

Miniaturized Dual/Multiband Antenna for Wireless Applications

A thesis submitted towards the fulfilment of requirement for the award of the degree of

Master of Engineering In Electronics and Communication Engineering

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DEPARTMENT

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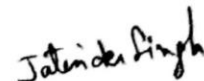
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DECLARATION AND CERTIFICATE

I hereby declare that the thesis entitled "Miniaturized Dual/Multiband antenna for Wireless Applications" is an authentic record of my own work carried out as the requirement for the award of degree of Masters of engineering in ECE at Electronics and Communication Department of Thapar University, Patiala under the guidance of Dr. Jaswinder Kaur (Assistant Professor), Electronics and Communication Department, Thapar University during the session 2014-2016.


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ABSTRACT

In last decade, there is vast development in communication field especially in wireless applications. Wireless applications cover GPS, GSM, Bluetooth, WLAN, WiMAX bands. GPS gives location access from anywhere wirelessly, Bluetooth transfers file without any physical connection, WLAN and WiMAX provides access of data wirelessly. WLAN (Wireless Area Network) and WiMAX (Worldwide interoperability for Microwave Access) both wireless applications are growing at a very fast rate in present era. WLAN and WiMAX both provide mobility and flexibility to user as he can move in a large area without signal disconnection. In present time, there is large demand for the antennas which can integrate many standards in single device. To cover all the standards, antenna should be wideband or multiband. But as the bands are increasing, size of antenna is increasing, so designing of small antenna is very difficult, for reception or transmission of information large bandwidth is required and small sizes antenna which can be placed in small size equipment. So researchers are working on the techniques to gain small size, multiband and wideband antenna. All of these requirements are fulfilled by microstrip patch antenna which is single layered structure. The presented work here includes the designing of antenna with microstrip line feeding technique using cavity model and transmission line model. The effect of slot and DGS is studied here which provides multiband, large bandwidth, and reduced size. The triangular and rectangular patch shapes are used here for WLAN and WiMAX applications. In this thesis, the rectangular patch which is cut into staircase with etched L-shape slot from ground as DGS geometry is presented which is of small size and provides proficient gain, return loss, radiation pattern and value for VSWR less than 2. This Staircase patch antenna provides band which shows resonance at 3.48 GHz and 5.73 GHz for WLAN and WiMAX applications. And triangular patch antenna provides bands at 3.38 GHz and 5.25 GHz, providing large bandwidth and proficient return loss. Both the antennas are fabricated and tested for practicality of design. Testing of antenna is done by VNA (Vector Network Analyser). Both the antennas provide dual band which can be used to cover present scenario demands.

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ABBREVIATIONS

VSWR	Voltage Standing Wave Ratio
RL	Return Loss
RFID	Radio Frequency Identification
DGS	Defected Ground Structure
MMIC	Monolithic Microwave Integrated Circuit
GPS	Global Positioning System
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
ACS	Asymmetric Coplanar Strip
SRR	Split Ring Resonator
UWB	Ultra-Wideband
CSRR	Complementary Split Ring Resonator
CSSRR	Complimentary Single Split Ring Resonator
DNG	Double Negative
SNG	Single Negative
DPS	Double Positive
CPW	Coplanar Waveguide
CST	Computer Simulation Technology
IEEE	Institute of Electrical and Electronics Engineers
VNA	Vector Network Analyzer
GSM	Global System for Mobile

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CHAPTER 1

INTRODUCTION

1.1 Overview

The antenna has a very crucial role in the wireless communication system as it yields reliability and great performance. An antenna is a metallic device which contributes as a transition region between free space and guiding structure like a transmission line, is used for receiving or radiating electromagnetic waves in order to communicate even in a longer distance. It acts as a transducer which turns one form of energy into other. An antenna consists of two parts; Transmitter and Receiver. A transmitting antenna uses waves that are produced by electrical signals inside a device such as a radio and turns them to waves that can travel in an open space. The receiving antenna uses free-space waves and turn them into guided waves (electrical signals) that are compatible with cables or wires [4]. In the present era, wireless communication is growing very fast in the communication field. There is some application listed under commercial and government applications such as satellite communication, mobile radio and Wireless communication where low profile, size, ease of installation, cost, aerodynamics profile, conformable and performance are major constraints. This gives the vision of designing new small size antenna which provides information exchange and multimedia communication from anywhere. Wireless local area networks (WLAN) and WIMAX (Worldwide Interoperability for Microwave Access) has become one of the principal interests in communication field as they don't require any license to work and covered under ISM bands. Table 1.1 gives the brief information about the frequencies under which different wireless application works.

1.2 IEEE Standards for WLAN

For WLAN's application, IEEE 802.11 standard was presented in 1997. IEEE 802.11b or 802.11 HR (High Rate) standards are proposed after few years and operate on the 2.4 GHz ISM band (2.4 - 2.484 GHz which provides a data rate up to 11 Mbps. In 1999, The IEEE 802.11a standard was approved which operates on the 5 GHz ISM bands (5.15 - 5.35 GHz and 5.725 -5.825 GHz). As there is a large change in bands which shows that 802.11a and 802.11b products are not compatible. Therefore, the IEEE proposed new standard i.e. 802.11g, which is compatible with both 802.11b and 802.11a technology.

Table 1.1 Various frequency bands for different wireless applications

Wireless Applications		Frequency Band (GHz)	Bandwidth (GHz)
GSM	GSM 900	0.8-0.96	0.07
	GSM 1800	1.71-1.805	0.095
	GSM 1900	1.85-1.99	0.14
IMT		2.3-2.4	0.1
		2.7-2.9	0.2
		3.4-4.2	0.8
		4.4-4.9	0.5
Bluetooth		2.4-2.5	0.1
WLAN		2.4-2.484	0.084
		5.15-5.35	0.2
		5.725-5.825	0.1
WiMAX		2.5-2.69	0.19
		3.4-3.69	0.29
		5.25-5.85	0.6

In 2003, The IEEE 802.11g standard was accepted. A dual band antenna is required for WLAN applications as 802.11a uses 5 GHz frequency band and 802.11b and 802.11g are using 2.4 GHz frequency band. Because of high-speed transfer rate, the popularity of WLAN is increased. This increased the development of dual-band/multiband broadband antennas [40]. Frequency, data rate and range for different IEEE WLAN standards are shown in Table 1.2.

Table 1.2 WLAN Standards

Parameters	802.11 a	802.11 b	802.11 g	802.11 n
Frequency (MHz)	5000-6000	2400	2400	2400/5000
Range (m)	120	140	140	250
Data rate (Mbps)	54	11	54	248
Type	LAN	LAN	LAN	LAN

1.3 IEEE Standards for WiMAX

IEEE 802.16 standard is for WiMAX technology which is also called Broadband Wireless Access. In June 2001, the WiMAX forum has created name WiMAX. The name WiMAX was created to promote conformity and interoperability of the standard. WiMAX is described by the forum as a standards-based technology which provides wireless broadband access as an alternative to DSL and cable. WiMAX has no uniform global licensed spectrum. Still, WiMAX forum has provided three licensed frequency

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 provides the data rate upto 70 Mbps over 50 Km. IEEE 802.16-2004 is also called IEEE 802.16d which developed the standard. Because of no support for mobility, it is referred to as "fixed WiMAX". IEEE 802.16-2004 replaces IEEE Standards 802.16-2001, 802.16c-2002, and 802.16a-2003. 802.16e-2005 is a further amendment to 802.16-2004 which introduced support for mobility. Because of this, it is also called as "mobile WiMAX" [40]. Bandwidth, data rate, and applications are shown in Table 1.3 for different WiMAX standards.

Table 1.3 WiMAX Standards

Parameters	802.16	802.16 a	802.16 e
Spectrum (GHz)	10-66	2-11	2-6
Channel bandwidth (MHz)	20,25 and 28	1.5 to 20	1.5 to 20
Data rate (Mbps)	32-134 (28 MHz)	75 (20 MHz)	15 (5 MHz)
Channel conditions	LOS	Non-LOS	Non-LOS
Typical cell radius (Km)	2-5	7-10 max 50	2-5
Application	Fixed	Fixed and Portable	Mobility

1.4 Types of Antenna

Here are some brief details about different types of antennas.

1.4.1 Aperture based antennas

- **Wire antennas:** These antennas are very familiar as they can be seen anywhere normally on automobiles, ships, buildings, spacecraft, aircraft etc. There are of many shapes like straight wire, loop, and helix.
- **Aperture antennas:** These antennas are very well known to the layman in present time as demand for the more innovatory antenna is growing and use of higher frequencies is also increasing where these antennas fit well. Aperture antennas have major use in spacecraft and aircraft applications as these antennas can be easily flush-mounted on the upper layer of spacecraft and aircraft. They can be protected from environmental hazardous conditions by covering in dielectric.
- **Microstrip antennas:** Microstrip antenna is comprised of a metallic patch and grounded substrate. They are majorly used in space applications, commercial and government applications. The metallic patch is of various shapes such as triangular, circular and rectangular etc. These antennas can be fabricated very easily by using PCB designing technique, conformal to planar and non-planar surfaces, less expensive, mechanically tough and provides flexibility in terms of impedance, polarization, resonant frequency, and radiation pattern.
- **Array antennas:** An array is comprised of many elements to provide desired radiation characteristics which cannot be provided by a single element. Antenna array is designed in such a way that it gives maximum directivity in a particular direction and excludes radiation in other directions [3].

1.4.2 Radiation Characteristics based antennas

- **Directional antennas:** As the name specifies it provide radiation in a particular direction to cover a particular area. They are also known as beam antennas as they receive and transmit in a specific direction.
- **Omni-directional antennas:** Omnidirectional antennas provides equal radiation pattern in all horizontal directions. The radiation pattern of the omnidirectional antenna is called “doughnut-shaped” radiation pattern. Omnidirectional antennas are commonly used in wireless routers and cellular phones [3].

1.4.3 Polarization Based Antenna

- **Circularly polarized antennas:** These antennas are capable of transmitting or receiving electric field of any direction. The electromagnetic field is emitted in a corkscrew-like fashion by these antennas. Electromagnetic waves are broadcasted on two planes by completing one round in a single wavelength.

- **Linearly polarized antenna:** These antennas provide reception and transmission of electromagnetic waves in either vertical plane or horizontal plane. The antenna must know RFID tag direction, its RFID tag and the plane of the antenna must be alike to get a uniform reception. With the development of technology, innovative antennas but with small size are required. That's why microstrip antenna came in the picture [3].

1.5 Antenna Parameters

1.5.1 Antenna impedance

Input impedance relates voltage to the current ratio at a pair of terminals or the impedance presented by an antenna at its terminals or the ratio of the appropriate components of the electric to magnetic fields at a point. Input impedance has real and complex parts and it is represented in its general form in the following equation:

$$Z_{in} = R_{in} + jX_{in} \quad (1.1)$$

where R_{in} represents resistive portion of the impedance and X_{in} represents the reactive portion of the impedance [1].

1.5.2 VSWR

VSWR is defined as the maximum to minimum voltage ratio along the transmission line. VSWR is normally measured during tuning and installation of the antenna. When a feedline is connected to antenna's transmitter for power transfer, maximum power will be transferred when input impedance and the characteristic impedance of antenna will be same. Because of some mismatching between input impedance and the characteristic impedance of transmission line, some of the energy reflects back and is not transferred from the transmitter. The reflected back energy leads to the formation of standing wave pattern. VSWR value should be very small for proper matching. Value for VSWR lies between 1-2 for proper function [1].

1.5.3 Directivity

The directivity of an antenna is a figure of merit which is defined as maximum power density radiated by the antenna in particular direction versus power density radiated by the isotropic antenna in all directions equally. Directivity is taken in that direction in which major lobe of the radiation pattern is present. Directivity has no units [1].

Mathematical formula for directivity

$$D = U / U_o$$

$$= 4\pi U / P_{\text{rad}} \quad (1.2)$$

where

U = radiation intensity (W/unit solid angle)

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

P_{rad} = total radiated power (W)

1.5.4 Gain

Gain is defined as key performance number which unites antenna directivity with electrical efficiency. Antenna gain can be measured by taking the ratio of radiation intensity in a particular direction to the radiation intensity which is got by when antenna radiates power isotopically.

$$\begin{aligned} \text{Gain} &= 4\pi \times \text{radiation intensity} / \text{total input (accepted) power} \\ &= 4\pi \times U(\theta, \phi) / P_{\text{in}} \end{aligned} \quad (1.3)$$

Gain is generally measured in decibels with respect to other antenna either an isotropic antenna (dBi) or a dipole (dBd) [1].

1.5.5 Radiation Pattern

An antenna radiation pattern can be named as far field pattern as well as antenna pattern. It is considered as a measure of a graphical representation or mathematical function of the antenna as a function of space coordinates. It is the illustration of strength graphically which is received by or transmitted by the antenna. Antenna radiation patterns are measured at a single frequency at one time and at single polarization. These patterns are showed with dB scale in rectilinear or polar form [1].

1.5.6 Antenna polarization

The polarization of the electromagnetic waves that are radiated from the antenna gives the polarization of an antenna. Polarization is basically given by the path traced by electric field vector as a function of time. Polarization can be categorized in three parts

- a. Linear polarization
- b. Elliptical polarization
- c. Circular polarization

When the linear path is followed by electric field vector as a function of time in space at a given point then the polarization is called linear polarization. Linear polarization is further classified into two parts as horizontal and vertical polarization. If electric field vector follows circular path then polarization is circular polarization and if the path is followed elliptically then polarization is elliptical polarization. These polarizations can be left and right handed. If the path is taken in a clockwise direction by electric field vector then the polarization is left-hand polarization and if the path is taken in anticlockwise direction then the polarization is right-handed polarization [1].

1.5.7 Return loss

Return loss is one of the important parameters especially in the case of microstrip antenna or transmission line. The return loss depicts how much power is lost in the signal that is reflected back because of some discontinuity or because of some mismatching. The reflected waves lead to standing waves because of mismatching occurs between antenna impedance and its characteristics impedance. Both parameters RL and VSWR are similar as both depict the matching. The RL can be calculated as

$$RL = -20 \log_{10}|\Gamma| \quad (1.4)$$

where

Γ - it is the reflection coefficient

The value for VSWR up to 2 is acceptable in practical applications that correspond to return loss having a value of 9.5 dB [1].

1.6. Introduction to Patch Antenna

In the present time, small size or small height antennas are required in high-performance aircraft, missile applications, satellite and spacecraft applications where weight, size, the cost for fabrication, ease of fixing, performance, aerodynamic profile and ease of making are the major constraints. Presently there are many other applications that belong to commercial and government applications, such as mobile radio and wireless communication that have the same specifications as required for above-mentioned applications. To cover these requirements, microstrip antennas comes in the picture. A microstrip antenna as the name depicts micro which means small size and of small height and it is adaptable to planar and non-planar surfaces. These antennas can be fabricated very easily by using printed circuit technology and cost is very less for fabrication. They

are mechanically potent and can be easily flush mounted on rigid surfaces and also suitable for monolithic microwave integrated circuit designs. During selection of particular patch and mode, they provide flexibility in terms of resonant frequency, radiation pattern, polarization, and impedance. A microstrip antenna can also be designed with variable polarization, resonant frequency, radiation pattern and impedance by adding new elements as varactor diodes, shorting pins. They provide low efficiency and small bandwidth. However in government security systems, an antenna with the narrow bandwidth is required. The bandwidth of the antenna can be increased up to 35% and antenna efficiency can be increased up to 90% by increasing the height of substrate if surface waves are not taken into considerations. But with the increase in height, the totally undesirable surface waves are induced which decrease the total available power meant for direct radiation. Antenna radiation pattern and polarization are degraded when surface wave moves within the substrate and dispersed at some discontinuities or at some bends. These discontinuities can be a truncation of substrate and ground. Surface wave elimination is possible with the help of cavities during maintaining of large bandwidth. Large bandwidth can be obtained by using stacking, by introducing slots and by DGS [2]. The structure of microstrip antenna is shown in Fig. 1.1 (a).

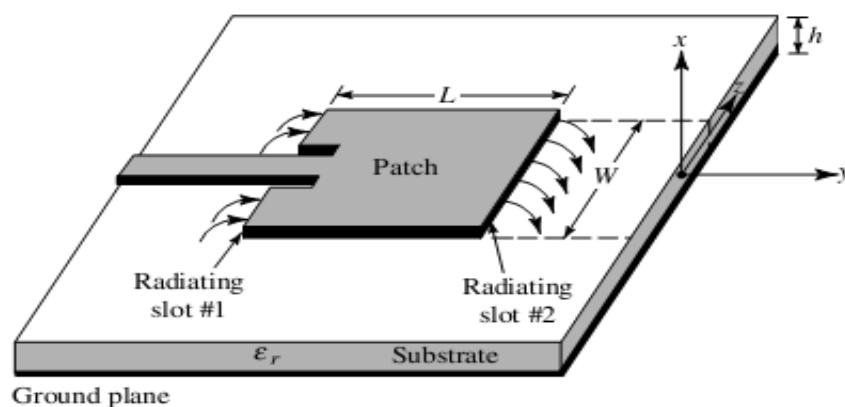


Fig. 1.1 (a) Structure of Microstrip Antenna [3]

Microstrip antenna can be many shapes as circular, rectangular, triangular, circular ring, square and elliptical etc. These common shapes are shown in Fig 1.1. (b). Rectangular microstrip configuration is mostly used because of simple analysis and easy designing. The patch is designed by taking thickness of metallic strip as $t \ll \lambda_0$ where λ_0 is free space wavelength and height of substrate as $h \ll \lambda_0$ but normally it is taken as $0.003 \lambda_0 <$

$h < 0.05\lambda_0$ above from the ground. Patch length is taken as $\lambda_0/3 < L < \lambda_0/2$. Dielectric constant can be of value $2.2 < \epsilon_r < 12$.

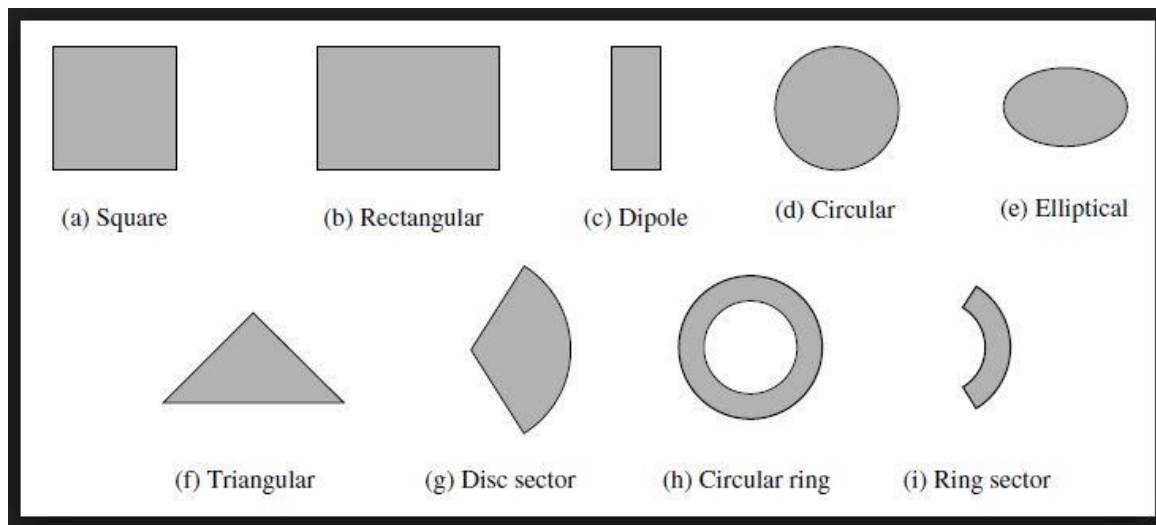


Fig. 1.1 (b) Common shapes for microstrip antenna [3]

1.6.1 Radiation mechanism of Microstrip Patch Antenna

Microstrip antenna radiates because of fringing. Field undergo fringing at patch edges because of finite dimensions. The patch antenna can be considered as an open circuited transmission line. The voltage reflection coefficient for the open circuit transmission line is -1 which means voltage and current are not in phase. The patch antenna as a half wavelength dipole antenna gives maximum voltage (say +V volts) at the end of the patch and gives minimum voltage (-V Volts) at the starting of the patch antenna. According to this consideration fields below the patch will be same as shown in Fig. 1.2 which roughly shows the bending of the fields around the edges [2]. The fringing field on the edge of the microstrip antenna gives the radiation by adding up in phase.

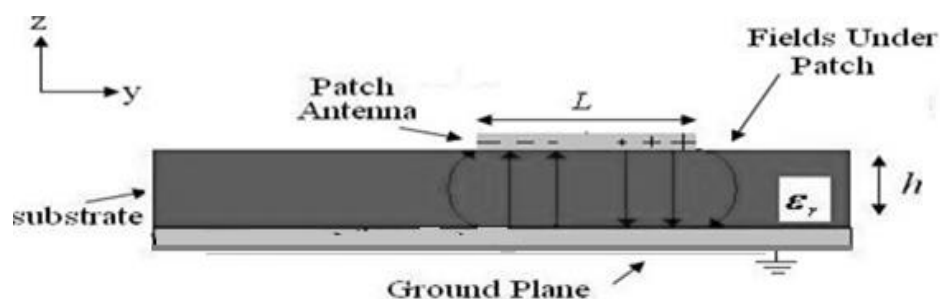


Fig. 1.2 Side view of patch antenna with E-fields [3]

Advantages of Microstrip Patch Antennas

- Thin profile

- Fabrication is easy.
- Supports linear as well as circular polarization.
- It is easy to feed.
- It is used in the array.
- Provides dual or multiband.
- Low cost.
- It can be easily integrated with microwave integrated circuits (MICs).

Disadvantage of microstrip patch antenna

- Inefficiency.
- Very narrow frequency bandwidth.
- Poor scan performance.
- Low gain.
- Low impedance bandwidth.
- Low power handling capacity.
- A Higher value of Q.

1.6.2 Feeding Techniques

There are many techniques that can be used to feed microstrip patch antennas. But four techniques that are very popular to feed the microstrip antenna are microstrip line, aperture coupling, coaxial probe and proximity coupling. Out of these four techniques, the microstrip line is very similar to coaxial probe in terms of operation and offers essentially one degree of freedom. The proximity coupled and aperture coupled both provides more than one degree of freedom as proximity coupled gives at least two degrees of freedom which covers the length of the feeding stub and the patch width-to-line width ratio and aperture coupled patch antenna gives four degrees of freedom in terms of slot size, its position, feed substrate parameters and the feed line width [5].

➤ **Microstrip feed line**

The microstrip feed line is made up of same conducting material as of patch, but small in dimensions as compare to patch. The microstrip line feed is strip whose fabrication is very easy and can easily be matched by adjusting inset position it's modeling is very simple. Parallel RLC network is the equivalent circuit that is applied to this feeding technique which represents the resonant patch and feed inductance of the microstrip feed line is represented by the series inductor. Electromagnetic field lines should be focused only on the microstrip line and

ground plane so that it bounds to strip line and excite patch to the radiate field [5]. The microstrip feed line and inset feed and its equivalent model are shown in Fig.3 (a) and Fig. 3 (b).

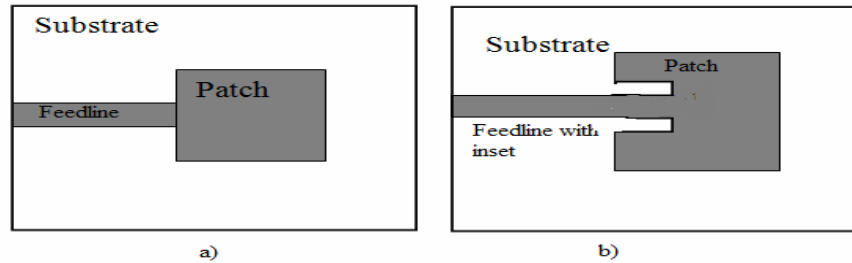


Fig. 1.3 (a) Geometry of Micro-Strip Feed line (a) directly feed (b) Inset feed [3]

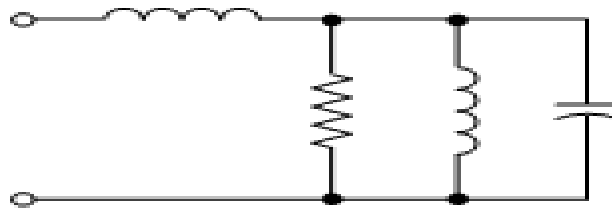


Fig. 1.3 (b) Equivalent circuit of microstrip feed line technique [3]

➤ **Coaxial probe**

The coaxial probe is used to feed patch antenna from the ground plane through the substrate. The coaxial probe has an inner conductor which is directly attached to a patch of a microstrip antenna and an outer conductor which connects ground plane. Like microstrip line feed, its fabrication and matching are very easy and it provides low spurious radiation. For thick substrates as $h > 0.02 \lambda$, coax probe gives narrow bandwidth. Its modeling is also difficult. If we talk about array design, they have no. of elements joined together so large no. of joints make fabrication difficult and also make it inefficient.

Coaxial probe feed has the same equivalent circuit as the microstrip feed line. Cross polarization radiation is produced by coax probe although it excites only dominant mode. Cross polarization occurs because of unevenness in feed line which generates higher modes [2]. The geometry and equivalent model are shown in Fig. 1.4 (a) and Fig. 1.4 (b).

➤ **Proximity coupled feed antenna**

Proximity coupled feed has two-layered substrate structure. It consists of microstrip line which resides on the lower substrate and terminates openly. In this

technique, the patch is printed on the upper substrate. As microstrip line and patch do no contact each other so it is called non-contacting feed.

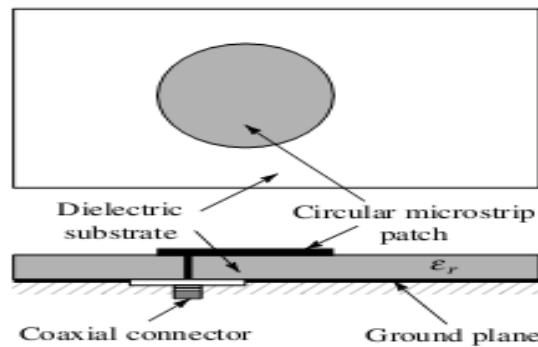


Fig. 1.4 (a) Geometry of Coaxial Probe Feed patches antenna Top view and Side view [3]

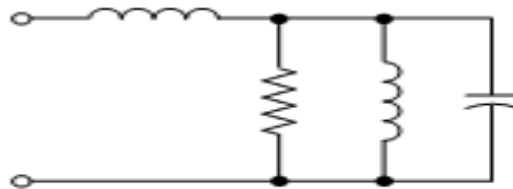


Fig. 1.4 (b) Equivalent circuit of coaxial probe technique [3]

Proximity coupled feed technique allows the feed line to stay on a thin substrate for reduction of spurious radiation and coupling and on the other hand patch stay on effectively thick substrate which improves bandwidth. This technique has fabrication problem as proper alignment is required between both the substrates which is difficult [5]. It provides capacitive coupling and gives rise in bandwidth up to 21%. The geometry and equivalent circuit model are shown in Fig. 1.5 (a) and Fig. 1.5 (b).

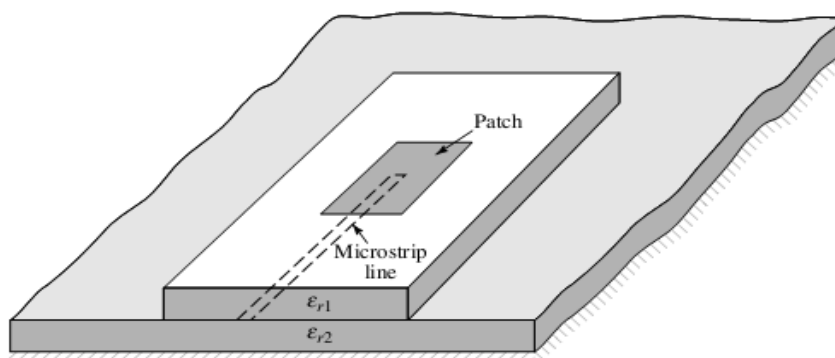


Fig. 1.5 (a) Geometry of Proximity Coupled microstrip patch antenna [3]

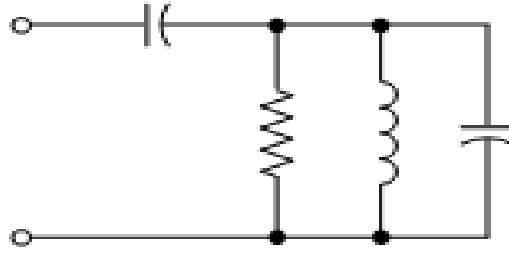


Fig. 1.5 (b) Equivalent circuit of Proximity Coupled microstrip patch antenna [3]

➤ **Aperture coupled feed**

Aperture coupled feed technique has also multi-layered substrate structure like proximity coupled feed. In this technique, ground plane separates microstrip line feed and patch. For providing coupling between patch and microstrip line, aperture or slot is cut from ground plane. The slot or aperture is cut symmetrical or from the center of ground so that it gives lower cross-polarization. Shape, size and location of the aperture decide how much feed is coupled from feed line to patch through the slot. As there is no contact between microstrip-line feed and patch because of ground plane which separates them causes a reduction in spurious radiation. Normally for the bottom substrate, the high dielectric material is used which bounds the field to the line and a dielectric material having low value for the dielectric is used for the upper substrate for optimization of radiation. Like proximity coupled feed it also has fabrication problem because of multiple layers [5]. Geometrical structure and equivalent model are shown in Fig.1.6 (a) and Fig. 1.6 (b). The comparison between all feed techniques is shown in Table 1.3.

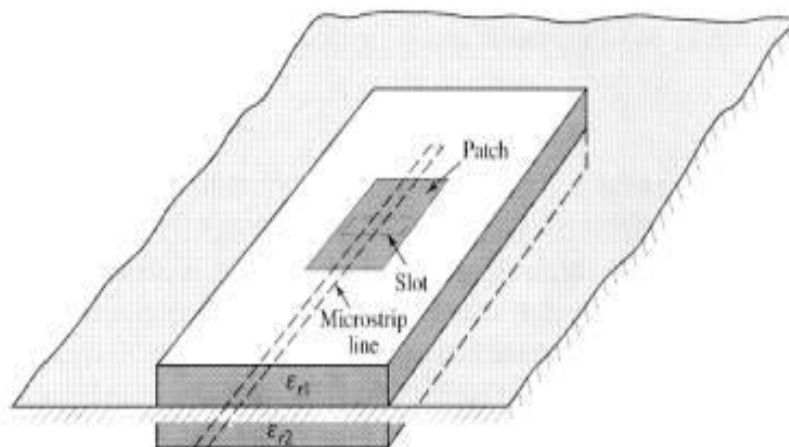


Fig. 1.6 (a) Aperture-coupled feed [3]

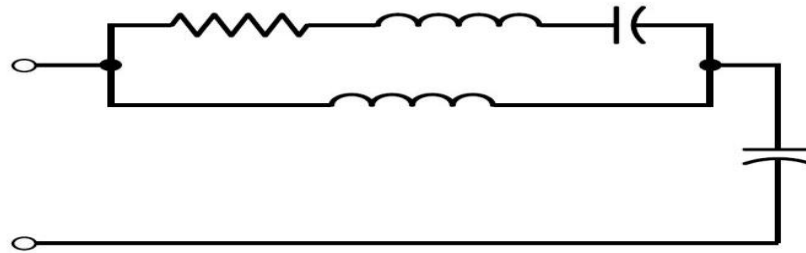


Fig. 1.6 (b) Equivalent model for aperture coupled feed [3]

1.6 Antenna Analysing Models

For analyzing microstrip antenna, there are three models which normally use to model the antenna. They are

- Transmission line model
- Cavity model
- Full wave model

Understanding of transmission line model is very easy among other two models. It provides very good perception about the antenna but at the same time it is not so accurate and also cannot be used to model coupling. Cavity model is better than transmission line model in terms of accuracy but more complex in nature. Full wave model is the most practical and accurate model among these two [3].

1.6.1 Transmission Line Model

The rectangular microstrip antenna is delineated by TL model as two slots which are separated by a transmission line of length 'L' having a low impedance Z_c . The microstrip line is covered with two dielectrics as one above the line which is air and second is a substrate, below the strip line. The field lines resides not only in the substrate but also in the air as the height of substrate is very less than width microstrip antenna and their ratio is $(W/h) \gg 1$ and also its dielectric constant is $(\epsilon) \gg 1$, because of which fringing takes place and leads to radiation mechanism of microstrip antenna as shown in Fig. 1.7. Fringing make antenna electrically longer as compared to its actual physical dimension. So to take fringing in effect, the concept of effective dielectric constant of (ϵ_r) is introduced.

The normally value of effective dielectric constant (ϵ_r) is less than the value of ϵ of the substrate ($1 < \epsilon_r < \epsilon$). ϵ_r also depends on upon the frequency of operation. When the frequency of operation is increased, the value of ϵ_r becomes equal to actual ϵ [3].

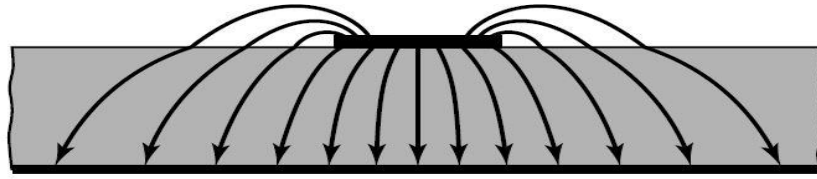


Fig. 1.7 Electric field lines

(a) Calculation of ϵ_r

ϵ_r is constant for low frequencies and its value increases with increase in frequency and at the end it approaches actual dielectric constant value. At low frequencies, its value is referred to as static value.

The value of ϵ_r can be mathematically calculated as

$$\epsilon_r = \frac{\epsilon+1}{2} + \frac{\epsilon-1}{2} \left[\frac{1}{\sqrt{1+\frac{12h}{W}}} \right] \quad \left(\frac{W}{h} > 1 \right) \quad (1.5)$$

(b) Calculation of Effective Length, Effective Width, and Resonant Frequency

As it is shown in Fig. 1.8 (a), $2\Delta L$ is the increment in the actual length of the patch because of fringing. Fig shows the top view and side view of the antenna. From the side view, it is well shown that the field lines that are bending at the edges, leads to increment in length electrically.

For calculation of effective length, ΔL is to be calculated first

ΔL can be calculated as

$$\frac{\Delta L}{h} = 0.412 \frac{(\epsilon_r+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon_r-0.258)\left(\frac{W}{h}+0.8\right)} \quad (1.6)$$

Effective length can be calculated as ($L=\lambda/2$ for dominant mode TM_{010} , if fringing effect is not considered)

$$L_{\text{eff}} = L + 2 \Delta L \quad (1.7)$$

Resonant Frequency for dominant mode TM_{010} without fringing

$$f_r = \frac{v_o}{2L\sqrt{\epsilon}} \quad (1.8)$$

v_o – Velocity of light

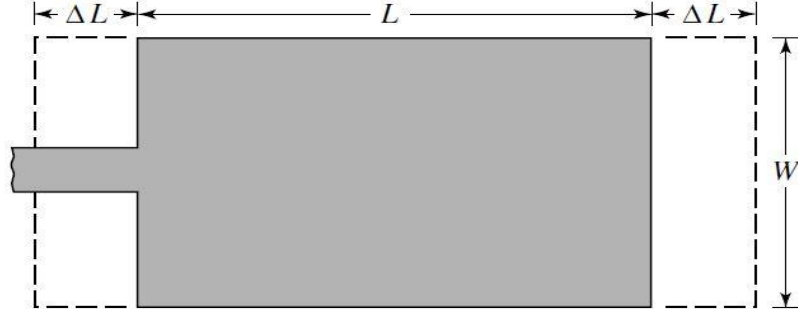


Fig. 1.8 (a) Top view of rectangular patch

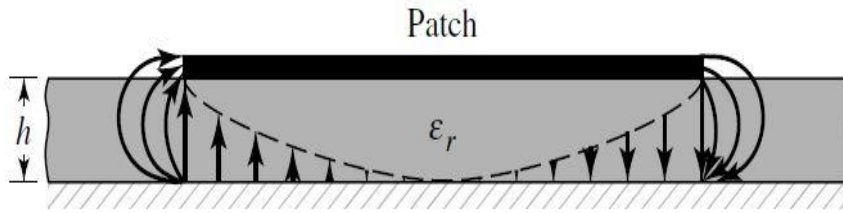


Fig. 1.8 (b) Bottom view of rectangular patch

Resonant Frequency for dominant mode TM_{010} with fringing

$$f_{rc} = \frac{1}{2L_{eff}\sqrt{\mu_o\epsilon_o\sqrt{\epsilon_r}}} \quad (1.9)$$

$$= q \frac{v_o}{2L\sqrt{L_{eff}}}$$

where q- fringe factor and can be mathematically written as

$$q = \frac{f_{rc}}{f_r} \quad (1.10)$$

Calculation of width of patch antenna

$$W = \frac{v_o}{2f_r} \sqrt{\frac{2}{\epsilon+1}} \quad (1.11)$$

1.6.2 Cavity Model

Microstrip antenna can be thought as a dielectric loaded cavity. The normalized fields that reside in the substrate can be accurately spotted if the dielectric is considered as cavity which is surrounded by four perfectly magnetic walls and below patch and ground as electric walls.

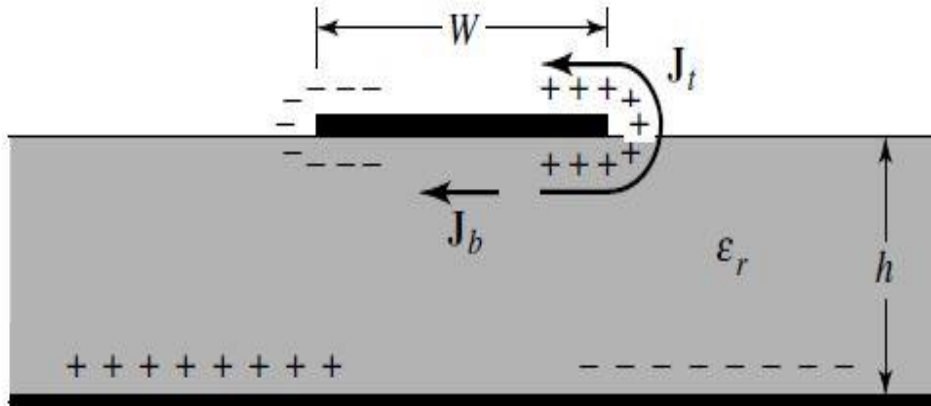


Fig. 1.9 Charge distribution on patch

Fig. 1.9 shows charge distribution on a patch which can be depicted by cavity model. Attractive mechanism and repulsive mechanism control the charge distribution. When feed is given to patch, charge accumulates on the patch and at ground plane also. Attractive mechanism acts on opposite charges on ground and bottom surface of the patch which helps charge to concentrate below patch surface. Repulsive mechanism acts on similar charges at ground and bottom surface of the patch which repel charges from bottom of the patch to its edges and to the top of the patch. These charges generate current densities J_b and J_t which can be seen from Fig. 1.9. Practically height to width ratio is very small, because of this attractive mechanism rules. A small amount of current flows on the edges and on the patch but it decreases with a decrease in height to width ratio. When zero current flows on the top of the patch, it will lead to no tangentially magnetic field ideally which do not disturb magnetic field and leads to consider all walls as perfect magnetic. But practically there will be a small tangential magnetic field. So cavity model gives a good approximation. This model generates good normalized electric and magnetic field distributions beneath the patch [3].

Calculation of resonant frequency

$$(f_r)_{mnp} = \frac{1}{2\pi\sqrt{\mu\epsilon}} \sqrt{\left(\frac{m\pi}{h}\right)^2 + \left(\frac{n\pi}{L}\right)^2 + \left(\frac{p\pi}{W}\right)^2} \quad (1.12)$$

Different modes can be calculated by filling the values of mnp. As for dominant mode $m=0, n=1, p=0$. This mode occur when $L > W > h$.

Resonant frequency for TM_{010} mode is

$$(f_r)_{010} = \frac{v_0}{2L\sqrt{\epsilon}} \quad (1.13)$$

If $L > W > L/2 > h$ then the next higher mode occurs i.e. TM_{001}

$$(f_r)_{001} = \frac{v_0}{2W\sqrt{\epsilon}} \quad (1.14)$$

If $L > L/2 > W > h$ then the second order mode occurs i.e. TM_{020}

$$(f_r)_{010} = \frac{v_0}{L\sqrt{\epsilon}} \quad (1.15)$$

1.8. DUAL/MULTIBAND ANTENNA

The term “DUAL BAND” means two bands and “MULTIBAND” means many bands. A multiband antenna is an antenna designed to operate in multiple bands of frequencies. As many wireless standards for communication have come in the picture, so it is a need of present time that a single antenna has to operate in multi bands so that it can handle as many standards such as the global positioning system, worldwide interoperability for microwave access and wireless area network standards as possible. For this reason, multiband antenna is studied. Multiband antennas comprise of design in which they activate one part of the antenna for one band, while another part will be active for another band. Multiband antennas may have less gain or be physically large in comparison to single-band antennas in order to accommodate the multiple bands. Multiband antenna based on its structure can generate various frequencies for different applications [7].

Advantages of Multiband antenna

- Single antenna can cover many bands
- It can be used for WLAN, WiMAX, Bluetooth, GPS applications

Disadvantages of multiband antenna

- Large size

- Less gain

1.8.1 Multiband generation Techniques

Attaining multiband in single device is the main requirement of today's wireless applications. Multiband but with the small size antenna, is the main problem. Multiband antenna can be designed but at the cost of large height or large length. So there are many techniques available which can be used to generate multiband.

- Using aperture coupled feeding technique
- Using of multi-slot antenna
- Using of DGS geometry
- Using of shorting pins
- Using of different shape of patch antenna
- Using of fractal geometry

Multiband antenna generated by using aperture coupled, shorting pins, and fractal geometry, leads to increase the size of antenna. As in aperture coupled, stacking of two layer of substrate is used. Similarly shorting pins increase the height of antenna. In fractal geometry, as the periodic repetition of same shape, leads to increase the length of antenna. Using of slotted antenna or DGS geometry, can be embedded on single layer substrate, so no increment in height. Both DGS and Slots provide capacitive loading which decreases the frequency of operation or shifts the higher frequency to lower frequency without increment in size as it increase its electrical length. So use of slotted antenna and DGS geometry is preferable and demand for DGS antennas are increasing day by day.

1.8.2 Bandwidth Increasing Techniques

Bandwidth is one of the important parameters in the antenna. Bandwidth can be expressed as the difference between the two frequencies (higher frequency and lower frequency). Bandwidth basically provides a spectrum in which antenna has to operate. More bandwidth means more speed. The bandwidth of an antenna can be increased by using stacking and DGS (Defected Ground Structures).

➤ Defected Ground Structure (DGS)

Microstrip antenna has many advantages but it has disadvantages too. Because of its advantages as cost efficient, light weight, integration with microwave circuits, variation in size (can be of mm or cm); it has become compatible with various wireless applications. But its disadvantages are prohibiting it from applications which require large bandwidth, large gain or large efficiency. There are some

photonic band gap structures which are well known for their high performance and can be used for antenna to attain compact size. These structures are Defective Ground Structures and Electronic Band Gap Structures. These structures have got attention as they help in reduction of size and rejection of unwanted frequencies. DGS can be obtained by carving a defect in a ground plane which comprises of any shape. This defect rearranges the whole current distribution in a ground plane which results in controlled excitation of waves in the substrate. Because of these characteristics of transmission line i.e. capacitance and inductance also affected. According to desired performance, the shape of the defect can be made simple or complex. When an antenna is designed using transmission line model for a particular frequency, the resulting design gets large size so is not suitable for mobile applications as it needs small size antenna. As present time is demanding for small size antenna, DGS is considered as a unique technique which allows reduction of size just by etching defect in ground.

The equivalent circuit of Defective Ground Structures is studied in terms of capacitance and inductance. The value of inductance and capacitance totally relies on the shape of defect, size and area of the defect, which is etched from the ground plane [39]. Desired frequency of operation can be achieved by changing the parameters of the defect. L and C can be mathematically calculated as

$$L = \frac{1}{4\pi^2 c f_0^2} \quad (1.16)$$

$$C = \frac{f_c}{2Z_0} \cdot \frac{1}{2\pi(f_0^2 - f_c^2)} \quad (1.17)$$

The dumbbell shape DGS and its equivalent circuit are shown in Fig. 1.10.

➤ **Stacking**

Narrow bandwidth problem can also be solved by using stacking. In this technique, substrates having different dielectric constant value are chosen. One patch is set up on the substrate which has a higher value of permittivity so that it can radiate (higher Value of permittivity allows radiations to bind loosely) and another one is on the lower value of permittivity (lower value of permittivity tightly bounds field). Both the substrates and patches arranged in the layered structure. Proper alignment should be there otherwise there will be coupling loss. This problem in stacked antenna is very common because of the presence of many layers. Aperture is used for providing coupling in patches in stacked patch antennas. If aperture in the form of the resonator is used then it can double the

bandwidth. If the separation is less between the patches then mutual coupling occurs which further leads to multi-band antenna and if the positions are accurate then antenna can generate multiband with large bandwidth. The lower frequency band is affected by changing parameters of the top patch and higher frequency band can be affected by changing the parameters of the lower patch [17]. Structure of stacking is shown in Fig. 1.11.

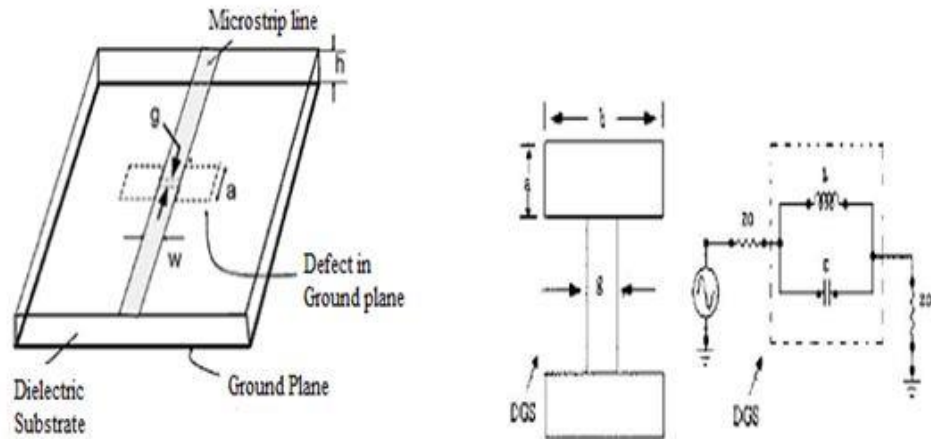


Fig. 1.10 DGS with its equivalent circuit

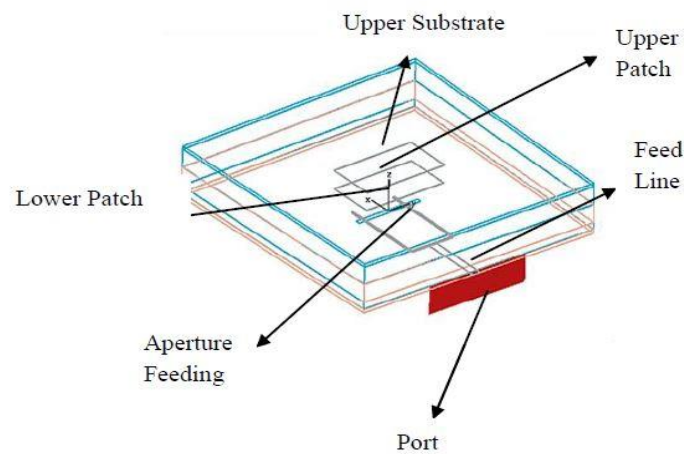


Fig. 1.11 Stacked patch antenna

Stacked patch antennas can also be analyzed by transmission line model. The only difference is taking the value of dielectric constant.

$$\epsilon'_r = \frac{2\epsilon_{eff} - 1 + A}{1 + A} \quad (1.18)$$

where A is

$$A = \left[1 + \frac{12h}{w}\right]^{-1/2} \quad (1.19)$$

1.9 Thesis Outline

The thesis is covered into 6 Chapters.

Chapter 1 gives the basic information of antenna and its types and standards used for wireless communication. It covers the microstrip antenna and feeding techniques, patch analysing methods and bandwidth increasing techniques.

Chapter 2 covers the literature survey for creation of dual/multiband antenna, different feeding techniques, size reduction techniques and bandwidth increasing techniques.

Chapter 3 covers design of staircase antenna with microstrip feed line and defected ground structure for WLAN and WiMAX applications with different stages for proper analysis of antenna.

Chapter 4 covers the designing of triangular patch antenna with modified ground for WLAN and WiMAX applications in five stages, simulation results, and radiation pattern regarding obtained bands.

Chapter 5 covers the fabrication and testing of staircase antenna, measured and simulation results of antenna.

Chapter 6 covers the conclusion of all the chapters and future scope in proposed work.

CHAPTER 2

LITERATURE REVIEW

This chapter discusses about the various design for patch antenna, various techniques for creation of dual/multiband and various techniques used for attaining the small size and large bandwidth, adapted by various researchers.

2.1 Literature Survey

Y.F.Cao et al. [2015] proposed multiband antenna having four bands for the WLAN, WiMAX, GPS applications. In making this antenna, stubs and slots are used. For feeding T shape strip and to cover all four bands, two E-shaped stub, and T shape stub has been used and all these stubs are used within rectangular slot etched from the rectangular patch. GPS covers 1.575 GHz to 1.665 GHz frequency band generated, IEEE 8.2.11 b & g WLAN system covers 2.4 GHz to 2.545 GHz, WiMAX covers 3.27 GHz to 3.97 GHz and IEEE 802.11 a WLAN covers 5.17 GHz to 5.93 GHz frequency band in this paper [7].

Seyed Amir Hossein et al. [2015] proposed an antenna with metamaterial cells. The proposed dual-band antenna structure comprises of U-shaped loaded metamaterial substrate, coplanar waveguide, patch and back conductor. Microstrip feed line is used for feeding to the antenna. To make antenna profile small, U-shaped and inverted U-shaped metamaterial loaded substrate is used and they are made in two layers. By using metamaterials, antenna size reduction up to 35% takes place when antenna work as wideband monopole antenna and size reduced up to 77 % when antenna work as a patch antenna [8].

A.K. Sharma et al. [2015] proposed a dual band slotted microstrip antenna which is fed by aperture coupling technique. The proposed antenna generates two bands which cover frequency 2.4 GHz and 2.5/3.5 GHz for WLAN and WiMAX. Creation of dual band is because of cutting a symmetrical π -shaped slot from the patch. Etching of π -shaped slot provides reacting loading because of which size reduction up to 37% takes place [9].

Le Kang et al. [2014] proposed a triband antenna in single layered structure and compact size. For reduction of size, the asymmetric coplanar strip is used to excite the antenna. In this paper, triband operation and good suppression of interference are obtained by etching

two rectangular SRR from the patch. It provides a very good bandwidth of 340 MHz, 390MHz, and 1110 MHz to cover all band of IEEE 802.1 a, b, g & n WLAN and all WiMAX bands [10].

Shu Liu et al. [2014] proposed an antenna which offers four bands for WLAN and WiMAX applications. In this paper, four U slots are etched from the rectangular patch and coaxial feed is used to excite these slots. Air is used here for the substrate. This antenna provides a good bandwidth and proficient gain. This antenna has single layered structure. The antenna is fabricated and measured results are comparable to simulated results [11].

Yaseer Ojaroudi et al. [2014] proposed a monopole ultra-wideband antenna having a very small size of dimensions $12 \times 18 \times 1.6 \text{ mm}^3$. This antenna is providing ultra-bandwidth of 1270 MHz and this design comprises of I shape slots etched from the ground and for band-notched characteristics, two rotated T shape are etched and are connected in the middle of I shape slot. This design provides a good return loss regarding ultra-band i.e. 3 GHz-15.7 GHz and it also notches two bands to avoid interfering to downlink X-band of the satellite (7.25 GHz – 7.75 GHz) and for WLAN (5 GHz-6 GHz) [12].

Md. Rezwanul Ahsan et al. [2014] proposed modified inverted shaped antenna which is compact in size and provides bands at multi-frequency. In multi-frequency, it covers band for C-band i.e. 4 GHz to 8GHz and WiMAX applications i.e. 2.5 GHz (2.4 GHz to 2.484 GHz), 3.5 GHz (3.4 GHz to 3.69 GHz) and 5.5 GHz (5.25 GHz to 5.85 GHz) and also provides good return loss and antenna pattern regarding corresponding results. The antenna design consists of $20 \times 20 \text{ mm}^2$ patch with etched slots from ground. A feeding technique to excite antenna is microstrip feedline. Simulation for proposed antenna is done in computer simulation technology microwave studio [13].

Mohammed M. Bait-Suwailam et al. [2013] proposed a novel design which comprises of two CSRR (Complementary Split Ring Resonator) which are etched from the ground to provide miniaturization to the antenna. After etching slotted complementary split ring resonator, size reduction up to 10% is seen and also provides a good far-field pattern [14].

X. L. Sun et al. [2013] proposed a patch antenna which shows dual band characteristics. In this paper antenna is presented with one tuneable frequency band. In this design, a

stem is created which is connected to two branches. These branches offer resonance at two different frequencies. First band cover frequency from 2.3 GHz to 2.4 GHz and which is fixed. Second band is tuneable and can be tuned to 3.3 GHz to 3.4 GHz, 3.4 GHz to 3.6 GHz and 3.6 GHz to 3.8 GHz which are WiMAX bands. Varactor diode adds the feature of tuneable frequency in this design which is connected to stem and branch which provide higher band. L shaped stub is added for biasing of varactor diode. In CST microwave studio, the radiation pattern, return loss and efficiency are analysed [15].

Kumar Goodwill et al. [2013] proposed an antenna design for the improvement in antenna performance for WLAN application. Capacitive matching is preferred here for the creation of dual band which is provided by CSSRR etched from the ground. For desired frequency, the dimensions of CSSRR and antenna patch are both important, and if there is any change in these dimensions then the whole band will shift. The fabrication of CSSRR is very simple and it is more preferable than CSRR as it does not interfere with current in dominant modes and also provide good return loss. The ease of fabrication of CSSRR is the major aspect of this design [16].

Deepak Gangwar et al. [2013] proposed antenna with stacking which is loaded with a complementary split ring resonator. The proposed antenna comprised of round CSRR in patch and DNG and SNG materials. Microstrip feeding is used to excite the antenna. The antenna offers multiband with very good gain and offers applications for mobile. Analysis of whole structure is done in Ansoft HFSS [17].

Chao-Ming Wu et al. [2012] proposed an antenna which provides ultra-wideband characteristics. The designed antenna is of compact size and provides an application for USB dongle. In this paper, multiple slots are cut into the rectangular patch which offers multiple frequency bands and also provides an increment in bandwidth. The proposed antenna provides frequency band from 2.86 GHz to 13.38 GHz and bandwidth of 10.42 GHz. Radiation pattern characteristics of this antenna are similar to monopole antenna and provides a gain greater than 3 dBi and can be used in USB device because of its small size [18].

Bimal Garg et al. [2012] proposed rectangular antenna having a rectangular patch which is loaded with interconnected framed shape metamaterial structure. The height of substrate is used 3.2 mm. Microstrip inset feed is used to attain good impedance matching. The antenna is designed to cover WLAN applications. Antenna size reduced

up to 30% area wise by loading of metamaterial structure which offers negative permittivity and increases the bandwidth and return loss [19].

Xulin Quan et al. [2012] proposed a compact antenna which is dual band and directional. The structure of antenna consists of longer and shorter dipoles. Longer dipoles provide a frequency for lower band shorter dipoles provide a frequency for higher band. Microstrip feedline is used to feed to the antenna. The antenna, as well as feed line, is placed on the same layer which is leading to single layer structure. For the lower band, the electrical length of the dipole is reduced by using capacitive loading at the ends of the patch; indirectly it provides a reduction in size. For lower and higher band, the proposed antenna provides a proficient gain of value 8 dBi and 9 dBi. The equivalent circuit is also presented in this paper for analysis. The designed antenna finds its application in WLAN and RFID reader applications [20].

A. K. Arya et al. [2011] proposed an antenna which provides dual bands. This antenna is using DGS for providing dual bands. This paper is based on stacking and DGS geometry for attaining dual band and large bandwidth. Large bandwidth is obtained by stacking and skew F shape DGS provide dual band characteristics. All the parametric analysis is done in CST Microwave studio. The antenna is fabricated and tested and measured results are similar to simulated [21].

A. Nouri et al. [2011] proposed an antenna which provides wideband characteristics as well as filtering. In this paper filtering and wideband characteristics are obtained by DGS and rectangular patch with arc-shaped steps. The shovel-shaped DGS geometry provides frequency notching for WLAN and short range communication. The arc-shaped steps provide the omnidirectional H-field pattern and good impedance matching. The designed antenna is small having dimensions $15 \times 18 \text{ mm}^2$. This design offers bandwidth of 128 % which covers band from 3.1-14 GHz but filters the frequency range 5.13 GHz to 6.1 GHz [22].

K. F. Lee at al. [2011] proposed patch antenna for dual band and triple band. In this design, U-shaped slots are etched into broadband patch antenna to gain dual band. For the triple band, another U-shape slot is introduced to broadband patch. Etching of slots is performed on different feeding probes, aperture coupled and coaxially feed. The simulated results (return loss and radiation pattern) are then compared with broadband patch antenna and found very similar [23].

Wen-Chung Liu et al. [2011] proposed a novel antenna which offers triple frequency band. For feeding of this antenna, microstrip feeding technique is used. In this paper, for enhancement of bandwidth, DGS technique is used. The structure of patch antenna comprises of inverted shaped L strips which are incorporated on the rectangular patch. Microstrip feed line is built in the form of cross shape. This antenna finds application in WLAN and WiMAX applications and of very compact size as $20 \times 30 \text{ mm}^2$. The antenna is fabricated and its measured results are in good agreement with simulated results. The radiation pattern of the antenna is similar to monopole antenna which can be seen from simulated results [24].

Yazi Cao et al. [2011] proposed an antenna which shows multiband characteristics. This antenna comprises of ground plane with two etched open ended slots. One slot is T shaped and another one is E shaped. This antenna provides five bands to cover GSM, DCS, PCS, UMTS and WLAN band. All of these bands can be obtained by five different slots having different length. This planar antenna provides flexibility of bending this antenna into E-shape and inverted T-shape [25].

Wei Hu et al. [2011] proposed an antenna which provides triband characteristics. This antenna consists of monopole radiator, square slot and symmetrical L shape strips are embedded into it. Coplanar waveguide feeding technique is used here to excite the antenna. By using this structure, the antenna provides three resonant frequencies to cover bands for WLAN and WiMAX applications. This antenna offers a single layered and compact structure. This antenna provides large bandwidths for WLAN and WiMAX bands [26].

Alireza Pourghorban Saghati et al. [2010] proposed an antenna which can be reconfigured within three frequencies. This design has some unique feature as it provides three electronic switches which select various groups of the resonant frequency. To attain different bands, sickle-shaped slots are etched from the ground plane. For reconfiguration purpose, three pairs of pin diodes are used which are fixed into slots of the ground plane. For achieving all resonances, seven states are performed. The main advantage of this antenna is that it can provide more than one frequency band at the same time that is basically the drawback in the reconfigurable antenna. The antenna is fabricated to check measured results and finds the result in very good agreement with simulated results [27].

Chan Hwang et al. [2010] proposed an antenna which provides multiband for mobile wireless applications. This antenna structure comprises of the crescent-shaped patch which acts as a radiator and DGS for ground. Microstrip feedline is used for feeding and fr4 material is used for the substrate. This antenna provides a good bandwidth of 58 % and proficient return loss [28].

Lin Dang et al. [2010] proposed a patch antenna which provides a triple band to cover WLAN and WiMAX applications. In this paper, antenna design having very simple structure is presented. This antenna comprises of microstrip feed line in front and ground plane from where some slots are cut. This antenna is fabricated and tested for the validity of design practically. Simulated results of this antenna provide bands at three frequencies (2.7 GHz, 3.5 GHz, and 5.6 GHz) and bandwidth regarding these bands is 600 MHz, 430 MHz, and 1300 MHz [29].

G. Singh et al. [2010] proposed a microstrip patch antenna size reduction technique. In this paper left-handed metamaterials having both permeability and permittivity negative, are used. For substrate, both DPS and DNG materials are used which provide the concept of phase compensation. Permeability and permittivity both are positive for DPS or double positive materials. Formation of resonator cavity takes place because of a combination of DPS and DNG materials. The thickness of slab depends on the ratio of DPS and DNG slabs. DNG material provides the phase compensation. In this paper, the property of metamaterials i.e. negative permeability or negative permittivity is used for reduction of size [30].

Z. S. Duan et al. [2009] proposed a novel antenna which provides broad beam-width and wide band characteristics. In this antenna structure, stubs and gaps are used. The antenna comprises of stacking of two layers and two arc gaps and three stubs are used in the upper patch. Broad beam-width is obtained because of gaps and stubs. In this electromagnetic coupling offers broadband. By using this design, impedance bandwidth of 34 % is obtained and 3 dB beam-widths of 60° are obtained in E-plane and H-plane. Antenna is fabricated and its measurement results are comparable to simulated one [31].

M. T. Islam et al. [2009] proposed a patch antenna for wireless applications. In this paper, new design technique i.e. inverted patch which is placed below the substrate and air are used to fill the gap between the ground and patch. Coaxial feed is used here to excite the antenna. This technique provides a compact size antenna. After designing this

antenna with multi-slotted patch, a wide bandwidth is obtained which is the order of 27.62 % and large gain of the order of 9.41 dBi [32].

R. Karimzadeh Baeel et al. [2007] proposed a compact microstrip patch antenna in which metamaterials are used to reduce the size of the antenna. The etched complementary split ring resonators from ground provide resonance at a lower frequency as it provides capacitive coupling and also provides a reduction in size. In this paper, CSRR is preferred over SRR and equivalent circuit for rectangular shaped CSRR is presented for the analysis of CSRR. For analysis of antenna, lumped circuit model is used. Miniaturization in the size of the patch can be seen from the circuit model use for CSRR. By using CSRR, the size of the antenna is reduced by 25% without any increment in the height of the substrate [33].

Jin-Sen Chen et al. [2005] proposed patch antenna with triangular ring slot. for feeding, coplanar waveguide feed is used which has tuning stub. In this paper, impedance matching is achieved by changing the length of tuning stub. Two designs are proposed here one is triangular ring slot antenna with coplanar waveguide feeding and in the second design triangular back patch is used. First resonance occurs when slot ring is at one guided wavelength and for attaining bi-directional pattern; slot ring size is increased and made it comparable to back patch [34].

Ricky Chair et al. [2005] proposed a half U-slot and half E-slot shaped antenna to show that they also bear the same wideband behavior as the U-slot shaped antenna and E-slot shaped antenna. In this paper, it is presented that U-slot shape antenna is large in size to obtain wideband characteristics. So the antenna is cut into half and by means of shorting pins, its size is further reduced and same wideband characteristics are obtained when the antenna is excited by coaxial feed. Simulated results of half geometry show that all antenna characteristics i.e. radiation pattern, gain and bandwidth is similar to full geometry. The half U-shape slot antenna provides bandwidth up to 28% and 90% increment in radiation efficiency. In second design half E shape slot antenna is used which also bears the same characteristics that are actually obtained from full E shape slot antenna [35].

B.L. Ooi et al. [2005] proposed a novel antenna which is wideband. Proximity coupled feeding technique is used to excite this antenna with a semi-circle probe. In this paper, when all corners of the rectangular patch are cut into flower petal, broadband

characteristics are obtained. The designed antenna provides 63% increase in bandwidth and also provides value for VSWR between 1 and 2 which shows good impedance matching. In this paper, two more designs are presented (rectangular shape and diamond shape) to compare the results with petal shape antenna [36].

Gh.Z. Rafi et al. [2004] proposed an antenna which offers wideband. The microstrip antenna consists of diamond shape patch with etched V-shape slot in the middle of the diamond patch. To excite this antenna, coaxial probe feeding technique is used. The antenna is made on a single layer of the substrate. Both diamond shape patch and V-shape slot are responsible for the broadband characteristics. This antenna provides 50% increase in bandwidth and also provides stable gain [37].

Ricky Chair et al. [2002] proposed patch antenna with multilayers having a compact size. To excite the antenna, the coaxial feed is used. In this paper, two designs are presented. In first design, rectangular patch antenna with two layers is used. The projection area for both the patch antenna as with single layer and two layers is made same. For two layered geometry, reduction in resonance takes place up to 50% and advancement in bandwidth up to 5 % is achieved which is shown by simulation and measured results. In second design bow tie shape as a patch is used which provides further 60% reduction in the frequency of resonance and advancement in bandwidth up to 12 % is achieved. Both designs provide proficient radiation pattern and return loss [38].

2.2 Research Gaps

- Multiband antenna is achieved but at the cost of large size which is to be reduced.
- Dual band antenna characteristics are obtained by using aperture coupling which increases its height.
- There is spurious radiation at 1.4 GHz, which is gap found here.
- Antenna provides dual band but using stacking, which leads to increase the size of antenna.
- Height of substrate = 3.2 mm is used for creation of dual band, which is the gap found here.
- Multiband antenna is designed but with a very complex design, that is the gap which is found here.

2.3 Thesis Objectives

- The main objective of this thesis is to design a dual band antenna with large bandwidth and good return loss.
- The second objective of the thesis is to design a small size antenna which can afford dual bands for WLAN and WiMAX applications.
- The third objective of this thesis is to design a dual band antenna but with simple structure and at single layered substrate.
- The fourth objective is to use microstrip feed line instead of aperture coupling which raises the height of antenna.

CHAPTER 3

DESIGN OF STAIRCASE ANTENNA WITH L-SHAPE DGS FOR WLAN AND WiMAX APPLICATIONS

3.1 Introduction

This chapter discuss about the complete design of staircase antenna. The various parameters used to design antenna is discussed here. Detailed discussion about effect of parameters of antenna on the various antenna characteristics i.e. return loss, VSWR, radiation pattern etc. is given. Patch antenna with DGS shows dualband/multiband behaviour, so this geometry is used here to attain dual band characteristics with large bandwidth. The designing of staircase antenna is divided into four steps for proper analysis of antenna.

3.2 Design of staircase antenna

The design of staircase antenna consist 4 stages. The first stage consists of staircase patch on fr4 substrate with ground. Microstrip feed for excitation of antenna is used. The second stage consists of etching of rectangular slot from ground as DGS geometry and the third stage consists of etching of L shape slot from ground for dual band. In the fourth stage, double T shape slot and flag shape strips are used to provide reacting loading to shift the bands and to increase bandwidth.

3.2.1 Proposed antenna parameters

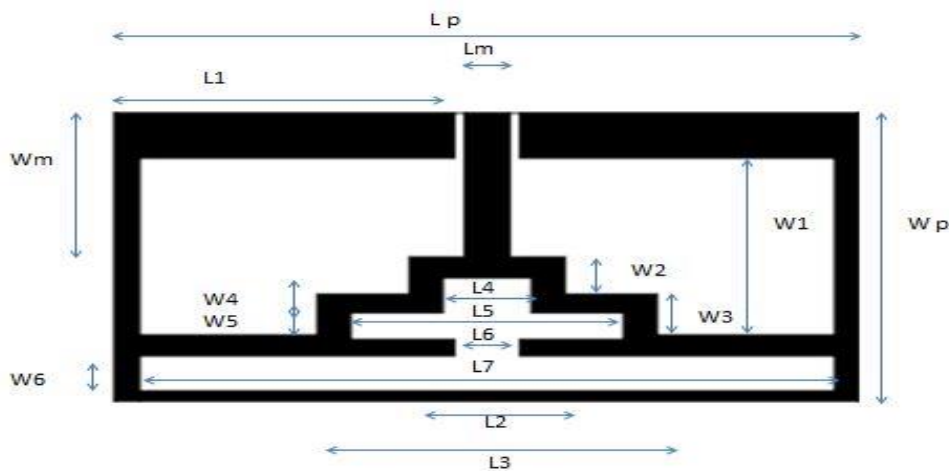


Fig. 3.1 (a) Top view of staircase antenna

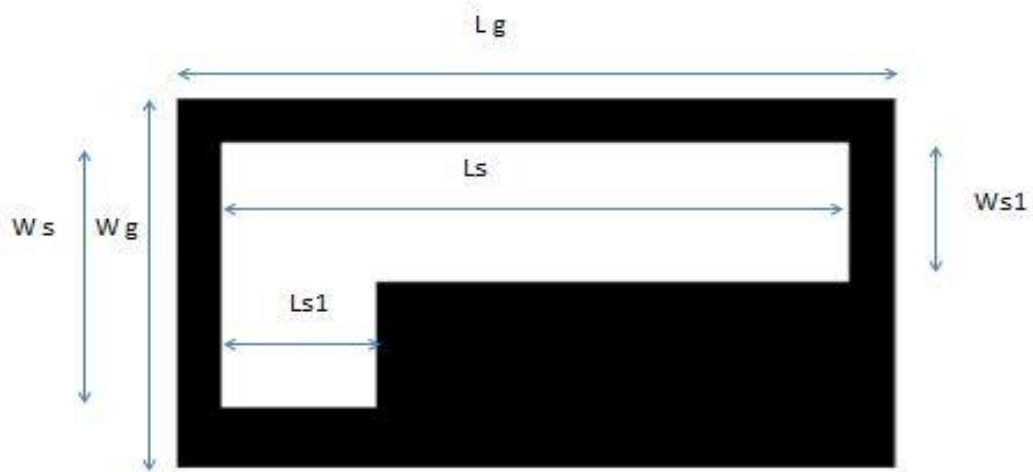


Fig. 3.1 (b) Back view of staircase antenna

Table 3.1 Dimensions used for antenna

(All dimensions in mm)

Parameters	L_p	L_g	W_p	W_g	L_1	L_2	L_3	L_4
Value	25	25	15	15	11.4	5.2	11.4	3
Parameters	L_5	L_6	L_7	W_1	W_2	W_3	W_4	W_5
Value	9.2	2.2	23.4	9.6	1.8	2	1.7	1.3
Parameters	W_6	L_s	L_{s1}	W_s	W_{s1}	W_m	L_m	h_s
Value	1.7	22	5.5	10.2	5.4	7.5	1.5	0.8
Parameters	T_s							
Value	0.0175							

The brief description about the parameters used for designing of antenna (as shown in Fig. 3.1) is shown in Table 3.1. The detailed description about designing of antenna is shown as below.

3.2.2 Stage 1 (Staircase antenna with copper ground)

The basic structure of antenna is designed using transmission line model. In this stage staircase patch is constructed on Fr4 substrate having permittivity 4.3 and tangential loss of 0.025 and thickness of $h_s = 0.8$ mm. The staircase patch has 3 symmetric stairs and excited with microstrip feed and its dimensions are shown in table which are according to Fig. 3.2. The dimension of substrate used is 25×15 mm² and copper with the same dimension $L_g \times W_g$ having thickness $t_s = 17.5$ micron is placed on substrate as ground. The dimension of microstrip line is kept $L_m = 1.5$ mm to attain 50Ω impedance

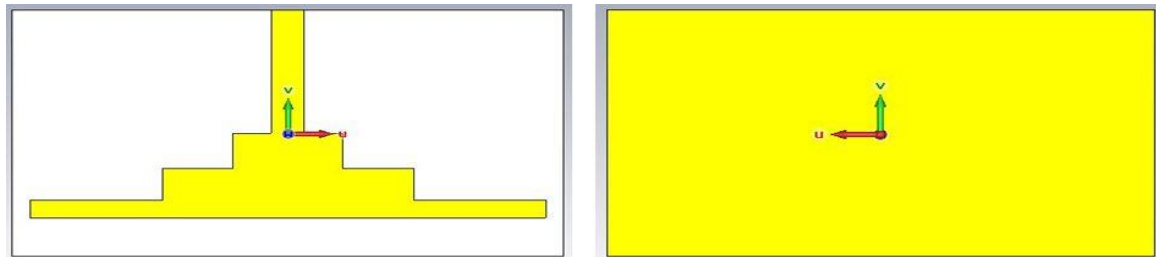


Fig. 3.2 (a) Staircase antenna

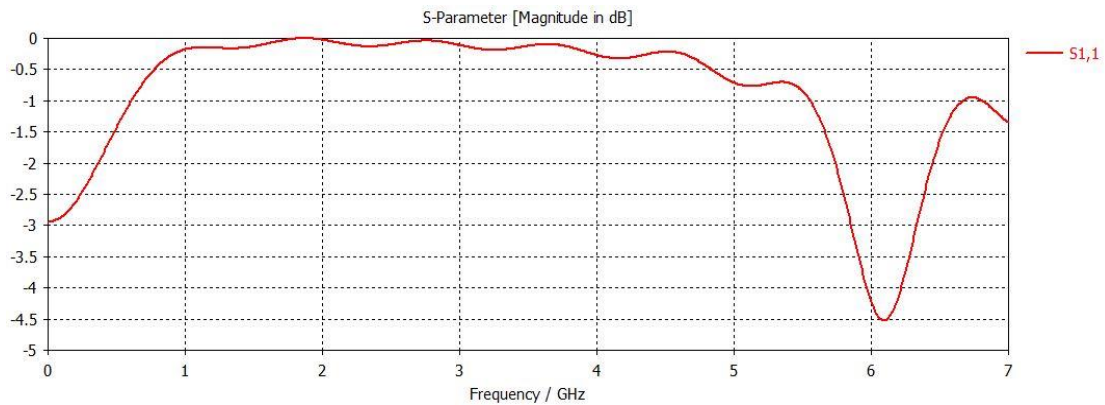


Fig. 3.2 (b) S_{11} results of stage 1

This stage covers frequency 6.06 GHz which is approx. to simulated result as shown in Fig. 3.2 (b) and this frequency can be mathematically calculated using transmission line model mathematical formulation as.

$$f_r = \frac{3 \times 10^{11}}{2 \times 15} \sqrt{\frac{2}{5.3}} = 6.1 \text{ GHz} \quad (3.1)$$

3.2.3 Stage 2 (Staircase antenna with rectangular shape DGS)

In this stage rectangular slot having dimensions $L_s \times W_{s1}$ ($22 \times 5.4 \text{ mm}^2$) is etched from the ground as DGS geometry as shown in Fig 3.3 (a). DGS geometry is used here to increase the bandwidth and to attain compact size as under microstrip patch it shows slow wave phenomenon because of increment in inductance of line and provides large electrical length in small area.

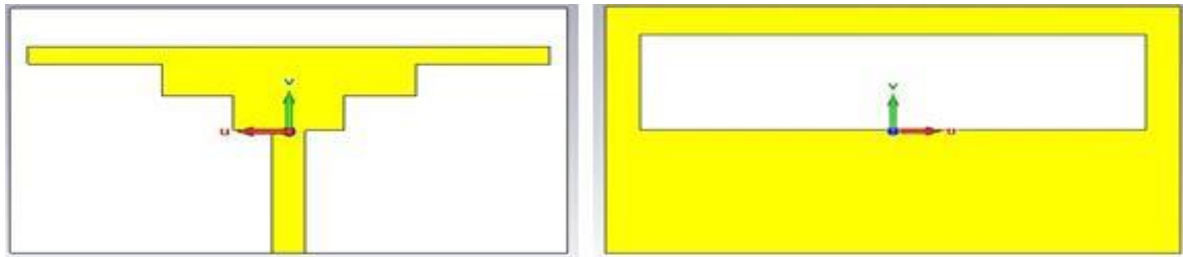


Fig. 3.3 (a) Antenna with rectangular slot

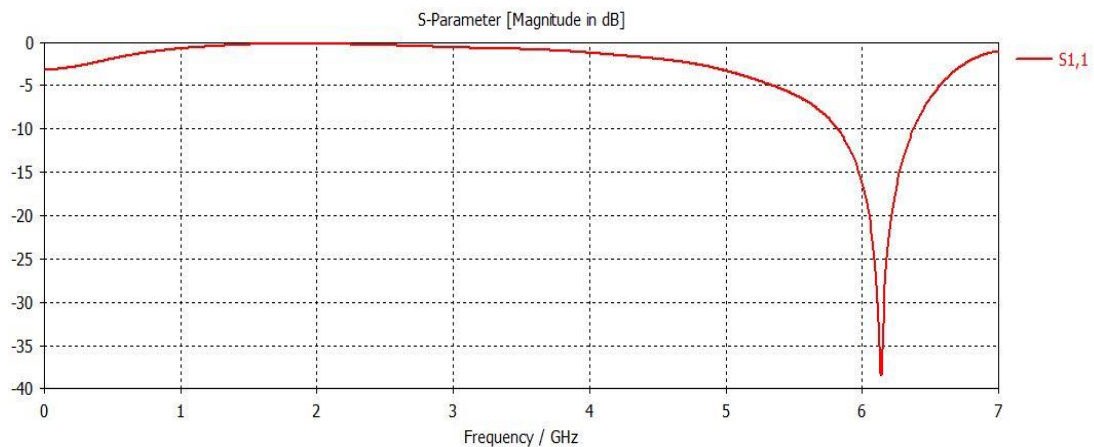


Fig. 3.3 (b) S_{11} results of stage 2

As the stage 1 provides frequency 6.06 GHz with return loss -4.5 dB which is not practically useable, so to decrease the antenna loss, stage 2 is performed. This stage reduces its loss to -38.42 dB and covers frequency band from 5.78 GHz to 6.34 GHz and also provide large bandwidth. Fig. 3.3 (b) shows return loss related to corresponding design. But this band needs to be shifted for WLAN applications.

3.2.4 Stage 3 (Staircase antenna with L-shape DGS)

In this stage, dual band creation is occurred as can be seen from the Fig 3.4 (b). Here L shape slot is etched as DGS from the ground for generation of dualband. D Guha and

Yahia M. M. Antar et al [6] gives the analysis of rectangular slot as DGS by transmission line model. According to them resonating frequency can be calculated as (f_m)

$$f_m = m \frac{c}{2d \sqrt{\epsilon_{eff}^{slot}}} \quad (3.2)$$

where d- length of slot

m-1,2,3.....

By changing the value of d, desired resonating frequency can be obtained. The above formula provides resonance at 3.42 GHz which is second band as can be seen from the Fig. 3.4 (b). This stage provides band 1 from 5.9 GHz to 6.45 GHz with return loss -19.8 dB and band 2 with return loss of -6.87 db. As both the bands are not useful at this time, further modification has to be done in design. For shifting of both the bands and to reduce the return loss, modification is done in stage 4.

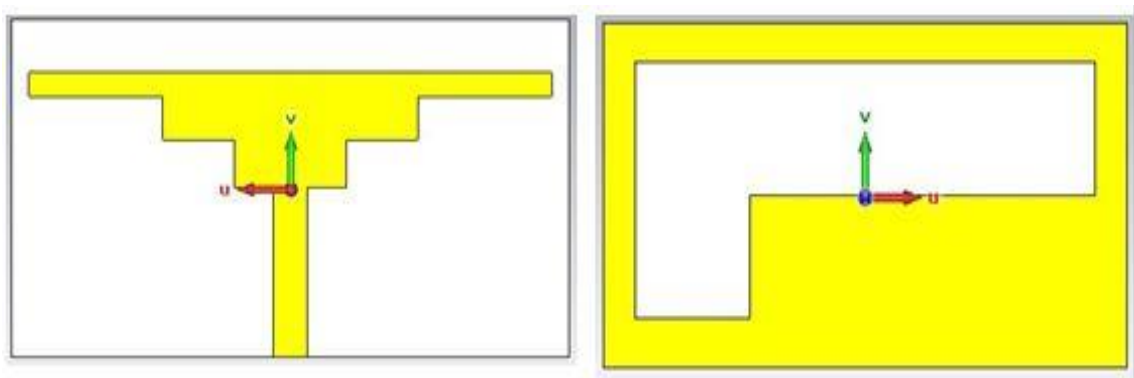


Fig. 3.4 (a) Antenna with L shape slot

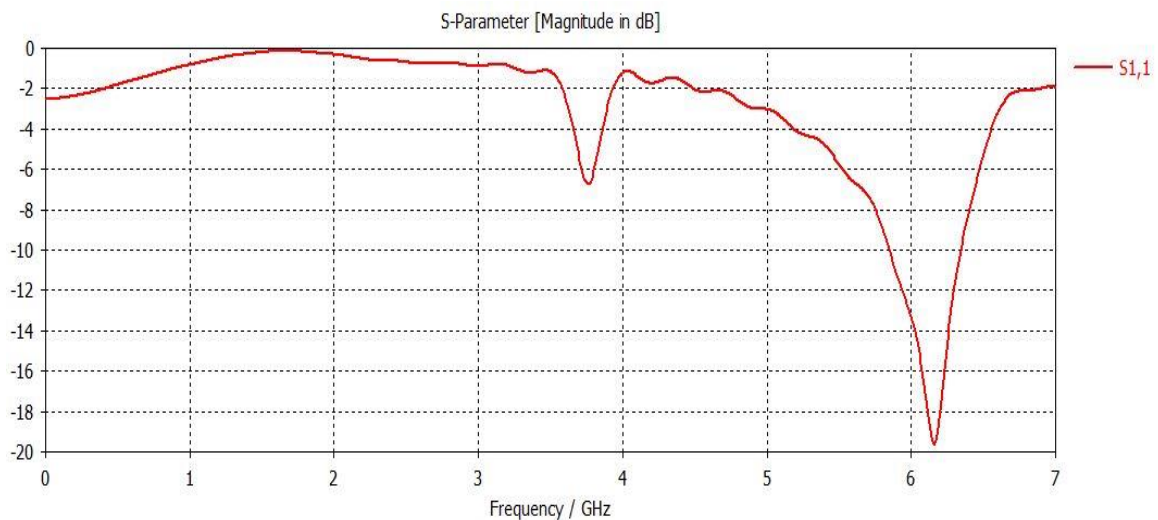


Fig. 3.4 (b) S_{11} results (Dual band)

3.2.5 Stage 4 (Proposed antenna)

For manipulating frequency, we need to use reactive loading, slots, parasitic element as they provide a possibility for new resonances [11]. To avoid stacking, parasitic element will be used on the same layer to maintain the low profile of antenna. For this, flag shape strips and double T shape slot is added to patch in this stage on the same layer as shown in Fig. 3.5 (a). The flag shape strips act as parasitic element which decreases the return loss of band 2 i.e. -30.12 dB and double T shape slot provides reactive loading which increases its bandwidth and covers band 3.4 GHz (3.28 GHz to 3.69 GHz), and also shifts band 1's lower frequency from 5.78 GHz to 5.46 GHz and covers band 5.46 GHz to 5.97 GHz as can be seen from Fig. 3.5 (b).

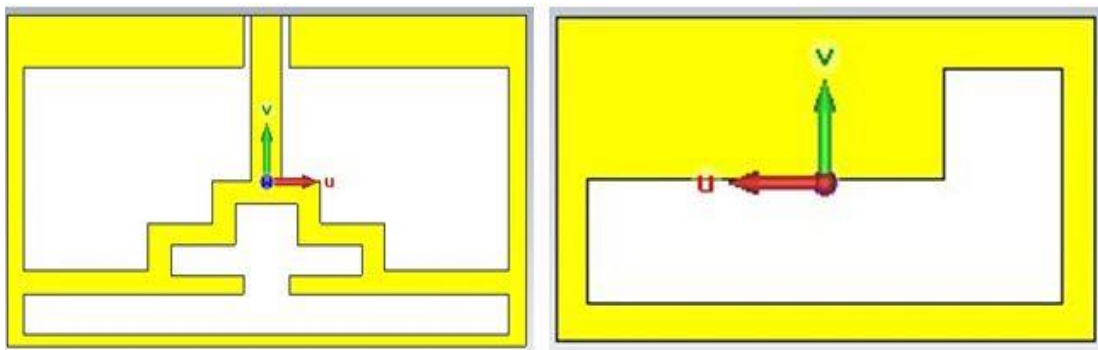


Fig. 3.5 (a) Proposed antenna

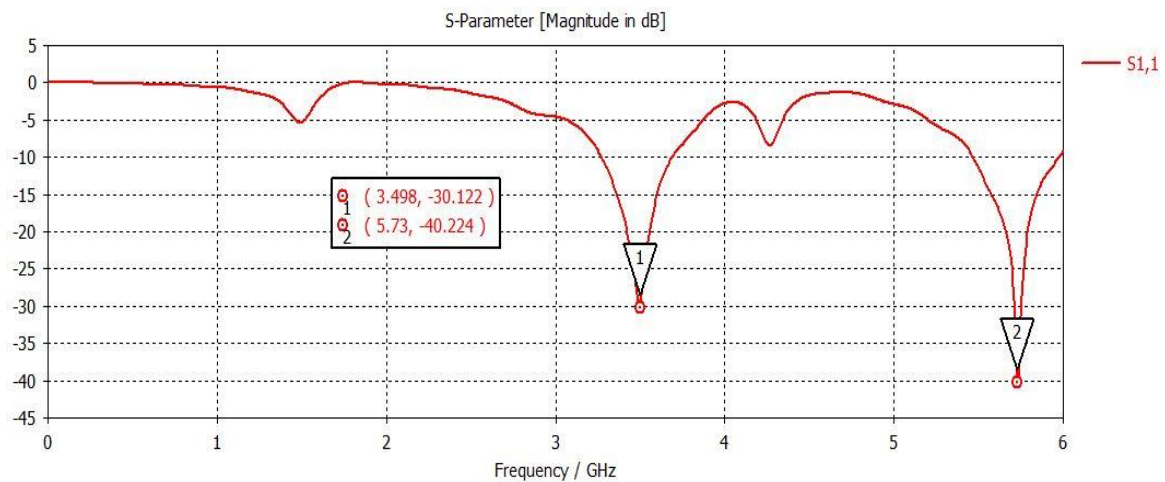


Fig. 3.5 (b) Final results

3.3 Results and Discussion

The CST simulated S_{11} results of proposed antenna are depicted by Fig 3.5 (b). Band 1 i.e. 5.73 GHz makes antenna useful for WLAN application and band 2 i.e. 3.49 GHz for

WiMAX application. Band 2 provides the bandwidth of 410 MHz by covering the frequency 3.28 GHz to 3.69 GHz and band 1 provides bandwidth of 500 MHz, corresponding to impedance bandwidth 8.75% and 11.71% with respect to appropriate resonant frequency, as shown in Table 3.2.

Table 3.2 Results comparison
(Frequency in MHz)

Bands	Band 1	Band 2
Actual frequency	5725-5825	3400-3690
Actual bandwidth	100	290
Obtained frequency	5460-5960	3280-3690
Obtained bandwidth	500	410

Fig. 3.6 shows surface current density at both the frequencies. The radiation regarding lower band depends upon DGS geometry, flag shape strips and bigger slot of double T shape whereas radiation regarding higher band depends upon double T shape slot and flag shape strips too; the red colour arrows depicts the high concentration of surface current.

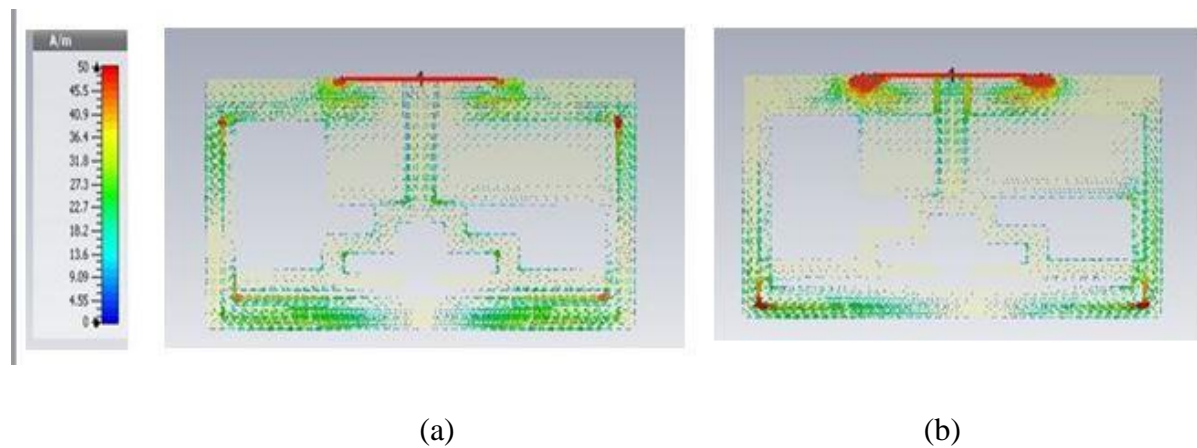
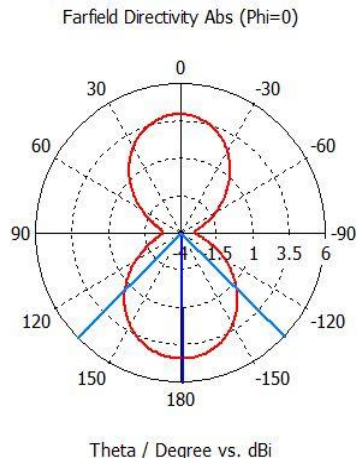


Fig. 3.6 Surface current density (a) at 5.73 GHz (b) at 3.49 GHz

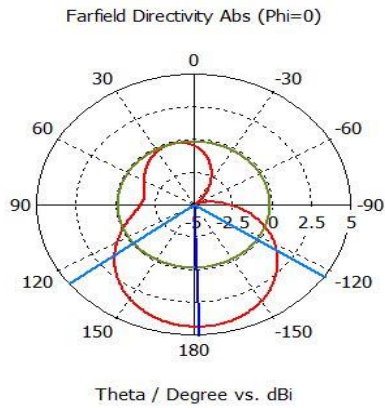
As a result of overall interaction within the structure, Fig 3.7 shows the simulated radiation pattern at frequency 3.49 GHz and 5.76 GHz. The radiation pattern at 5.73 GHz shows broadside array pattern with 3 dB angular width of 91.2° and directivity of 4.38 dBi and at frequency 3.49 GHz provides directive pattern with 3 dB angular width of 108.9° and directivity of 4.32 dBi. Three dimensional patterns are also shown in Fig. 3.8.



— farfield (f=5.73) [1]

Frequency = 5.73
 Main lobe magnitude = 4.38 dBi
 Main lobe direction = -179.0 deg.
 Angular width (3 dB) = 91.2 dea.

(a)

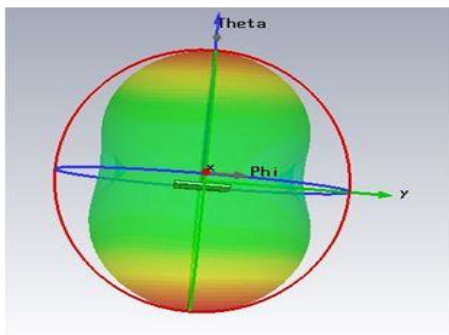


— farfield (f=3.498) [1]

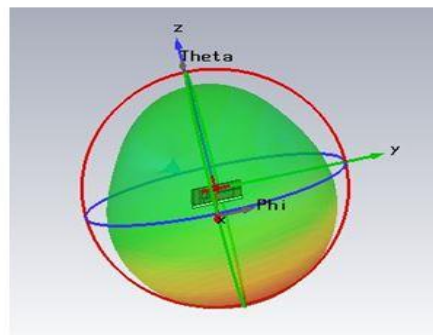
Frequency = 3.498
 Main lobe magnitude = 4.32 dBi
 Main lobe direction = -178.0 deg.
 Angular width (3 dB) = 108.9 deg.
 Side lobe level = -4.5 dB

(b)

Fig 3.7 Radiation pattern (a) at 5.73 GHz (b) at 3.49 GHz



(a)



(b)

Fig. 3.8 3D pattern (a) at 5.73 GHz (b) at 3.49 GHz

VSWR states as voltage standing wave ratio which shows impedance matching. Fig 3.9 shows the VSWR value for both the frequencies as 1.06 for 3.49 GHz and 1.031 for 5.73 GHz which shows the good impedance matching and makes it useful practically.

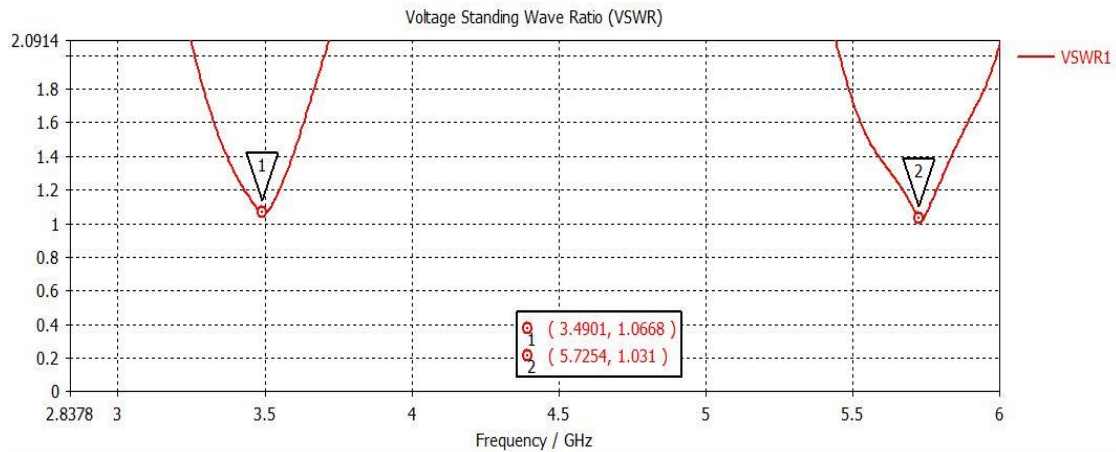


Fig. 3.9 VSWR results for both frequencies

3.2.6 Conclusion

The staircase shaped antenna with defected ground as L shape slot for WLAN and WiMAX applications is presented here. To study the antenna, simulations are done in different stages. According to simulation results, proposed antenna generate two frequency bands at about 3.49 GHz and 5.73 GHz, can be used for WLAN, and WiMAX applications. To avoid stacking, all the modifications and manipulations are done on the top and bottom layer of the substrate, thus using only one layer of substrate. The design is made through CST 2014 Microwave Studio.

CHAPTER 4

DESIGN OF TRIANGULAR PATCH ANTENNA WITH MODIFIED GROUND PLANE FOR WLAN AND WiMAX APPLICATIONS

4.1 Introduction

This chapter shows the designing of triangular patch with modified ground. Radiation pattern, return loss and VSWR for proposed antenna are discussed here. The antenna is designed using slot. The designing of proposed antenna consists of four steps.

4.2 Antenna Design

The designing of triangular patch antenna is analysed in five stages. In first stage triangular patch and rectangular ground are constructed on substrate. In second stage triangular patch and I shape ground structure is used. In third stage triangular slot is etched from triangular patch and I shape ground is used. Fourth stage consists of slotted triangular patch and rectangular shape slot etched from middle of I shape ground. The final stage is comprised of slotted patch and slotted ground.

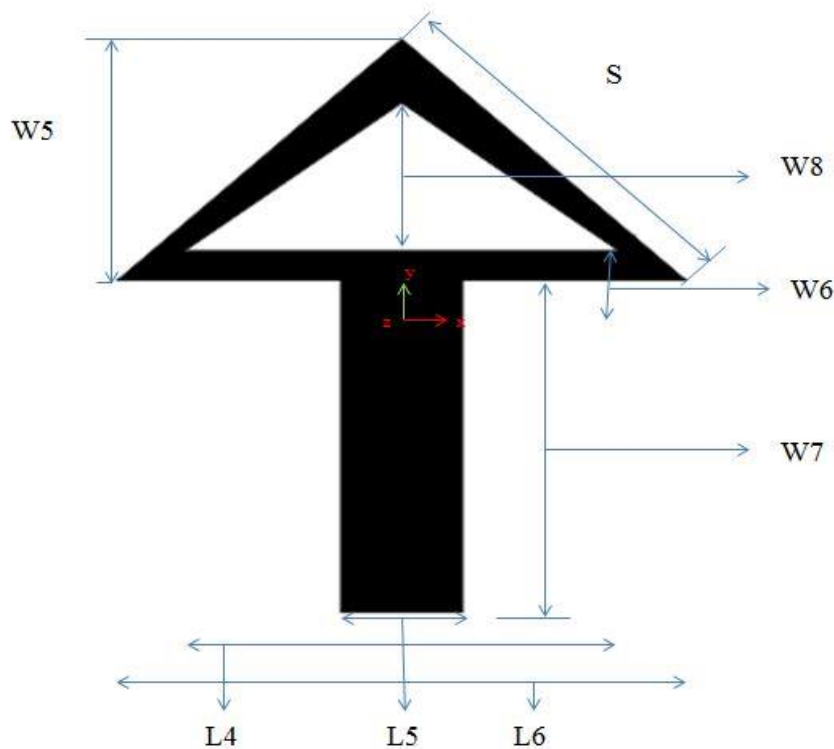


Fig. 4.1 (a) Top view of Triangular Antenna

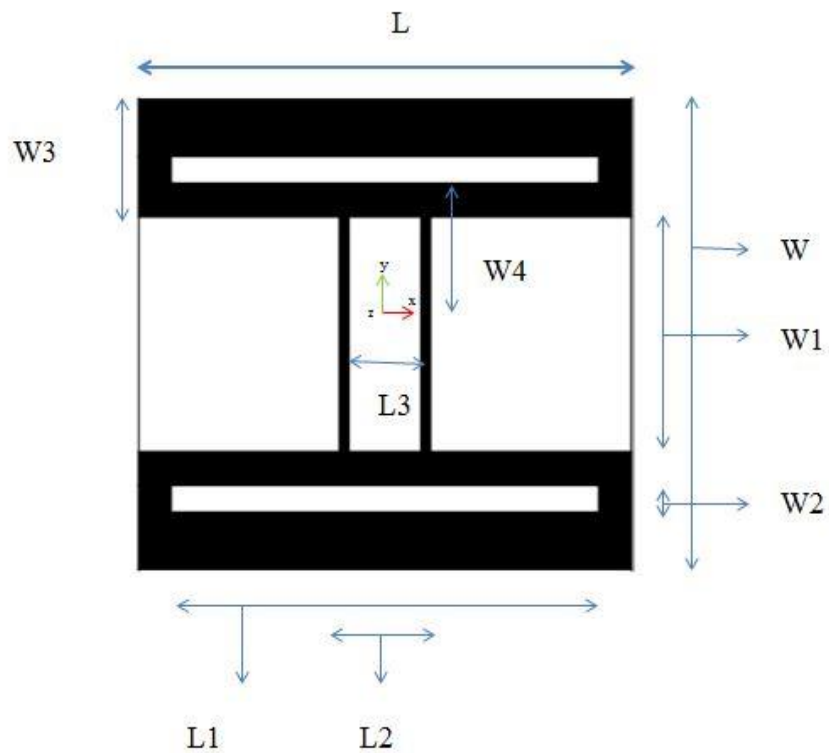


Fig. 4.1 (b) Ground view of Triangular antenna

Table 4.1 Dimensions for Designing Triangular Antenna

(All dimensions are in mm)

Parameters	L	L1	L2	L3	L4	L5	L6	W
Value	15	13	2.78	2.2	10	2.78	13	14
Parameters	W1	W2	W3	W4	W5	W6	W7	W8
Value	7	0.8	3.5	4.5	5.67	1.5	7.83	3.5
Parameters	S	hs	t					
Value	5.67	1.57	0.0175					

Table 4.1 shows the all parameters that are used to create antenna and Fig. 4.1 shows the proposed antenna top view and ground view. The explanation of all five stages is below.

4.2.1 Stage 1 (Triangular Antenna)

Here triangular patch having area $\frac{1}{2} \times 13 \times 6.5 \text{ mm}^2$ and ground having dimension of $15 \times 14 \text{ mm}^2$ are placed on Fr4 substrate having height of $h_s = 1.57 \text{ mm}$ and permeability $= 4.3$ with copper thickness $t = 0.0175 \text{ mm}$. The antenna is designed according to cavity model. According to cavity model resonant frequency can be obtained by using following formula [18].

$$f_{mn} = \frac{ck_{mn}}{2\pi\epsilon_r^2} \quad (4.1)$$

where

f_{mn} = frequency of resonance

mn subscripts refers to TM modes

c = velocity of light

ϵ_r = dielectric constant

k_{mn} = Wave number

k_{mn} can be calculated as

$$k_{mn} = \frac{4\pi(m^2+n^2+mn)^{1/2}}{3a} \quad (4.2)$$

where a = side length of triangle

Fundamental frequency is given by following formula

$$f_{10} = \frac{2c}{3a_{eff} \epsilon_{eff}^{1/2}} \quad (4.3)$$

where a_{eff} can be calculated as

$$a_{eff} = a + \frac{h}{\epsilon_r^{1/2}} \quad (4.4)$$

where h = height of substrate

and ϵ_{eff} can be calculated as

$$\epsilon_{eff} = \frac{1}{2}(\epsilon_r + 1) + \frac{1}{4} \frac{(\epsilon_r + 1)}{\sqrt{(1 + \frac{12h}{a})}} \quad (4.5)$$

By using above formulas, triangular patch antenna is designed whose overall size is $15 \times 14 \text{ mm}^2$ as shown in Fig. 4.2 (a). The CST simulations results are shown in Fig. 4.2

(b). The calculated and CST simulations results value are shown in Table 4.2 by varying side length of triangular patch.

Table 4.2 Simulated and calculated results

a_{eff} in (mm)	Calculated results(GHz)	Simulated results(GHz)
11.21	10.31	10.1
10.40	10.75	10.76
8.79	12.70	12.52
7.18	15.57	15.64

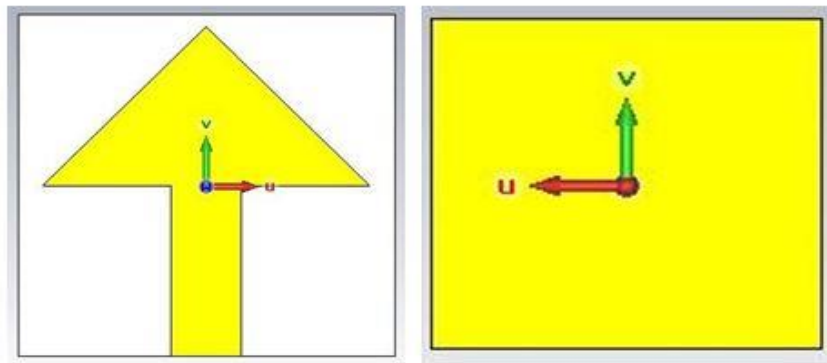


Fig. 4.2 (a) Triangular antenna

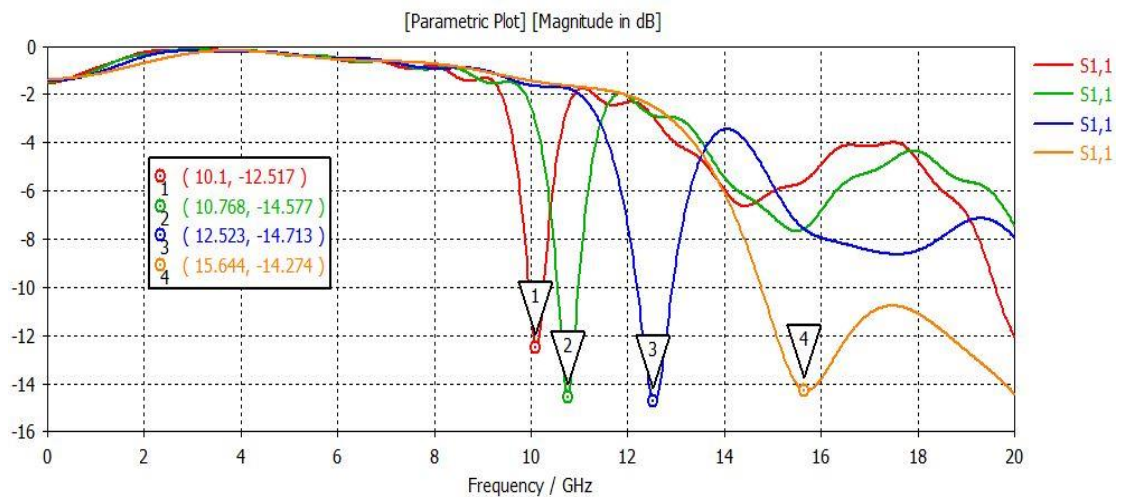


Fig. 4.2(b) S_{11} results of stage 1

As the designed antenna resonate at higher frequency which is not a desirable frequency. So to attain desirable results further modification is done in further stages without changing its overall area as $15 \times 14 \text{ mm}^2$.

4.3.2 Stage 2 (Triangular Antenna with I shape Ground)

Stage 1 is performed to show small size antenna provide resonance at higher frequency. To make the same antenna useful for lower frequencies, next stages are performed. In this stage triangular patch with “I” shape ground plane is designed to generate band 1 at 3.38 GHz i.e. 3.4-3.69 GHz for WiMAX. The dimensions of “I” shape ground and triangular patch are optimized to resonate at 3.43 GHz. The ground is modified in I shape which actually shifts the frequency from 10.1 GHz to 3.43GHz. Fig. 4.3(a) shows designed antenna and Fig. 4.3(b) shows simulation return loss.

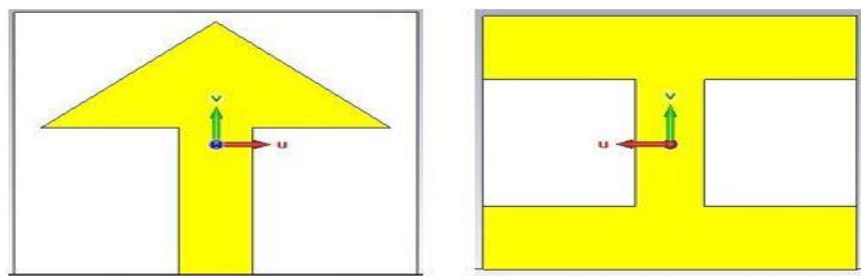


Fig. 4.3 (a) Triangular antenna design with I shape ground

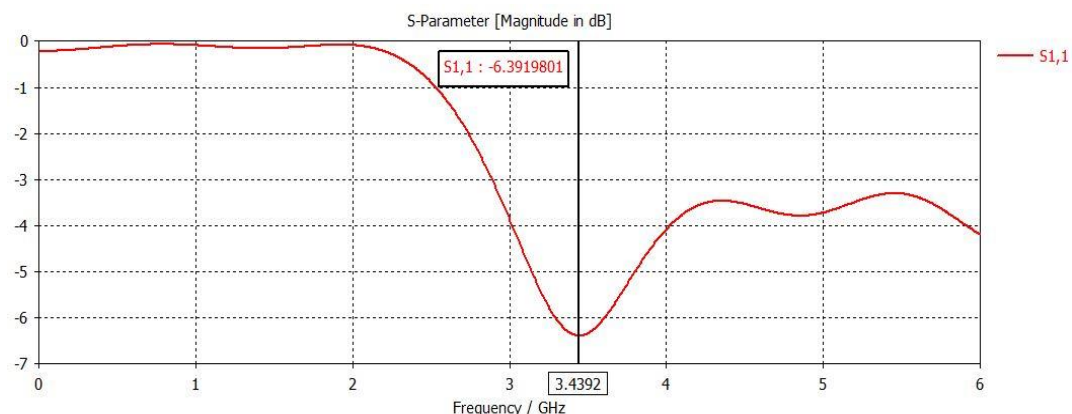


Fig. 4.3 (b) S_{11} Results of stage 2

4.3.3 Stage 3 (Slotted Triangular Antenna with I shape Ground)

Triangular shape slot is etched from triangular patch to increase the return loss at band 1. From [7] by etching slots, antenna provides better return loss and shifts resonances from higher frequencies to lower frequency by means of increasing path length of electric current and helps in reduction of size. Return loss are increased to -9.8 dB from -6.3 db. The slot is of dimension $\frac{1}{2} \times 9 \times 3.5 \text{ mm}^2$. Fig. 4.4 shows the simulation result and designed antenna.

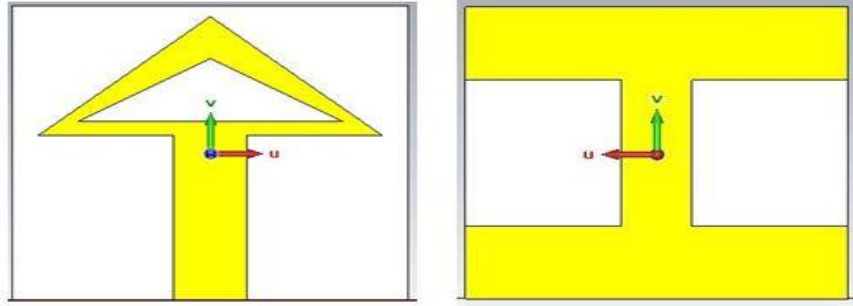


Fig. 4.4 (a) Triangular antenna with triangular slot

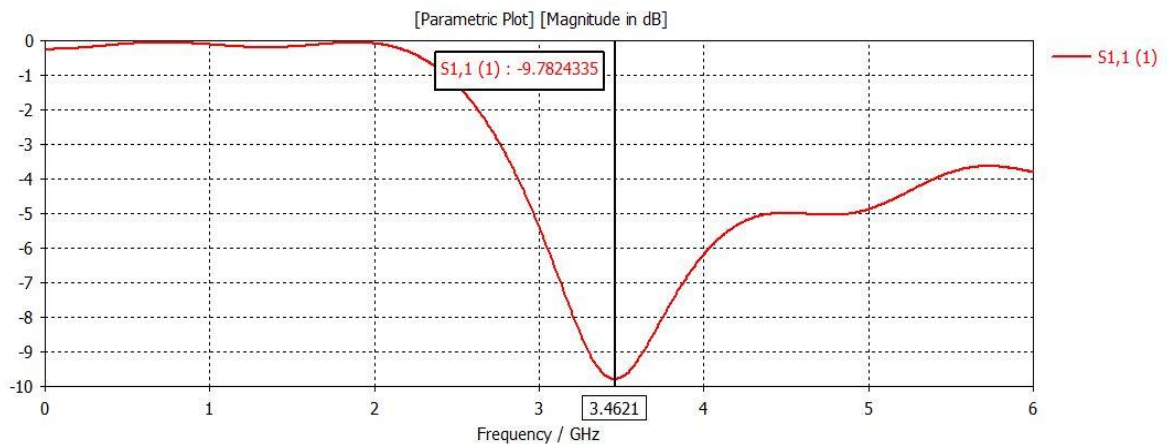


Fig. 4.4 (b) S₁₁ results of stage 2

4.3.4 Stage 4 (Slotted Triangular Antenna with rectangular slot in I shape Ground)

Rectangular slot having dimensions of $7 \times 2.2 \text{ mm}^2$ is etched from ground in middle of “I” shape ground to provide large return loss i.e. -27.5 dB as can be seen from the Fig. 4.5(b). It also provides large bandwidth of 900 MHz bandwidth which can be seen from S₁₁ results as shown in Fig. 4.5(a).

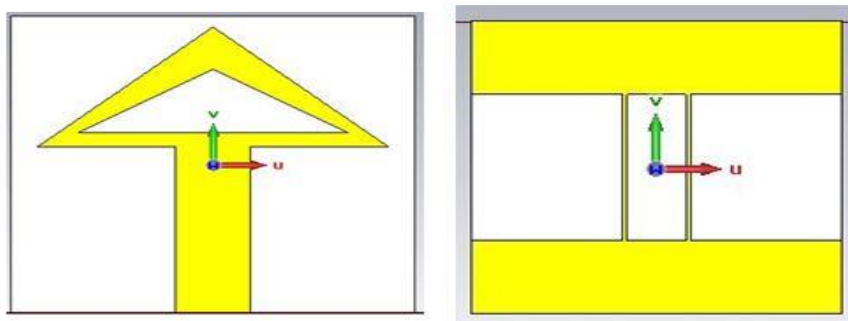


Fig. 4.5 (a) Triangular antenna with slot in I

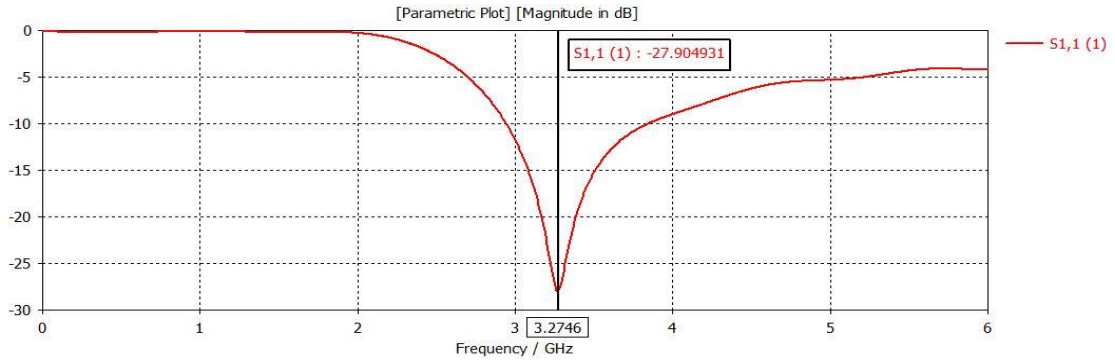


Fig. 4.5 (b) S_{11} results of stage 4

4.3.5 Stage 5 (Proposed Antenna)

The proposed antenna is dual band antenna. As said earlier [29] slots are best candidates for creation of multiband and for providing large bandwidth. Two rectangular slots having dimension of $10 \times 0.8 \text{ mm}^2$ are etched from ground plane which generates band 2 i.e. 4.97-5.38 GHz. It provides return loss of -54.10 dB. The proposed antenna and final simulation results are shown in Fig. 4.6.

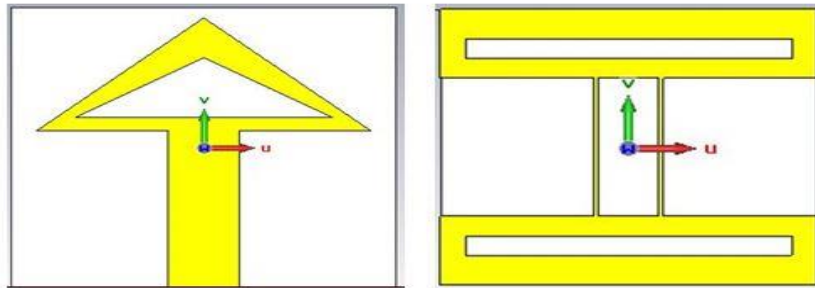


Fig. 4.6 (a) Proposed antenna

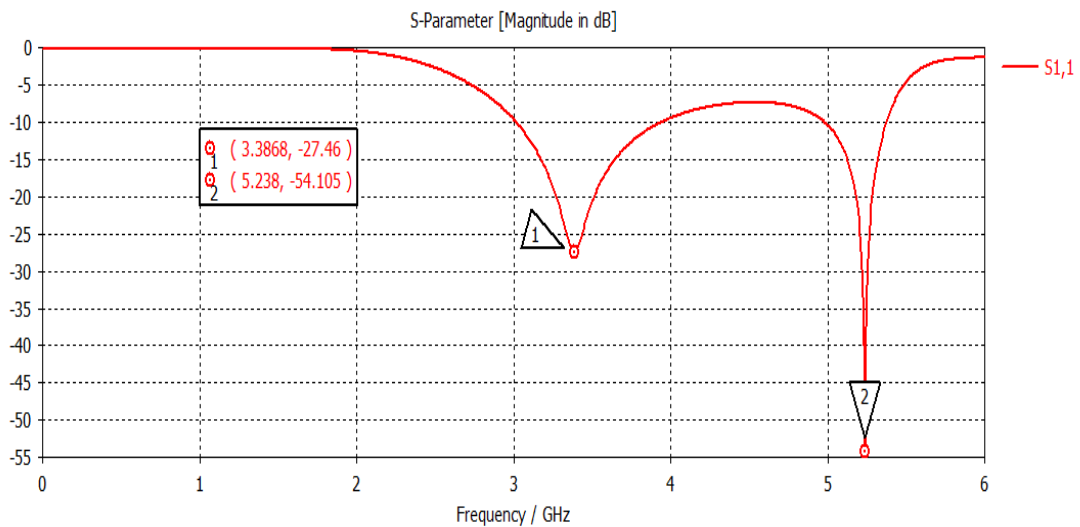


Fig. 4.6 (b) Final results

4.4 Results and Discussion

The CST simulated S_{11} results of arrow shape antenna are depicted by Fig. 4.6(b). Band 1 i.e. 3.38 GHz makes antenna useful for WiMAX application and band 2 i.e. 5.23 GHz for WLAN application. Band 1 provides the large bandwidth of 930 MHz by covering the frequency 3.02-3.95 GHz and band 2 provides bandwidth of 410 MHz by covering the frequency 4.97–5.38 GHz corresponding to impedance bandwidth of 26.6% and 7.92% with respect to appropriate resonant frequencies, also shown in Table 4.3.

Table 4.3 Result Comparison

(All frequency in MHz)

Bands	Band 1	Band 2
Actual frequency	3400-3690	5125-5325
Actual bandwidth	290	200
Obtained frequency	3020-3950	4970-5380
Obtained bandwidth	930	410

Fig 4.7 shows surface current density at both the frequencies. The radiation regarding lower band depends upon triangular slot in front and on rectangular slot in middle of I in ground whereas surface current density is more concentrated on triangular slot of patch and on rectangular slots etched from ground regarding radiation of higher band; the red colour arrows depicts the high concentration of surface current.

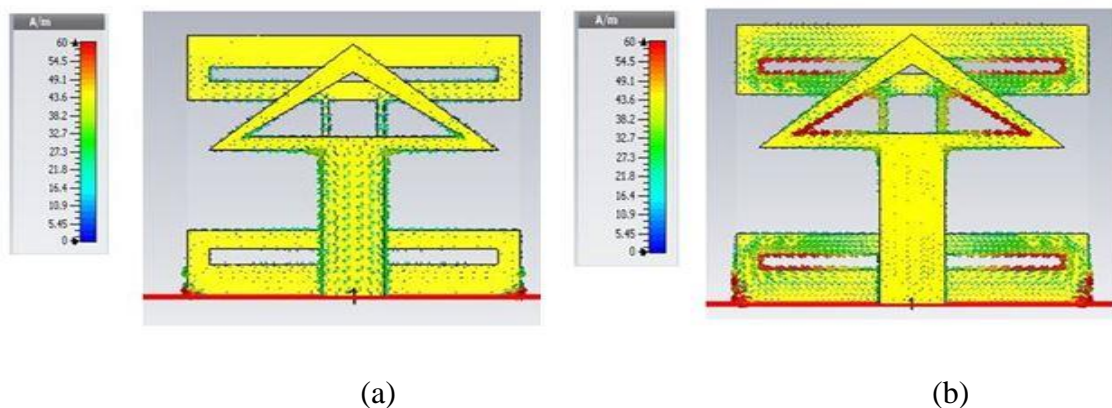


Fig. 4.7 Surface current density (a) at 3.38GHz (b) at 5.23 GHz

With the overall analysis of triangular antenna, Fig. 4.8. shows the simulated radiation pattern at frequency 3.38 GHz and 5.23 GHz. The radiation pattern at 3.38 GHz shows angular width of 101.4° and main lobe magnitude of 2.63 dBi and at frequency 5.38 GHz provides shows 3 dB angular width of 101° and main lobe magnitude of 3.21 dBi.

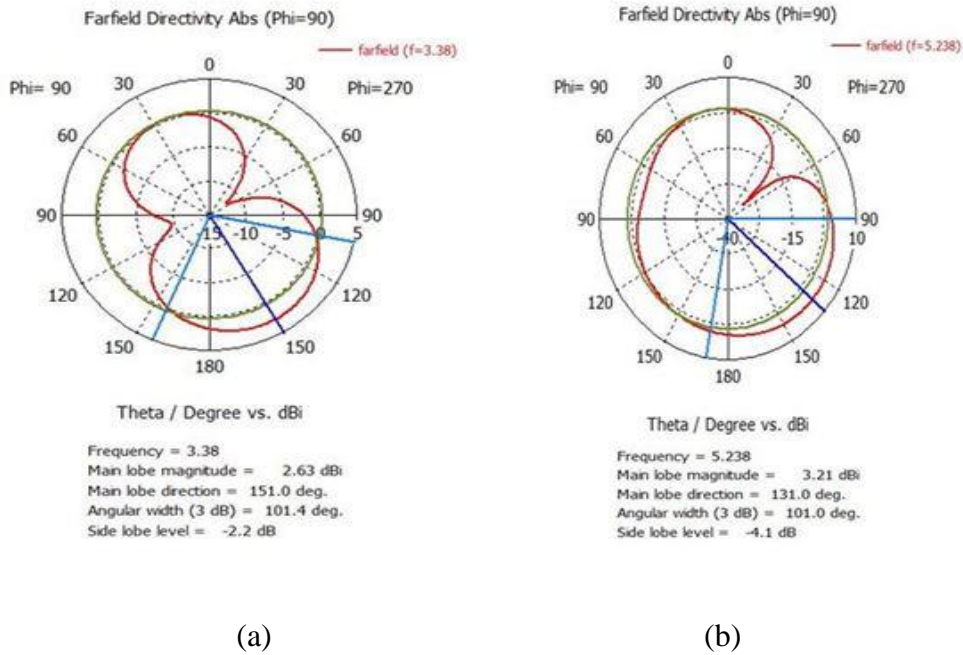


Fig. 4.8 Radiation pattern (a) at 3.38 GHz (b) at 5.23 GHz

Fig. 4.9. shows the VSWR value for both the frequencies as 1.08 for 3.38 GHz and 1.037 for 5.27 GHz which shows the good impedance matching as value for both the frequencies is approximately equal to 1 and makes it useful practically.

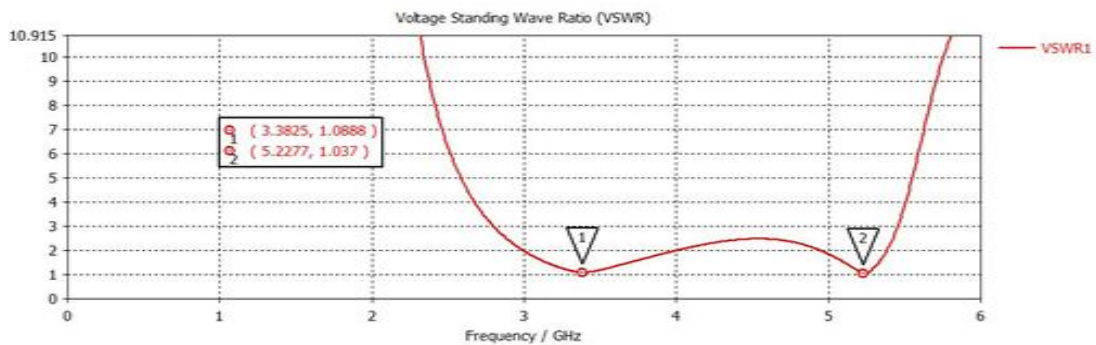


Fig. 4.9 VSWR results

4.5 Conclusion

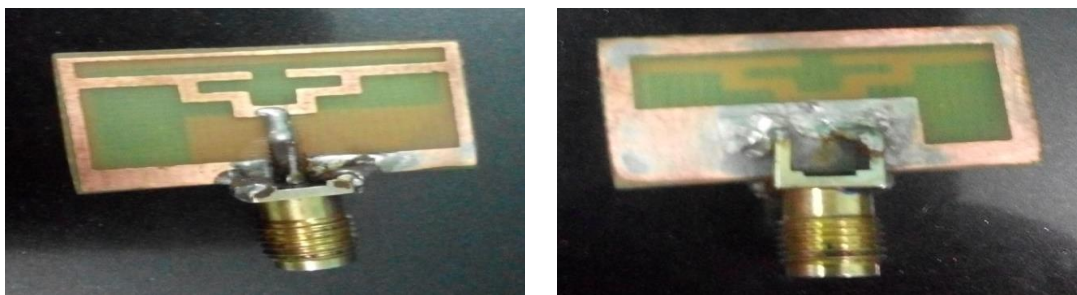
The arrow shape antenna with triangular slot and modified ground with etching slots in 'I' shape ground is presented here. For analysis of the antenna, simulations are done in 5 stages. According to final simulation results, arrow shape antenna create two frequency bands at about 3.38 GHz and 5.73 GHz, can be used for WiMAX and WLAN applications. For making one layer antenna all the moderation is done on the top and bottom layer of the substrate. The design is made through CST 2014 Microwave Studio.

CHAPTER 5

FABRICATION, TESTING, AND RESULT DISCUSSION OF DESIGNED ANTENNA

This chapter discuss about the fabrication of Staircase rectangular patch and Triangular patch antenna. VNA (Vector Network Analyser) is used for testing of antenna. The measured results are presented and discussed here.

5.1 Fabrication of Staircase Antenna with L-shape DGS



(a)

(b)

Fig. 5.1 Fabricated antenna (a) Front view (b) Back view

Antenna is fabricated using PCB designing technique. Steps involved in fabrication of antenna are as follows.

- ❖ The antenna layout is drawn in ORCAD and printing of this layout is taken on transparent sheet.
- ❖ Take and clean the copper sheet.
- ❖ According to dimensions of antenna, copper is sliced using PCB cutter.
- ❖ Dipping of copper in photo resistive solution is done then for drying the antenna, oven is used.
- ❖ UV rays are used to take the print of layout on copper sheet.
- ❖ Etching solution of ferric chloride is used for melting of copper and then washed.

5.1.1 Testing of Antenna

VNA (Keysight E5063A) is used for testing of antenna. Firstly SMA connector is connected to microstrip line of antenna as shown in Fig. 5.1. The coaxial cable is connected to SMA connector for testing.

5.1.2 Results and Discussion

The comparison of simulated and measured results of proposed antenna i.e. S_{11} (dB) Vs frequency (GHz) are shown in Fig. 5.3.

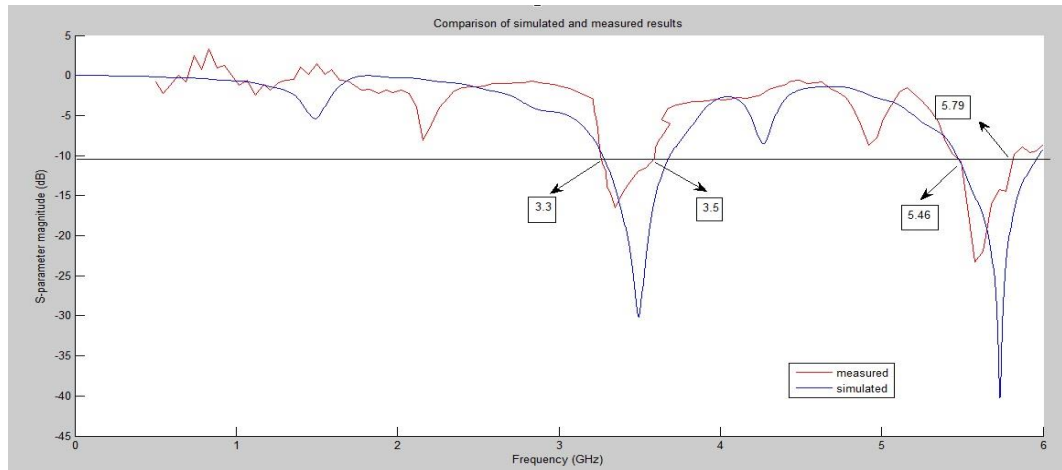


Fig. 5.2 Comparison of simulated and measured results

Table 5.1 Comparison of simulated and measured results

Bands	Band 1 (GHz)	Band 2 (GHz)
Simulated frequency range	3.28-3.69	5.46-5.96
Simulated bandwidth	0.41	0.5
Measured frequency range	3.31-3.53	5.46-5.79
Measured bandwidth	0.22	0.33

The lower resonating frequency band in simulated results covers frequencies ranging from 3.28 GHz to 3.69 GHz and higher band covers 5.46 GHz to 5.96 GHz. Lower band in measured result is quite shifted and thus covers only the frequency ranging from 3.31 to 3.53 GHz and higher band covers 5.46 GHz to 5.79 GHz. Lower resonating band of antenna is generated because of DGS geometry consisting of L-shaped slot and flag shape strips in the patch and higher band is generated because of double T shape slot and flag shape strips in the patch. The double T shape slot embedded in the patch and flag shape strips at the boundary are used to provide reactive loading so as to shift the bands and to increase the bandwidth. According to Table 5.1, impedance bandwidth corresponding to both the measured bands is 6.43% and 5.86% at appropriate resonant frequencies, so reasonable agreement is achieved beyond a frequency deviation $\leq 5.5\%$ if compared to

simulated impedance bandwidth which was 8.75% and 11.71% as mentioned in chapter 3, cannot be avoided if we take the effects of SMA connector and manufacturing defect.

5.2 Fabrication of Triangular Patch antenna with modified ground plane

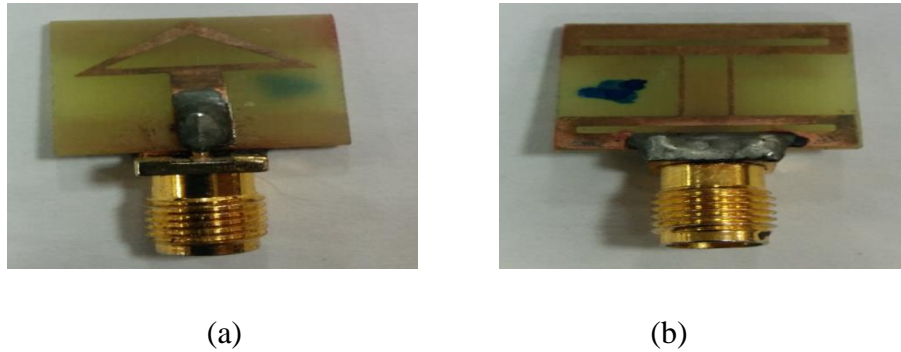


Fig. 5.3 Fabricated triangular antenna (a) Top view (b) Bottom view

5.2.1 Results and Discussion

The proposed antenna simulated and measured results are shown in fig 5.5.

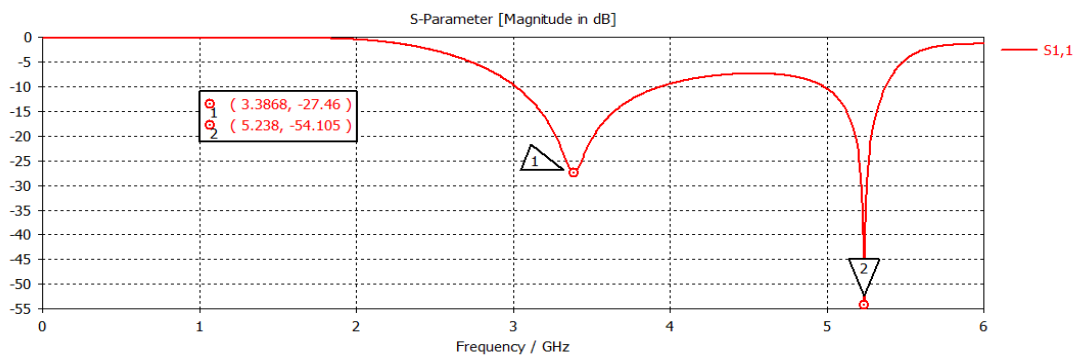


Fig. 5.4 (a) Simulated results of Triangular antenna

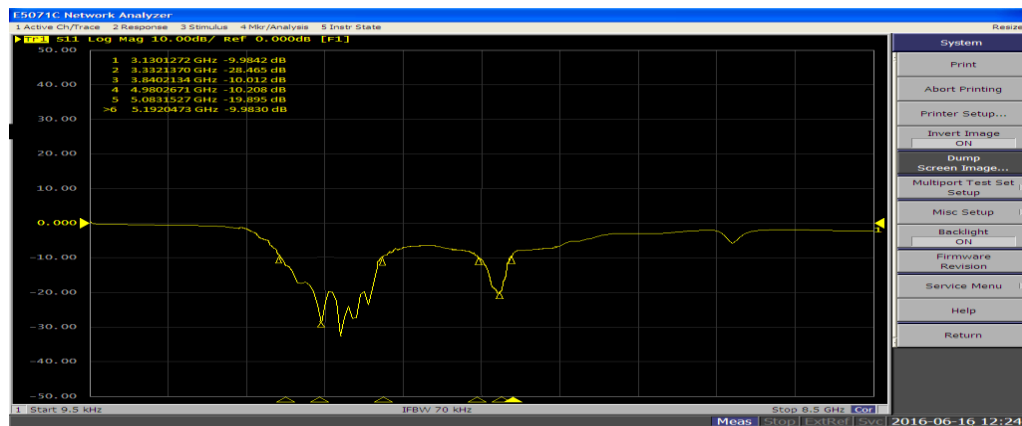


Fig. 5.4 (b) Measured results

Table 5.2 Comparison of simulated results and measured results

Bands	Band 1 (GHz)	Band 2 (GHz)
Simulated frequency range	3.05-3.95	4.97-5.38
Simulated bandwidth	0.9	0.4
Measured frequency range	3.13-3.84	4.91-5.15
Measured bandwidth	0.71	0.24

The lower resonating frequency band in simulated results covers frequencies ranging from 3.05 GHz to 3.95 GHz and higher band covers 4.91 GHz to 5.15 GHz. Lower band in measured result is quite shifted and thus covers only the frequency ranging from 3.13 GHz to 3.84 GHz and higher band covers 4.91 GHz to 5.15 GHz. The radiation regarding lower band depends upon triangular slot in front and on rectangular slot in middle of 'I' in ground whereas triangular slot of patch and rectangular slots etched from ground are responsible for radiation of higher band. According to Table 5.1, impedance bandwidth corresponding to both the measured bands is 20.37% and 5.6% at appropriate resonant frequencies, so reasonable agreement is achieved beyond a frequency deviation $\leq 6.2\%$ as compared to simulated impedance bandwidth which was 26.6% and 7.92% as mentioned in chapter 4, cannot be avoided if we take the effects of SMA connector and manufacturing defect.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

The objective of this thesis report is to present dual band antenna which can be used for wireless applications as two different antennas cannot be used for two different wireless applications, so both the bands are integrated in single device.

In chapter 1, theory related to antenna is discussed. This consists of introduction, IEEE standards, types of antenna, antenna characteristics, feeding techniques and bandwidth increment techniques are discussed.

In chapter 2, literature review is discussed which is given by many researchers. Here different techniques for multiband creation, bandwidth increment and size reduction are discussed.

In chapter 3, rectangular microstrip patch antenna for WLAN and WiMAX applications is presented. Rectangular shaped patch antenna comprises of a staircase pattern with double T-shape slot and a pair of flag shaped strips. An L-shape slot is embedded into the ground plane which works as a perfect DGS thus enhancing bandwidth. The proposed antenna is suitable for WiMAX (3.4 GHz- 3.69 GHz) and WLAN (5.125 GHz – 5.325 GHz) applications. Impedance bandwidth for <math><10\text{ dB}</math> for WiMAX (3.28 GHz – 3.69 GHz) is 410 MHz and for WLAN (5.46 GHz – 5.96 GHz) is 500 with return loss of -30.11 dB and -40.22 dB.

In chapter 4, a triangular patch antenna comprising triangular shaped slot etched from the triangular patch is proposed. Symmetrical rectangular slots have been etched from I shape ground thus making it a modified ground plane. The structure designed is feasible for WiMAX (3.4 GHz - 3.69 GHz) and WLAN (5.725 GHz - 5.825 GHz) applications. Etching slots in the patch and ground plane provide capacitive loading which increases electrical length of antenna, so reduction in frequency, small size of antenna is obtained. Impedance bandwidth for <math><10\text{ dB}</math> for WiMAX (3.02 GHz to 3.95 GHz) is 930 MHz and for WLAN (4.97 GHz to 5.38 GHz) is 410 MHz with return loss of -27.45 dB and -54.10 dB.

In chapter 5, fabrication of antennas and measured results are presented. For staircase antenna, lower band in measured result is quite shifted and thus covers only the frequency ranging from 3.31 to 3.53 GHz and higher band covers 5.46 GHz to 5.79 GHz with impedance bandwidth of 8.75 % and 11.71 % at appropriate resonant frequencies over measured bands with frequency deviation < 5.5 % and for triangular antenna, lower band in measured result is quite shifted and thus covers only the frequency ranging from 3.13 GHz to 3.84 GHz and higher band covers 4.91 GHz to 5.15 GHz having impedance bandwidth of 20.37% and 5.6% at appropriate frequencies over the measured bands with frequency deviation <6.2%. So measured results are in quite agreement with simulated one and show its practicality for WLAN and WiMAX applications.

5.2 Future Scope

The designed antennas are suitable for WLAN and WiMAX applications with proficient return loss. Still improvement can be done in many ways in future.

- The designed antenna is dual band, so antenna can be converted into multiband by inserting many different shapes.
- Stacking can be used to obtain large bandwidth but at the cost of large height.
- High gain can be obtained by using antenna array.
- CSRR (complementary split ring resonator) can be used instead of DGS for further reduction in size.
- Coaxial feeding technique and coplanar waveguide feeding technique can be used instead of microstrip line for good impedance matching.
- Insertion of many slots as U-shaped slot, V-shaped slot, I-shaped slot and E-shaped slot can be used for multiband operation and enhancing bandwidth.

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Jatinder Singh, Jaswinder Kaur, “Staircase antenna with L-shape DGS for WLAN and WiMAX applications”, *IET Microwaves Antennas and Propagation*, 2016.
(Communicated)

Jatinder Singh, Jaswinder Kaur, “Triangular patch antenna with modified ground plane for WLAN and WiMAX applications”, *International Journal of Electronics*, 2016.
(Communicated)