A TOMB SHAPED UWB ANTENNA WITH WLAN/WIMAX BAND REJECTION

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Submitted By

Akanksha Upadhyay

801661001

Under Supervision of

Dr. Rajesh Khanna
Professor

ELECTRONICS AND COMMUNICATION ENGINEERING DEPARTMENT

THAPAR INSTITUTE OF ENGINEERING & TECHNOLOGY
(A DEEMED TO BE UNIVERSITY), PATIALA, PUNJAB

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DECLARATION

I, Akanksha Upadhyay hereby declare that the work presented in this thesis entitled "**A TOMB SHAPED UWB ANTENNA WITH WLAN/WIMAX BAND REJECTION**" in fulfillment of the requirement for the award of degree of Master of Engineering submitted at Electronics and Communication Engineering department, Thapar Institute of Engineering & Technology (Deemed to be University), Patiala is an authentic record of work carried out under supervision of Dr. Rajesh Khanna (Professor, ECED, Thapar Institute of Engineering & Technology) from January 2017 to July 2018. The matter presented in this has not been submitted either in part or full to any other university or institute for the award of any other degree.

Date: 11 July 2018

Akanksha Upadhyay

It is certified that the above statement made by the candidate is correct to the best of my knowledge and belief.

Date: 11 July 2018

Dr. Rajesh Khanna
Professor, ECED
TIET, Patiala

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Akanksha Upadhyay
(801661001)

ABSTRACT

Ultra-Wideband is generally a technology for transmission of information scattered over a wide operating bandwidth. For decades it has been used mainly for military purposes. In the year 2002, a spectrum of 3.1 GHz - 10.6 GHz is assigned by Federal Communication Commission (FCC) to (UWB) technology for commercial use. Therefore from that time onwards UWB technology is considered as the most favourable technology for attaining high data rates, realising the dream of high speed wireless personal area network (WPAN) and providing good quality facilities to consumers.

In this thesis two antennas are designed and studied. CST STUDIO SUITE is employed to create prototype of antenna and do the simulations. First a tomb shaped microstrip patch antenna is designed for UWB applications. Antenna performance depends on various parameters of the tomb shaped microstrip patch antenna. Therefore an analysis is done to see the effect of various design parameters of the antenna on the return loss. Finally the designed antenna is fabricated and experimental results are shown. A comparison between simulated and experimental results is done.

As the power emission levels assigned to UWB systems by FCC are very low so they are easily interfered by neighboring communication systems. So a tomb shaped antenna having a capability to notch three bands is introduced next for use in UWB applications. Two identical L slots are inscribed in the coplanar ground to get the notched band. The notched band depends on various parameters of the L slots inscribed in ground of tomb shaped microstrip patch antenna. L slot parameters like length, width etc. are varied and return loss curves are plotted for comparing the impact of different values of the parameters. Finally the designed antenna is fabricated and experimental results are shown. A comparison between simulated and experimental results is done.

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LIST OF ABBREVIATIONS

FCC	Federal Communication Commission
UWB	Ultra Wideband
WPAN	Wireless Personal Area Network
WiMAX	World Interoperability for Microwave Access
WLAN	Wireless Local Area Network
CPW	Coplanar Waveguide
VNA	Vector Network Analyzer
VSWR	Voltage Standing Wave Ratio
EBG	Electromagnetic Band-Gap
SRR	Split Ring Resonator
PET	Polyethylene Terephthalate
CSRR	Circular Split Ring Resonator
DSRC	Dedicated Short Range Communications
SRR	Split Ring Resonator
CRR	Closed Ring Resonator
ERR	Electric Ring Resonator
DVC	Digital Variable Capacitor
EBG	Electromagnetic Band Gap
CMT -EBG	Conventional Mushroom Type - Electromagnetic Band Gap
ELV - EBG	Edge Located Vias - Electromagnetic Band Gap
LCP	Liquid Crystal Polymer
VNA	Vector Network Analyzer
SMA	Sub Miniature Version A
CST	Computer Simulation Technology
FR4	Flame Retardant 4
PSO	Particle Swarm Optimization

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Nowadays, wireless communication technology has become an important part of our lives. Antenna is an integral part of wireless communication technology. Antenna is basically a device which is used to convert electrical signal to electromagnetic waves and vice versa. Antenna can be used as a transmitter or receiver of electromagnetic waves [1]. Antenna as a transmitter converts electrical signal given at the input into electromagnetic waves and radiates them in space. On the other hand antenna as a receiver converts received electromagnetic waves from space into electrical signal. Antenna has applications in systems like radio broadcast, radars, satellite communication, spacecrafts, cellular phones, wireless phones, defence and military [2]. Moreover industries are introducing new wireless devices which are small in size and employ compact antennas. Increase in use of antennas in aircrafts, spacecrafts, mobile phones and satellite communication develops a need for low profile and small sized antennas.

A microstrip antenna is a suitable candidate for such requirements as it is having low weight, small size, low cost, easy installation and conformability. They have low manufacturing costs as they employ printed circuit technology in which feeding line and antenna pattern are engraved on one side of substrate whereas ground plane can be on same side or the back side of the substrate. The best substrates are one having low value of dielectric constant and more thickness. This leads to large bandwidth, improved efficiency but at the cost of large antenna size. Generally microstrip antenna have patch of various shapes like square, rectangular, circular, triangular and elliptical. But we can also use any other continuous patch shape. The size and shape of patch determines the frequency at which it will operate. They are generally used at higher frequencies i.e. radio and microwave frequencies. There is no use of employing microstrip antenna at lower frequency as size of required antenna increases at lower frequency. The feeding of microstrip antenna can be done in many ways such as: microstrip line, aperture coupling, proximity coupling and coaxial probe [3].

Microstrip antennas have gained popularity nowadays due to their thin and planar profile, easy and simple fabrication, the effortless integration of the antenna and circuit on the same board and the feasibility of employing active devices e.g. microwave integrated circuits with the antenna to form active antennas. Microstrip antennas are mechanically very robust having low profile which can be placed on any planar and non-planar surfaces with ease. As the research and development in domain of microstrip antenna is growing day by day, it is anticipated that microstrip antennas will take the place of conventional antennas.

Nowadays, a wireless technology is required to interconnect all the devices wirelessly that are found in an individual's surroundings. These devices can be computer, portable device, tablets or cell phones. These connections should be reliable and of short range. This technology should have the ability for fast data transfer and storage. So there is a need of a new technology which provides higher data rates as compared to existing technologies. As we know that to achieve high data rates either the bandwidth or the transmitted power need to be increased. Transmitted power cannot be increased because plenty of portable devices work on battery. Increased power may lead to interference with other systems which need to be prevented. Therefore to realize high data rates, vast bandwidth is required [4].

Ultra-Wideband (UWB) is generally a technology for transmission of information scattered over a wide operating bandwidth. For decades it has been used mainly for military purposes. In the year 2002, a spectrum of 3.1 GHz - 10.6 GHz is assigned by Federal Communication Commission (FCC) to (UWB) technology for commercial use [5]. Therefore from that time onwards UWB technology is considered as the most favourable technology for realising the dream of high speed wireless personal area network (WPAN), attaining high data rates and providing good quality facilities to consumers.

UWB devices are divided into three categories (1) radar systems used in vehicles (2) communications and measurement systems includes indoor and hand-held systems and (3) imaging systems includes wall imaging system, through wall imaging system, medical system and surveillance system [5].

UWB technology uses pulse waveforms that are compressed in time domain instead of frequency domain [6]. This leads to a signal spread over wide bandwidth and having low power spectral density. As the power of the signal is being distributed over wide frequency range, the impact on any frequency is lower than acceptable noise floor, as shown in Figure 1.1. The modulation schemes used for encoding UWB signals are pulse position modulation, pulse amplitude modulation and binary phase shift keying.

Some of the benefits of UWB technology are high data rates e.g. hundreds of Mbps - several Gbps, do not interfere crucially with neighbouring systems as its power emission levels are below noise floor, high security and reliability in communication and less complex communication systems. UWB systems can be used in sensor networks, for positioning and tracking purposes, in wireless personal area networks (WPAN), radar, medical imaging, intelligent collision avoidance systems etc.

So this study describes design of an UWB antenna covering a wide bandwidth. Various bandwidth enhancement methods are also explained. As the power emission levels assigned to UWB systems by FCC are very low so they are easily interfered by neighbouring communication systems like World Interoperability for Microwave Access (WiMAX), Wireless Local Area Network (WLAN), C band and X band satellite communication. One of the ways to avert the interference is to use band-stop filters but at the cost of increased complexity and size. So the best technique to avert interference is to design an UWB antenna having band notching capability in itself.

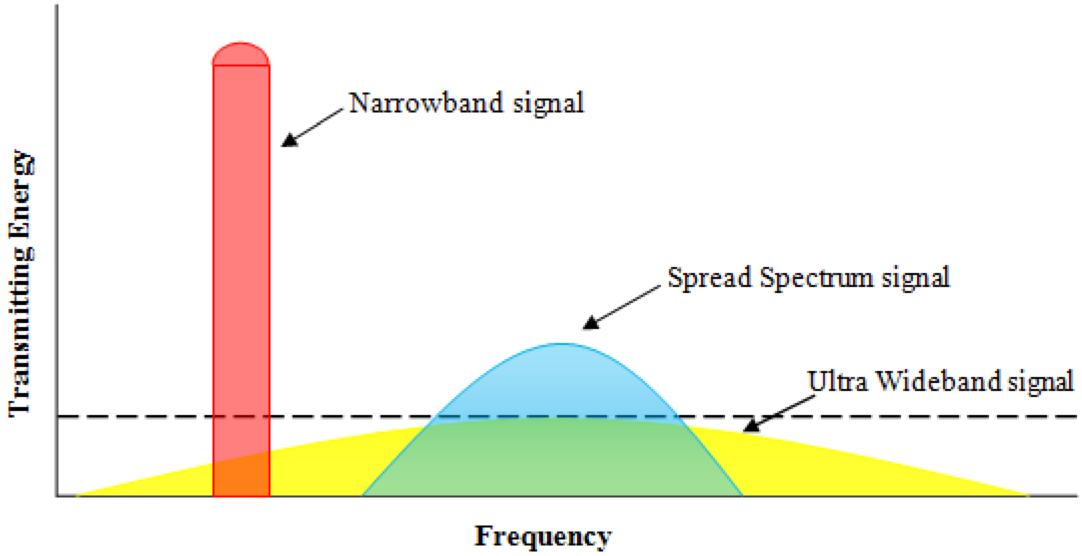


Figure 1.1 UWB technology spreads transmitting energy over wide frequency (Reproduced from [7]).

1.2 MOTIVATION

In recent years UWB technology came across numerous advancements. In spite of that some researchers are still working on this technology to make its upmost use. One of the biggest obstacles is to design antenna for use in UWB applications. Design considerations of UWB antenna are different and very stringent as compared to narrowband antenna.

Nowadays there is a rising need of small sized, planar and low cost antenna for UWB applications. The horn antenna is having non planar geometry, large size and hence incompatible with indoor systems and hand held devices [8]. The antenna for UWB applications should have omnidirectional radiation pattern as it offer user mobility and liberty in positioning transmitter and receiver. But the cavity backed, thick substrate antenna has directional characteristics which are not suitable for indoor applications [9].

One of the biggest requirements of UWB antenna is to attain vast impedance bandwidth and maintain the radiation efficiency. But the horn antenna is radiating only in bandwidth of 1.22 GHz [8]. So there is a need to use bandwidth enhancement techniques. Some of the techniques for enhancing bandwidth are by modifying ground and radiating patch of the antenna. But bandwidth was not enhanced to much extent using these techniques [10-12].

In addition to attaining wide bandwidth, one more constraint is present in UWB antenna design. As the power emission levels are very low for UWB technology, neighbouring communication systems like WiMAX, WLAN, C band and X band can interfere with it. So some band notching techniques can be employed like cutting slots on patch [13], etching slot resonators on ground [14], etching parasitic stubs [15], using metamaterials [16] and using a hybrid combination of two or more techniques [17].

In this thesis, the microstrip patch antenna for UWB applications is studied in detail to unravel its working, get to know the process that results in UWB characteristics and acquire the procedure to design such antenna. Also a microstrip patch antenna for rejecting the interference caused by interfering bands is designed and analysed for its working. As there are multiple constraints and obstacles for design of antenna for UWB applications, motivation for designing antenna is evident.

1.3 OBJECTIVES OF THE WORK

CST STUDIO SUITE is employed to create prototype of antenna and do the simulations. The objectives of this thesis are:

- To design a novel microstrip patch antenna for UWB applications by using coplanar waveguide (CPW) feeding technique.
- Fabrication and Testing of proposed UWB antenna.
- To introduce some band notching technique in designed UWB antenna for rejecting the interference from neighboring narrowband wireless systems.
- Fabrication and Testing of proposed UWB antenna with band notching properties.

1.4 OUTLINE OF THE THESIS

This study is arranged in five chapters as following:

The **second chapter** involves the work done by the various researchers in the field of UWB antennas. At first, various designs of microstrip patch antenna for UWB applications are discussed. Researchers used various techniques to design antennas having wide impedance bandwidth. After that various techniques to reject the interference caused to UWB systems from already prevailing wireless technologies are discussed. .

In **third chapter,** design of new tomb shaped microstrip patch antenna is presented for use in UWB applications. CST STUDIO SUITE is employed to create prototype of antenna and do the simulations. Antenna performance is determined by various design parameters of the tomb shaped microstrip patch antenna. Therefore an analysis is done in this chapter to see the effect of various design parameters of the antenna on the return loss. Finally the designed antenna is fabricated and experimental results are shown and the simulated and experimental results are compared.

In **fourth chapter,** design of tomb shaped antenna exhibiting triple band notch characteristics is presented for use in UWB applications. CST STUDIO SUITE is employed to create prototype of antenna and do the simulations. The technique used for generating band notch is by creating slots in the coplanar ground. Two identical L slots are inscribed in the coplanar ground to get the notched band. The notched band depends on various design parameters of the L slots. Therefore an analysis is done in this chapter to see the impact of various parameters of the L slot on the notched band. Finally the designed antenna is fabricated and experimental results are shown and the simulated and experimental results are compared.

In **fifth chapter,** conclusions drawn from simulations and experimental testing of antennas are presented. Additionally in this section the proposals for future work are proposed.

CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

This section involves the work done by the various researchers in the field of UWB antennas. At first, various designs of microstrip patch antenna for UWB applications are discussed. Researchers used various techniques to design antennas having wide impedance bandwidth. Various techniques to reject the interference caused to UWB systems from already existing wireless technologies is discussed next. Some of interference rejection techniques discussed below are cutting various shaped slots in patch, use of electromagnetic band-gap (EBG) structures, using metamaterials like split ring resonators (SRRs) and use of parasitic elements.

2.2 SURVEY OF RESEARCH PAPERS

Chao Deng *et al.* [18] presented a design of novel CPW-fed microstrip UWB antenna and some techniques to broaden the impedance bandwidth. This antenna consists of a modified rectangular patch with coplanar ground. Unmodified microstrip patch antenna have a fractional bandwidth of around 70%. Therefore to enhance the bandwidth of antenna, it is modified by carving an M-shape at bottom of the patch along with tapering of CPW ground and making a T-shaped CPW ground. M shaped notch is used mainly to broaden the bandwidth. Tapering is done to reduce the capacitance between patch and the ground. T-shaped ground leads to better impedance matching as current density increase on its surface. Fractional impedance bandwidth of 164% for S11 < -10dB is achieved by antenna and verified by simulated and experimental results.

Anil Kr Gautam *et al.* [19] proposed the design of a compact UWB microstrip antenna with CPW-feeding. The proposed antenna presents a way for minimization of the monopole antenna. Height of antenna is lowered by etching of inverted strips of L-shape over the original antenna. Normally antennas are designed to resonate at certain frequencies. But this is not the case with UWB antenna in which two or more resonant structures operating at their own resonances are required. The overlapping of their resonances leads to wideband performance. By modifying patch, not only the size of monopole is reduced but also the impedance matching condition for entire UWB range is improved. This antenna achieves good impedance matching over bandwidth of 2.6 GHz - 13.04 GHz (10.44 GHz).

S. Hakimi *et al.* [20] presented a novel transparent antenna with CPW feed for use in UWB applications AghT-8 is used as radiating patch and ground whereas polyethylene terephthalate (PET) is used as substrate. In this design broadening of the bandwidth is done by using different techniques. First of all the staircase technique is employed in the rectangle shaped patch of the antenna to increase the overlapping of resonant frequencies. After that tapering is done using quarter circle slots cut from the ground. Moreover, the tapered ground is mounted by two major and minor symmetrical rectangular stubs. This leads to significant increase in the impedance bandwidth from 3.15 GHz - 32 GHz for VSWR < 2. So a very compact and flexible antenna is designed with very large impedance bandwidth by modifying conventional antenna.

Nasser Ojaroudi [21] proposed an antenna having simple square shaped radiating patch and back side of the substrate have a partial ground. The main aim of this design is to employ some techniques to improve the impedance bandwidth of the antenna for use in UWB applications. First of all two slots of L-shape are cut in the ground of the antenna. By cutting L-shaped slots current path is changed and hence the capacitance and inductive values change which leads to change in input impedance value. After that, two L-shaped stubs are etched on opposite side of the radiating patch. These stubs are coupled with lower edge of the radiating patch electromagnetically. A coupling is generated between the radiating patch and ground because of stubs having L-shape. Earlier the antenna was radiating only from 3.1 GHz - 10.9 GHz. But after employment of L-shaped slots and stubs the antenna started radiating up to 18.31 GHz. An omnidirectional radiation pattern is observed in H-plane while a radiation pattern similar to that of a dipole antenna is observed in E-plane.

Zain Ul Abedin *et. al.* [22] designed a square radiating patch antenna in which a partial ground is etched on back side of the substrate. The radiating patch is modified by cutting steps on its lower edges in order to enhance the impedance bandwidth of the antenna. Due to this method a capacitive coupling is created between modified square radiating patch and ground plane. Antenna is radiating from 2.33 GHz - 12.4 GHz and thus is suitable for use in UWB applications.

Dang Trang Nguyen *et al.* [23] designed a very compact UWB antenna which is also rejecting the interference caused by three of the bands namely WiMAX (3.3 GHz - 3.7 GHz), WLAN (5.15 GHz - 5.825 GHz), and downlink of X-band satellite communication systems (7.25 GHz - 7.75 GHz). Earlier the conventional rectangular patch antenna was not radiating in whole UWB spectrum of 3.1 GHz - 10.6 GHz. But after using bevelling technique in patch and the coplanar ground impedance bandwidth increased. Bevelling ensured blocking of leaky currents at the edges of the patch and hence improves impedance bandwidth. This leads to good impedance matching over frequency range from 3.1 GHz-10.6 GHz. In this antenna design triple band notch characteristics are achieved by cutting three quarter wavelength slots in radiating patch. Effects of various parameters related to slot like width, length, location and inclination of slot were observed to find best optimized arrangement of the slots. The designed antenna show good radiation characteristics for 2.45 GHz to 10.65 GHz and also notched three desired bands.

Seyed Ramin Emadian *et al.* [24] designed an antenna for UWB applications for notching two interfering bands and having enhanced bandwidth. The antenna consists of a rectangle shaped patch fed by a trident shaped feed line with coplanar ground plane. Trident shaped feed line is employed for broadening the impedance bandwidth. Two C-shaped stubs are etched on back side of the substrate to notch two bands namely WLAN (5.1 GHz - 6.2 GHz) and WiMAX (3 GHz - 3.8 GHz). These stubs are connected with patch through cylindrical vias. C-shaped stub has a total length of $\lambda/2$ at its centre notch frequency. At the notch frequency current density is concentrated over these stubs and is opposite in direction to current in patch, hence cancels each other. This leads to cancellation of radiation fields and hence leads to no radiation at those frequencies. The designed antenna radiates over the frequency band of 2.5 GHz - 25 GHz. H-plane has omnidirectional radiation pattern whereas E-plane radiation patterns are directional.

Seyed Ramin Emadian *et al.* [25] proposed an antenna for UWB applications having a very small size of 15×15 mm^2 that consists of a patch having rectangle shape whose corners are bevelled fro broadening of the impedance bandwidth by removing discontinuity between CPW feeding line and radiator patch. In addition, one more method is employed to increase bandwidth up to 23 GHz, by cutting a pair of slots in shape of semicircle in the coplanar ground plane which provides better coupling between patch and ground. In this antenna two different methods are used to notch WiMAX (3.1 GHz - 3.9 GHz) and WLAN (5.1 GHz - 5.6 GHz) bands. A pair of slits having S-shape is cut in ground plane for notching out WiMAX band. A ring slot of elliptical shape is cut in beveled rectangular patch for notching out WLAN band. The parametric analysis show that as the gap increases between two ends of the elliptical slot, the middle frequency of notched band move towards lower frequencies. This antenna is radiating in bandwidth ranging from 2.6 GHz to more than 23 GHz.

Amanpreet Kaur *et al.* [26] presented a UWB Antenna with CPW-feeding technique. This antenna consists of an octagonal shaped radiating patch which is embedded with two quarter wavelength stubs on each side. The stub with longer length is used to reject lower WLAN band (5.15 GHz - 5.35 GHz) and with shorter length is used to reject upper WLAN band (5.725 GHz - 5.825 GHz). Resonators in form of slots are embedded in the feed line to reject WiMAX (3.3 GHz - 3.6 GHz) and X-band (7.25 GHz - 7.75 GHz). At the notch frequencies maximum current flows in the concerned resonators and stubs whereas very less current is present in the radiating patch. Hence at the notching frequencies there is no radiation from the patch. This antenna radiates in frequency spectrum of 3.1 GHz - 10.6 GHz and provides no radiation in interfering bands.

M. S. A. Rani *et al.* [27] presented design of a UWB antenna in which AgHT-4 is used, which is a silver coated thin film on PET substrate. AgHT-4 is a very thin and flexible material. This antenna design presents band notch using Circular Split Ring Resonators (CSRR) that is one embedded on the radiating patch and two on coplanar ground plane. First of all a dual port network is designed to test electromagnetic behaviour of CSRR and compared with that of copper material. AgHT-4 shows high insertion loss and surface loss. So a single CSRR cannot produce a good notch hence some modifications are done in it to improve the notching behaviour of the antenna. Two arc shaped slots are added to CSRR and then rings are embedded with four gaps. These modified CSRRs are etched on both sides of the coplanar ground plane which leads to a notched band from 5.2 GHz - 6.2 GHz and rejects WLAN band and DSRC band.

Jawad Y. Siddiqui *et al.* [28] designed an antenna for use in UWB applications and demonstrated the effect of employing Split Ring Resonator (SRR). This designed antenna is radiating from 2.6 GHz - 10.8 GHz when SRR is not employed in the design. After that two symmetric square shaped SRR are etched on back side of circular monopole antenna having a coplanar ground plane. SRRs are located on backside of feed line. The notch is created because of the electromagnetic coupling among feeding line and the SRRs. The electromagnetic signal flowing in the feed line creates magnetic fields along the axis of SRR and hence induces current in SRRs. These currents lead to resonance at some frequency that is decided by geometry of the SRR. The resonant frequency gets notched by SRRs. By changing the geometry of SRRs, notched bands can be changed.

Jawad Y. Siddiqui *et al.* [29] proposed a UWB antenna with CPW-feeding. This study presents a multiple functionality antenna. Three configurations of antenna are described for different applications. In all the configurations a circular monopole patch is used having coplanar ground and two square SRRs on back side of substrate. In first configuration ground and feed line are shorted with shunt strips which provides a very narrowband performance at 6.39 GHz. Axis of SRRs should be aligned with shunt strips to from a band-pass filter. In second configuration antenna acts a UWB antenna radiating in band of 2.6 GHz - 10.8 GHz with band notch characteristics. In third configuration the SRRs are replaced by CRRs which leads to restored UWB characteristics of the antenna. Closing of rings leads to destruction of magnetic resonance between feed line and SRRs and hence removes notched band.

Irina B. Vendik *et al.* [30] designed a circular patch UWB antenna having CPW-feeding. This antenna has an impedance bandwidth of 2.5 GHz - 12 GHz. An ERR is used on backside of the feed line to create notched bands. Dimensions of Electric Ring Resonator (ERR) are varied to get the desired notched band. First ERR is used to create a single band notch and then it is modified to give double and triple band notches. The equivalent circuit of ERR is an L-C tank circuit. ERR with single ring forms a single mode resonator which resonates at 5.8 GHz. Single ring is modified to form double ring structure to act as double mode resonator. The low frequency notch is given by inner ring while high frequency notch is given by mutual inductance between outer and inner ring. Three rings are used along with an interdigitated capacitor to give triple band notch characteristics at centre frequencies of 3.5 GHz, 5.8 GHz and 7.5 GHz. Then a Digital Variable Capacitor (DVC) is used in place of lumped capacitor to convert antenna into reconfigurable antenna.

Jawad Y. Siddiqui *et al.* [31] designed a circular monopole patch antenna with CPW feeding. SRRs are incorporated at back of the substrate to create dual notches and a wideband notch. Firstly two SRR pairs are etched on backside of substrate having different lengths. The notched band at centre frequency of 5.33 GHz is induced by larger SRR pair while notched band at centre frequency of 7.9

GHz is induced by smaller SRR pair. SRR axis should be in alignment with the gap between ground plane and the feed line for proper notching of bands. The notch is created because of the electromagnetic coupling among the feeding line and the SRRs. The electromagnetic signal flowing in the feed line creates magnetic fields along the axis of SRR and hence induces current in SRRs. For wideband notching characteristics from 6.2 GHz - 7.02 GHz pair of SRRs are used which are having almost similar dimensions. The notches in this design are independent of radiator variations. More number of notches can be made by using more SRRs.

A. Chaabane *et al.* [32] designed a UWB antenna with microstrip feeding in which back side of the substrate contains the ground plane. The radiating patch and the ground are modified to get a better impedance matching. The ground is truncated so that the inductive effect of the patch can be reduced by capacitive effect of the truncated ground and sum up to give total resistive performance. The patch is notched from bottom to change the gap between radiating patch and the ground. This is done to couple the inductive and capacitive behaviours of radiating patch and the ground. Next, the radiating patch is notched from upper end to remove low density current area and hence implement minimization of patch area. A slot having C-shape is cut in the radiating patch and inverted slot having U-shape is incorporated in the feed line to create two band notches at 3.2 GHz - 4.1 GHz for WiMAX and 5.2 GHz - 5.96 GHz for WLAN respectively. These slots are half wavelength long. The rejected bandwidth can be independently controlled by varying dimensions of the respective slots and without affecting other notched bands. Shifting of notched band towards lower frequencies is possible by increasing the total length of the slots. At 3.55 GHz maximum amount of current is gathered around C slot whereas at 5.58 GHz maximum amount of current is gathered about U slot of feed line. Hence antenna does not radiate at these frequencies and band notch is created.

You-Zhi Cai *et al.* [33] presented a rectangular radiating patch having truncated partial ground plane UWB antenna structure. The feed line splits into two structures on the connecting points with the patch. This is done to suppress horizontal current modes and make vertical current modes to dominate. The antenna covers whole of the UWB band (3.1 GHz - 10.6 GHz). The spiral shaped slots which are mirror image of each other are cut from feed line to create band notch properties as these slots act as bandstop filter. VSWR increases as number of slots are increased on feed line. As longitudinal length of slot is increased number of notched bands increases. Moreover to notch three bands author employed two spiral slots on the feed line. WiMAX (3.3 GHz - 3.88 GHz), WLAN (4.96 GHz - 6.23 GHz), and ITU (7.9 GHz - 8.7 GHz) bands are notched by this design. The longer slot notches the 3.5 GHz and 8.3 GHz. The smaller length slot notches the frequency at 5.4 GHz. Gain of antenna is observed to be 3 dB - 5 dB.

Zahirul Alam *et al.* [34] proposed a rectangular patch antenna having a partial ground plane etched on back side of substrate. The feed used in this design is unsymmetrical to enhance the bandwidth. This antenna is radiating from 3.1 GHz -14.68 GHz. A slot having L-shape is cut in the radiating patch to notch WLAN band (5.17 GHz - 5.98 GHz). This slot having L-shape behaves as a half wavelength resonator. The length of L slot resonates at the middle of the desired notched band. When resonant frequency travels through L slot all the current centres across slot and lowers current in patch hence creating a notch. The parametric variations of L slot show that length has more effect on band notch then its width. As the L slot's length is increased, the notched band moves towards lower frequency bands. In H-plane omnidirectional radiation pattern is observed while a pattern similar to that of a dipole in E-plane is observed.

A.S. Fazal *et al.* [35] designed a compact UWB antenna equipped with CPW feeding technique. It radiates in bandwidth from 3.03 GHz - 11.34 GHz and hence is suitable for UWB applications. Later on two inverted slots having L-shape are incorporated in the radiating patch to notch a band ranging from 4.9 GHz - 6.2 GHz. At 5.5 GHz maximum current is gathered on inverted L slots and inner side of the antenna. Antenna has a gain of 5 dBi in whole band except notched band.

Prameet Lawas *et al.* [36] presented a rectangular radiating patch antenna with a partial ground for UWB applications. The patch of the antenna is modified by cutting two steps from both the corners. This is done to increase the impedance bandwidth of the antenna. This antenna covers a wide band ranging from 2.79 GHz - 11.03 GHz. Inverted L-shaped slots are cut from edges of the patch. The parametric analysis show that with increasing length of L slot, the notch band shifts to lower frequencies. The bandwidth of notch increases with increasing width of the L slot. This antenna provides band rejection in range 4.88 GHz - 5.94 GHz for WLAN applications.

Taimoor Naeem *et al.* [37] designed a rectangular patch antenna radiating from 3.2 GHz - 12.2 GHz. So it is suitable for UWB applications. Dual notch band rejection is acquired by incorporating slots having U-shape and L-shape in the patch of the antenna. Notched bands are WLAN lower band (5.15 GHz to 5.35 GHz) and WLAN upper band (5.725 GHz to 5.825 GHz). Parameters of slots were varied to see their effect on the width of notched band. When the length of each slot increases, the respective notched band moves to the lower frequencies. Gain of antenna is measured to be 5.2 dBi.

Ajay Yadav *et al.* [38] presented a square shaped antenna with CPW feeding technique which radiates in 3 GHz to 11 GHz. Dual band rejections is obtained by cutting nested slots having L-shape and C-shape slot in the radiating patch. L slot notches WLAN band (5.1 GHz - 5.8 GHz) and U slot notches C band (3.8GHz - 4.2 GHz). Width of both slots can be varied to control notched bandwidth and centre frequency of notched band is controlled by length of the slot. Band notch shifts towards lower frequency range as the length of the slots are increased. The antenna shows omnidirectional pattern in H plane and doughnut shaped in E plane.

Kai Yu *et al.* [39] proposed the design of a rectangular patch antenna having modified partial ground on back side of Rogers 4003 substrate. The polygon shaped ground of the antenna is modified by embedding a rectangular cut in it to broaden the bandwidth of the antenna. Two slots having L-shape are cut into the patch and one rake shaped element having five teeth is etched on one side of the feed line. They collectively notch four bands namely WiMAX (3.3 GHz - 3.6 GHz), C-band (3.9 GHz - 4.0 GHz, WLAN (5.6 GHz - 5.9 GHz) and International Telecommunications Union (ITU) (7.9 GHz - 8.2 GHz). The bandwidth and range of notched band can be controlled by varying parameters of the slot. The radiation pattern observed in H-plane is omnidirectional while a pattern similar to that of a dipole in E-plane. This antenna is radiating from 2.7 GHz to 12.0 GHz.

Ajay Yadav *et al.* [40] designed a circular patch UWB antenna having a partial ground which is etched on rear side of the substrate. The designed antenna radiates from 3 GHz - 13.5 GHz. A half wavelength long circular split ring slot is made in the radiating patch to reject the interference from WLAN band (3.3 GHz - 3.6 GHz). Surface currents at different frequencies are compared to see the effect of slot in the patch. At 3.5 GHz most of the current is gathered around split ring slot in patch but on the other hand at other frequencies current remains at feed line and lower part of the patch.

Tapan Mandal *et al.* [41] worked on a hexagonal patch antenna having CPW feeding technique. This antenna radiates from 3.06 GHz – 13.6 GHz frequency range. To reject the interference from other bands like WLAN band and WiMAX band some resonators are added to the antenna structure. Two slots having L-shape are cut in the coplanar ground plane to notch the WLAN band. The notched frequencies of both L slots get combined and form a single band notch. The parametric analysis show that by varying length of the slot, notched band varies and by varying width the bandwidth of the notch varies significantly. After that two vertical stubs are etched on backside of the substrate to notch WiMAX band. As we lengthen the I-shaped stub the band which is notched move towards lower frequencies. The I-shaped stubs reflects back all the power towards input and hence creates a mismatch at 5.5 GHz. Gain of antenna is 6dB except at the notched bands.

T. Mandal *et al.* [42] presented a hexagonal shaped radiating patch antenna with partial ground plane. The antenna is radiating in the band 3.11 GHz – 13.15 GHz for S11 < -10 dB. Radiating patch of the antenna is modified by inserting a slot having U-shape on the hexagonal radiating patch of the antenna. This slot is introduced to notch WLAN (5.15 GHz -6.17 GHz) band. The radiation pattern is observed as omnidirectional in H-plane whereas directional in E-plane. From the study of this paper it is found that length of slot has more effect on notching characteristics than width of the slot. As we start increasing total length of the slot, notched band starts shifting towards lower frequencies.

M. Gopikrishna *et al.* [43] proposed the design of a square radiating patch antenna having CPW feeding for UWB applications. Coplanar ground plane is modified by cutting small rectangular patches on its upper end. This is done mainly to broaden impedance bandwidth i.e. from 2.87 GHz – 14GHz. In order to reject interference from WLAN band two quarter wavelength slits are made in the square patch. Parametric study shows that length and width of the slits can control band notch characteristics. As slot length is elongated the notched band moves to lower frequencies. By increasing distance from centre of the patch bandwidth of the notch also increases. The group delay is also measured which is 5.2 ns for notched band and 500 ps for rest of the band.

Avez Syed *et al.* [44] presented a square radiating patch antenna with CPW feeding. The square patch is bevelled from bottom and coplanar ground is also modified. These modifications of the patch and the ground plane lead to enhancement of the bandwidth. The designed antenna radiates from 2.9 GHz – 13.7 GHz. A circular split ring is etched in the modified radiating patch to generate the notch at WLAN (5.1 GHz – 5.9 GHz) frequency band. The notched band's centre frequency relies on radius of the circular split ring slot. As the radius is increased the notched band moves towards lower frequencies. Effect of gap between two ends of slot is also observed which show that when the gap is increased, the band which is notched moves to higher frequencies. Gain of antenna is 4.4 dBi except at notched bands.

K.G. Jangid *et al.* [45] worked on design of a circular patch UWB antenna with coplanar ground plane. A comparison is made between antenna using infinite ground plane and coplanar ground plane which shows that bandwidth increases in latter case. Current distribution is higher in lower half of the patch and in feed line. This provides a bandwidth of 1.54 GHz (2.99 GHz – 4.53 GHz) only. Moreover to increase the bandwidth, coplanar ground of the antenna is defected by introducing two L slits. New impedance bandwidth is from 2.68 GHz – 12.53 GHz. A slot having U-shape is cut into the circular patch to reject the interference caused b the WLAN (5.13 GHz – 5.75 GHz) band. It is observed that notched bandwidth can be adjusted by varying length and width of the slits. The maximum gain achieved by the antenna is 3.86 dBi.

Avisikta Das *et al.* [46] presented a elliptical shaped radiating patch with semicircle shaped partial ground for UWB applications. It consists of three step quarter wavelength feed line. Modification of ground plane and feeding line is done basically to increase the spectrum for which antenna is radiating. As observed from the current distributions maximum current is concentrated in stepped feed line and outer edges of the patch. This antenna radiates from 2.86 GHz - 14.9 GHz having fractional bandwidth of 135 %. Two quarter wavelength vertical slits are cut into elliptical patch to reject the interference caused by WiMAX (3.1 GHz - 4.8 GHz) and X band satellite link (9.6 GHz -11.2 GHz). Gain value for designed antenna varies from 5 dB - 6.5 dB. The current distribution shows that current is concentrated around feed region and slots at notched bands. In this way patch do not radiate at those frequencies and hence a notch is created. In this antenna bidirectional radiation pattern is observed in E-plane whereas omnidirectional radiation pattern is observed for H-plane.

Mohammad Yazdi *et al.* [47] presented a circular radiating patch antenna with partial ground plane for UWB applications. This antenna is designed on RT/Duroid 4003 substrate. To reject WLAN band mushroom like Electromagnetic Band Gap (EBG) structure is used in this design. EBG consists of square shaped metallic patches around the feed line. They are connected to ground plane through shorting cylindrical shaped pins called vias. EBG forms a LC array such that the currents in vias leads to L and C is a result of gap between patches of EBG structure. The centre of the notch frequency is determined by width of the patches and gap between them in EBG structure. As the gap between EBG patches increases notched band start moving towards higher frequencies. Although increasing the gap between feeding line and EBG structure make VSWR of the notched band to decrease. The antenna has an operating bandwidth of 3.1 GHz - 10.6 GHz in which a band of 0.7 GHz is rejected around 5.5 GHz.

Lin Peng *et al.* [48] introduces a new technique to create rectangular shaped notch band. For use in UWB applications an elliptical shaped radiating patch with coplanar ground plane is designed. It shows impedance bandwidth from 2.74 GHz - 11 GHz. After that a rectangular shaped EBG patch is etched behind the CPW feeding line and shorted with feed line using vias. CPW feeding line acts as a ground to the EBG structure. This creates a notch band from 4.49 GHz - 6.08 GHz. But the notched band is spike shaped which rejects useful frequencies also. Moreover a perfect notch can be attained by combining two or more resonances. So one more EBG is placed below the first EBG and shorted to CPW feeding line. They lead to resonances at 5.05 GHz and 5.95 GHz which merge together to form a single notched band. So a rectangular band notch is achieved from 5.19 GHz - 6.05 GHz. By adjusting parameters of EBG structures, notched bands and their bandwidths can be changed. In this design by making slight changes in the position of the EBG structure satellite communication's X-band (7.1 GHz- 7.76 GHz) is notched easily.

Lin Peng *et al.* [49] presented an elliptical radiating patch having partial ground plane antenna for use in UWB applications. This design uses mushroom type EBG structure for creating notched band. This technique allows controlling notched band and its bandwidth by varying EBG parameters. For notching a single band interfering with UWB band two configurations are used: Conventional mushroom type (CMT) - EBG and Edge located vias (ELV) - EBG. In CMT-EBG structure, patch of EBG is etched near the feed line which is joined to ground through a vias in its centre whereas in ELV-EBG patch of EBG is placed near the feed line but connected to the ground through vias at the edge. CMT-EBG provide band notch from 5.15 GHz - 5.96 GHz for VSWR = 8 and ELV-EBG provides band notch from 5.27 GHz - 5.94 GHz for VSWR = 26. So ELV-EBG is better than the other configuration of EBG. At notching frequency the current is concentrated on EBG while at other frequencies current remains evenly distributed all over the antenna. This shows that EBG only affects the notched band. A dual band notch is obtained from same antenna by employing one more EBG structure on the other side of the feed line. Two notched bands for WLAN are created: 5.20 GHz – 5.72 GHz and 5.99 GHz – 6.23 GHz. There are some discrepancies between measures and simulated results caused by testing environment, soldering of the SMA connector, losses of the substrate etc.

T. Li *et al.* [50] presented a circular radiating patch with partial ground plane for UWB applications. This antenna radiates from 3 GHz – 13 GHz. On both sides of the feed line EBG structures are employed to reject the interferences produced by WiMAX and WLAN band to UWB operation. The

EBG used in this antenna design has a cylindrical shaped shorting pin at the edge. This pin connects both of the EBG to ground plane. EBGs act as LC circuit. The shorting pin contains current which make it behave as inductor while voltage gap between ground and patch make it behave as a capacitor. The rejection of WiMAX (3.3 GHz – 3.7 GHz) and WLAN (5.69 GHz – 5.9 GHz) is achieved through larger EBG structure in which two L slots are cut. While WLAN band rejection (5.14 GHz – 5.46 GHz) is achieved by smaller EBG. For smaller EBG a square ring is cut at the outer edge of the patch.

D. O. Kim *et. al.* [51] proposed the design of a square radiating patch antenna with coplanar ground plane. Substrate used in this antenna design is Rogers 4003. The patch is modified by cutting steps from bottom corners and ground is modified by cutting one step on the inner edge on both sides. These modifications are done to improve the matching and enhance the bandwidth. The antenna radiates from 3.1 GHz -10.6 GHz. Three different techniques are used in single antenna to get band notches. A meander shaped quarter wavelength resonator is etched above the patch to notch WiMAX band (3.3 GHz – 3.7 GHz). Two square shaped SRRs are etched in coplanar ground plane to notch WLAN band (3.15 GHz – 3.825 GHz). The ITU band (8.05 GHz – 8.4 GHz) is rejected by cutting a half wavelength slot having inverted U-shape in the radiating patch. This antenna design places the entire band notching structures in such a way that mutual coupling reduces.

G Shrikanth Reddy *et. al.* [52] proposed a semi elliptical radiating patch antenna having partial ground for UWB applications. The ground of the antenna is modified by creating multiple steps to improve impedance matching characteristics. This antenna covers whole UWB band (3.1 GHz – 11 GHz). A square shaped spiral resonator is etched on radiating patch which forces antenna to radiate around 2.45 GHz in Bluetooth range. Square shaped spiral is modified to form a trapezoidal shape and number of turns of spiral is increased to reduce the area around it and improve the performance. Next step is to reduce the interference from neighbouring bands. A method to reject four bands is shown in this study. Three half wavelength rectangular spirals are etched besides feed line. Parameters of all these spirals are different and optimized to get sharp rejection at respective bands. One spiral notches two bands WiMAX (3.3 GHz - 3.65 GHz) and ITU (8.018 GHz - 8.4 GHz) band simultaneously. Other two spirals notch upper (5.72 GHz - 5.83 GHz) and lower (5.12 GHz - 5.3 GHz) WLAN. The current distributions show that at notch frequencies current is concentrated along respective spirals. Gain of antenna is 5.5 dBi for UWB antenna and 3 dBi for Bluetooth.

Hari Shankar Mewara *et. al.* [53] designed a UWB antenna having a Y-shaped patch and a partial ground. Ground is bevelled at its edges and a slot is cut parallel to feed line to increase the bandwidth. The impedance bandwidth of this antenna is from 2.86 GHz – 13.3 GHz. In this paper U-shaped and C-shaped slots are cut on ground and radiating patch to avoid the interference caused by WiMAX, WLAN, X - band, ITU and Radio Navigation band. Five band notches are created using slot resonators. Slots having U-shape and C-shape are cut in the radiating patch and three C-shaped slots are cut in defected ground to create the notches. Length of each resonator depends on resonating frequency of the notched band. Input impedance characteristics are studied to form the equivalent circuit of the designed antenna.

Qing-Xin Chu *et. al.* [54] proposed the design of a rectangular patch antenna having coplanar ground for use in UWB applications. The antenna is radiating from 3.1 GHz – 10.6 GHz. Two nested slots having C-shape are cut in the rectangular patch to create two band notches. Band notch are centred at 3.4 GHz for WiMAX band and 5.5 GHz for WLAN band. Equivalent circuits of antenna by are presented in the paper. CPW feed can be modelled as transmission line having characteristic impedance Z_o. In UWB antenna there are multiple adjacent resonant frequencies. Therefore radiating elements of antenna can be represented by multiple parallel RLC circuits connected in series. Slots are represented by short circuit and open circuit.

Qiang Wang *et. al.* [55] proposed a circular patch antenna having partial ground on other side of FR-4 substrate. Ground is modified by cutting its edges in shape of arc and making a stepped slot parallel to feed line. This is done to make antenna radiate from 2.9 GHz – 13.4 GHz. Three bands namely WiMAX, WLAN and X- band downlink satellite communication band are notched by using slots on ground and radiating patch. Nested arc slots are made in circular radiating patch to notch WiMAX and WLAN bands. One U-shaped slot is cut in ground parallel to feed line to notch X band satellite communication band. It is observed from the current distributions that maximum amount of current flows around arcs and U slot at respective resonant frequencies. At pass band frequencies current concentrates on feed line and outer edges of the patch. This shows that slots does not have any impact on pass band frequencies. The radiating patch acts as multiple RLC parallel circuits connected in series and slots act as short circuits.

N. Ojaroudi *et. al.* [56] presented the design of a square radiating patch antenna in which ground is etched on the rear side of the substrate for UWB applications. A square slot is cut from the ground and two L-shaped parasitic stubs are etched in middle of substrate to make antenna radiate in wide spectrum. A new resonant frequency is added by adding L-shaped strips at 11.5 GHz. Hence the antenna starts radiating from 2.98 GHz – 16.73 GHz. A stub having inverted T-shape is etched on same side of ground to notch WLAN band from 5.05 GHz – 5.9 GHz.

Mohammad Ojaroudi *et. al.* [57] presented a square radiating patch antenna in which ground plane have rectangular slot on the rear side of the FR4 substrate. A stub having inverted T-shape is etched on ground plane to increase the bandwidth in which antenna is radiating. After inserting T shaped stub one more resonance at 10 GHz is added and bandwidth gets enhanced. A rotated C shaped stub is added around T strip to reject the intrefrence from the unwanted WLAN band (5.03 GHz – 5.94 GHz). As observed from the current distribution, maximum amount of current at the notched frequency is concentrated around the C-shaped stub.

Pritam S. Bakariya *et. al.* [58] proposed an antenna having rectangular radiating patch and partial ground on back side of substrate. Some methods like bevelling lower ends of the radiating patch and upper end of the ground plane are used to increase impedance bandwidth of designed antenna. It provides a large impedance bandwidth from 3 GHz - 15 GHz. Next challenge is to reject the frequency bands interfering with the UWB system. An arc shaped slot is carved in the upper half of the radiating patch to create a band rejection around 3.5 GHz for notching out WiMAX band. The length of slot has impact on notched band range. When the width of the slot is increased the notched band moves towards higher frequency because capacitance of the slot line decrease. Hence with decrease in capacitance, frequency increases. Also a SRR is inscribed in the lower half of the patch to reject the interference from WLAN band at 5.5 GHz. Finally two slots having C-shape are cut on the ground to notch out X-band at 7.5 GHz. The slots have length equal to half of the wavelength corresponding to their respective resonant frequencies. The value of each rejected band can be controlled separately by changing parameters of respective slots without affecting other notch bands.

LC Tsai [59] designed an antenna in which radiating patch has heptagonal shape in which ground is on the rear side of the substrate. This antenna is radiating from 2.63 GHz - 10.86 GHz. In this paper two different techniques namely L slots etching and SRR etching are used to create two band notches. Two SRRs are cut in the ground to reject the interference caused by WiMAX band from 3.4 GHz - 3.69 GHz. After that two L slots are cut in the heptagonal radiating patch to notch out WLAN band from 5.15 GHz - 5.85 GHz. Combinations of two techniques are used to reject the interferences form neighbouring narrowband systems.

Wei Xiao *et. al.* [60] presented a flexible antenna for UWB applications using 50 µm thick Liquid Crystal Polymer (LCP) which is acting as a substrate. The copper used for radiating patch and trapezoidal ground is 18 µm. The antenna is radiating in UWB spectrum of 3.1 GHz - 10.6 GHz. The band notching capability is incorporated in antenna by cutting three nested SRRs in the shape of ellipse in the radiating patch. These produce notching effect at C band (3.7 GHz -4.2 GHZ), lower WLAN (5.15 GHz - 5.35 GHz) and upper WLAN (5.725 GHz - 5.825 GHz). However there is interference between elliptical SRRs as the size of antenna is small. So to compensate for these interferences an elliptical shape capacitive load is added on back side of the radiating patch. After observing VSWR curves of with and without capacitive loads we can see that antenna having capacitive load reduces the interference between upper WLAN and lower WLAN band. In this way a good notching characteristics are obtained.

Y. S. Seo *et. al.* [61] designed an antenna having trapezoidal shaped radiating patch in which partial ground is etched on rear side of the substrate. The antenna radiates in range of 3.07 GHz - 12.19 GHz. Hence it is suitable for use in UWB systems. But to reject the interference caused by neighbouring narrowband systems a slot having inverted U-shape is etched in the trapezoidal patch. Length of slot is equal to half of the wavelength which corresponds to notching frequency. This slot notches a band form 5.12 GHz - 6.14 GHz. This range corresponds to WLAN system. If we increase length of slot the centre if notched band shifts towards lower frequencies. After observing current distribution of the antenna it is seen that at 5.5 GHz maximum current is gathered about U slot which leads to notching characteristics.

From survey of various research papers it is found that we have various techniques to increase the impedance bandwidth of microstrip patch antenna to make it work in UWB band. After that some methods were studied and discussed to reject interferences from neighbouring wireless systems. In the next chapter, design of UWB antenna is discussed along with parametric analysis.

CHAPTER 3

TOMB SHAPED UWB ANTENNA DESIGN

3.1 INTRODUCTION

UWB is generally a technology for transmission of information scattered over a wide operating bandwidth. For decades it has been used mainly for military purposes. Since FCC allowed unlicensed use of UWB technology, many researchers and academicians has shown interest in UWB systems for its development. An antenna which has a fractional bandwidth greater than 0.20, can be used for UWB applications [5]. Fractional bandwidth can be given as:

$$BW = 2\frac{(f_H - f_L)}{(f_H + f_L)}, \tag{3.1}$$

where f_L is lower frequency and f_H is upper frequency of -10 dB points. Centre frequency is calculated by taking average of upper frequency and lower frequency i.e. $(f_H + f_L)/2$.

One of the significant difficulties in designing of micro-strip antenna for UWB applications is accomplishing wide impedance bandwidth. So to fulfil the need of wide impedance bandwidth some of the bandwidth improvement strategies have been expressed as following: gradually decreasing and T-forming of ground alongside grooving of M - shape at the base of the patch [18], utilizing upturned L-strip on the radiating patch [19], utilizing a feed line having trident shape toward one side which is close to the patch [24], tapering of the patch and engraving half circle apertures in ground plane [25], engraving parasitic components and cutting apertures [62], and using staircase like strip on the radiating patch [63]. Coplanar waveguide (CPW) feeding technique are utilized for the most part in UWB applications since they give less scattering, easy to manufacture, wide impedance bandwidth and lower loss at higher frequencies which prompt better execution for UWB applications [64]. In the tomb shaped antenna increased impedance bandwidth is obtained by chamfering of elliptical shaped radiating patch and utilizing staircase strategy in the coplanar ground plane.

In this chapter, a new tomb shaped microstrip patch antenna is designed for UWB applications. CST STUDIO SUITE is employed to create prototype of antenna and do the simulations. Antenna performance is determined by various parameters of the tomb shaped microstrip patch antenna. Therefore an analysis is done in this chapter to see the effect of various design parameters of the antenna on the return loss. The design parameters of antenna are varied and return loss curves are plotted for different parameter values for comparison. Finally, the designed tomb shaped antenna is fabricated, tested and experimental results are shown. A comparison between simulated and experimental results is done.

3.2 ANTENNA DESIGN

The designed tomb shaped antenna consists of a modified patch and modified coplanar ground. Elliptical patch is modified by beveling it from upper and lower half. Coplanar ground is modified by adding staircase at upper edges of the ground. The substrate used to make this antenna is FR4 and1.6 mm is taken as its thickness. Radiating patch and ground are coplanar in CPW feeding approach i.e. they are etched on the same plane of FR4 substrate. Figure 3.1 depicts the layout and parameters of the tomb shaped antenna. Copper is used for making ground plane and radiating patch having thickness of 0.035 mm. W_f is the width of CPW feeding line having value 3.2 mm. The feeding line and the finite coplanar ground plane are separated by a spacing of 0.6 mm. The tomb shaped antenna has an overall size of 50×38×1.6 mm^3. Dimensions of the tomb shaped UWB antenna are presented in Table 3.1.

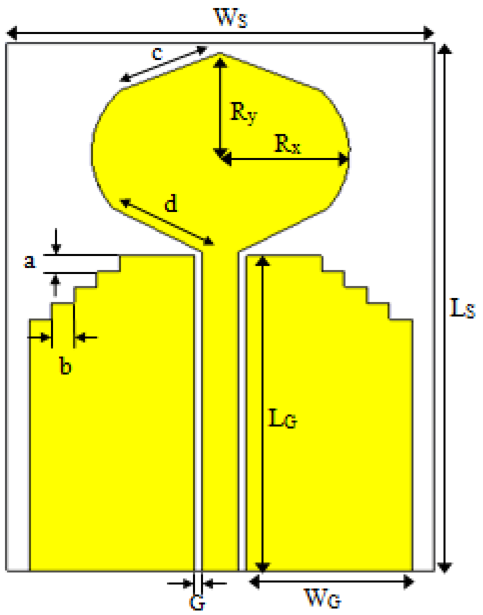


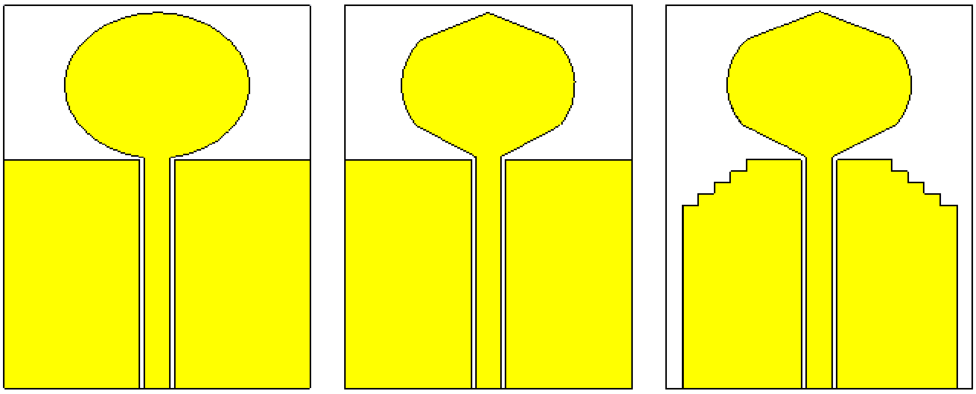
Figure 3.1 Configuration of proposed UWB antenna

TABLE 3.1

DIMENSIONS OF THE TOMB SHAPED UWB ANTENNA

Parameters	Size (mm)	Parameters	Size (mm)
W_S	38	G	0.6
L_S	50	a	1.5
R_x	11.5	b	2
R_y	9.5	c	9.6
L_G	29.8	d	8.9
W_G	21	W_f	3.2

Now the design procedure of tomb shaped antenna will be discussed. The antenna structures are shown in Figure 3.2 and their respective return loss curves are shown in Figure 3.3. A Basic Antenna is designed first, having elliptical radiating patch and CPW-fed ground plane as shown in Figure 3.2 (a). But this antenna is only radiating from 2.8 GHz - 3.7 GHz, 5.9 GHz - 7.2 GHz, 9.07 GHz - 9.9 GHz, 11.88 GHz - 13.2 GHz, 14.9 GHz - 15.8 GHz and not radiating for entire impedance bandwidth of 2.8 GHz - 18 GHz. Therefore upper and lower half of elliptical patch are beveled to form Beveled Antenna as shown in Figure 3.2 (b). This antenna is radiating in two bands ranging from 2.5 GHz - 6.06 GHz and 6.25 GHz - 18 GHz. Beveled Antenna is further modified by adding staircase to the upper ends of the ground plane to form Final Antenna as shown in Figure 3.2 (c) which is radiating from 2.8 GHz - 18 GHz.



(a) Basic Antenna (b) Beveled Antenna (c) Final Antenna

Figure 3.2 Evolution of antenna design.

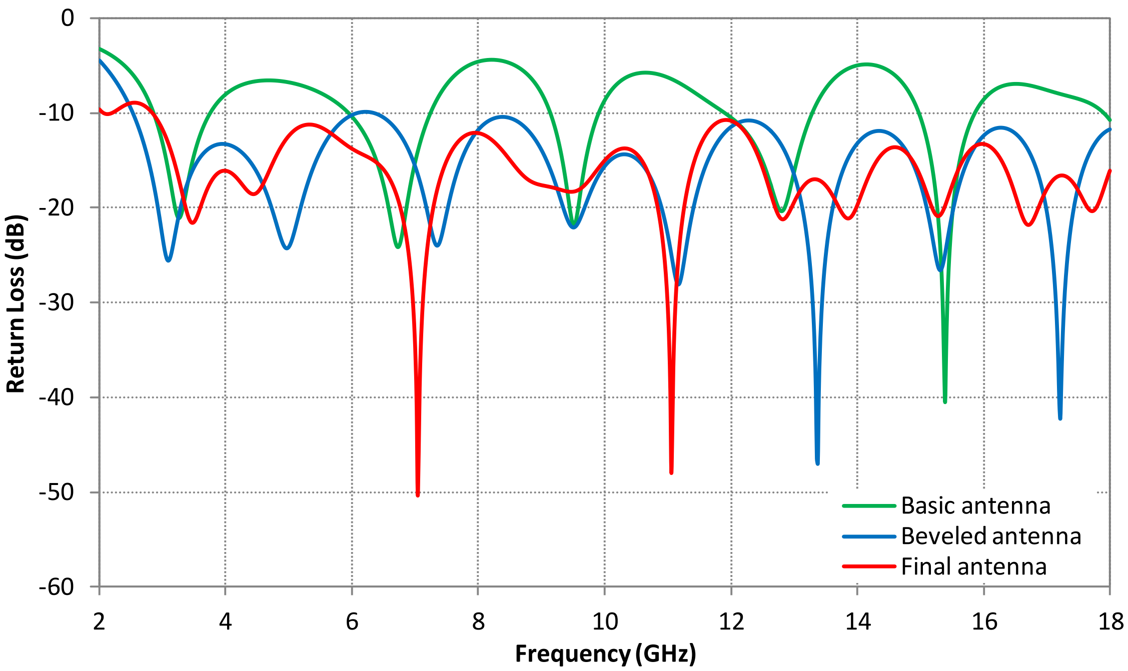


Figure 3.3 Simulated Return Loss vs. Frequency curve for different antenna structures.

3.3 PARAMETRIC STUDIES OF ANTENNA

Effects of varying size of different parameters of the tomb shaped antenna have been discussed in this section. In this analysis, return loss curves are drawn to compare the effect caused by varying size of the parameters. Single parameter is varied while keeping others constant.

3.3.1 Impact of varying radius 'R_x' and 'R_y' of the ellipse on return loss of the antenna

Different values of R_x are taken in the range of 9.45 mm to 13.45 mm and their return loss curves are plotted for comparison in Figure 3.4. It is observed that return loss of tomb shaped antenna degrades at 6.7 GHz, 12.7 GHz and 15.2 GHz as R_x decrements from 11.45 mm to 9.45 mm and return loss degrades at 6.7 GHz, 9.3 GHz, 12.7 GHz and 15.2 GHz as R_x increments from 11.45 to 13.45 mm. In this way, ideal estimation of R_x is taken as11.45 mm.

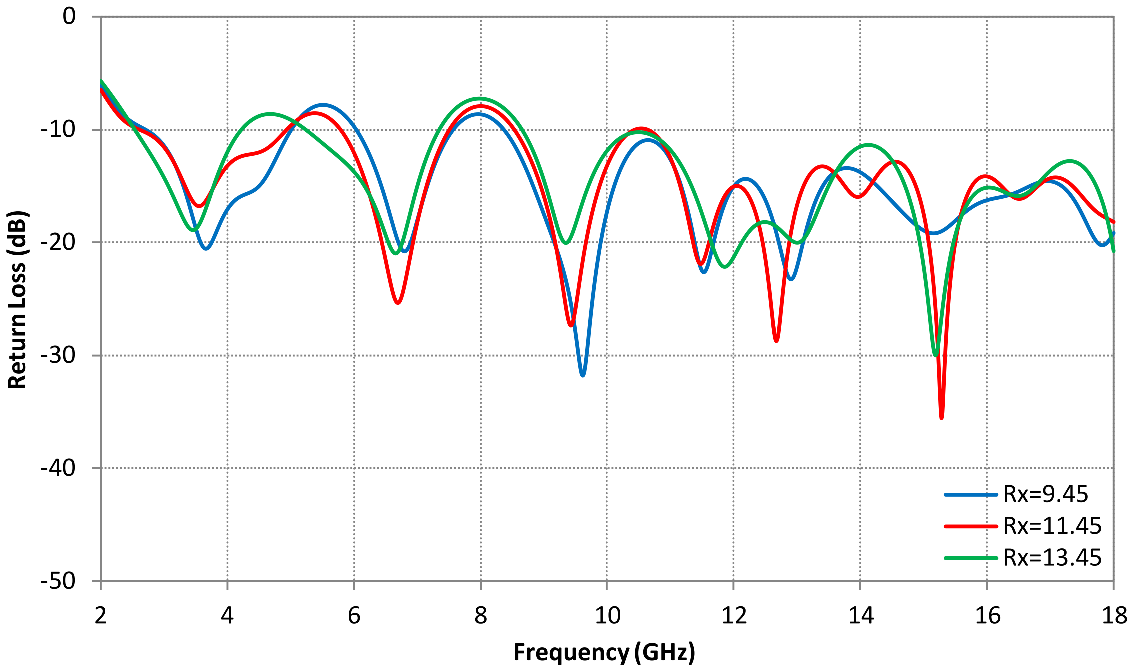


Figure 3.4 Simulated Return Loss vs. Frequency curve for different values of R_x.

Different values of R_y are taken in the range of 9.25 mm to 9.75 mm and their return loss curves are plotted for comparison in Figure 3.5. It is observed that return loss changes slightly when R_y is decreased from 9.5 mm to 9.25 mm whereas return loss degrades further when R_y increments from 9.5 mm to 9.75 mm at 6 GHz -10 GHz and 11 GHz - 18 GHz bands. In this way, ideal estimation of R_y is taken as 9.5 mm.

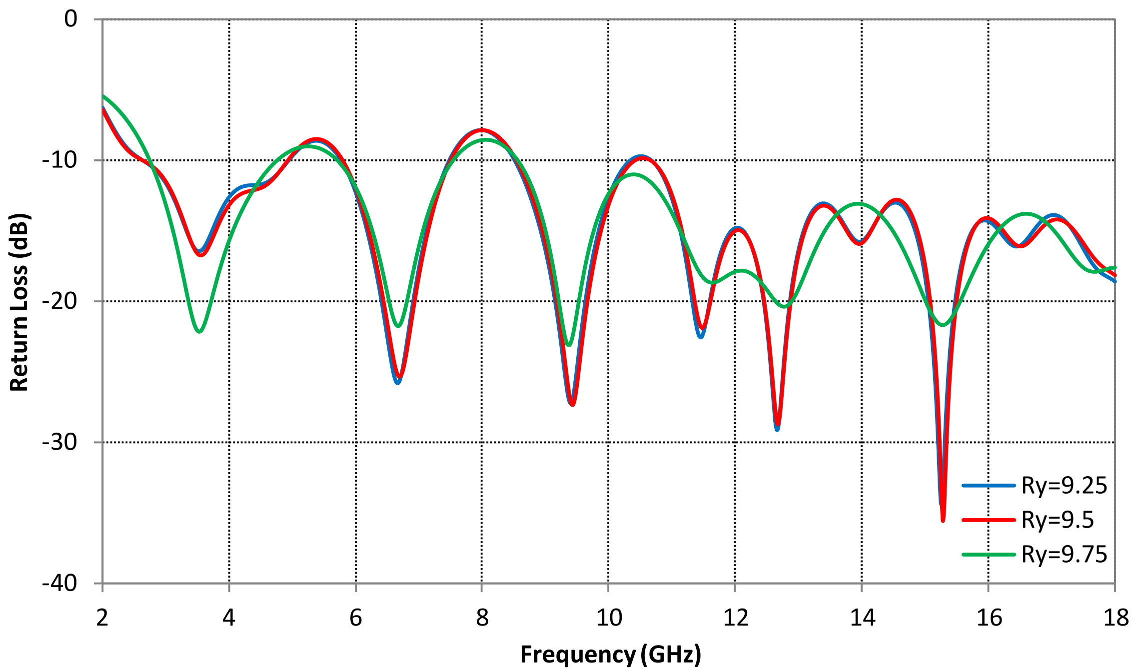


Figure 3.5 Simulated Return Loss vs. Frequency curve for different values of R_y.

3.3.2 Impact of varying the beveling parameters ‘c’ and ‘d’ on return loss of the antenna

Different values of beveling length ‘c’ are taken in the range of 8.6 mm to 10.6 mm and their return loss curves are plotted for comparison in Figure 3.6. When ‘c’ is reduced from 9.6 mm to 8.6 mm there is slight change in return loss whereas the return loss degrades at 3.1 GHz, 6.96 GHz, 9.37 GHz, 11.56 GHz and 17.23 GHz when ‘c’ is increased from 9.6 mm to 10.6 mm.

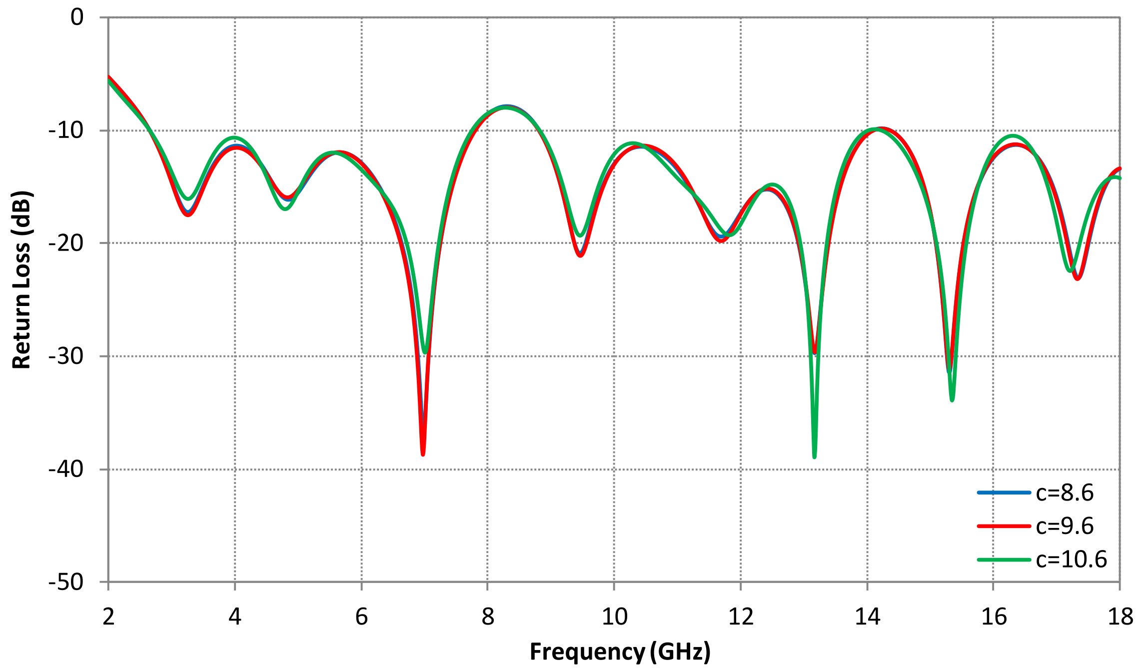


Figure 3.6 Simulated Return Loss vs. Frequency curve for different values of ‘c’.

Different values of beveling length ‘d’ are taken in the range of 6.9 mm to 10.9 mm and their return loss curves are plotted for comparison in Figure 3.7. It is observed that return loss of tomb shaped antenna degrades as the value of ‘d’ decrements from 8.9 mm to 6.9 mm at 3.08 GHz, 4.9 GHz, 9.5 GHz - 11.3 GHz, 13.37 GHz, 17.2 GHz and return loss degrades as d increments from 8.9 mm to 10.9 mm at 3.04 GHz, 6.01 GHz, 7.27 GHz, 8.41 GHz, 11.12 GHz, 13.3 GHz and 15.26 GHz . In this way, ideal estimation of ‘d’ is taken as 8.9 mm.

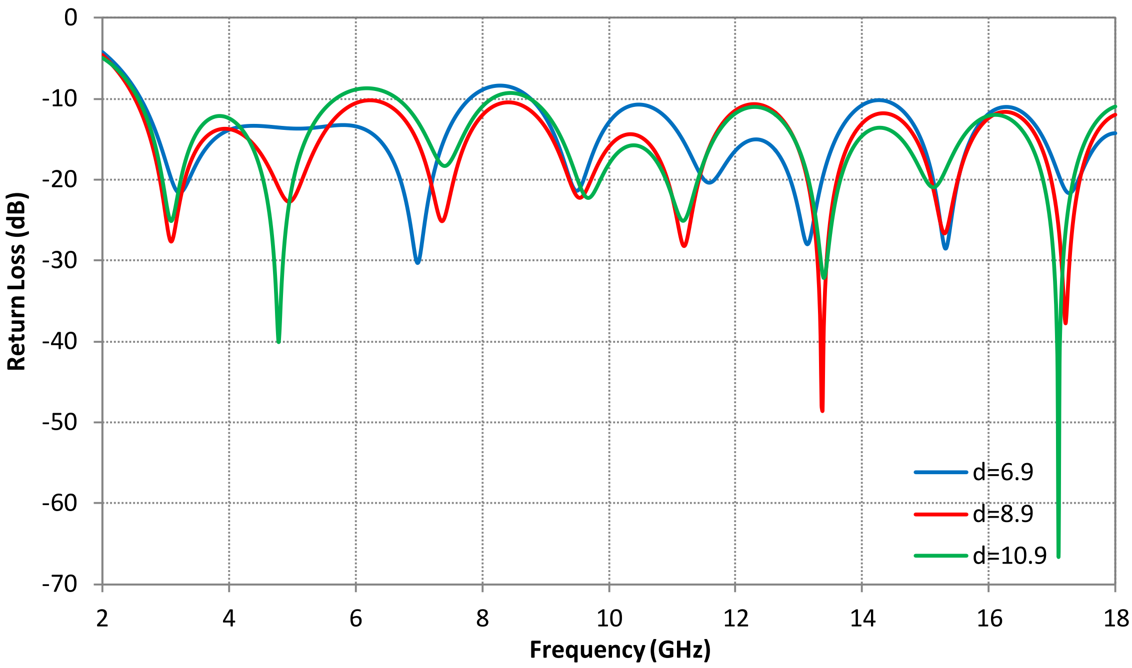


Figure 3.7 Simulated Return Loss vs. Frequency curve for different values of ‘d’.

3.3.3 Impact of varying the staircase parameters ‘a’ and ‘b’ on return loss of the antenna

Different values of length of staircase ‘a’ are taken in the range of 0.5 mm to 2.5 mm and their return loss curves are plotted for comparison in Figure 3.8. It is observed that when ‘a’ decrements from 1.5 mm to 0.5 mm, the return loss of the tomb shaped antenna degrades at 4 GHz, 7.04 GHz, 8.44 GHz, 11 GHz, 12.75 GHz, 13.8 GHz, 16.6 GHz and 17.6 GHz whereas return loss degrades at 4.49 GHz, 5.35 GHz, 7.04 GHz, 9.35 GHz, 11 GHz, 12.7 GHz and 16.6 GHz as ‘a’ increments form 1.5 mm to 2.5 mm. In this way, ideal estimation of ‘a’ is taken as 1.5 mm.

Different values of width of staircase ‘b’ are taken in the range of 1.5 mm to 2.5 mm and their return loss curves are plotted for comparison in Figure 3.9. It can be deduced that return loss of tomb shaped antenna degrades at 4.5GHz, 7.04 GHz, 9.21 GHz and 16.83 GHz when ‘b’ decrements from 2 mm to 1.5 mm and when ‘b’ is incremented from 2 mm to 2.5 mm return loss degrades at 4.2 GHz, 7 GHz, 11 GHz 12.7 GHz, 13.9 GHz and 17.64GHz. In this way, ideal estimation of ‘b’ is taken as 1.5 mm.

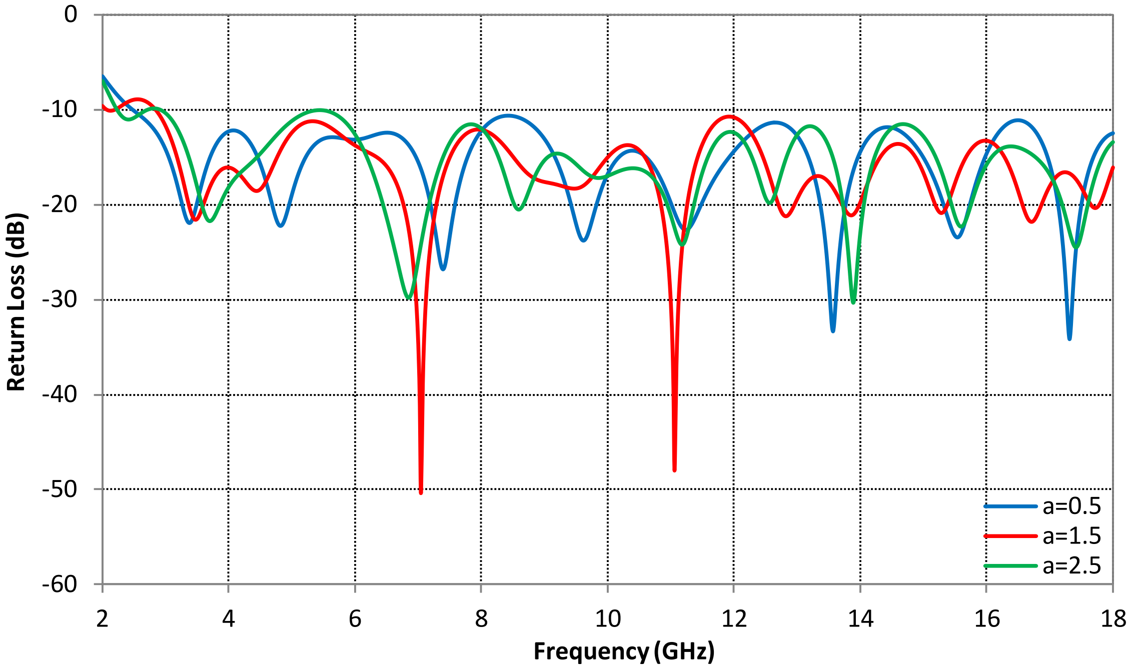


Figure 3.8 Simulated Return Loss vs. Frequency curve for different values of ‘a’.

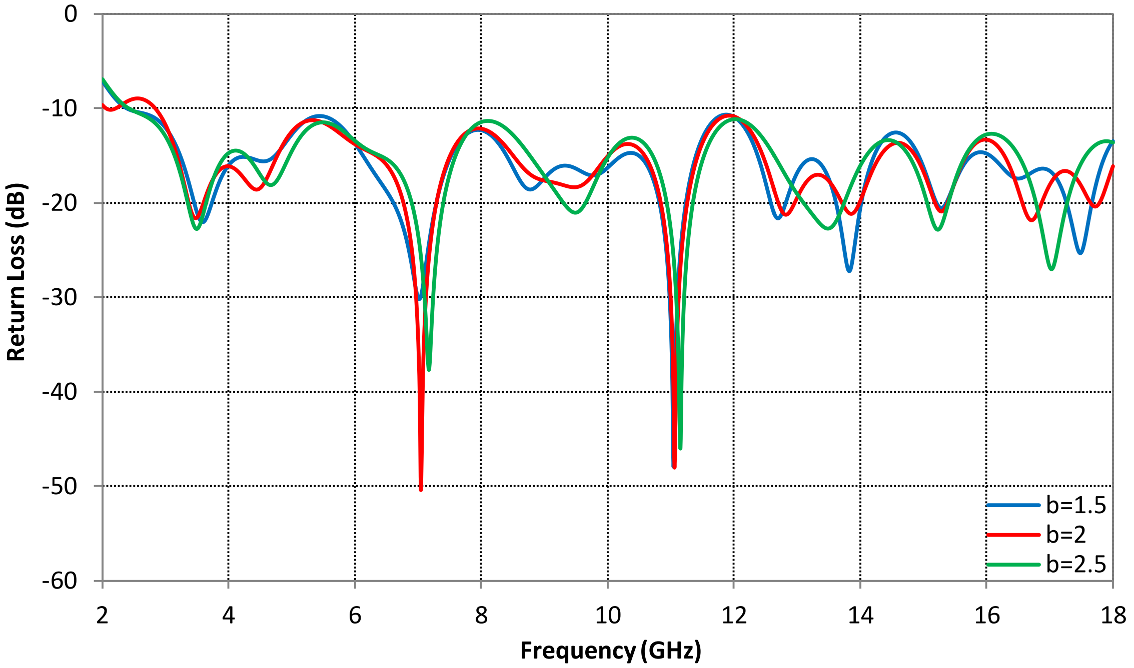


Figure 3.9 Simulated Return Loss vs. Frequency curve for different values of ‘b’.

3.4 FABRICATION AND MEASUREMENT

Fabrication and experimental testing of the tomb shaped UWB antenna is done to examine the actual working of the antenna in terms of parameters like return loss and VSWR. The tomb shaped UWB antenna after manufacturing is depicted in Figure 3.10. KEYSIGHT E5063A vector network analyzer (VNA) is employed to compute the values of return loss and VSWR.

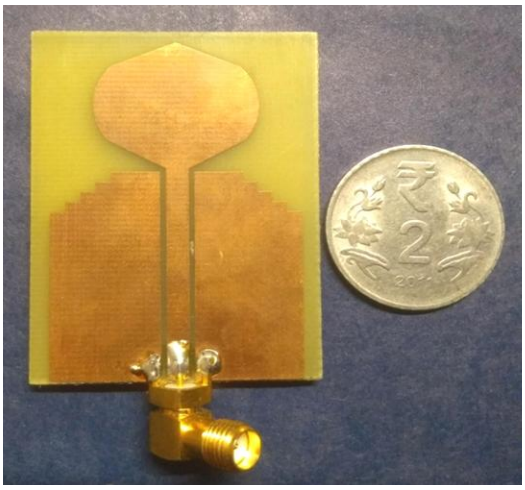


Figure 3.10 The fabricated antenna.

3.5 RESULTS AND DISCUSSION

Figure 3.11 depicts the graph plotted for comparing measured and simulated return loss of the designed UWB antenna. After observing the plots it can be deducted that measured result and simulated result are in compliance with each other to a large extent.

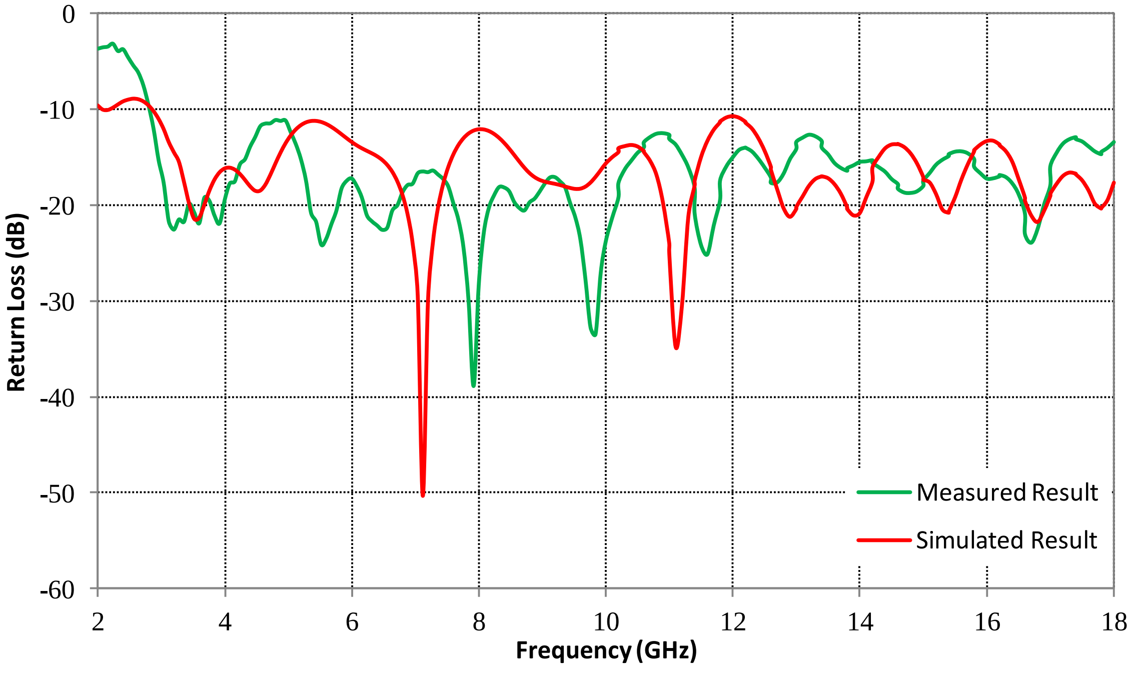


Figure 3.11 Simulated and measured Return Loss of proposed UWB antenna.

There are always some errors in measured results because of soldering done to join SMA connector to antenna feed line, fabrication tolerance and SMA connector. This leads to deviation of measured result from simulated results. So as can be seen from computed results, the proposed tomb shaped antenna exhibits ultra-wideband characteristics from 2.8 GHz to 18 GHz.

Figure 3.12 depicts the graph plotted between measured and simulated Voltage Standing Wave Ratio values of the designed UWB antenna with L slots. Measured result curve of VSWR shows that antenna is radiating from 2.8 GHz - 18 GHz with a value of VSWR < 2.

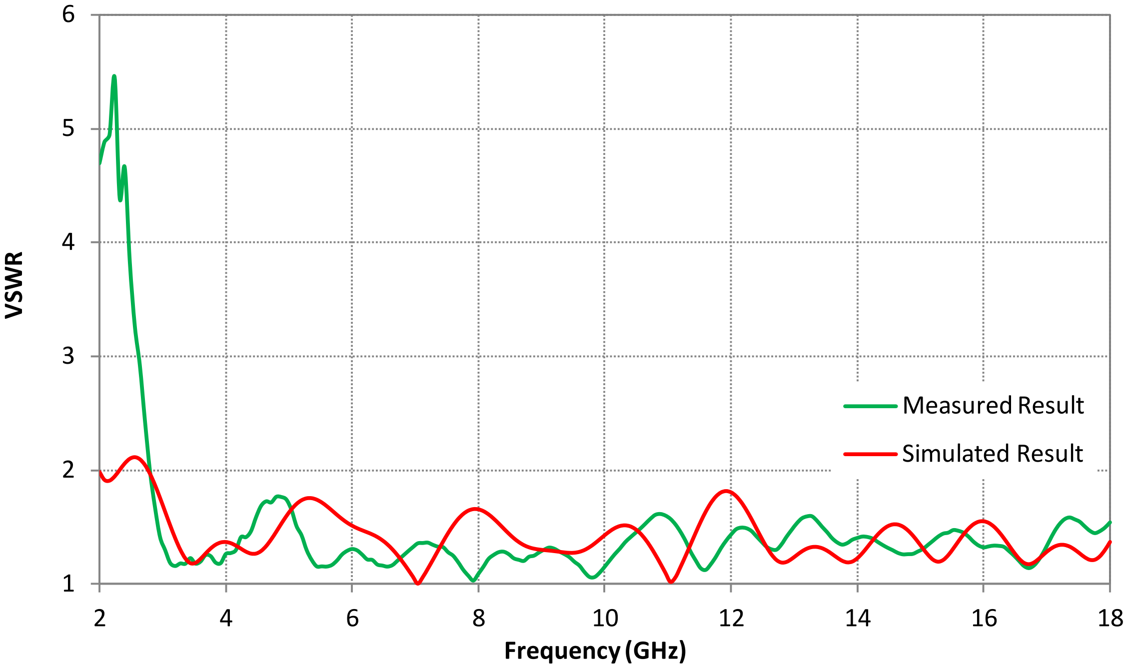


Figure 3.12 Simulated and measured Voltage Standing Wave Ratio of proposed UWB antenna.

Figure 3.13 depicts the curve between simulated Gain and frequency of the UWB antenna. Maximum Gain is 4.32 dB at 17.2 GHz and minimum values are 1.37 dB and -0.12 dB at 6 GHz and 2 GHz respectively.

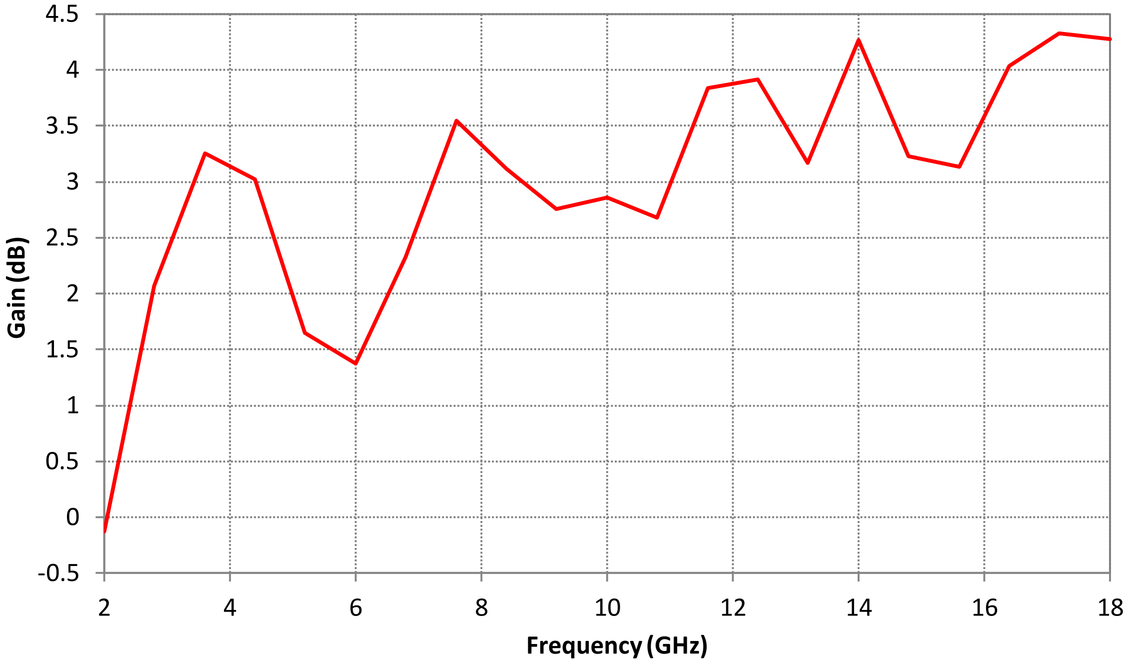


Figure 3.13 Simulated Gain vs. Frequency plot

Surface current distributions of the tomb shaped antenna are depicted in Figure 3.14 at 5 GHz, 11GHz, and 17 GHz frequencies. It is observed from the figure that the current is densely distributed in staircase at lower frequency of 5 GHz but gradually diminishes as frequency is increased further. Current prevails in lower half of the antenna for entire bandwidth. However upper half of the antenna has high current density at higher frequencies and hence has the most impact on higher frequencies.

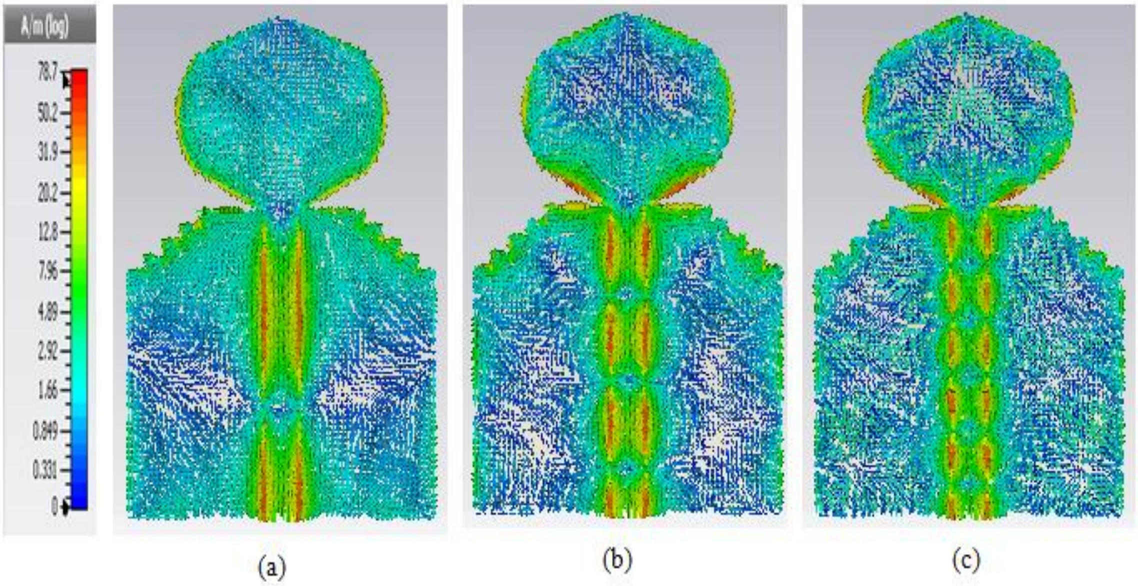


Figure 3.14 Surface current distributions on the antenna at (a) 5 GHz, (b) 11 GHz, and (c) 17 GHz.

Figure 3.15 depicts the simulated and measured radiation patterns at 3 GHz, 5GHz and 7GHz. Radiation pattern is presented by two planes namely E - plane and H - plane. E - plane signifies y-z plane and H - plane signifies x-z plane of three dimensional radiation pattern. It is observed that H-plane shows omnidirectional radiation pattern whereas E-plane shows bidirectional radiation pattern.

In this chapter a tomb shaped UWB antenna is designed, fabricated and its results are measured experimentally using a vector network analyzer (VNA). A comparison is done between simulated and measured results of the antenna. In the next chapter some technique is incorporated in order to create band notching characteristics in the tomb shaped UWB antenna.

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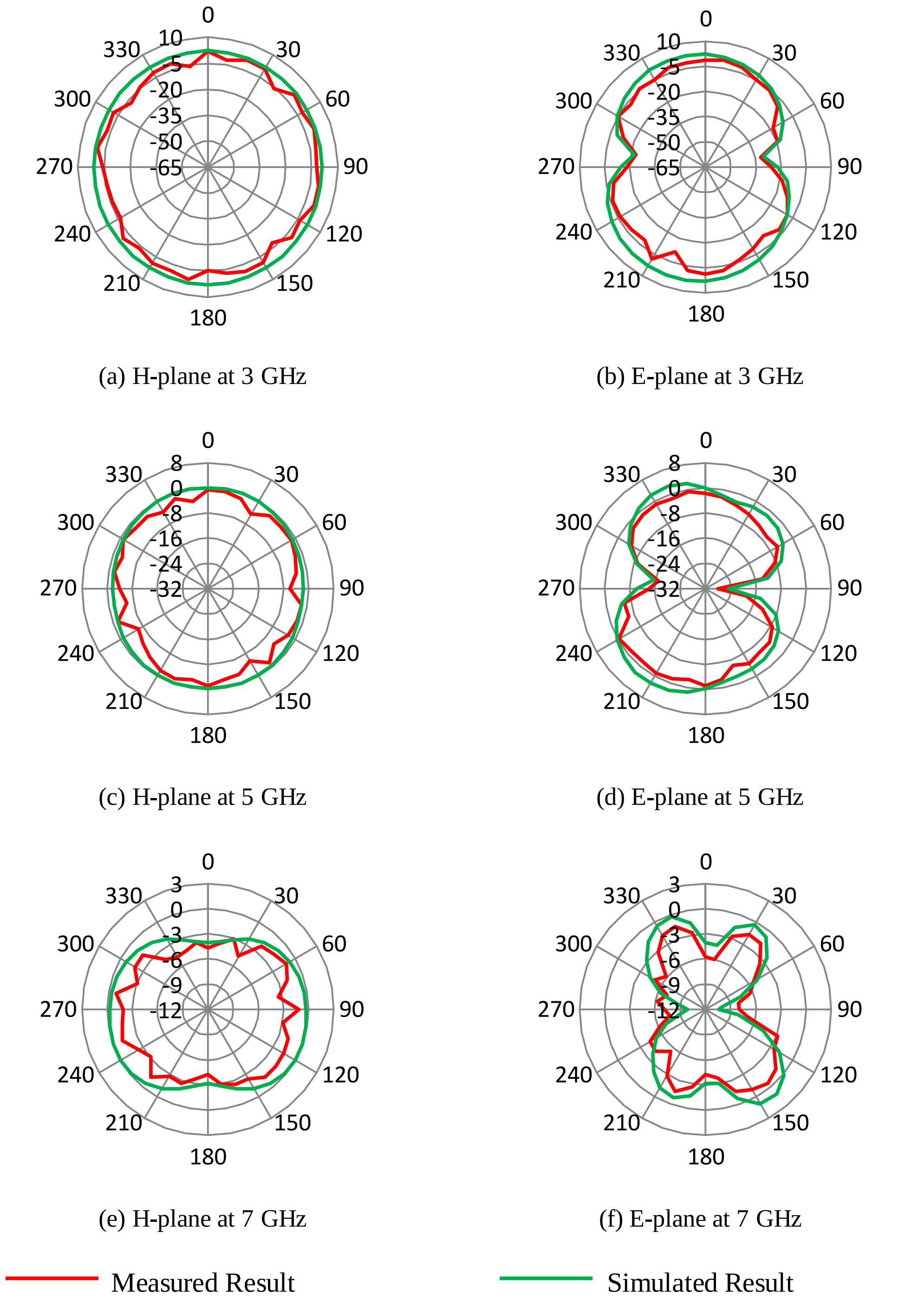


Figure 3.15 Simulated and measured radiation patterns of tomb shaped UWB antenna.

CHAPTER 4

TOMB SHAPED UWB ANTENNA DESIGN FOR TRIPLE BAND REJECTION

4.1 INTRODUCTION

As the power emission levels assigned to UWB systems by FCC are very low so they are easily interfered by neighbouring communication systems like

- World Interoperability for Microwave Access (WiMAX) ranging from 3.3 GHz - 3.7 GHz and 5.25 GHz - 5.85 GHz.
- Wireless Local Area Network (WLAN) ranging from 5.15 GHz - 5.35 GHz and 5.725 - 5.825 GHz
- C band ranging from 3.7 GHz - 4.2 GHz.
- Mission critical frequency band ranging from 4.4 GHz - 4.99 GHz.

Band-stop filters can be employed to reject the interference caused by neighbouring communication systems but this will lead to increased complexity and size of the system. Therefore the best method to reject the interference is to design an antenna having band notching capability in itself.

Various techniques have been studied and used for creating band notches and avoid the interference from neighbouring communication systems. So some band notching techniques can be employed like cutting slots on patch [13], using metamaterials [48-50], etching stubs [65], etching split ring resonators on patch and coplanar ground [66], cutting slots on feed line [67], etching parasitic stubs [68] and combination of multiple techniques [69].

In this chapter design of tomb shaped antenna having a capability to notch three bands is introduced for use in UWB applications. CST STUDIO SUITE is employed to create prototype of antenna and do the simulations. The technique of creating slots in the coplanar ground is used for notching three bands. Two identical L slots are inscribed in the coplanar ground to get the notched band. The notched band depends on various parameters of the L slots inscribed in ground of tomb shaped microstrip patch antenna. Therefore an analysis is done in this chapter to observe the impact of various parameters of the L slot on width and range of notched band. L slot parameters like length, width etc. are varied and return loss curves are plotted for comparing the impact of different values of the parameters. Finally the designed antenna is fabricated, tested and experimental results are shown. A comparison between simulated and experimental results is done.

4.2 ANTENNA DESIGN

The designed tomb shaped antenna for notching three bands consists of a modified patch, modified coplanar ground and two identical L shaped slots. Elliptical patch is modified by beveling it from upper and lower half. Coplanar ground is modified by adding staircase at upper edges of the ground. The substrate used to make this antenna is FR4 and1.6 mm is taken as its thickness. Radiating patch and ground are coplanar in CPW feeding approach i.e. they are etched on the same plane of FR4 substrate. Figure 4.1 depicts the layout and parameters of the tomb shaped antenna having two identical L slots in ground plane. Copper is used for making ground plane and radiating patch having thickness of 0.035 mm. W_f is the width of CPW feeding line having value 3.2 mm. The feeding line and the finite coplanar ground plane are separated by a spacing of 0.6 mm. The tomb shaped antenna has an overall size of 50×38×1.6 mm^3.

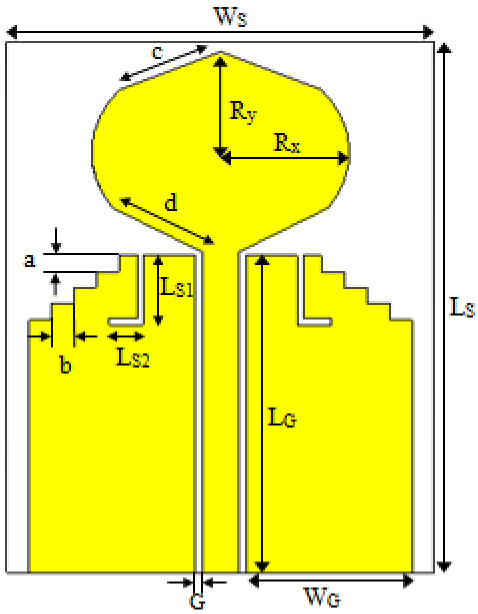


Figure 4.1 Configuration of proposed UWB antenna with L slots in the ground.

Two slots are etched in coplanar ground each having L-shape to notch three bands: WiMAX band, WLAN spectrum and mission critical frequency band. Slot length is equal to one fourth of the wavelength corresponding to resonant frequency of notched band. High current reflections are generated by the L slot at its resonant frequency and behaves as a band stop filter. The size of various L slot parameters can be calculated using the subsequent equations. The effective wavelength of the slot is given by [70]:

$$\lambda_{eff\_slot} = \lambda_0 / \sqrt{\varepsilon_{eff\_slot}} \quad (4.1)$$

Where free space wavelength is represented by λ_0 and the effective dielectric constant is represented by ε_{eff_slot}

$$\varepsilon_{eff\_slot} = (\varepsilon_r + 1)/2 \quad (4.2)$$

Therefore, the required slot length L_{slot} can be calculated by formula given below:

$$L_{slot} = \lambda_{eff_{slot}}/4 = C/(4 \times f_{notch} \times \sqrt{\varepsilon_{eff_{slot}}}) \quad (4.3)$$

Where f_{notch} represents desired resonant frequency at which notch is created and 'C' represents speed of light. Thus, overall length of L shaped slot can be stated as:

$$L_{slot} = L_{S1} + L_{S2} \quad (4.4)$$

Dimensions of the tomb shaped UWB antenna having L shaped slots are presented in Table 4.1. w_1 and w_2 are the widths of L_{S1} and L_{S2} lengths of the L slot respectively. G_L is the distance of L slot from end of the ground which is close to feed.

TABLE 4.1

DIMENSIONS OF THE TOMB SHAPED UWB ANTENNA WITH L SLOTS

Parameters	Size(mm)	Parameters	Size(mm)
W_S	38	a	1.5
L_S	50	b	2
R_x	11.5	L_{S1}	6.5
R_y	9.5	L_{S2}	3
L_G	29.8	G_L	4.6
W_G	21	w_1	0.5
G	0.6	w_2	0.7

4.3 PARAMETRIC STUDIES OF ANTENNA

Effects of varying size of different parameters of the tomb shaped antenna having L slots in the ground have been discussed in this section. In this analysis, return loss curves are drawn to compare the effect caused by varying size of the parameters of L slot. Single parameter is varied while keeping others constant.

4.3.1 Impact of varying L_{S1} and L_{S2} lengths of L slot on return loss of the antenna

Different values of L_{S1} are taken in the range of 4.5 mm to 8.5 mm and their return loss curves are compared in Figure 4.2. It can be deduced that notched band of designed antenna moves from 3.86

GHz - 6.17 GHz to 4.6 GHz - 7.6 GHz when L_{S1} decrements from 6.5 mm to 4.5 mm whereas notched band moves from 3.86 GHz - 6.17 GHz to 3.3 GHz - 5.5 GHz when L_{S1} increments from 6.5 mm to 8.5 mm. In this way, ideal estimation of L_{S1} is taken as 6.5 mm because it has best return loss and notches the required band.

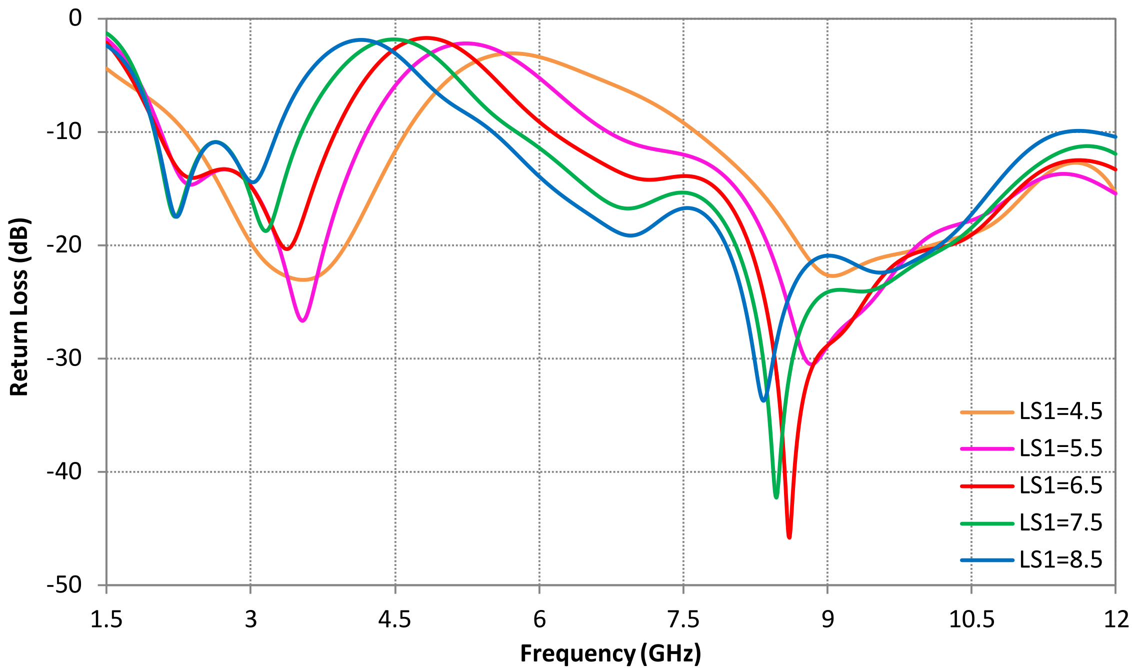


Figure 4.2 Simulated Return Loss vs. Frequency curve for different values of L_{S1}.

Different values of L_{S2} are taken in the range of 1 mm to 5 mm and their return loss curves are compared in Figure 4.3. It can be deduced that notched band of designed antenna moves from 3.86 GHz - 6.17 GHz to 4.6 GHz - 7.8 GHz when L_{S2} is decremented from 3 mm to 1 mm whereas when L_{S2} increments from 3 mm to 5 mm notched band moves from 3.86 GHz - 6.17 GHz to 3.4 GHz - 5.6 GHz. In this way, ideal estimation of L_{S2} is taken as 3 mm because it has best return loss and notches the required band.

4.3.2 Impact of varying 'w_1' and 'w_2' widths of L slot on return loss of the antenna

Different values of w_1 are taken in the range of 0.3 mm to 0.9 mm and their return loss curves are compared in Figure 4.4. It can be deduced that notched band of designed antenna moves from 3.86 GHz - 6.17 GHz to 3.7 GHz - 5.8 GHz as w_1 decrements from 0.5 mm to 0.3 mm whereas notched band moves from 3.86 GHz - 6.17 GHz to 3.9 GHz - 6.7 GHz when w_1 increments from 0.5 mm to 0.9 mm. In this way, ideal estimation of w_1 is taken as 0.5 mm because it has best return loss and notches the required band.

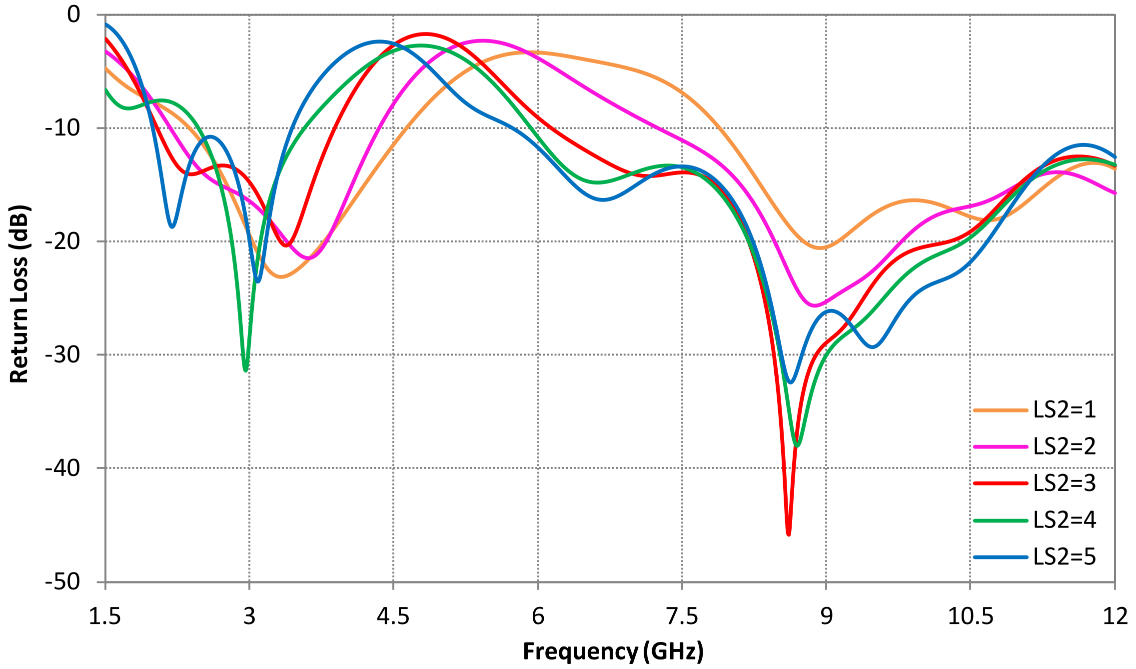


Figure 4.3 Simulated Return Loss vs. Frequency curve for different values of L_{S2}.

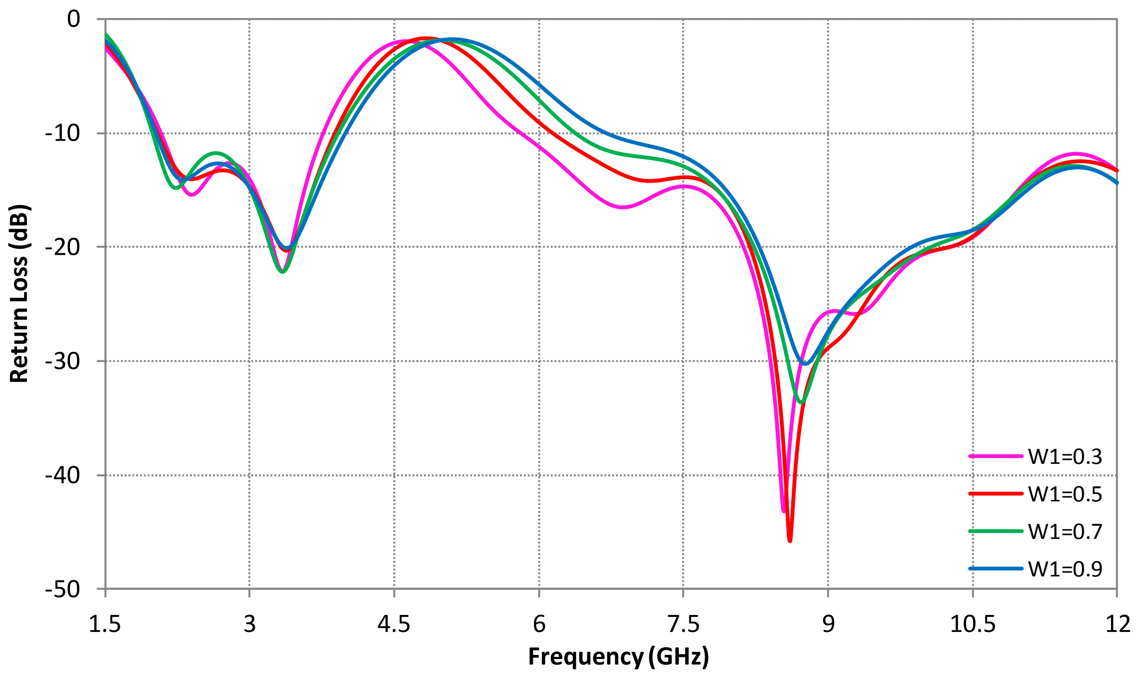


Figure 4.4 Simulated Return Loss vs. Frequency curve for different values of w_1.

Different values of w_2 are taken in the range of 0.3 mm to 0.9 mm and their return loss curves are compared in Figure 4.5. It can be deduced that notched band of designed antenna moves from 3.86 GHz - 6.17 GHz to 3.9 GHz - 6.3 GHz when w_2 decrements from 0.7 mm to 0.3 mm whereas notched band moves from 3.86 GHz - 6.17 GHz to 3.6 GHz - 6.02 GHz when w_2 is incremented from 0.7 mm to 0.9 mm. In this way, ideal estimation of w_2 is taken as 0.7 mm because it has best return loss and notches the required band.

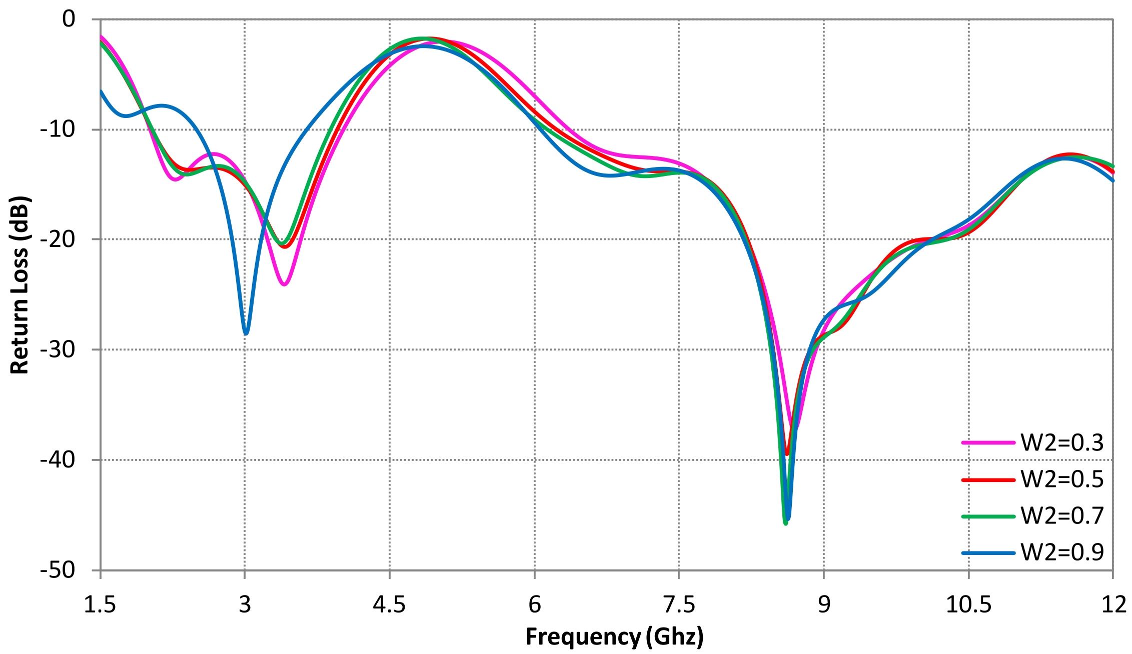


Figure 4.5 Simulated Return Loss vs. Frequency curve for different values of w_2.

4.3.3 Impact of Varying G_L on return loss of the antenna

Different values of G_L are taken in the range of 1.6 mm to 5.6 mm and their return loss curves are compared in Figure 4.6. It can be deduced that G_L impacts the width of the notched band. When G_L increments from 4.6 mm to 5.6 mm the width of notched band decreases from 3.86 GHz - 6.17 GHz to 3.9 GHz - 5.8 GHz whereas when G_L decrements from 4.6 mm to 1.6 mm the width of notched band increases from 3.86 GHz - 6.17 GHz to 3.5 GHz - 8 GHz. In this way, ideal estimation of G_L is taken as 4.6 mm because it has best return loss and notches the required band.

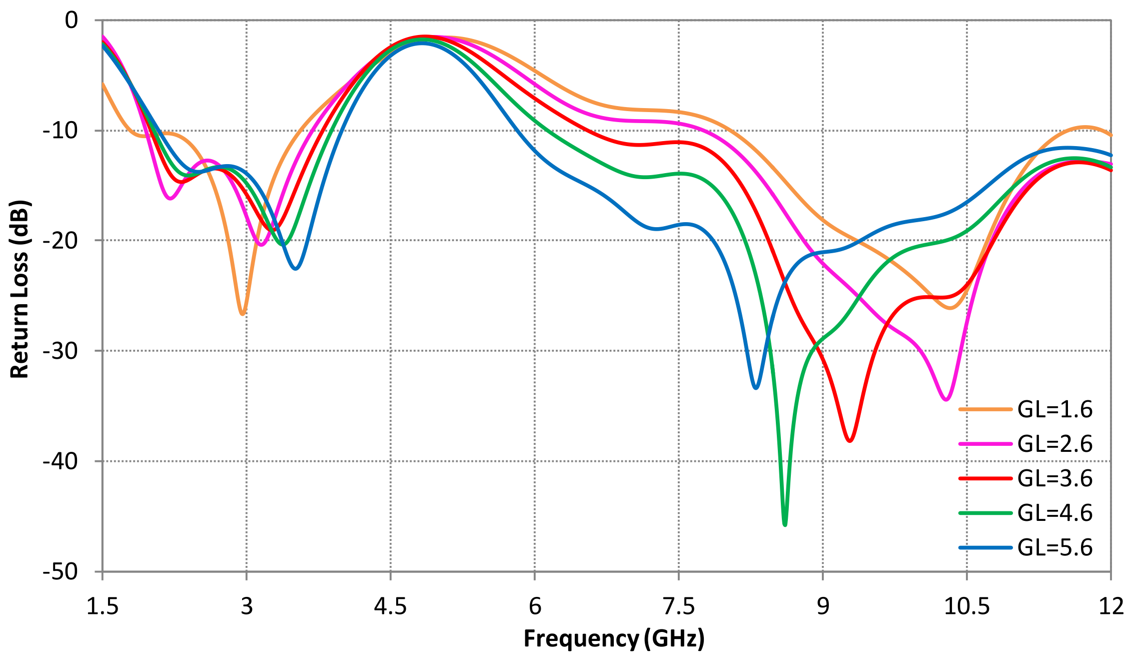


Figure 4.6 Simulated Return Loss vs. Frequency curve for different values of G_L.

4.4 FABRICATION AND MEASUREMENT

Fabrication and experimental testing of the tomb shaped UWB antenna having two L slots is done to examine the actual working of the antenna in terms of parameters like return loss and VSWR. The tomb shaped UWB antenna having L slots after manufacturing is depicted in Figure 4.7.

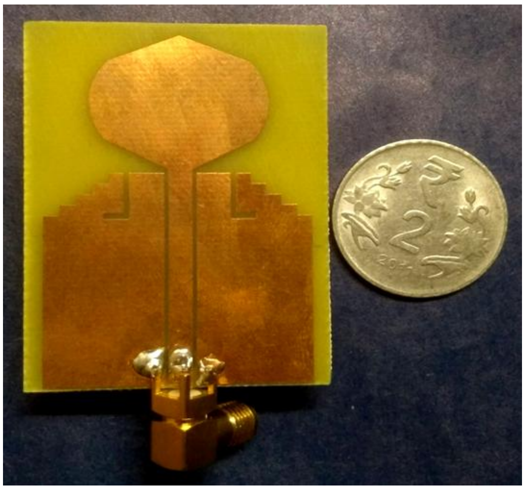


Figure 4.7 The fabricated UWB antenna with L slots.

KEYSIGHT E5063A vector network analyzer (VNA) is employed to measure the values of return loss and VSWR as depicted in Figure 4.8.

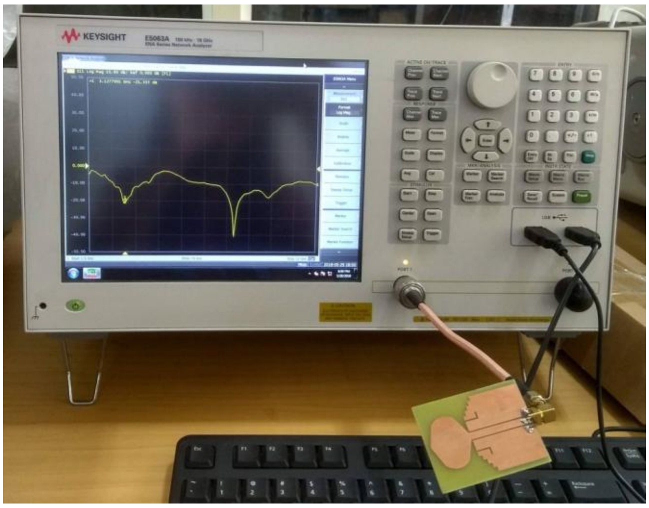


Figure 4.8 Testing of fabricated antenna using VNA.

4.5 RESULTS AND DISCUSSION

Figure 4.9 depicts the graph plotted for comparing measured and simulated return loss of the designed UWB antenna with L slots. After observing the plots it can be deducted that measured result and simulated result are in compliance with each other to a large extent.

There are always some errors in measured results because of soldering done to join SMA connector to antenna feed line, fabrication tolerance and SMA connector. This leads to deviation of measured result from simulated results. So the measured results show that proposed tomb shaped antenna with two L slots exhibits an ultra-wideband characteristics from 2.6 GHz to 3.8 GHz and 6.28 GHz to 10.58 GHz and a band notch from 3.81 GHz - 6.27 GHz.

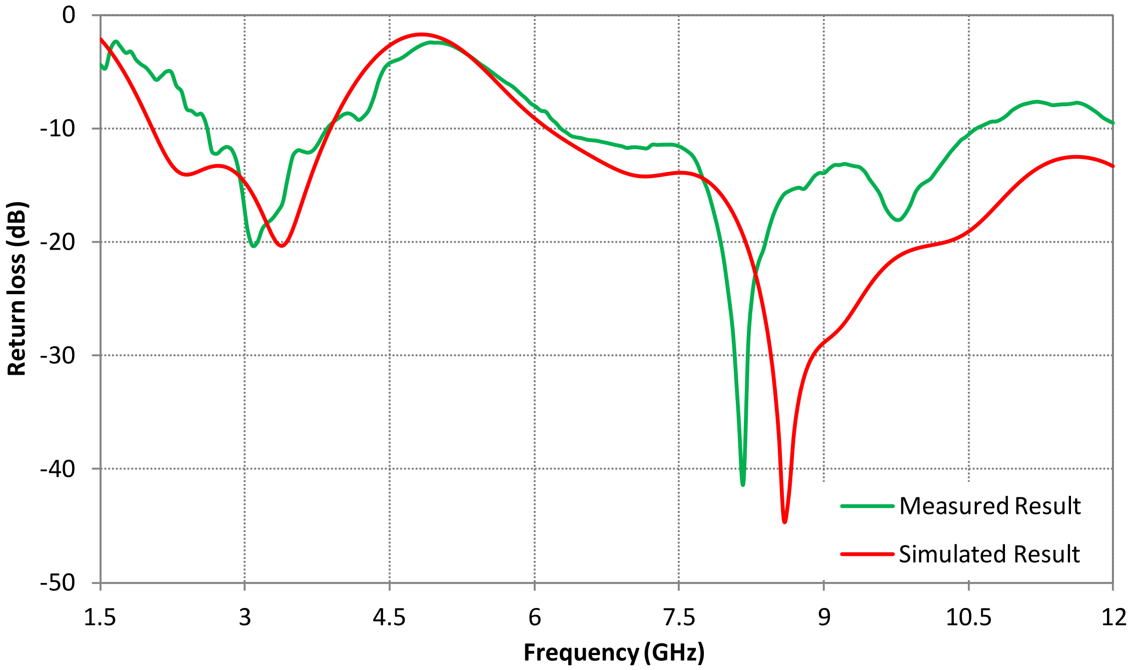


Figure 4.9 Simulated and measured Return Loss of proposed UWB antenna with L slots.

Figure 4.10 depicts the graph plotted between measured and simulated Voltage Standing Wave Ratio (VSWR) values of the designed UWB antenna with L slots. Measured result curve of VSWR shows that antenna is not radiating from 3.81 GHz - 6.27 GHz with a value of VSWR = 7. The notched bands are WiMAX ranging from 5.25 GHz - 5.85 GHz, WLAN ranging from 5.15 GHz - 5.35 GHz and 5.725 - 5.825 GHz and mission critical frequency band ranging from 4.4 GHz - 4.99 GHz.

Surface current distributions of the tomb shaped antenna having two identical L slots are depicted in Figure 4.11 at 2.5 GHz, 4.8GHz, and 8.6 GHz frequencies. It is observed from the figure that the current is almost evenly distributed over whole of the antenna at lower frequency of 2.5 GHz. Current becomes densely distributed around L slots at the resonant frequency of the notched band. However at 8.6 GHz the current again is distributed evenly in all parts of the antenna.

Figure 4.12 depicts the simulated and measured radiation patterns at 3.4 GHz, 4.6GHz and 7GHz. Radiation pattern is presented by two planes namely E-plane and H-plane. E-plane signifies y-z plane and H-plane signifies x-z plane of three dimensional radiation patterns. It is observed that H-plane shows omnidirectional radiation pattern whereas E-plane shows bidirectional radiation pattern.

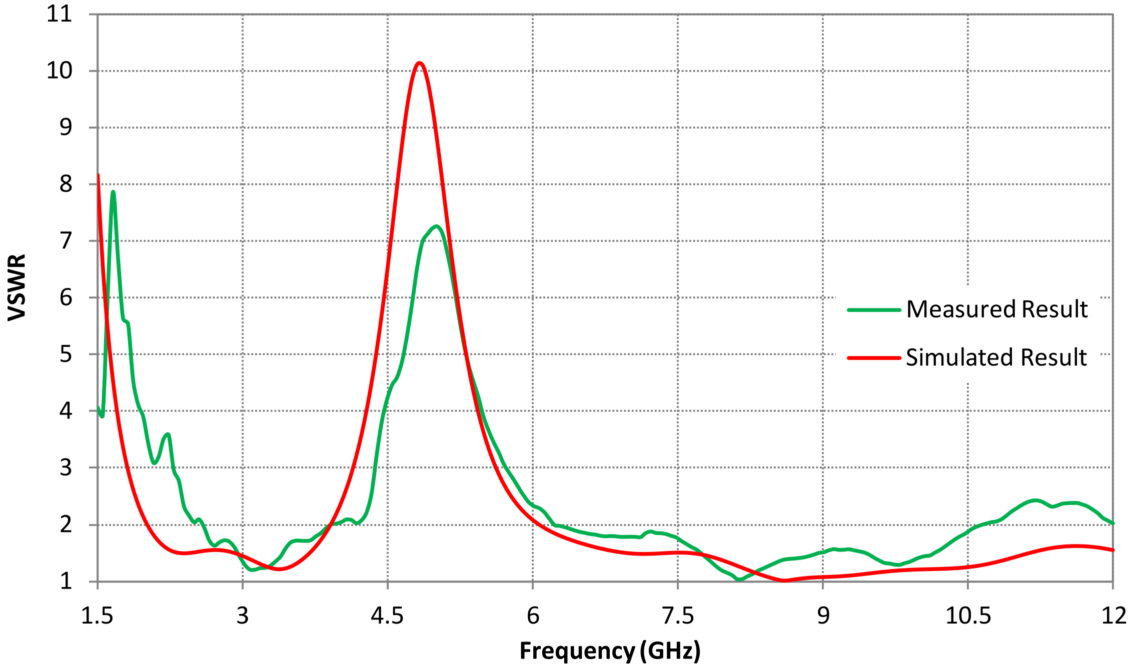


Figure 4.10 Simulated and measured Voltage Standing Wave Ratio of proposed UWB antenna with L slots.

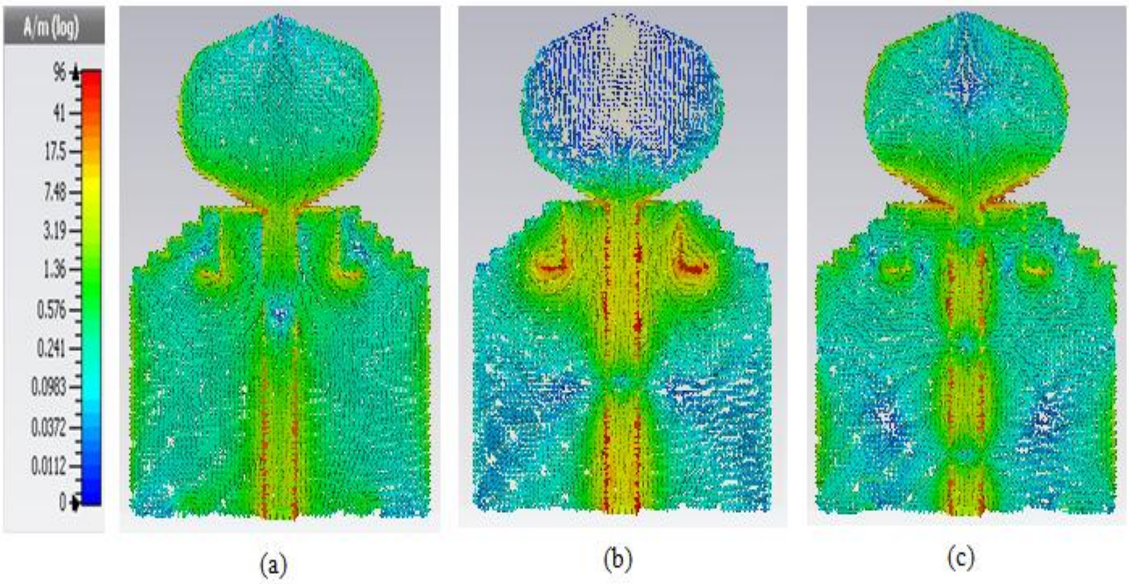
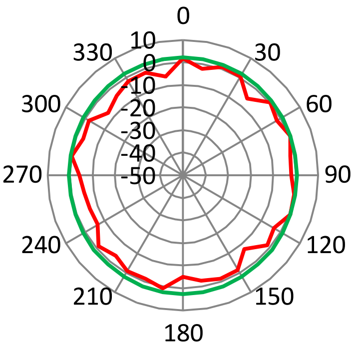
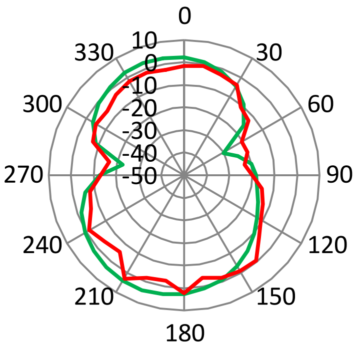


Figure 4.11 Surface current distributions on the antenna at (a) 2.5 GHz, (b) 4.8 GHz, and (c) 8.6 GHz.

In this chapter a tomb shaped UWB antenna is employed with two L shaped slots in the coplanar ground structure to get triple notch band characteristics. This antenna is designed, fabricated and its results are measured experimentally using a vector network analyzer (VNA). A comparison is done between simulated and measured results of the antenna. The next chapter will conclude the work done in this thesis and also discuss the future scope of the work done.

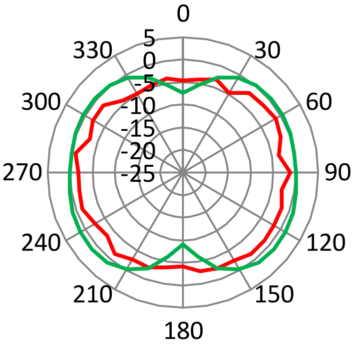


(a) H-plane at 3.4 GHz

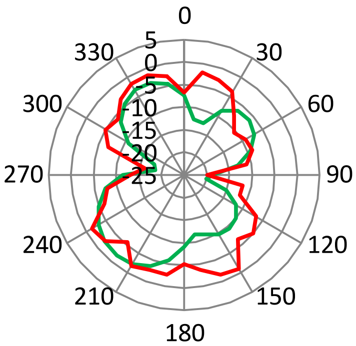


(b) E-plane at 3.4 GHz

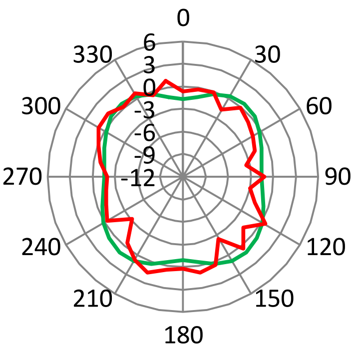
s



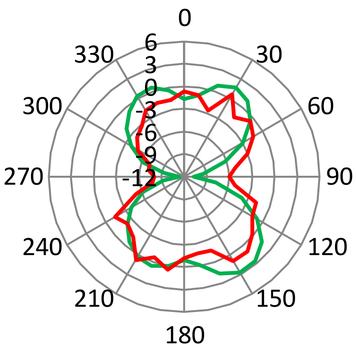
(c) H-plane at 4.6 GHz



(d) E-plane at 4.6 GHz



(e) H-plane at 7 GHz



(f) E-plane at 7 GHz

Measured Result Simulated Result

Figure 4.12 Simulated and measured radiation patterns of tomb shaped UWB antenna with L slots.

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CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION

In this chapter, summary of all the work undertaken in this thesis is given and then the conclusion and future work are presented.

Nowadays, a wireless technology is required to interconnect all the devices wirelessly that are found in an individual's surroundings. So there is a need of a new technology which provides higher data rates as compared to existing technologies. UWB technology is the key solution to attain such high data rates as it occupies large bandwidth. Antenna being the only non digital part of the UWB system, it remains a difficult task to design an antenna for UWB applications as it have rigorous specifications as compared to narrowband antenna. Therefore antenna design and its analysis are presented in this study for use in UWB system.

In this thesis two antennas were designed for UWB applications. At first tomb shaped antenna is designed to work in UWB range from 2.8 GHz to 18 GHz without any band notches. Various techniques were employed to increase overlapping of frequencies and hence large impedance bandwidth is achieved. CST STUDIO SUITE is employed to create prototype of antenna and do the simulations. The performance of tomb shaped antenna depends on its various parameters. Hence parametric analysis is done to observe the impact of various dimensional parameters of the designed antenna on the return loss. The design parameters of antenna are varied and return loss curves are plotted for different parameter values for comparison. Finally the designed antenna is fabricated and experimental results are shown. A comparison between simulated and experimental results is done.

Next the tomb shaped antenna is modified by employing two L slots in the ground to create band notch from 3.81 GHz - 6.27 GHz. Cutting slots to create notch is the easiest and simplest way which provide desired notch by changing path of current. The notched bands are WiMAX ranging from 5.25 GHz - 5.85 GHz, WLAN ranging from 5.15 GHz - 5.35 GHz and 5.725 - 5.825 GHz and mission critical frequency band ranging from 4.4 GHz - 4.99 GHz. CST STUDIO SUITE is employed to create prototype of antenna and do the simulations. Analysis is done to see the impact of various parameters of the L slot on the notched band. L slot parameters like length, width etc. are varied and their return loss curves are compared for different values of the parameters. Finally the designed antenna is fabricated and experimental results are shown. A comparison between simulated and experimental results is done.

Finally the comparison between simulated and experimental results show that designed antennas have ultra wide bandwidth which makes them suitable for use in UWB systems. Various antenna parameters like VSWR, surface current distributions, gain and radiation patterns are also studied for both the antennas which show the suitability of antennas designed for use in UWB applications.

5.2 FUTURE SCOPE

In view of the conclusions drawn, future work is possible in the following areas:

Firstly, in this thesis antenna measurements took place in anechoic chamber. But UWB antennas are meant to be embedded in laptops, portable devices or hand held devices. Thus the effect of devices and human body on antenna needs to be evaluated.

Secondly, the UWB antennas will be integrated in mobile phones, portable devices and wireless personal area network devices. So there is a need of small sized antennas. Thus new techniques need to be discovered and employed in designing small sized antennas for practical UWB applications.

Thirdly, in some applications directional antennas having high gain are required for increasing the data rate and range of transmitted data. Thus future work can be carried out in field of designing antenna arrays suitable for such applications.

Fourthly, the designed antenna can be made reconfigurable by using switches in the design. In this way antenna can perform multiple tasks.

Lastly, work need to be done on optimization techniques like particle swarm optimization (PSO) or genetic algorithm to obtain the optimized dimensions of the antenna.

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LIST OF PUBLICATIONS

Communicated

- Akanksha Upadhyay, Rajesh Khanna, “A compact size CPW-fed tomb shaped antenna for UWB applications,” communicated to International Journal of Microwave and Wireless Technologies on 4 July 2018.