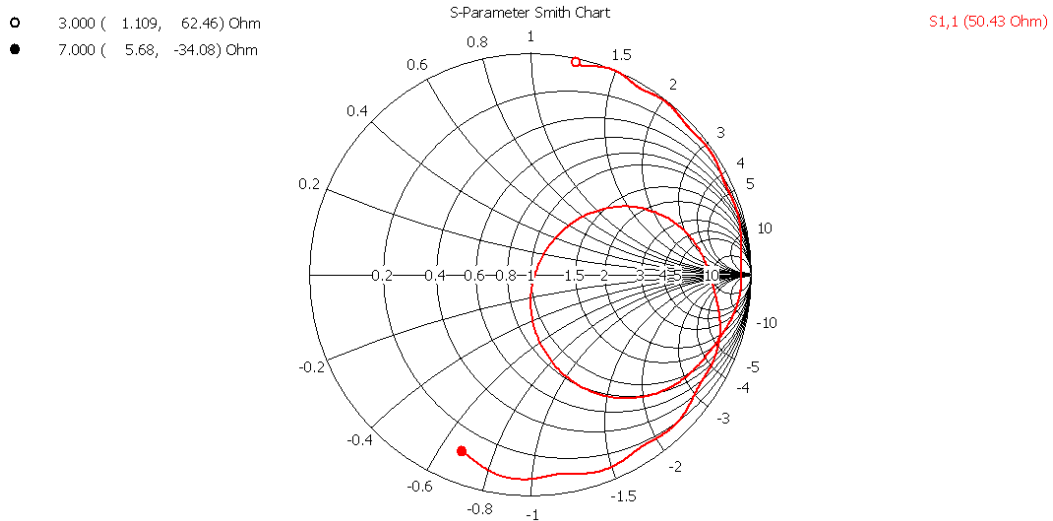


Figure 4.5 Smith Chart of coaxial feed antenna

4.2.5 Voltage Standing Wave Ratio (VSWR)

The VSWR plot for coaxial feed antenna is shown in Figure 4.6. Ideally, VSWR must lie in the range of 1-2 which has been achieved for the frequency 5.2 GHz, near the operating frequency value. The value for VSWR is 1:1.038.



Figure 4.6 VSWR Versus Frequency Plot of coaxial feed antenna

4.3 Designing of Single Band Rectangular Microstrip Antenna using microstrip line feeding technique:

This section describes the design of single band rectangular Microstrip patch antenna using microstrip line feeding technique satisfying the given specifications-

Frequency(f_r)	5.2 GHz
Dielectric constant(ϵ_r)	4.4
Substrate Height(h)	1.6 mm

As for the substrate selection, the major consideration will be the dielectric constant. A high dielectric constant will result in a smaller patch size but this will generally reduce bandwidth efficiency and might have difficulty in fabricating a very small patch size antenna.

4.3.1 PATCH DIMENSION:

Length (L) = 12.636 mm
 Width (W) = 25.8 mm

GROUND DIMENSION:

Length (Lg) = 22.83 mm
 Width (Wg) = 27.154 mm

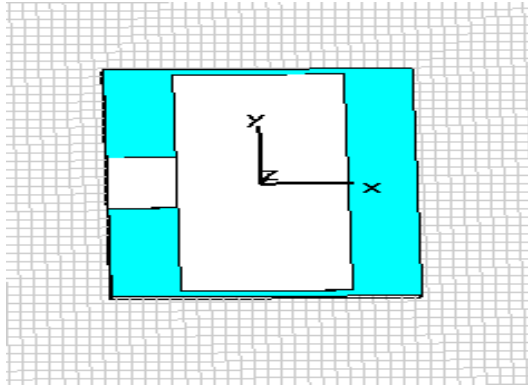


Figure 4.7 Geometry of Proposed Antenna using Microstrip line feed

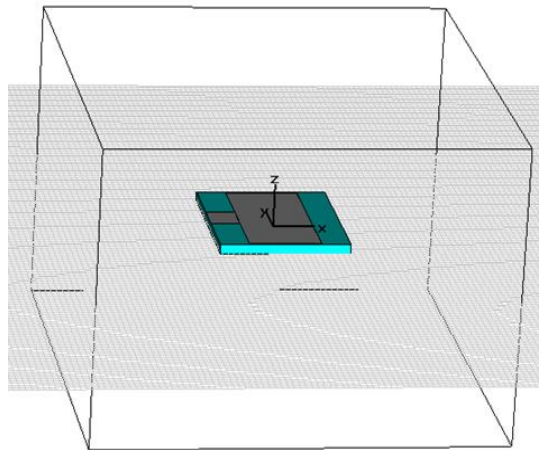


Figure 4.8: Designed structure on CST microwave studio

4.3.2 Return Loss of microstrip line feed antenna

Figure 4.9 shows the S_{11} parameters (return loss) for the proposed antenna.

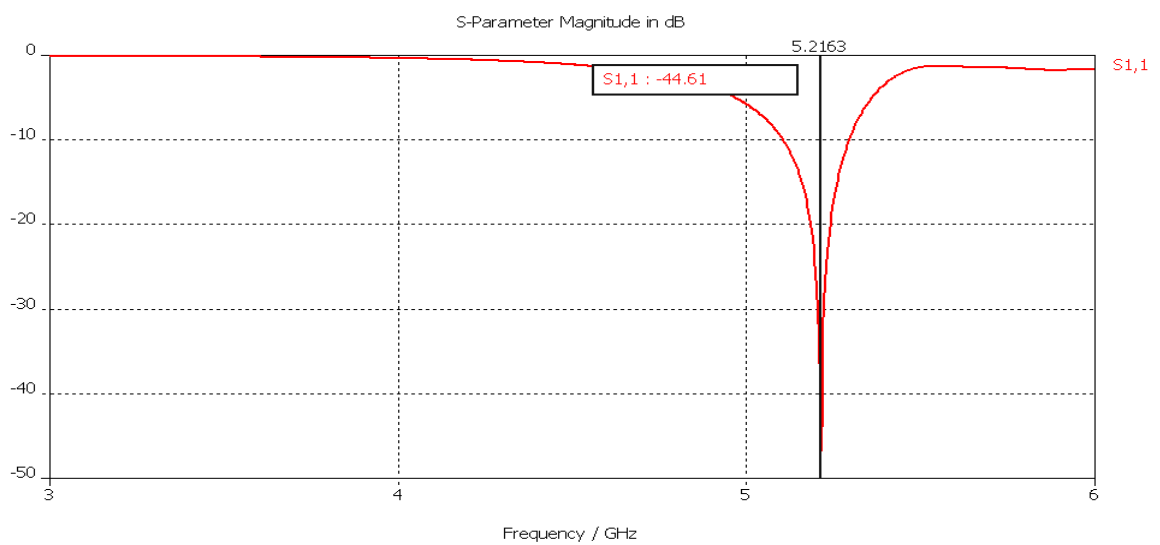


Figure 4.9 Return Loss of microstrip line feed antenna (S_{11} in dB)

The designed antenna resonates at 5.2 GHz. The return loss at 5.2 GHz frequency is -44.61 dB as shown in Figure 4.9.

4.3.3 Bandwidth of microstrip line feed antenna

The bandwidth of the antenna bandwidth of antenna can be calculated from return loss versus frequency plot. The bandwidth of the proposed patch antenna is 196 MHz is shown in Figure 4.10 and resonant frequency is 5.20 GHz which is very close to WLAN standard.

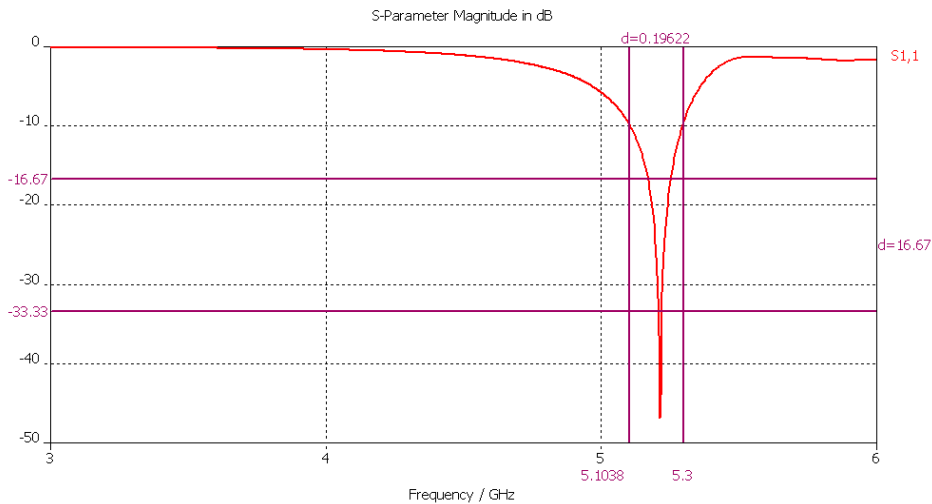


Figure 4.10 Bandwidth of microstrip line feed antenna (S_{11} in dB)

4.3.4 Smith Chart of microstrip line feed antenna

The Smith Chart plot represents that how the antenna impedance varies with frequency. The value of impedance should lie near 50 ohms in order to perfectly match the port with the antenna, as shown in Figure 4.11. The antenna impedance for this antenna is 50.89 Ω .

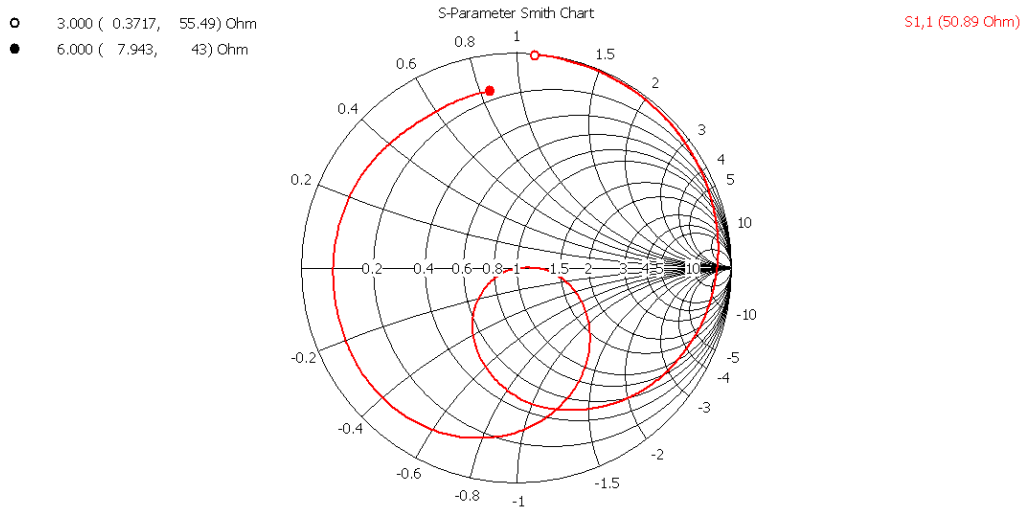


Figure 4.11 Smith Chart of microstrip line feed antenna

4.3.5 Voltage Standing Wave Ratio (VSWR) of microstrip line feed antenna

The VSWR plot for microstrip line feed antenna is shown in Figure 4.12. Ideally, VSWR must lie in the range of 1-2 which has been achieved for the frequency 5.2 GHz, near the operating frequency value. The value for VSWR is 1:1.032.

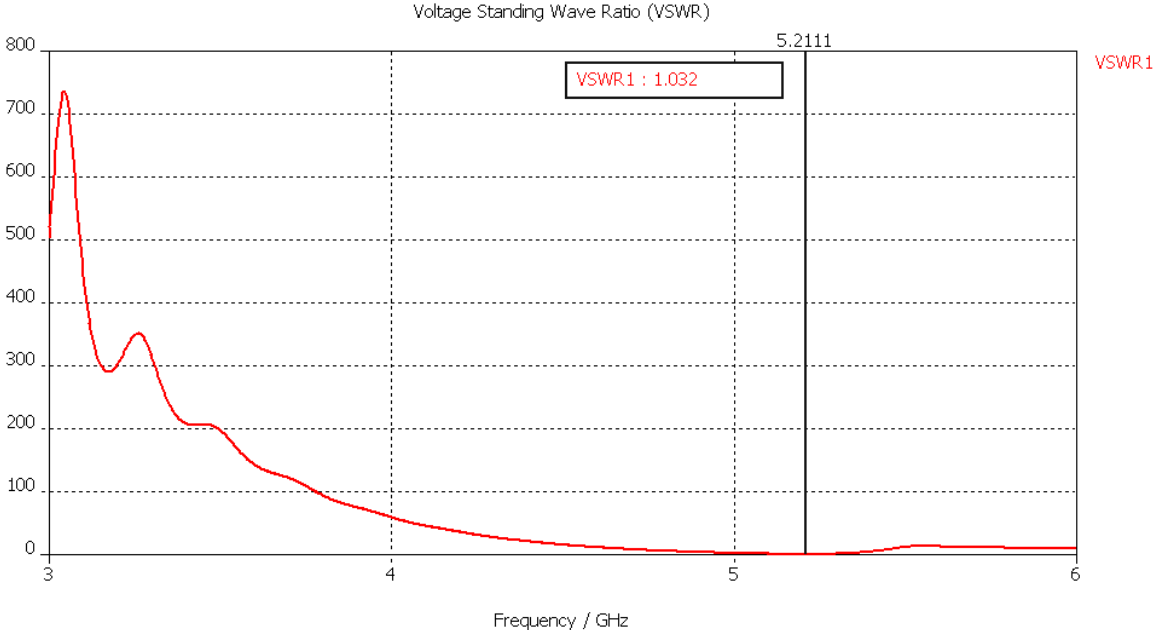


Figure 4.12 VSWR Versus Frequency Plot of microstrip line feed antenna

DUAL BAND MICROSTRIP PATCH ANTENNA DESIGNS USING DEFECTED GROUND STRUCTURE (DGS)

In this chapter, Defected Ground Structure (DGS) and its effect has been discussed. The design is simulated on CST Microwave Studio Software. Finally, the results obtained from the simulation are demonstrated.

5.1. Defected Ground Structure

A Defected Ground Structure (DGS) is an etched lattice shape, which locates on the ground plane. Defected ground structure (DGS) is realized by etching defects in the backside metallic ground plane under a microstrip line. A basic and widely used DGS cell is composed of two wide defected areas and a narrow connecting slot such as H shape narrow at middle or U shape with narrow at bottom.

The name for this technique simply means that a “defect” has been placed in the ground plane, which is typically considered to be an approximation of an infinite, perfectly-conducting current sink. DGS allows the designer to place a notch (zero in the transfer function) almost anywhere [42].

DGS is an etched periodic or non-periodic cascaded configuration defect in ground of a planar transmission line (e.g., microstrip, coplanar and conductor backed coplanar wave guide) which disturbs the shield current distribution in the ground plane cause of the defect in the ground. This disturbance will change characteristics of a transmission line such as line capacitance and inductance. In a word, any defect etched in the ground plane of the microstrip can give rise to increasing effective capacitance and inductance [21].

5.2. Dual Band Antenna Concept

In principle, multi-band planar antennas should operate with similar features, both in terms of radiation and impedance matching, at two or more separate frequencies. It is known, a simple rectangular Microstrip patch can be regarded as a cavity with magnetic walls on the radiating edges. The first three modes with the same polarization can be indicated by TM₁₀, TM₂₀ and TM₃₀. TM₁₀ is the mode typically used in practical applications; TM₂₀ and TM₃₀ are associated with a frequency approximately twice and triple of that of the mode. This provides the possibility to operate at multiple frequencies.

In practice, the TM₂₀ and TM₃₀ modes cannot be used owing to the facts that the pattern has a broadside null and the pattern has grating lobes. The simplest way to operate at dual frequencies is to use the first resonance of the two orthogonal dimensions of the rectangular patch, i.e., the TM₁₀ and the TM₀₁ modes. In this case, the frequency ratio is approximately equal to the ratio between the two orthogonal sides of the patch. The obvious limitation of this approach is that the two different frequencies excite two orthogonal polarizations. Anyway, this simple method is very useful in low-cost short-range applications, where polarization requirements are not pressing.

The most popular technique for obtaining a dual-frequency behaviour is to introduce a reactive loading to a single patch, including stubs[43], notches [44], pins [38, 45], capacitors [44], and slots [46-47]. In [6] [20], by these reactive-loading approaches, one can modify the resonant mode of the patch, so that the radiation pattern of the higher order mode could be similar to that of the fundamental mode. This indicates that the use of a single feed for both frequencies on a single radiating element can be realized. In 1995, a rectangular patch with two narrow slots etched close to and parallel to the radiating edge was used to obtain the dual-frequency operation proposed by S. Maci [46].

In this dual-frequency design, the two operating frequencies are associated with the TM₁₀ and TM₃₀ modes of the un-slotted rectangular patch. In addition, this two operating frequencies have the same polarization planes and broadside radiation patterns, with a frequency ratio within the range of 1.6-2.0 for the inset feed case.

The above approach characterizes a first category of dual-frequency patch antennas, which will be identified as 1) orthogonal mode dual-frequency patch antenna [46]. This category can be extended to any kind of patch shape that offers two cross-polarized resonant modes. Most of the other dual-frequency patch antennas found in the literature can be subdivided into 2) multi-patch dual frequency antennas, and 3) reactively-loaded dual-frequency patch antennas.

In this section, design examples of some recent advances in regular-size Microstrip antennas, mainly with a single-feed, single-layer Microstrip structure, are presented. The dual-frequency designs presented are divided into two groups, depending on whether the two operating frequencies have the same polarization plane or orthogonal polarization planes.

5.3. Dual Band Defected Ground Microstrip Patch Antenna for WLAN/WiMax and Satellite Application

A microstrip patch antenna for Wi-Max and GSM application is proposed. The antenna has a frequency bandwidth of 1.24 GHz (4.6053 GHz – 5.8481 GHz) for WLAN and Wi-Max and 1.04 GHz (6.124 GHz – 7.16 GHz) for Satellite application. The microstrip antenna has a planar geometry and consists of a defected ground, a substrate, a patch, a feed, one slot in patch and A defected ground structure consists of a pie (Π) slot and reduced area from all three sides except the feed side. Results show that the proposed antenna has promising characteristics for Wi-Max, WLAN and Satellite application at 5.5 GHz frequency for WiMax, 5.2 GHz and 5.8 GHz for WLAN and 6-7 GHz for satellite application respectively. The microstrip patch antenna has been analysed for various dimensions of ground and slots respectively.

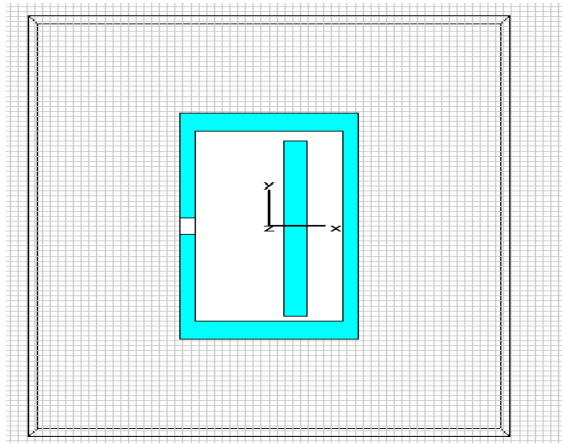


Figure 5.1: Front view of dual band defected ground microstrip patch antenna for WLAN/WiMax and Satellite Application

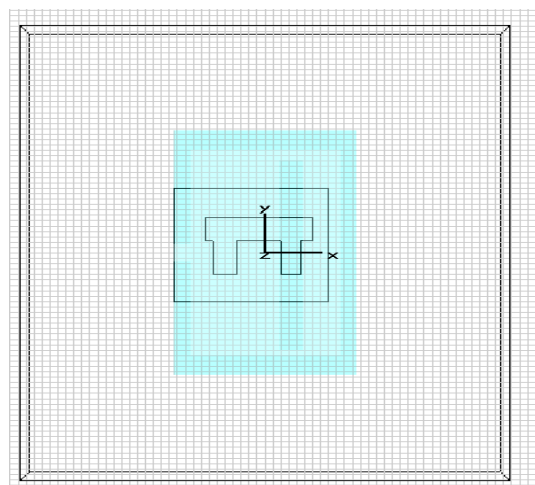


Figure 5.2: Back view of dual band defected ground microstrip patch antenna for WLAN/WiMax and Satellite Application

5.3.1 PATCH DIMENSION:

Length (L) = 18.84 mm

Width (W) = 38 mm

Height (H) = 0.02 mm

SUBSTRATE DIMENSION

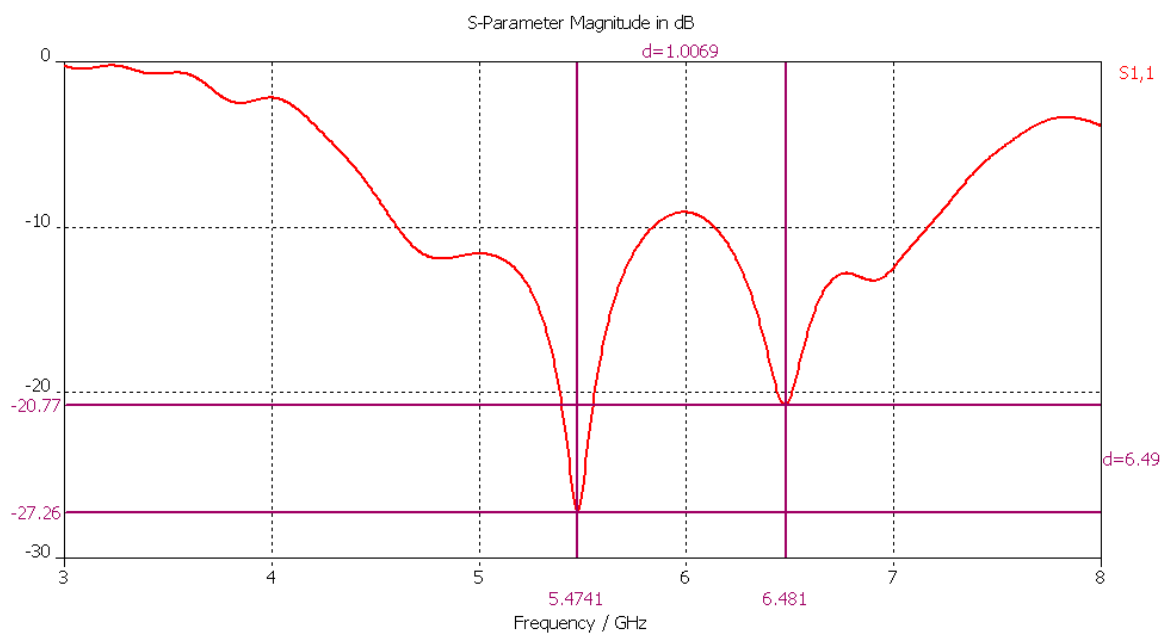
Length (L_s) = 22.83 mm

Width (W_s) = 45.154 mm

Height (H_s) = 1.6 mm

5.3.2 Return Loss of dual band antenna for WiMax and Satellite application

Figure 5.3 shows the S_{11} parameters (return loss) for the proposed antenna. The designed antenna resonates at 5.47 GHz and 6.4 GHz frequencies respectively. The return loss for 5.47 GHz is -27.26 dB and the return loss for 6.4 GHz is -20.77 dB which covers the minimum required value of return loss of -10 dB.



**Figure 5.3 Return Loss of dual band antenna for WiMax and Satellite application
(S_{11} in dB)**

5.3.3 Bandwidth of dual band antenna for WiMax and Satellite application

The bandwidth of the proposed patch antenna is 1.241 GHz at frequency is 5.47 GHz which covers (WiMax 5.5, WLAN 5.2 and WLAN 5.8) these three bands and 1.041 GHz at frequency 6.4 GHz, which covers the satellite band ranging from 6-7 GHz. The bandwidth for 5.47 GHz frequency and 6.4 GHz frequency is shown in Figure 4.4 and Figure 4.5 respectively.

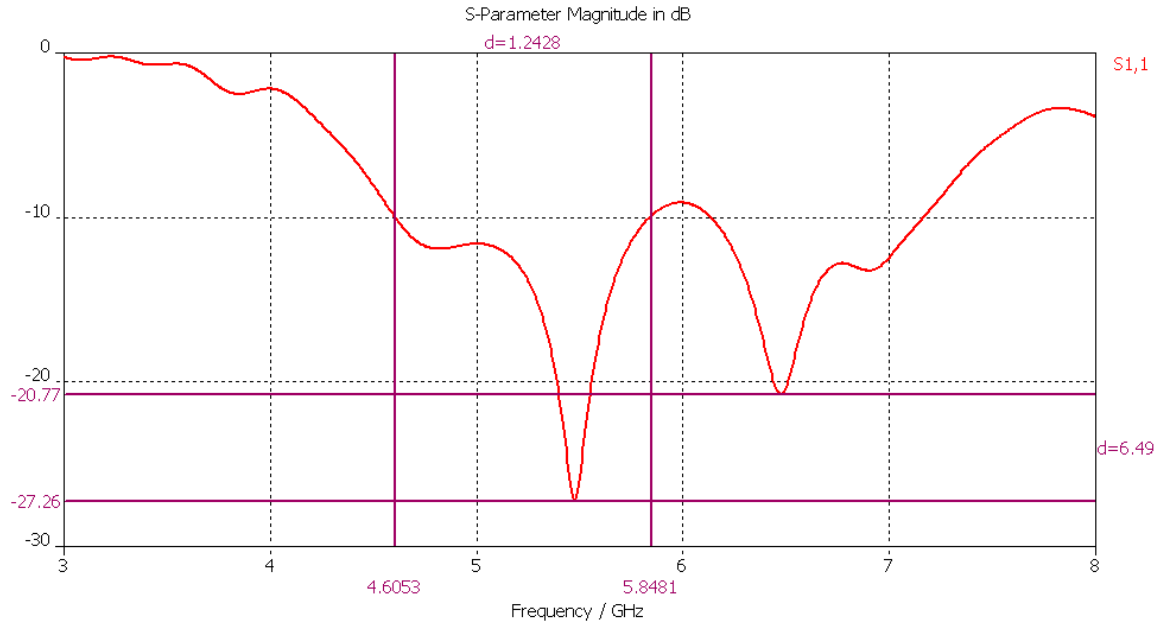


Figure 5.4 Bandwidth of dual band antenna for 5.47 GHz band (S_{11} in dB)

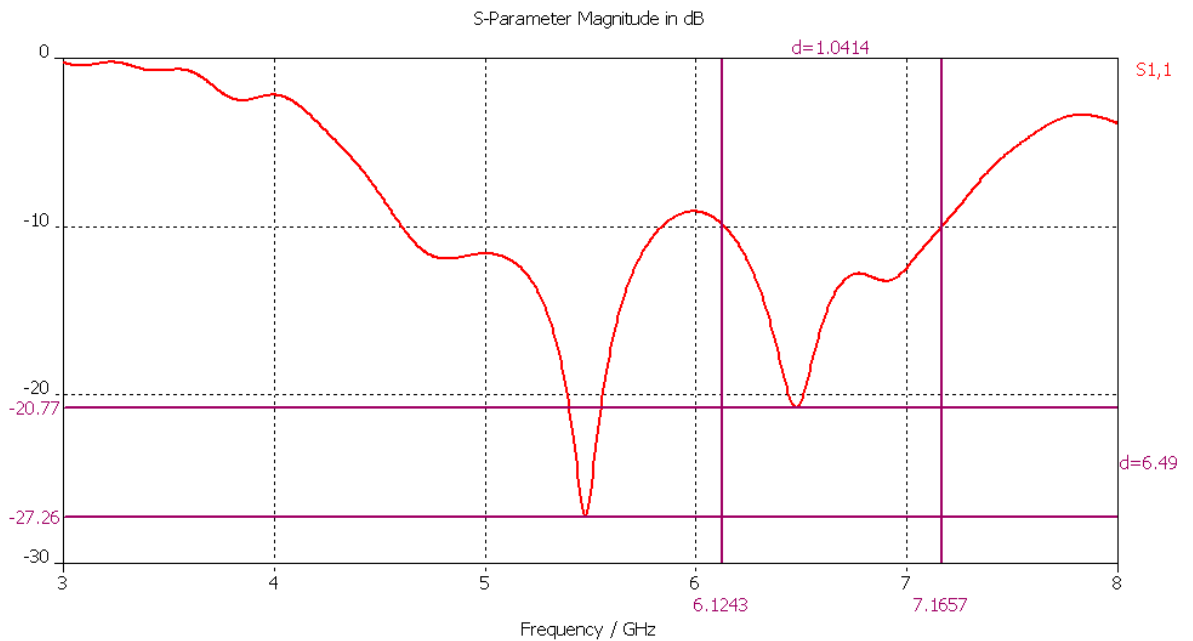


Figure 5.5 Bandwidth of dual band antenna for 6.4 GHz band (S_{11} in dB)

5.3.4 Smith Chart of dual band antenna for WiMax and Satellite application

The Smith Chart plot (Figure 4.6) represents that how the antenna impedance varies with frequency. The achieved antenna impedance is 49.68 ohm as shown in Figure 4.6, which is very close to the required impedance of 50 ohm.

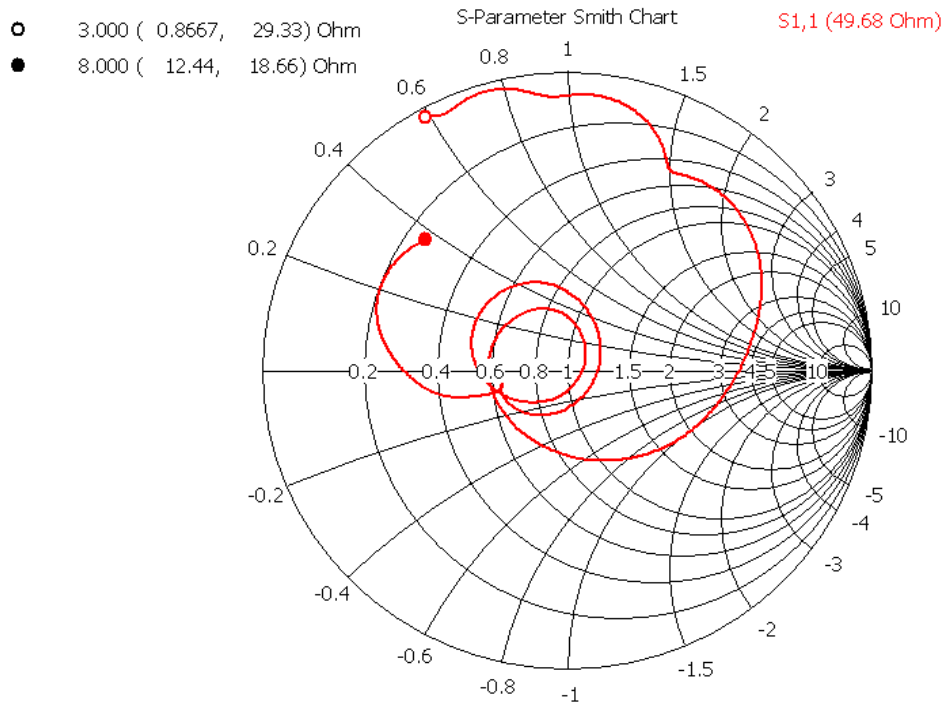


Figure 5.6 Smith Chart of dual band antenna for WiMax and Satellite application

5.3.5 Voltage Standing Wave Ratio (VSWR) of dual band antenna for WiMax and Satellite application

Ideally, VSWR must lie in the range of 1-2 which has been achieved for 5.47 GHz and 6.4 GHz frequency, near the operating frequency value. The VSWR ratio at 5.5GHz frequency is 1:1.105 and is shown in Figure 5.7. The VSWR ratio at 5.8 GHz frequency is 1:1.203 and is shown in Figure 5.8.

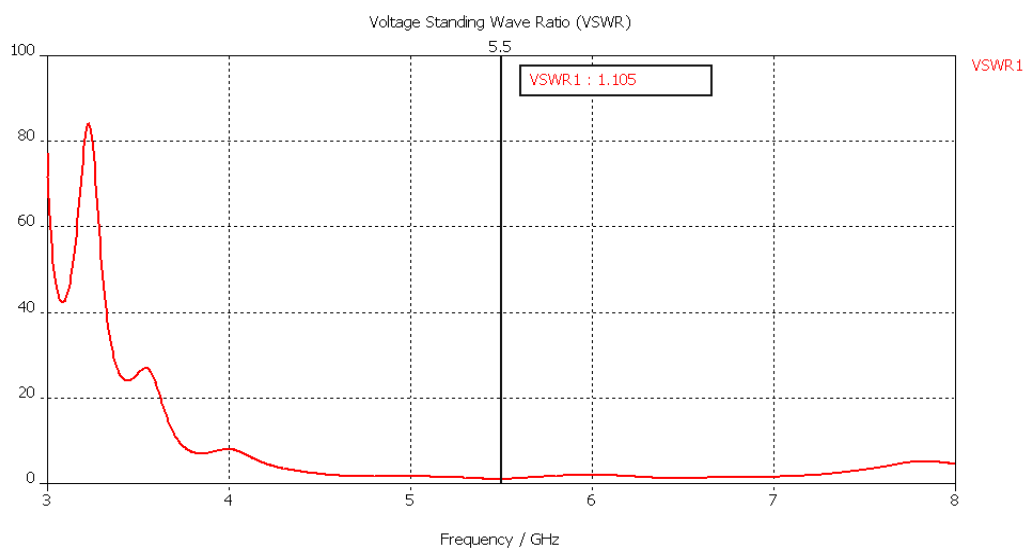


Figure 5.7 VSWR Versus Frequency Plot at frequency 5.5 GHz

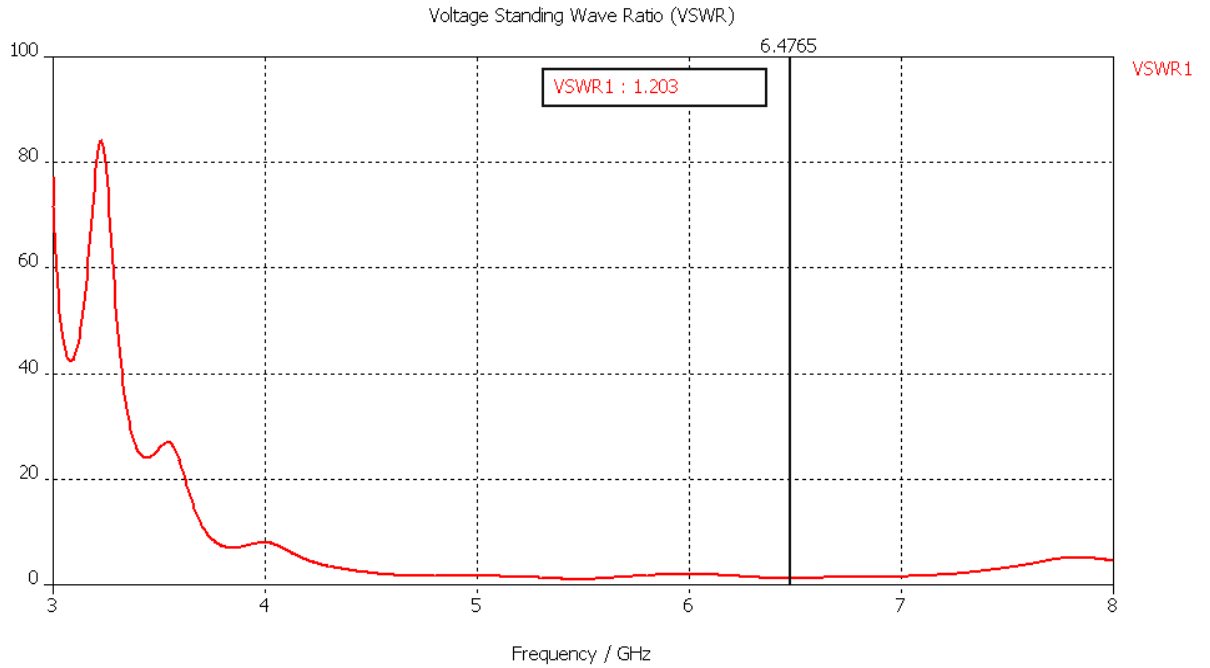


Figure 5.8 VSWR Versus Frequency Plot at frequency 6.4 GHz

4.3.6 Radiation Pattern of dual band antenna for WiMax and Satellite application

The radiation pattern showing the directivity for the designed antenna has been shown in Figure 5.9 and Figure 5.10. The directivity for 5.47 GHz frequency is 5.586 dBi and for 6.4 GHz frequency is 5.983 dBi. In general, the value of directivity should be greater than 5 dBi. The radiation pattern showing the gain for the desired antenna has been shown in Figure 5.11 and Figure 5.12.

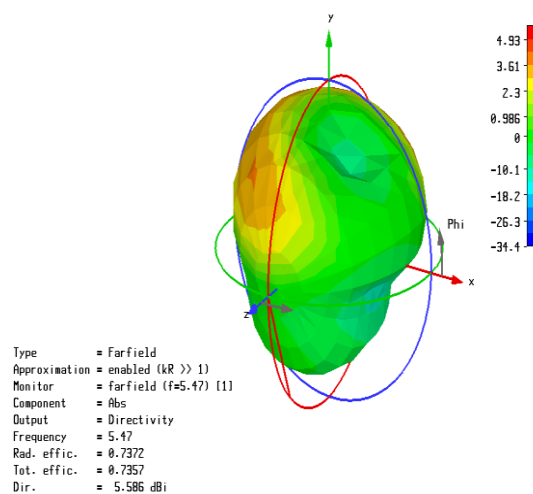


Figure 5.9 Radiation Pattern showing directivity at 5.47 GHz frequency.

The gain for 5.47 GHz frequency is 4.262 dB and for 6.4 GHz frequency is 4.668 dB. In general, the value of gain should be greater than 5 dB but in some cases it is acceptable to 3 dB. And in case of Defected Ground Structure it does not exceed 5 dB in maximum cases, which is a GAP of using Defected Ground Structures. But this GAP can be removed by using Meta Materials.

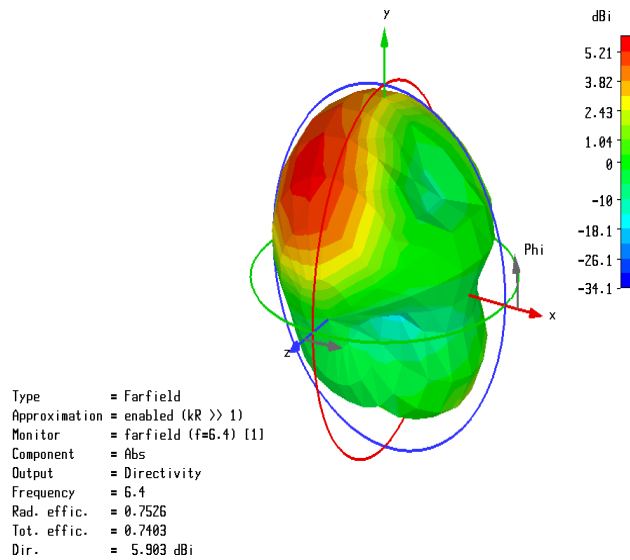


Figure 5.10 Radiation Pattern showing directivity at 6.4 GHz frequency.

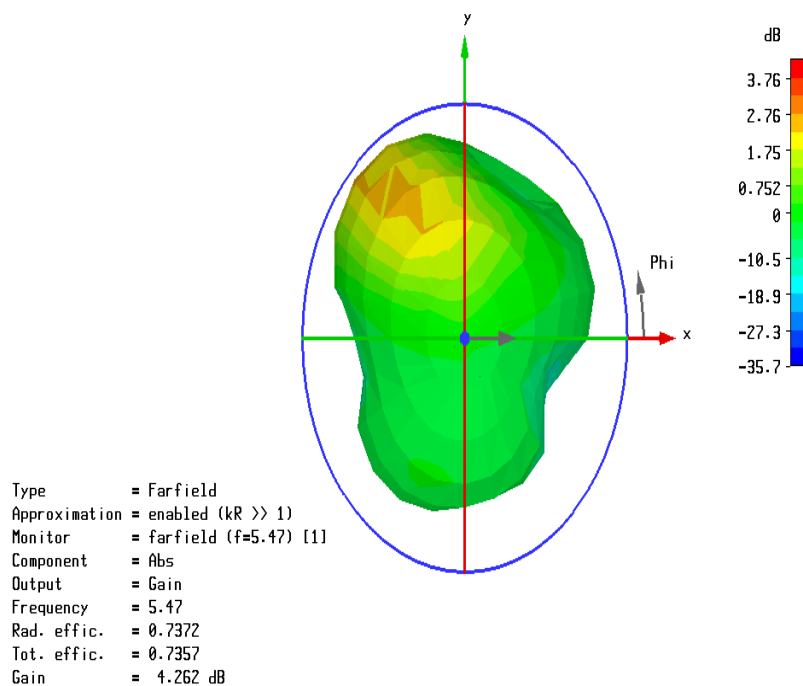


Figure 5.11 Radiation Pattern showing Gain at frequency 5.47 GHz

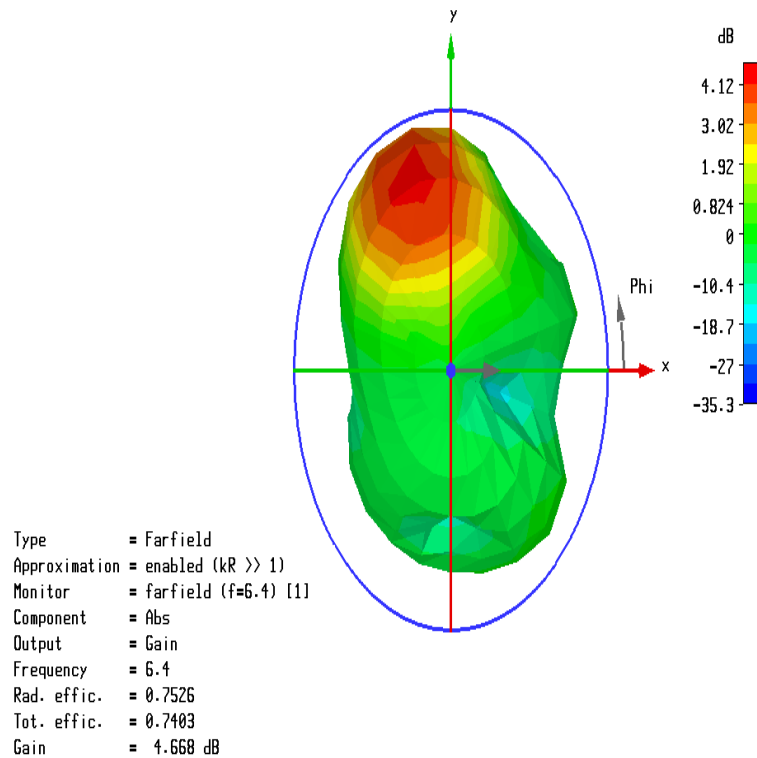


Figure 5.12 Radiation Pattern showing Gain at frequency 6.4 GHz

5.4. Design of Dual Band Microstrip Patch Antenna for GSM and WiMax Application

A microstrip patch antenna for Wi-Max and GSM application is proposed. The antenna has a frequency bandwidth of 583 MHz (3350MHz - 3933 MHz) for Wi-Max and 366 MHz (1600 MHz – 1900MHz) for GSM application. The microstrip antenna has a planar geometry and consists of a plane ground, a substrate, a patch, a feed, two slits on patch and a reduced ground. The basic theory and design are analyzed, and simulation using CST Microwave Studio commercial software is employed to optimize the antenna's properties. Results show that the proposed antenna has promising characteristics for GSM and Wi-Max application at 1.8 GHz frequency and 3.5GHz respectively. The microstrip patch antenna has been analysed for various dimensions of ground and slits as shown in Figure 5.13.

5.4.1 PATCH DIMENSION:

Length (L) = 18 mm

Width (W) = 32 mm

Height (H) = 0.07 mm

SUBSTRATE DIMENSION

Length (L_s) = 35 mm

Width (W_s) = 50 mm

Height (H_s) = 1.524 mm

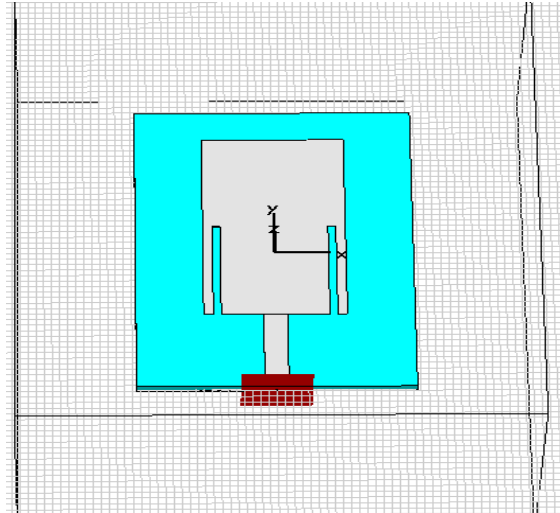


Figure 5.13: Front View of Dual Band Microstrip Patch Antenna for GSM and WiMax Application

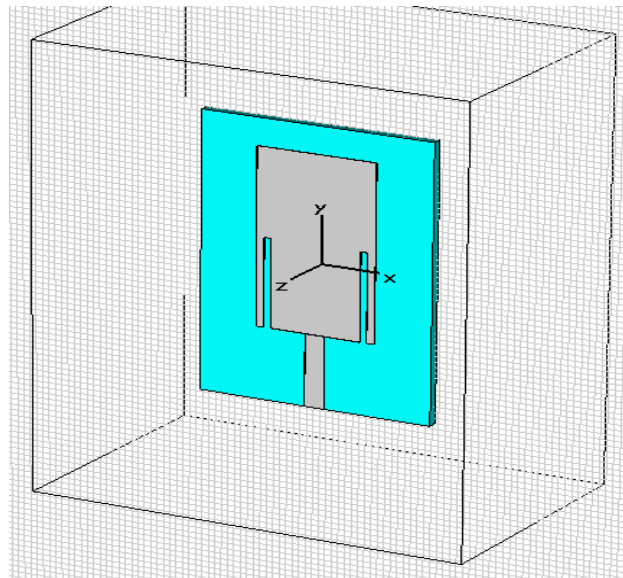


Figure 5.14: Back View of Dual Band Microstrip Patch Antenna for GSM and WiMax Application

5.4.2 Return Loss of Dual Band Microstrip Patch Antenna for GSM and WiMax Application

Figure 5.15 shows the S11 parameters (return loss) for the proposed antenna. The designed antenna resonates at 1.8 GHz and 3.5 GHz respectively. The return loss for 1.8 GHz is -20.8 dB and the return loss for 3.5 GHz is -30.98 dB which covers the minimum required value of return loss of -10 dB.

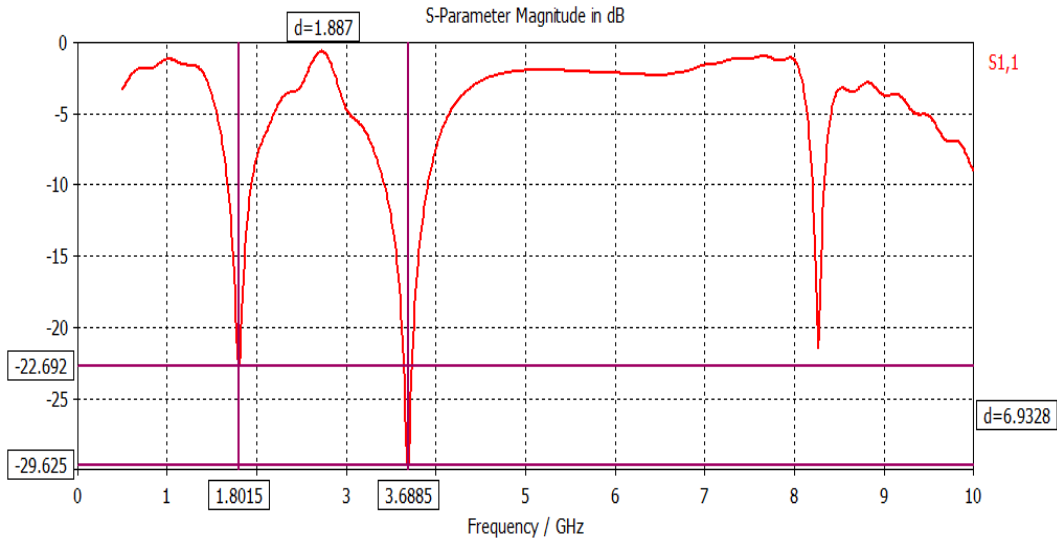


Figure 5.15: Return Loss of Dual Band Microstrip Patch Antenna for GSM and WiMax Application (S_{11} in dB)

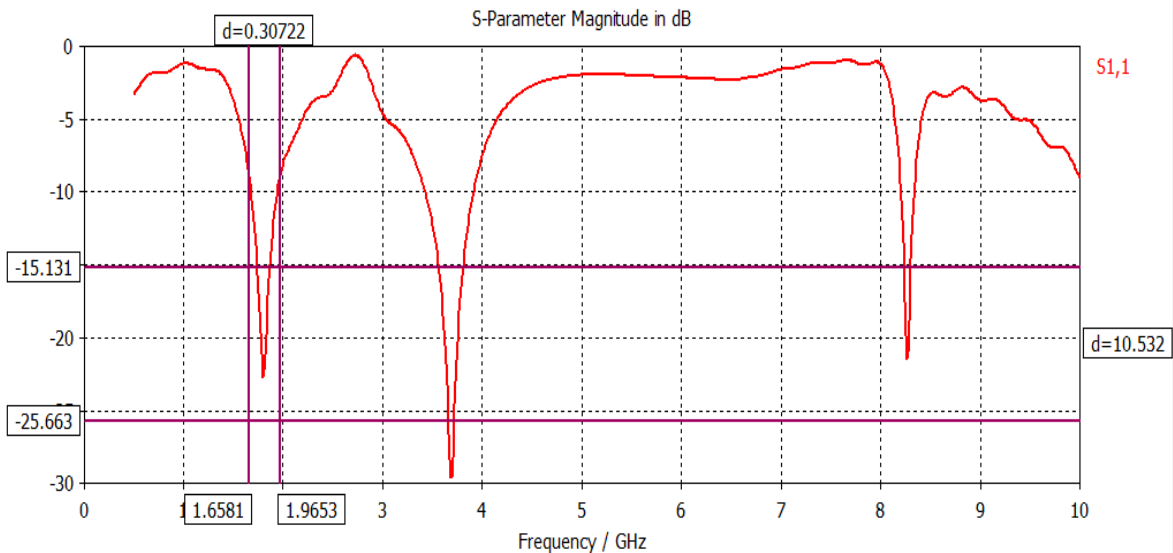


Figure 5.16: Bandwidth of Dual Band Microstrip Patch Antenna at 1.8 GHz frequency (S_{11} in dB)

5.3.3 Bandwidth of Dual Band Microstrip Patch Antenna for GSM and WiMax Application

The bandwidth of the antenna can be said to be those range of frequencies over which the return loss is greater than -10 dB (corresponds to a VSWR of 2). Thus, the bandwidth of antenna can be calculated from return loss versus frequency plot. The bandwidth of the proposed patch antenna is 307 MHz for 1.8 GHz frequency and 540 MHz for 3.5 GHz frequency. The bandwidth for 1.8 GHz and 3.5 GHz frequency has been shown in Figure 5.16 and Figure 5.17 respectively.

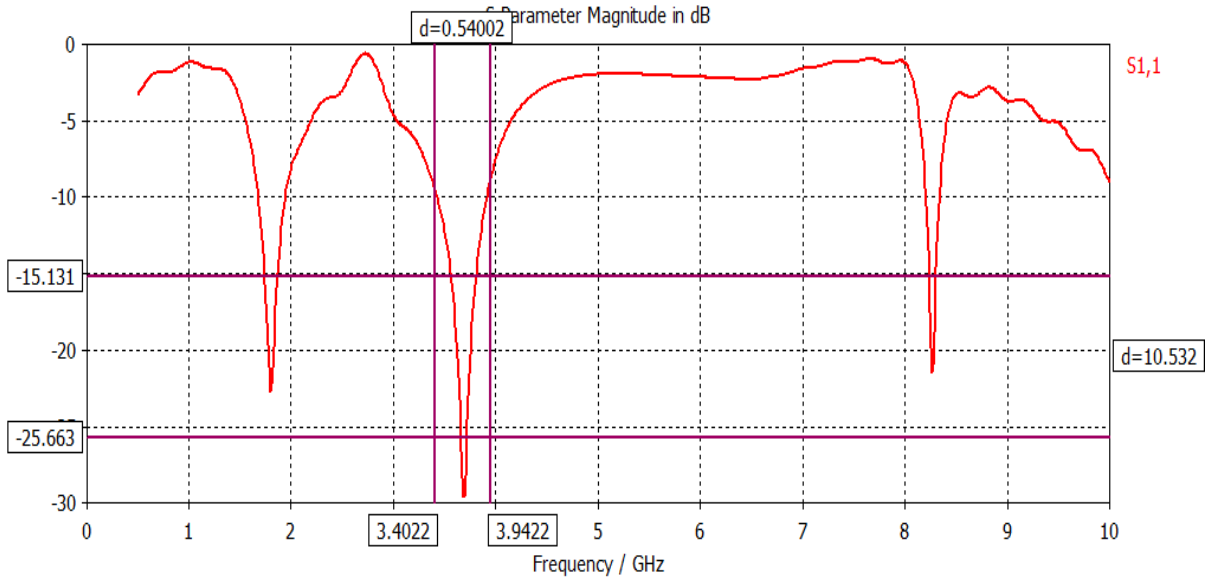


Figure 5.17: Bandwidth of Dual Band Microstrip Patch Antenna at 3.5 GHz frequency (S_{11} in dB)

5.4.4 Smith Chart of Dual Band Microstrip Patch Antenna for GSM and WiMax Application

The Smith Chart plot (Figure 4.18) represents that how the antenna impedance varies with frequency. The achieved antenna impedance is 49.98 ohm as shown in Figure 5.18, which is very close to the required impedance of 50 ohm.

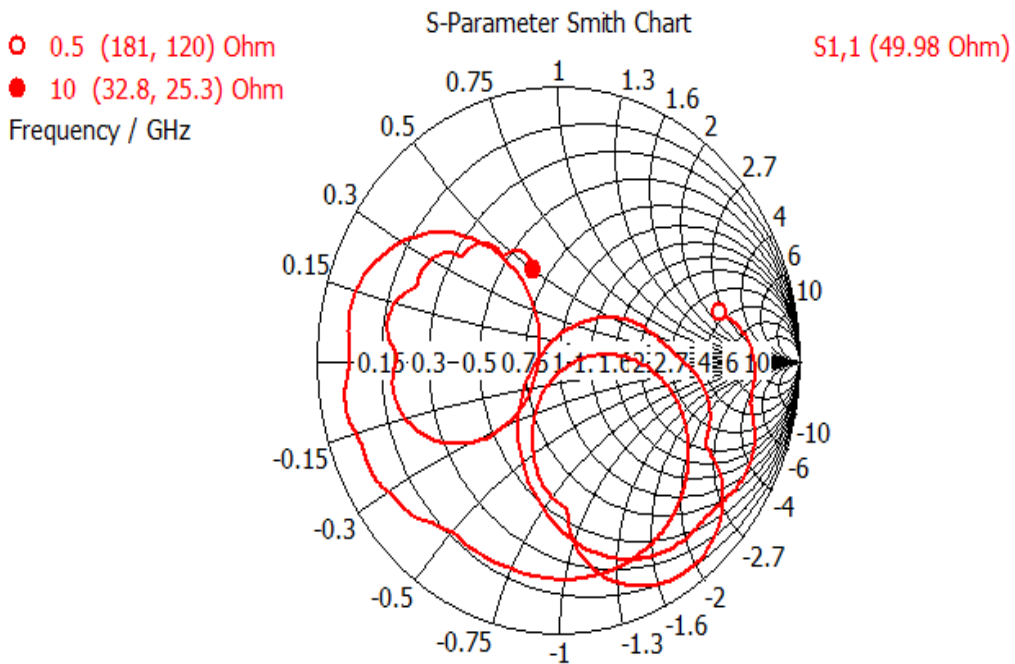


Figure 5.18: Smith Chart of Dual Band Microstrip Patch Antenna for GSM and WiMax Application

5.4.5 Voltage Standing Wave Ratio (VSWR) of Dual Band Microstrip Patch Antenna for GSM and WiMax Application

Ideally, VSWR must lie in the range of 1-2 which has been achieved for 1.8 GHz and 3.5 GHz frequency, near the operating frequency value. The VSWR ratio at 1.8 GHz frequency is 1:1.159 and is shown in Figure 5.19. The VSWR ratio at 3.5 GHz frequency is 1:1.07 and is shown in Figure 5.20.

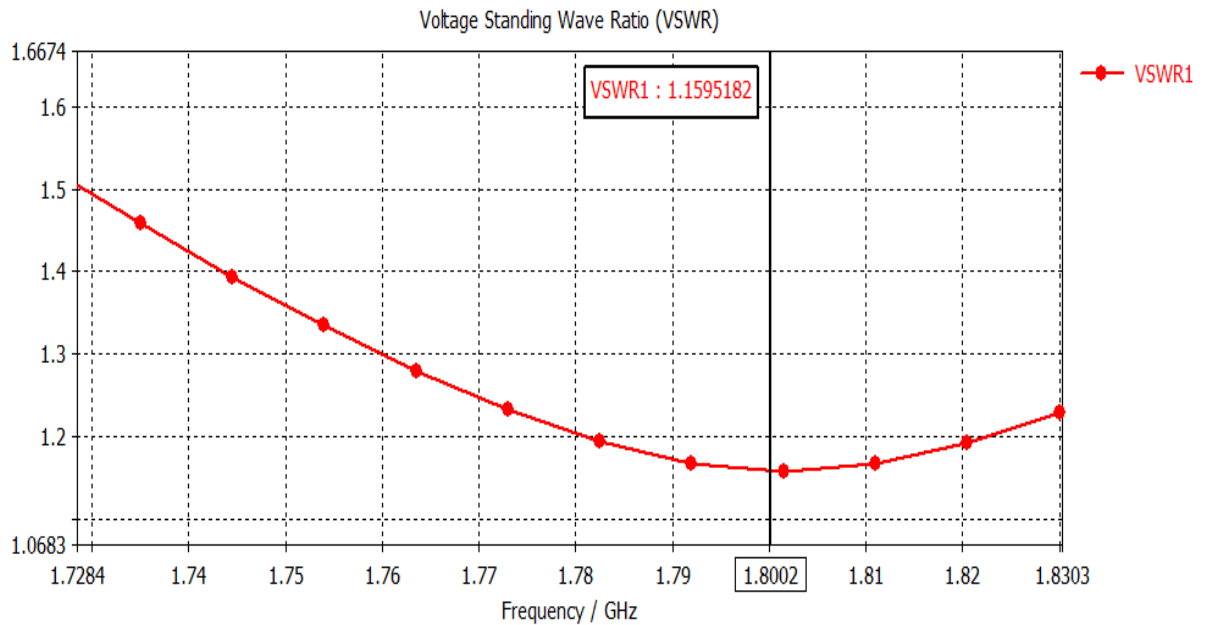


Figure 5.19: VSWR Versus Frequency Plot of Dual Band Microstrip Patch Antenna at 1.8 GHz frequency

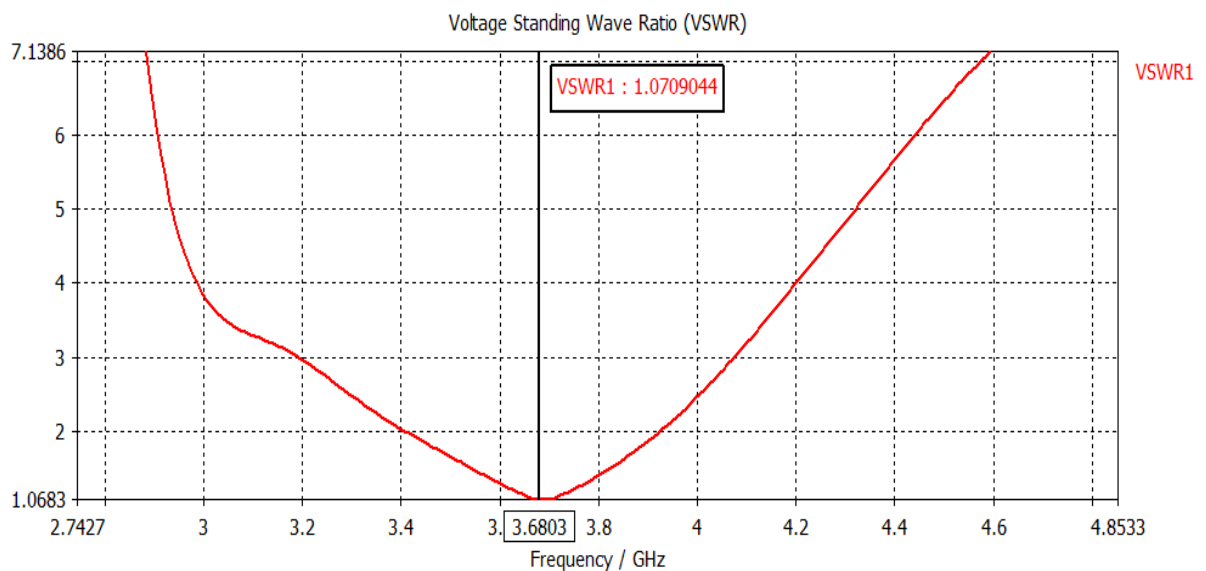


Figure 5.20: VSWR Versus Frequency Plot of Dual Band Microstrip Patch Antenna at 3.5 GHz frequency

5.4.6 Radiation Pattern of Dual Band Microstrip Patch Antenna for GSM and WiMax Application

The radiation pattern showing the directivity for the designed antenna has been shown in Figure 5.21 and Figure 5.22. The directivity for 1.8 GHz frequency is 1.903 dBi and for 3.5 GHz frequency is 3.635 dBi. In general, the value of directivity should be greater than 5 dBi. The gain for 1.8 GHz frequency is 2.268 dB and for 3.5 GHz frequency is 3.742 dB. In general, the value of gain and directivity should be greater than 5 dB but in some cases it is acceptable to 3 dB. And in case of Defected Ground Structure it does not exceed 5 dB in maximum cases, which is a GAP of using Defected Ground Structures. But this GAP can be removed by using Meta Materials.

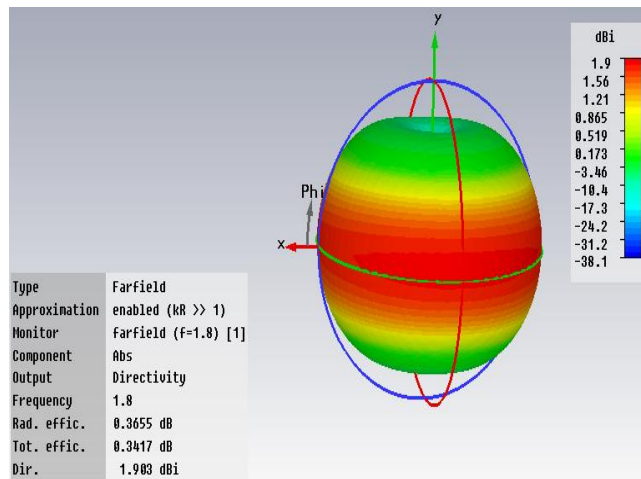


Figure 5.21: Radiation Pattern showing directivity at frequency 5.47 GHz

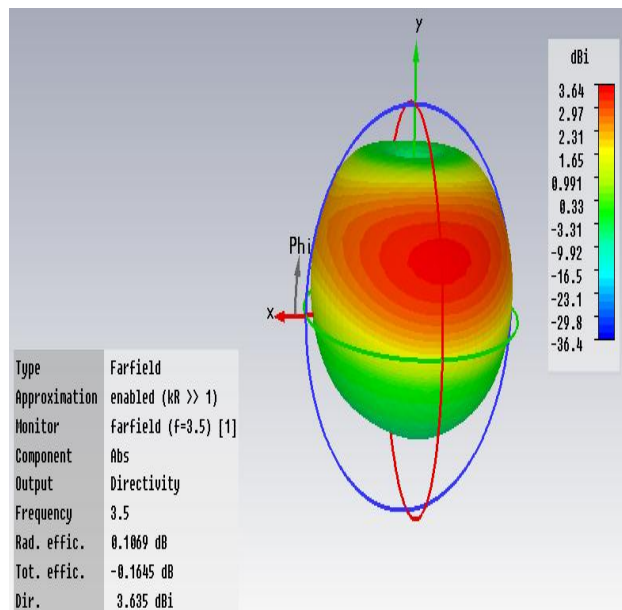


Figure 5.22 Radiation Pattern showing directivity at frequency 6.4 GHz

5.5. Design of Dual Band Microstrip Patch Antenna Using Two Slits and Reduced Ground Plane

A microstrip patch antenna for Wi-Max and WLAN application is proposed. The antenna has a frequency bandwidth of 495 MHz (3403MHz - 3901 MHz) for Wi-Max and 260 MHz (5569 MHz – 5830MHz) for WLAN application. The microstrip antenna has a planar geometry and consists of a defected ground, a substrate, a patch, a feed, two slits and a defected ground. The basic theory and design are analyzed, and simulation using CST Microwave Studio commercial software is employed to optimize the antenna's properties.

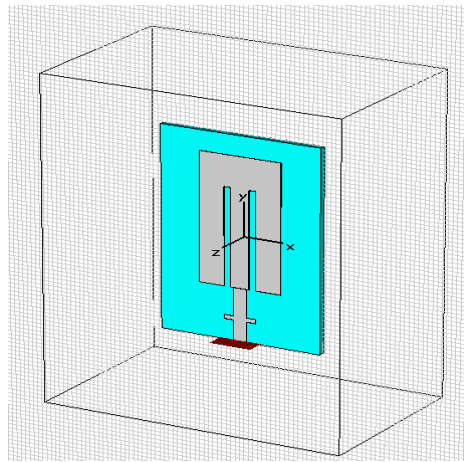


Figure 5.23: Front View of Dual Band Microstrip Patch Antenna Using Two Slits and Reduced Ground Plane

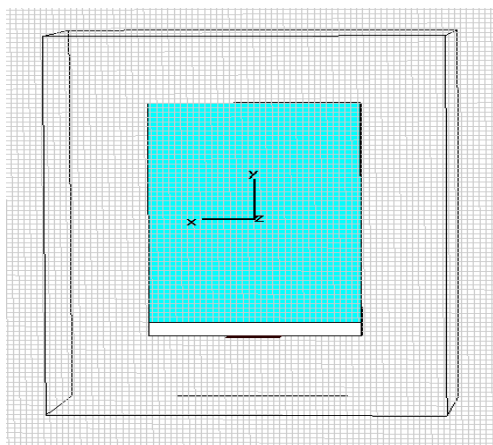


Figure 5.24: Back View of Dual Band Microstrip Patch Antenna Using Two Slits and Modified Ground Plane

Results show that the proposed antenna has promising characteristics for WLAN and Wi-Max application at 5.8 GHz frequency and 3.5GHz respectively. The microstrip patch antenna has been analysed for various dimensions of ground and slits respectively.

5.5.1 PATCH DIMENSION:

Length (L) = 18 mm

Width (W) = 32 mm

Height (H) = 0.07 mm

SUBSTRATE DIMENSION

Length (L_s) = 35 mm

Width (W_s) = 50 mm

Height (H_s) = 1.524 mm

5.5.2 Return Loss of Dual Band Microstrip Patch Antenna Using Two Slits and Reduced Ground Plane

Figure 5.25 shows the S11 parameters (return loss) for the proposed antenna. The designed antenna resonates at 3.5 GHz and 5.8 GHz frequencies respectively. The return loss for 3.5 GHz is -41.71 dB and the return loss for 6.4 GHz is -20.67 dB which covers the minimum required value of return loss of -10 dB.

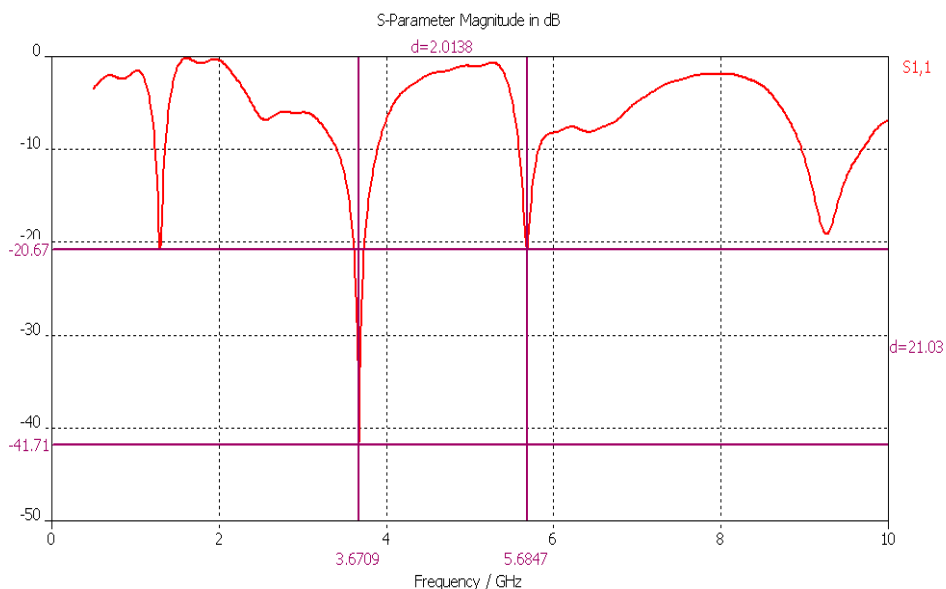


Figure 5.25: Return Loss of Dual Band Microstrip Patch Antenna Using Two Slits and Modified Ground Plane (S_{11} in dB)

5.5.3 Bandwidth of Dual Band Microstrip Patch Antenna Using Two Slits and Reduced Ground Plane

The bandwidth of the antenna can be said to be those range of frequencies over which the return loss is greater than -10 dB (corresponds to a VSWR of 2). Thus, the bandwidth of antenna can be calculated from return loss versus frequency plot. The bandwidth of the proposed patch antenna is 497 MHz for 3.5 GHz frequency and 260 MHz for 5.8 GHz frequency. The bandwidth for 3.5 GHz and 5.8 GHz frequency has been shown in Figure 5.26 and Figure 5.27 respectively.

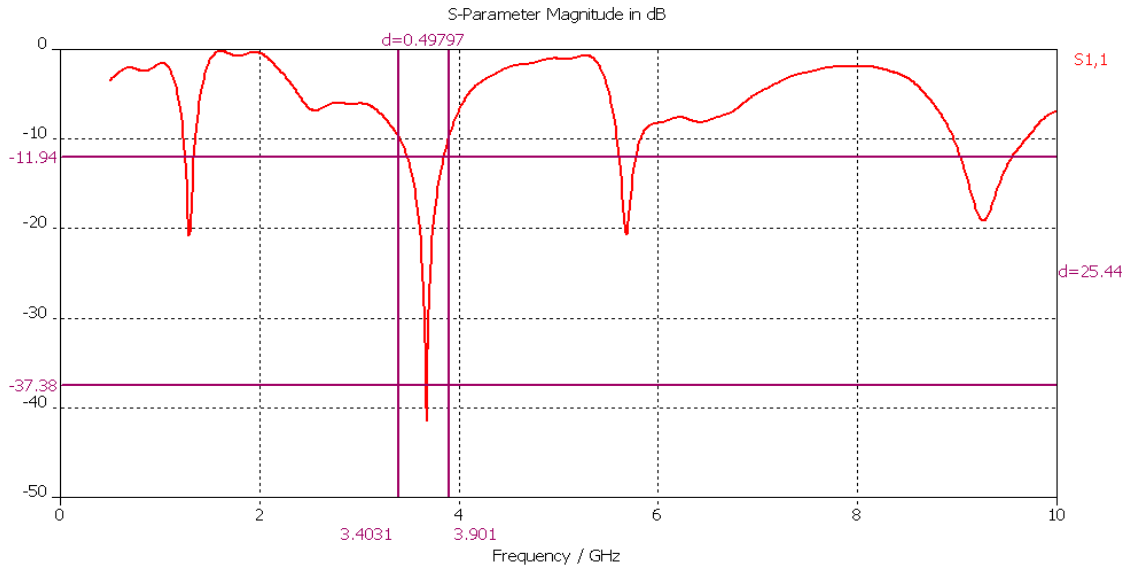


Figure 5.26: Bandwidth of Dual Band Microstrip Patch Antenna Using Two Slits and Reduced Ground Plane at 3.5 GHz frequency

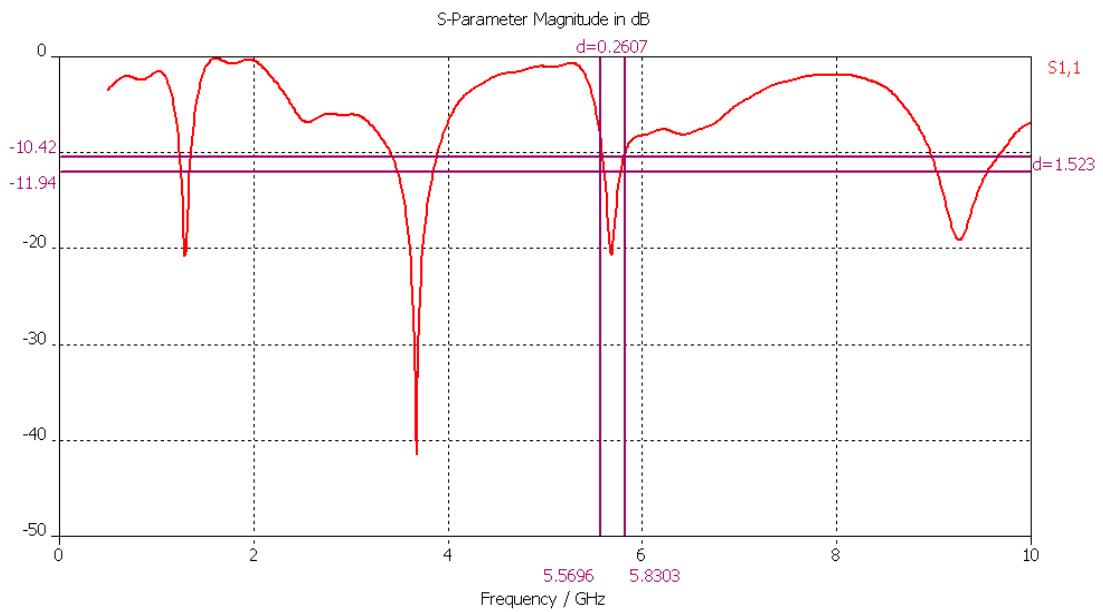


Figure 5.27: Bandwidth of Dual Band Microstrip Patch Antenna Using Two Slits and Reduced Ground Plane at 5.8 GHz frequency.

5.5.4 Smith Chart of Dual Band Microstrip Patch Antenna Using Two Slits and Reduced Ground Plane

The Smith Chart plot (Figure 4.28) represents that how the antenna impedance varies with frequency. The achieved antenna impedance is 51.03 ohm as shown in Figure 5.28, which is very close to the required impedance of 50 ohm.

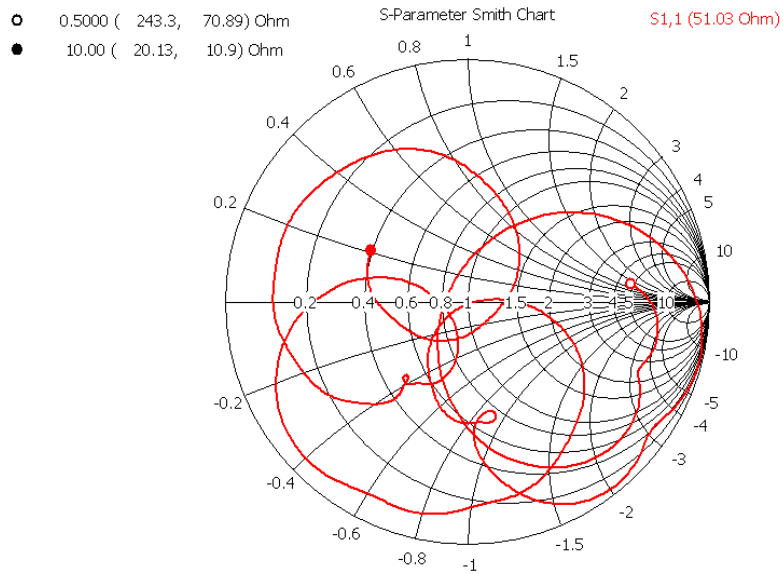


Figure 5.28: Smith Chart of Dual Band Microstrip Patch Antenna Using Two Slits and Reduced Ground Plane

5.5.5 Voltage Standing Wave Ratio (VSWR) of Dual Band Microstrip Patch Antenna Using Two Slits and Reduced Ground Plane

Ideally, VSWR must lie in the range of 1-2 which has been achieved for 3.5 GHz and 5.8 GHz frequency, near the operating frequency value. The VSWR ratio at 3.69 GHz frequency is 1:1.05 and is shown in Figure 5.29. The VSWR ratio at 5.8 GHz frequency is 1:1.231 and is shown in Figure 5.30.

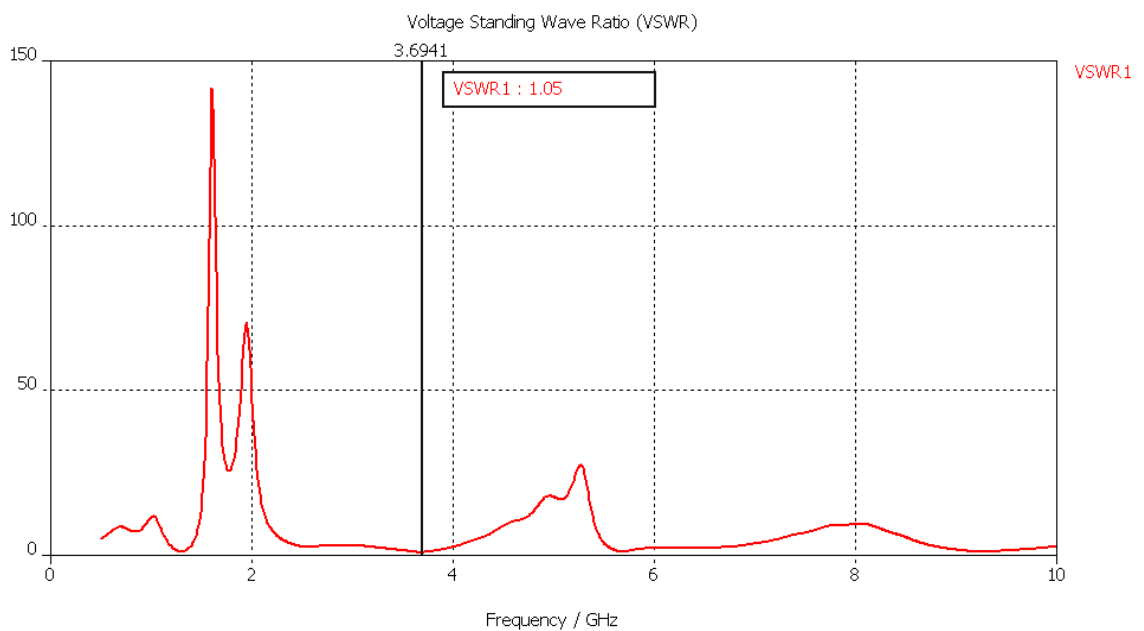


Figure 5.29: VSWR Versus Frequency Plot at frequency 3.5 GHz

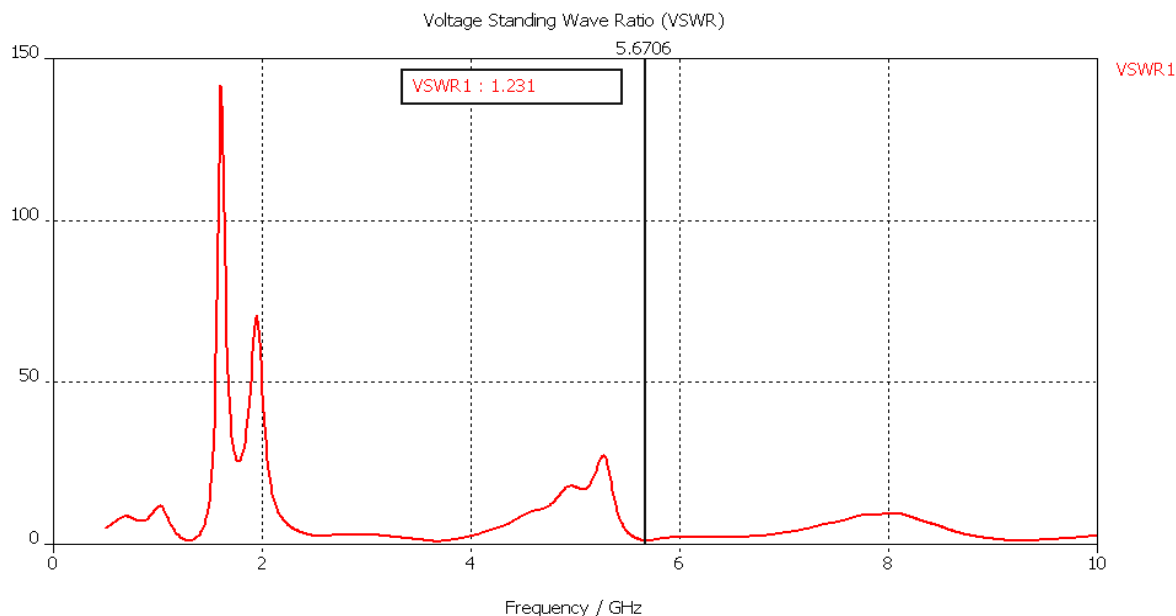


Figure 5.30: VSWR Versus Frequency Plot at frequency 5.8 GHz

5.5.6 Radiation Pattern of Dual Band Microstrip Patch Antenna Using Two Slits and Reduced Ground Plane

The radiation pattern showing the directivity for the designed antenna has been shown in Figure 5.31 and Figure 5.32. The directivity for 3.5 GHz frequency is 3.664 dBi and for 5.8 GHz frequency is 5.064 dBi.

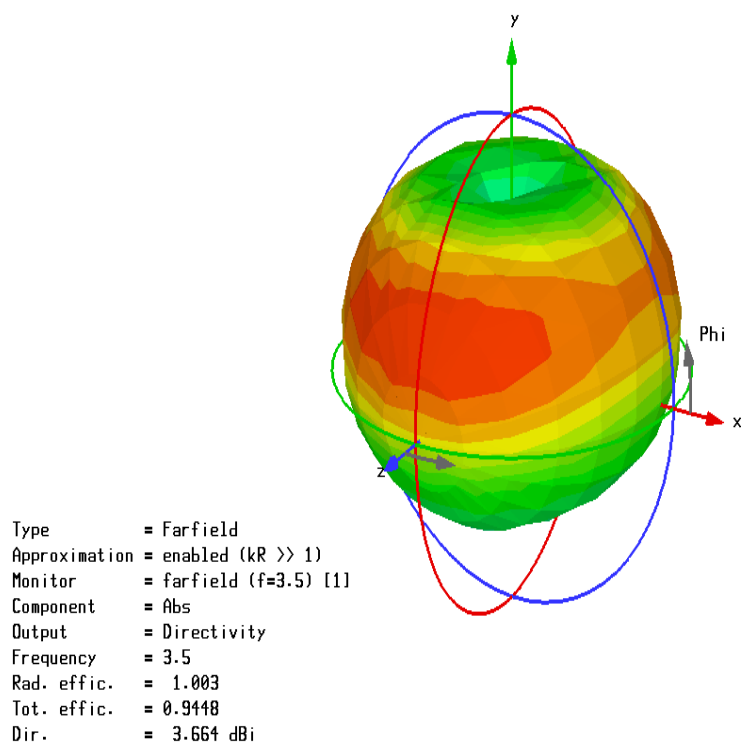


Figure 5.31: Radiation Pattern showing directivity at frequency 3.5 GHz

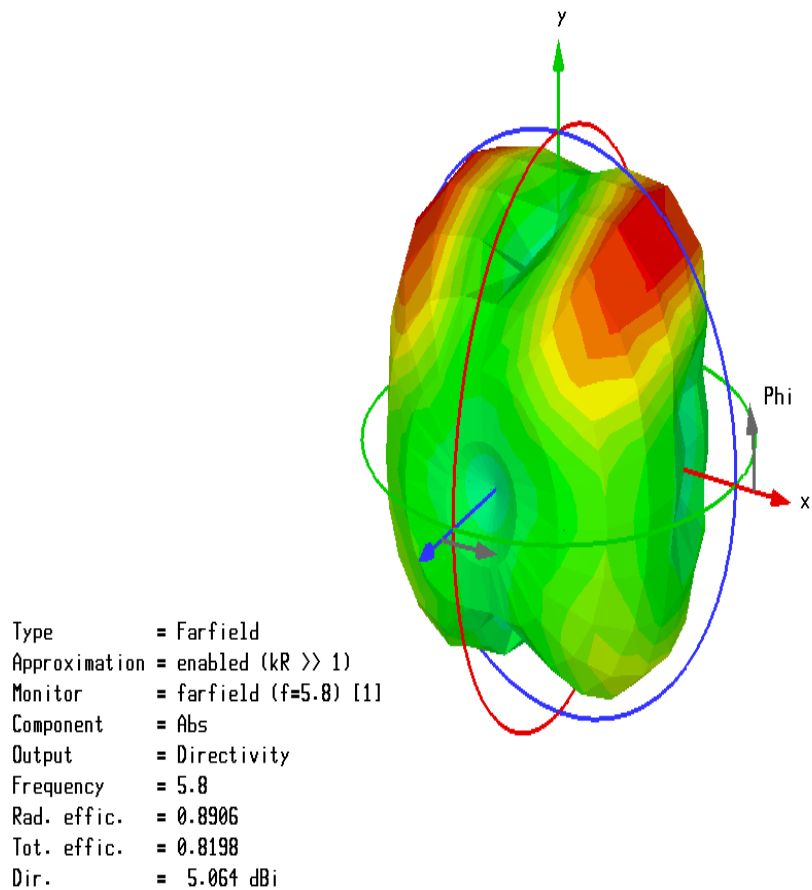


Figure 5.32: Radiation Pattern showing directivity at frequency 5.8 GHz

In general, the value of directivity should be greater than 5 dBi. The gain for 3.5 GHz frequency is 3.679 dB and for 5.8 GHz frequency is 4.561 dB. In general, the value of gain and directivity should be greater than 5 dB but in some cases it is acceptable to 3 dB. And in case of Reduced Ground Plane it does not exceed 5 dB in maximum cases, which is a GAP of using Reduced Ground Plane. But this GAP can be removed by using Meta Materials.

DUAL BAND MICROSTRIP PATCH ANTENNA USING DUAL PATCH

In this chapter, Dual Patch on a single substrate has been employed and its effect has been discussed. The design is simulated on CST Microwave Studio Software. Finally, the results obtained from the simulation are demonstrated and discussed.

6.1 Design of Dual Band Microstrip Patch Antenna Using Dual Patch

A microstrip patch antenna for Wi-Max and WLAN application is proposed. The antenna has a frequency bandwidth of 138 MHz (5.7087 GHz – 5.8474 GHz) for WLAN and 65 MHz (3.45 GHz – 3.522 GHz) for WiMax. The microstrip patch antenna has a planar geometry and consists of a ground, a substrate, two patches and a combined feed. The basic theory and design are analyzed, and simulation using CST Microwave Studio commercial software is employed to optimize the antenna's properties. Results show that the proposed antenna has promising characteristics for Wi-Max and WLAN at 3.5 GHz frequency for WiMax and 5.8 GHz for WLAN application respectively. The microstrip patch antenna has been analysed for various dimensions of both patch and various locations of patch so that the effect of mutual coupling could be nullified.

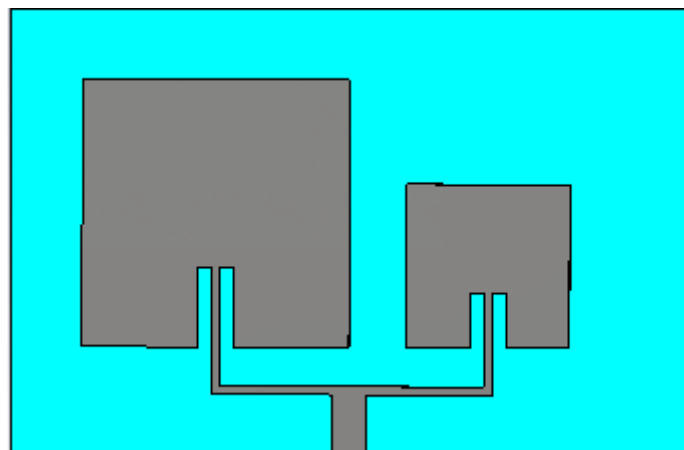


Figure 6.1: Design of dual band antenna using dual patch

Results show that the proposed antenna has promising characteristics for WLAN and Wi-Max application at 5.8 GHz frequency and 3.5GHz respectively. The microstrip patch antenna has been analysed for various dimensions of ground and slits respectively.

6.2 PATCH DIMENSION For 3.5 GHz: SUBSTRATE DIMENSION For 3.5 GHz:

Length (L_1) = 19.6 mm

Width (W_1) = 19.6 mm

Height (H_1) = 0.07 mm

Length (L_{S1}) = 32.5 mm

Width (W_{S1}) = 50 mm

Height (H_{S1}) = 1.524 mm

6.3 PATCH DIMENSION For 5.8 GHz: SUBSTRATE DIMENSION For 5.8 GHz:

Length (L_2) = 11.95 mm

Width (W_2) = 11.95 mm

Height (H_2) = 0.07 mm

Length (L_{S2}) = 32.5 mm

Width (W_{S2}) = 50 mm

Height (H_{S2}) = 1.524 mm

6.4 Return Loss of dual band microstrip patch antenna using dual patch

Figure 6.2 and 6.3 shows the S_{11} parameters (return loss and bandwidth) for the proposed antenna. The designed antenna resonates at 3.5 GHz and 5.8 GHz frequencies respectively. The return loss for 3.5 GHz is -37.78 dB and the return loss for 5.8 GHz is -46.315 dB which covers the minimum required value of return loss of -10 dB.

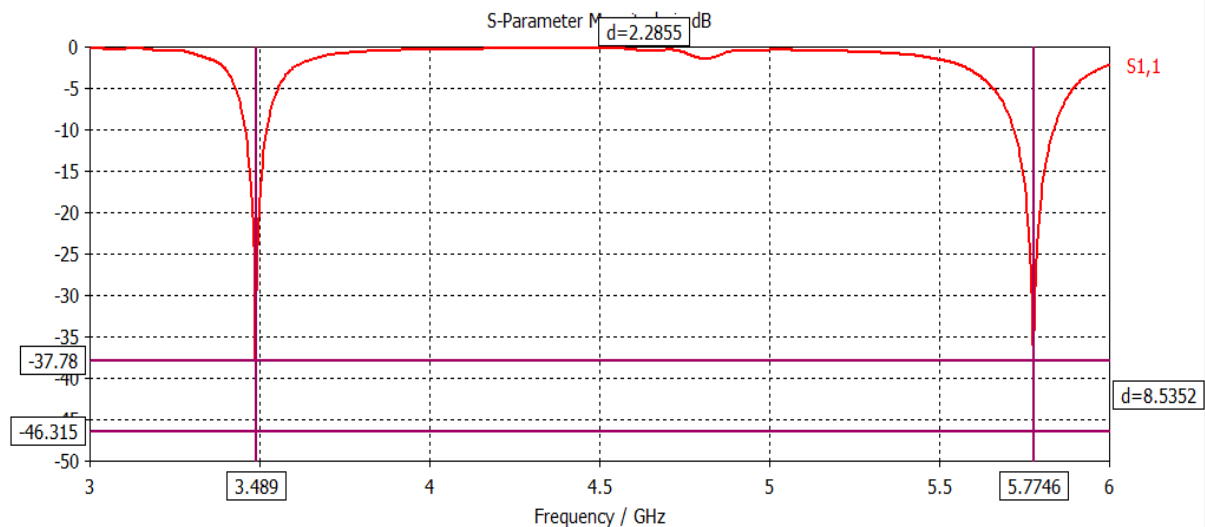


Figure 6.2: Return Loss of dual band microstrip patch antenna using dual patch

6.5 Bandwidth of dual band microstrip patch antenna using dual patch

The bandwidth of the antenna can be said to be those range of frequencies over which the return loss is greater than -10 dB (corresponds to a VSWR of 2). Thus, the bandwidth of antenna can be calculated from return loss versus frequency plot. The bandwidth of the proposed patch antenna is 65 MHz for 3.5 GHz frequency and 138 MHz for 5.8 GHz frequency. The bandwidth for 3.5 GHz and 5.8 GHz frequency has been shown in Figure 6.3 and Figure 6.4 respectively.

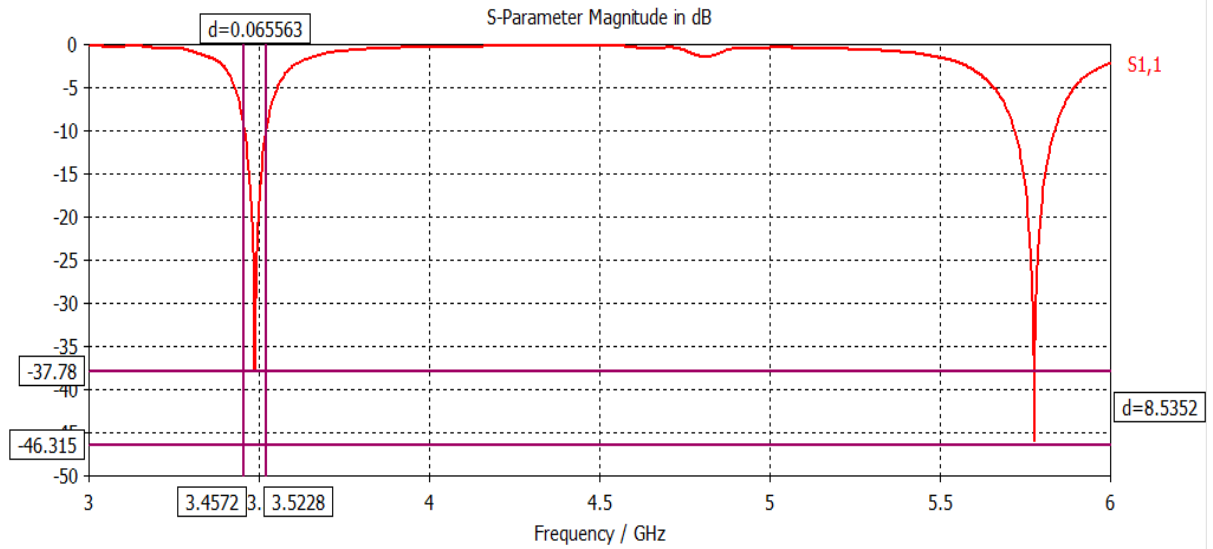


Figure 6.3: Bandwidth at 3.5 GHz frequency

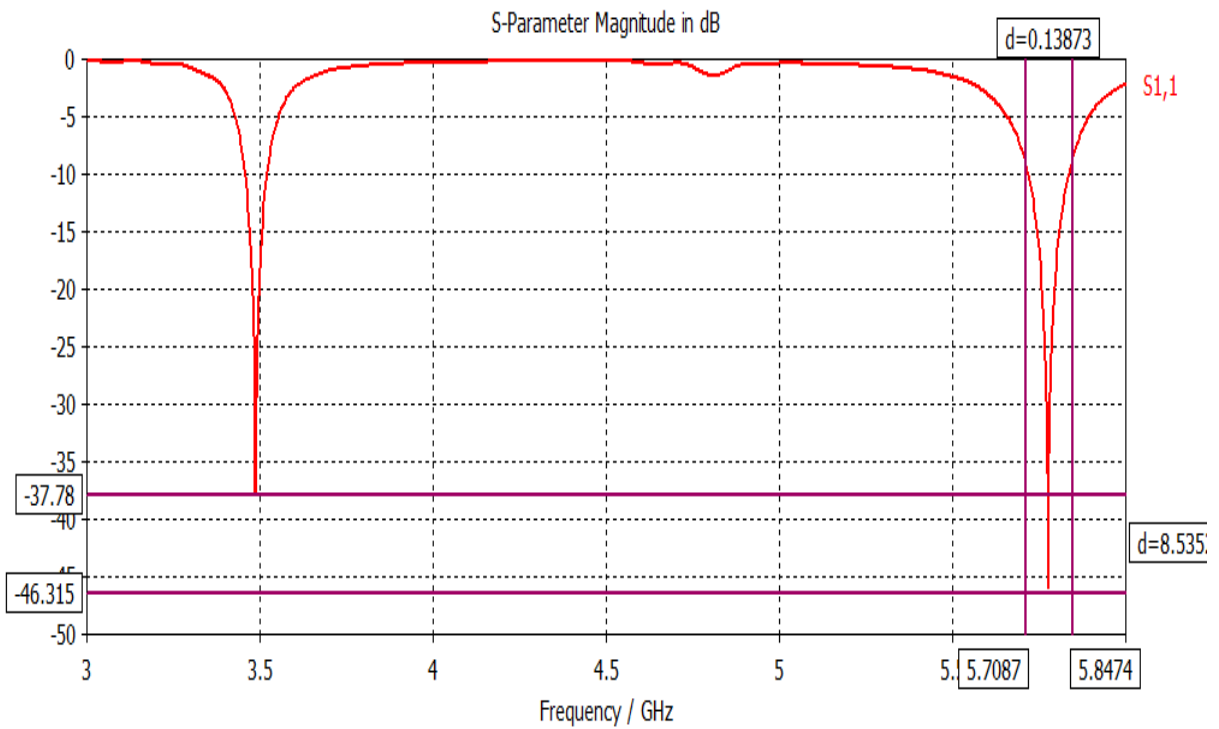


Figure 6.4: Bandwidth at 5.8 GHz frequency

6.6 Smith Chart of dual band microstrip patch antenna using dual patch

The Smith Chart plot (Figure 6.5) represents that how the antenna impedance varies with frequency. The achieved antenna impedance is 51.03 ohm as shown in Figure 6.5, which is very close to the required impedance of 50 ohm.

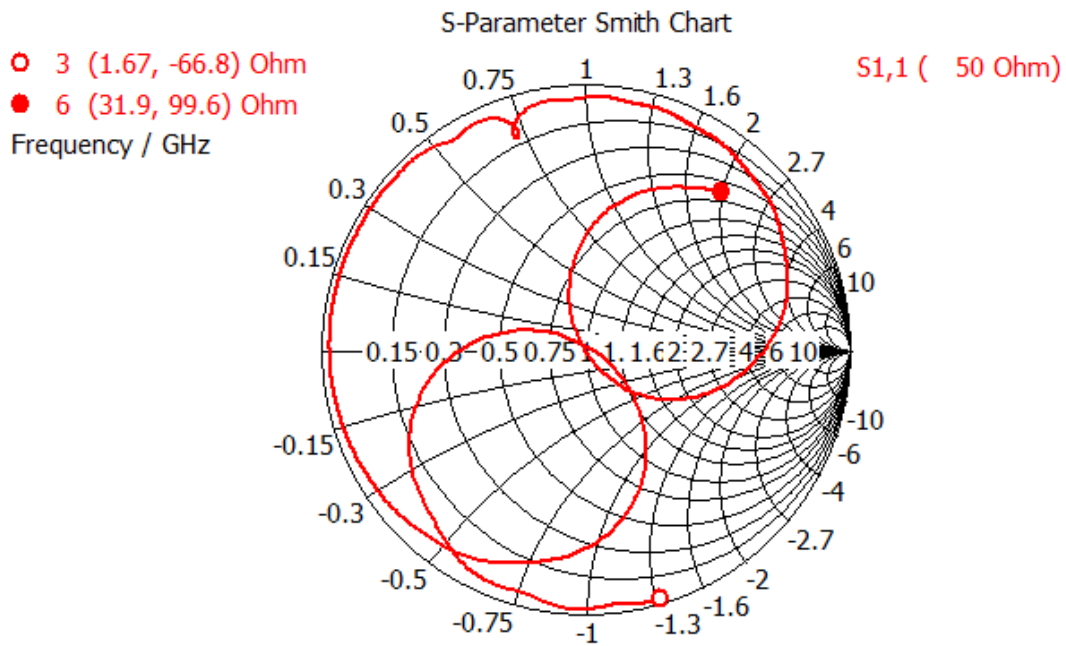


Figure 6.5: Smith chart of dual band microstrip patch antenna using dual patch

6.7 Voltage Standing Wave Ratio (VSWR) of dual band microstrip patch antenna using dual patch

Ideally, VSWR must lie in the range of 1-2 which has been achieved for 3.5 GHz and 5.8 GHz frequency, near the operating frequency value. The VSWR ratio at 3.5 GHz frequency is 1:1.026 and is shown in Figure 6.6. The VSWR ratio at 5.77 GHz frequency is 1:1.010 and is shown in Figure 6.7.

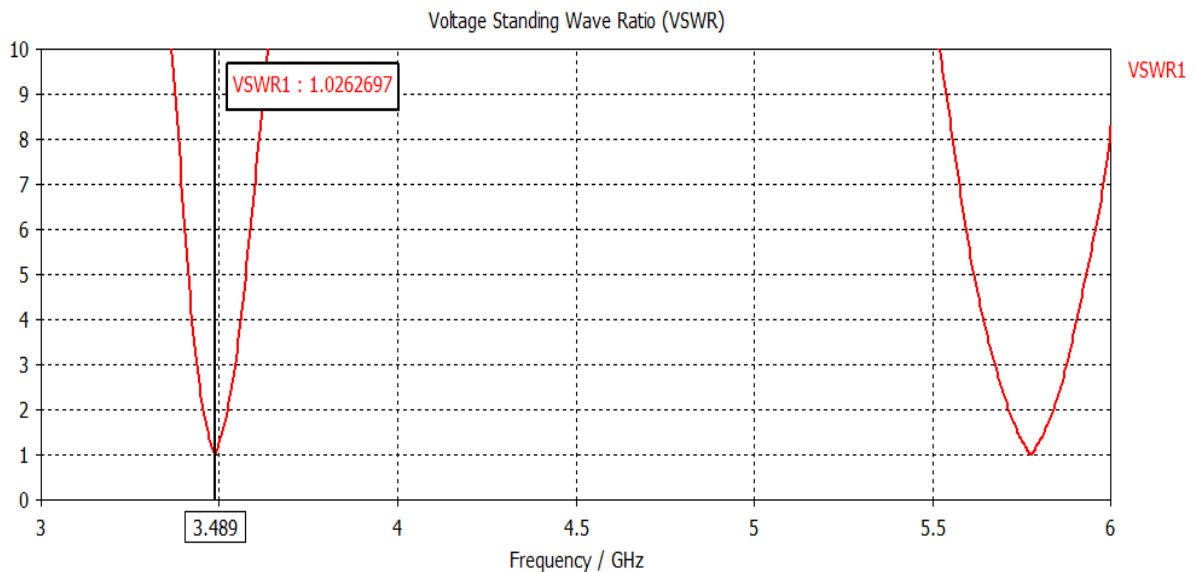


Figure 6.6: VSWR at 3.5 GHz frequency

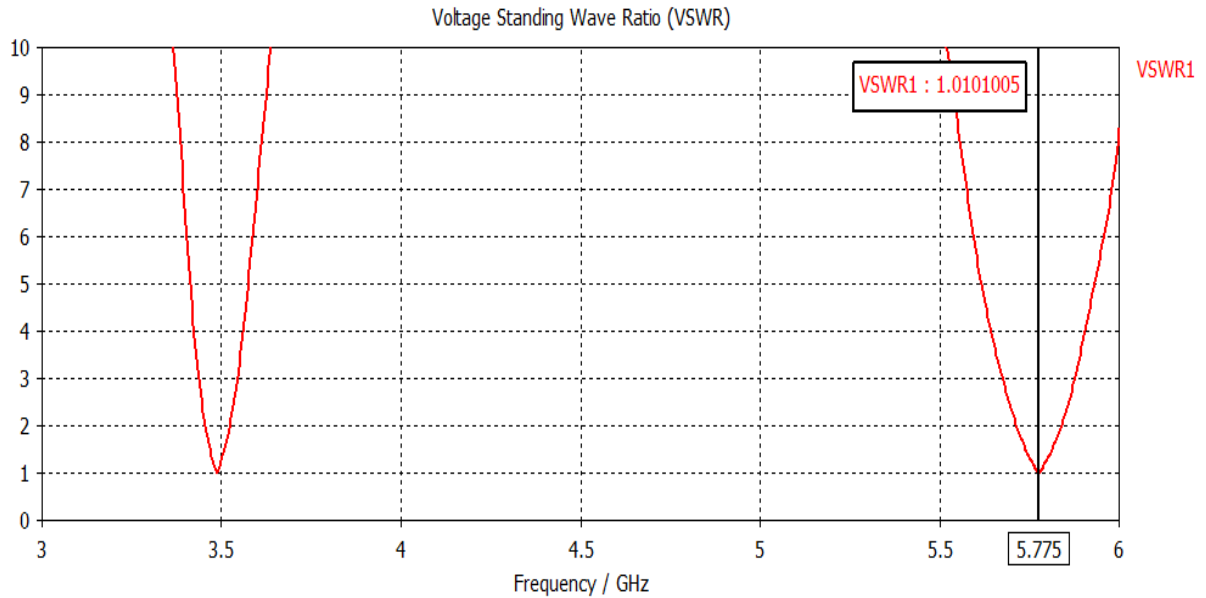


Figure 6.7: VSWR at 5.8 GHz frequency

5.8 Radiation Pattern of dual band microstrip patch antenna using dual patch

The radiation pattern showing the directivity for the designed antenna has been shown in Figure 6.8 and Figure 6.9. The directivity for 3.5 GHz frequency is 6.424 dBi and for 5.8 GHz frequency is 7.131 dBi.

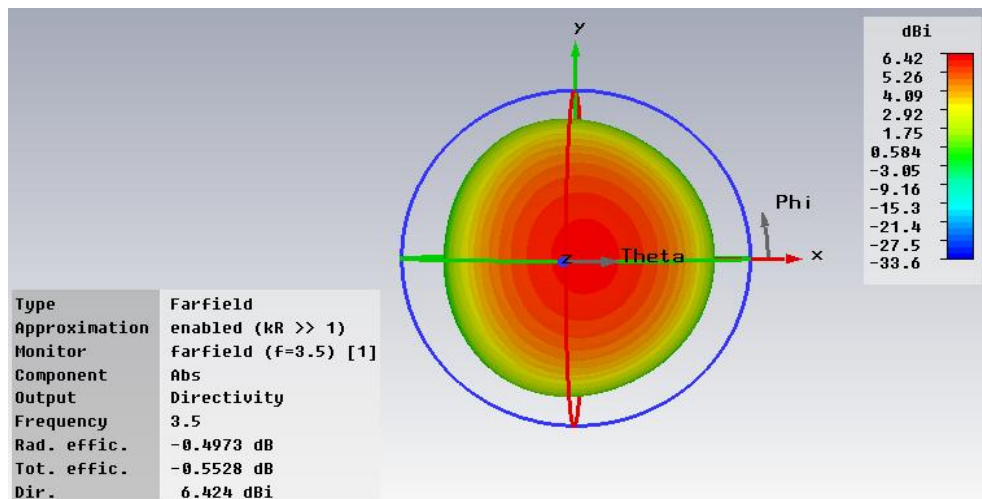


Figure 6.8: Directivity at 3.5 GHz frequency

In general, the value of directivity should be greater than 5 dBi. The radiation pattern showing the gain for the desired antenna has been shown in Figure 6.10 and Figure 6.11. The gain for 3.5 GHz frequency is 5.927 dB and for 5.8 GHz frequency is 6.749 dB. In general, the value of gain should be greater than 5 dB but in some cases it is acceptable to 3 dB.

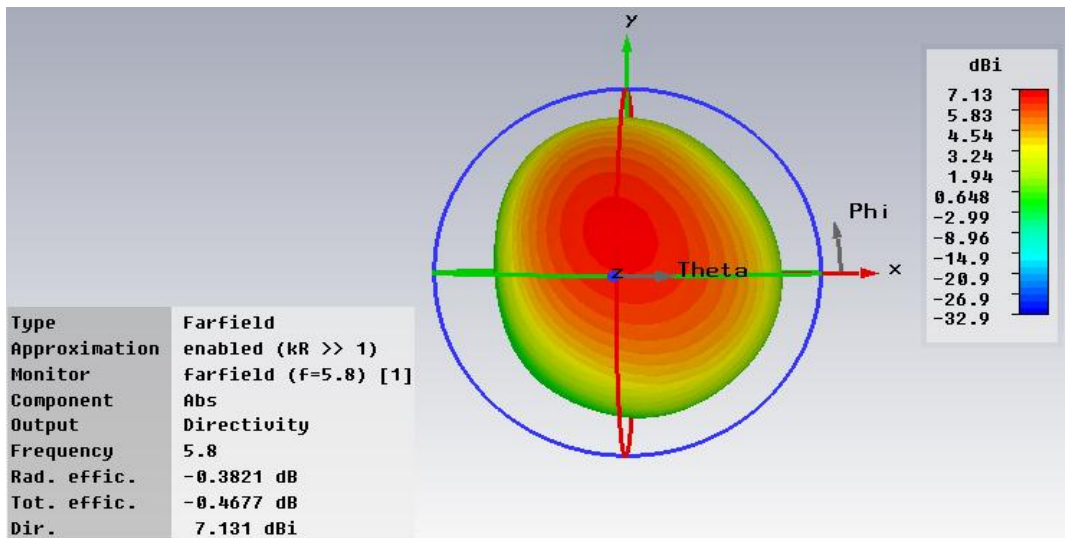


Figure 6.9: Directivity at 5.8 GHz frequency

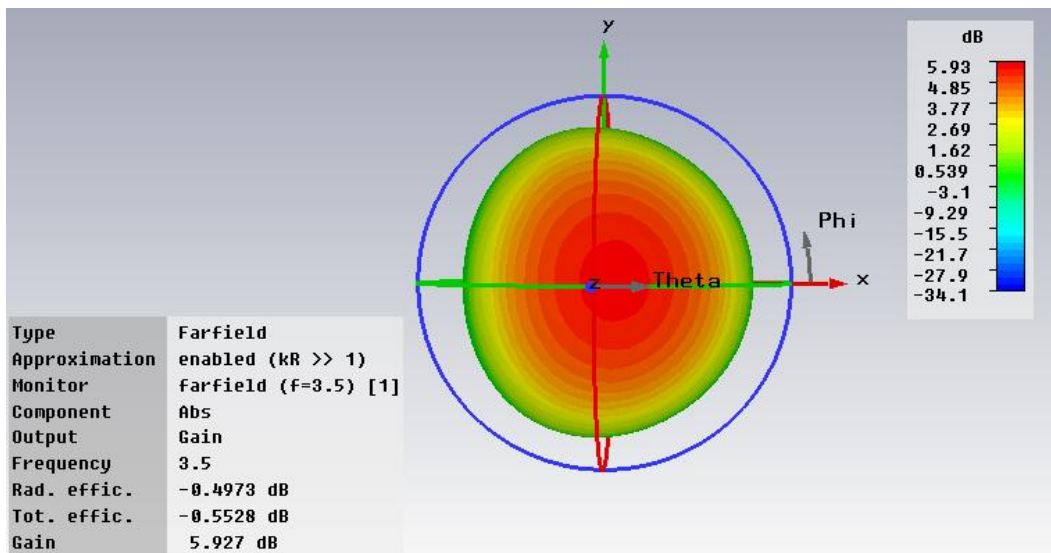


Figure 6.10: Gain at 3.5 GHz frequency

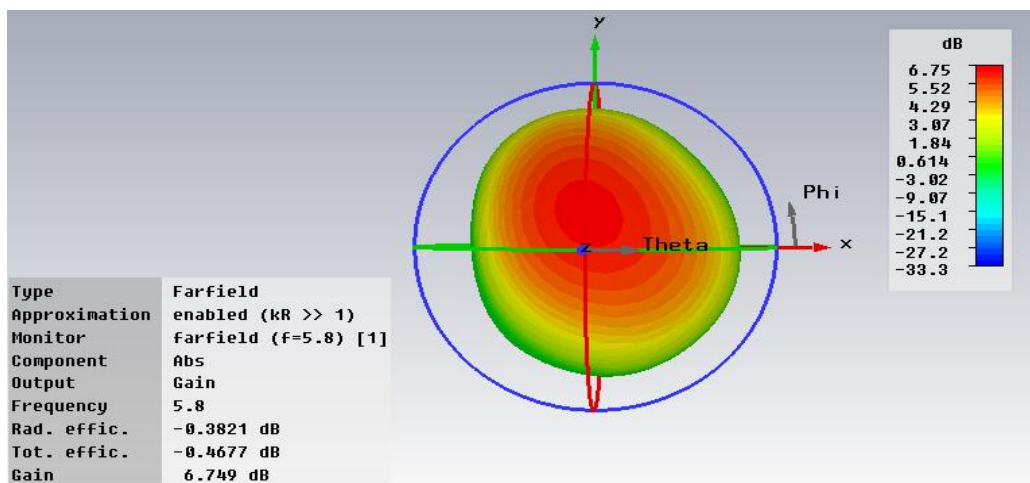


Figure 6.11 Gain at 5.8 GHz frequency

In this case the value of gain and directivity both is very good for both 3.5 GHz and 5.8 GHz. The only drawback or GAP of this design is that its bandwidth for 3.5 GHz i.e. for WiMax is 65 MHz, which is very less as compared to 290 MHz which is minimum required bandwidth for 3.5 GHz WiMax band.

The bandwidth of this design could be increased by using various bandwidth enhancement techniques, like employing DGS in ground and slots in patch. The work is continuously going on to achieve even better results; than obtained ones.

Chapter 7

Conclusion and Future Scope

7.1. Conclusion

The single frequency rectangular patch antenna has been designed for the frequency 5.2 GHz using microstrip line feeding and coaxial feeding technique. Dual band defected ground microstrip patch antenna for WLAN/WiMax and Satellite application has been designed. Dual band microstrip patch antenna for GSM and WiMax application has been designed. Dual band microstrip patch antenna using two slits and Reduced ground structure has been designed. Dual band antenna using dual patch has been designed. The designs have been successfully simulated using CST Microwave Studio software.

In microstrip line feed antenna for WLAN application, the return loss is -44.61dB, bandwidth is 196 MHz, the antenna impedance is 50.89 ohm and the VSWR ratio is 1:1.032.

In coaxial feed antenna the return Loss is -34.57 dB, bandwidth is 160 dB, the antenna impedance is 50.43 ohm and the VSWR ratio is 1:1.038.

In dual band defected ground microstrip patch antenna for wlan/WiMax and satellite application, bandwidth for 5.5 GHz band and 6-7 GHz band is 1.24 GHz (4.6053 GHz - 5.8481 GHz) and 1.04 GHz (6.124GHz – 7.16 GHz) respectively and the Gain for 5.5 GHz band and 6-7 GHz band is 4.262 dB and 4.668 dB respectively.

Dual band microstrip patch antenna for GSM and WiMax application, bandwidth for GSM band and WiMax band is 366 MHz (1600 MHz – 1900 MHz) and 583 MHz (3350 MHz - 3933 MHz) respectively and the Gain for GSM band and WiMax band is 2.268 dB and 3.742 dB respectively.

Dual band microstrip patch antenna using two slits and reduced ground structure, Bandwidth for 3.5 GHz band and 5.8 GHz band is 495 MHz (3.403 GHz - 3.901 GHz) and 260 MHz (5.569 GHz – 5.830 GHz) respectively and the Gain for 3.5 GHz band and 5.8 GHz band is 3.679 dB and 4.561 dB respectively.

Dual band antenna using dual patch, Bandwidth for 3.5 GHz band and 5.8 GHz band is 65 MHz (3.4572 GHz – 3.5228 GHz) and 138 MHz (5.7087 GHz – 5.8474 GHz) respectively and the Gain for 3.5 GHz band and 5.8 GHz band is 5.927 dB and 6.7498 dB respectively.

Design	Frequency	Return Loss	Bandwidth	Directivity	Gain	VSWR
Single band microstrip patch antenna using microstrip line feed	5.2 GHz	-44.61 dB	196 MHz	6.394 dBi	7.89 8 dB	1:1.032
Single band microstrip patch antenna using coaxial feed	5.2 GHz	-34.57 dB	160 MHz	4.049 dBi	3.84 5 dB	1:1.038
Dual band defected ground microstrip patch antenna for WLAN/WiMax and Satellite application	5.5 GHz	-27.26 dB	1.24 GHz	5.586 dBi	4.26 2 dB	1:1.105
	6-7 GHz	-20.77 dB	1.04 GHz	5.983 dBi	4.66 8 dB	1:1.203
*Dual band microstrip patch antenna for GSM and WiMax application	1.8 GHz	-20.8 dB	366 MHz	1.903 dBi	2.26 8 dB	1:1.159
	3.5 GHz	-30.98 dB	583 MHz	3.635 dBi	3.74 2 dB	1:1.070
Dual band microstrip patch antenna using two slits and reduced ground structure	3.5 GHz	-41.71 dB	495 MHz	3.664 dBi	3.67 9 dB	1:1.05
	5.8 GHz	-20.67 dB	260 MHz	5.064 dBi	4.56 1 dB	1:1.231
**Dual band antenna using dual patch	3.5 GHz	-37.78 dB	65 MHz	6.424 dBi	5.92 7 dB	1:1.026 2
	5.8 GHz	-46.315 dB	138 MHz	7.131 dBi	6.74 98 dB	1:1.010

Table 3: Concluded results of all the designs

*** this design does not achieve the desired value of gain and directivity, which should be 5 but here it is 2.268 dB for gain and 1.903 dBi for directivity.**

**** this design does not achieve the desired bandwidth for 3.5 GHz band, which should be 290 MHz but here it is only 65 MHz.**

7.2. Future Scope

- Based on gathered observations while completing this thesis topics were identified which would benefit for further investigation.
- At present, facility for the fabrication of patch antenna is not available at our institute the same work will be performed later. The simulated and measured results will be compared. So, on the basis of these compared results, one can say that the designed antenna will be working perfectly for a specific application.
- In this thesis, optimization of parameters has been done manually. One can use inbuilt optimizer to optimize the parameters using optimization techniques. One can optimize the parameters via. Writing the program using MATLAB to optimize the various parameters, then calibrating MATLAB with CST.
- Multiband patch antenna can be designed for various wireless applications like WLAN, WiMax etc.
- Wideband and ultra-wideband patch antenna can be designed which is helpful in telecommunication, and high speed data transmission systems.

PUBLICATIONS

1. Neha Ahuja, Rajesh Khanna and Jaswinder Kaur, “Design of Single Band Rectangular Patch Antenna for WLAN Application”, International Journal of Computer Applications (IJCA), April 2012. ISSN: 0975-8887.
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