

**DESIGN AND ANALYSIS OF ULTRA WIDE BAND
MICROSTRIP ANTENNA WITH BAND-NOTCHED
CHARACTERISTICS**

Thesis submitted towards the partial fulfilment of the requirements for
the award of degree of

**MASTER OF ENGINEERING
IN
WIRELESS COMMUNICATION**

Submitted By

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(Established under the section 3 of UGC Act, 1956)

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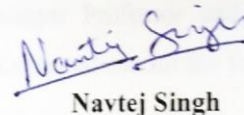
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DECLARATION

I, Navtej Singh, hereby declare that the work, which is being presented in the thesis entitled "**Design and Analysis of Ultrawide Band Microstrip Antenna with Band-Notched Characteristics**" by me in partial fulfillment of the requirements for the award of degree of Master of Engineering in Wireless Communication from Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of **Mr. Sukhwinder Kumar**, Lecturer, Electronics and Communication Engineering Department.

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

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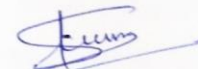


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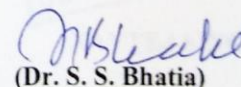
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ACKNOWLEDGEMENT

I would never been able to finish my thesis without the supervision of faculty of my department, help from friends, and provision from my family.

I would like to utter my deepest thankfulness to my guide, **Mr. Sukhwinder Kumar**, Lecturer, ECED, Thapar University, Patiala, for his excellent guidance, caring, patience, and providing me with an excellent atmosphere for doing research.

I would like to thank **Dr. Sanjay Sharma**, Professor and Head, ECED, Thapar University, Patiala, for granting us with sufficient facilities and infrastructure to carry our work.

I would like to acknowledge **Dr. Hemdutt Joshi**, Assistant Professor and Program Coordinator (WC), ECED, Thapar University, Patiala, for being a source of inspiration for us during our research work.

I would also like to thank **Bhupinder Singh, Jashanpreet Singh** and **Rajesh Sharma**, who as good friends were always willing to help and give their best suggestions.

Finally, I would like thank my parents. They were always supporting me and inspiring me with their best wishes.

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ABSTRACT

In the present day scenario of growing wireless communications, demand for compact, low-profile, ultrawide band (UWB), multiple functionality, pure polarization, and low cost antennas have arisen remarkably. Due to which, research studies in the field of microstrip patch antennas have drastically increased in the past few years. For short range and high data rate applications, wireless systems require ultrawide band microstrip antennas which operate in the frequency band of 3.1 to 10.6 GHz. But in the UWB frequency band there are some other frequency bands such as WLAN, WiMAX, C band etc. These bands can cause interference with the UWB band. Several techniques have been developed to avoid the inference from these bands.

In this report, design and analysis of two UWB microstrip antennas with notched band characteristics are presented. The first design consists of a semi-circular disc with a dual stepped triangular patch. Also, a slot in the shape of a circular arc is cut on the circular patch which generates a notched band from 4.8 to 6.2 GHz for WLAN band. The antenna operates at an ultrawide frequency band of 9.7 GHz ranges from 2.8 to 12.5 GHz. Maximum gain of the antenna is 5.3 dB.

The second antenna design has dual notched band characteristics. It consists of a mirrored E-shaped structure inscribed inside a circular ring radiator. This E-shaped structure creates a stop band at 3.12 to 3.88 GHz to avoid interference from WiMAX band with center frequency 3.5 GHz. Trapezoidal shaped ground plane having a semicircular notch is used to enhance the bandwidth of the antenna. The impedance bandwidth of the antenna ranges from 2.7 to 11.95 GHz which covers the UWB frequency range. To create a second notch band, an H-shaped parasitic element is etched above the ground plane on the bottom side of the antenna. This element creates a stop band at 4.78 to 5.48 GHz to avoid interference from WLAN band (5.15 to 5.825 GHz). Fabricated design and the measured results of the antenna are also shown in this report.

Keywords: Microstrip antenna, ultrawide band, WLAN, WiMAX, band-notched, circular patch antenna.

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LIST OF ABBREVIATIONS

CDMA	Code Division Multiple Access
CPA	Circular Patch Antenna
CMT-EBG	Conventional Mushroom Type Electromagnetic Band Gap
CSLA	Coupled Sectorial Loop Antennas
EDGE	Enhanced Data Rates for GSM Evolution
EIRP	Equivalent Isotropically Radiated Power
ENG TL	Epsilon Negative Transmission Line
EBG	Electromagnetic Band-Gap
FDMA	Frequency Division Multiple Access
FCC	Federal Communication Commission
FDTD	Finite-Difference Time-Domain
FPA	Fabry-Perot Antennas
GPS	Global Positioning System
GSM	Global System for Mobile
GPRS	General Packet Radio Service
GA	Genetic Algorithm
HSPA	High Speed Packet Access
HPBW	Half-Power Beamwidth
HIPERLAN	High Performance Radio LAN
IUSPE	Inverted U-Shaped Parasitic Element
LPs	Linear Polarizations

LAS	Loaded Arc Shaped Stub
MAM	Multipurpose Admittance Matrix
OFDM	Orthogonal Frequency Division Multiplexing
RF	Radio Frequency
SMA	Subminiature Version A
UMTS	Universal Mobile Telecommunications System
VNA	Vector Network Analyzer
VSWR	Voltage Standing Wave Ratio
WLAN	Wireless Local Area Network
WiMAX	Worldwide Interoperability for Microwave Access

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INTRODUCTION

1.1. Wireless Communication

Wireless communication is the transfer of the data between two or more points which are indirectly connected to each other. The term “Wireless” came into general usage to refer to a radio transmitter or receiver constituting its use in wireless communication such as in mobile networks and mobile broadband internet. It also refers to any type of application that is employed without using wires. It includes different types of duplex radios and cellular phones that are mobile and portable. Other examples of wireless communication are global positioning system (GPS), cordless computer peripherals, satellite television etc. [1].

Wireless communication is the fastest growing division of the communications industry. These communication systems play very critical role in our everyday life. During the last few years, a number of enhancements have been noticed in the field of wireless mobile technologies. There has been a surge of research activities in this area. This is due to a several factors. First, there has been an increase in demand for tether less connectivity wireless data applications. Second, the progress in VLSI technology has enabled small-area and low-power implementation of sophisticated signal processing algorithms and coding techniques. Third, the success of second-generation (2G) digital wireless standards, especially, the IS-95 code division multiple access (CDMA) standard, provides a concrete example that good ideas from communication theory can have a major impact in practice [2].

Wireless systems allow long range communications that are difficult or inconceivable to employ with the use of wires. The most common usage of wireless systems is to connect the wireless device data communication users who travel to different locations. Other important use of wireless networks is to connect mobile networks through antennas using satellite communication. Radio frequency (RF) communication, microwave communication, infrared communication, short range electromagnetic induction communication, ultrasonic short range communication etc. Categorization of wireless mobile communication system on the basis of various generations it has gone through is presented here.

1.1.1. First Generation

The first generation wireless communication technology was analog i.e. voice based communication system. It used analog frequency modulation technique to send the voice signals. The available frequency channels were shared by the users by using frequency division multiple access (FDMA) technique. First generation wireless phones exploited analog technology. These devices were heavy and communication was unreliable [3].

1.1.2. Second Generation

The second generation of mobile communication technology is digital. Digital cellular services are extremely used world-wide. They display a significant improvement in the voice quality because analog signals are much liable to distortions as compared to digital signals. This technology also shows increased capacity because voice signals can be multiplexed in a more efficient manner. It gives the various services such as WAP (internet on small devices), digital voice call and short messaging service (SMS).

Global system for mobile (GSM), time division multiple access (TDMA) and code division multiple access (CDMA) are examples of second generation wireless standards [3]. In the multiple access technique, each user is assigned a unique code division channel so that users can send or receive data at the same time in the same frequency band. Packet switching technique has been introduced in the second generation systems. It is a technique in which the data to be sent is fragmented into packets and routed by the network between different nodes based on their address. General packet radio service (GPRS) is a radio technology for GSM networks that uses packet-switching protocols [4]. The data transmission speed of the second generation system is approximately 64 Kbps.

The second generation technology has improved many drawbacks of the first generation, like the limited bandwidth capacity, poor voice quality, less data security. Since both the first generation the second generation of wireless communication system are voice oriented systems and their bandwidths are narrow, they are not sufficient to provide high data rate services. That is why more advanced systems are needed i.e. the third generation of wireless communication system.

1.1.3. Third Generation

The third generation of wireless mobile communication technology provides pretty high speed wireless communication to accommodate more useful services like data, video, multimedia and voice. Enhanced data rates for GSM evolution (EDGE), high speed packet access (HSPA) and universal mobile telecommunications system (UMTS) are the various standards which are used in third generation wireless technology. 3G systems have improved features for multimedia communications i.e. digital data, voice and video communication. It supports to handle services like e-mail, fax, messaging, internet, video-conferencing etc. Also, it provides bandwidth and high data transmission rate (more than 2 Mbps) and routing flexibility for repeaters, satellites, WLANs etc. [5].

1.1.4. Fourth Generation

The fourth generation wireless communication system is expected to provide the data transmission rate of 20 Mbps by implementing OFDM (orthogonal frequency division multiplexing) technique and for better allocation of network resources to multiple clients by using multiple carriers simultaneously. The capacity of the fourth generation wireless communication systems can be much higher than the third generation mobile wireless communication system by utilizing some certain air interface that aids bigger fluctuation of data transmission rate, various needed quality of service and packet switching. The third generation networks are based on both packet-switching and circuit-switching networks, but the fourth generation networks will be exploiting only packet switching and may connect all the users anywhere around the globe [3].

1.1.5. Fifth Generation

Fifth generation is to be a new technology that will deliver all the possible applications, by using only one universal device, and interconnecting most of the already existing communication infrastructures. The fifth generation principal is to be a re-configurable, multi-technology principal. Cognitive radio (CR), software defined radio (SDR)-configurability enabler, reconfigurable-interoperability between several types of wireless access network, adaptive coupling reconfigurable integration, nanotechnology and Cloud computing are main challenges for the development of the fifth generation communication systems [6].

1.2. Antennas in Wireless Communication

The antenna is one of the most vital parts, for wireless communication systems. Transmitters and receivers communicate with each other with the help of antennas. As stated in the IEEE standards definition of antennas, the antennas are basically the means of transmitting and receiving radio waves. So, the antenna is the transitional structure between the free space and the guiding space [7]. Antennas act as a transducer which changes the electrical energy to the electromagnetic energy and guide that energy into a particular direction as required by the system. Radio transmitters and receivers are used to send and receive signals in the networks including radio broadcast, point to point communication links and many short range networks.

1.2.1. Types of Antennas

Classification of antennas on various different ways is as follows:-

1.2.1.1. Based on Aperture

- **Wire antennas:** These antennas are well known to layman as these antennas can be seen commonly like on automobiles, buildings, ships, aircrafts, spacecrafts etc. There are different shapes of these antennas like straight wire, loop, and helix.
- **Aperture antennas:** These antennas are more known to the layman in present day than in the past because of the growing demand for more complex form of antennas and also for usage of higher frequencies. Aperture antennas are majorly used in aircrafts and spacecrafts because they can be simply flush-mounted on their upper layer. Also, they can be shielded with an insulator to save them from harsh surrounding conditions [8].
- **Microstrip antennas:** They have utilization in space applications, government and commercial applications. Microstrip antennas comprise of a metallic patch on a grounded substrate. The metallic patch can be of various configurations such as rectangular, circular etc. These antennas are of low profile, adapted to planar and non-planar surfaces, easy and less expensive to fabricate with the use of modern printed-circuit technology, mechanically durable when installed on hard surfaces and very flexible in terms of impedance, resonant frequency, radiation pattern and polarization.

- **Array antennas:** In order to get the required radiation patterns, which is not feasible with a single antenna, an assembly of radiating elements is used which is called an array. The arrays should be aligned in such a way that the radiations accumulate to produce maximum radiation in a specific direction or directions and minimum radiations elsewhere as required [8].

1.2.1.2. Based on Radiation Characteristics

- **Directional antennas:** They are also called as beam antennas, which transmit and receive in a specific direction. A directional antenna is designed to maximize its radiations in the direction of a particular location or to cover a specific area.
- **Omni-directional antennas:** These antennas transmit and receive equally well in all horizontal directions in a flat, two-dimensional geometric plane. Omni-directional antennas are used in cellular phones, wireless routers.

1.2.1.3. Based on Polarization

- **Circularly polarized antennas:** These antennas are able to transmit or receive electric field vectors of any direction. They emit electromagnetic fields in a corkscrew-like fashion and broadcast electromagnetic waves on two planes making one complete revolution in a single wavelength.
- **Linearly polarized antenna:** These antennas transmit or receive electromagnetic waves in a single plane i.e. either vertical plane or horizontal plane. RFID tag direction must be known to the antenna, the plane of the antenna and its RFID tag must be similar to get a consistent reception [9].

The main requirement in today's wireless scenario is to reduce the size of the antenna and reduce its power consumption. So, by keeping this in the mind microstrip patch antennas come into the picture.

1.3. Microstrip Patch Antennas

The applications in today's wireless communication systems generally require miniaturization of antennas in order to reduce the size of mobile devices. Therefore, reduction of size and bandwidth improvement, both are becoming significant design features for practical implementation of microstrip antennas. Due to this, there has been a surge in research studies to attain small size and large bandwidth of microstrip

antennas. Remarkable advancements in the designing of small sized microstrip antennas with ultrawide bandwidth, multi-frequency bands, dual- polarization and gain enhancements have been seen over the last few years. Microstrip patch antennas generally have a conducting patch mounted on the top of a grounded dielectric substrate, and have low power consumption, light weight, ease of fabrication, and compatibility to mounting interface. Since, microstrip antennas have small frequency bandwidth comparatively, bandwidth improvement is usually required for practical applications [9].

Basically, a microstrip patch antenna includes a radiating patch on the upper side of a substrate which is made of a dielectric material, on the bottom side of the substrate there is a metallic ground plane. The patch is generally made of conducting material like copper or gold and can be of any feasible structure. The radiating patch, the feed line and the ground plane are generally engraved by a photomechanical process on the substrate. For a rectangular patch, the length 'L' of the patch is usually $0.3333\lambda_0 < L < 0.5\lambda_0$, where ' λ_0 ' is the free-space wavelength. The patch is selected to be very thin such that $t \ll \lambda_0$ (where 't' is the thickness of the patch). The height 'h' of the dielectric substrate is very crucial in the antenna design and typically are in the range usually $0.003\lambda_0 \leq h \leq 0.05\lambda_0$. The permittivity of the substrate (ϵ_r) is generally in the range $2.2 \leq \epsilon_r \leq 12$ [6]. Fig. 1.1 and Fig. 1.2 show the top and the side view of the microstrip patch antenna.

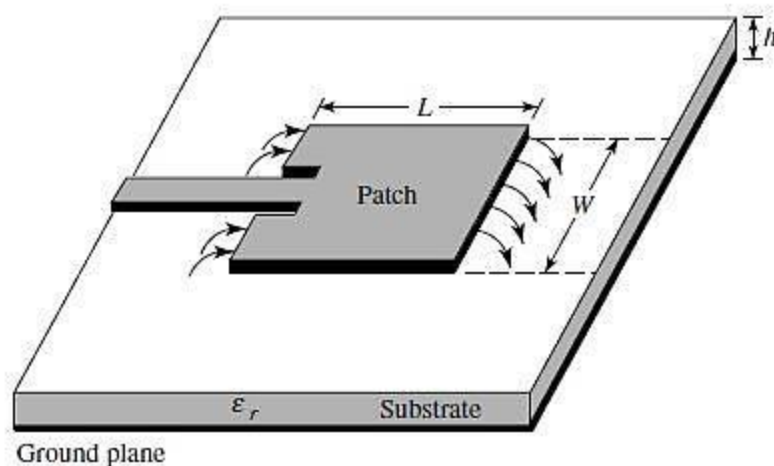


Fig. 1.1. Top view of microstrip antenna [7].

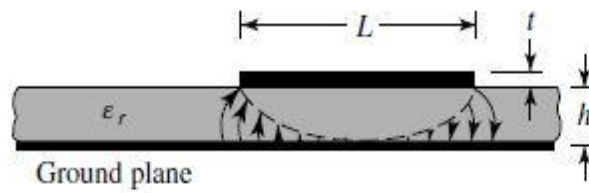


Fig. 1.2. Side view of microstrip antenna [7].

Designing techniques are related to the changing substrate properties like height and permittivity. The bandwidth can be increased by increasing substrate height. But it will cause loss of the power which will further reduce level of its performance and characteristics by bringing in surface waves. Different types of methods are presented in research studies like stacking, cutting slots, partial ground plane, parasitic patches etc. to improve the characteristics of the microstrip antenna. Desired resonance frequency, radiation pattern and polarization can be achieved by selecting a specific shape while designing the antenna. By attaching loads like PIN diode, varacter diodes to the design of a microstrip antenna, polarization, resonance frequency and radiation patterns of the antenna can be easily configured [9].

1.3.1. Circular Microstrip Patch Antenna

A circular patch is majorly used design configuration of microstrip patch antennas. In the rectangular microstrip antennas, the field variation below the patch is defined in terms of sine or cosine functions. But in the case of circular microstrip antennas, the field variations are defined in terms of the Bessel function [10]. Fig. 1.3 shows the structure of the circular microstrip patch antenna.

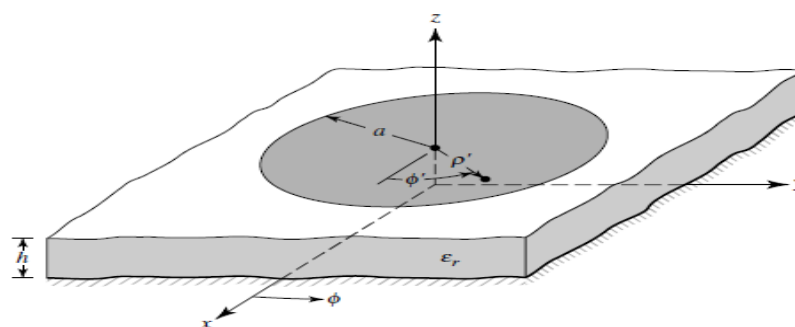


Fig. 1.3. Structure of circular microstrip patch antenna [7].

The modes presented by the circular microstrip antenna can be deduced by considering the patch, ground plane, and the substrate as a circular cavity. The modes that are mainly presented by a circular microstrip antenna whose height of the substrate is small ($h \ll \lambda$) are TM^z where 'z' is taken at 90° to the plane of the patch, as shown in the above figure. To the extent that dimensions of the patch are concerned, for the circular patch there is only one controlling factor which is radius of the patch. Changing the radius of the patch does not change the order of the modes, but it changes the absolute value of the resonant frequency of each. The circular microstrip antenna can only be studied suitably by using the cavity model. The cavity is made up of two perfect electric conductors at the top and the bottom which represent the patch and the ground plane respectively.

The resonance frequency of a circular microstrip antenna is found using the formula [10]

$$f_r = \frac{K_{nm}c}{2\pi a_e \sqrt{\epsilon_e}} \quad (1.1)$$

where, K_{nm} is the m^{th} root of the derivative of the Bessel function of order 'n'. For the fundamental TM_{11} mode, the value of K_{nm} is 1.84118. The ' a_e ' and ' ϵ_e ' are the effective radius and the effective dielectric constant of the circular microstrip antenna, respectively. The fringing fields near the circumference of the circular microstrip antenna are taken into consideration by replacing the patch radius ' a ' by the effective radius ' a_e '

$$a_e = a \left[1 + \frac{2h}{\pi a \epsilon_r} \left\{ \ln \left(\frac{a}{2h} \right) + 1.41 \epsilon_r + 1.77 + \frac{h}{a} (0.268 \epsilon_r + 1.65) \right\} \right]^{1/2} \quad (1.2)$$

The value of ϵ_e is obtained by using

$$\epsilon_e = C(a, h, \epsilon_0 \epsilon_r) / C(a, h, \epsilon_0) \quad (1.3)$$

where, $C(a, h, \epsilon_0 \epsilon_r)$ and $C(a, h, \epsilon_0)$ are the total capacitances of the dominant TM_{11} mode of circular microstrip antenna with and without a dielectric substrate, respectively. These can be calculated as

$$C(a, h, \varepsilon_0 \varepsilon_r) = \frac{0.8525 \varepsilon_0 \varepsilon_r \pi a^2}{h} + 0.5 C_f \quad (1.4)$$

In the above equation, the first term is the main capacitance of the disc and the second term is the fringing capacitance, C_f , which is given by

$$C_f = 2a\varepsilon_0 \left[\ln\left(\frac{a}{2h}\right) + 1.41\varepsilon_r + 1.77 + \frac{h}{a}(0.268\varepsilon_r + 1.65) \right] \quad (1.5)$$

$C(a, h, \varepsilon_r)$ is calculated by putting $\varepsilon_r = 1$ in (1.4) and (1.5). For thin substrates, ε_r should be used instead of ε_e in (1.1), and for thick substrates ($h > 0.05 \lambda_0$), ε_e should be used [10].

1.3.1.1. Design Procedures

On the basis of the cavity model calculation, a design method is defined which creates practical designs of circular patch antennas for the dominant TM_{110}^z mode. In the design procedure, the permittivity of the substrate (ε_r), the height of the substrate h and the resonant frequency (f_r) and are previously known. A first-order approximation to the solution of equation (1.2) for ‘ a ’, is to find ‘ a_e ’ and to substitute that into equation (1.2) for ‘ a_e ’ and for ‘ a ’ in the logarithmic function.

To determine the actual radius ‘ a ’ of the patch the following formula is used [8]

$$a = \frac{F}{\left\{ 1 + \frac{2h}{\pi \varepsilon_r F} \left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726 \right] \right\}^{1/2}} \quad (1.6)$$

where,
$$F = \frac{8.791 \times 10^9}{f_r \sqrt{\varepsilon_r}}$$

1.3.2. Antenna Parameters

➤ **Return loss:** It is the difference between forward and reflected power, in dB, generally measured at the input to the coaxial cable connected to the antenna. If the power transmitted by the source is P_t and the power reflected back is P_r , then the return loss is given by P_r . For maximum power transfer the return loss should be as small as possible. This means that the ratio P_r/P_t should be as small as

possible, or expressed in dB, the return loss should be minimum. Return Loss is determined in dB as follows [9]

$$RL = -20 \log |\Gamma|, \quad \text{Here } |\Gamma| = V_0^- / V_0^+ = (Z_L - Z_0) / (Z_L + Z_0) \quad (1.7)$$

where $|\Gamma|$ is the reflection coefficient,

V_0^- is the reflected voltage,

V_0^+ is the incident voltage,

Z_L and Z_0 are the load and characteristic impedance.

- **Directivity:** It is defined as the ratio of radiation intensity in a given direction from the antenna to the radiation intensity averaged over all the directions. The average radiation intensity is equal to the total power radiated by the antenna divided 4π . If the direction is not specified, the direction of maximum radiation intensity is implied. The directivity of the non-isotropic source is equal to the ratio of its radiation intensity in a given direction over that of an isotropic source. In numerical form, directivity is given by [9]

$$D = U/U_0 = 4\pi U_{\max} / P_{\text{rad}} \quad (1.8)$$

where, U is the radiation intensity (W/unit solid angle), U_0 is the radiation intensity of an isotropic antenna (W/unit solid angle), U_{\max} is the maximum radiation intensity (W/unit solid angle) and P_{rad} is the total power radiated (W).

- **Gain:** It is defined as the ratio of the intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna is radiated isotropically. The radiation intensity corresponding to the isotropically radiated power is equal to power accepted (input) by the antenna divided by 4π . When the direction is not stated, the power gain is usually taken in the direction of maximum radiation [7]

$$\text{Gain} = 4\pi \frac{\text{radiation intensity}}{\text{total input power}} \quad (1.9)$$

- **Bandwidth:** It is defined as “the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard.” The bandwidth can be considered to be the range of frequencies, on either side of a center frequency (usually the resonance frequency for a dipole), where the antenna characteristics (such as input impedance, pattern,

beam-width, polarization, side lobe level, gain, beam direction, radiation efficiency) are within an acceptable value of those at the center frequency [6].

- **Beam width:** The beamwidth of a pattern is defined as the angular separation between two identical points on opposite side of the pattern maximum. In an antenna pattern, there are a number of beam widths. One of the most widely used beamwidths is the Half-Power Beamwidth (HPBW) i.e. the angle between the two directions in which the radiation intensity is one-half value of the beam.
- **Efficiency:** It is used to take into account losses at the input terminals and within the structure of the antenna. Such losses may be due, to
 1. Reflections because of the mismatch between the transmission line and the antenna
 2. I²R losses (conduction and dielectric)

In general, the overall efficiency can be written as

$$e_0 = e_r \times e_c \times e_d \quad (1.10)$$

where, e_0 is the total efficiency (dimensionless)

e_r is the reflection(mismatch) efficiency

e_c is the conduction efficiency (dimensionless)

e_d is the dielectric efficiency (dimensionless)

1.3.3. Feeding Methods

Various types of feeding techniques are used in microstrip patch antennas. The standard feeding methods used in designing of microstrip patch antennas are, microstrip line feeding, coaxial-probe feeding, aperture-coupled feeding and proximity-coupled feeding [6].

- **Microstrip line feeding:** The microstrip feed line is a conducting metallic strip, generally of much shorter width as compared to the radiating patch. This feeding method has the advantage that it has ease of fabrication because it is on the same plane as of the radiating patch. The disadvantage of this feeding technique is that the spurious radiations and surface waves from the feed line, which causes a rise in the cross-polarization level.

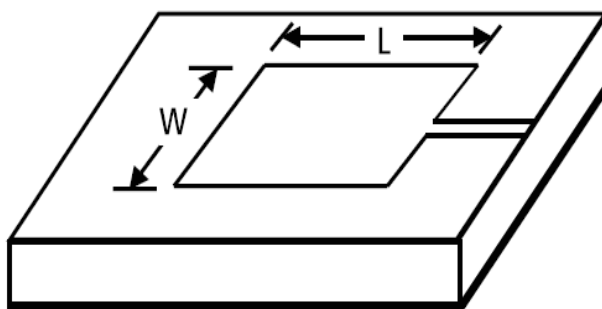


Fig. 1.4. Microstrip line feeding [10].

- **Coaxial-probe feeding:** In the coaxial or probe feeding technique, the center conductor of the coaxial connector is connected to the patch. This feed can be placed at any suitable place within the patch for matching with its input impedance. The major drawback of the coaxial probe feed is that it is not exactly planar because to connect the ground and the patch a hole is made in the dielectric substrate and the connector extends outside ground plane. .

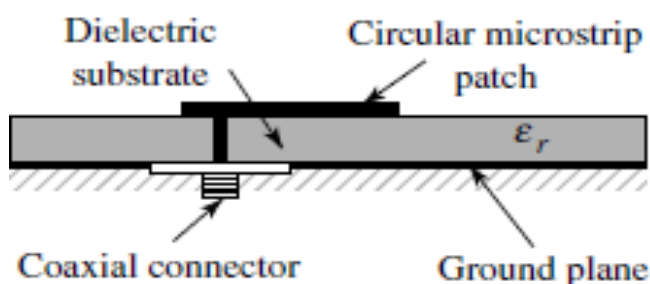


Fig. 1.5. Coaxial-probe feeding [7]

- **Proximity-coupled feeding:** In the proximity coupling technique, the feed line is located between the patch and the ground plane, which are separated by two dielectric substrates. The spurious feed radiations get eliminated by using proximity coupled feeding technique. In this method two dielectric substrates are used, so two different dielectric materials can be used, one for the patch and the other for the feed line to optimize the individual performances. There is an increase in the bandwidth as there is an increase in the overall substrate thickness of the microstrip antenna. The drawbacks are that the two substrates need to be lined up exactly and that the overall thickness of the antenna increases [9].

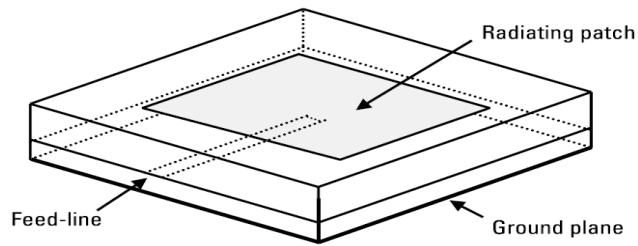


Fig. 1.6. Proximity-coupled feeding [10]

- **Aperture-coupled feeding:** In the aperture-coupled feeding technique, the electromagnetic coupling from the microstrip feedline to the radiating patch is done via small aperture or slot cut in the ground plane. The coupling aperture or the slot cut is generally placed beneath the patch which leads to minimize the cross-polarization level because of symmetry of the configuration. The amount of coupling from the patch to the feed line is decided by the shape, the size, and the location of the aperture [8].

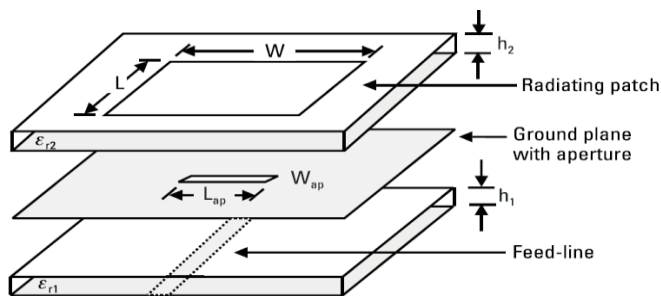


Fig. 1.7. Aperture-coupled feeding [10]

1.3.4. Ultrawide Band (UWB) Microstrip Antennas

After years of research studies on ultrawide band wireless communication systems, a large number of applications have been found in short range and high speed wireless systems such as, in military applications, medical applications, radars, robotics and other wireless communication systems like personal area networks, wireless local area networks and wide area networks. In 2002, the Federal Communication Commission (FCC) in United States allocated the band in the range from 3.1 to 10.6 GHz having the equivalent isotropically radiated power (EIRP) less than -41.3dBm/MHz for unlicensed radio communication in UWB applications [11]. For the operation of these systems such antennas are required which can function over a wide range of

frequency as well as give good radiation characteristics across the bandwidth [12]. In these systems, the antenna acts as a bandpass filter and have tendency to transform the spectrum of the unmodulated signals. Usually, it is bit difficult to design an antenna to accomplish all the conditions in an ultrawide band communication system, such as ultrawide bandwidth, omnidirectional radiation patterns, high gain, high antenna radiation efficiency, and small size. But different configurations such as magnetic slot antennas, tapered slot antennas disc monopole antennas etc. makes it possible to achieve all above mentioned conditions that show the ultrawide band characteristics [11].

In the ultrawide band frequency range there exist other wireless narrowband standards like wireless local area network (WLAN) having frequency bands from 5.15 to 5.35 GHz and 5.725 to 5.825 GHz, Worldwide Interoperability for Microwave Access (WiMAX) having frequency band from 3.3 to 3.6 GHz, and other C-band systems having range from 3.7 to 4.2 GHz, which tends to cause undesired interference with the functioning of UWB systems. The existence of this undesired interference makes it necessary to append other operations to UWB systems, such as including a stop band filter to remove the adverse interference from the system. But this addition of the stop band filter needlessly enlarges the size of the UWB systems. So, to reduce the size of these systems, ultrawide band antennas are required to be possessed of band-notched property at the interfering frequency bands. Various techniques such as inverted U-shaped strips, multipurpose admittance matrix (MAM) and genetic algorithm, vertical coupling strip, symmetrical slots, pi-slot, a pair of T-shaped strips, an E-shaped slot on the patch, Γ -shaped stubs in the radiation patch, a modified G-slot defected ground structure in the feeding line, and L shaped slits make it possible for UWB antennas to have band notched properties without increasing the size of the system. The main drawbacks of the above mentioned planar microstrip antenna structures are, they shows a single notched-band characteristic, polarization is linear and they cover a relatively more area [13].

1.3.5. Advantages of Microstrip Patch Antennas

- Light weight, low volume and low profile configurations, which can be transformed.
- Low fabrication cost, readily available for mass production.

- Linear and circular polarizations are possible with simple feed.
- Dual-frequency and dual-polarization antennas can be conveniently made.
- No cavity backing is needed.
- Can be easily integrated with microwave integrated circuits.
- Feed lines and matching networks can be fabricated together with the antenna structure.

1.3.6. Limitations of Microstrip Patch Antennas

- Narrow bandwidth and related tolerance issues are there.
- Gain is less.
- Large ohmic loss is there in the feed structure of the arrays.
- Mostly microstrip antennas radiate in the half-space.
- Complex feed structures are needed for high-performance of the antenna arrays.
- Polarization purity is hard to obtain.
- Microstrip antenna has poor end-fire radiations, excluding tapered slot antennas.
- Additional radiations are emitted by feeds and junctions.
- Less power control capacity.
- Higher levels of cross-polarization and mutual coupling are present in array environment at higher frequencies.
- Excitation of surface waves is likely to happen.
- Microstrip antennas fabricated on a substrate with a high dielectric constant are strongly desired for simple integration with MMIC RF front-end circuitry. Though, the use of high dielectric constant substrate gives poor efficiency and narrow bandwidth [8].

1.4. Objective of the Thesis

For short range and high data rate applications, wireless systems require ultrawide band microstrip antennas which operate in the frequency band of 3.1 to 10.6 GHz. But in the UWB frequency band there are some other frequency bands such as WLAN, WiMAX, C band etc. These bands can cause interference with the UWB band. Motivation behind this thesis is to present some antenna designs for ultrawide band applications. Some techniques are also presented to create single or dual notched bands to avoid the inference from these bands to UWB band. Objective of the presented thesis is:-

- To design a printed monopole microstrip patch antenna for ultrawide band applications.
- To design an UWB microstrip antenna for single band notched characteristics and present its parametric studies.
- To design an UWB microstrip antenna for dual band notched characteristics and present its fabricated design, measured and simulated results.

1.6. Methodology

- A printed patch antenna has been designed for UWB applications with notched band characteristics. In the design, a semi-circular patch is used and a dual stepped triangular patch is mounted upon it. These steps are made to enhance the bandwidth of the antenna. A partial ground plane is used in the design which also incorporates in bandwidth enhancement. To create a stop band to avoid interference from WLAN band, a slot has been cut in the shape of a circular arc on the circular patch.
- A printed monopole antenna has been designed for UWB systems with dual notched band characteristics. In the design, a trapezoidal shaped ground plane having a semi-circular notch has been used to obtain ultrawide bandwidth. To obtain dual notched band characteristics a mirrored E-shaped structure is inscribed inside a circular ring patch and an H-shaped parasitic element is etched above the ground plane on the bottom side of the antenna.

1.7. Thesis Organization

Thesis report is divided into six chapters.

Chapter 1 gives the introduction about present day wireless communication systems and their evolution. It covers basics of microstrip patch antennas and their various types. It also gives some insight to the UWB antennas and some techniques to obtain notched band characteristics. Equations used for the calculation of different antenna parameters are also given in this chapter.

Chapter 2 covers the literature survey of some circular microstrip antennas, ultrawide band antennas, ultrawide band antennas with band notched functionality.

Chapter 3 presents the design of a planar semi-circular disc monopole patch antenna for UWB applications. This antenna consists of a semi-circular patch with a stepped triangular patch mounted on it. A slot in the shape of an arc is cut on the semicircular patch to create a notched band. Simulated return loss, VSWR, gain and radiation patterns are shown and discussed in this chapter.

Chapter 4 presents the design of an ultrawide band printed monopole antenna with dual notched band characteristics. The antenna consists of a mirrored E-shaped structure inside the circular ring radiator and an H-shaped parasitic element above the patch to create two stop bands. Simulated return loss, VSWR, gain and radiation patterns are shown and discussed in this chapter.

Chapter 5 gives the fabricated design and measured results of the ultrawide band antenna with dual band characteristics. Simulated and the measured results are also compared and discussed in this chapter.

Chapter 6 includes the concluding remarks about the presented thesis report. It also gives the insight about some future works which can be done for the enhancement of output characteristics of UWB antennas.

LITERATURE SURVEY

This chapter gives us an insight about the advancement of the UWB Microstrip antennas and various research studies regarding them over the past few years.

2.1. Study of Circular Patch Antennas

In [14] a printed circular monopole patch antenna for UWB applications is studied. The -10 dB return loss bandwidth of the proposed patch antenna is in the range from 2.69 to 10.16 GHz i.e. 7.47 GHz bandwidth. Partial ground plane with a small feed gap is used in this configuration. It has been shown that the performance of the antenna can be optimized by changing the feed gap and the radius of the patch. Gain of the antenna is in the range from 3.5 to 6.7 dB. The antenna shows good omnidirectional radiation patterns over the whole frequency bandwidth.

A circular microstrip patch antenna consisting of a coupled annular ring structure with center feedings proposed [15]. The slot gap between the patch and the annular ring influence the magnetic coupling between them which leads to various operation bandwidths of the antenna. The resonance frequency of the antenna is 5.8 GHz having impedance bandwidth of 12.8% with a gain of 5.7 dBi. The antenna shows omnidirectional radiation patterns in which for the H-plane pattern the cross polarization level is 15 dB more as compared to the co-polarization level and the for the E-plane pattern the cross polarization level is nearly 18 dB less than the co-polarization level.

Dual frequency wideband circular microstrip patch antennas are discussed in [16]. These patch antennas are based on epsilon negative transmission line (ENG TL). Omnidirectional monopole type radiations are obtained by using infinite wavelength property. Basically the ENG TL unit cell is a mushroom like structure having a circular metallic patch which is grounded through a hole. The ENG antenna can be obtained by fixing these circular unit cells one over another with no gaps, under open boundary conditions. The -10 dB return loss impedance bandwidth of the antenna ranges from 4.99 to 6.08 GHz. The average gain of the antenna over the frequency bandwidth is 5.5 dB.

W. C. Lai *et al.* [17], presented a design of a circular patch antenna having multi-polarization properties and symmetric geometry. The antenna design consists of twelve PIN diodes which are located on a circular ring slot on the circular patch and by operating (switching on and off) these diodes in a specific manner, six linear polarizations (LPs) at 30° intervals can be created. By including the polarization diversity property, a receiving antenna can change its polarization effectively to match with the polarization of the receiving signals which maximizes the receiving power. The resonant frequencies for the six linear polarizations are in the range from 2.32 to 2.48 GHz and the gain of the antenna from 2.64 to 3.52 dBi. The resistance due to ON-state of the diode causes the loss of efficiency of the antenna and it can be enhanced by using good switches like MEMS switches.

The concept of equalization of the E-plane and the H-plane co-polarization radiation patterns of a circular patch antenna (CPA) is discussed in [18]. The radius of the patch and the ground plane size affect the radiation patterns of a circular patch antenna. The effective size of the patch is controlled by the dielectric constant of the substrate material of the antenna. So, by controlling the permittivity of the dielectric substrate of the antenna, the E-plane and the H-plane co-polarization radiation patterns can be equalized provided that there is an infinite ground plane. It is shown that for a given dielectric constant of the substrate, there is a particular ground plane size, which gives almost equal E-plane and H-plane co-polarization radiation patterns. In order to achieve equal radiation patterns, larger ground planes and high dielectric constant substrate materials are needed. The application of pattern equalization can be found in the global positioning systems (GPS).

A half circular patch antenna having a half circular ring is presented in [19]. In the antenna design both the half circular patch and the narrow half circular ring (having larger radius) are linked by the microstrip feed line in the centre. This antenna operates at two resonant frequencies, 0.9 and 1.8 GHz. The bandwidth characteristics of the antenna can be optimized by changing the radii of the ring and the patch of the antenna, lower resonant frequency will be obtained by the larger radius, and vice versa. The antenna gives a gain of 4.83 and 3.26 dBi at the two resonant frequencies, respectively. Since this antenna generates two resonant frequencies, it can find applications in personal communication devices where large bandwidth is not needed.

2.2. Microstrip Antennas for Ultrawide Band Systems

A compact single element ultrawide band microstrip antenna is discussed in [12]. The antenna consists of two parallel adjacent magnetically coupled sectorial loop antennas (CSLA) which are connected symmetrically. The frequency bandwidth of the antenna ranges from 3.7 to 11.6 GHz. The voltage standing wave ratio (VSWR) of the antenna is less than 2.2 for the frequency range 1.78 to 14.5 GHz, which means it provides a broadband impedance matching over an 8.5:1 frequency range. The antenna exhibits symmetric radiation patterns up to frequency 8 GHz but as the frequency increases, it becomes less directional and shows radiations in the other directions. Modifications in the design are made to reduce the size and the weight of the antenna without changing its bandwidth.

S.K. Jenget *al.* [11], proposed a planar microstrip antenna for ultrawide band systems. The antenna is composed of a broadband tapered slot feeding pattern and two curved metallic strips which act as radiators. At the feeding point a parasitic element is constituted to enhance the impedance matching of the antenna. It shows the impedance bandwidth of 7.5 GHz from 3.1 to 10.6 GHz. This antenna exhibits unstable radiation patterns with the variation of the frequency. Highest gain of the antenna is near about 7.3 dBi.

A dual polarized ultrawide band microstrip antenna is analysed in [20]. The feeding of the antenna is done using a square ring slot technique. It is optimized for the frequency range from 3.5 to 4.5 GHz and also it uses a back reflector to enhance its bandwidth characteristics. The coupling impedance to the patch gets affected by the cavity; also it adds capacitance between the back reflector and the ground plane. The gain of the antenna is in the range from 7.6 to 10 dB over the whole frequency bandwidth.

An ultrawide band printed monopole patch antenna having a coplanar waveguide (CPW) feeding technique is presented in [21]. The antenna bandwidth characteristics are studied by implementing the finite-difference time-domain (FDTD) methodology. Moreover, genetic algorithm (GA) is used to analyse the design of the printed monopole patch antenna to achieve the ultrawide-band characteristic. The -10 dB return loss bandwidth of the antenna ranges 3.3 to 10.55 GHz i.e. 7.25 GHz.

In [22], design of an ultrawide band microstrip patch antenna with an annular slot customized for radiation pattern diversity is proposed. The antenna composes of an annular slot on a square metallic patch. Also, to get radiation pattern diversity two ports are printed on the bottom side of the substrate of the antenna design. Two shorts are created on the patch of the antenna to achieve high isolation between ports; one is created between the feeding lines of the two ports and the other one is in its opposite position. By using the amount of the diversity gain and the power correlation coefficient between the ports, results of the radiation pattern diversity scheme is calculated. The -10 dB return loss impedance bandwidth of the antenna ranges from 3 to 12 GHz. This antenna can find applications in WiMAX, WLAN, HIPERLAN and many more.

R. K. Khokle *et al.* [23], presented a horizontally polarized microstrip patch antenna for UWB systems. The ultrawide band characteristics of the antenna are obtained by using a stepped microstrip feed line. The stepped feeding technique is used to lower the impedance given by the slot. If the step size is increased, the polarization purity will reduce. Both the length and the width of the stepped-slot on the ground plane affect the resonant frequencies as well as impedance matching of the antenna. The impedance bandwidth of the antenna ranges from 3.2 to 13.2 GHz giving a 10 GHz bandwidth. Lower resonant frequencies are obtained by the stepped-slot on the ground plane and the higher frequencies are obtained by the stepped microstrip feed line. The maximum gain attained by the antenna is 4.5 dBi.

Methods to improve the bandwidth of an ultrawideband monopole slot antenna are discussed in [24]. The first method is to cut slots on the ground plane of the antenna, due to which, additional resonant frequencies are generated which add up to the previously present resonant frequencies and thus enhance the bandwidth of the antenna. The second method is to cut new slots on the antenna and threading the conventional mushroom type electromagnetic band gap (CMT-EBG) structure; this will increase the bandwidth of the antenna. The impedance bandwidth obtained from the first configuration is 9.27 GHz which ranges from 1.73 to 11 GHz. The impedance bandwidth obtained from the CMT-EBG configuration is 9.47 GHz which ranges from 1.53 to 11 GHz. Addition of the new slots or the CMT-EBG structure has nominal effects on the radiation patterns. Average gain of the antenna is 3 dBi.

2.3. Study of UWB Patch Antennas with Band-Notch Characteristics

A small ultrawideband (UWB) printed microstrip patch antenna with dual band-notched characteristics is analysed. The antenna composes of a circular ring patch having a pair of Y-shaped resonant metallic structure implanted inside the radiating patch. The ground plane of the antenna is partial and of trapezoidal shape and a semi-circular notch is cut in the trapezoidal ground plane near the circular ring patch which enhances the wide band characteristics of the antenna by increasing the impedance matching. There is an inverted U-shaped parasitic element (IUSPE) above the ground plane. The antenna shows dual notched band characteristics. The first notched band at WiMAX or C band is due to the pair of Y-shaped structure inside the patch. By changing the radius of the circular ring patch, notched band can be adjusted for rejection of WiMAX or C band. The second notched band is at WLAN band which is due to the presence IUPSE above the ground plane [13].

Design of an ultrawide band printed monopole antenna is studied in [25]. The antenna design consists of a semi-circular radiating patch and above it there is another rectangular patch having two steps. Partial ground plane with a small feed gap is used in the antenna design. Also, there is a small circular slot on the radiating patch positioned slightly below the center of the semi-circular patch. The dimension of the feed gap and the radius of the circular slot influence the impedance matching between the microstrip feed line and the antenna. The impedance bandwidth characteristics of the antenna depend majorly on these two aforementioned parameters. There is an arc slot etched on the patch below the circular slot to get band notched characteristics from 5 to 6 GHz. The antenna radiates for an ultrawide bandwidth of 8.4 GHz ranges from 3 to 11.4 GHz.

In [26], a compact ultrawide band patch antenna having an L-shaped slot is proposed. The antenna design consists of an inverted F-shaped patch and a rectangular ground plane with an L-shaped slot. Wide impedance bandwidth can be achieved by adjusting the dimensions of the L-shaped slot on the ground plane of the antenna. The antenna gives the impedance bandwidth of 8.85 GHz in the range from 3.05 to 11.9 GHz. By changing the dimensions of the stubs of the radiating patch, notched bands can be obtained in the lower WLAN band (5.15 to 5.35 GHz) and the higher WLAN band (5.725 to 5.825 GHz).

In [27], a multiband planar printed monopole patch antenna for ultra-wide band (UWB) applications is presented. In the design of the antenna a chorded half circular radiator with is used to enhance the bandwidth. A tapered sickle-shaped slot is cut in the half circular radiator which gives band-notched characteristic to reject the WiMax band (3.4 to 3.69 GHz). The antenna operates in the frequency range of 1.5 GHz to 5.5 GHz. The gain of the antenna ranges from 0.7 to 3.2 dBi.

An ultrawide band printed monopole antenna with dual band notched functionality is discussed in [28]. The antenna consists of a microstrip-fed square radiating patch having a pair of L-shaped slots on the edges for single notched band characteristics for WLAN band (5.2 to 5.8 GHz), and an E-shaped slot at the center for dual notched band characteristics for WLAN band, WiMAX band (3.5 GHz or 5.5GHz) and C-band (4 GHz). A V-shaped extrude is created in the ground plane of the antenna to excite additional resonant frequencies which leads to enhancement of the bandwidth of the antenna. The angle between the V-shaped strips is very crucial for the excitement of the new resonant frequencies. The impedance bandwidth shown by the antenna ranges from 2.89 to 17.83 GHz.

Design of a microstrip patch antenna having parasitic elements for ultrawide band systems is studied in [29]. The antenna is consists of a half-circular patch constituted with a rectangular patch of the same width above it. By increasing the length of a rectangular patch, the lower frequency can be reduced more effectively thus enhancing the bandwidth characteristics of the antenna. Partial ground plane is used in the antenna design. Above the ground plane a combination of rectangular and semi-circular loop of parasitic element is embedded. This parasitic element creates a notched band from 5.13 to 5.85 GHz which corresponds to WLAN band.

A microstrip patch antenna with single and dual band notched functionality for ultrawide band applications is proposed in [30]. For single notched band characteristics, the antenna is designed by cutting a slot from the radiating patch and appending a single strip to it and the rejected band is controlled by the length, width and the position of the strips. This antenna design rejects the frequency band for 5.09 to 5.84 GHz. For dual rejection band characteristics, the antenna instead of single strip, two separated strips are added after cutting a slot on the patch. This antenna design rejects two bands which are 5.09 to 5.36 GHz and 5.72 to 5.825 GHz.

A design of an UWB microstrip antenna for band rejection characteristics by using parasitic elements is described [31]. The antenna design comprises of a half-circular disc radiating patch and the semi-circular ground plane which is in opposite direction as that of the radiating patch. By adjusting the radius of the semi-circular patch, the antenna gives ultrawide band characteristics. Also, there is a small gap between the patch and the ground plane. Four metallic strips, two on the each side (the top and the bottom) as parasitic elements are added in the radiating aperture of the antenna to obtain the rejection bands. The rejection bands are adjusted by changing the length and the position of the parasitic elements, so that three antenna designs are formed. First design gives a notched band from 5 to 6 GHz, the second design gives a notched band from 4 to 7 GHz and the third design gives three rejection bands which are from 4.5 to 5.5 GHz, 6.5 to 7.5 GHz, and 8.5 to 9.5 GHz. The impedance bandwidth of the antenna is from 3 to 11 GHz and the gain of the antenna varies from 0.2 to 3.9 dBi.

Methods for improving bandwidth of a printed monopole microstrip antenna with single and dual notched band functionality are discussed [32]. A microstrip fed rectangular radiating patch is used in the antenna design. For bandwidth enhancement, two of L-shaped slots are etched on the partial ground plane of the antenna. By adjusting the dimensions of these slots, new resonant frequencies can be generated which leads to enhancement of the bandwidth. For single notched band characteristics, a U-shaped parasitic element is used which is located above the ground plane. In this design, the horizontal part of the U-shaped element is perpendicular to the vertical portion of the radiating patch which makes the coupling between them weaker which leads to the rejection of a single band at WLAN band (5.1 to 5.9 GHz). For dual notched band characteristics, an E-shaped parasitic element is used above the ground plane which rejects two frequency bands from 3.35 to 4.15 GHz and 5.15 to 5.95 GHz for WiMAX and WLAN band.

A band notched microstrip antenna with circular slot for UWB systems is presented in [33]. The antenna consists of a circular ring radiating patch with a circular slot cut on the ground plane and above the patch there is a parasitic half-circular annular strip which is included to reject the WLAN frequency band 5.15 to 5.825 GHz. Also there is a T-shaped element near the inner side of the circular ring patch which is responsible to reject C band 3.7 to 4.2 GHz. The antenna exhibits constant gain.

Reconfiguration ability to reject the frequency bands is obtained with the use of three PIN diode switches connected with the antenna. Two PIN diodes are positioned at the edges of the parasitic metallic strip to connect the strip with the circular ring radiating patch. The third PIN diode joins the T-shaped element with the circular ring patch to control the rejection band at C band. By operating the PIN diode switches, the antenna can be switched to single notched band mode or dual notched band mode for rejecting WLAN and C band.

N.Ojaroudi *et al.* [34], proposed an ultrawide band antenna with dual notched band characteristics. The antenna comprises of a microstrip-fed square radiating patch with inverted T-shaped slot which gives an ultrawide bandwidth by generating some resonances at lower frequencies. Around the T-shaped slot there is another C-shaped slot at the bottom of the patch which gives a single band notch at WiMAX/C band (3.4 to 4.3 GHz). An inverted T-shaped parasitic element is added inside the inverted T-shaped slot at the center of the square patch, to obtain two notched bands at WLAN band (5.2 to 5.8GHz) and at WiMAX/C band (5 to 5.5 GHz). The impedance bandwidth of the antenna ranges from 2.71to 12.06 GHz.

In [35], an ultrawide band planar slot antenna with band rejection function is presented. The antenna design consists of a rectangular radiating patch with a tapered parasitic element above it. In the ground plane of the antenna there is a rectangular and a triangular slot, both the slots are constituted with each other. Inside the slot there is a pair of symmetric parasitic element. These parasitic elements cause two rejection bands at 3.5 to 3.8 GHz and 5.12 to 5.84GHz which are to stop interference from WiMAX and WLAN band respectively.

Design of a planar patch antenna having an I-shaped parasitic element for band notched characteristics for laptop functions is described in [36]. I-shaped parasitic stub is embedded on the bottom side of the antenna and it is electrically parted from the radiating patch and the ground plane. The electrical length of the I-shaped parasitic stub is nearly a half-wavelength of the centre frequency i.e. 5.49 GHz. A rectangular radiating patch is used in the design and the impedance matching is done by tapering the sides of the patch. The frequency band notched by the antenna is from 5.09 to 5.9 GHz. As the gap between the parasitic element and ground plane increases the notched band gets narrow due to less coupling between feed line and stub.

A microstrip slot antenna for exchangeable single and dual band rejection functionality for ultrawide band systems is discussed [37]. In the antenna design, two symmetrical improved slits are cut on the microstrip feed-line which generates extra resonant frequencies and gives wideband characteristics to the antenna. These slits disturb the current distribution in the microstrip feedline and vary the electromagnetic coupling between the ground plane and the feedline which generates additional resonant frequencies which can be altered according to the preferred frequency band by changing the size of the notches. In order to generate the notched bands a pair of inverted U-shaped slots is cut on the radiating patch of the antenna. To get exchangeable single/dual rejection bands PIN diodes are used as a switch. The notched bands generated by this antenna are at WiMAX/C band and WLAN band.

In [38], a small printed slot antenna with band notch properties for wideband applications is presented. The antenna design consists of a microstrip fed square radiating patch. A rectangular slot is etched on the feed line and inside that slot an S-shaped parasitic element is embedded which generates additional resonances, hence enhances the bandwidth of the antenna. In the square radiating patch, a square a lot is etched and a pair of L-shaped metallic strips of different sizes is placed inside it. The current get concentrated on the boundaries of the two L-shaped metallic strips at the rejection frequency, due to which high attenuation near that frequency can be generated as desired by changing the dimensions of the strips. The notched band generated by this antenna is in the range of 5.13 to 6.04 GHz. The return loss impedance bandwidth of the antenna is from 3.05to 12.76 GHz.

Y. Li *et al.* [39], a compact printed antenna with segmented patch for band rejection characteristics is proposed. In the antenna design, two symmetrical slots are cut vertically through the circular radiating patch which divides the patch into three parts. Basically, the side patches act as two different parasitic elements and there occurs a magnetic coupling between the side patches and the centre patch, which leads to the generation of a notched band. The parameters of the antenna design which affects the characteristics of the notched band are the position of slots from the center of the antenna, the gap between the side portions and the middle portion of the patch and the radius of the circular radiating patch. The antenna notched the frequency band from 5.1 to 6.1 GHz i.e. for the WLAN band.

Designs of four ultrawide band planar monopole antennas for notched band properties are described in [40]. In all the antenna designs, there is a CPW-fed semi-circular disc radiating patch on the upper side of the top of the dielectric substrate and a semi-circular ground plane on the lower side of the bottom of the substrate. There is a rectangular slot at the center of the patch. The first antenna design is for single wide notched band, the second is for single narrow notched band, the third is for dual notched bands and the fourth design is for triple notched bands. For single wide notched band, two strips are horizontally placed at the center line below the patch of the antenna. For single narrow notched band, a quarter wavelength slot is cut in the feed line just below the patch a strip is placed in it. For dual notched bands, two extra strips are added in the rectangular slot of the patch. For triple notched bands, two horizontal strips are placed additionally at the center of the antenna below the patch. These four antenna designs generate notched bands at 3.3 to 3.6 GHz, 5.15 to 5.35 GHz and 5.725 to 5.825 GHz frequencies.

DESIGN OF A PLANAR SEMI-CIRCULAR STEPPED TRIANGULAR MONOPOLE PATCH ANTENNA

A design of planar semi-circular disc monopole patch antenna for UWB applications is discussed in this chapter. The antenna comprises of a semi-circular disc with a dual stepped triangular patch. Also, a slot in the shape of a circular arc is cut on the circular patch which generates a notched band. The design of the antenna is explained in the following section.

3.1. Design of the Proposed Antenna

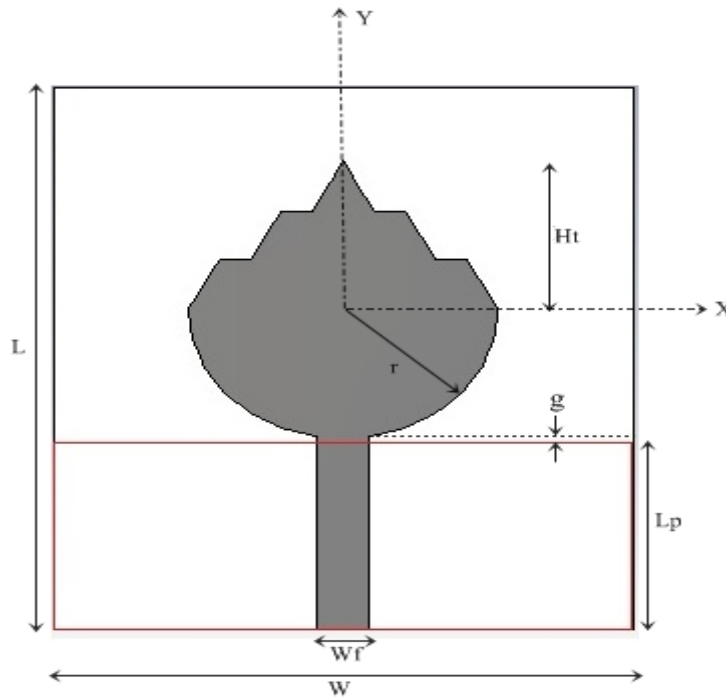


Fig. 3.1.Geometry of the antenna.

In the design of the antenna, a semi-circular patch of radius ‘ r ’ and a dual stepped triangular patch of height ‘ H_t ’ is mounted just above it. The steps on the triangular patch are symmetric and of same size. The patch of the antenna is fed by a 50Ω microstrip feed line having width ‘ w_f ’. Rogers RT duroid 5880 substrate with dielectric constant $\epsilon_r= 2.2$ is used in the antenna design. A partial ground plane of length ‘ L_p ’ is used to achieve UWB characteristics. The feed gap, which is the space between the feeding point and the partial ground plane, is ‘ g ’.

The dimensions of the antenna parameters are given below:-

Table 3.1. Dimensions of the antenna parameters.

Length of the substrate (L)	45 mm
Width of the substrate (W)	40 mm
Radius of the circular patch (r)	10.8 mm
Height of the triangular patch (H _t)	12 mm
Width of the feed line (W _f)	3.6 mm
Thickness of the substrate	1.575 mm
Length of the ground plane (L _p)	15.55 mm
Feed gap (g)	1 mm

3.2. Results and Discussions

3.2.1. Return Loss (S₁₁)

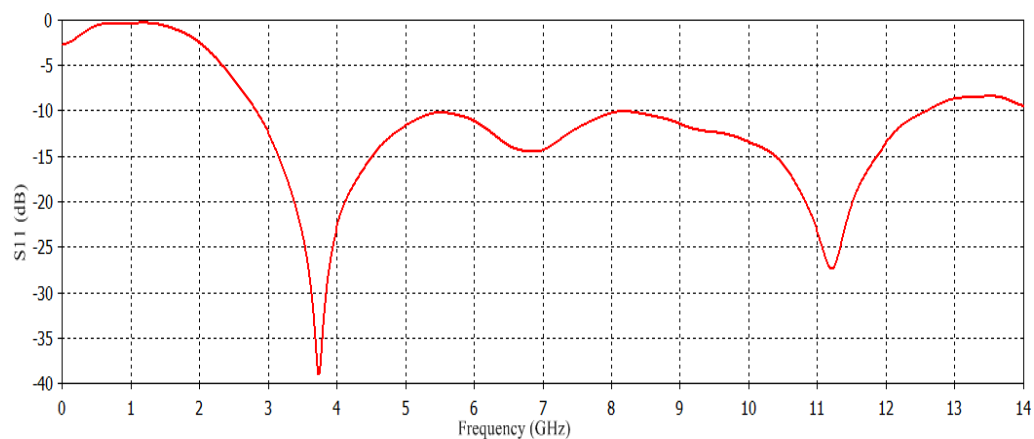


Fig. 3.2. Return loss (in dB) v/s frequency plot.

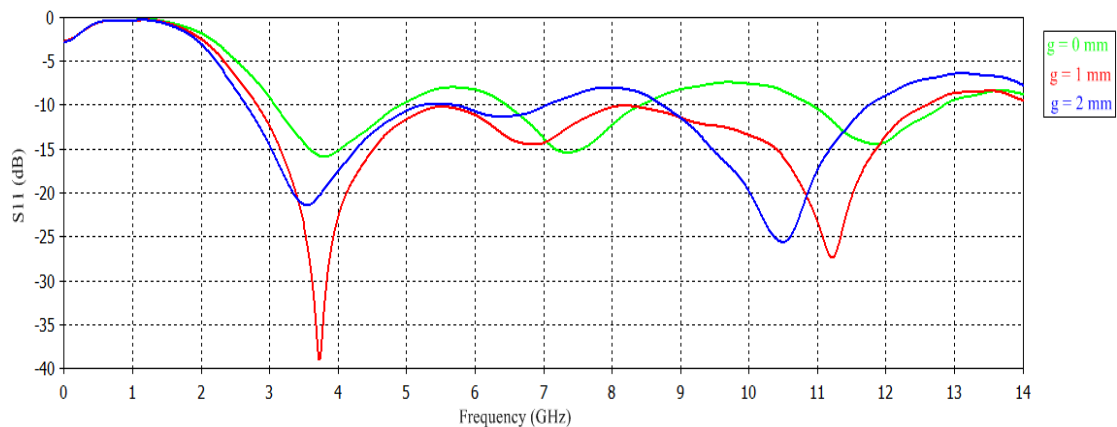


Fig. 3.3. Simulated return loss plot for $g = 0$ mm, $g = 1$ mm and $g = 2$ mm.

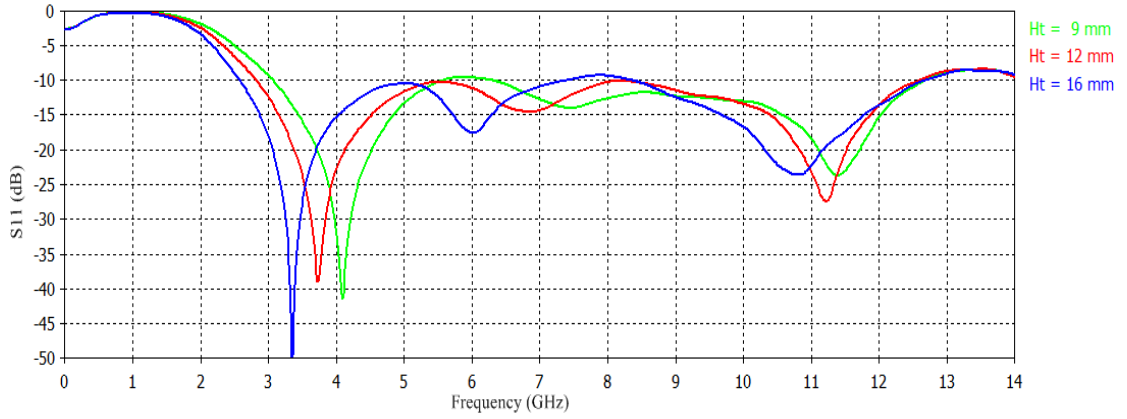


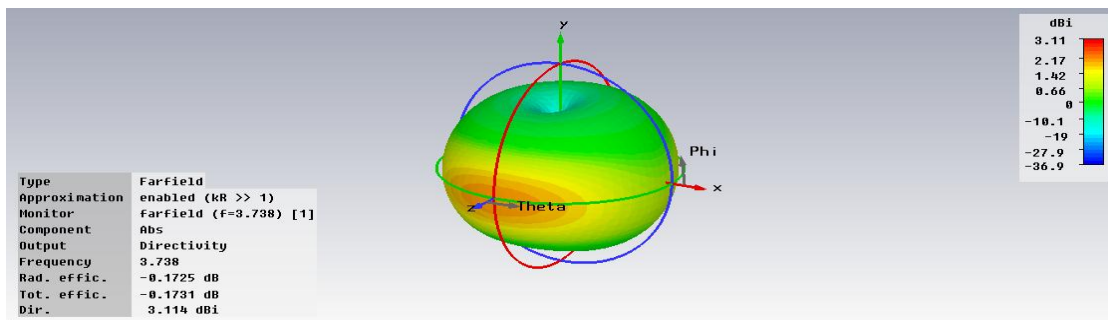
Fig. 3.4. Simulated Return loss plot for $H_t = 9$ mm, $H_t = 12$ mm and $H_t = 16$ mm.

The simulations are performed using CST Microwave Studio package [41]. The simulated return loss (S_{11} in dB) plot for the antenna is shown in Fig. 3.2. It can be observed from the plot that the -10 dB impedance bandwidth for the antenna is from 2.8 to 12.5 GHz, giving a total bandwidth of 9.7 GHz, which is an ultrawide bandwidth.

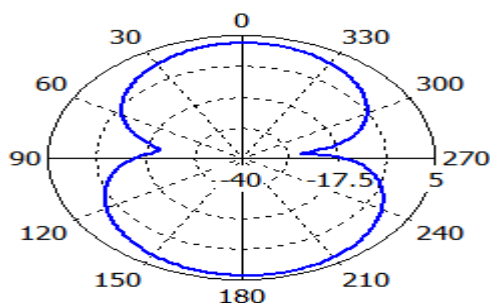
The triangular patch mounted on the top of the half circular patch is used in the design because triangular patch gives better suppression for side lobes than a rectangular patch [42]. The symmetric steps on the triangular patch in the proposed design increases the antenna perimeter without perturbing the current circulation of the antenna. Due to this, the surface current takes longer path and this decreases the lower resonant frequency which leads to obtain maximum frequency bandwidth [25]. The partial ground plane used in the antenna design enhances the bandwidth, because the current is majorly distributed in the upward direction (z - axis) on the top boundary of the ground plane. Due to this, the upper portion of the ground plane which is near to the circular patch work as the radiator for the antenna, which will eventually increase the bandwidth of the antenna [14].

Fig. 3.3 and Fig. 3.4 show the change in the return loss curve with the change in the feed gap (g) and the height of the triangular patch respectively. It can be noticed from the above plots that the feed gap and the height of the patch have much impact on the impedance bandwidth of the antenna. The return loss and the bandwidth of the antenna increase if the height of the patch is increased and vice versa. The optimum simulated results for the antenna come for the feed gap value $g = 1$ mm and the triangular patch height $H_t = 12$ mm.

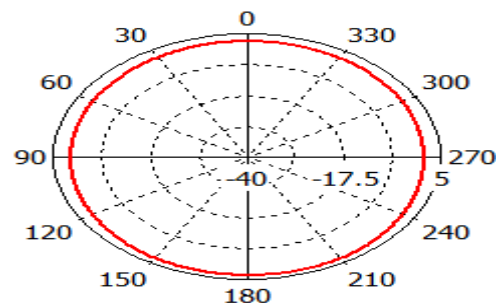
3.2.2. Radiation Patterns at Various Frequencies



(a)

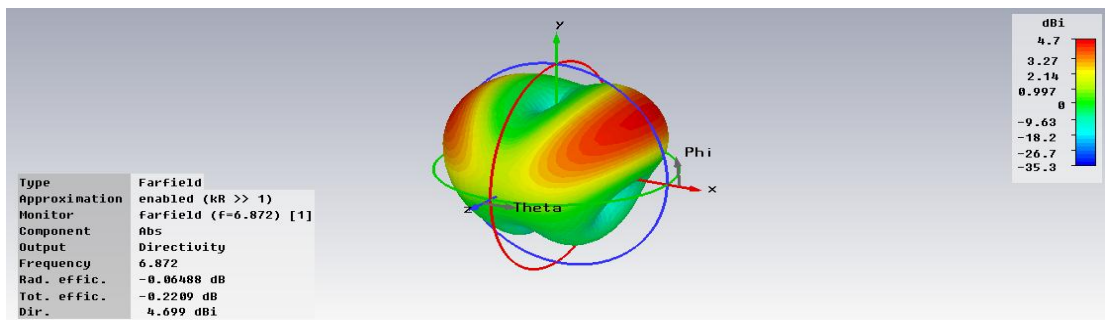


(b)

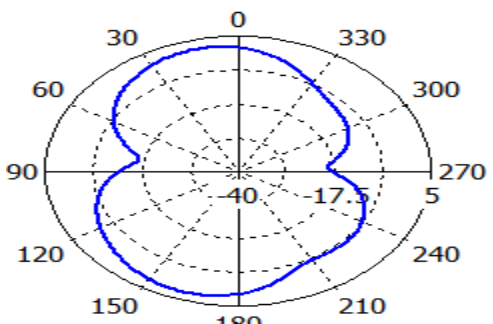


(c)

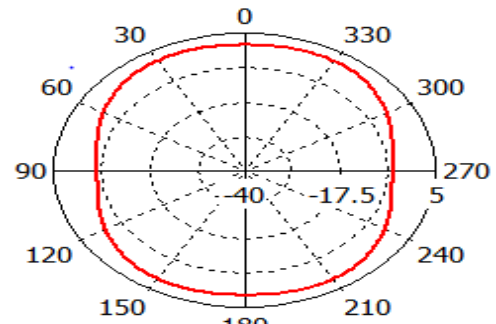
Fig. 3.5. Radiation patterns at $f = 3.7$ GHz (a) in three dimensions (b) E-plane (c) H-plane.



(a)

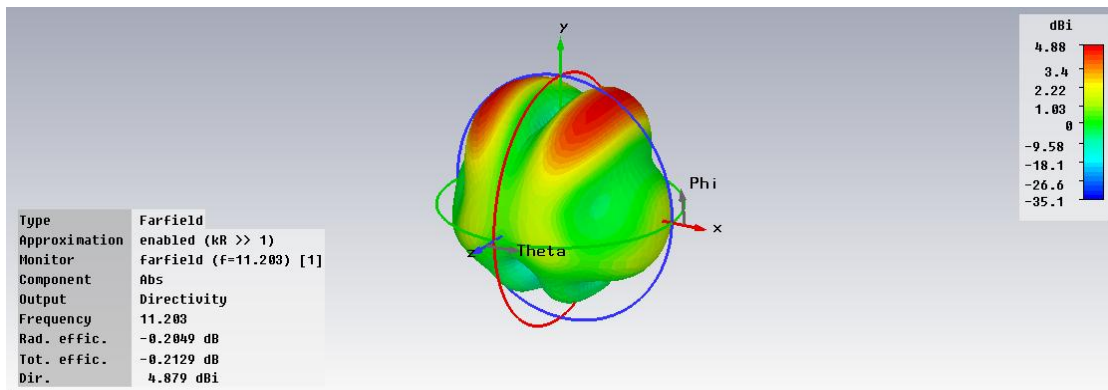


(b)

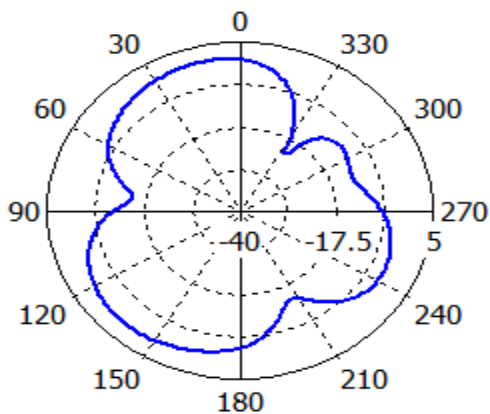


(c)

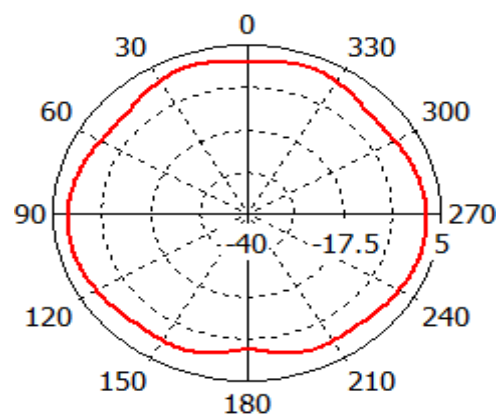
Fig. 3.6. Radiation patterns at $f = 6.9$ GHz (a) in three dimensions (b) E-plane (c) H-plane.



(a)



(b)



(c)

Fig. 3.7. Radiation patterns at $f = 11.2$ GHz (a) in three dimensions (b) E-plane (c) H-plane.

Normalized radiation patterns are calculated to show the antenna's performance at UWB frequency range. Fig. 3.5, Fig. 3.6 and Fig. 3.7 show the radiation pattern at frequencies 3.7 GHz, 6.9 GHz and 11.2 GHz respectively. E-plane, H-plane and three dimensional radiation patterns are shown in the figures.

It can be observed that H-plane radiation pattern is omnidirectional at lower frequency (3.7 GHz) and is almost omnidirectional at higher frequencies (6.9 GHz and 11.2 GHz). As from the figures, it can be observed that the E-plane radiation pattern becomes more directional with increase in the frequency. The antenna shows monopole type E-plane radiation pattern at frequency $f = 3.7$ GHz. E-plane patterns have a null in the broad side and the main beam is around 120° . The antenna shows stable H-plane radiation patterns throughout the bandwidth. On the whole, by observing these radiation patterns at all the frequencies, it can be concluded that the antenna works pretty same as most of the printed monopole microstrip antenna.

3.2.3. Gain of the Antenna

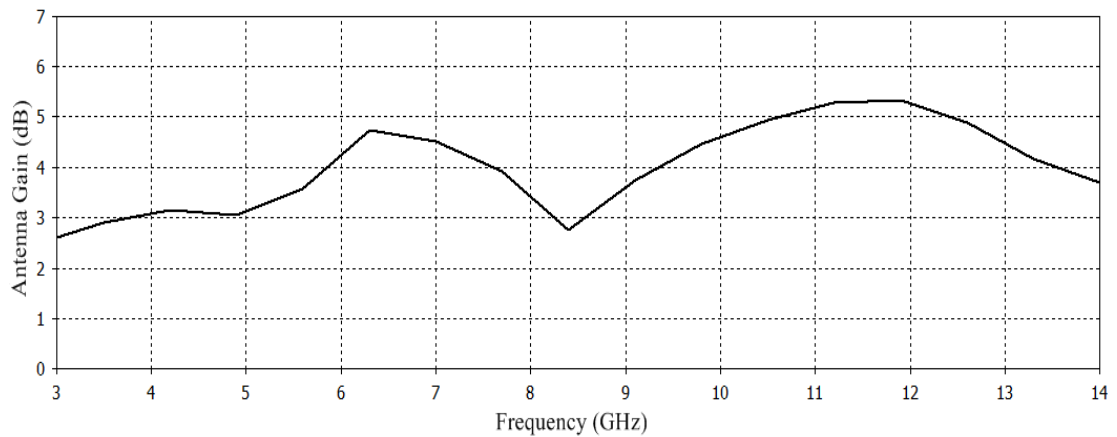


Fig. 3.8. Simulated antenna gain v/s frequency.

The antenna gain (in dB) versus frequency plot is shown in Fig. 3.8. From the plot it can be noticed that higher gain is obtained at higher frequencies. In the frequency band, the minimum gain is 2.8 dB at 8.4 GHz and the maximum gain is 5.3 dB at 11.9 GHz.

3.3. Antenna Design for Band Notched Characteristics

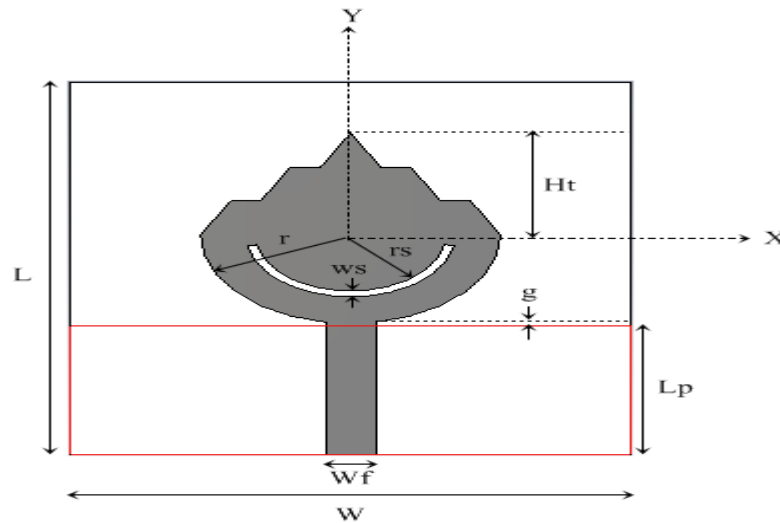


Fig. 3.9. Geometry of the antenna for notched band.

In order to obtain band notched characteristics a slot in the shape of an arc is cut on the circular patch above the feed point as shown in Fig. 3.9. The radius of the slot from the center of the circular patch is ' r_s ' and the width of the slot is ' w_s '. The angle of the arc slot is 160° . Notched band obtained by this design can be adjusted by changing the value of slot parameters.

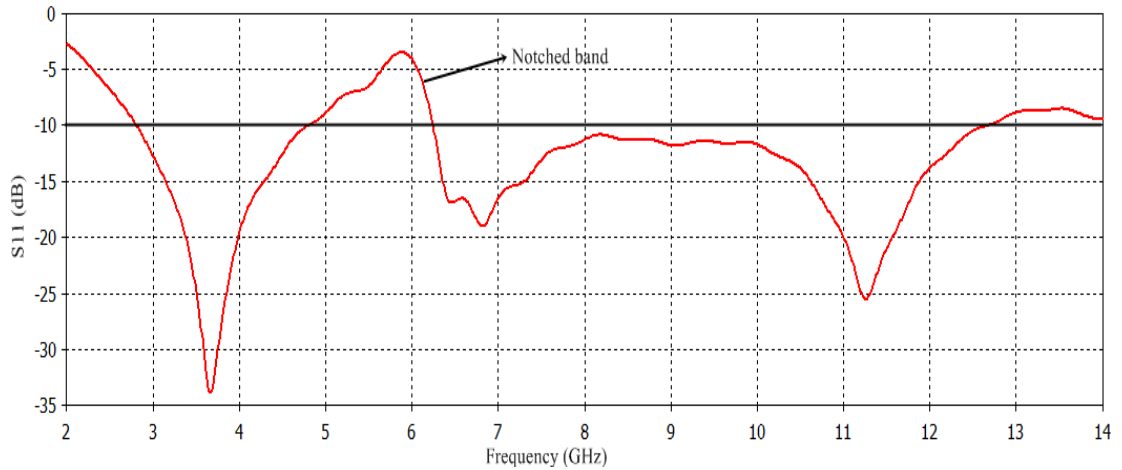


Fig. 3.10. Return loss v/s frequency plot showing the notched band.

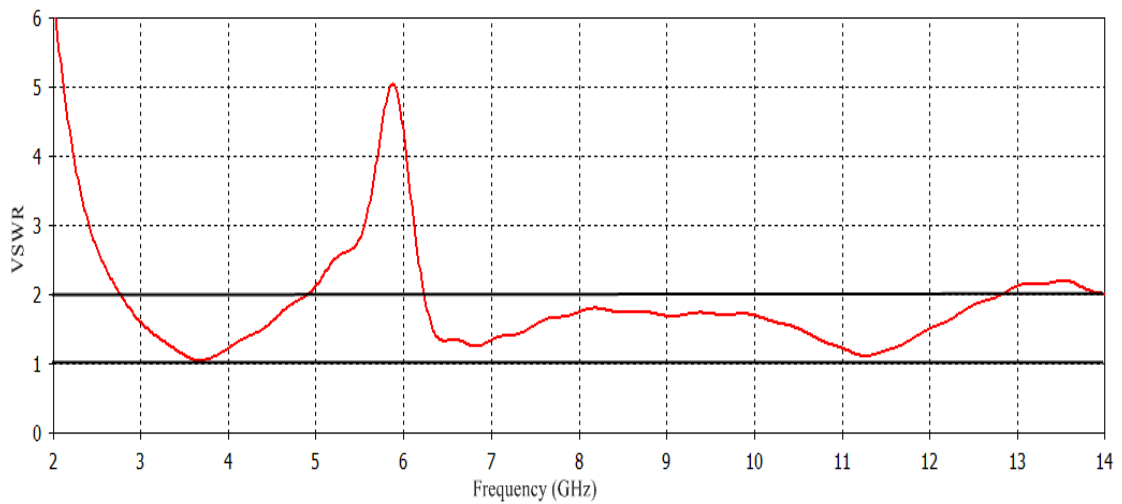


Fig. 3.11. VSWR magnitude of the antenna.

Return loss (S_{11}) in dB with respect to frequency plot is shown in Fig. 3.10. From the plot it can be noticed that by incorporating the slot in the antenna design a notched band is generated in the frequency range from 4.8 GHz to 6.2 GHz. The return loss curve for the above mentioned range is above -10 dB line. That means the antenna is not radiating for this frequency band and it will remove any interference causing from this band. The WLAN band ranges from 5.15 GHz to 5.825 GHz. So, this antenna will mitigate any interference from the WLAN band as it comes in the range of the notched band by the antenna. Simulated Voltage Standing Wave Ratio (VSWR) magnitude with respect to frequency is shown in Fig. 3.11. To show UWB characteristics by an antenna, it is required that the VSWR should remain in the range of 1 to 2 throughout the frequency band [43]. But, in the given plot the curve is above 2 in the notched band.

DESIGN OF AN UWB PRINTED MONOPOLE ANTENNA WITH DUAL BAND NOTCHED CHARACTERISTICS

Design of an ultrawide band printed monopole antenna with dual notched band characteristics is discussed in this chapter. Different techniques to create single or dual rejection bands are studied here. To create notched band at Worldwide Interoperability for microwave access (WiMAX) band, a mirrored E-shaped structure is inscribed inside the circular ring radiator. An H-shaped parasitic element is etched above the ground plane to generate a notched band at Wireless local area network (WLAN) band. The design of the antenna is explained below.

4.1. Design of the Antenna for Single Notch Band

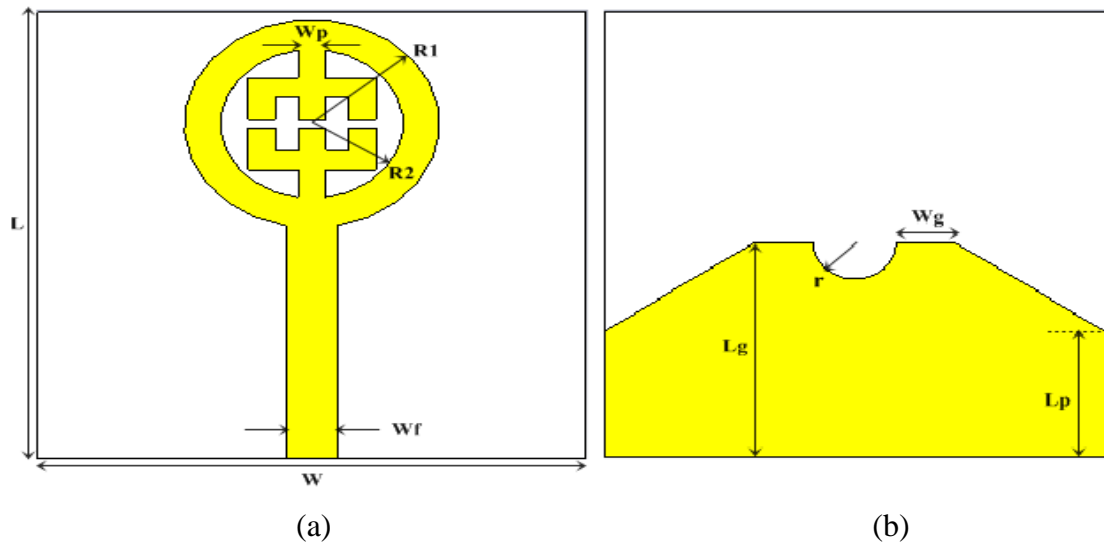


Fig. 4.1. Antenna design for single notched band (a) top view (b) bottom view.

In the design of the antenna, a circular ring patch is used with the outer radius ' R_1 ' and the inner radius ' R_2 '. An E-shaped mirrored structure is inscribed inside the ring patch with thickness ' W_p ' as shown in Fig. 4.1 (a). This structure is used to create a notched band. The patch is fed by microstrip line feed of width ' W_f '. FR4 substrate with $\epsilon_r = 4.3$ is used in the antenna design. On the bottom side of the antenna, there is a partial ground plane of trapezoidal shape having a semicircular notch (as shown in Fig. 4.1(b)) of radius ' r '. This notch is made to increase impedance matching.

Table. 4.1. Dimensions of the antenna parameters.

Length of the substrate (L)	30 mm
Width of the substrate (W)	30 mm
Thickness of the substrate	1.6 mm
Outer radius of the patch (R_1)	7 mm
Inner radius of the patch (R_2)	5 mm
Thickness of E-shaped structure (W_p)	1.5 mm
Width of the feed line (W_f)	2.8 mm
Radius of the notch (r)	2.5 mm
L_g	14 mm
L_p	8 mm
W_g	3.5 mm

4.2. Results and Discussions

4.2.1. Return Loss (S_{11})

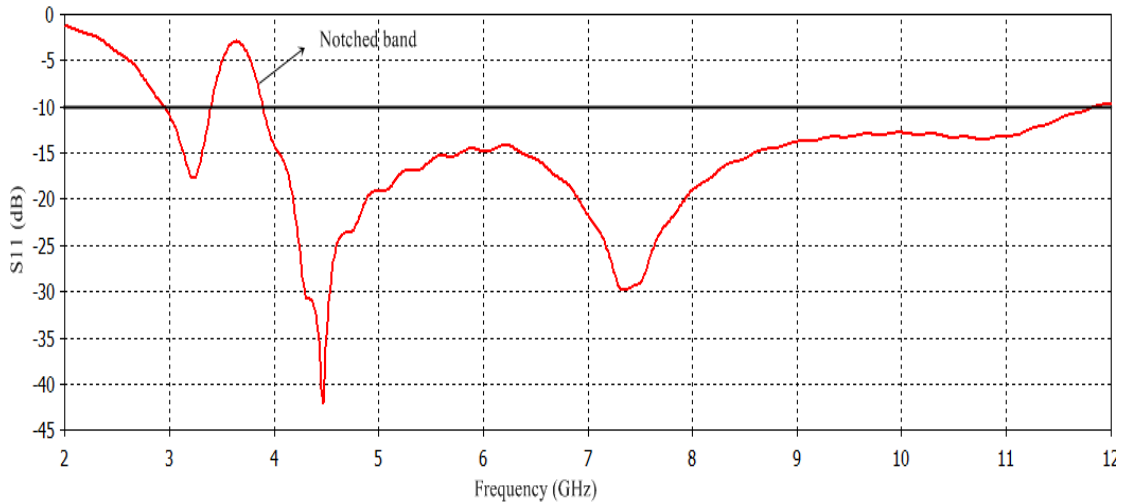


Fig. 4.2. Return loss (S_{11}) curve showing single notched band.

The simulations are performed using CST Microwave Studio package [41]. The simulated return loss (S_{11} in dB) plot for the antenna is shown in Fig. 4.2. It can be observed from the plot that -10 dB impedance bandwidth of the antenna is from 2.9 to 11.8 GHz, giving a total bandwidth of 8.9 GHz, which is an ultrawide bandwidth. A notched band is generated from 3.4 GHz to 3.9 GHz due to the presence of mirrored E-shaped structure inside the patch. This rejection band is created to mitigate the interference from the WiMAX band with center frequency 3.5 GHz.

4.2.2. Voltage Standing Wave Ratio (VSWR)

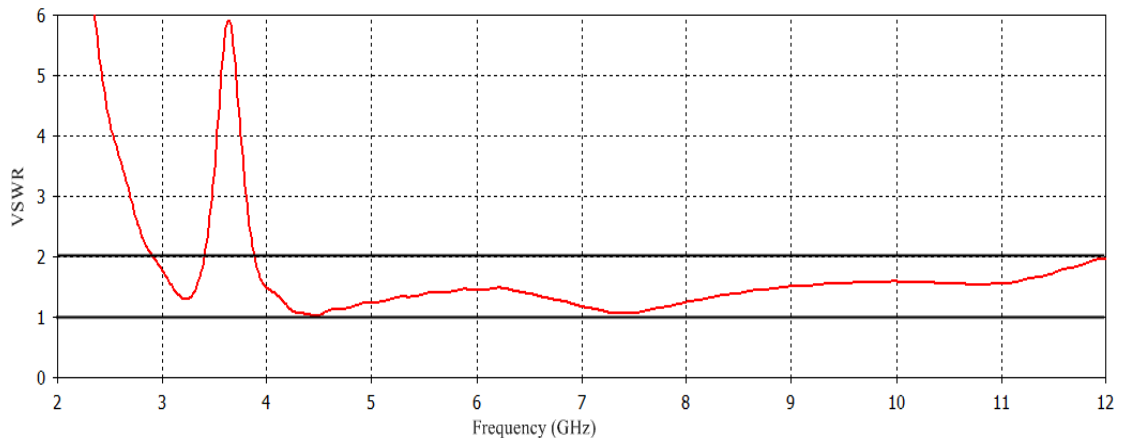


Fig. 4.3. VSWR versus frequency plot.

From Fig. 4.3, it can be noticed that the curve goes above the VSWR magnitude 2 for the notched band i.e. 3.4 to 3.9 GHz and remains between 1 and 2 for the rest of the frequency range.

4.2.3. Gain of the Antenna

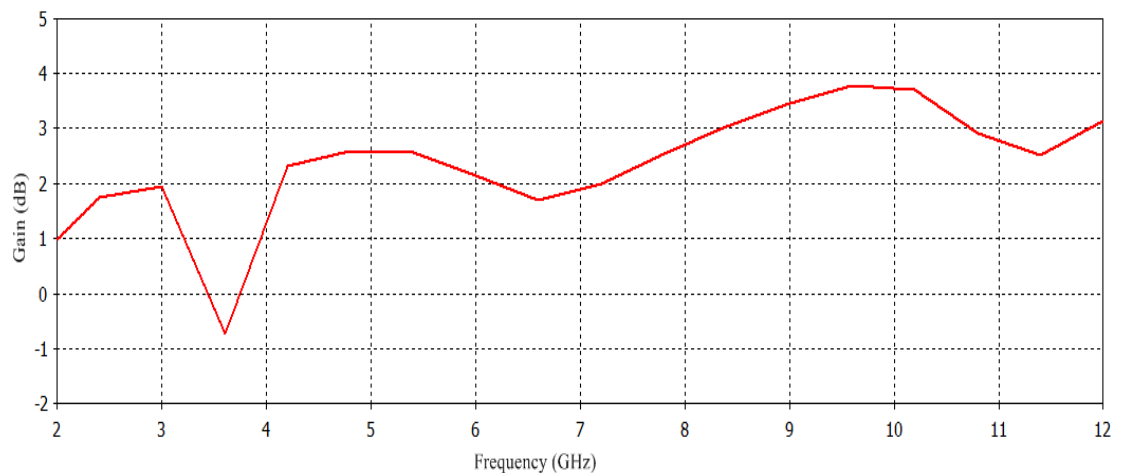


Fig. 4.4. Antenna gain (in dB) versus frequency plot.

From the antenna gain versus frequency plot (Fig. 4.4), it can be observed that the gain is increasing with the increase in frequency. Highest gain obtained is 3.8 dB at 9.6 GHz. For the notched band (3.4 GHz to 3.9 GHz), there is a drop in the gain up to -0.7 dB. The reason for the creation of this rejection band by using the E-shaped elements is that the direction of flow of the current in the circular ring radiator and the E-shaped elements becomes opposite to each other, thereby cancelling out the resultant radiation field vector [13]. Due to this cancellation of the fields, the antenna is not able to radiate in a particular frequency band i.e. 3.4 GHz to 3.9 GHz.

4.3. Design of the Antenna for Dual Notch Band

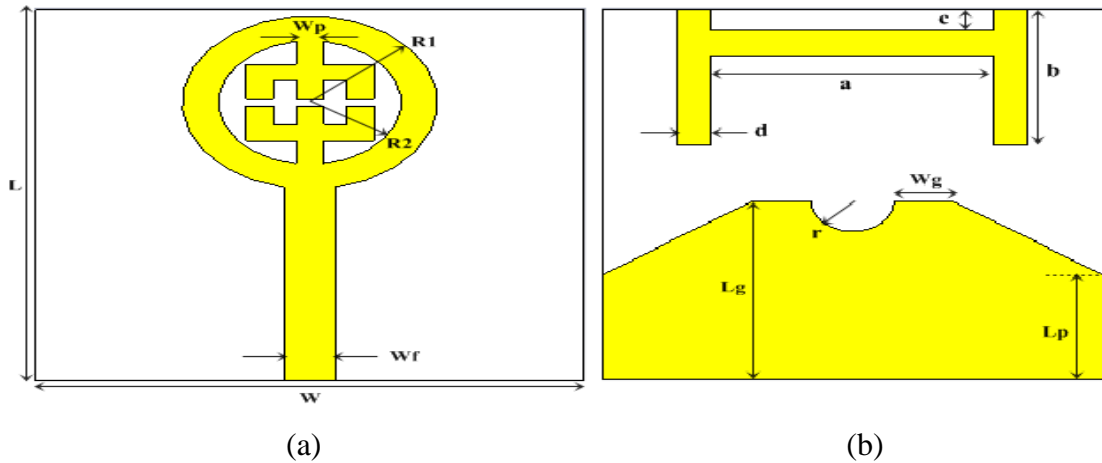


Fig. 4.5. Antenna design for dual notched bands (a) top view (b) bottom view.

To create two rejection bands an H-shaped parasitic element is etched on the bottom side of the substrate above the ground plane. Dimensions of the parasitic element are; $a = 17$ mm, $b = 11$ mm, $c = 1.7$ mm and $d = 2$ mm.

4.3.1. Return Loss (S_{11})

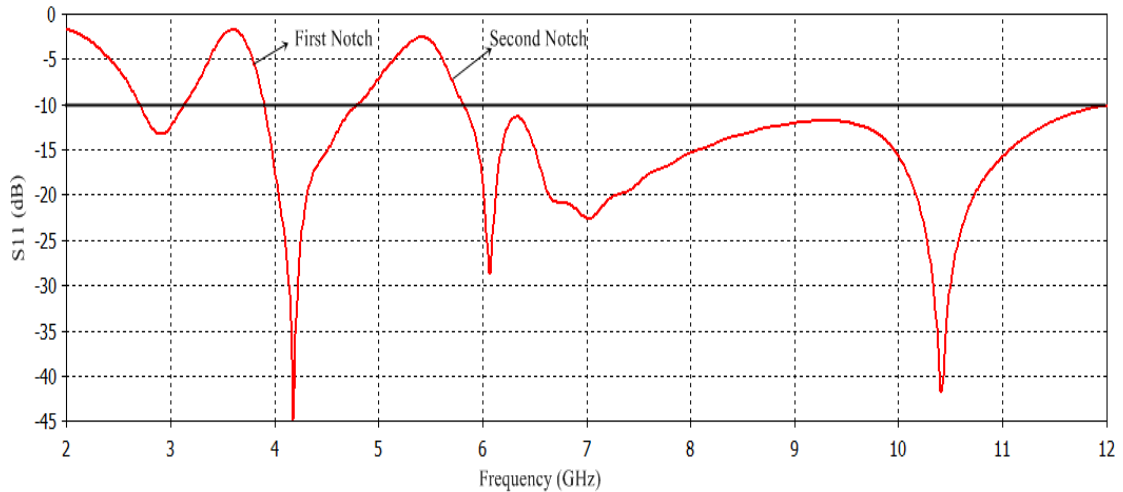
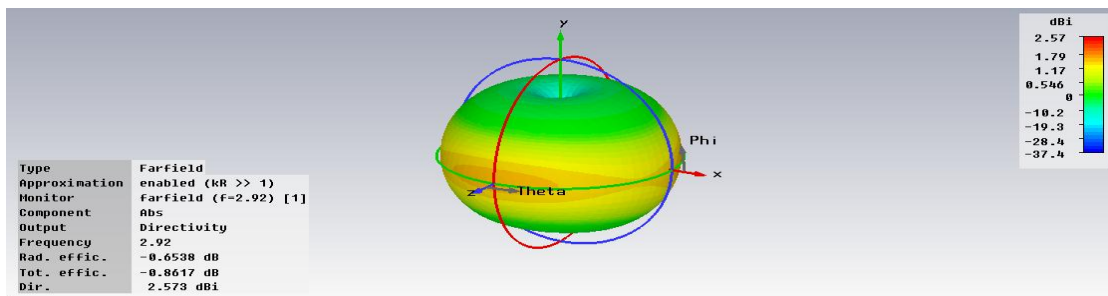


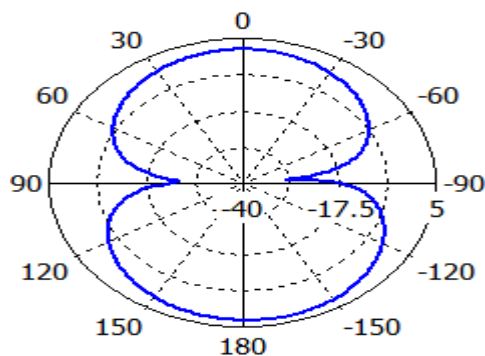
Fig. 4.6. Return loss (S_{11}) curve showing dual notched bands.

Simulated return loss for the whole frequency range is shown in Fig. 4.6. -10 dB return loss impedance bandwidth of the antenna is in the frequency range from 2.7 GHz to 11.95 GHz. As it can be noticed from the shown plot that there are two notched bands (above -10 dB line), one is from 3.12 GHz to 3.88 GHz and second is from 4.78 GHz to 5.84 GHz. The second notch is generated due to the use of the H-shaped parasitic element which creates a rejection band at WLAN band (5.15 GHz to 5.825 GHz). The first notch is for WiMAX band rejection.

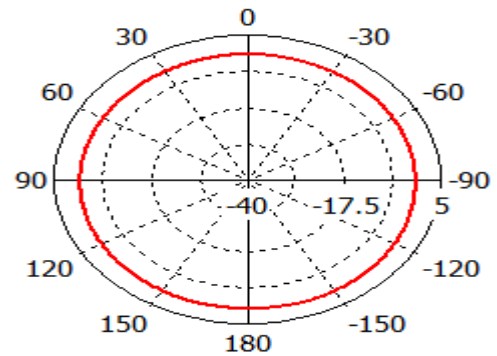
4.3.2 Radiation Patterns at Various Frequencies



(a)

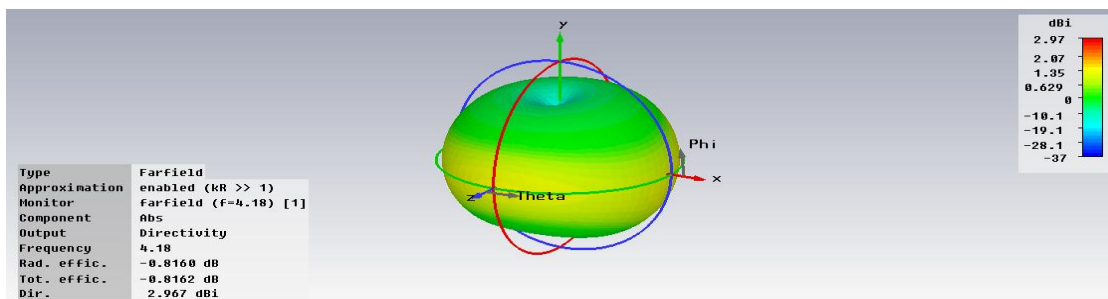


(b)

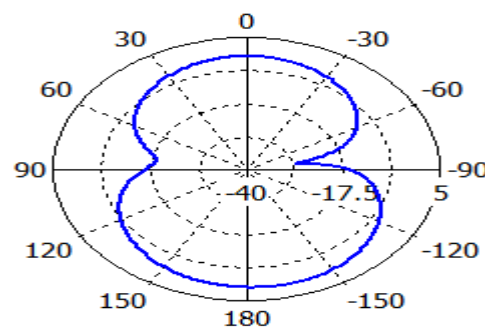


(c)

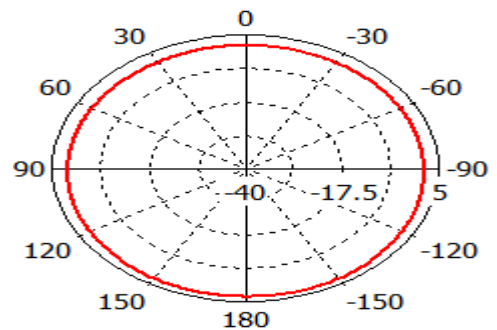
Fig. 4.7. Radiation patterns at $f = 2.92$ GHz (a) in three dimensions (b) E-plane (c) H-plane.



(a)

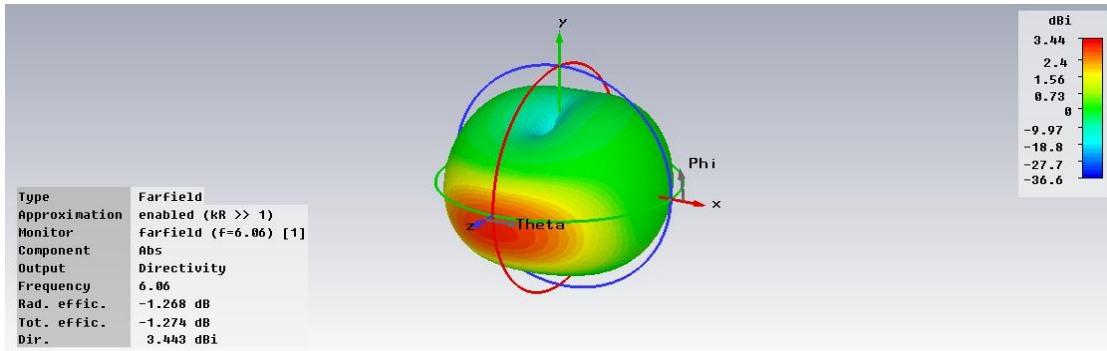


(b)

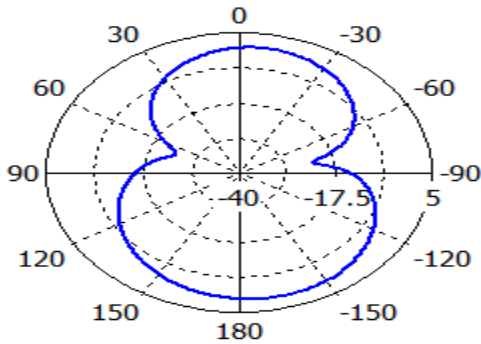


(c)

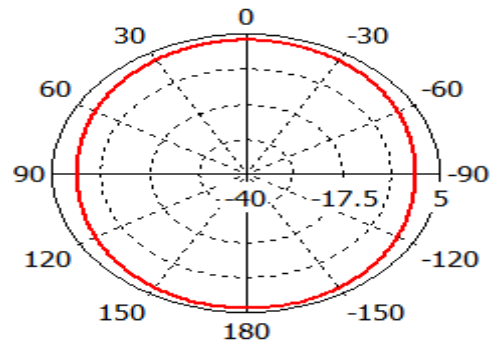
Fig. 4.8. Radiation patterns at $f = 4.18$ GHz (a) in three dimensions (b) E-plane (c) H-plane.



(a)

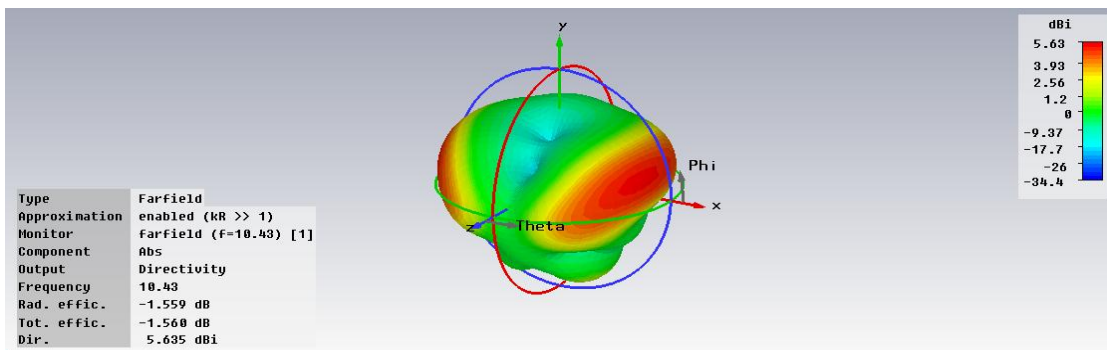


(b)

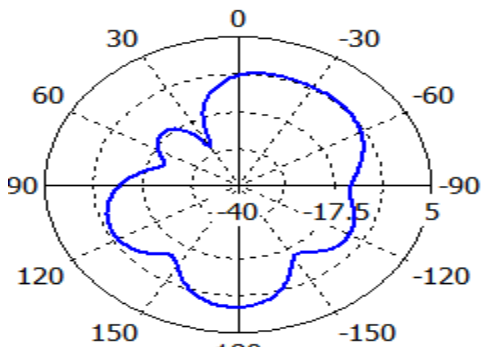


(c)

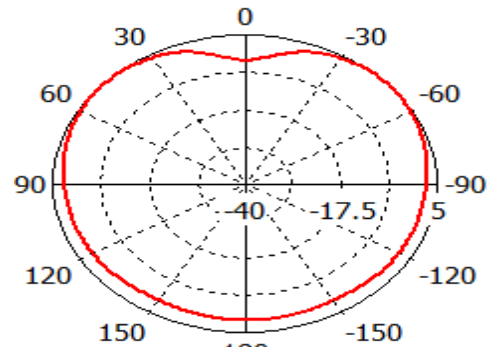
Fig. 4.9. Radiation patterns at $f = 6.06$ GHz (a) in three dimensions (b) E-plane (c) H-plane.



(a)



(b)



(c)

Fig. 4.10. Radiation patterns at $f = 10.43$ GHz (a) in three dimensions (b) E-plane (c) H-plane.

Normalized radiation patterns are calculated to show the antenna's performance at UWB frequency range. Fig. 4.7, Fig. 4.8, Fig. 4.9 and Fig. 4.10 show the radiation pattern at frequencies 2.92 GHz, 4.18 GHz, 6.06 GHz and 10.43 GHz respectively. E-plane, H-plane and three dimensional radiation patterns are shown in the figures.

It can be observed that H-plane radiation pattern is omnidirectional at lower frequencies (2.92 GHz and 4.18 GHz) and is nearly omnidirectional at higher frequencies (10.43 GHz). As from the figures, it can be observed that the E-plane radiation pattern becomes more directional with increase in the frequency. The antenna shows monopole type E-plane radiation pattern at frequency $f = 2.92$ GHz. The antenna shows stable H-plane radiation patterns throughout the bandwidth. On the whole, by observing these radiation patterns at all the frequencies, it can be concluded that the antenna works pretty same as most of the printed monopole microstrip antenna.

4.3.3. Voltage Standing Wave Ratio (VSWR)

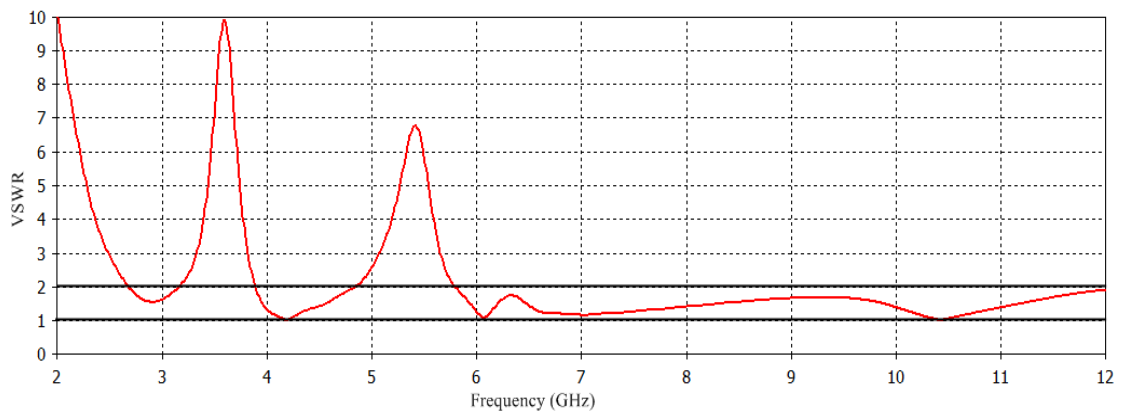


Fig. 4.11.VSWR v/s frequency plot.

4.3.4. Gain of the Antenna

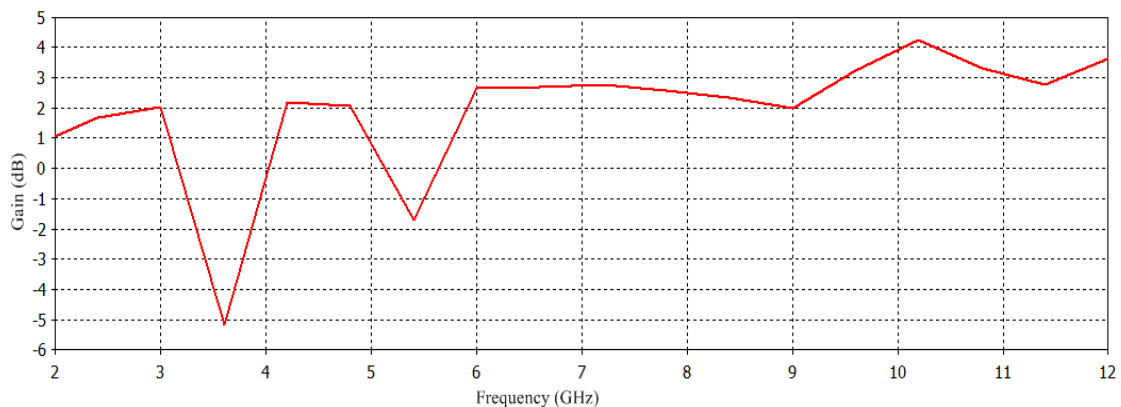


Fig. 4.12.Antenna gain for dual notched bands.

VSWR plot (Fig. 4.11) and the antenna gain plot (Fig. 4.12) clearly shows the dual notched band characteristics of the antenna. The VSWR curve is above 2 for the notched frequency bands 3.12 GHz to 3.88 GHz and 4.78 GHz to 5.84 GHz which shows that the antenna does not radiate in these bands.

The first band notch is due to the inclusion of the mirrored E-shaped structure inside the circular ring radiator of the antenna. The current directions in both are in opposite direction to each other due to which the radiation field vectors of both cancel each other and a band of frequency is created for which the antenna does not radiate. The second notch is due to the H-shaped parasitic element above the ground plane of the antenna. By the inclusion of the H-shaped element to the antenna design, the capacitance between the radiating patch and the element increases, this leads to storage of energy rather than radiating it and thus creating a notched band [13]. These bands can be adjusted by changing the dimensions of parameters of these elements.

The gain of the antenna drops to -5.3 dB and -1.8 dB for the two notched bands, as shown in Fig. 4.11. These drops in gain for the notched bands are due to the inability of the antenna to radiate in these frequency bands. It implies that the antenna has the potential to mitigate the interference from the WiMAX band and the WLAN band. The highest gain of the antenna is 4.2 dB at 10.2 GHz frequency.

FABRICATION, TESTING AND RESULT DISCUSSION OF UWB PRINTED MONOPOLE ANTENNA

In this chapter, fabricated design of an ultrawide band printed monopole antenna with dual notched band characteristics is presented. Testing of the antenna has been done on a vector network analyser (VNA). Measured results are also shown and discussed in this chapter.

5.1. Fabricated Antenna Design

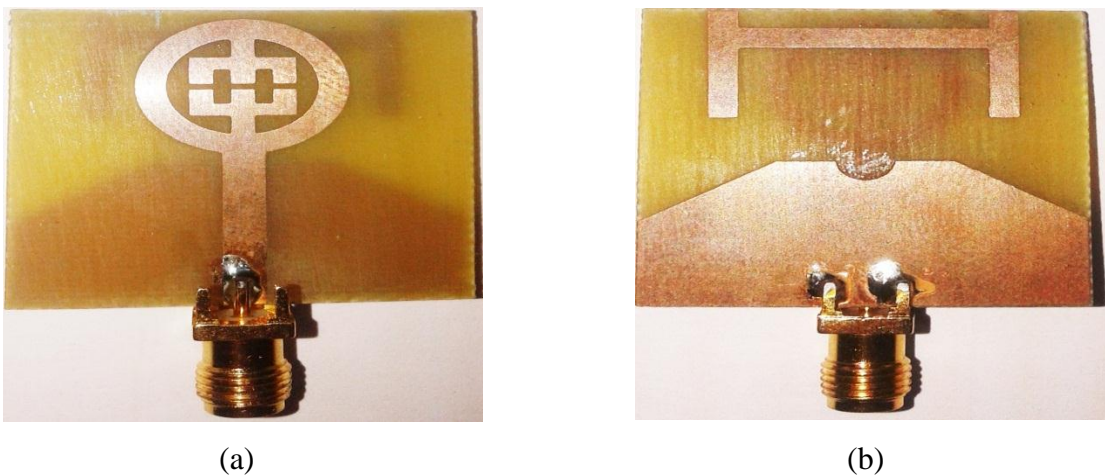


Fig. 5.1. Design of the fabricated antenna (a) top view (b) bottom view.

Fabrication of an antenna involves a process called printed circuit board (PCB) designing. Steps of PCB designing process:-

- Layout of the antenna is designed on a designing tool named OrCAD and its print is taken on a transparent paper to develop the negative of the design.
- A copper sheet is cut according to the dimensions of the substrate using a PCB cutter.
- Copper sheet is dipped in the photo resistive solution and then it is kept in the oven for drying for 10 to 15 minutes.
- The printed paper and the copper sheet are put under the ultraviolet (UV) rays to get the print of the design on the copper sheet.
- The PCB is washed in the etching solution which contains ferric chloride and it is washed afterwards.

5.2. Antenna Testing

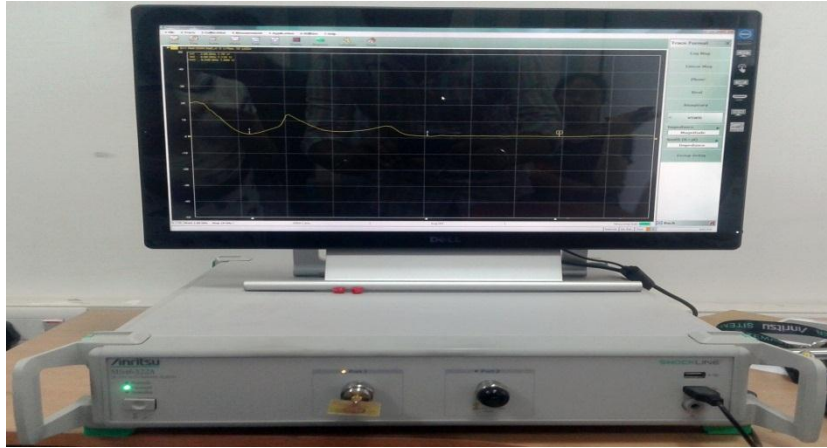


Fig. 5.2. Vector network analyser.

To test the antenna, a subminiature version A (SMA) connector has been soldered to the antenna as shown in Fig. 5.1. SMA connector helps to connect the antenna to the testing instrument for testing. Testing of the antenna has been done using vector network analyser (VNA) model Anritsu M546322A.

5.3. Measured Results and Discussions

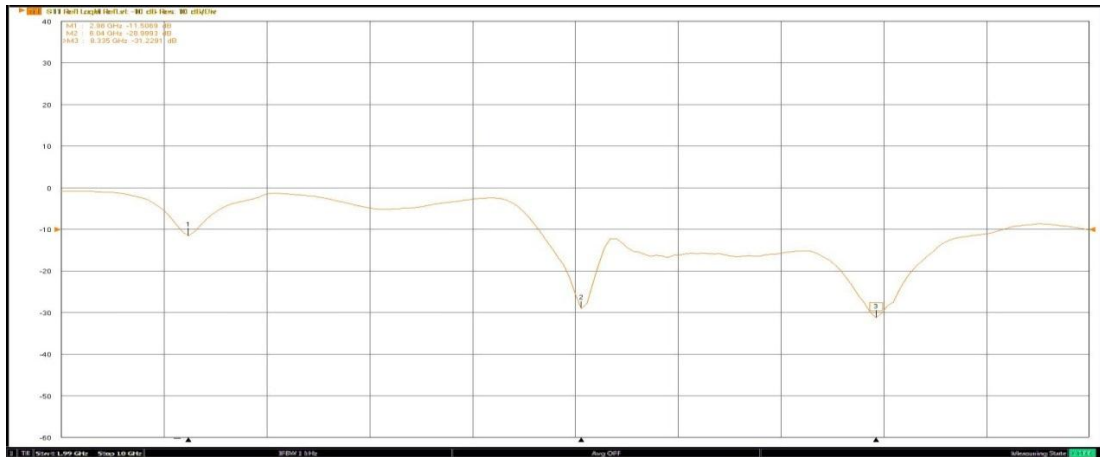


Fig. 5.3. Measured return loss of the antenna.

Measured return loss (S_{11} in dB) versus frequency plot is shown in Fig. 5.3. -10 dB return loss impedance bandwidth of the antenna is 8 GHz, ranges from 3.2 to 11.2 GHz. A stop band is generated by the antenna from 3.4 to 6.6 GHz for rejecting WiMAX, WLAN and C bands. Minimum return loss is -31 dB at 9.9 GHz. This stop band is due to the inclusion of the mirrored E-shaped structure inside the circular ring radiator and the H-shaped parasitic element above the ground plane of the antenna.

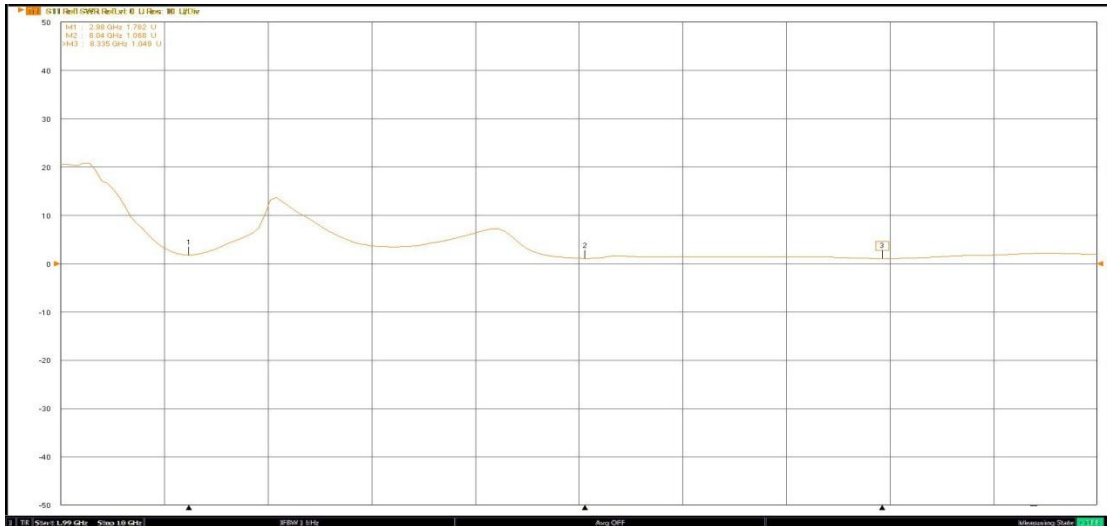


Fig. 5.4. VSWR versus frequency plot.

As shown in Fig. 5.4, the curve goes above VSWR magnitude 2 from 3.4 to 6.6 GHz. It means that the antenna has created a notched band does not radiate for this frequency range. The VSWR curve for rest of the frequency range is between 1 and 2 which shows that the antenna has a wide bandwidth and is suitable UWB applications. Some differences between the simulated results and the measured results have been noticed here. Simulated impedance bandwidth of the antenna 8.79 GHz, ranges from 2.9 GHz to 11.8 GHz. But the measured results show that the antenna operated in the frequency range from 3.2 to 11.2 GHz. Also, simulated results show that the antenna creates two stop bands, one is from 3.4 to 3.9 GHz and the other is from 4.78 GHz to 5.84 GHz for rejection of WiMAX and WLAN bands. But the measured results show only one stop band from 3.4 to 6.6 GHz. However, the S_{11} curve do lowers down towards -10 dB line near 5 GHz frequency but it doesn't cross it. These differences in the simulated and the measured results may be due to some fabrication errors or improper impedance matching between the antenna and the testing equipment.

CONCLUDING REMARKS AND FUTURE SCOPE

In this report, designs of two microstrip patch antennas for ultrawide band applications are discussed. These antennas were designed to create notch bands at the WLAN and WiMAX bands to mitigate the interference from these bands. These UWB antennas are compact and have applications for various short range communication systems. Conclusion of the report and the future work which can be done for the enhancement of output characteristics of UWB antennas are given in this chapter.

6.1. Concluding Remarks

In chapter 3, design of a UWB printed monopole semi-circular with stepped triangular antenna has been presented. -10 dB return loss impedance bandwidth of the antenna is 9.7 GHz which is in the range of 2.8 GHz to 12.5 GHz. Gain of the antenna varies from 2.8 dB to 5.3 dB over the frequency spectrum. Clearly, the designed antenna gives best performance for the feed gap of 1mm and the height of the triangular patch of 12 mm. To create a notched band, a slot in the shape of an arc is cut on the circular radiating patch. It gives a rejection band from 4.8 GHz to 6.2 GHz which is good for creating a stop band at the WLAN band (5.15 GHz to 5.825 GHz). Optimum results come for the radius of the slot from the center of the circular patch $r_s = 7.5$ mm and the width of the slot $w_s = 7$ mm. The antenna also shows good omnidirectional radiation patterns.

In chapter 4, design of a printed monopole antenna for UWB applications with dual notched band characteristics has been discussed. -10 dB impedance bandwidth of the antenna is from 2.9 to 11.8 GHz, giving a total bandwidth of 8.9 GHz. This antenna exhibits two notched bands, one is from 3.18 to 3.88 GHz and the other is from 4.78 to 5.84 GHz. These rejection bands are achieved to mitigate the interference from the WiMAX and WLAN band with the UWB frequency band of the antenna. Stop band at WiMAX band is obtained by using a mirrored E-shaped structure inside the circular ring radiating patch. To create a stop band at WLAN band, an H-shaped parasitic element above the ground plane is used. The antenna gives the ultrawide bandwidth using the trapezoidal shaped ground plane having a semicircular notch near the

radiating patch. The gain of the antenna drops to -5.3 dB and -1.8 dB for the two notched bands and the highest gain of the antenna is 4.2 dB at 10.2 GHz frequency. Good omnidirectional radiation patterns are shown by the antenna over the frequency bandwidth.

In chapter 5, fabricated design and its measured results of the above mentioned antenna are shown. Measured results show that the antenna operates in the range of 3.2 to 11.2 GHz frequency, giving a wide bandwidth of 8 GHz. One stop band from 3.4 to 6.2 GHz is generated by the antenna. Some differences between the simulated and the measured results have been noted. Simulated results show that the antenna operates for 8.9 GHz bandwidth from 2.9 to 11.8 GHz and creates two notched bands, one is from 3.18 to 3.88 GHz and the other is from 4.78 to 5.84 GHz for WiMAX and WLAN bands.

6.2. Future Scope

Various methods like cutting a pair of U-shaped slots and a C-shaped slot [44], including an inverted T-shaped element [45], a loaded arc shaped stub (LAS) [46] etc. can be used to create adjustable multiple notched bands. Metamaterials (MTMs) can be used for miniaturization of the antenna design [47]. Different techniques from electromagnetic band-gap (EBG) antennas, Fabry-Perot antennas (FPA) and resonant cavity antennas, LWAs can be used for directivity enhancement and spurious radiation reduction [48].

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