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DESIGN OF ULTRA-WIDEBAND ANTENNAS WITH SIGNAL REJECTION CHARACTERISTICS FOR BIOMEDICAL APPLICATIONS

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ABSTRACT

The allocation of the 3.1-10.6 GHz spectrum by the Federal Communications Commission (FCC) for Ultra Wideband (UWB) radio applications has presented many exciting opportunities and challenges for the researchers in academia and industry for the exploitation of several novel antenna design suitable for UWB communication. The successful transmission and reception of short pulses used for UWB communication that occupies the entire 3.1-10.6 GHz spectrum require an antenna with characteristics like linear phase, low dispersion and VSWR ≤ 2 throughout the entire band. Linear phase and low dispersion are marked by low values of group delay and is imperative for transmitting and receiving a pulse for distortion free communication. VSWR ≤ 2 is required for proper impedance matching throughout the UWB band which ensures at least 90% of total power radiation is achieved by the designed antenna. On the other hand, there are other narrowband system that operates at 5.15-5.85 GHz are occupied by Wireless Local Area Network (WLAN), which causes electromagnetic interference to the UWB systems. To avoid this interference, a band- notch filter is required which is achieved by adding slots in the radiating patch or the ground plane. This helps to remove the necessity of using band rejection filter with the UWB antenna for rejecting the interfering frequency band.

By adding slots either in the radiating patch or ground plane of the UWB we can eliminate the interference of the operating frequency band of WLAN systems. The focus of this research is to develop miniaturized novel antennas for the UWB 3.1-10.6 GHz band with signal rejection characteristics which has WLAN (5.15-5.85 GHz) band rejection and achieves a physically compact, planar profile, sufficient impedance bandwidth, high radiation efficiency and nearly Omni-directional radiation pattern well suited biomedical applications like medical monitoring, medical sensor data collection and medical imaging systems.

Keywords: Ultra wideband (UWB), VSWR, band-notch, WLAN, gain, group delay.

DEDICATION

To my beloved parents, my sister, my brother and all my friends who supported me during this undertaking.

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ADS	Agilent Advanced Design System
BW	Bandwidth
CPW	Coplanar Waveguide
CSRR	Complimentary Split Ring Resonator
EIRP	Effective Isotropically Radiated Power
E- Plane	Elevation Plane
EM	Electromagnetic
EMI	Electromagnetic Interference
FCC	Federal Communications Commission
H-Plane	Horizontal Plane
IC	Integrated Circuit
IEEE	Institute of Electrical and Electronics Engineers
ITU -R	International Telecommunication Union Radio
OFDM	Orthogonal Frequency-Division Multiplexing

MMIC	Monolithic Microwave Integrated Circuit
PCMA	Printed Circular Monopole Antenna
RF	Radio Frequency
SMA	Sub -Miniature Version A
SRR	Split Ring Resonator
3-D	Three Dimensional
UWB	Ultra Wideband
VSWR	Voltage Standing Wave Ratio
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network

ORGANIZATION OF THESIS

TITLE:

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CHAPTER 1

INTRODUCTION

1.1 Overview

In 2002, the Federal Communications Commission (FCC) [1] has released the regulation for UWB (Ultra-wideband) technology, allocating the frequency spectrum from 3.1 to 10.6 GHz for UWB communication. Ultra-wideband is one of the most emerging radio technology that can be used at very low energy levels for short-range high-bandwidth communications by using a large portion of the radio spectrum. UWB has traditional applications in radar imaging and wireless communication. Most recent applications target sensor data collection, medical applications, precision locating and tracking applications.

Ultra-wideband (UWB) is one of the most promising technologies for medical imaging systems, medical sensor data collection systems, future high-data rate wireless communications and high-accuracy radars. Compared with conventional broadband wireless communication systems, the UWB system operates within an extremely wide bandwidth in the microwave band and at a very low emission limit. Due to the system features and unique applications, antenna design is facing a variety of challenging issues such as broadband response in terms of impedance, phase, gain, radiation patterns as well as small or compact size. Ultra Wideband was traditionally accepted as pulse radio, but the FCC and ITU-R now define UWB in terms of a transmission from an antenna for which the emitted signal bandwidth exceeds the lesser of 500 MHz or 20% of the center frequency. Thus, pulse-based systems wherein each transmitted pulse instantaneously occupies the UWB bandwidth, or an aggregation of at least 500 MHz worth of narrow band carriers, for example in orthogonal frequency-division multiplexing (OFDM) fashion can gain access to the UWB spectrum under the rules. Pulse-based UWB radars and imaging systems tend to use low repetition rates, typically in the range of 1 to 100 mega pulses per second. On the other hand, communications systems favor high repetition rates, typically in the range of 1 to 2 Giga-pulses per second, thus enabling short-range gigabit-per-second communications systems. Each pulse in a pulse-based UWB system occupies the entire UWB band which reaps the benefits of relative immunity to multipath fading (but non-immune to inter symbol interference). Whereas, carrier-based systems are subject to both deep fades and inter-symbol interference.

1.2 UWB Wireless Systems

The term ‘ultra-wideband’ (UWB) refers to a radio technology for the transmission of information spread over an extremely large operating bandwidth (3.1 -10.6 GHz) where the electronic systems should be able to correlate with other electronic users. UWB technology has been around for decades. Its original applications were mostly in military systems. However, the first Report and Order by the Federal Communications Commission (FCC) authorizing the unlicensed use of UWB on February 14, 2002, gave a huge boost to the research and development efforts of both industry and academia [2]. The aim is to provide an efficient use of frequency spectra while enabling short-range but high-data-rate wireless personal area network (WPAN) and long-range but low-data-rate wireless connectivity applications, as well as radar and imaging systems, as shown in Table 1.1

Table 1.1 UWB applications and the associated frequency range.

Applications	**Frequency Range (GHz)**
Indoor Communication Systems	3.1-10.6
Ground-Penetration radar, wall imaging	3.1-10.6
Through-wall imaging systems	1.61-10.6
Surveillance system	1.99-10.6
Medical imaging systems	3.1-10.6
Vehicular radar systems	22-29

1.3 Technical Terms related to UWB

1. **UWB bandwidth** is the frequency range bounded by the points that are 10 dB below the highest power emission with the upper edge f_h and the lower edge f_l. Thus, the center frequency f_c of the UWB bandwidth is designated as

$$f_c = \frac{f_h + f_l}{2} \tag{1.1}$$

Accordingly, the **fractional bandwidth** *BW* is defined as

$$BW = 2\,\frac{f_h - f_l}{f_h + f_l} \tag{1.2}$$

$$BW = \frac{f_h - f_l}{f_c} \tag{1.3}$$

2. A UWB transmitter is an intentional radiator that, at any point in time, has a fractional bandwidth *BW* of at least 20% or has a UWB bandwidth of at least 500 MHz, regardless of the fractional bandwidth.

3. Effective isotropically radiated power (EIRP) represents the total effective transmit power of the radio, i.e. the product of the power supplied to the antenna with possible losses due to an RF cable and the antenna gain in a given direction relative to an isotropic antenna. The EIRP, in terms of dBm, can be converted to the field strength, in dB V/m at 3 meters, by adding 95.2. With regard to this part of the rules, EIRP refers to the highest signal strength measured in any direction and at any frequency from the UWB device, as tested in accordance with the procedures specified in Part 15.31(a) and 15.523 of the FCC rules.

1.4 Regulations

A February 14, 2002 Report and Order by the FCC authorizes the unlicensed use of UWB in the range of **3.1 to 10.6 GHz**. The FCC power spectral density emission limit for UWB emitters operating in the UWB band is -41.3dBm/MHz [2]. This is the same limit that applies to unintentional emitters in the UWB band, the so called Part 15 limit. However, the emission limit for UWB emitters can be significantly lower (as low as -75dBm/MHz) in other segments of the spectrum. More than four dozen devices have been certified under the FCC UWB rules, the vast majority of which are radar, imaging or locating systems. According to the FCC, any transmitting system which emits signals having a bandwidth greater than 500MHz or 20% fractional bandwidth can gain access to the UWB spectrum.

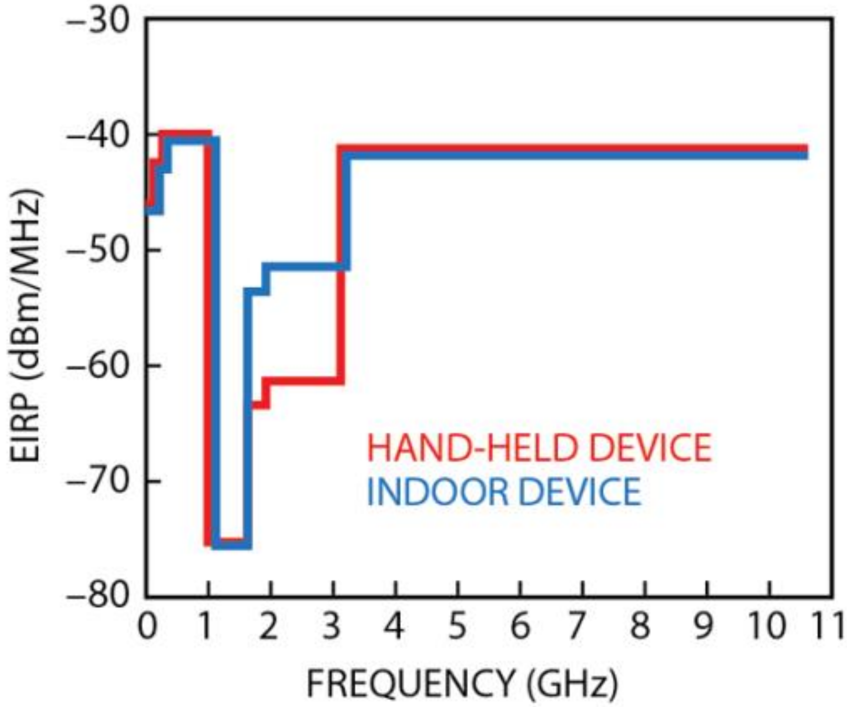


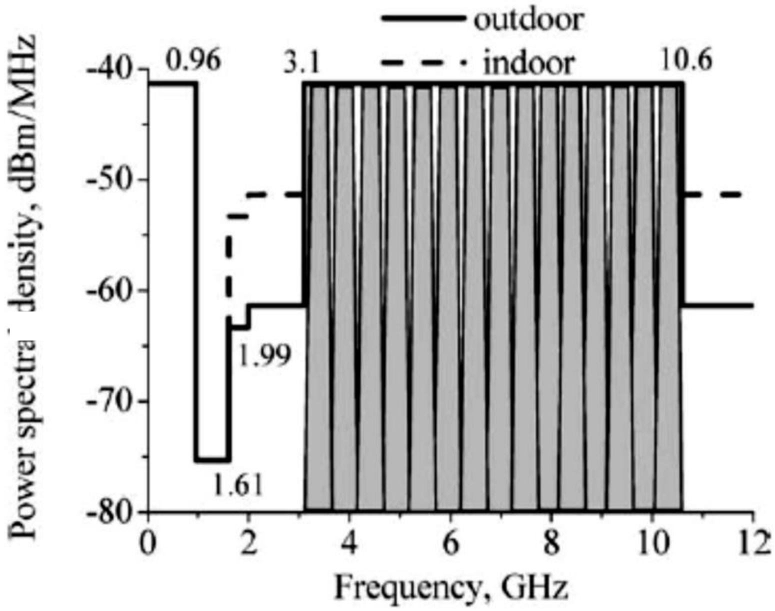
Fig. 1.1 FCC emission limit masks for indoor and outdoor UWB applications.

Orthogonal frequency-division multiplexing (OFDM) method with a collection of narrowband carriers of at least 500MHz can utilize the UWB spectrum under the FCC's rules. The extremely large spectrum provides the room to use extremely short pulses in the order of picoseconds. Thus, the pulse repetition or data rates can be low or very high, typically several Giga pulses per second. The pulse rates are dependent on the applications. For instance, radar and imaging systems prefer low pulse rates in the range of a few mega pulses per second. Pulsed or OFDM communication systems tend to use high data rates, typically in the range of 1–2 Giga pulses per second, to achieve gigabit-per-second wireless connection. The use of high data rates can enable the efficient transfer of data from digital camcorders, wireless printing of digital pictures from a camera without the need for an intervening personal computer, as well as the transfer of files among cell phones and other handheld devices such as personal digital audio, video players, and laptops.

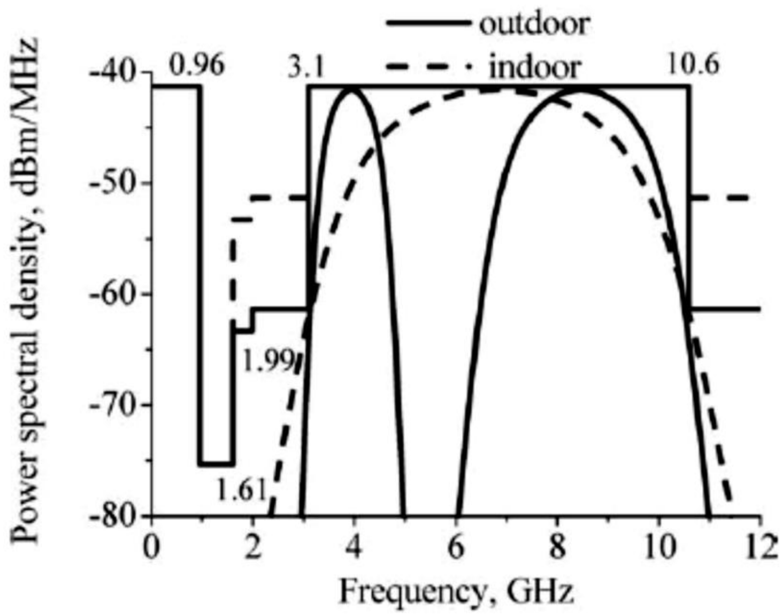
1.5 Challenges in UWB Design

Due to the system features and unique applications, antenna design is facing a variety of challenging issues such as broadband response in terms of impedance, phase, gain, radiation patterns as well as small or compact size. One of the challenges in design of UWB antennas is that, the antenna should cover the operating bandwidth. Since the response and specifications of antenna vary according to system requirement therefore it is important for an antenna engineer to be familiar with the system requirement before designing the antenna. The frequency-domain response includes impedance, radiation, and transmission. The impedance bandwidth is measured in terms of return loss or voltage standing wave ratio (VSWR). Usually, the return loss should be less than −10 dB or VSWR<2:1.

The radiation performance includes radiation efficiency, radiation patterns, polarization, and gain. The radiation efficiency is an important parameter especially for small antenna design. The radiation patterns show the directions where the signals will be transmitted. The requirements of UWB antennas are dependent on modulation schemes. For OFDM based systems the entire spectrum can be divided into 15 sub-bands, with each band having a bandwidth of 500MHz as shown in Fig. 1.2(a). Alternatively the entire UWB band can be occupied by a single pulse or several pulses, as shown in next Fig. 1.2(b).



(a)



(b)

Fig. 1.2 FCC spectra of (a) OFDM and (b) pulse-based UWB systems.

Due to the different occupancy of the UWB band in the two types of UWB system shown in above Fig. 1.2 the considerations for selection of the source pulses and templates, and design of antennas are distinct [3]. In an OFDM-based system, each sub-band having a few hundred megahertz (larger than 500 MHz) can be considered as broadband. The design of the antenna is more focused on achieving constant frequency response in terms of the radiation efficiency, gain, return loss, radiation patterns, and polarization over the operating band, which may fully or partially cover the UWB bandwidth of 7.5 GHz. For pulse-based systems, in order to prevent the distortion of the received pulses, an ideal UWB antenna should produce radiation fields of constant magnitude and a phase shift that varies linearly with frequency.

1.6 Medical Applications of UWB

UWB exhibits some distinct features like penetration through the obstacles which makes it easy to take the images of human organs well suited for medical applications. It also possess low radiation due to the FCC limit of use of low radio power pulse less than - 41.3 dBm/MHz for indoor applications. This feature results in low radiation which has little influence on the environment. This low radiation features make it safe for human body for the short distance communication mostly suitable for hospital application. Some of the recent examples of UWB in medical applications are observed in Medical monitoring applications like; Patient motion monitoring, Wireless vital signals monitoring of human body, and monitoring of medicine storage. Other medical application areas are in medical imaging; for Heart Imaging, Ear-Nose-Throat Imaging, and Obstetrics Imaging. Some of its recent application also targets; Underwater Medicine Measurements, Military Medicine, and Emergency medicine arena for detection of heartbeat of human beings buried under rubbles struck by natural disaster (commonly known as ‘‘Rubble Rescue Radar’’).

1.7 Organization of the report:

In **chapter 2,** a comprehensive review of different UWB antenna design topologies adopted to achieve single and multiband rejection characteristics is presented. As discussed in this chapter several antenna designs for UWB systems are described and its various practical aspects are analyzed and discussed. This review helps to understand the fundamentals of antenna design required to obtain optimized results suitable for its applications in several domain.

In **chapter 3**, a planar ultrawideband antenna with single band rejection characteristics is studied. A rejection band, located at 5.5GHz WLAN band, is created using a compact C- shaped slot with split gap at the folded arms on the ground plane of the CPW feed line. The slots occupy less space compared to other slotted structures. The proposed antenna yields an impedance bandwidth of 2.34 GHz - 10.74 GHz with VSWR<2 except at the notched bands.

In **chapter 4**, a Compact Planar Self-Affine Sierpinski Carpet Fractal Planar Monopole Antenna with Band Notch characteristics for UWB Communication is proposed. This carpet fractals are introduced in the same UWB antenna design with WLAN rejection characteristic proposed in chapter 3. This fractals structure is introduced in the radiating circular patch which helps to achieve improved impedance matching, increase in gain, and miniaturization compared to the proposed structure in chapter 3. A rejection band, located at 5.5GHz WLAN band, is created using a pair of the same compact C-shaped slot with split in the folded arms slots on the ground plane of the CPW feed line. The slots occupy less space compared to other slotted structures. The proposed antenna yields an impedance bandwidth of 2.31-10.61 GHz with VSWR<2 except at the notched bands. The antenna gain varies from 2 dBi to 6 dBi over the band with the dips at the rejection band.

General conclusion has been drawn in **chapter 5,** on the basis of the work done in this Master's thesis research project and ends with an optimistic note on encouraging result that drives us to further broaden the horizon of our study and experimentally investigate new designs which could be useful for UWB communication and its different application fields.

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CHAPTER 2

REVIEW ON ANTENNA DESIGNS FOR UWB APPLICATION

2.1 Objective

The primary objective of this chapter is to present a comprehensive review on different antenna topologies followed to achieve single and multiband rejection characteristics well suited for UWB applications. This overview helps us to analyze the performance criteria and optimized design requirements of different antenna topologies which are widely used for UWB applications.

2.2 Introduction

Ultra-wideband (UWB) [1] is one of the most promising technologies for future high-data rate wireless communications, high-accuracy radars, and imaging systems, compared with conventional broadband wireless communication systems. Antenna is one of the key factors in UWB systems. This review will address the antenna design issues in UWB systems. The UWB technology and regulatory environment is briefly introduced, general information on UWB systems is provided. The challenges in UWB antenna design are described. The special design considerations for UWB antennas are summarized.

2.3 UWB Antenna Requirements

All of the fundamental parameters namely radiation pattern, impedance bandwidth, half power beam width, directivity, efficiency, gain, polarization must be considered in designing antennas for any radio application, including Ultra Wideband. However, there are additional challenges for Ultra Wideband. By definition, an Ultra Wideband antenna must be operable over the entire 3.1- 10.6 GHz frequency range. Therefore, the UWB antenna must achieve almost a decade of impedance bandwidth, spanning 7.5 GHz. Another consideration that must be taken into account is group delay. Group delay is given by the derivative of the unwrapped phase of an antenna. If the phase is linear throughout the frequency range, the group delay will be constant for the frequency range. This is an important characteristic because it helps to indicate how well a UWB pulse will be transmitted and to what degree it may be distorted or dispersed. It is also a parameter that is not typically considered for narrowband antenna design because linear phase is naturally achieved for narrowband resonance.

Radiation pattern and radiation efficiency are also significant characteristics that must be taken into account in antenna design. A nearly omnidirectional radiation pattern is desirable in that it enables freedom in the receiver and transmitter location. This implies maximizing the half power beam width and minimizing directivity and gain. Conductor and dielectric losses should be minimized in order to maximize radiation efficiency. Low loss dielectric must be used in order to maximize radiation efficiency. High radiation efficiency is imperative for an ultra-wideband antenna because the transmit power spectral density is excessively low. Therefore, any excessive losses incurred by the antenna could potentially compromise the functionality of the system. In this research, the primary application focuses on integrated circuits for portable electronic applications. Therefore, the antenna is required to be physically compact and low profile, preferably planar. Several topologies will be evaluated and presented, considering tradeoffs between each design. For specific IC radio applications in this research, the UWB antenna requirements can be summarized in the following Table2.1

Table 2.1 UWB antenna requirements

VSWR Bandwidth	3.1 – 10.6 GHz
Radiation Efficiency	High (>70%)
Phase	Nearly linear; constant group delay
Radiation Pattern	Omnidirectional
Directivity and Gain	Low
Physical Profile	Small, Compact, Planar
Half Power Beam-width	Wide (> 60 °)

2.4 Study of UWB Antennas

2.4.1 Basic dipole antenna and log periodic antenna

With the advancement in the UWB technology different types of antenna designs were given. The preliminary designs which were introduced comprises of basic dipole antenna and log periodic antenna. Our research work was mainly focused on the printed planar structure because of its special applications so most of the literature review was focused on the design consideration of planar patch antenna and mainly highlights the existing planar designs for UWB communication with band rejection characteristics.

2.4.2 Patch Antennas

Other types of antennas which fit into these applications of UWB are patch antennas. Different designs have been given by the researchers in this context. A basic patch antenna comprises of a 50Ω matched feed line, a matching section and the radiating patch. Patch antennas are broadly classified as microstrip fed patch antennas and CPW fed patch antennas. A conventional microstrip antennas consist of a pair of parallel conducting layers separating a dielectric medium, referred to as the substrate. In this configuration, the upper conducting layer or "patch" is the source of radiation where electromagnetic energy fringes off the edges of the patch and into the substrate. The lower conducting layer acts as a perfectly reflecting ground plane, bouncing energy back through the substrate and into free space. Although similar in operation to a microstrip transmission line, the patch antenna is much larger in volume providing a distinct contrast between the two. Physically, the patch is a thin conductor that is an appreciable fraction of a wavelength in extent, parallel to a ground plane and a small fraction of a wavelength above the ground plane. In most practical applications, patch antennas are rectangular or circular in shape.

Commercial substrate materials are readily available for use at RF and microwave frequencies, specifically for the design of microstrip antennas and printed circuits. Selection is based on desired material characteristics for optimal performance over specific frequency ranges. Common manufacturer specifications include dielectric constant, dissipation factor (loss tangent), thickness, and Young's modulus. Values for dielectric constants range from $2.2 \leq \varepsilon_r \leq 12$ for operation at frequencies ranging from 1 to 100 GHz. The thickness of the substrate is of considerable importance when designing microstrip antennas. The most desirable substrates for antenna performance are the ones that are thick with a low dielectric constant of 10. This tends to result in an antenna with a large bandwidth and high efficiency due to the loosely bound fringing fields that emanate from the patch and propagate into the substrate. However, this comes at the expense of a large volume antenna and an increased probability of surface wave formation.

On the other hand, thin substrates with high dielectric constants reduce the overall size of the antenna and are compatible with MMIC devices, since the fringing fields are tightly bound to the substrate. With thin substrates, coupling and electromagnetic interference (EMI) issues are less probable. However, because of the relatively higher loss tangents (dissipation factors), they are less efficient and have relatively smaller bandwidths. Therefore, there is a fundamental trade-off that must be evaluated in the initial stages of the microstrip antenna design - to obtain loosely bound fields to radiate into free space while keeping the fields tightly bound for the feeding circuitry and to avoid EMI. The basic difference between the microstrip patch antenna and CPW fed antenna is that in CPW fed antenna the ground plane and feed line is in the same plane (same side of the substrate), while in microstrip antenna the ground plane and the feed line are on either side of the substrate.

2.4.2.1 A Planar Microstrip-Line Fed Elliptical UWB 5.2 GHz/5.8 GHz Notch Antenna with U-Shaped Slot

The elliptical monopole UWB antenna [2] was fabricated on an h=1.6 mm FR4 epoxy substrate with the dielectric constant ε_r =4.4 and loss tangent tanδ=0.002. The radiating element is fed by 50Ω microstrip transmission line, which is terminated with a sub miniature SMA connector for the measurement purpose. The VSWR graph cuts the VSWR=2 line at 2.76 GHz and remains below the line till 17.68 GHz. This depicts that there is good impedance matching between the microstrip transmission line and the elliptical radiating element. Within the allocated spectrum frequency bandwidths for UWB, there are some other narrow band communication systems, such as wireless local area network (WLAN) in the 5.15–5.825 GHz band and satellite communication system operating in 7.9-8.4 GHz range. To overcome this problem, various UWB antennas with a band-notched function have been developed not only to mitigate the potential interference but also to remove the requirement of an extra band stop filter in the system.

Band−notch characteristics can be introduced by incorporating slots into the antenna's main radiator. This elliptical monopole UWB antenna has band-notch characteristic from 5.02-6.46 GHz band (denoted as antenna 2). By removing a U-shaped slot from the elliptical radiating patch of antenna 1, a band notch function is created. In general, the main aim behind the design methodology of the notch function is to tune the total length of the U-shaped slot approximately equal to the half guided wavelength (λ_g) of the desired notch frequency, which provides the input impedance singular. At the desired notch frequency, the current distribution is around the U-shaped slot. Hence, a destructive interference for the excited surface current will occur, which causes the antenna to be nonresponsive at that frequency. The input impedance closer to the feed point, changes abruptly making large reflections at the required notch frequency.

According to Cohn [3], a half wavelength slot can be served as a resonator, because in the air regions of the slot, the magnetic field lines make curve and return to the slot region at half the guided wavelength interval. Hence to generate a resonance at a desired frequency, the physical length of the slot should be approximately equal to half of the guided wavelength for the given notch frequency (f_n) and is given by the expression for the length of the slot for a given notch frequency (f_n) is given by (2.1)

$$L = \frac{\lambda_g}{2} \tag{2.1}$$

$$\lambda_g = \frac{c}{f_n \sqrt{\varepsilon_{eff}}} \tag{2.2}$$

Where L is the total length of the slot, ε_{eff} *is* the effective dielectric constant of CPW feed-line and *c* is the speed of light in free space.

From the simulated VSWR plot of the above discussed antenna for the different N of the U-shaped slots it was observed, the adjustment of the band notched frequency can be done by varying the length (N) of the U-shaped slot. By decreasing N from 5.7 to 4 mm, the tip of the notched band shifted from 5.0 GHz to 6.0 GHz. The total length *L* of the U-shaped slot for the antenna 2 is denoted as *L*= (2N+0.5+0.5+9) mm. The performance of the simulated VSWR of the antenna 2, which provides the desired centre notch frequency of 5.5 GHz. From the results it is very clear that, the desired filtering property is achieved by introducing a U-shaped slot. Compared to antenna 1 design, the single band-notched UWB antenna effectively blocks out the 5-6 GHz and still performs excellent impedance matching at other frequencies of UWB band. To avoid interference with two or more wireless communication systems, multi-band rejection UWB antennas were developed. Some of these kinds of antennas are further discussed.

2.4.2.2 Ultra-Wideband Antenna using Meandered Slots for Dual Band Notched Characteristics

An UWB antenna using meander slots for dual band notched characteristics [4] was also reviewed to understand responses for dual band rejection. The given antenna is printed on a low-cost FR4 substrate with the thickness of 1.6mm and the dielectric constant of 4.4. The radiator is a semi-elliptical patch of the radius R = 18 mm, and XR = 1:3. XR is the axial ratio of the elliptical which forms the semi-elliptical patch. Two meandered slots are etched from the radiator to obtain the notched bands. The upper one can notch the frequency from 3.3-3.7 GHz and the lower one corresponds to the 5.12-5.37 GHz band. From the gain response of the antenna a sharp gain decrease at the notched band was observed which supports that antenna can avoid the potential interference with the existing WiMAX lower WLAN communication system well.

2.4.2.3 Analysis of Planar Ultrawideband Antennas with On-Ground Slot Band-Notched Structures

Band rejection characteristics can also be achieved by introducing slots in the ground plane. A simple microstrip-fed circular disk patch antenna with a partially modified ground plane is used in our study. The tapered microstrip line provides impedance conversion. The round-corner of the ground is used for bandwidth enhancement, especially for the improvement of high frequency impedance matching. The band-notched resonator is a pair of square ring resonators which can also be viewed as slot resonators. The antenna is fabricated on a thin dielectric substrate with a low relative permittivity of 2.65, a loss of $\tan\delta = 0.001$ and a thickness of 0.5 mm. The 50 Ohm feed line is terminated with a standard SMA connector to facilitate the measurement and connection with other standard microwave modules. From the measured antenna gain of the band-notched antenna with quarter-wavelength slots it was observed that significant gain reduction over the desired notch was achieved.

2.4.2.4 Multiple Stop bands Ultra Wide Band Antenna

Multi band rejection characteristics can also be achieved in the same manner by introducing slots in the coplanar ground plane. The structure of the CPW-fed circular monopole multiple stop bands ultra-wide band antenna [6], which consists of a planar circular monopole radiation cell and CPW fed line. And three pairs of quarter wavelength L-shape resonance slots are connected with the CPW feed line. The CPW feed line and radiation circular monopole is printed on a single layer substrate with $\varepsilon_r = 2.65$ and the thickness of 1mm. The VSWR plot verifies the multi-band rejection characteristics of the antenna. The prototype antenna has the bandwidth from 1GHz to 7GHz with three stop bands at 2.4GHz, 3.5GHz and 5.8GHz respectively. The radiation pattern plot verifies that the antenna has nearly omnidirectional radiation patterns within pass bands.

2.5 Conclusion

In this chapter a vivid review of the development process of single band, dual band and broad band UWB antenna is presented. It is seen that some of the topologies followed in UWB antenna design have been directly borrowed from techniques followed to achieve wideband performance. This overview helps us to analyze the performance criteria and optimized design requirements of different antenna topologies which are widely used for UWB applications and provides optimum help to analyze and design compact antennas useful for UWB applications. Detail study of this review helps to understand the necessary characteristics like return loss, radiation pattern, gain and VSWR of the antenna which provides the foundation for the design and analysis of new compact antenna useful for UWB application. Hence, the antenna design considerations for the latest UWB applications are addressed in this chapter. Several antenna designs are exemplified to show the recently developed technologies for UWB antenna designs in specific UWB applications which provide the foundation for the design of an optimized antenna for the proposed work and also highlights the sequential improvement in the characteristics of the antenna over different topologies.

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CHAPTER 3

PROPOSED NOVEL UWB ANTENNA

3.1 Objective

The primary objective of this chapter is to present the concept of a novel planar monopole UWB antenna having ultra-wideband resonance with a sharp band-notched characteristics for rejecting interference from narrow band WLAN (5.15–5.825GHz) communication systems that simultaneously satisfies UWB communications for biomedical applications.

3.2 Introduction

Ultra-wideband (UWB) is an emerging radio technology that can be used at very low energy levels for short-range high-bandwidth communications by using a large portion of the radio spectrum. In 2002, the Federal Communications Commission (FCC) [1] has released the regulation for UWB technology, allocating the frequency spectrum from 3.1 to 10.6 GHz for UWB. The allocation of the frequency band of 3.1-10.6 GHz by the FCC for Ultra Wideband radio applications has presented many exciting opportunities and challenges in the antenna design arena for researchers. UWB antenna is the most key element in UWB systems. Due to low profile, light weight and ease of fabrication, wideband operation and capability of high data rate planar UWB antenna are under constant exploitation by researchers in academia and in industry. During the past few years various designs of UWB antenna [2, 3] have been proposed to meet the requirements of different UWB applications. The key issue in the design of UWB antenna is their compact size and wide band width [4]. Among the proposed antenna design, the planar slot antennas [5, 6] became very popular due to omnidirectional radiation pattern, compact size stable radiation pattern and ease of fabrication. UWB antenna can be fed by microstrip line [7] or coplanar waveguide (CPW) [8]. A CPW transmission line has advantages of less dispersion, low radiation leakage and broad band response. The frequency-domain response includes impedance, radiation, and transmission. The impedance bandwidth is measured in terms of return loss or voltage standing wave ratio (VSWR). Usually, the return loss should be less than −10 dB or VSWR<2:1. Linear phase and low dispersion are important characteristics which is ensured by low values of group delay and is imperative for transmitting and receiving a pulse with minimal distortion for UWB communication. For optimum performance, VSWR $\leq$ 2 is required for proper impedance matching throughout the band which ensures at least 90% of total power radiation is achieved by the antenna. Other factors like compatibility with an integrated circuit also requires an unobtrusive, electrically small and planar printed design.

Most recent applications of UWB targets medical sensor applications for data collection, precision locating, tracking applications and medical imaging applications for the detections of different sized tumor/cancer cells. Within the allocated spectrum frequency bandwidths for UWB, there are some other narrow band communication systems; for example, wireless networks with standards such as IEEE 802.11a for wireless local area network (WLAN) systems operating in 5.15–5.825GHz (5.15 - 5.35 GHz and 5.725- 5.825 GHz) frequency band in USA which may cause interference to the UWB systems. To avoid this interference design of UWB antenna with band rejection filter is required. However, the use of such filter increases the complexity of the UWB systems. To overcome this problem, various UWB antennas with a band-notched function (i.e. band rejection for signal rejection characteristics) of the interfering frequency band have been developed not only to mitigate the potential interference but also to remove the requirement of an extra band stop filter in the system. Most of the research work for band rejection has been done by introducing slots in the radiating patch, ground plane, on the feed line or by using split-ring resonator (SRRs) nearby the feed line of the antenna. Some of the recent examples includes embedding proper U shaped slot [9, 10], a C-shaped slot [11], H- shaped slot [12], arc shaped slot [13], V-shaped slot [14], Square slot [15] in the radiating patch, square shaped slot in the ground plane [16]. Use of split-ring resonators (SRRs) and complementary split-ring resonators (CSRRs) to design reconfigurable multiple band-notched UWB antennas have also been reported lately [17-20]. Band−notch characteristics can also be introduced by open loop resonator structures [21]. These methods can achieve a good band-notched function but can cause a little complexity in the design procedure of the UWB antennas.

In this research work, we propose a novel and compact CPW-fed planar monopole UWB antenna with the corner circular arc ground plane for improved impedance matching and optimum UWB performance. A very narrow, simple and compact folded C-shaped slot is added on the ground planes of the CPW feed line to eliminate rejection of interfering

WLAN narrow band signals. The proposed slot structure reduces the complexity in the design procedure of the UWB antenna due to its simple and compact design. The incorporated slots introduces a very sharp notch at desired central notch frequency 5.5 GHz of WLAN band. This antenna merely occupies a compact size of 36 x 41 mm^2.

3.3 **Antenna Design Process**

All of the fundamental parameters namely return loss response, radiation pattern, impedance bandwidth, half power beam width, directivity, efficiency, gain, polarization must be considered in designing antennas for any radio application. However, there are additional challenges for UWB communication. Due to the system features and unique applications, antenna design is facing a variety of challenging issues in terms of impedance, power, gain, radiation patterns as well as small or compact size. Since antenna size and frequency of operation impose limitations on maximum attainable gain and bandwidth [22], [23] compromises have to be made to obtain optimum performance to satisfy design requirements.

Radiation pattern and radiation efficiency are also significant characteristics that must be taken into account in antenna design. A nearly omnidirectional radiation pattern is desirable because it enables freedom in the receiver and transmitter location. This implies maximizing the half power beam width and minimizing directivity and gain. Conductor and dielectric losses should be minimized in order to maximize radiation efficiency. Low loss dielectric must be used in order to maximize radiation efficiency. Therefore, any excessive losses incurred by the antenna could potentially compromise the functionality of the system.

The antenna design process is illustrated on a flow chart shown in Fig. 3.1. In a typical design process, modelling and simulation tools can be checked against measurements. Once the antenna application is selected, system requirements can be used to start the designing process. The proper choice of materials like substrate and metallic conductors are important factors of antenna construction for simulating its Layout. Antenna parametric study and optimization is performed until design requirements are met in simulation. Antennas are usually analyzed with electromagnetic modelling and 3-D EM (Electromagnetic) simulation software. Antenna is first modelled, simulated, and optimized on a computer by monitoring the frequency response, antenna gain, and impedance which give to a designer a good understanding of the antenna behavior. If design requirements are satisfied, the antenna design is ready. Otherwise, the design is further modified and optimized until requirements are met. In the last step of the design process, fabrication of the prototypes are done and their performance is measured extensively.

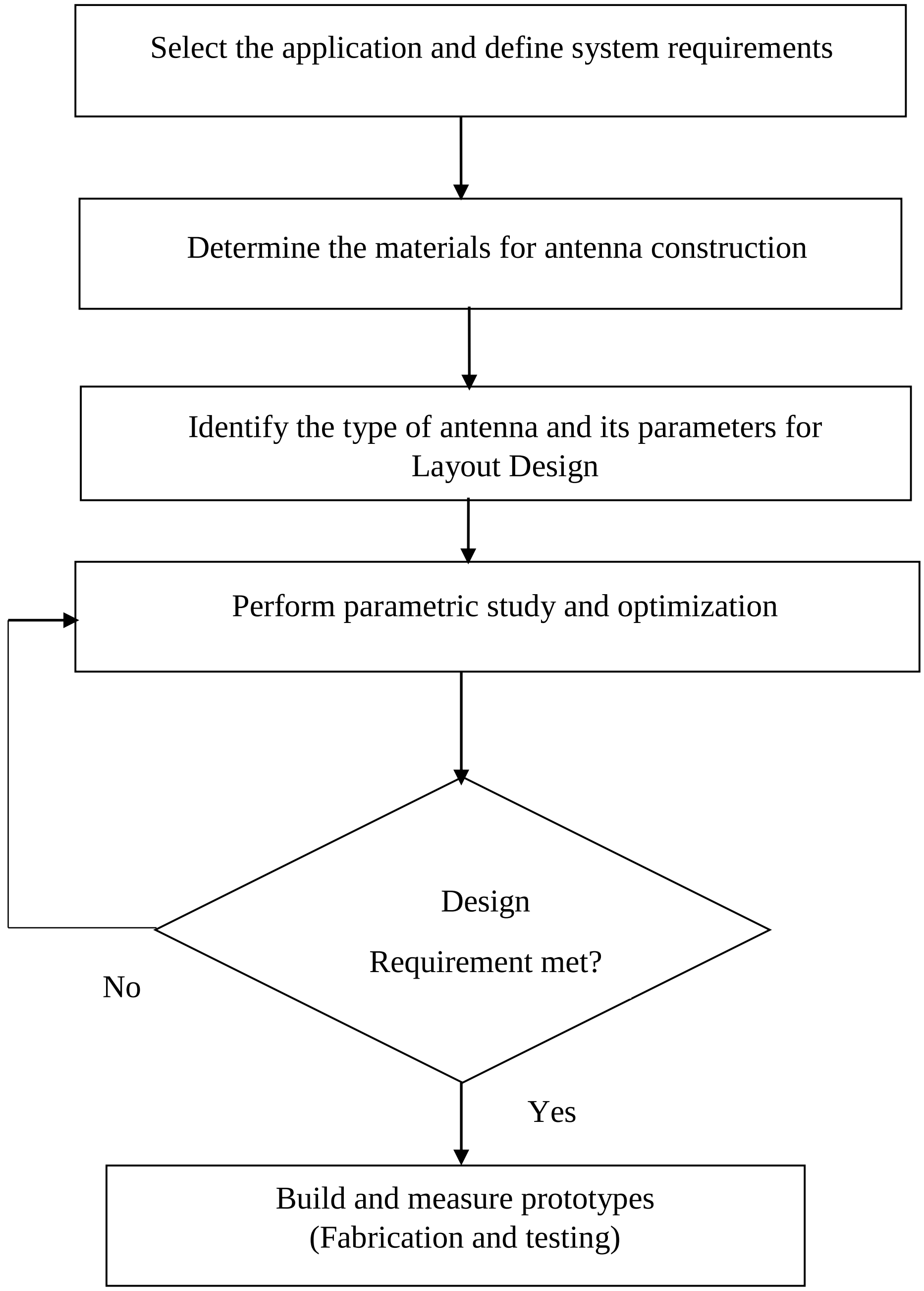


Fig.3.1. Antenna design process.

3.4 Proposed UWB Antenna Design and Optimization

The geometry of the proposed a novel planar monopole CPW-fed UWB antenna with the corner circular arc ground plane is shown in Fig.3.2. This antenna is simulated and designed in the 3D Agilent Advanced Design System (ADS) EM simulation software. This antenna is realized on Rogers RO 3006 substrate with thickness of 0.375 mm, loss tangent tanδ=0.0025 and relative dielectric constant ε_r of 6.15. The initial design aspects of the proposed printed circular monopole antenna (PCMA) for ultra-wide band applications were selected as per the design equations specified for printed monopole antenna for UWB applications in [24] and later was optimized using ADS simulation software for the proposed application.

In the past few years various designs using modified shaped monopole antenna [25-26] have been reported which presents an efficient technique to increase significantly the antenna bandwidth. In addition to this, the ground plane of the antenna has a significant effect on the performance of the antenna in terms of impedance matching and bandwidth of the antenna. Many new designs using modified shaped ground plane replacing the conventional use of rectangular ground plane have been reported recently [27- 29]. In our work, we have modified the conventional rectangular ground plane of the CPW-fed line by embedding circular arc at the corners of the ground plane to achieve better impedance matching and extremely wide bandwidth. This antenna merely occupies a compact size of 36 x 41 mm^2 which is small enough for UWB communication and is smaller than those reported in [30 – 33].

The radius of the circular radiating patch is optimized to 11 mm and a thin rectangular strip of optimum length (L = 29.75 mm) and width (W = 2.48 mm) is superimposed with the circular radiating patch to improve the impedance matching and achieving optimum UWB performance. The 50Ω coplanar waveguide (CPW) transmission line with finite ground plane Lg and Wg is used for feeding the antenna. The vertical gap between the radiation patch and the ground plane (H) has an important effect on the impedance matching of the proposed antenna. An optimised value of gap H is found to be 2.45 mm.The optimized value of CPW center feedline strip is of length 19 mm ($L_f = L_g + H$) and central strip width of CPW feed of 3 mm (w_f). The spacing (g_f) between the feedline and ground plane is set as 0.45 mm. These parameters are optimized to get 50 ohm input impedance. The length (L_g) and the width (W_g) of the ground planes are important design parameters of this monopole antenna. For this design, the optimized value of the width of the CPW planes on both sides of the central feed line is taken as 16.05 mm (W_g) and length as 16.55mm (L_g). The end corners of both the ground plane is modified to circular arc shape of radius (R_1) with an optimized value of 10.5 mm. The corner circular arc shaped ground plane is used for bandwidth enhancement, especially for the improvement of high frequency impedance matching for achieving optimum UWB performance. The antenna shape and its dimensions were optimized by simulations using the industry standard commercial EM simulation software ADS. The final dimensions of the proposed antenna are tabulated in Table 3.1. The configuration of the proposed UWB antenna without band-notched characteristics as shown in Fig.3.2.

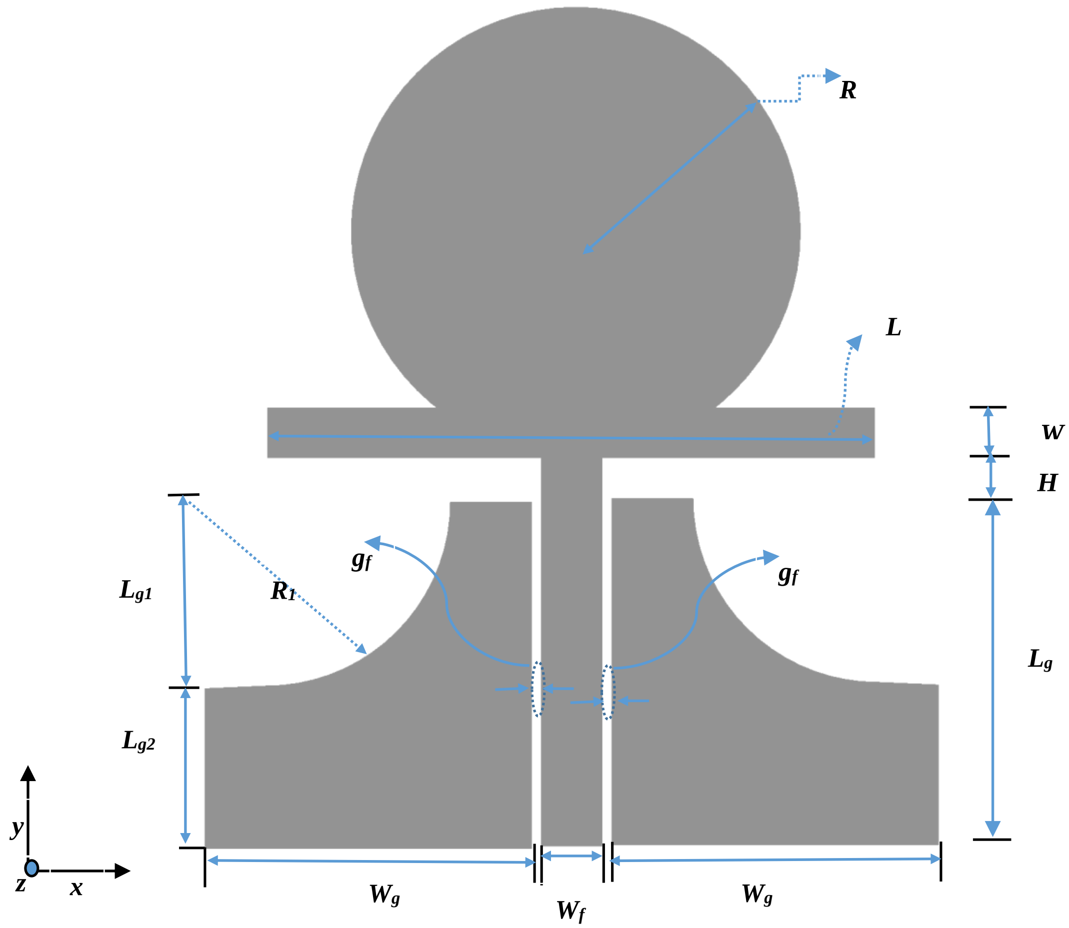


Fig. 3.2. Geometry of the proposed UWB antenna

Table 3.1 Optimized parameters of proposed antenna

Antenna parameters	Value(mm)
L	29.75
W	2.48
L_g	16.55
W_g	16.05
R	11
R_1	10.5
H	2.45
W_f	3
g_f	0.45
L_{g1}	8.68
L_{g2}	7.87

Simulation results of Proposed UWB antenna without band-notched characteristics:

The proposed antenna structure exhibits ultra-wideband resonance characteristics with good impedance matching whose return loss response and VSWR plots are depicted in the Fig. 3.3 (a) and (b) respectively. All of the simulation plots shown in this research work is generated in ADS simulation software which gives results close to the ones like achieved after fabrication measurement results. In this section the detailed results showing the resonance characteristics i.e. the return loss, the VSWR response, group delay and input impedance response of the proposed UWB antenna covering the entire UWB band (3.1-10.6 GHz) are discussed to show that the proposed antenna has the desired result and operates effectively. This antenna does not possess signal rejection characteristics. It can be observed from Fig. 3.3 (a) which shows the return loss of the proposed UWB antenna with the optimum performance by covering the entire UWB band and possess wideband resonance. The impedance bandwidth at -10 dB (i.e. the frequency range over which impedance of the antenna remains 50 Ω or below -10 dB) is 8.81 GHZ (11.14 GHz – 2.33 GHz). Within the impedance bandwidth the antenna will work best where forward travelling wave is transmitted.

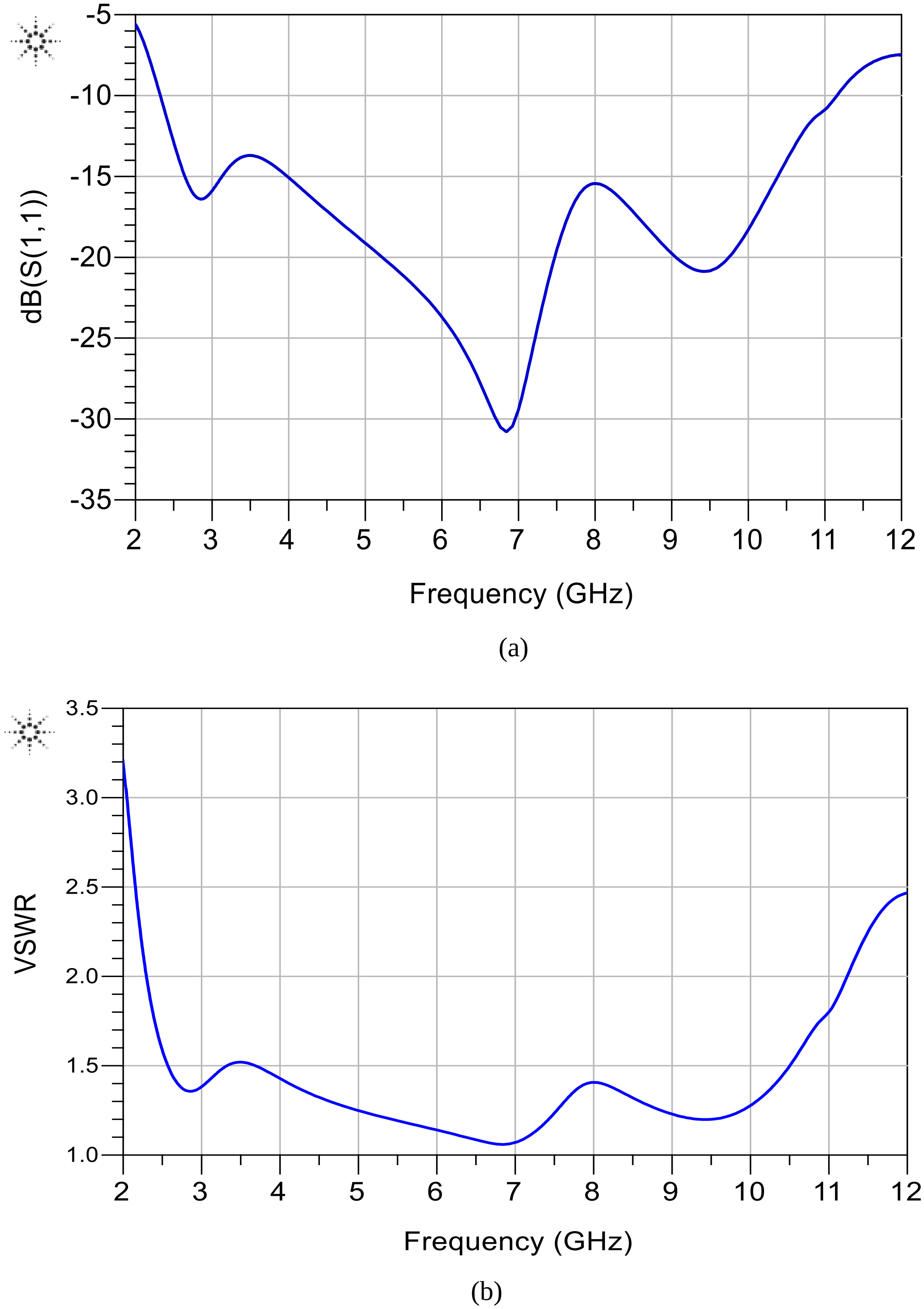
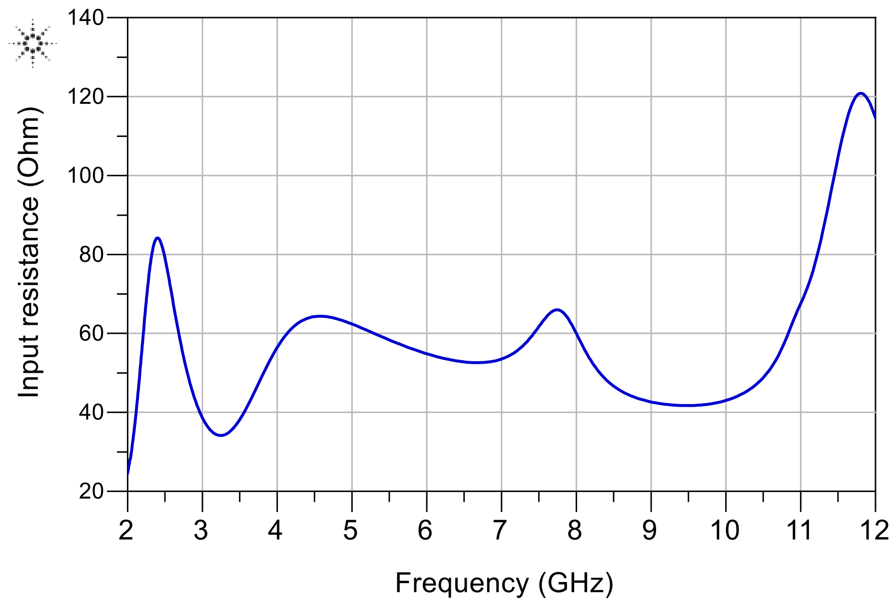


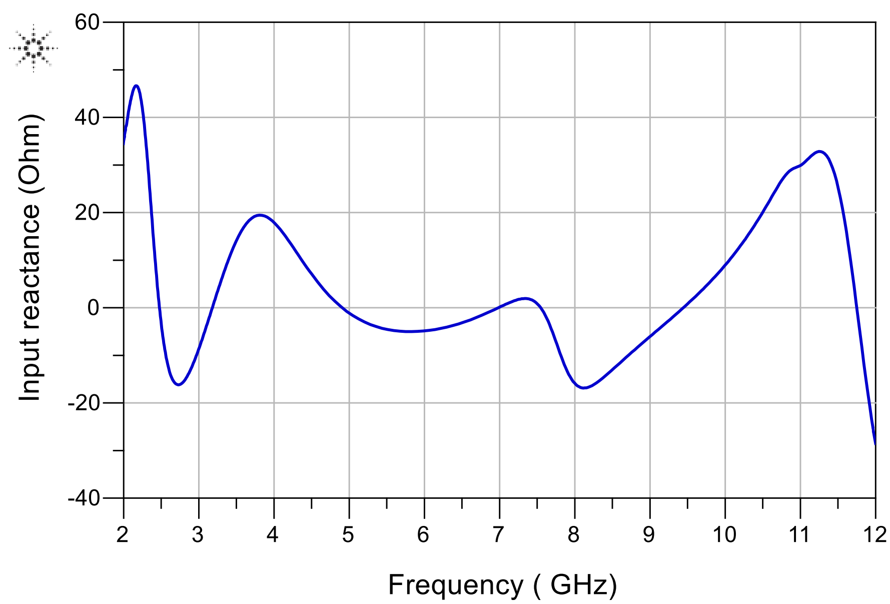
Fig.3.3. Simulated Frequency response of the proposed UWB antenna without band-notched characteristics: (a) Return Loss response, and (b) VSWR plot.

The first resonance occurs around 3.0 GHz, second resonance occurs around 7 GHz and the third resonance occurs around 9.5 GHz. It is evident from the return loss plot that within the UWB band the proposed antenna possess optimum impedance matching by achieving return loss below -10 dB from 2.33GHz to 11.14 GHz and yields an ultra-wide -10 dB impedance bandwidth. The VSWR response of the proposed antenna is illustrated in Fig. 3.3(b) which shows that VSWR is below 2 for the entire UWB band. It is almost below 1.5 for the desired tuned UWB frequency range which depicts optimal impedance matching of the proposed antenna. The simulated input impedance of the proposed antenna is shown in Fig. 3.4. It depicts the simulated input resistance and the input reactance of the proposed UWB antenna without band-notched characteristics. As shown in Fig. 3.4 (a), the low return loss (< - 10 dB) occurs over the UWB frequency range (3.1 – 10.6 GHz) when the input impedance if matched to 50 Ω. This shows that the input resistance of the UWB antenna is close to 50 Ω while the input reactance as shown in Fig. 3.4 (b) is almost zero (not far from zero and remains small across a wide frequency range of UWB communication) for the chosen optimum dimensions of the UWB antenna .

Another important characteristics which is studied for UWB antenna is group delay. It helps to indicate how well a UWB pulse will be transmitted and the degree to which it may be distorted or dispersed. Ultra -wideband antenna system which uses narrow pulses to transmit signals for high data rate should be distortion free and to ensure this, temporal characterization is required. Fig. 3.5 shows the simulated group delay of the proposed UWB antenna. The antenna shows a nearly flat response in the UWB range i.e. from 3 to 11 GHz band where the variation of group delay is less than 1ns in the operating band. This ensures satisfactory time domain characteristics and distortion free transmission of the UWB pulses.



(a)



(b)

Fig.3.4. Simulated input impedance plot of the proposed UWB antenna without WLAN band-notched characteristics: (a) input resistance, and (b) input reactance.

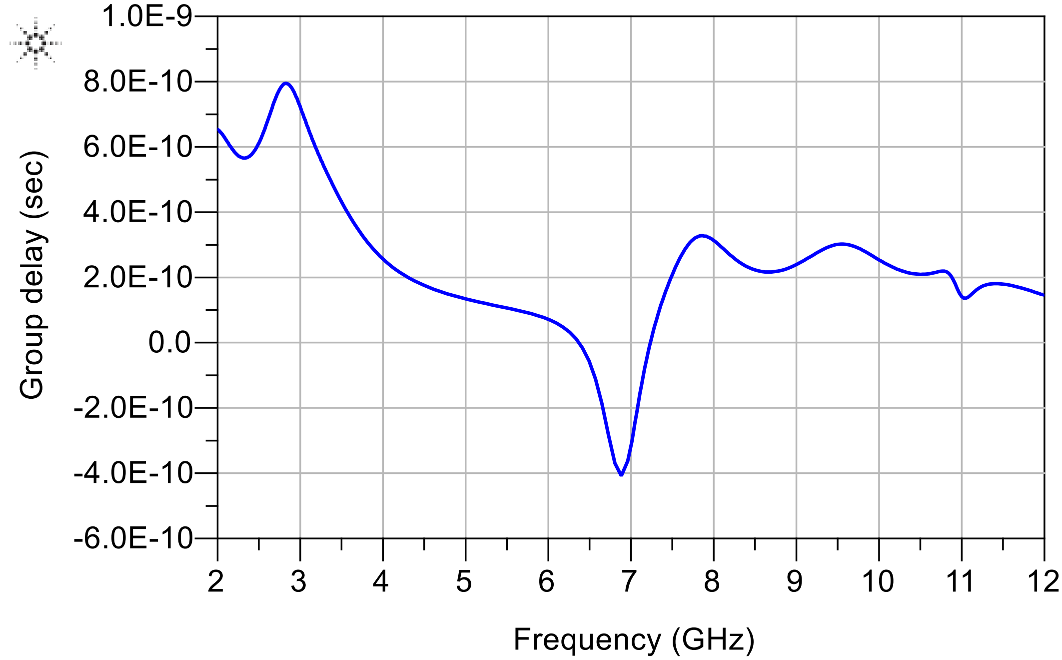


Fig.3.5 Simulated group delay plot of the proposed UWB antenna.

3.5. Scheme used for Band-Notch Characteristics

The UWB antenna with band notch characteristics has VSWR ≤ 2 for the entire UWB band but experiences a sudden increase around the desired notch frequencies. The frequency band notched characteristics can be introduced by using one of the two methods. The conventional method to achieve a band notch response is incorporating slots on the radiating patch which causes addition of perturbation in the surface current flowing in the antennas radiating element. Another novel method of band rejection is by cutting slots on the ground plane of the coplanar waveguide (CPW) feeding a planar UWB monopole. These slots block the currents at the desired notch frequency. Also, by adding slots on the antenna feed line, perturbation of the surface current takes place which in turn introduces band notch characteristics or it acts as a filter to reject the limited band. In fact, these slots produce a destructive interference for the excited surface currents, causing the antenna to be non-responsive at frequencies which depend on the slots dimensions and positions.

One of the most important factor that needs to be calculated is the total length of the slot which is approximately half of the guided wavelength *(λ_g)* of the desired notch frequency. The equation for finding the total length *(L_{slot})* of the slot is deduced as in equation (1). By tuning the total length of the slot relative to the notch frequency, a destructive interference takes place causing the antenna to be non-radiating or non-responsive at that frequency. The notch center frequency can be easily tuned by changing the total length of the slot designed for desired notch frequency. In addition to this design parameters, the width and location of the slot can also adjust the rejection band.

$$L_{slot} = \frac{\lambda_g}{2} \qquad (1)$$

$$\lambda_{g} = \frac{c}{f_{notch}\sqrt{\varepsilon_{eff}}} \qquad (2)$$

Combining equation (1) and (2) expression for notch frequency can be calculated as in equation *(3)*,

$$f_{notch} = \frac{c}{2L_{slot}\sqrt{\varepsilon_{eff}}} \qquad (3)$$

$$\varepsilon_{eff} = \frac{\varepsilon_{r+1}}{2} \qquad (4)$$

Where, f_{notch} is the center frequency of the WLAN system that is 5.5 GHz, ε_{eff} is the effective dielectric constant of the substrate, which can be calculated using equation (4) and *c* is the speed of light in free space.

The proposed structure shown in Fig.3.2 is then modified by embedding slots in both the ground planes of the UWB antenna to get a band-notch characteristics. The physical geometry of the proposed UWB antenna with signal rejection characteristics is shown in Fig.3.6. A compact narrow C shaped slot with a split in its folded arms for controlling notch frequency is embedded in both the ground plane. These slots are responsible for introducing rejection of interfering signals from WLAN (5.15–5.825GHz) narrowband communication systems. In addition to the length of the slots, width and location of the slots can also adjust the rejection bands. Thus, for achieving the desired sharp notch at 5.5 GHz slots are placed closed to the feed line on both the ground planes at a vertical distance of 0.28 mm (y-axis distance from the top of the ground plane) and a horizontal distance of 0.53 mm (x-axis distance from corners of the ground planes which are nearby feed line). The total initial length of the compact C-shaped slot etched on the ground plane nearby the feed line was deduced using equation (3) and was later optimized as deduced in equation (5) for achieving a sharp notch at 5.5 GHz. All the optimization were performed using ADS simulation software. The optimized dimension of the slot incorporated for band rejection are tabulated in Table 3.3.

$$L_{slot} \approx 2 \times W_1 + 2 \times L_1 - h_1 - 4 \times T_s \qquad (5)$$

The proposed C-shaped slot with a split gap in the folded arms is compact and also possess a very sharp notch 5.5 GHz which is the most desirable feature of the UWB antenna having band-notched characteristics and shows maximum peak value of the VSWR for the designs reported in the [30-36] which depicts optimal rejection of interfering narrowband WLAN systems.

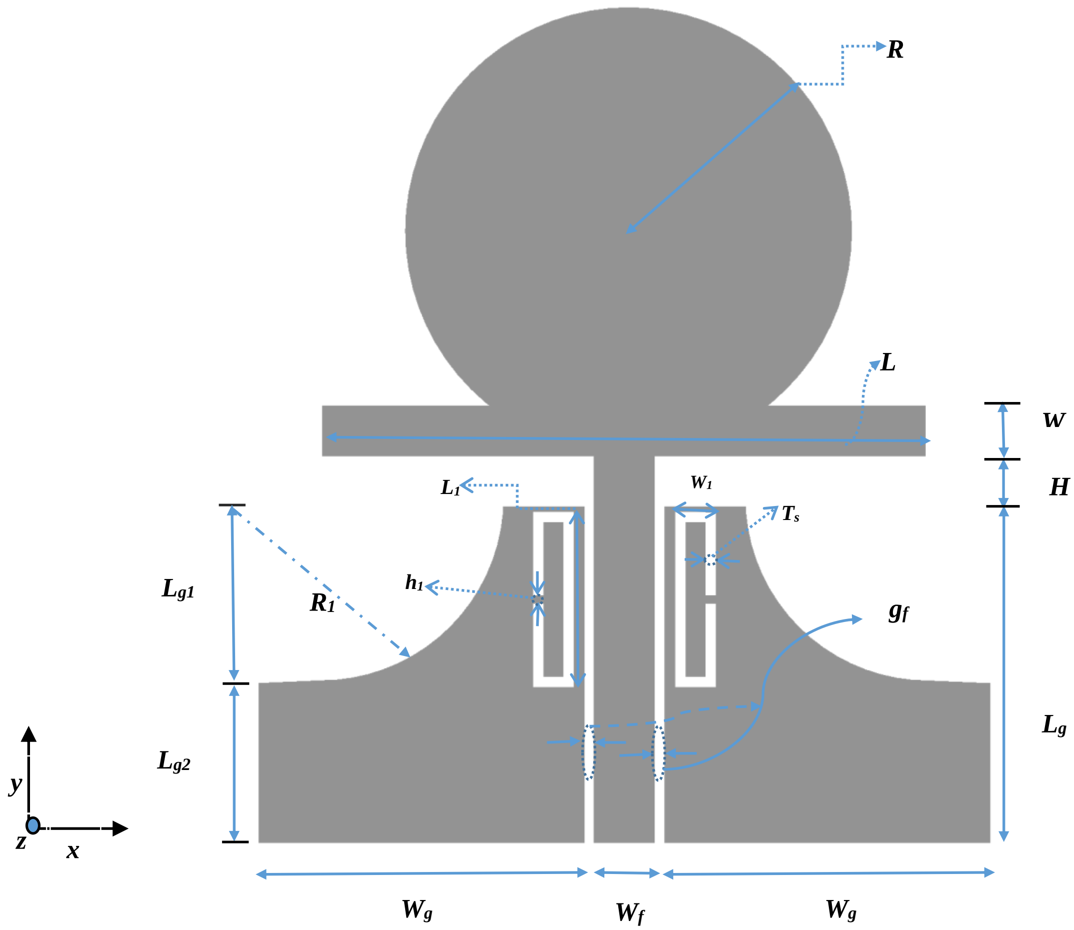


Fig. 3.6. Geometry of the proposed UWB antenna with WLAN Band-notched characteristics

Table 3.2 List of Antenna Parameters

Antenna parameters	Value(mm)
L	29.75
W	2.48
L_g	16.55
W_g	16.05
R	11
R_1	10.5
H	2.45
W_f	3
g_f	0.45
L_{g1}	8.68
L_{g2}	7.87

Table 3.3 Slots parameters for band-notch

Slot parameters	**Value(mm)**
L_1	8.6
W_1	2
T_s	0.5
h_1	0.4082

3.6 Parametric Study

Parametric study is one of the significant analysis performed for the antenna design process which helps in the optimization of antenna dimension and is done until design requirements are met in simulation. This helps for achieving desired optimum performance. The fine tuning of the antenna geometry depends on the gap between the ground plane and the radiating patch. Fig. 3.7 shows how the impedance matching of the proposed UWB antenna varies with the vertical gap *H* which is the distance between the ground plane and the radiating patch with other parameters remaining constant. The gap *H* effects the return loss of the antenna which depicts the impedance matching of the antenna system.

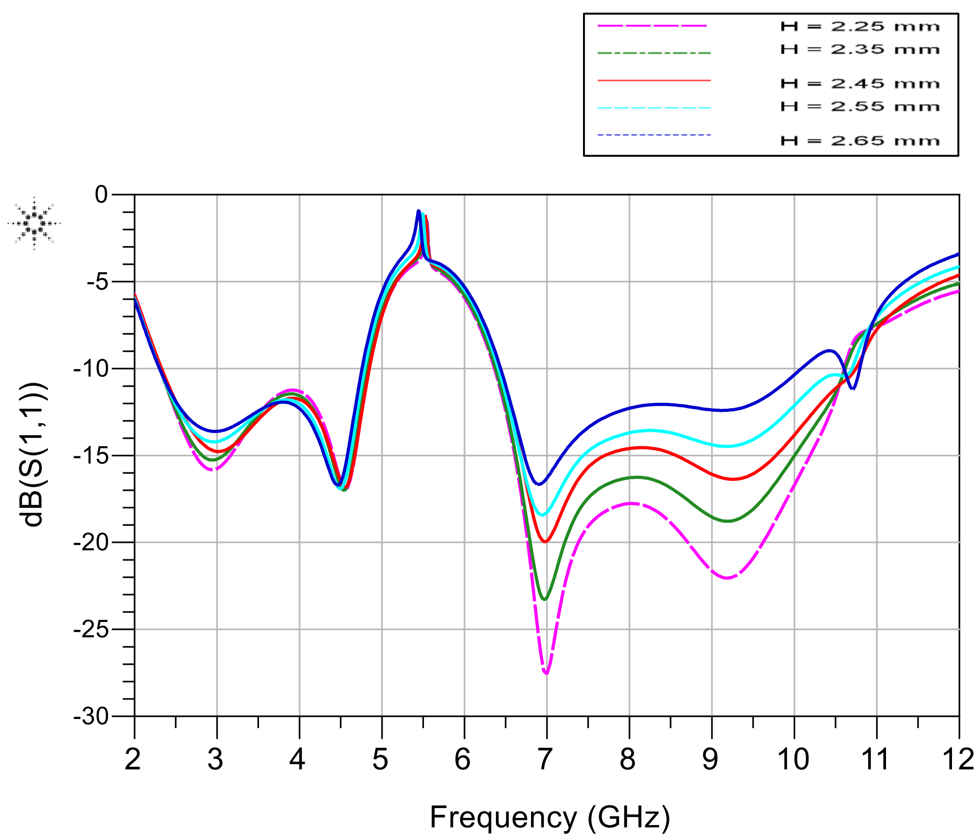


Fig.3.7. Reflection coefficients of proposed antenna for parametric study by varying *H*. Other parameters are $h_1 = 0.4082$, $W_1 = 2$, $T_s = 0.5$, $L_1 = 8.6$. *(All dimensions are in mm).*

It can be seen from the figure that the change in the value of H effects the impedance matching and the bandwidth of the antenna. When H is increased impedance matching reduces to some extent in the lower frequency band but impedance matching in the higher frequency band reduces significantly. With the increase in this vertical gap bandwidth of the operating band increases. As H changes, notched band width changes to some extent which in turn effects the total operating bandwidth of the antenna. This changes is seen due to electromagnetic coupling between ground plane and the radiating patch. However, notch frequency remains almost constant. Thus, this parameter mainly effects the impedance matching and the bandwidth of the antenna. The optimal gap of 2.45 mm having the satisfactory impedance matching in both the lower and upper frequency band with the bandwidth covering an extremely wide frequency range from 2.34 GHz – 10.74 GHz is selected.

During the primary investigation of the antenna it was observed that the dimensions of the slot L_1, W_1, T_s and vertical folded split gap h_1, as shown in Fig.3.6, plays a crucial role in the resonant behavior of the proposed slot. Therefore these slot dimensions are put to parametric study for the selection of optimum slot dimensions required for achieving the desired notch frequency. To fully understand the characteristics of the proposed folded C-shaped slot structure, a parametric study is carried out using ADS simulation software. Simulation results on the return loss response with different values of L_1, W_1, T_s and the folded split gap h_1 for slot are shown in Fig. 3.8, Fig.3.9, Fig. 3.10 and Fig. 3.11 respectively. Symmetry about the vertical axis running along center of the feed line of the antenna is maintained. The dimension of left and right vertical slots is same. Fig. 3.8 and Fig. 3.9 shows that higher the values of L_1 and W_1 , the resonance frequency of the notch band peak shifts backward towards lower frequency. In addition to this, with the increase in both the slot parameters L_1 and W_1 the operating bandwidth of the UWB antenna also reduces significantly. However, Fig. 3.10 shows that with the increase in the slot thickness, the resonance frequency of the notch band shift forward towards higher frequency range and the bandwidth of the UWB antenna also increases significantly. This property provides a great freedom to the antenna designers to select the notched band and to make optimum selection of slot dimension for introducing band rejection characteristics.

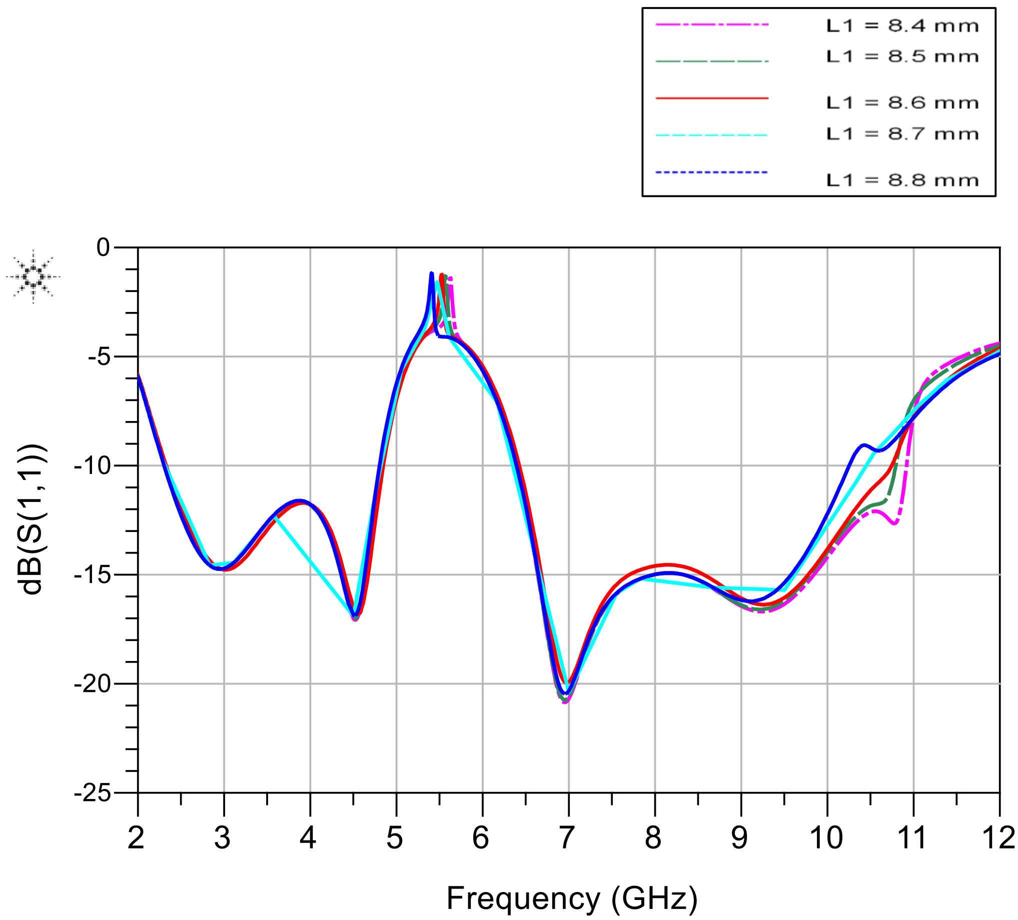


Fig.3.8. Reflection coefficients of proposed antenna for parametric study by varying L_1. Other parameters are $h_1 = 0.4082$, $W_1 = 2$, $T_s = 0.5$, $H = 2.45$. *(All dimensions are in mm).*

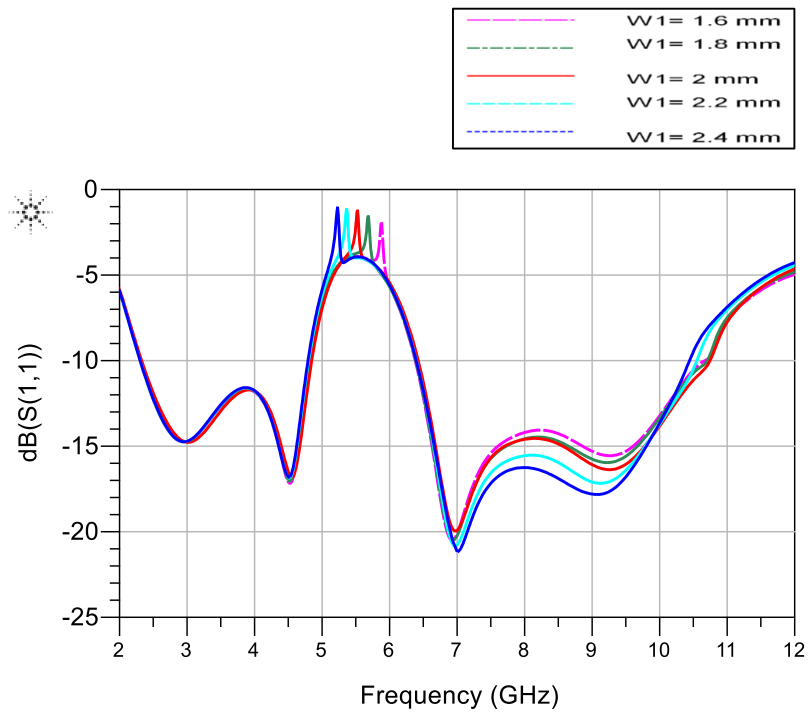


Fig.3.9. Reflection coefficients of proposed antenna for parametric study by varying W_1. Other parameters are $h_1 = 0.4082$, $L_1 = 8.6$, $T_s = 0.5$, $H = 2.45$. *(All dimensions are in mm).*

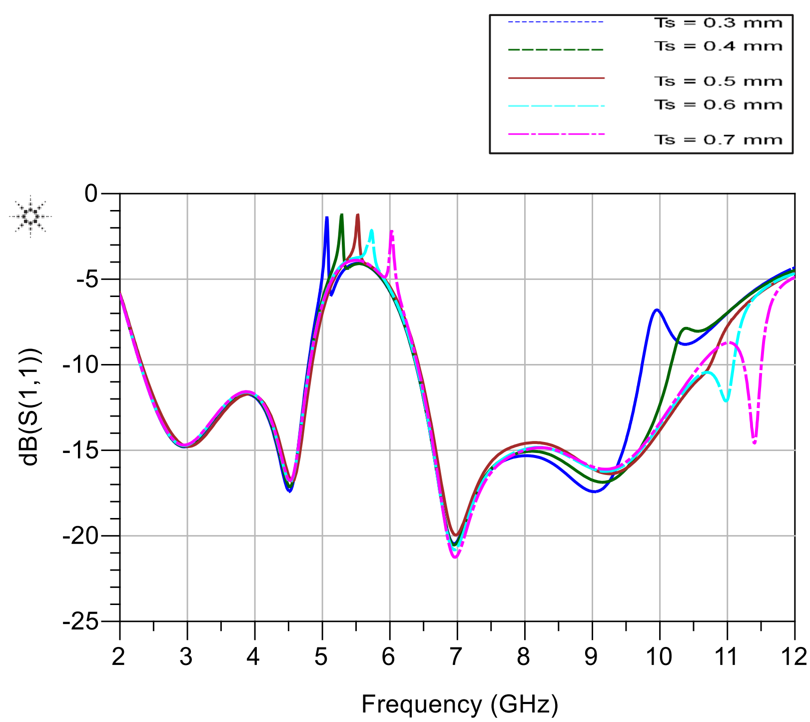


Fig.3.10. Reflection coefficients of proposed antenna for parametric study by varying T_s. Other parameters are $h_1 = 0.4082$, $W_1 = 2$, $L_1 = 8.6$, $H = 2.45$. *(All dimensions are in mm).*

Lastly, the vertical split gap h_1 between the folded arms of the C-shaped slot is varied by keeping all the other parameters of slot and antenna constant. With the increase in h_1, the peak of the notch band shifts forwards toward the higher frequency band and the bandwidth of the antenna also increases to some extent. The increase in h_1 results in decrease in the total length of the slot which causes the peak of the notch band to move forward towards higher frequency band. Whereas, reducing h_1 results in increase of total length of the slot causing backward shift of peak of notch band towards lower frequency with respective to the desired notch at 5.5 GHZ. The choice of this gap is very important factor for slot dimension as it effects the peak of the notch band frequency.

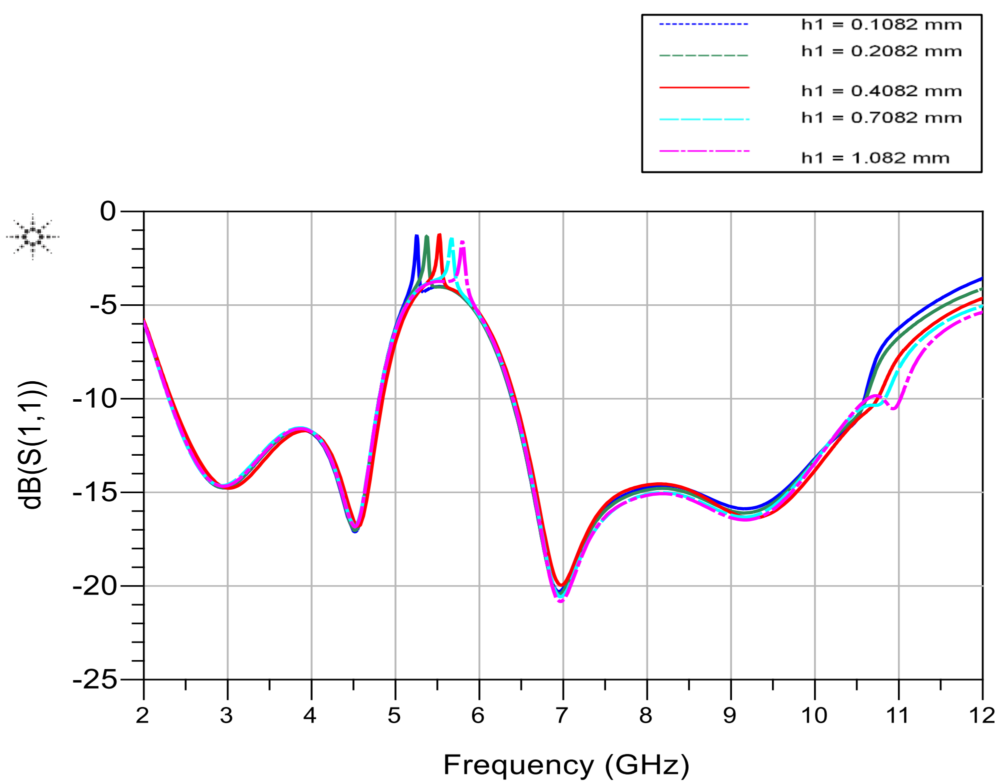
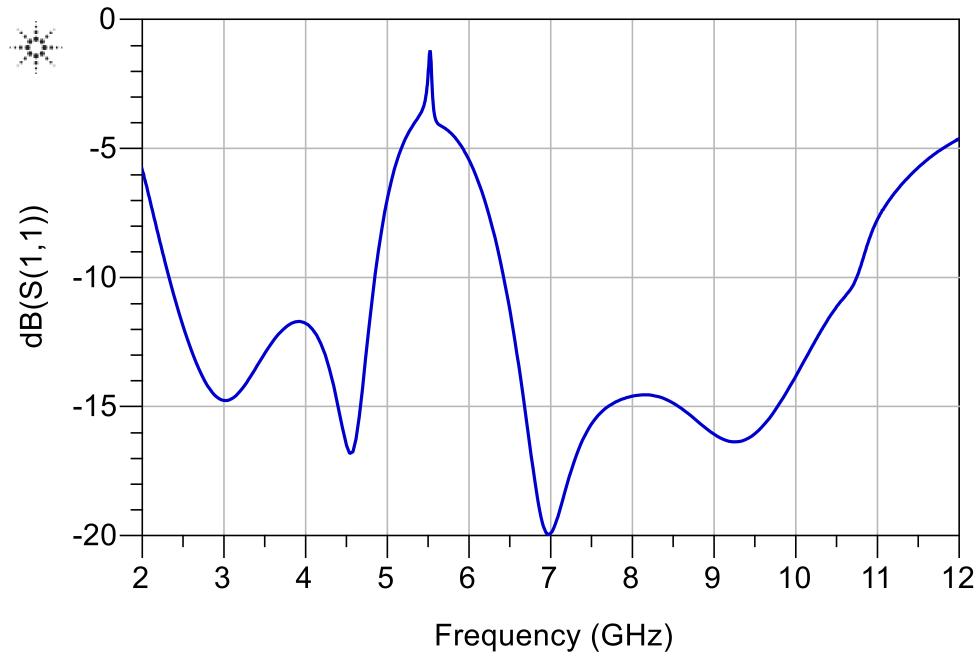


Fig.3.11. Reflection coefficients of proposed antenna for parametric study by varying h_1. Other parameters are $L_1 = 8.6$, $W_1 = 2$, $T_s = 0.5$, $H = 2.45$. *(All dimensions are in mm).*

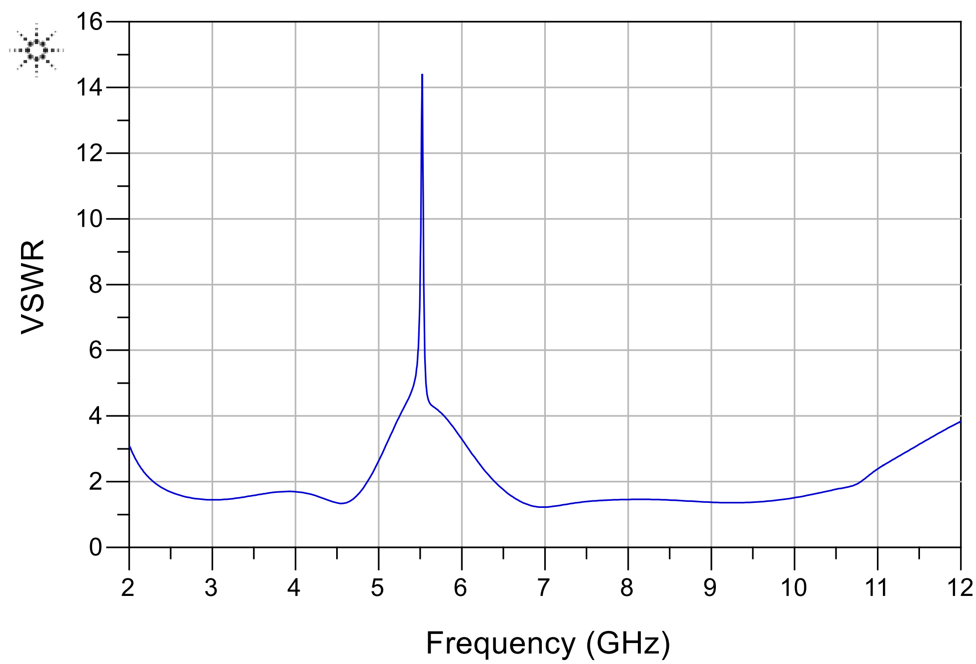
3.7 Results and Discussion

The Agilent Advanced Design System (ADS) software was used to simulate and analyze the performance and functionality of the proposed UWB antenna with single WLAN band rejection characteristics. In this section the detailed result showing the resonance and radiation characteristics i.e. the return loss, VSWR plot, the input impedance plot, group delay, the radiation pattern, current distribution and gain, radiation efficiency plot and the power radiation plot of the proposed UWB antenna with WLAN signal rejection characteristic are discussed to show that the proposed antenna is having desired result and is operating effectively. The simulated S11 (dB) i.e. the return loss and the VSWR plot of the final design of the proposed antenna is shown in Fig. 3.12 which describes the resonance characteristics of the proposed antenna. It can be observed from the Fig.3.12 (a) which depicts return loss response of the antenna is below -10 dB from 2.34 GHz – 10.74 GHz (except at notched band centred around 5.5GHz with high return loss of -1.203 dB at the 5.5 GHz notch frequency) and covers the entire UWB band (3.1-10.6GHz). It is very clear that the desired filtering property is achieved by introducing a compact folded C-shaped slots in the antenna structure.

The sharp notch is one of the most desirable features used for signal rejection in UWB system which eliminates the use of filter for the rejection of interfering bands. VSWR as shown in Fig.3.12 (b) shows good impedance matching with VSWR< 2 for the UWB frequency range and a high VSWR of 14.409 around notch frequency 5.5 GHz yielding sharp notch at the desired rejection band of WLAN system. The simulated input impedance of the proposed antenna is shown in Fig. 3.13. It depicts the simulated input resistance and the input reactance of the proposed UWB antenna with band-notched characteristics.



(a)



(b)

Fig.3.12. Simulated Frequency response of the proposed UWB antenna with WLAN band-notched characteristics: (a) Return Loss response, and (b) VSWR plot.

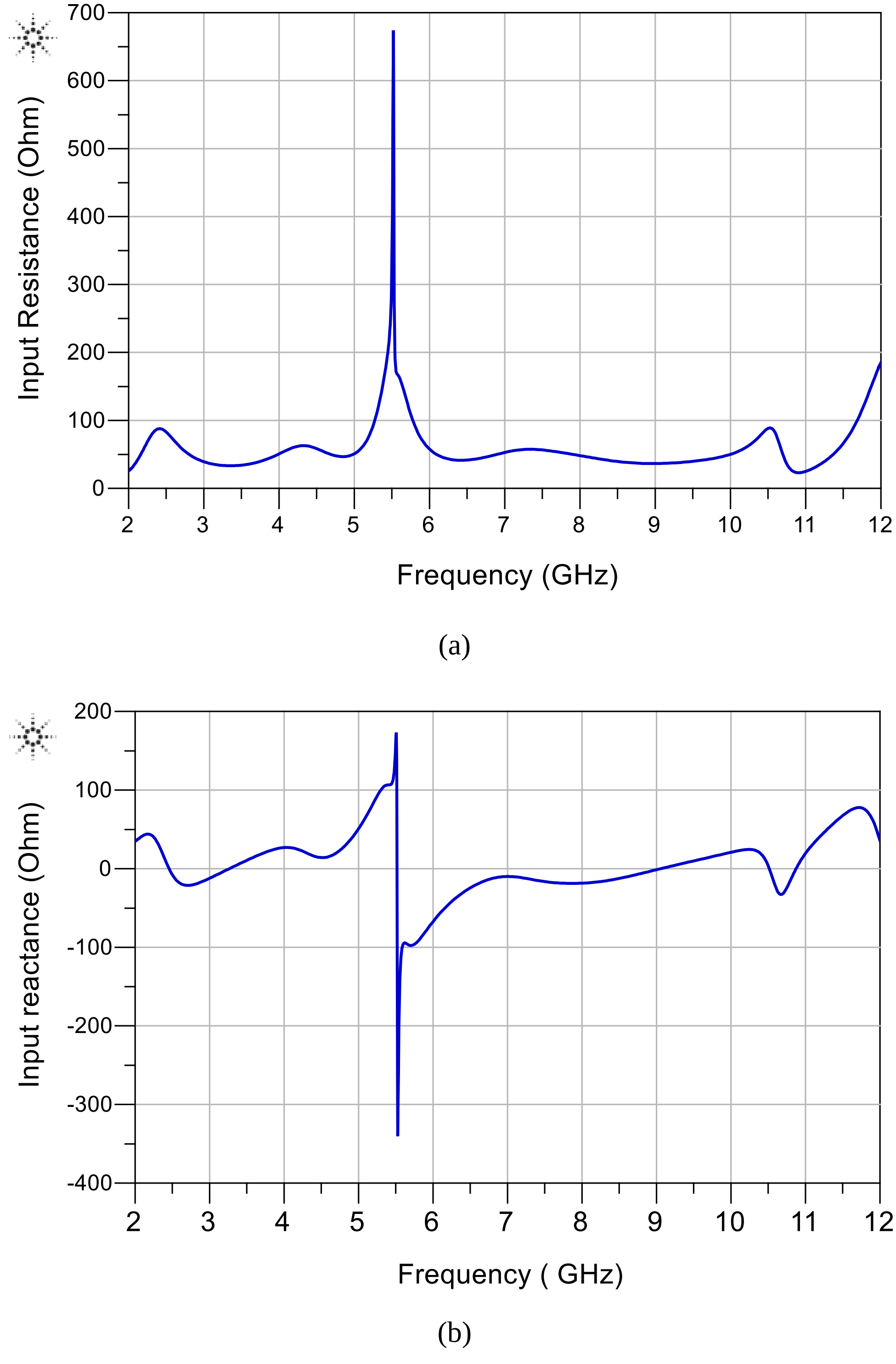


Fig.3.13. Simulated input impedance plot of the proposed UWB antenna with WLAN band-notched characteristics: (a) input resistance, and (b) input reactance.

As shown in Fig. 3.13 (a), the low return loss (< - 10 dB) occurs over the UWB frequency range (3.1 – 10.6 GHz) when the input impedance (resistance) if matched to 50 Ω except with the large excursion of 674 Ω observed at 5.5 GHz notch frequency and also depicts the high input impedance over the WLAN (5.15 GHz-5.85 GHz). This high value of impedance observed for WLAN frequency band makes clear that the proposed antenna becomes unresponsive and rejects the signal sent over interfering WLAN frequency band. While the input reactance as shown in Fig. 3.13 (b) is almost zero (not far from zero and remains small across a wide frequency range of UWB communication) except with the excursion made at the notch frequency band. It is clear from the input reactance plot that the input reactance of the proposed antenna almost vanishes due to cancellation of capacitive and inductive impedance. However, small amount of capacitive impedance is present at the notch frequency band due to the additional capacitive effect introduced by the folded split gap h_1 capacitance in the proposed antenna structure.

Return loss results of the reference antenna without notched characteristics and the proposed antenna with band notched characteristics are also shown in Fig. 3.14 for comparison. Moreover, it can be observed that by adding slot on both the ground plane the desired signal rejection characteristics can be achieved without sacrifice of the operating bandwidth and impedance matching of the UWB antenna. UWB antenna should be distortion free and to ensure this, group delay of the UWB antenna is simulated. Fig. 3.15 shows the group delay of the proposed antenna. The antenna shows nearly flat response in the UWB range (with group delay below 1 ns) except at notched bands where group delay makes large excursion with a group delay exceeds 2 ns. Thus, the proposed antenna structure has linear phase and good pulse handling capability.

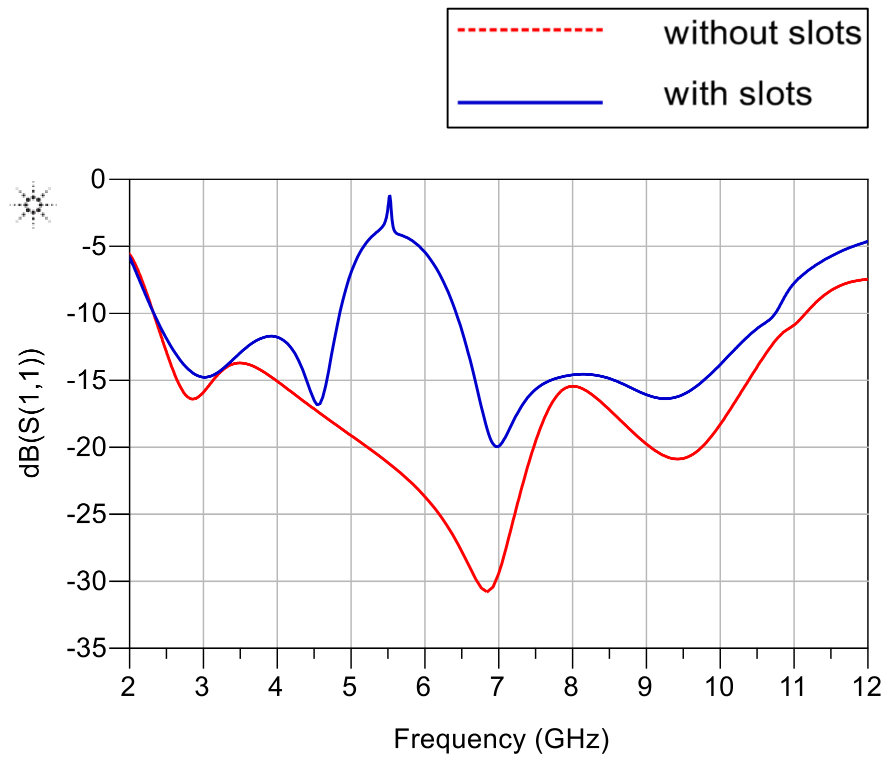


Fig.3.14. Comparison of Simulated Return loss response of the proposed UWB antenna with and without slots in the ground planes for WLAN band-notched characteristics.

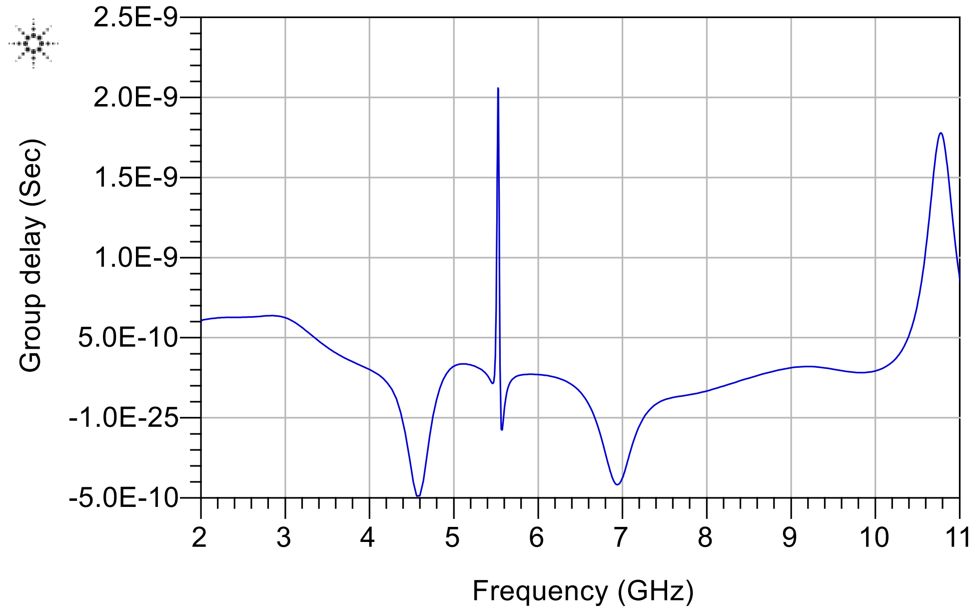
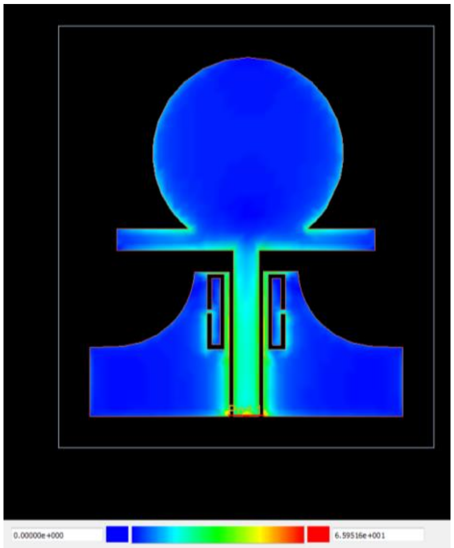
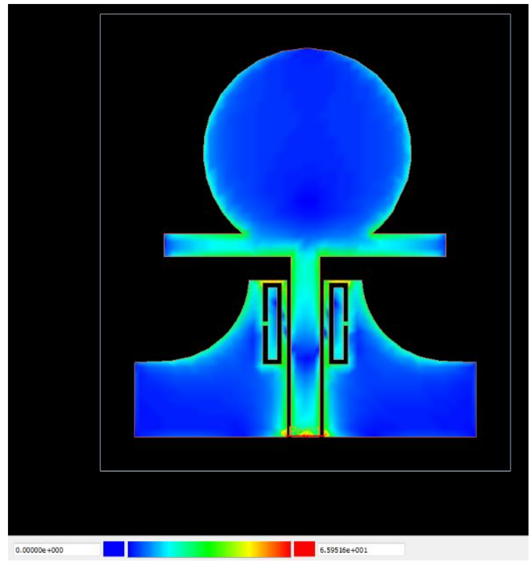


Fig.3.15 Simulated group delay plot of the proposed UWB antenna with WLAN Band-notched characteristics.

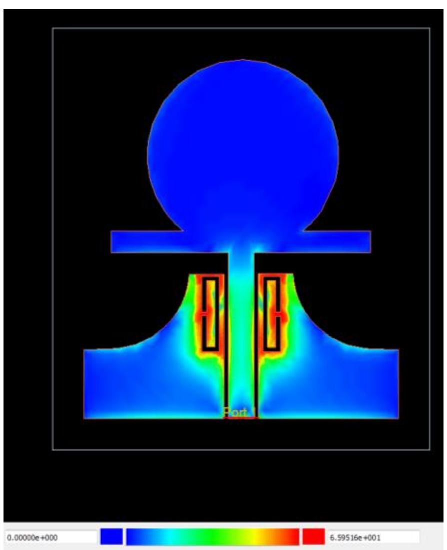
The surface current distribution on the proposed UWB at 3.1 GHz, 4.5 GHz, 5.5 GHz, and 10 GHz are shown in Fig. 3.16 (a),(b),(c), and (d) respectively.



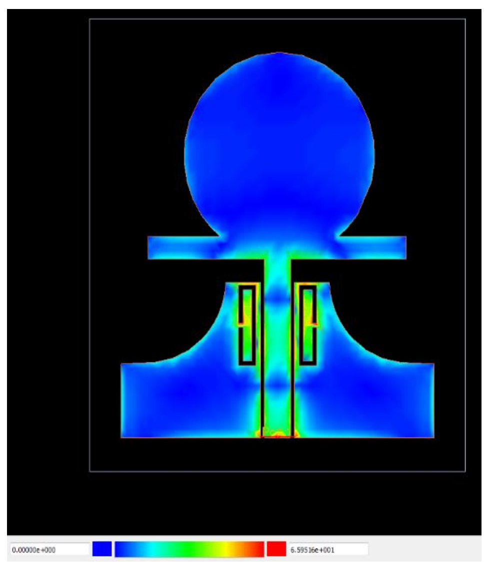
(a)



(b)



(c)

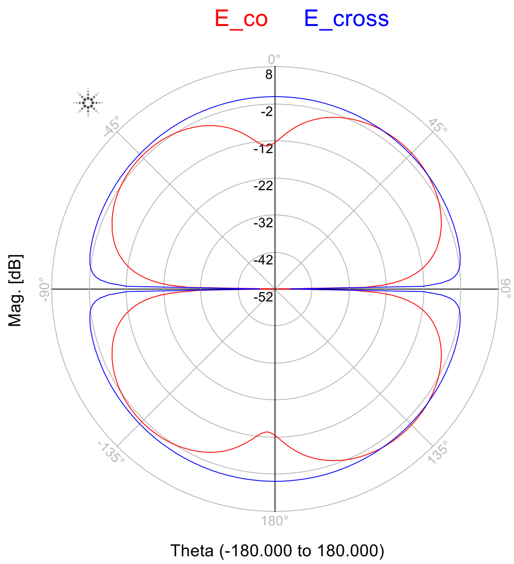


(d)

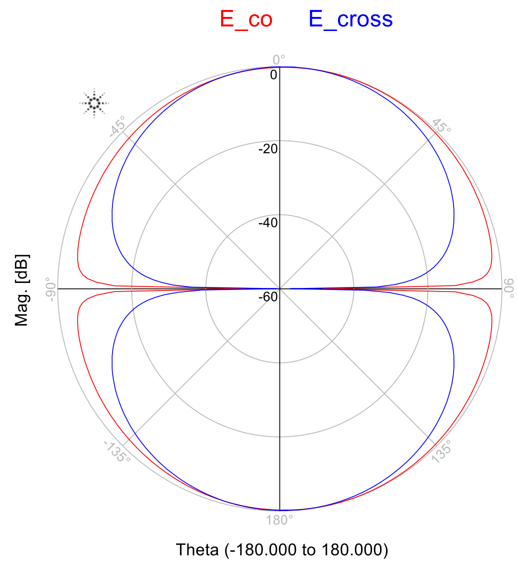
Fig.3.16. Simulated current distribution on the antenna: (a) 3.1 GHz, (b) 4.5 GHz, (c) 5.5 GHz, and (d) 10 GHz.

Fig.3.16 depicts the simulated current distribution on the proposed UWB antenna which shows that current is mainly distributed over the rectangular monopole attached to the circular radiating patch and along the circumference of the circular disc monopole antenna at 3.1 GHZ, 4.5 GHz and 10 GHz. Whereas, for notch band the current distribution density is maximum around the embedded C-shaped slots which explains that the strong concentration of current around the slots at 5.5 GHz makes the antenna non-radiating for the signals of WLAN band systems and thus it prevents the radiation at this particular frequency which supports the elimination of interfering signals within the UWB spectrum and the band stop filtering is achieved.

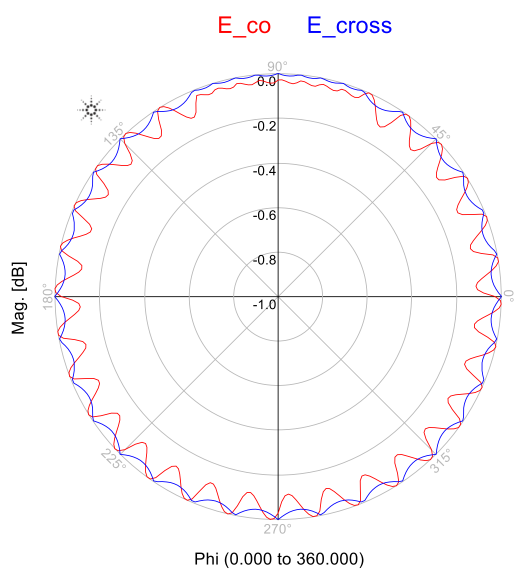
Another important characteristics that needs to be studied is the radiation pattern of the proposed UWB antenna. The radiation pattern is the graphical representation of the radiation properties of the antenna as a function of space. It is important to state that an antenna radiates in all directions at least to some extent. So the radiation pattern is actually three-dimensional. It is common, however to describe this 3D pattern with two planar patterns called principal plane patterns. These principal plane patterns can be obtained by making two slices through the 3D pattern through the main value of the measurement. In the discussion of principal plane patterns, the terms azimuth plane pattern (H- Plane) and elevation plane (E-Plane) pattern are encountered. The term azimuth is commonly found in reference to “the horizontal” whereas the term elevation refers to “the vertical”. The proposed antenna is oriented in y-axis so the radiation pattern along y-z and x-y are the elevation plane pattern (E-Plane) and the radiation pattern along x-z axis is the azimuth plane pattern (H- Plane). Fig.3.17, Fig. 3.18 and Fig.3.19 depicts the radiation characteristics i.e. the E-plane and H-Plane radiation patterns of the proposed antenna at operating frequency within the UWB range at 3.1 GHz, 7 GHz, and 10 GHz respectively.



(a)

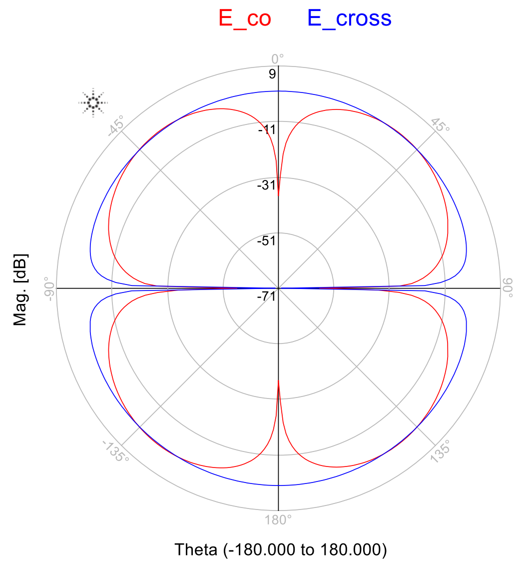


(b)

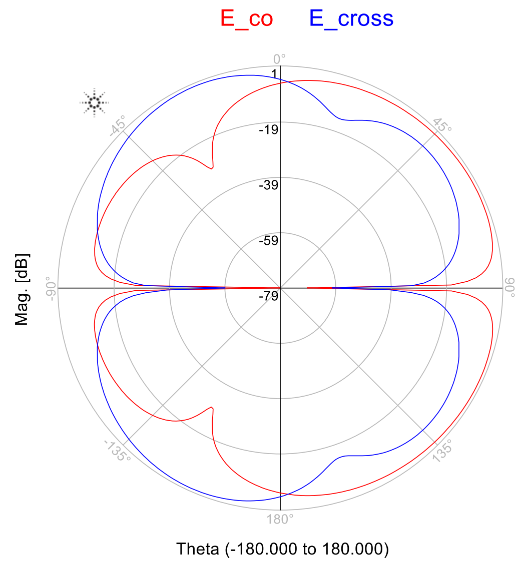


(c)

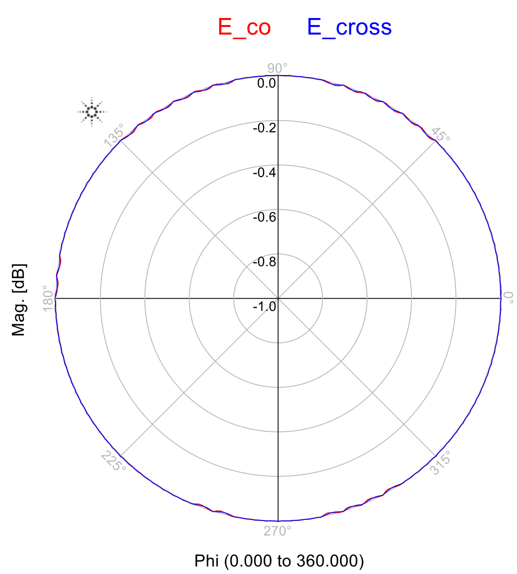
Fig. 3.17. Simulated Radiation pattern at 3.1 GHz: (a) E-plane (x-y) pattern, (b) E-plane (y-z) pattern, and (c) H- Plane (x-z) pattern.



(a)

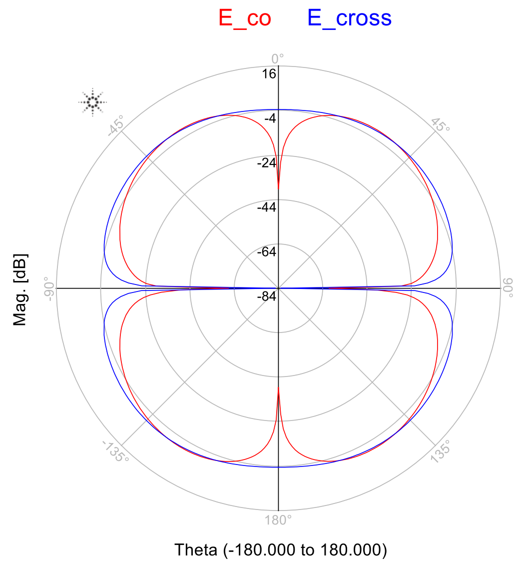


(b)

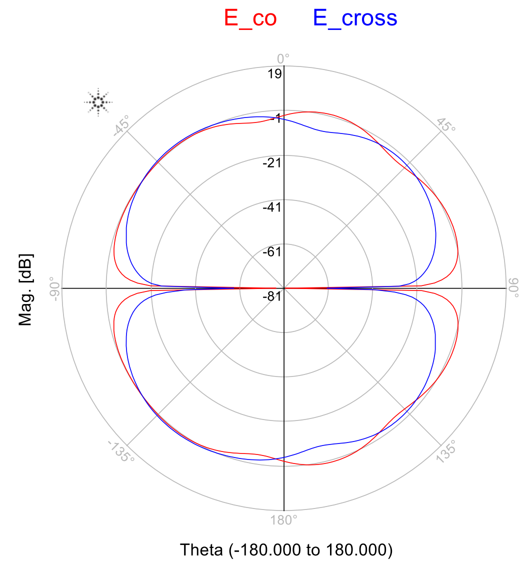


(c)

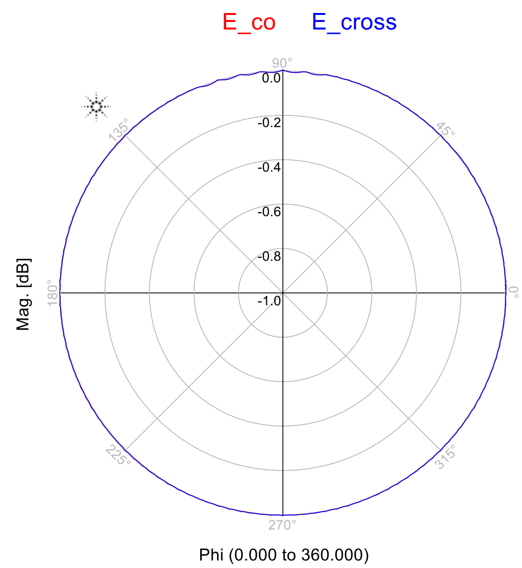
Fig. 3.18. Simulated Radiation pattern at 7GHz: (a) E-plane (x-y) pattern, (b) E-plane (y-z) pattern, and (c) H- Plane (x-z) pattern.



(a)



(b)

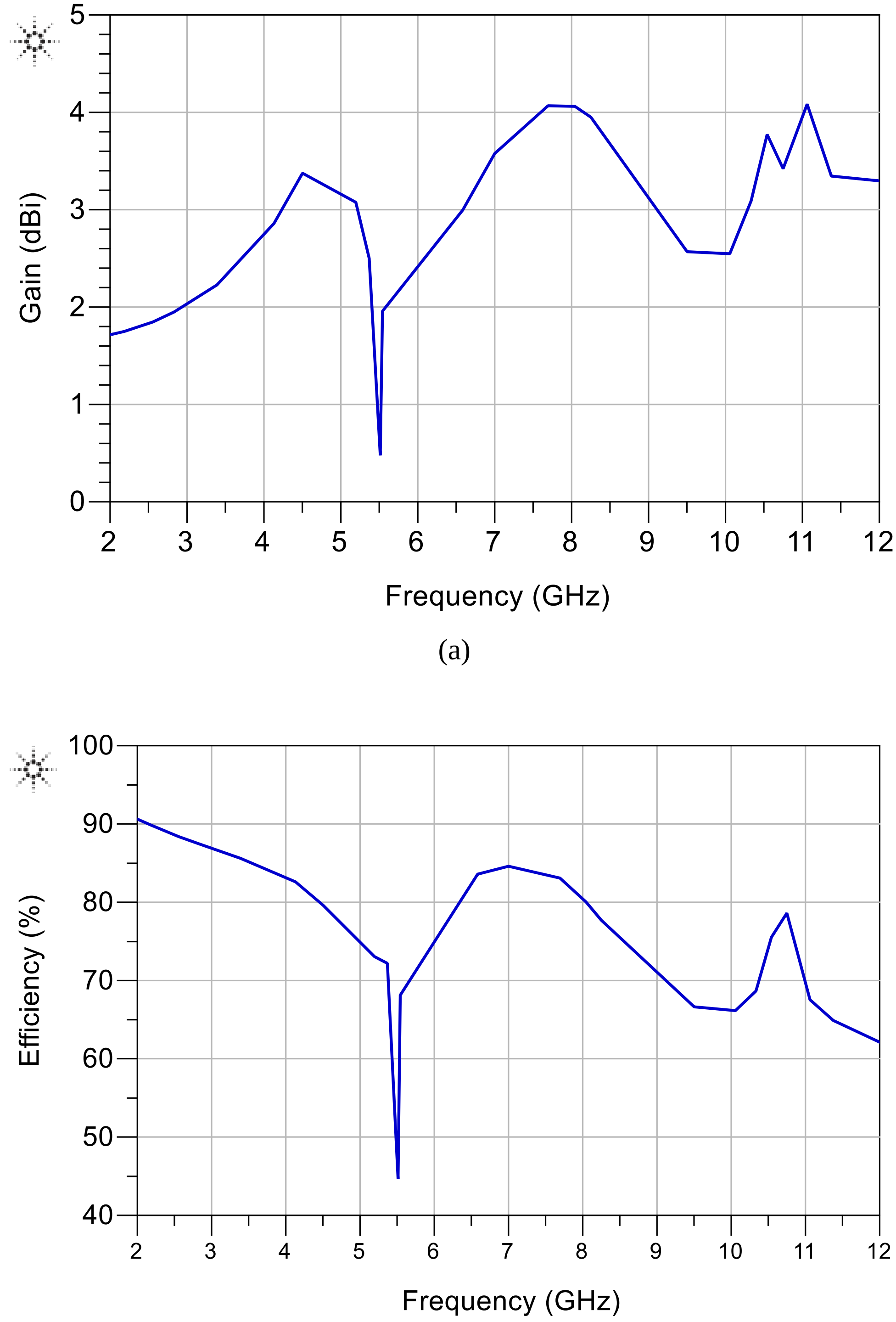


(c)

Fig. 3.19. Simulated Radiation pattern at 10 GHz: (a) E-plane (x-y) pattern, (b) E-plane (y-z) pattern, and (c) H- Plane (x-z) pattern.

It is noticed that simulated radiation pattern remains unaltered in each band. The pattern remains almost Omni-directional in the azimuthal plane (H- Plane) and the E-plane patterns are monopole like bidirectional radiation patterns. This radiation patterns observed for the proposed structure satisfies the omnidirectional radiation pattern requirement of the UWB antenna.

The simulated gain and the radiation efficiency plot is shown in Fig. 3.20 (a) and (b) respectively. The antenna has consistent gain which varies from 2 dBi to 4 dBi for the UWB frequency range except at notched band. The sharp decrease of gain around 5.5 GHz is observed which confirms the rejection of WLAN frequency band. The radiation efficiency of the proposed antenna varies from 86 % to 68 % over the UWB frequency range (3.1 GHz – 10.6 GHz) except at the notched band. The sharp decrease in radiation efficiency to 44 % at 5.5 GHz depicts that the antenna has poor radiation efficiency and does not radiate for the desired WLAN rejection band. Furthermore, the power radiation plot is shown in Fig. 3.21 which supports that there is no power radiated by the proposed antenna at the notched band. All these responses supports that the proposed UWB antenna is unresponsive for the signals transmitted for WLAN systems.



(a)

(b)

Fig.3.20. Simulated results of the proposed UWB antenna with WLAN Band-notched characteristics: (a) gain plot, and (b) radiation efficiency plot.

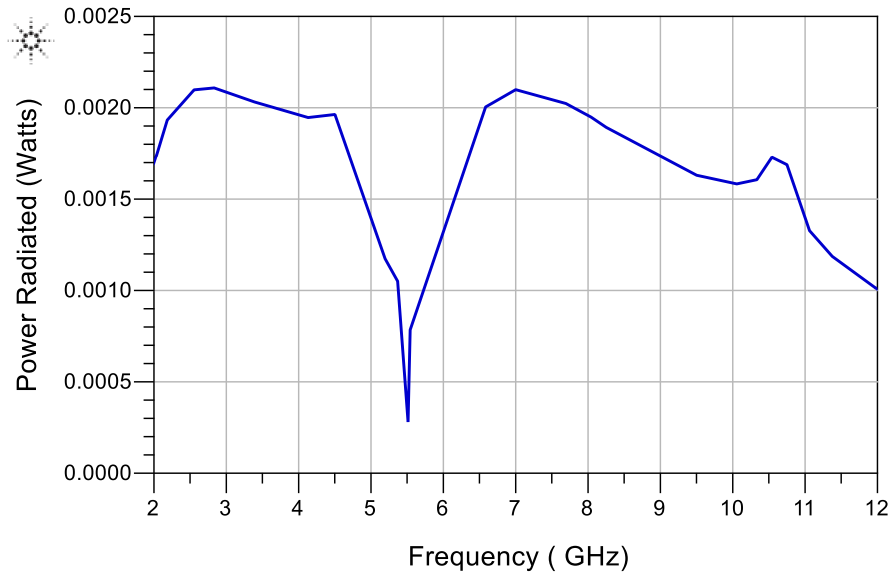


Fig.3.21. Simulated power radiation plot of the proposed UWB antenna with WLAN Band-notched characteristics.

3.8 **Conclusion**

A novel planar monopole antenna with corner circular arc shaped based ground plane and a compact folded C-shaped slot with split gap controlling the notch-band frequency is investigated in this work. It exhibits a - 10dB bandwidth from 2.34 GHz till 10.74 GHz with a sharp notch rejection of signals from narrow band WLAN systems. The antenna shows satisfactory omnidirectional radiation characteristics throughout its operating band with simulated peak gain varying from 2dBi to 4dBi.The proposed structure also shows high radiation efficiency for the entire UWB range which is one of the most desirable feature of UWB antenna. This antenna has a stable frequency response with wideband resonance, moderate gain and the radiation characteristics are suitable for collection of data from medical sensor network, medical imaging systems, sensing/monitoring systems and wireless communication.

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CHAPTER 4

A SELF-AFFINE SIERPINSKI CARPET FRACTAL UWB ANTENNA

4.1. Objective

The primary objective of this chapter is to present the concept of introduction of fractals structure in the proposed structure. A novel compact planar Sierpinski carpet fractal monopole antenna using self-affine shaped fractal based radiating structure is investigated in this work.

4.2. Introduction

UWB technology is one of the most emerging radio technology which is gaining importance and becoming very attractive for the researchers in academia and in industry due to high transmission rate, immunity to multipath interference, low power consumption, omnidirectional radiation characteristics and ultra wide bandwidth [1, 2]. To design compact antenna antennas with ultra-wideband resonance with larger impedance bandwidth and optimum impedance matching over the entire UWB band is one of the key issue in the design process of the UWB antenna. These unique features of UWB systems have attracted strong interest among antenna designers. Fractals antenna based upon the introduction of carpet fractals replaces the need of usual rubbery stalk used for antenna protection. This fractal introduction in the antenna structure increases the robustness and the radiation efficiency of the antenna which contributes in the increase of antenna gain and impedance matching significantly. Because of this advantages, use of fractal based antenna structure is gaining more popularity. Many famous fractals geometry [3] are being used nowadays for antenna design like linear fractal geometry (Koch curve and the Koch snowflake), the Sierpinski structure(Sierpinski triangle and the Sierpinski carpet), the Dragon structure, the Tree structure (The Tree, H- Tree, Pythagorean Tree structure) , the Circular Apollonius circle structure, the Cantor set, the Hilbert Curve, the Minkowski curve, etc.

The self – similar and space filling fractal geometries have been successfully used for designing compact multiband [4] wideband [5, 6], and UWB antennas [7, 8] lately. To introduce the novelty in the carpet fractals geometry application and use of simple fractals for UWB communication which provides ease of integration and fabrication process, we have proposed a second iteration self-affine sierpinski carpet fractals which was proposed recently in [9].

4.3. Self- Affine Sierpinski Carpet Fractal Antenna Design

The geometry of the proposed self – affine sierpinski carpet fractal antenna is shown in Fig.4.1. This antenna is simulated and designed in the 3D Agilent Advanced Design System (ADS) EM simulation software. This antenna is realized on Rogers RO 3006 substrate with thickness of 0.375 mm, loss tangent tanδ=0.0025 and relative dielectric constant ε_r of 6.15. This proposed structure has same dimensions as the antenna that was proposed in chapter 3. The antenna design parameters and slot parameters for WLAN rejection are similar to the proposed structure in Fig. 3.6. From current distribution pattern shown in Fig. 3.16 which depicts that current is mainly distributed mainly along the circumference of the circular disc monopole antenna. The current density is low in the middle area of the solid circular path. Thus, the current will not be effected if the middle area is removed [10]. Using this concept, a self-affine sierpinski carpet fractal structure is introduced in the circular radiating patch.

The design consideration of a self- affine sierpinski carpet fractal structure is somewhat different that the design adopted for the self-similar sierpinski fractals. In self-similar sierpinski carpet fractal same scaling factor is used to for the second iteration of fractals introduction after the first iteration of adding generator is introduced in the structure. For example, if a generator set of rectangular dimension having length (L_c) and width (W_c) is taken out from the circular patch. For the second iteration, the scaling factor *'r'* is used to finding both the lenth (l_{c1}) and width (w_{c1}) of the rectangular fractal. The equation for finding dimension of self- similar fractals is: $(l_{c1}, w_{c1}) = (rL_c, rW_c)$, where, $r = 1/3$ is usually used for finding the dimensions of second iteration fractals in self-similar fractals. However, for self-affine fractals, different scaling factors are used for the second iteration of adding fractals. The equation for finding dimension of self- affine fractals is: $(l_{c1}, w_{c1}) = (sL_c, rW_c)$, where, $r = 1/3$ and the scaling factor s can be selected by the designer. This property of self-affine fractals gives more freedom to the designers to choose fractals of different dimensions according to their design and application requirement.

In our proposed work, we have introduced a self-affine sierpinski carpet fractal in the circular patch. For the first iteration, a rectangular generator of dimension (L_c ,W_c) is cut out from center of the circular patch. For the second iteration, 8 self- affine fractals of rectangular structure having dimension $(l_{c1}, w_{c1}) = (sL_c, rW_c)$, where, $r = 1/3$ and the scaling factor $s = 0.5$ are introduced in the circular disc at a distance of 0.5 mm from the central generator rectangular slot. This novel concept of self-affine sierpinski carpet fractal design is reported in the recently published book [9]. The optimized design parameters of antenna with slots parameters for WLAN rejection and fractal design parameters are shown in Table 4.1 and Table 4.2 respectively.

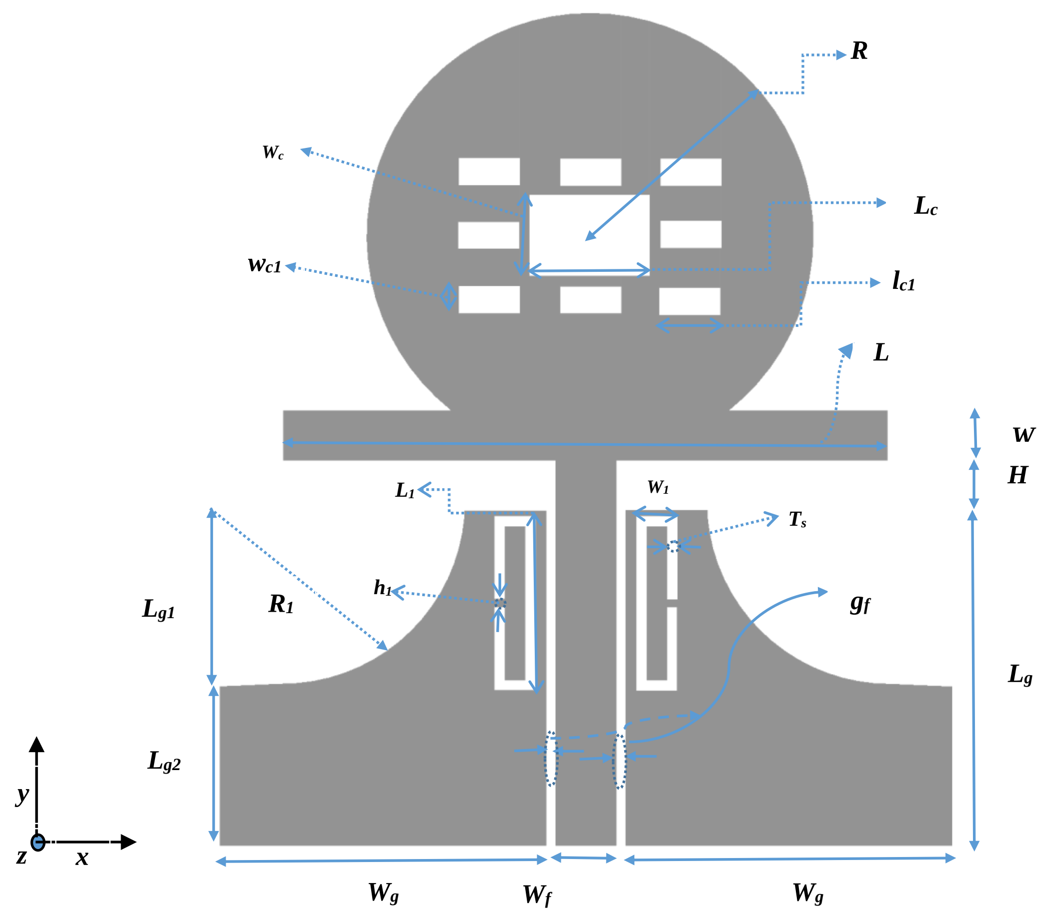


Fig. 4.1. Geometry of the proposed UWB antenna with self-affine Sierpinski carpet fractals.

Table 4.1 List of Antenna Design Parameters

Antenna parameters	Value(mm)
L	29.75
W	2.48
L_g	16.55
W_g	16.05
R	11
R_1	10.5
H	2.45
W_f	3
g_f	0.45
L_{g1}	8.68
L_{g2}	7.87

Table 4.2 List of Slot and Fractals Parameters

Slot parameters	**Value(mm)**
L_1	8.6
W_1	2
T_s	0.5
h_1	0.4082
Fractals parameters	**Value (mm)**
L_c	6
W_c	4
l_{c1}	3
w_{c1}	1.33

4.4. Results and Discussion

The Agilent Advanced Design System (ADS) software was used to simulate and analyze the performance and functionality of the proposed self-affine sierpinski carpet fractal UWB antenna with single WLAN band rejection characteristics. In this section the detailed result showing the resonance and radiation characteristics i.e. the return loss, VSWR plot, the input impedance plot, group delay, the radiation pattern, current distribution and gain, radiation efficiency plot and the power radiation plot of the proposed UWB antenna are discussed to show that the proposed antenna is having desired result and is operating effectively. Return loss results of the reference band notched UWB antenna without sierpinski carpet fractals and the proposed antenna with sierpinski carpet fractals is shown in Fig.4.2 for comparison. Moreover, it can be observed that by adding self-affine sierpinski carpet fractals in the radiating circular patch the impedance matching (S11 characteristics) is significantly improved in both the lower and upper frequency band of UWB operating region.

The simulated S11 (dB) i.e. the return loss and the VSWR plot of the final design of the proposed fractal UWB antenna is shown in Fig. 4.3 which describes the resonance characteristics of the proposed antenna. The improved return loss response of the antenna can be observed from Fig.4.3 (a) which is below -10 dB are from 2.31 GHz – 10.61 GHz (except at notched band centred around 5.5GHz with high return loss of -1.203 dB at the 5.5 GHz notch frequency) and covers the entire UWB band (3.1-10.6GHz). It is very clear that the desired filtering property is achieved by introducing a compact folded C-shaped slots in the antenna structure. The sharp notch is one of the most desirable features used for signal rejection in UWB system which eliminates the use of filter for the rejection of interfering bands. VSWR as shown in Fig.4.3 (b) shows good impedance matching with VSWR< 2 for the UWB frequency range and a high VSWR of 14 around notch frequency 5.5 GHz yielding sharp notch at the desired rejection band of WLAN system. The simulated input impedance of the proposed antenna is shown in Fig. 4.4. It depicts the simulated input resistance and the input reactance of the proposed fractal UWB antenna with band-notched characteristics.

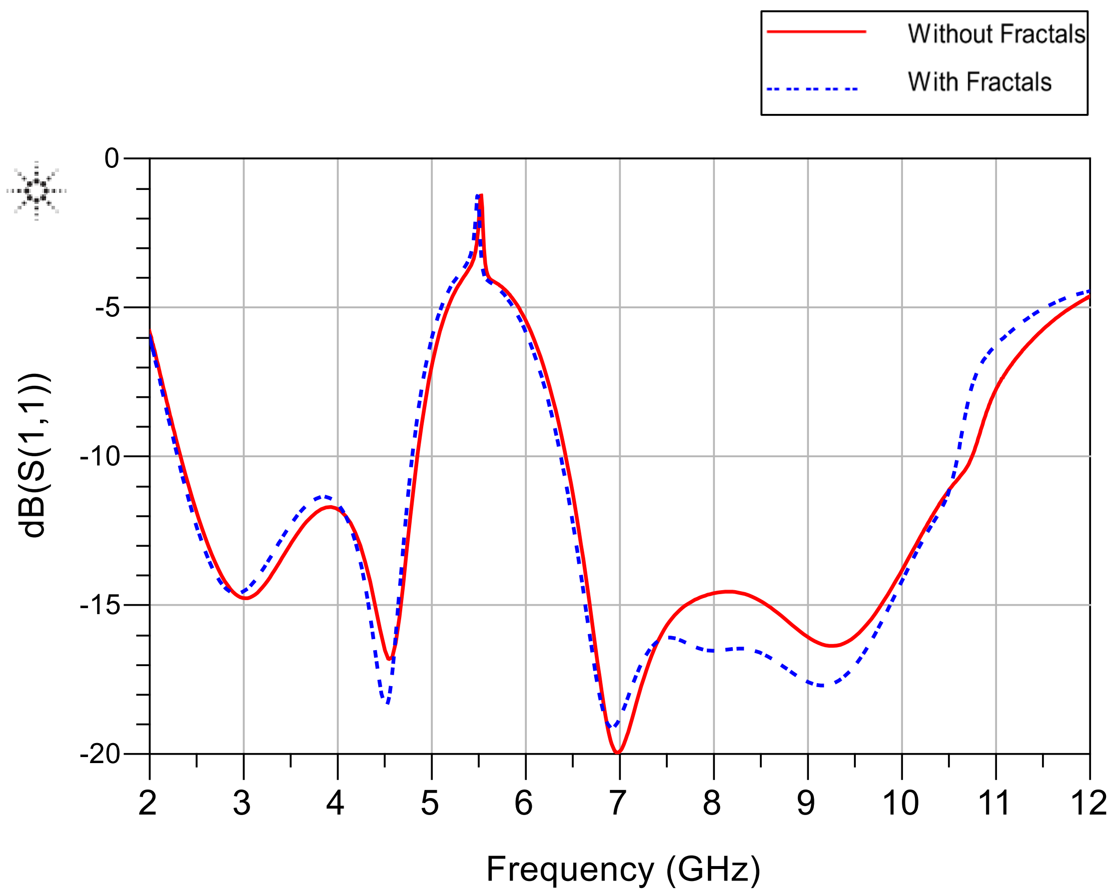
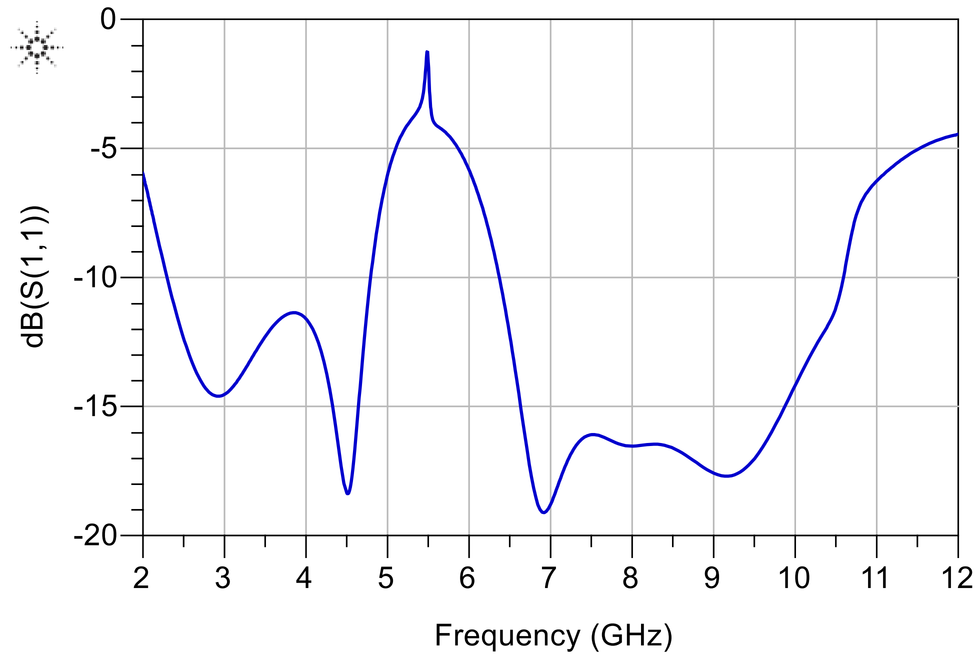
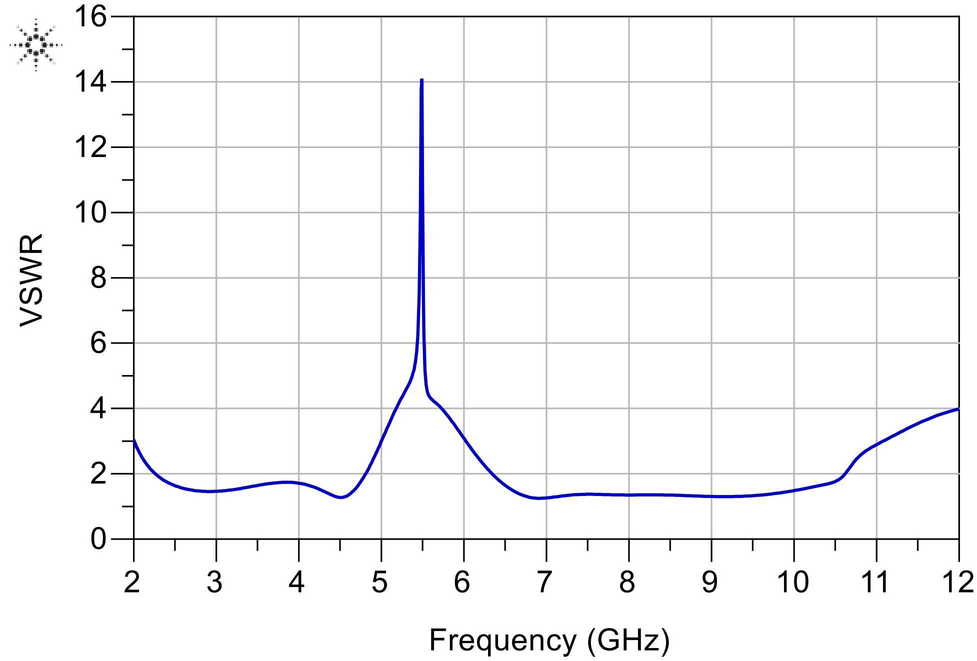


Fig.4.2. Comparison of Simulated Return loss response of the proposed UWB antenna with and without sierpinski carpet fractals in the radiating patch

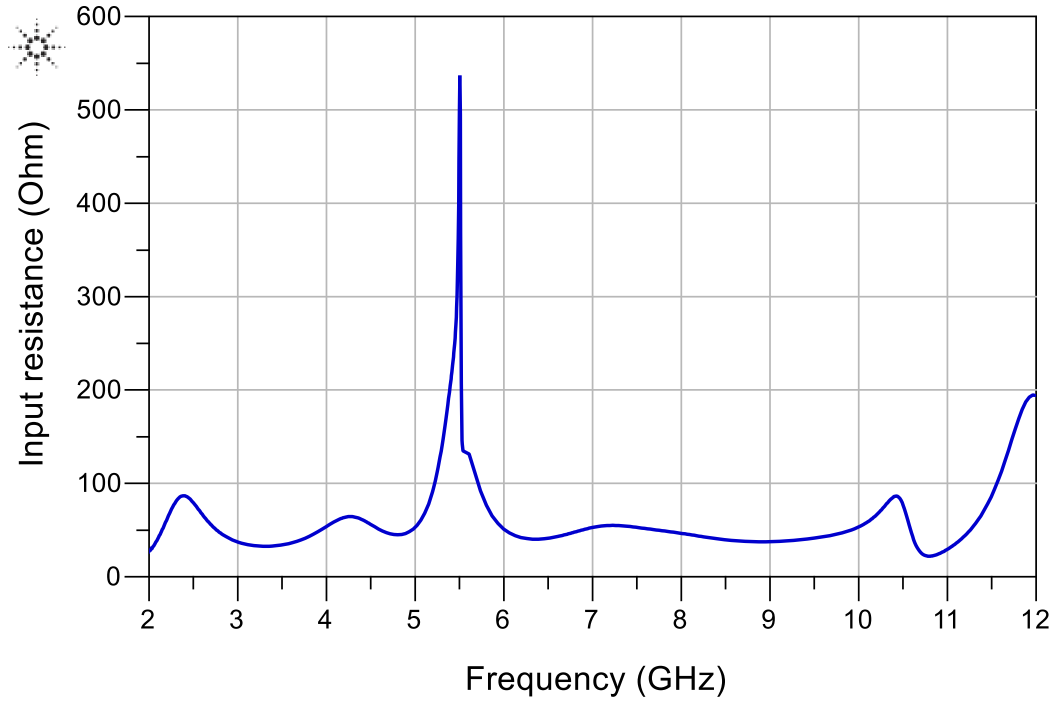


(a)

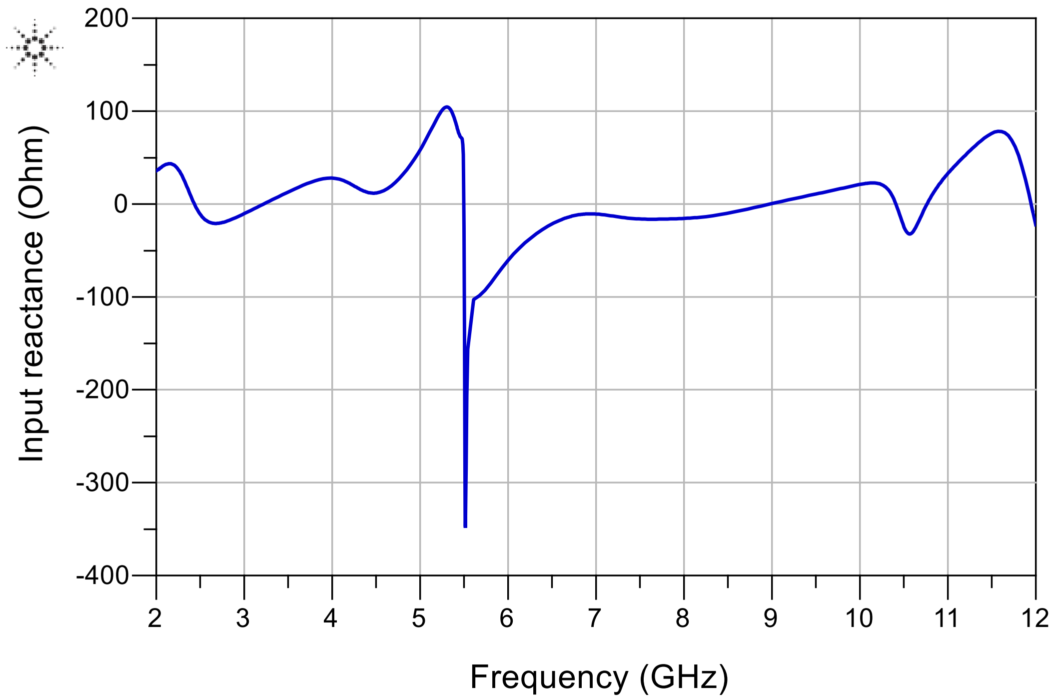


(b)

Fig.4.3. Simulated Frequency response of the proposed UWB antenna with self-affine Sierpinski carpet fractals and WLAN band-notched characteristics: (a) Return Loss response, and (b) VSWR plot.



(a)



(b)

Fig.4.4. Simulated input impedance plot of the proposed UWB antenna with self-affine Sierpinski carpet fractals and WLAN band-notched characteristics: (a) input resistance, and (b) input reactance.

As shown in Fig. 4.4 (a), the low return loss (< - 10 dB) occurs over the UWB frequency range (3.1 – 10.6 GHz) when the input impedance (resistance) if matched to 50 Ω except with the large excursion of 537 Ω observed at 5.5 GHz notch frequency and also depicts the high input impedance over the WLAN (5.15 GHz-5.85 GHz). This high value of impedance observed for WLAN frequency band makes clear that the proposed antenna becomes unresponsive and rejects the signal sent over interfering WLAN frequency band. While the input reactance as shown in Fig. 4.4 (b) is almost zero (not far from zero and remains small across a wide frequency range of UWB communication) except with the excursion made at the notch frequency band. It is clear from the input reactance plot that the input reactance of the proposed antenna almost vanishes due to cancellation of capacitive and inductive impedance. However, small amount of capacitive impedance is present at the notch frequency band due to the additional capacitive effect introduced by the folded split gap h_1 capacitance and the capacitance introduced by the fractal structure. UWB antenna should be distortion free and to ensure this, group delay of the UWB antenna is simulated.

Fig. 4.5 shows the group delay of the proposed fractal UWB antenna. The antenna shows nearly flat response in the UWB range (with group delay below 1 ns) except at notched bands where group delay makes large excursion with a group delay approaches 2 ns. Thus, the proposed antenna structure has linear phase and good pulse handling capability.

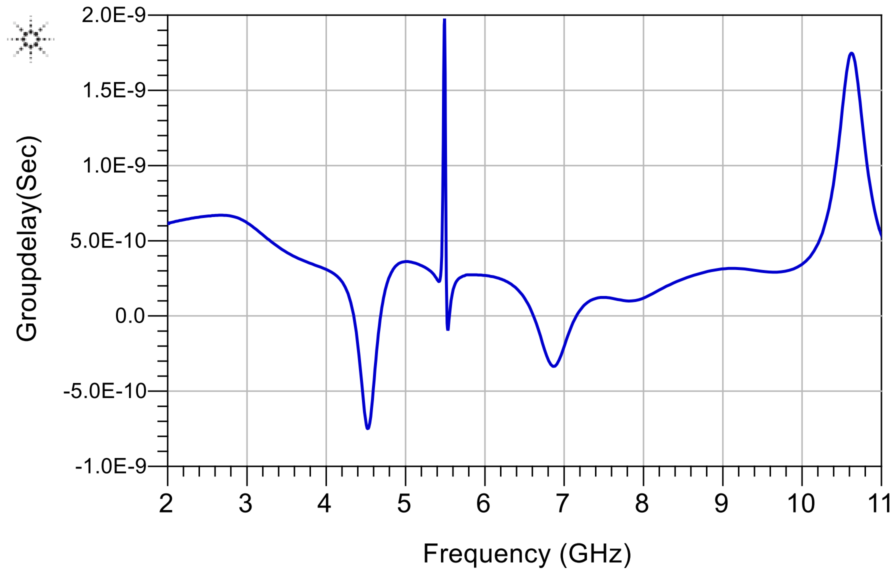
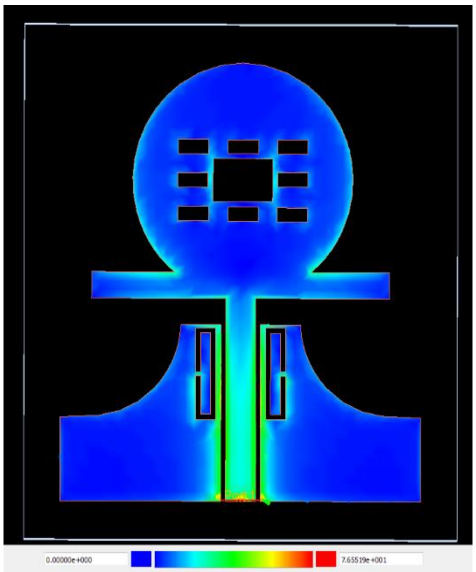
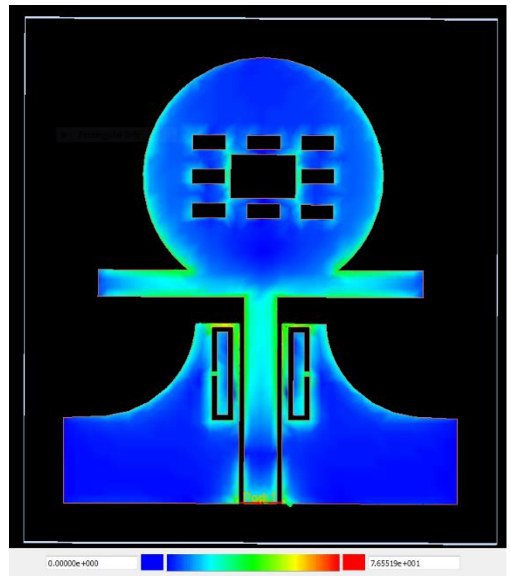


Fig.4.5 Simulated group delay plot of the proposed UWB antenna with self-affine Sierpinski carpet fractals and WLAN Band-notched characteristics.

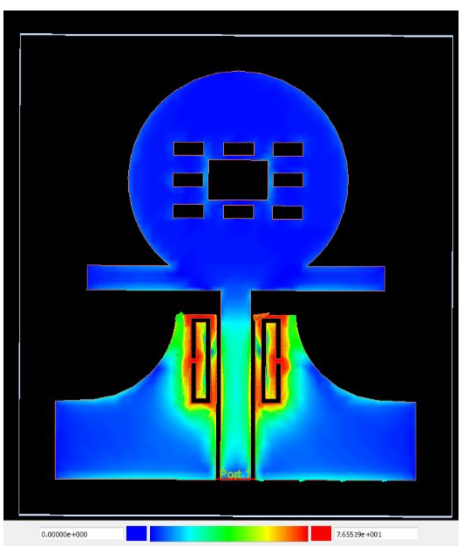
The surface current distribution on the proposed UWB at 3.38 GHz, 4.5 GHz, 5.5 GHz, and 10.5 GHz are shown in Fig. 4.6 (a),(b),(c), and (d) respectively. This plot depicts the simulated current distribution on the proposed UWB antenna which shows that current is mainly distributed over the rectangular monopole attached to the circular radiating patch, along the circumference of the circular disc monopole antenna and along the edges of the added fractals at 3.38 GHz, 4.5 GHz and 10.5 GHz. Whereas, for notch band the current distribution density is only concentrated around the embedded C-shaped slots which explains that this strong concentration of current around the slots at 5.5 GHz makes the antenna non-radiating for the signals of WLAN band systems and thus it prevents the radiation at this particular frequency which supports the elimination of interfering signals within the UWB spectrum and the band stop filtering is achieved. Another important characteristics that needs to be studied is the radiation pattern of the proposed UWB antenna. Fig.4.7, Fig. 4.8 and Fig.4.9 depicts the radiation characteristics i.e. the E-plane and H-Plane radiation patterns of the proposed antenna at operating frequency within the UWB range at 3.45 GHz, 8.25 GHz, and 10 GHz respectively.



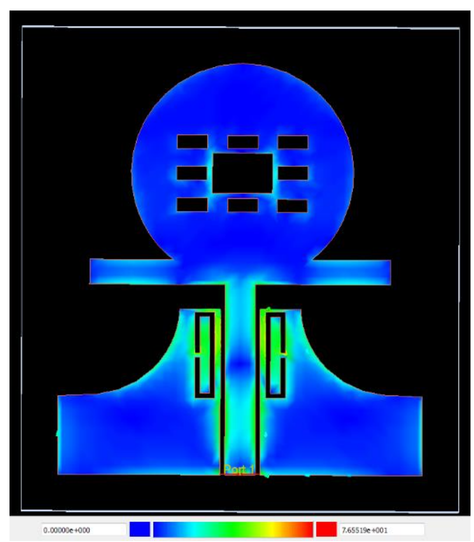
(a)



(b)



(c)



(d)

Fig.4.6. Simulated current distribution on the antenna: (a) 3.38 GHz, (b) 4.5 GHz, (c) 5.5 GHz, and (d) 10.5 GHz

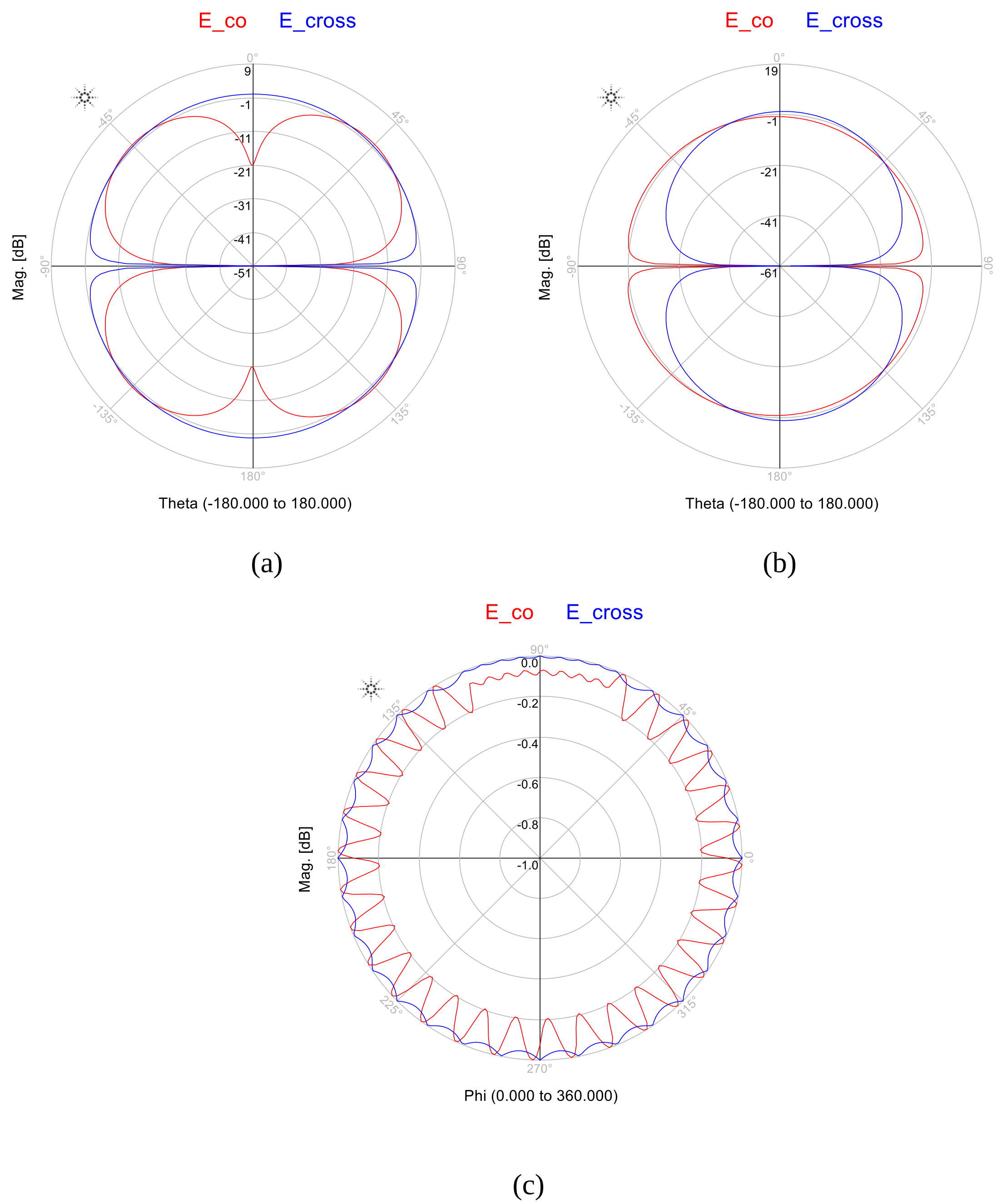


Fig. 4.7. Simulated Radiation pattern at 3.45 GHz: (a) E-plane (x-y) pattern, (b) E-plane (y-z) pattern, and (c) H- Plane (x-z) pattern.

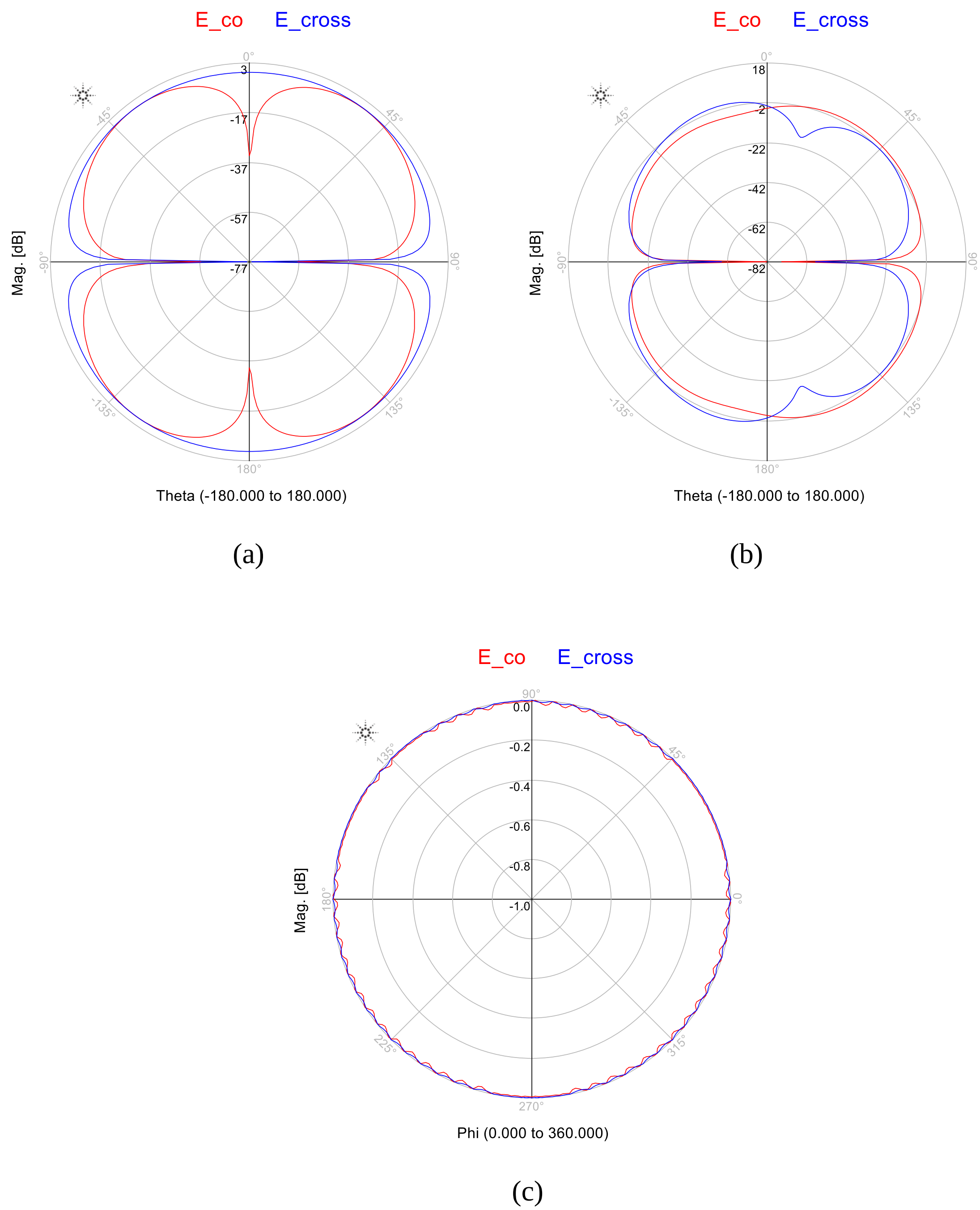
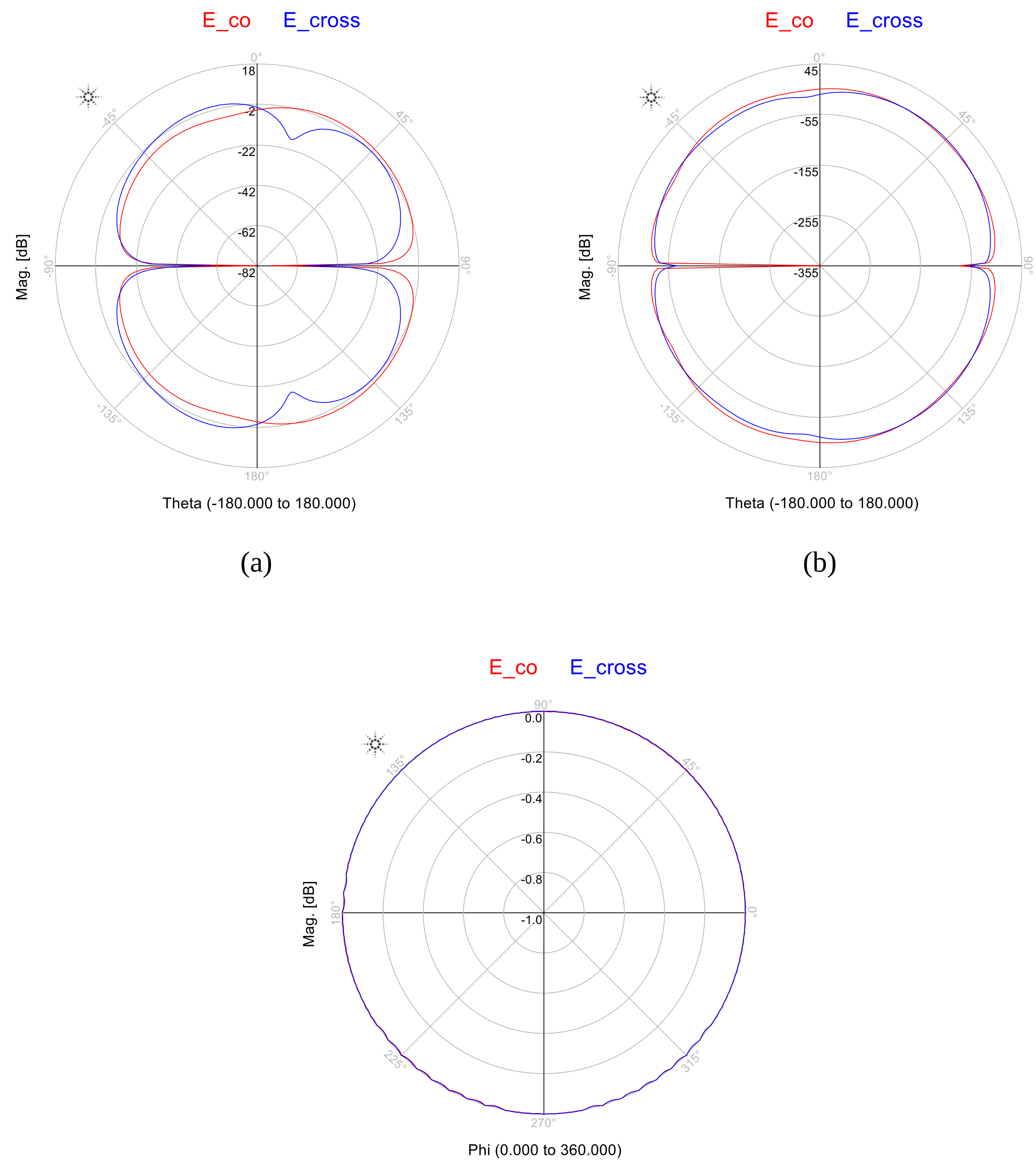


Fig. 4.8. Simulated Radiation pattern at 8.25 GHz: (a) E-plane (x-y) pattern, (b) E-plane (y-z) pattern, and (c) H- Plane (x-z) pattern.



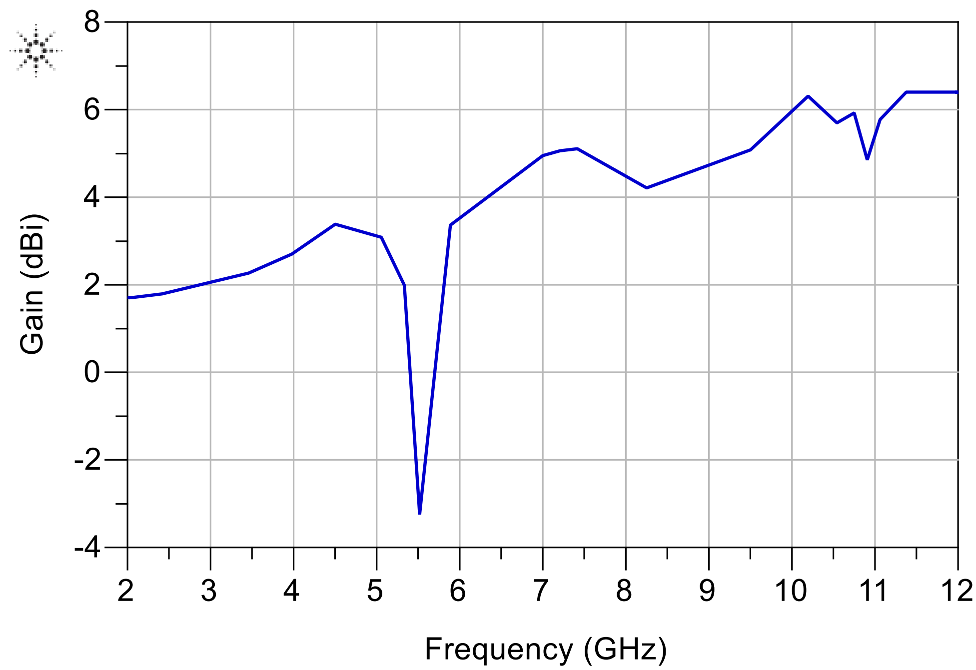
(a) (b)

(c)

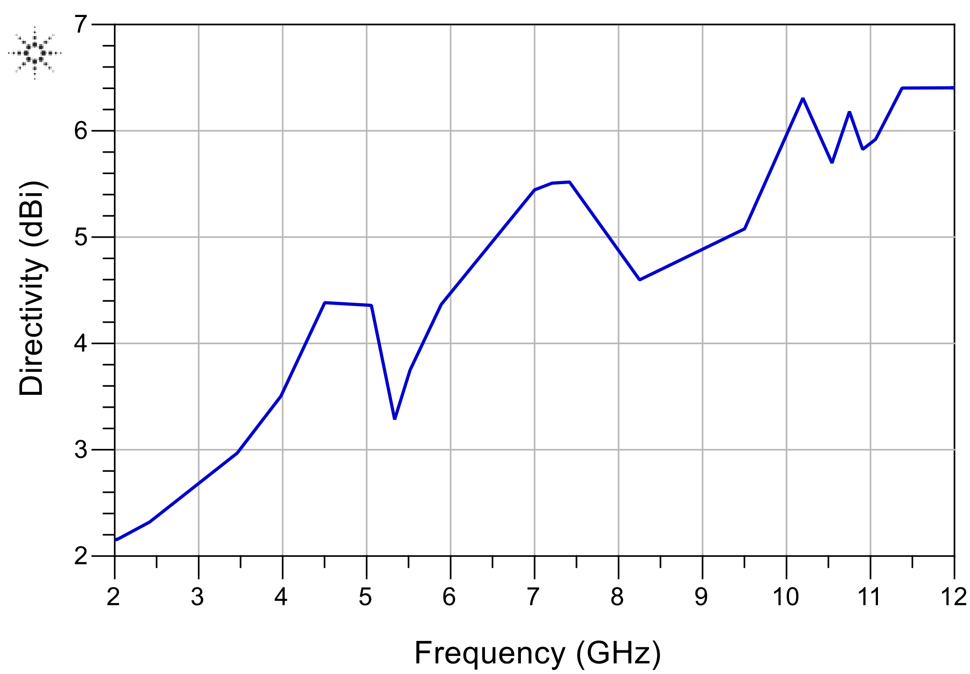
Fig. 4.9. Simulated Radiation pattern at 10 GHz: (a) E-plane (x-y) pattern, (b) E-plane (y-z) pattern, and (c) H- Plane (x-z) pattern.

It is noticed that simulated radiation pattern remains unaltered in each band. The pattern remains almost Omni-directional in the azimuthal plane (H- Plane) and the elevation plane (E-plane) patterns are monopole like bidirectional radiation patterns. The radiation patterns observed for the proposed UWB antenna with carpet fractals structure satisfies the omnidirectional radiation pattern requirement of the UWB antenna.

The simulated gain and directivity plot of the proposed fractal UWB antenna is shown in Fig. 4.10 (a) and (b) respectively. The antenna has consistent gain which varies from 2 dBi to 6 dBi for the UWB frequency range except at notched band. The sharp decrease of gain around 5.5 GHz is observed which confirms the rejection of WLAN frequency band. At notched band, a sharp decrease of antenna gain to -3 dBi. The simulated radiation efficiency and power radiation plot is shown in Fig. 4.11 (a) and (b) respectively. The radiation efficiency of the proposed antenna varies from 85 % to 99.9 % over the UWB frequency range (3.1 GHz – 10.6 GHz) except at the notched band. The sharp decrease in radiation efficiency to 20 % at 5.5 GHz depicts that the antenna has very poor radiation efficiency and does not radiate for the desired WLAN rejection band. Furthermore, the power radiation plot supports that there is no power radiated by the proposed antenna at the notched band. All these responses supports that with the introduction of self-affine sierpinski carpet fractals, the UWB antenna achieves optimum gain, and radiation efficiency along with the better rejection of WLAN band signals by reducing radiation efficiency to 20 % and gain to -3 dBi.

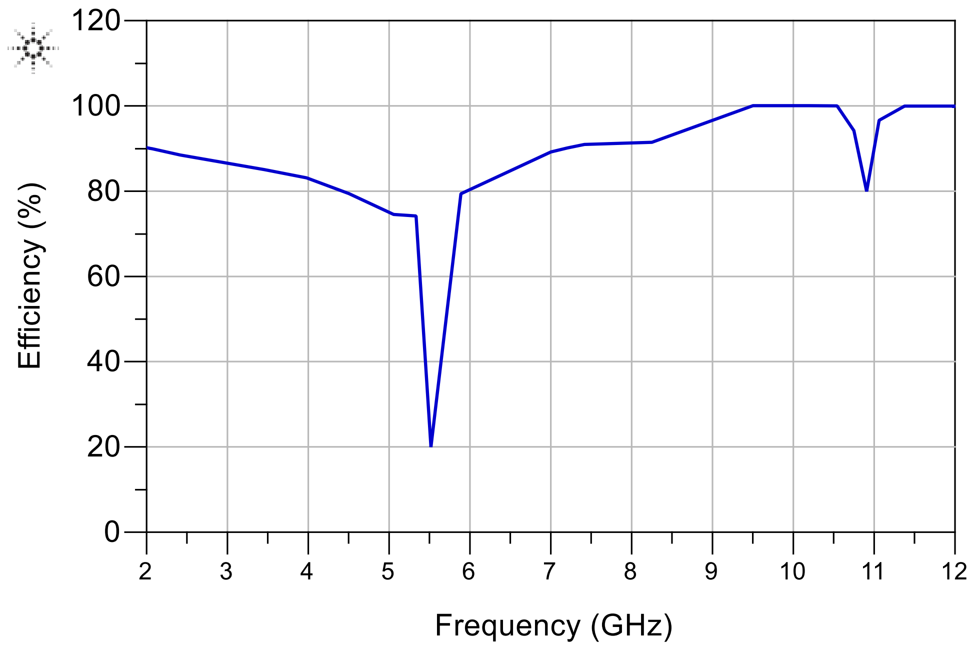


(a)

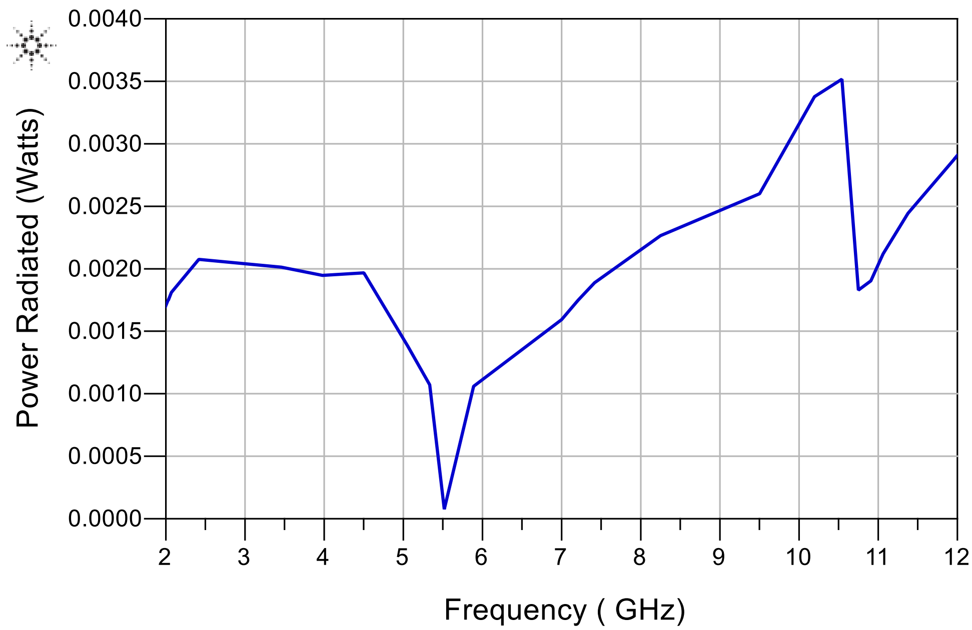


(b)

Fig.4.10. Simulated results of the proposed UWB antenna with self-affine Sierpinski carpet fractals and WLAN Band-notched characteristics: (a) gain plot, (b) directivity plot.



(a)



(b)

Fig.4.11. Simulated results of the proposed UWB antenna with self-affine Sierpinski carpet fractals and WLAN Band-notched characteristics: (a) radiation efficiency plot, and (b) power radiation plot.

4.5 Conclusion

A Compact Planar Self-Affine Sierpinski Carpet Fractal Planar Monopole Antenna with Band Notch characteristics for UWB Communication is proposed. This fractals structure is introduced in the radiating circular patch which helps to achieve improved impedance matching, increase in gain, and miniaturization compared to the proposed initial structure. The proposed antenna yields an impedance bandwidth of 2.31-10.61 GHz with VSWR<2 except at the notched bands. The antenna gain is significantly improved and varies from 2 dBi to 6 dBi over the band with the dips of -3 dBi at the rejection band. The significant improvement of radiation efficiency of the antenna is achieved with a variation of efficiency from 85 % to 99.9% for UWB frequency range which marks the optimal performance of the proposed fractal UWB antenna.

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CHAPTER 5

GENERAL CONCLUSION AND FUTURE WORK

5.1 Objective

The objective of this chapter is to present the summary of the work done for the partial fulfillment of the Master's project and ends with an optimistic note on encouraging result for the further studies that will be taken up in future that will drives us to further broaden the horizon of our study and experimentally investigate new designs which could be useful for UWB communication.

5.2 General Conclusion

The project entitled "*Design of Ultra-Wideband antenna with Signal Rejection Characteristics for Biomedical Applications*", conducted as a thesis research project of Master's degree in Electrical and Computer Engineering was completed successfully within the time boundary. The project is basically based on UWB technology and deals with the compact antenna design useful for UWB communication.

In **chapter 1**, the basic introduction of UWB starting with its history, system components, frequency band allotment and its different types has been discussed in detail to make UWB familiar by presenting its general viewpoint. UWB applications, its advantages over other technology like barcode reading and challenges which needs to be considered while its implementation has been discussed in detail to provide a basic framework about UWB technology.

A comprehensive review was presented in **chapter 2** covering the important milestones in the UWB antenna design paradigm. With development in wireless communication the need for ultra-wideband antenna became inevitable. In chapter the rapid development of different configuration of antenna and its functional characteristics well suited for UWB communication has been discussed in detail which laid the foundation for the design of novel antenna with signal rejection characteristics well suitable for UWB communications. The main objective of this chapter is to present a comprehensive review on different antenna topologies followed to achieve ultra -wideband resonance with band rejection characteristics well suited for UWB applications. This overview helped to analyze the performance criteria and optimized design requirements of different antenna topologies which are widely used for UWB applications.

In **chapter 3**, a planar ultrawideband antenna with single band rejection characteristics is studied. A rejection band, located at 5.5GHz WLAN band, is created using a compact C- shaped slot with split gap at the folded arms on the ground plane of the CPW feed line. The slots occupy less space compared to other slotted structures. The proposed antenna yields an impedance bandwidth of 2.34 GHz - 10.74 GHz with VSWR<2 except at the notched bands. The parametric study of the vertical feed gap between ground plane and the radiating patch along with the study of variation of slot parameters added for rejection characteristics is also well discussed to provide important change in characteristics of the antenna observed by varying the slot parameters which are more sensitive and special care is to be taken during designing process. The proposed antenna shows a moderate gain that varies from 2 dBi to 4 dBi for the UWB range with the exception of low gain at notch band. It also exhibits strong radiation efficiency which is one of the most important considerations to be met for the design of UWB antenna. The group delay is almost consistent and below 1 ns which ensures distortion less pulse transmission. In addition to this, the radiation pattern of the antenna shows omnidirectional radiation pattern which supports the uniform transmission of signal/ data irrespective of the orientation of the antenna's direction.

In **chapter 4**, a Compact Planar Self-Affine Sierpinski Carpet Fractal Planar Monopole Antenna with Band Notch characteristics for UWB Communication is proposed. This carpet fractals are introduced in the same UWB antenna design with WLAN rejection characteristic proposed in chapter 3. This fractals structure is introduced in the radiating circular patch which helps to achieve improved impedance matching, increase in gain, and miniaturization compared to the proposed structure in chapter 3. A rejection band, located at 5.5GHz WLAN band, is created using a pair of the same compact C-shaped slot with split in the folded arms slots on the ground plane of the CPW feed line. The slots occupy less space compared to other slotted structures. The proposed antenna yields an impedance bandwidth of 2.31-10.61 GHz with VSWR<2 except at the notched bands. The antenna gain varies from 2 dBi to 6 dBi over the band with the dips at the rejection band. The improvement of impedance matching and increased gain and radiation efficiency of the antenna with the introduction of fractals are desirable features as it improves the performance of the UWB antenna and also results in its miniaturization.

5.3 Future Work

Future work with regard to UWB antenna design includes developing lower profile antennas specifically for medical imaging having a wider operating bandwidth. Vivaldi antenna designs having frequency notching for the 802.11a interferer band occurring at 5.15-5.35 GHz and 5.725-5.825 GHz can also be considered with regard to antenna design. Other compact design of UWB antenna would be also explored using several novel compact geometry of antenna. As far as future goals and additions for this project, several novel fractal designs well suited for UWB applications having compact size can be added in the existing design. The design undertaken in this work can be extended to explore other fractal geometries like Koch curves and Hilbert Curves for achieving dual band rejection as possible antennas for UWB application.