DESIGN MIMO ANTENNA FOR UWB APPLICATIONS

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Under the Guidance of

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This is to certify that project report entitled "**DESIGN MIMO ANTENNA FOR UWB APPLICATIONS**" submitted by **ALADDIN BABIKER** (Roll No. 2K17/MOC/11) in partial fulfillment of the requirement for the award of degree MASTER OF TECHNOLOGY in Microwave and Optical Communication at DELHI TECHNOLOGICAL UNIVERSITY is a record of the original work carried out by him under my supervision.

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DECLARATION

I hereby declare that the thesis work entitled "**DESIGN MIMO ANTENNA FOR UWB APPLICATIONS**" which is being submitted to Delhi Technological University, in partial fulfillment of requirements for the award of degree of Master of Technology (Microwave and Optical Communication) is a bonafide report of Major Project-II carried out by me. The material contained in the report has not been submitted to any university or institution for the award of any degree.

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ABSTRACT

Ultra Wide Band (UWB) technology is rapidly developing area in the field of Wireless Communication. There are many challenges in this field, one of the challenge is to design an antenna which covers the entire UWB frequency range, the another challenge is to design an UWB Multiple input-Multiple output (MIMO) antenna which will increase the channel capacity and will allow several users to access the various services at the same time. The objective of this thesis is to design UWB antenna that operates in the frequency range from 3.1 to 10.6 GHz. Another objective is to design UWB MIMO antenna. The thesis starts with designing and implementing UWB antennas with discussions covering their operation, electrical behavior and performance. UWB antenna was designed and analyzed using microstrip feeding technique to achieve low profile. In Communication systems, Multiple Input–Multiple Output (MIMO) technology, which involves the use of multiple antennas at both the transmitter and receiver, is used to significantly enhance the data transmission performance and channel capacity. Antenna for this system was designed, to ensure that isolation between elements should be less than - 15 dB. The UWB MIMO antenna consists of four elements and designed with substrate FR-4 having the size 43mm x 43mm x 0.8mm. Results the designed antenna has an impedance bandwidth from 2.6GHz to 10.8GHz as well as isolation i.e. $S21 \leq -18$ dB. Radiation efficiency up to 0.95. Envelope correlation coefficient ($ECC \leq 0.007$) , TARC (≤ -34dB) and diversity gain (≥ 9.96 dB).

Keywords – Ultra wideband: UWB. Multiple input-Multiple output: MIMO. Total Active Reflection Coefficient: TARC. Envelope correlation coefficient: ECC. Diversity Gain: DG.

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Abbreviations	**Description**
ABW	Absolute Bandwidth
AR	Axial Ratio
BW	Bandwidth
CPW	Coplanar waveguide
DGS	Defected ground structure
EIRP	Effective isotropic radiated power
FBW	Fractional Bandwidth
FCC	Federal Communication Commission
FDTD	Finite difference time domain
FE	Finite element
FIT	Finite integration technique
HFSS	High Frequency Structure Simulator
IEEE	Institute of Electrical and Electronics Engineer
LNA	Low Noise Amplifier
MIMO	Multiple Input Multiple Output
NB	Narrow band
PCB	Printed Circuit Board
PSD	Power spectral density

RL	Return loss
SM	Spatial multiplexing
SNR	Signal to noise ratio
UWB	Ultra-Wideband
VSWR	Voltage standing wave ratio
Wi-Fi	Wireless-Fidelity
WIMAX	Worldwide interoperability for Microwave Access
WLAN	Wireless Local area network

CHAPTER ONE

INTRODUCTION

1.1 History and Background

Ultra-wideband communications is basically different from all different communication strategies because it employs extremely narrow RF pulses to speak between transmitters and receivers. Utilizing short-duration pulses as the building blocks for communications without delay generates a very extensive bandwidth and offers many advantages, such as large throughput, covertness, robustness to jamming, and coexistence with contemporary radio offerings.

Ultra-wideband communications is no longer a new technology; in fact, it used to be first employed by Guglielmo Marconi in 1901 to transmit Morse code sequences across the Atlantic Ocean using spark gap radio transmitters. However, the advantage of a large bandwidth and the functionality of performing multiuser systems supplied by electromagnetic pulses were in no way regarded at that time.

Approximately fifty years after Marconi, modern-day pulse-based transmission won momentum in army applications in the form of impulse radars. Some of the pioneers of new UWB communications in the United States from the late 1960s are Henning Harmuth of Catholic University of America and Gerald Ross and K. W. Robins of Sperry Rand Corporation . From the 1960s to the 1990s, this science was confined to army and Department of Defense (DoD) functions below classified applications such as exceedingly tightly closed communications. However, the recent development in micro processing and quick switching in semiconductor science has made UWB prepared for industrial applications. Therefore, it is extra suitable to consider UWB as a new name for a long-existing technology.

As concern in the commercialization of UWB has improved over the previous a number of years, builders of UWB structures started out pressuring the FCC to approve UWB for commercial use. In February 2002, the FCC authorized the First Report and Order (R&O) for industrial use of UWB science below strict strength emission limits for a number of devices.

Figure 1-1 summarizes the development timeline of UWB.

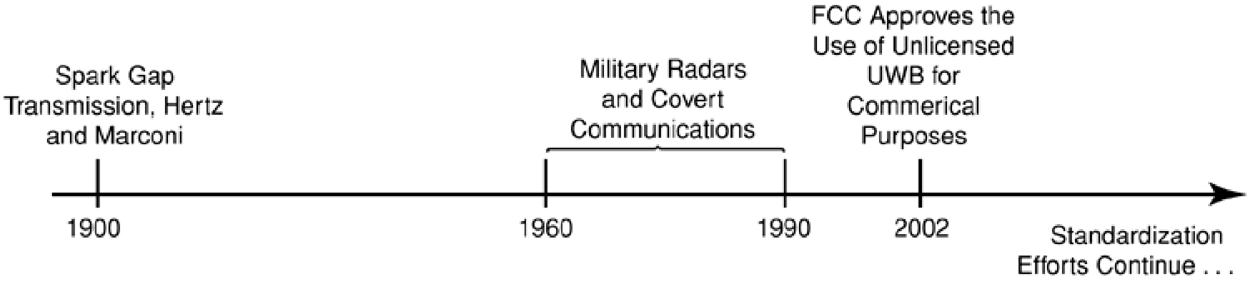


Figure 1.1 A brief history of UWB developments

1.2 Motivation and challenges of Ultra Wide Band (UWB) antenna design

The potential of Ultra Wide Band (UWB) technology is massive due to its remarkable benefits such as the capability of providing excessive speed data quotes at short transmission distances with low power dissipation. The swift boom in wireless communication structures has made UWB wonderful science to exchange the conventional wireless technologies in today’s use like Bluetooth and W LANs, etc. A lot of survey has been carried out to improve UWB LNAs, mixers and complete frontends but no longer that a lot to develop UWB antennas. Recently, educational and industrial communities have realized the tradeoffs between antenna format and transceiver complexity. In general, the transceiver complexity has been increased, with the introduction of superior wireless transmission techniques. In order to boost the performance of transceiver without sacrificing its expensive architecture, superior antenna design must be used as the antenna is a fundamental part of the transceiver. Also, the complexity of the general transceiver is reduced. The UWB technology offers the real wireless freedom with existing long range radio applied sciences such as Wi-Fi, worldwide interoperability for microwave access (Wi MAX), wireless local area network (WLAN), and cellular wide area communications by changing short wired links. UWB offers the desirable cost-effective, power-efficient, excessive bandwidth solution for transmitting multiple digital video and audio streams information amongst the short range devices.

There are many challenges to overcome, in implementation of UWB technology. The main mission is to design an antenna with an operating bandwidth protecting the entire UWB (3.1-

10.6 GHz) and successful of receiving on related frequencies at the same time [FCC (2002)]. The hardest mission in designing a UWB antenna is to achieve wide impedance bandwidth with high radiation efficiency. The concurrent surge of wireless devices, with excessive degree of miniaturization and high frequency of operation, has enhanced the concern in designing high overall performance antenna types. Therefore, there is a growing demand for small and low fee UWB antennas that are capable to provide satisfactory overall performance in each time and frequency domains. The trend in recent wireless systems, which includes UWB based systems, are to construct small, low-profile integrated circuits so as to be well suited with mobile wireless devices. Also, the size affects the gain and bandwidth. Therefore, the dimension of the antenna is regarded as one of the fundamental problems in UWB device design. Recently, there is a demand to amplify the data rate of existing wireless communication systems. The transmitted power degree of UWB signals is strictly restricted in order for UWB devices to peacefully coexist with other wireless systems. Such strict strength limitation poses great challenges for designing UWB systems. One main difficult is to achieve the desired performance at sufficient transmission range the usage of limited transmitted power. Another difficult is to design UWB waveform that efficiently utilizes the bandwidth and power allowed by using the FCC spectral mask. Moreover, to ensure that the transmitted strength stage satisfies the spectral mask, adequate characterization and optimization of transmission methods (e.g., adaptive power control, responsibility cycle optimization) may additionally be required.

1.3 Ultra wide band Technology

The word “ultra-wideband” (UWB) normally refers to signals or systems that either have a massive relative bandwidth or a giant absolute bandwidth. The UWB systems are broadly used in massive number of functions such as radar, clinical imaging, collision detection systems in cars, etc. These systems have various benefits such as potentially low complexity, low cost, low average transmission power, low power consumption, noise immune system, and resist to serve multipath and jamming, massive throughput, covertness, coexistence with present day radio services, very proper time domain decision allowing for place and monitoring applications, high transmission speed and wide frequency bandwidth. The important advantage of this technology over different applied sciences is robust traits to multipath environments, low degree of interference with different systems, and use of expended spectrum methods at low power levels [J. D. Taylor 1995, Ghavami et al. 2004 and Allen et al. 2007].

The modern-day applications are very excessive data intensive and require giant bandwidth. The maximum possible data rate or channel capacity (bits/second) of a band-limited transmission channel with additive white Gaussian noise is given with the aid of Shannon’s formula:

$$C = Blog_2(1 + SNR) \tag{1.1}$$

Where C is channel capacity and B is channel bandwidth [Ghavami et al. 2004].

Shannon’s formula offers that the channel capacity can be improved by linear extend in bandwidth and exponential amplify in transmission power. The amplifying in transmission power is not acceptable because apart from other significant disadvantages, it will adversely affect battery life of battery powered contemporary mobile/wireless devices. The UWB technology can without difficulty facilitate high data quotes at low energy as it inherently supports giant bandwidth. This has attracted the academia and enterprise to boost science to empower UWB systems to serve new bandwidth hungry applications along with high-quality of service.

1.3.1 FREQUENCY

The frequency bandwidth of an antenna can be expressed in phrases of both the absolute bandwidth (ABW) and the fractional bandwidth (FBW).Assuming that the antenna bandwidth has a lower edge frequency of f_L, a higher part frequency of f_U and a center frequency of f_C. The ABW is defined as the difference between the higher and the lower edge frequencies of operation while the FBW can be defined as the proportion of the ratio between the absolute bandwidth and the center frequency as given in Eq. (1-1)and Eq. (1-2), respectively:

$$ABW = f \tag{1.2}$$

$$FBW = \frac{ABW}{f_c} = \frac{f_u - f_L}{f_c} X100 \tag{1.3}$$

$$\text{where } f_c = \frac{f_u + f_L}{2} \tag{1.4}$$

Another definition for the bandwidth in case of broadband antennas which is the ratio of the higher edge frequency f_U to the lower edge frequency f_L, as given in Eq. (1.3):

$$BW = \frac{fu}{fl} \tag{1.5}$$

By large absolute bandwidth we commonly refer to a system with greater than 500 MHz bandwidth, in accordance with the FCC definition of UWB radiation such a big bandwidth provides particular benefits with respect to signal robustness, data content material and/or implementation simplicity, however lead to fundamental variations from conventional, narrowband systems. Difference between the traditional narrowband system and the ultra-wide band system is the traditional NB radio systems use NB signals which are sinusoidal waveforms with a very narrow frequency spectrum in each transmission and reception. While an Ultra-wideband radio system can transmit and get hold of very short period pulses. These pulses are considered UWB signals due to the fact they have very narrow time period with very giant instant bandwidth starting from 500 MHz up to 7.5 GHz [M.-G. di Benedetto et al(2006); B.Allen et al.(2006)] .

The effective isotropic radiated power (EIRP) is a necessary characteristic of radar and communication transmitter R. J. Mailloux (2005), which can be described as the product of its gain and enter power. Figure 1.3 indicates the FCC spectral mask of the indoor UWB EIRP emission level. It can be seen that the maximum signal power is restricted to −41.3 dBm per MHz all through the entire UWB frequency range from 3.1 to 10.6 GHz. All the UWB systems and devices have to work within these spectral masks for legal operation in order to comply with the FCC requirements and regulations.

The below figure illustrates the spectral masks for indoor UWB systems. According to the spectral mask, the PSD of UWB signal measured in 1 MHz bandwidth should no longer exceed -41.3 dBm, which complies with the Part 15 ordinary emission limits to efficaciously manage radio interference. For specifically sensitive bands, such as the global positioning system (GPS) band (0.96 - 1.61 GHz), the PSD restrict is much lower.

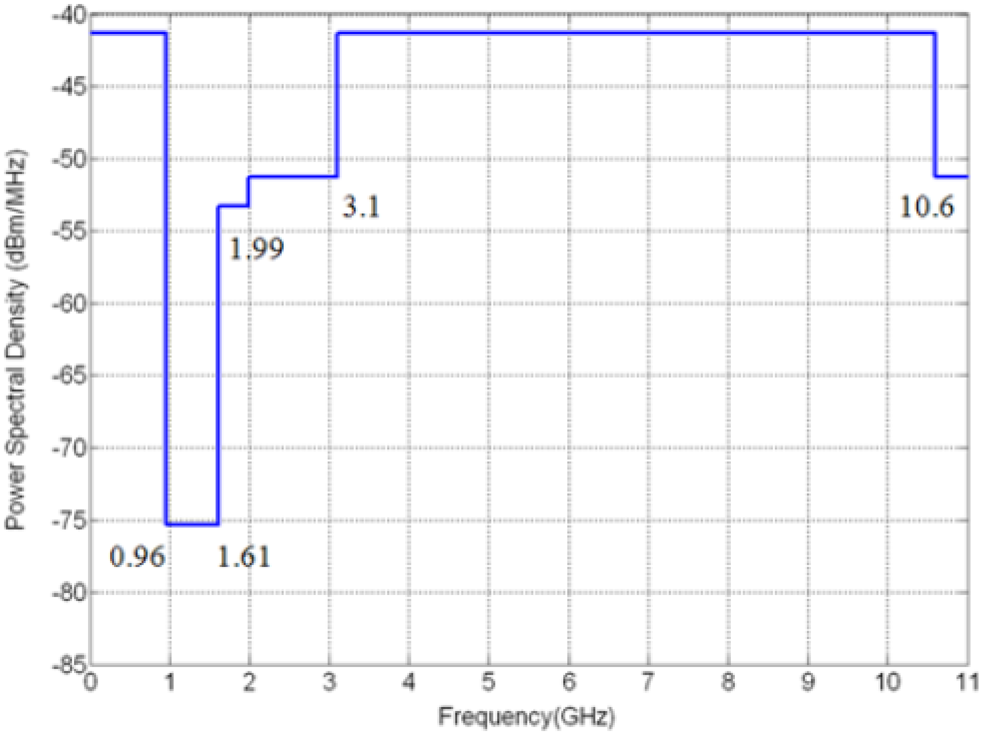


Figure 1.2 FCC spectral masks for indoor UWB systems (reproduced from FCC (2002)

As depicted in Fig.1.2, such ruling lets in the UWB devices to overlay existing narrowband systems, while making sure enough attenuation to limit adjoining channel interference. Although solely the US allows operation of UWB devices currently, regulatory efforts are under way in many countries, especially in Europe and Japan. Market drivers for UWB technology are many even at this early stage, and are predicted to include new purposes in the subsequent few years.

1.4 Merits of UWB

- Share the Frequency Spectrum

The FCC’s power requirement of – 41.3 dBm/MHz (75 nW/MHz) for UWB systems, comes in the class of unintended radiators such as laptop video display units and TVs. Such power restriction lets in UWB systems to live below the noise flooring of a narrow band receiver and permits UWB signals to coexist with modern narrowband and wideband radio services without interference. The main reason of the UWB wireless communication to coexist without causing interference to different services such as GPS, WLAN, WIMAX and mobile network system is low power spectral density .

Ultra-wide band communications spread transmitting power across a extensive spectrum of frequency as illustrated in Fig. 1.3.

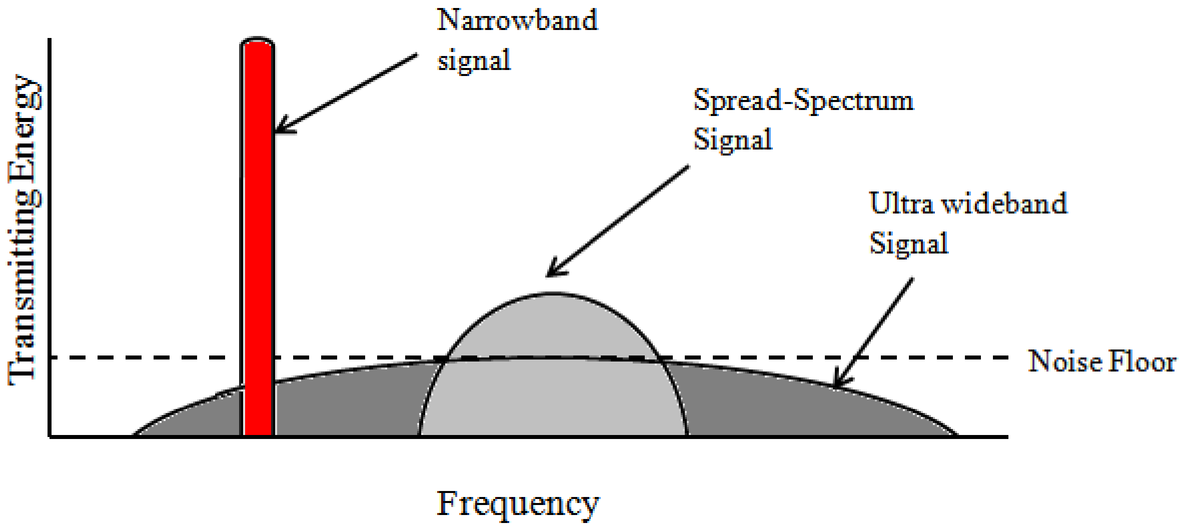


Fig. 1.3 Ultra-wideband communications spread transmitting energy across a wide spectrum of frequency

- Large Channel Capacity

Channel capacity is defined as the most amounts of data that can be transmitted per second over a communication channel. The large channel capacity of UWB communication systems as given via Shannon's system is defined by using equation 3.1. The UWB communication systems can aid real-time excessive definition video streaming due to their massive bandwidth.

- Ability to Work with Low Signal to Noise Ratio

Larger bandwidth supplied by means of UWB communication systems make them successful of offering top overall performance in communication channels with low SNRs. This no longer only offers massive channel capacity but also provides high overall performance in noisy environment.

- Security

UWB communication system has an inherent immunity to detection and interception due to their low transmission power. Such low transmission energy offers high degree of security in opposition to detection and interception for applications like army communication services. Practically, it is especially tough to filter a pulse signal from a background of electronic noise. Thus, it will become almost impossible for exterior user to detect the signal.

- Resistance to Jamming

Narrowband frequency spectrums exist in the UWB spectrum which covers a broad range of frequencies and gives high processing gain for UWB signals. Processing gain is a measure of a radio system’s resistance to jamming – growing reliability in opposed environment.

- High Performance in Multipath Channels

Multipath interference is unavoidable in wireless communication channels. Effect of multipath is greater outstanding in narrowband signals and reasons signal degradation up to – 40 dB. On the different hand, very short period of UWB pulses makes them much less sensitive to multipath outcomes and permits handing over greater signal power even in unfavorable conditions.

- High Data Transfer Rates

The data transmission is done over high transfer rates of 500Mb/s over 5m, 250Mb/s over 10m, 200Kb/s over 50m, 10Kb/s over 100m due to availability of large amount of bandwidth.

- Low Cost

UWB technology did now not require any carrier signal for transmission. Also, there is no requiring for a Radio Frequency (RF) converter or modulator. Hence, transmitters and receivers are simpler and easier to design and apply at low cost.

- Low Power Consumption

UWB technology needs less than 1 mW of power to transmit hundreds of Kbps as a long way as 5 meters due to absence of carrier signal. Thus, UWB devices work successfully at low energy levels.

1.5 Working of UWB

UWB data transmission behavior is, not similar from conventional narrowband RF and spread spectrum (SS) applied sciences like Bluetooth and Wi- Fi, as it does not requires carrier signal to transfer information. A UWB transmitter works by sending billions of pulses of low responsibility cycles throughout 3.1 GHz to 10.6 GHz at a restricted transmit power of -41dBm/MHz, which transmits with power level minimum than one thousand times of a common cell phone. Due to the low emission restriction on power, the different radio systems think about UWB signal as noise, which outcomes in a low probability of interception and detection. The corresponding receiver then converts the received sinusoidal pulses into data.

These pulses are carrying data in coded structure and extraordinarily brief with a capacity of nearly limitless number of users, which improves speed through listening for a acquainted pulse sequence dispatched through the transmitter. UWB share the same wireless transmission medium with a number of users simultaneously transmitting pulses using spread spectrum technology. Therefore, UWB gives a superior wireless connectivity amongst WPAN devices due to its high data throughput doable in short-range at very low power. UWB operates in single-band mode and multi-band mode; single-band mode is similar to spread spectrum technology, whereas, in case of multi-band mode total frequency spectrum is divided into smaller, non-overlapping bandwidths above 500 MHz Multi-band is preferred due to the fact it uses whole UWB spectrum to transmit coded pulses.

One of the largest benefits of UWB technology is increased channel capability compared to different technology, which can be defined the use of Shannon’s capability limit equation (1-4). UWB systems data is transferred via the RF spectrum channel. Shannon’s equation shows, capacity increasing as a function of bandwidth faster than the signal to noise ratio.

1.6 Multiple antenna Techniques

In addition to the wants of high speed data transfers, there is as well an problem of quality control, which consists of low error charge and high capacity. In order to maintain specific Quality of Service (QoS), multipath fading impact has to be dealt with. As the transmitted signal is mirrored on to several objects on its way to the receiver, the signal is faded and distorted. This phenomenon is known as multipath fading. Co-channel interference refers to the interference caused via different signals the usage of the identical frequency.

Hence multiple antennas are to decrease the error rate as well as to enhance the quality and capacity of a wireless transmission. This is done with the aid of directing the radiation only to the intended route and adjusting the radiation in accordance to the traffic condition and signal environment. All multiple antennas are equipped with a number of antennas either in the transmitter or the receiver or each of them. A state-of-the-art signal processor and coding technology are the key factors in multiple antennas. Multiple antenna techniques can be dividing into three classes namely, Spatial Diversity (SD), Spatial Multiplexing (SM) and Adaptive Antenna System (AAS).

1.6.1 Spatial Diversity

Spatial diversity is a part of antenna diversity methods in which multiple antennas are used to enhance the quality and reliability of a wireless link. Usually in densely populated areas, there is no clear Line of Sight (LoS) between the transmitter and the receiver. As a result, multipath fading impact happens on the transmission path. In spatial diversity various receive and transmit antennas are positioned at a distance from one another. Thus if one antenna experiences a fade, any other one will have a LoS or a clear signal. Figure 1.4 illustrates the fundamental precept of Spatial Diversity.

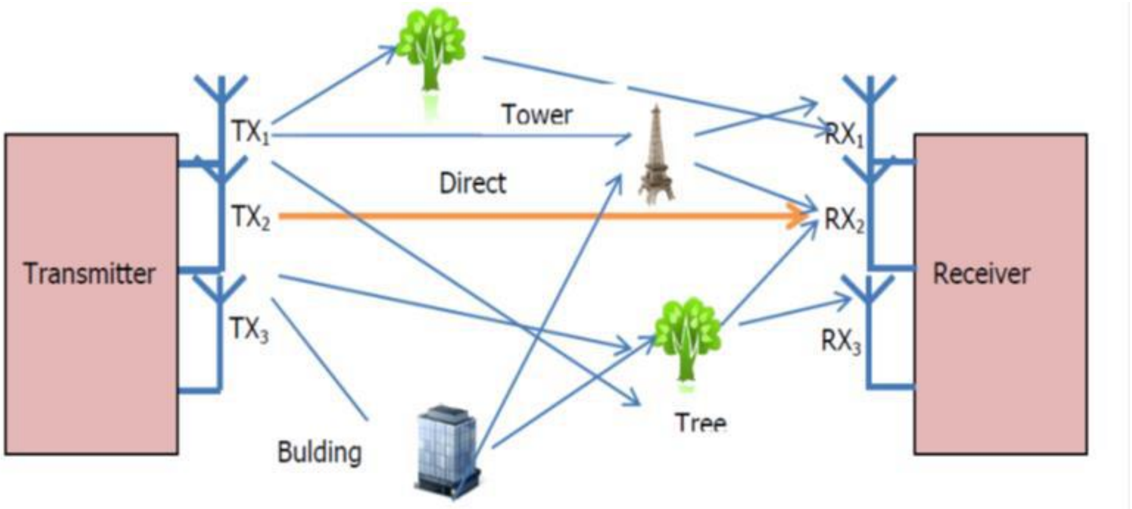


Fig 1.4 Spatial Diversity

In figure 1.4 a number of antennas are positioned at a distance from one another. There are a number of obstacles on the signal’s path. However, it can be observed in the figure that from transmitter TX2 there is a clear LoS to receiver RX2. Despite the multipath fading impact having happened in other receivers, the receiver can get an acceptable, signal.

In the case of base stations in a macro cellular environment, with massive cells with excessive antennas, a distance up to 10 wavelengths is required to make certain a low mutual fading correlation. However, in case of hand held devices, due to the fact of lack of space, 1/2 of wavelength is sufficient for the expected result. The cause in the back of this space is usually in the macro/cell scenario, the fading of which is caused by means of multipath correlations that have happened in the near region of the terminal. Therefore, from the terminal side, different paths arrive in a lot wider angle, as a consequence requiring smaller distances, whereas from the transmitter side, the path angle is rather low. That is why a large distance is required.

1.6.2 Spatial Multiplexing

Multiple antenna systems can make parallel data streams via different antennas. This is to be achieved in order to enhance the data transfer rate. This procedure is known as spatial multiplexing Y.S Shin et al (2007).

The bit stream which is to be transmitted is divided or de multiplexed into various data segments. These segments are then transmitted via different antennas simultaneously. Since a number of antennas are in use, bit rate will increase fast without the requirement of more bandwidth or extra transmission power. The signal captured with the aid of the receiving antenna is a combination of all individual segments. All of them are separated at the receiver the use of an interference cancellation algorithm. A common multiplexing scheme acknowledged as BLAST used to be developed by way of Bell Labs.

1.6.3 Adaptive Antenna System:

In adaptive antenna systems, more than one antenna is used both in the transmitting and receiving side of a communication link to optimize the transmission over the channel. An AAS system will focus its transmit power in the direction of a receiver and it will focus its power in the direction of the transmitter while receiving. The method used in the AAS is recognized as beam forming. Figure 1.5 shows the basic precept of AAS.

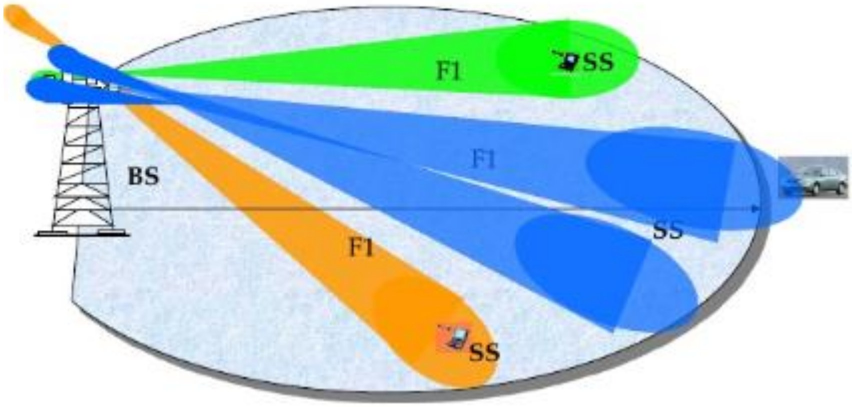


Fig.1.5 Adaptive Antenna System

The beam forming enables directional signal transmission or reception without manually guidance the antennas. In this beam forming technique, various transmitters are set apart from one another. They all transmit the same signal with different angle differences and delay. As a result, the interference that occurred in all the transmitters can be used to steer a signal to a specific direction. In adaptive antenna systems, signals can be targeted simultaneously on many faraway devices. The form of these beams can be managed in such a way that the strength of signal between the transmitter and receiver is usually maximum. The adaptive antenna system can increase the link quality via combining the consequences of multipath propagation as well as by means of exploiting different data streams from several antennas.

1.7 Multiple Input Multiple Output (MIMO)

MULTIPLE-INPUT-MULTIPLE-OUTPUT (MIMO) technology has attracted interest in modern wireless communication systems. A large enhance in channel capacity is done without the required of extra bandwidth or transmits power by using deploying many antennas for transmission to acquire an array gain and diversity gain, thereby enhancing the spectral affectivity and reliability. MIMO antenna systems require excessive decoupling between antenna ports and a compact dimension for application in mobile devices.

Multiple-Input Multiple-Output (MIMO) uses more than one antenna on each the transmitter and receiver. They have dual capability of combining the SIMO and MISO technologies. They can additionally expand capacity by the use of Spatial Multiplexing (SM). The MIMO technique has some clear advantages over Single-input Single-output (SISO) methods. The fading is significantly eliminated with the aid of spatial diversity; low power is required compared to different methods in MIMO.

1.8 MIMO Antenna in Ultra-wideband

Recently, there is a demand to enhance the data rate of present wireless communication systems. The application of diversity techniques, most usually assuming two antennas in a mobile terminal, can increase the data rate and reliability without sacrificing additional spectrum or transmitted power in rich scattering environments. MIMO UWB systems can in addition expand the channel capacity as compared to conventional MIMO systems for narrowband applications. To combat the multipath fading trouble in an indoor UWB wireless communication system, an

UWB diversity antenna system is a promising candidate. However, for a MIMO antenna to be applied in a multifunctional mobile device, the following challenges are to be regarded during the design of these antennas.

1.8.1 Design Challenges in UWB MIMO antenna systems

- Isolation: Mutual coupling between antennas is a main concern when designing MIMO systems. Mutual coupling no longer only affects the antenna efficiency however additionally influences the correlation. Isolation less than -16 dB is required during the working location of the antenna system.
- Bandwidth: Return loss (in dB) should be less than -10 dB from 3.1 to 10.6 GHz so that the impedance bandwidth covers the complete UWB. Simultaneous enhancement of isolation and impedance bandwidth in a single antenna design is one of the hardest challenges that exist in the design of a UWB MIMO antenna system.
- Size: Recently, MIMO has been adapted to portable phones, which use a number of communication technologies such as WCDMA, WIMAX, WLAN, and UWB in order to realize high speed data transmission. Obviously, such a utility requires a compact wide-band MIMO antenna due to the fact of the restricted space available in wireless devices. Hence a compact UWB MIMO antenna system with low mutual coupling amongst the antennas is preferred for UWB applications.

1.8.2 Isolation and Bandwidth Enhancement

Various techniques and isolation constructions can be delivered for simultaneous enhancement of bandwidth and isolation in a UWB MIMO antenna system. Mutual coupling can be decreased by means of introducing reflectors in the ground plane. Stubs are delivered in some designs to decrease mutual coupling. To expand impedance bandwidth, slots can be introduced in the patch. Several research have been carried out on several MIMO antenna systems with two and 4 radiating elements and many techniques have been proposed to enhance isolation between the antenna elements. Various structures like mushroom–shaped EBG constructions have been proposed to decrease mutual coupling by using suppressing the ground current flowing between the radiating elements. Low mutual coupling can additionally be obtained via neutralization techniques and decoupling networks. Recently, Defected Ground Structures (DGS) are used to improve antenna overall performance characteristics like dimension reduction, gain and bandwidth enhancement, and they are additionally used in reduction of mutual coupling between antenna elements.

1.9 Objectives

The overall objective of this thesis is to design a suitable small size and low cost antennas that can operate effectively in the entire UWB range. Following are the progressive work objectives.

- To Design and test UWB antenna with good performance for UWB communications applications.
- To Design and analyze UWB MIMO antenna with high isolation capabilities.

1.10 Organization of thesis

This thesis focuses in designing antenna which works in the ultra-wide band frequency range for different communication applications.

The thesis starts with designing and implementing ultra-wide band antenna with discussions covering its operations and performance analysis.

Secondly antenna with Ultra wide Band MIMO technologies has been designed which reduces the challenges of signal fading, multi-path, increasing interference and limited spectrum. MIMO technology exploits multi-path to provide higher data throughput, and simultaneous increase in range and reliability all without consuming extra radio frequency.

It consists of five chapters,

Chapter 1 Gives the brief introduction of the UWB technologies and UWB MIMO technologies its challenges and the objectives of the work done.

Chapter 2 Provides the review of the work done in UWB antennas and the design challenges in UWB MIMO antenna systems are studied.

Chapter 3 Presents the materials methodologies used in the thesis to design and analyze structures of the UWB antennas and the UWB MIMO antenna.

Chapter 4 In this chapter the electrical behavior and performances of antenna designed is analyzed and discussed.

Chapter 5 Offers conclusion and guidelines for future work.

CHAPTER TWO

LITERATURE REVIEW

The standard goal of this thesis is to design a suitable small dimension and low cost MIMO antenna that can work successfully in the UWB range.

Liang (2006) reported when Federal Communications Commission (FCC) released a bandwidth of 7.5GHz (from 3.1GHz to 10.6GHz) for ultra-wideband (UWB) wireless communications, UWB is advancing very fast as a wireless communication technology for high data rate. As is the case in traditional wireless communication systems, an antenna also plays a very important role in UWB systems. However, there are many challenges in the designing a UWB antenna more than designing the narrow band antenna. An appropriate UWB antenna should be able of operating over an ultra-wide bandwidth as assign by the FCC. At the same time, satisfactory radiation characteristics over the all frequency range are also necessary. Another essential requirement of the UWB antenna is a time domain performance, i.e. a good impulse response with minimal distortion. Author’s work focuses on UWB antenna design and analysis. Studies have been undertaken covering the area of UWB fundamentals and antenna theory. Also Extensive investigations were carried out on two different types of UWB antennas. The first type of antenna studied in the work is circular disc monopole antenna. The vertical disc mono pole produces from conventional straight wire mono pole by replacing the wire element with a disc plate to improve the operating bandwidth. Based on the conception of vertical disc mono pole, two more compact versions featuring low-profile and compatibility to printed circuit board are proposed and studied. Both of them are printed circular disc mono poles, one fed by a micro-strip line, while the other fed by a co-planar waveguide (CPW). The second kind of UWB antenna is elliptical/circular slot antenna, which it can be fed by either micro-strip line or CPW also. The performances and characteristics of UWB disc monopole and elliptical/circular slot antenna are investigated in both frequency domain and time domain. The design parameters for realizing optimal working of the antennas are also analyzed extensively for understanding the antenna operations. It has been demonstrated numerically and experimentally that two kinds of antennas are appropriate for UWB wireless communications.

Chao *et al*. (2015) presented a very (UWB) multiple- input multiple-output (MIMO) antenna with high isolation. The proposed antenna, consisting of two UWB slot antennas, has a very compact dimension 22mm x 26mm, which is less than many of UWB antennas only with single antenna element. A T-shaped slot is etched on the ground to enhance the impedance matching characteristic in the low-frequency and decrease the mutual coupling for the frequencies => 4 GHz. By etching a line slot to remove original coupling, isolation enhancement at the 3–4 GHz band is achieved. The antenna possesses a low mutual coupling of less than -18 dB over the operating band from 3.1–10.6 GHz. The performance of this antenna both by simulation and by experiment indicates that the proposed antenna is a good candidate for UWB applications.

J. Chandrasekhar Rao *et al*. (2016) presented a novel Co planar Wave guide (CPW) fed Multiple Input Multiple Output (MIMO) ultra-wideband (UWB) antenna with a dimension of 26mm x 40mm x 0.8mm for mobile devices applications. Two monopole elements with CPW fed are the elements of MIMO antenna and are positioned perpendicular to each different to achieve sample diversity. To improve the isolation between elements and to increase impedance bandwidth, a long protruding ground stub is etched on the ground plane. The author found that the proposed antenna can cover the frequency band from 2.3-12.5 GHz with isolation bigger than -20 dB over the whole frequency band. A height realized achieve of 4.5 dBi and efficiency of bigger than 90% is done through the proposed antenna model.

Gunjan et al (2017) presented a very compact reconfigurable ultra-wideband (UWB) stepped-slot antenna for cognitive radio (CR) applications. The proposed antenna operates in two modes: UWB mode for sensing utility and communicating mode for various narrow/wideband communication applications. The UWB mode of antenna is got by creation of three resonances that lie in UWB spectrum. The narrow/wide communicating bands are got by exceptional switching states of 5 p-i-n diodes. The impedance bandwidth of the proposed antenna in UWB mode is 2.8−10.7 GHz. The communication bands (3.2−4.5, 4.3−7.8, and 7.9−11.2 GHz) cover the complete UWB spectrum. The proposed antenna has the compact size of 21 × 9 mm2. A prototype of the designed antenna is fabricated and measured. The measured results are in top agreement with the simulated results that validate the proposed approach of reconfigurable UWB antenna format for CR applications.

CHAPTER THREE

MATERIALS AND METHDOLOGY

Our goal in this thesis the design of inexpensive ultra-wideband antenna and the designing of UWB MIMO antenna. This chapter focuses on the historical past and design methodology which was used in designing this antenna and also the layout of MIMO UWB system. Starting from the preliminary diagram for single element of UWB antenna we developed exceptional novel antenna structures for UWB MIMO applications.

This chapter is organized as follows: Section 3.1 software simulation used in designing UWB antenna and UWB MIMO. The antenna designed in this thesis is based on Finite Element (FE) method as used in Ansoft High Frequency Structure Simulator (HFSS). Section 3.2 explained the fundamental antenna parameters are .The operation principles and design methodologies of UWB slot antenna and the UWB MIMO antenna are addressed in Section 3.4.

3.1 Software

Ansoft HFSS uses the FE numerical technique in order to generate an EM field solution for different 3D problems. First, the finite element technique is based on dividing the whole big problem space into small regions or sub-regions called elements. Then the first simulation software program is Ansoft High Frequency Structure Simulator (HFSS). Ansoft HFSS advanced solver and high-performance computer technology have made it an essential powerful EM field simulation tool for engineers, researchers and scientists in academia doing accurate and rapid design of high-frequency and high speed electronic components. It is based on a three-dimensional (3D) full-wave finite element (FE) method which is a frequency-domain numerical technique for solving Maxwell's equations. Ansoft HFSS uses the FE numerical technique in order to generate an EM field solution for different 3D problems. First, the finite element technique is based on dividing the whole big problem space into small regions or sub-regions called elements. Then the fields in each finite element are formulated by local functions. Ansoft HFSS automatically converts the whole problem structure into a finite element mesh which consists of a large number of very small 3D tetrahedral shapes as shown in Figure 3.1. Each single tetrahedron is a four-sided pyramid as presented in Figure 3.2. It can be seen that the meshing or discretization operation done by Ansoft HFSS is very coarse in almost the whole structure while it is very fine at some regions which need more accuracy such as near wave port, metallic edges or discontinuities. After finalizing the mesh operation of the whole structure, the solution process starts with two dimensional (2D) port solutions as the structure excitation then followed by the field solution of the full 3D problem including fields at all vertices, midpoints and interior points as in Figure 3.2. The program exploits the computed 2D fields on ports to be used as boundary conditions to solve the 3D fields of the whole structure; the fields in each finite element are formulated by local functions.

Also we use MATLAB software to calculate some UWB MIMO antenna parameters .

3.2 Material

FR4 substrates are used in the designing of all antennas in the thesis FR4 epoxy glass substrates are the material of choice for most PCB applications. The material is very low cost and has excellent mechanical properties, making it ideal for a wide range of electronic component applications. As more and more microwave systems aimed at consumer markets are developed, there is a considerable interest in minimizing the cost of these systems. Substantial cost savings could be realized by using FR4 in place of costly PTFE based substrates for microwave circuits and antennas. The use of FR4 is unlikely to be viable for antenna feeding structures due to its high losses. However, for high density microwave circuits where path lengths are short and for broadband antenna elements, where losses and absolute dielectric constant values are less critical, the material could be used in place of more conventional microwave substrate materials, offering significant cost savings.

3.3 Fundamental Antenna Parameters

To describe the performance of an antenna, definitions of various parameters are necessary. In practice, there are several commonly used antenna parameters, including bandwidth, radiation pattern, directivity, gain, input impedance, and so on.

Bandwidth

Bandwidth (BW) is the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard. The bandwidth can be considered to be the range of frequencies, on either side of the center frequency, where the antenna characteristics are within an acceptable value of those at the center frequency. Generally, in wireless communications, the antenna is required to provide a return loss less than -10dB over its frequency bandwidth.

The frequency bandwidth of an antenna can be expressed as either absolute bandwidth (ABW) or fractional bandwidth (FBW). If f_H and f_L denote the upper edge and the lower edge of the antenna bandwidth respectively. The ABW is defined as the difference of the two edges and the FBW is designated as the percentage of the frequency difference over the center frequency, as given in Equation (3.1) and (3.2) respectively.

$$ABW = f_H - f_L \tag{3.1}$$

$$FBW = 2(f_H - f_L) / (f_H + f_L) \tag{3.2}$$

For broadband antennas, the bandwidth can also be expressed as the ratio of the upper to the lower frequencies, where the 0antenna performance is acceptable, as shown in Equation (3-3).

$$BW = f_H / f_L \tag{3.3}$$

Radiation Pattern

The radiation pattern (or antenna pattern) is the representation of the radiation properties of the antenna as a function of space coordinates. In most cases, it is determined in the far-field region where the spatial (angular) distribution of the radiated power does not depend on the distance. Usually, the pattern describes the normalized field (power) values with respect to the maximum values. The radiation property of most concern is the two or three-dimensional (2D or 3D) spatial distribution of radiated energy as a function of the observer's position along a path or surface of constant radius. In practice, the three-dimensional pattern is sometimes required and can be constructed in a series of two-dimensional patterns. For most practical applications, a few plots of the pattern as a function of for some particular values of frequency, plus a few plots as a function of frequency for some particular values of will provide most of the useful information needed, where and are the two axes in a spherical coordinate system.

For a linearly polarized antenna, its performance is often described in terms of its principle E plane and H-plane patterns. The E-plane is defined as the plane containing the electric-field vector and the direction of maximum radiation whilst the H-plane is defined as the plane containing the magnetic-field vector and the direction of maximum radiation.

There are three common radiation patterns that are used to describe an antenna's radiation property:

- Isotropic: A hypothetical lossless antenna having equal radiation in all directions. It is only applicable for an ideal antenna and is often taken as a reference for expressing the directive properties of actual antennas.
- Directional: An antenna having the property of radiating or receiving electromagnetic waves more effectively in some directions than in others. This is usually applicable to an antenna where its maximum directivity is significantly greater than that of a half- wave dipole.
- Omni-Directional: An antenna having an essentially non-directional pattern in a given plane and a directional pattern in any orthogonal plane.

Directivity

To describe the directional properties of antenna radiation pattern, directivity D is introduced and it is defined as the ratio of the radiation intensity U in a given direction from the antenna over that of an isotropic source. For an isotropic source, the radiation intensity U_0 is equal to the total radiated power P_{rad} divided by 4π. So the directivity can be calculated by:

$$D = \frac{U}{U_0} = \frac{4\pi U}{P_{rad}} \qquad (3\text{-}4)$$

If not specified, antenna directivity implies its maximum value, i.e. D_0

$$D_0 = \frac{U_{max}}{U_0} = 4\pi\frac{U_{max}}{P_{rad}} \qquad (3\text{-}5)$$

Gain

The antenna absolute gain according to is defines as “the ratio of the intensity in a given direction to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically.” Antenna gain G is closely related to the directivity, but it takes into account the radiation efficiency e_{rad} of the antenna as well as its directional properties, as given by:

$$G = e_{rad}.D \tag{3.6}$$

VSWR

VSWR stands for Voltage Standing Wave Ratio, and is also referred to as Standing Wave Ratio (SWR). VSWR is a function of the reflection coefficient, which describes the power reflected from the antenna. If the reflection coefficient is given by Γ, then VSWR is defined as:

$$\mathrm{VSWR} = \frac{1+|\Gamma|}{1-|\Gamma|} \tag{3.7}$$

The VSWR is always a real and positive number for antennas. The smaller the VSWR is, the better the antenna is matched to the transmission line and the more power is delivered to the antenna. The minimum VSWR is 1.0. In this case, no power is reflected from the antenna, which is ideal. Often antennas must satisfy a bandwidth requirement that is given in terms of VSWR.

For instance, an antenna might claim to operate from 100-200 MHz with VSWR<3. This implies that the VSWR is less than 3.0 over the specified frequency range. This VSWR specification also implies that the reflection coefficient is less than 0.5 over the quoted frequency range.

Impedance Bandwidth

Impedance bandwidth indicates the bandwidth for which the antenna is sufficiently matched to its input transmission line such that 10% or less of the incident signal is lost due to reflections. Impedance bandwidth measurements include the characterization of the VSWR and return loss throughout the band of interest.

Polarization

Antenna polarization indicates the polarization of the radiated wave of the antenna in the far-field region. The polarization of a radiated wave is the property of an electromagnetic wave describing the time varying direction and relative magnitude of the electric-field vector at a fixed location in space, and the sense in which it is traced, as observed along the direction of propagation. Typically, this is measured in the direction of maximum radiation. There are three classifications of antenna polarization: linear, circular and elliptical. Circular and linear polarizations are special cases of elliptical polarization. Typically, antennas will exhibit elliptical polarization to some extent. Polarization is indicated by the electric field vector of an antenna oriented in space as a function of time. Should the vector follow a line, the wave is linearly polarized. If it follows a circle, it is circularly polarized (either with a left hand sense or right hand sense). Any other orientation is said to represent an elliptically polarized wave.

3.3.1. Specific parameters for UWB antennas

In UWB systems, the previous fundamental and classical parameters must be considered in designing antennas but there are more challenges to monitor them and some additional parameters.

Bandwidth

First of all, what distinguishes a UWB antenna from other antennas is its ultra wide frequency bandwidth. According to the FCC's definition, a suitable UWB antenna should be able to yield an absolute bandwidth of not less than 500 MHz or a fractional bandwidth of at least 0.2. Moreover, UWB antenna must be operable and must have stable impedance matching over the entire 3.1-10.6 GHz frequency range in the case of I-UWB following the FCC defined spectral mask. Sometimes, it is also demanded (e.g., in Europe) that the UWB antennas should provide the band-rejected characteristic to coexist with other narrowband devices and services occupying the same operational band [1].

Radiation Pattern

Directional or omni-directional radiation properties are needed depending on the practical application. Omni-directional patterns are normally desirable in mobile and hand-held systems.

For radar systems and other directional systems where high gain is desired, directional radiation characteristics are preferred. High radiation efficiency is usually required for antennas but it is imperative and essential 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.

Size and Cost

A suitable antenna needs to be small and of light weight enough to be compatible to the application. As we are projecting UWB for the applications that include especially mobile and portable devices, therefore it is highly desirable that the antenna should feature low profile and compatibility for integration with printed circuit board (PCB).

Specific parameters to be required to characterize UWB antennas are now described.

Compliance with Spectral Masks

A good design of UWB antenna should be optimal for the performance of overall system. To avoid the possible inband/outband interference between the UWB systems and existing electronic systems, the antenna should be designed such that the overall device (antenna and RF front end) complies with the mandatory power emission mask given by the FCC or other regulatory bodies. The emission limits will be determined by both the selection of source pulse and design of antennas in UWB systems.

Impulse Response

Omagnetics, therefore UWB antenna is required to achieve good time domain characteristics (i.e., good impulse response). The idea is simply to characterize the LTI (Linear Time Invariant) system by its response to an impulsive excitation instead of amplitude and phase and measurements versus frequency (i.e., swept frequency response). For the narrowband case, it is approximated that an antenna has same performance over the entire bandwidth and the basic parameters, such as gain and return loss, have little variation across the operational band. In contrast, I-UWB systems often employ extremely short pulses for data transmission. In other words, enormous bandwidth has been occupied, thus the antenna can't be treated as a “spot filter” any more but a “band-pass filter”. In this case, the antenna imposes more significant impacts on the input signal. As a result, a good time domain performance (i.e., minimum pulse distortion in the received waveform) is a primary concern of a suitable UWB antenna because the signal is the carrier of useful information [2]. Therefore, it is indispensable and important to study the antenna's characteristics in time domain.

Group Delay

It is an important parameter that represents the degree of distortion of UWB signal. Group delay is a measure of the slope of the transmission phase response. The linear portion of the phase response is converted to a constant value and deviation from linear phase is transformed into deviations from constant group delay. The variations in group delay cause signal distortion, just as deviations from linear phase cause distortion. It can be given as

$$group\ delay = -\frac{\Delta\varphi}{\Delta\omega} \tag{3.8}$$

Where φ is the total phase shift in radians, and ω is the angular frequency in radians per unit time, equal to $2\pi f$, where f is the frequency. The group delay variations induced by the radiation pattern of the antenna will affect the overall receiver system performance, since it can bring relatively large timing errors. An antenna gain versus frequency without nulls, means a linear phase response, hence a constant group delay.

3.4 UWB Antenna Design Methodology

Design and analysis of UWB antenna is more challenging compared to narrowband antennas because it possess a wide operating band as specified by FCC and required compactness in antenna with the desired antenna characteristics. Such design and development of UWB antenna possesses several advantages over conventional data transmission in case of indoor communication. Hence, a compact UWB antenna has to be designed very carefully to enhance the system performance. The size of the antenna can be reduced significantly with the use of high dielectric (εr) substrates [Balanis, 2005]. High εr substrates help to reduce size but at the same time it also deteriorates the radiation efficiency of the antenna. Earlier the author Bokhari et al. in 1996 uses the meandering technique in antenna design by cutting slots in the non-radiating part of the design to achieve compactness. This technique helps to increase the effective electrical path length but it reduces the operating bandwidth due to capacitive loading. It is demonstrated that by etching rectangular and L-shaped slot in the ground plane; fractional bandwidth up to 125% is achieved. However, most of these antennas are larger in dimensions, which make them difficult to integrate with portable commercial devices. Thus, these techniques are not very efficient for compact wideband antennas.

The applications of UWB technology for indoor communication are very promising. However, it offers a great challenge among the antenna designer community because of its detrimental interference issues with other existing narrowband systems and services such as worldwide interoperability for microwave access (WiMAX) in 3.3- 3.8 GHz, wireless local area network (WLAN) in 5.15-5.85 GHz and X-band in 7.9-8.4 GHz, which operates in the frequency range of 3.1-10.6 GHz. It is desirable in wireless communications to avoid any interference between different users present in the UWB spectrum. Although, FCC has allowed UWB devices operation in this wide range with a restricted power level compliant with the emission mask, to avoid the concern related to potential interference. The rapid growth in wireless communication forces the regulatory authorities to allow the transmission in higher and wider frequency spectrum in order to achieve high wireless channel capacity. It is achieved by using the diversity/MIMO technology in rich scattering environment without additional power or spectrum. MIMO technology uses multiple antennas at the transmitter and receiver terminal of transmission system. The UWB system is also susceptible to multipath fading problems similar to other wireless communication systems. The use of MIMO technology helps to improve diversity gain and multipath fading. UWB MIMO technology requires high isolation among antenna elements to combat multipath fading. However, the compact UWB MIMO antenna for portable applications in a given smaller area causes the degradation in diversity performance due to presence of various mutual coupling among the antenna elements. In addition, UWB system faces the severe interference challenges with existing narrowband system such as WLAN from 5.15-5.825 GHz, which lies in the UWB spectrum.

3.5 Multiple-Input-Multiple-Output Communication Systems

3.5.1 Brief Description of MIMO Communication Systems

In a traditional radio system, there is single antenna used at transmitter and at receiver. This system is referred to as a single-input-single-output (SISO) System. The capacity of such systems is limited by means of Shannon-Nyquist criterion. In order to expand channel capacity of the SISO systems to meet growing demands for high-speed communications, the bandwidth and transmission energy have to be improved significantly. However it is now not a possible solution as mentioned earlier. Recent tendencies have proven that the usage of MIMO systems should significantly amplify the capacity in wireless communication without growing the transmission strength and bandwidth [3, 4]. Rayleigh fading occurs by way of multipath has been a source of problem for traditional wireless systems. However, to amplify the channel capacity, MIMO systems take advantage of multipath rather of mitigating it. MIMO wireless systems have demonstrated the workable of extended capacity in wealthy multipath environments. Such systems function through exploiting the spatial houses of the multipath channel, thereby providing a new dimension which can be used to decorate performance. A common MIMO system is shown in Fig. 3.1 with multichannel concept. The performance improvements through the use of MIMO systems are due to array gain, diversity gain, spatial multiplexing gain, and interference reduction [5]. A quick description of these is given below:

1. Array Gain: Array gain is the enhancement of signal high-quality at the receiver via signal processing. The SNR at the receiver can be increased by means of combining coherently the signals acquired at every antenna [5].
2. Diversity Gain: Diversity is a powerful method to mitigate fading in wireless links. Diversity techniques depend on transmitting the signal over more than one independently fading paths (in time/frequency/space) [5]. The received signals can be mixed collectively in some most excellent way to yield a signal with higher SNR.
3. Spatial Multiplexing Gain: MIMO channels provide an improve in capacity for no extra energy or bandwidth expenditure. This gain, referred to as spatial multiplexing gain, is realized by transmitting unbiased data signals from the individual antennas. Under favorable channel conditions, such as rich scattering, the receiver can separate the extraordinary streams, yielding an improve in the capacity [5].

MIMO Channel Model

The MIMO channel communication takes advantage of multipath propagation. The MIMO channel can be described by the following matrix:

$$y = Hx + n$$

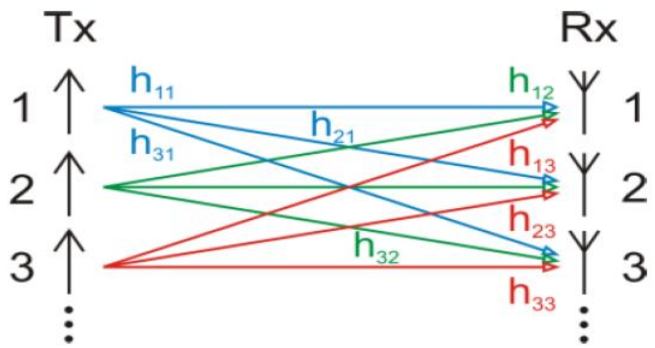


Fig. 3.1 MIMO Channel Model.

In order to understand MIMO better, it is necessary to look into its channel model as shown in Figure. For a system with M_T transmitters and M_R receivers, the MIMO channel at a given time may be represented by $M_T \times M_R$ matrix as demonstrated below,

$$H = \begin{bmatrix} H_{1,1} & H_{1,2} & \cdots & H_{1,M_T} \\ H_{2,1} & H_{2,2} & \cdots & H_{2,M_T} \\ \vdots & \vdots & \ddots & \vdots \\ H_{M_R,1} & H_{M_R,2} & \cdots & H_{M_R,M_T} \end{bmatrix}$$

Where $H_{m,n}$ is the channel gain between the m-th receive and n-th transmit antenna. The n-th column of H is called as the spatial signature of the n-th transmit antenna. The geometry of M_T differentiates the signals launched from the transmitter.

Structures of MIMO

The Multiple Input multiple Output (MIMO) method can be divided into various forms depending on uses. MIMO is basically the combination of all the multiple antenna techniques such as SISO, SIMO and MISO. It can use the beam forming or the spatial Multiplexing methods. MIMO can be categorized into two types, multi-antenna types and multi-user types. Multi-antenna types are listed below:

- SISO (Single-input Single-output) - is a conventional radio system where neither the transmitter nor receiver have multiple antenna.
- SIMO (Single-input Multiple-output) - is a special case when the transmitter has a single antenna.
- MISO (Multiple-input Single-output) - is a special case when the receiver has a single antenna. Spatial multiplexing techniques make the receivers very complex, and therefore they are typically combined with Orthogonal Frequency Division Multiple Access (OFDMA) modulation, where the problems created by a multi-path channel are handled efficiently.

The IEEE 802.16e standard incorporates MIMO-OFDMA. MIMO is also planned to be used in Mobile radio telephone standards such as recent 3GPP and 3GPP2. MIMO technology can be used in non-wireless communications systems .Home networking standard ITU-T G.9963, which defines a power-line communications system uses MIMO techniques to transmit multiple signals over multiple AC wires (phase, neutral and ground).

3.5.2. Specific parameters for MIMO antennas:

Like the case of UWB, there are also some additional parameters other than the fundamental parameters to be taken into account while designing MIMO antennas.

Mutual Coupling and Isolation

In MIMO applications, the signals transmitted by multiple antenna elements are generally supposed to be independent or uncorrelated. But in reality, the current induced on one antenna produces a voltage at the terminals of nearby elements, termed as mutual coupling [6]. It means there is always mutual coupling present between nearby antenna elements. However, for MIMO applications, the mutual coupling should be minimized to as low value as possible. In a contradictory way, it should be noted that it is also studied that mutual coupling can help to reduce the correlation between the different channel coefficients in nearby placed antenna elements scenario, thus escalating the capacity [7]. This is an important issue for the antenna community. In a general way the coupling has an adverse effect and mutual coupling has to minimize [8].

The port-to-port isolation is defined as the transmission of power between two of the input ports of the multiport antenna under test. It is characterized by |S21| parameter. It must be noted that isolation is a positive quantity and is given as

$$Isolation = -10log_{10}|S_{21}|^2 \tag{3.9}$$

In MIMO systems, to maximize the energy radiated by an antenna, it should be ensured that negligible amount of transmitted energy is lost into the ports of other antennas terminated by the matched impedances. In other words, MIMO systems require the | S21| to be minimized to as low value as possible as isolation is directly related to the antenna efficiency. A lot of research has been done on the reduction of mutual coupling and the enhancement of the isolation. It is worth mentioning that the mutual coupling is characterized most of the times by the isolation in the literature. However, in [9], it is stated that isolation is not the exact representation of mutual coupling, as it is possible that there is very good isolation but it is not necessary for mutual coupling to be low in this case. Hence, to evaluate the mutual coupling, it is better to observe the surface current distributions on the non-excited radiating element, when nearby radiating element, is excited. Although the ports may be isolated, there is a possibility of having large induced currents in the neighboring antenna, which, in turn, affects the radiation pattern of the antenna considered.

Mean Effective Gain

The performance of MIMO systems is also characterized by the mean effective gain (MEG) of the antennas. The MEG is a statistical measure of the antenna gain that can be defined as the ratio of the mean received power of the antenna and the total mean incident power. It can be expressed by the following equation as in [10]

$$MEG = \int_0^{2\pi}\int_0^{\pi}\left(\frac{XPR}{1+XPR}G_\theta(\theta,\varphi)P_\theta(\theta,\varphi) + \frac{1}{1+XPR}G_\varphi(\theta,\varphi)P_\varphi(\theta,\varphi)\right)sin\theta d\theta d\varphi \tag{3.10}$$

where P_θ and P_φ are the angular diversity functions of the incident power with respect to θ and φ directions respectively, G_θ and G_φ are the gains with respect to θ and φ directions respectively, and XPR represents the cross-polarization power gain.

The MEG is then equal to the total antenna efficiency divided by two or -3 dB [11] and it is independent of the radiation patterns. In order to achieve good diversity gain, the ratio of the MEG between the two antennas should close to unity in order to ensure that average received power by each antenna is nearly equal [12].

Correlation Coefficient

The correlation coefficient is a parameter of great importance for the systems providing diversity. The signals received in the diversity systems can be correlated to some extent. The correlation coefficient is a mathematical and statistical tool that measures the degree of similarity among the received signals. Its modulus varies from 0 to 1. Ideally, diversity systems require a correlation coefficient of zero or low by default.

Usually, the envelope correlation is presented to evaluate the diversity capabilities of MIMO systems [13]. This parameter is always real and by definition gives the correlation among the amplitudes of the signals at antennas. For Rayleigh fading channel, the envelope correlation can be given as follows:

$$\rho_e = |\rho_c|^2 \tag{3.11}$$

It is clear that correlation should be preferably computed from 3D radiation patterns but it becomes tedious. However, assuming that the diversity system will operate in a uniform multipath environment, the correlation coefficient can be calculated from S-parameters using the following equation in [14]

$$\rho_e = \left| \frac{S_{11}^{*} S_{12} + S_{21}^{*} S_{22}}{\sqrt{1-|S_{11}|^2-|S_{21}|^2} \cdot \sqrt{1-|S_{22}|^2-|S_{12}|^2}} \right|^2 \tag{3.12}$$

It offers a simple procedure compared to the radiation pattern approach, but it should be emphasized that this equation is strictly valid when the following assumptions are fulfilled:

- Antennas should have high efficiency and no mutual losses.

- Antenna system is positioned in a uniform multipath environment which is not strictly the case in real environments; however, the evaluation of some prototypes in different real environments has already shown that there are no major differences in these cases.

- Load termination of the non-measured antenna is 50 Ω. In reality, the radio front-end module does not always achieve this situation, but the 50 Ω evaluation procedure is commonly accepted.

All these limitations are clearly showing that in real systems the envelope correlation calculated based on of the help of the S_{ij} parameters is not the exact value, but nevertheless is a good approximation. In addition, it should be noted that antennas with an envelope correlation coefficient less than 0.5 are recognized to provide significant diversity performance.

Diversity Gain

The diversity gain (DG) is a figure of merit used to quantify the performance level of diversity techniques. The DG is the slope of the error probability curve in terms of the received SNR in a log-log scale. However, the DG can also be defined as the increment of the SNR at a given probability, normally 1% or 10% [15]. Such DG can easily be calculated by looking at the cumulative distribution function (CDF) curves of the SNR, and comparing the combined SNR using some specific diversity technique with the SNR of an un-coded SISO communication system. Mathematically, it can be expressed as

$$DG = \frac{(SNR)_c}{(SNR)_r} \tag{3.13}$$

Where indices “c” and “r” are used for the combined and the reference. In this context, DG can be defined as the difference between a combined CDF as compared to a reference CDF at a certain level of CDF [16]. Depending on the reference CDF, it is possible to write three definitions for the diversity gain:

- Apparent diversity gain - Difference between power levels in dB (at certain CDF level), between CDF of combined signal, and CDF of signal at the port with the strongest average signal levels.

- Effective diversity gain - Difference between power levels in dB (at certain CDF level), between CDF of combined signal, and CDF of signal at the port of an ideal single antenna (corresponding to radiation efficiency of 100%), measured in the same environment.

- Actual diversity gain - Difference between power levels in dB (at certain CDF level), between CDF combined signal, and CDF of signal at the port of an existing practical single antenna that is to be replaced by the diversity antenna under test, measured at the same location (for example, relative to a head phantom).

The DG is also related to the correlation coefficient. The relation between DG and correlation coefficient can be given approximately by

$$DG = 10\sqrt{1-|\rho|^2} \tag{3.14}$$

This relationship clearly shows that the lower the correlation coefficient the higher will be the diversity gain. Therefore, high isolation is required between the antennas otherwise the DG will be low. Further, whatever the combining method is being used, the maximum diversity gain is obtained when the correlation coefficient is zero.

Total Active Reflection Coefficient

The reflection coefficient does not accurately characterize the radiation efficiency and bandwidth of a MIMO antenna. Instead of simple reflection coefficient, the array's total active reflection coefficient (TARC) can be used so that it accounts for both coupling and random signal combination. Thus, TARC provides a more meaningful measure of MIMO efficiency. For a desired port excitation, summation of the available power at all excitation ports is assumed as incident power, radiated power as transferred power, and the difference between these two as reflected power. The square root of the ratio of reflected power and incident power is defined as the TARC [17], mathematically given by

$$\Gamma_a^t = \frac{available\ power - radiated\ power}{available\ power} \tag{3.15}$$

The TARC of MIMO antenna is calculated by applying different combinations of excitation signals to each port. There is no need to define the TARC as a complex number since the phase reference plane does not have any physical meaning for a multiport antenna. The TARC is a real number between zero and one. When the value of the TARC is equal to zero, all the delivered power is radiated and when it is equal to one, all the power is either reflected back or goes to the other ports.

Channel capacity loss (CCL)

Channel capacity loss is very important parameter for MIMO antenna; it measures the capacity loss in channel at certain frequency per unit time. The unit of (CCL) is bit/sec/Hz.

3.6. Summary on UWB MIMO antenna characteristics

In context of UWB where the whole band approved by FCC is required to be covered in one shot, the design of antenna becomes challenging enough. The characteristics of the antennas are required to be stable for the wide frequency band. Moreover, time domain measurements like dispersion and group delay become significant in addition to conventional frequency domain characteristics. Furthermore, the development of future UWB-MIMO communication systems brings more challenges for the antenna design. MIMO antennas are required to be characterized for mutual coupling, correlation and diversity gain. However, a detailed study on characterization of MIMO antennas for UWB is among the current hot topics of research. Also, the design of UWB-MIMO antenna system is always confronted with the same constraints like cost, size, ease of fabrication and integration with other circuits as in the case of single antenna design. Having the specific parameters used essentially for the analysis of UWB and MIMO antennas, the current research orientations with a state of the art are now detailed.

CHAPTER FOUR

RESULTS AND DISCUSSION

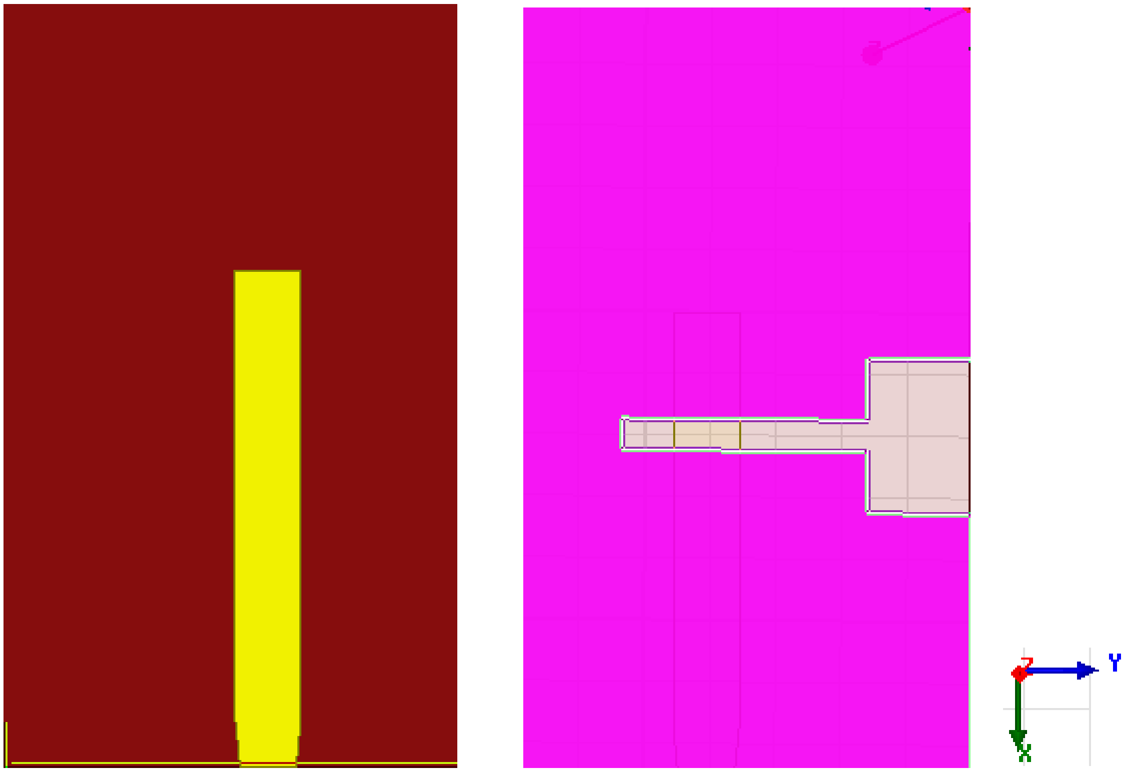
This chapter presents the design verification of the antennas using High Frequency Structure simulator (HFSS). The simulation results of different parameters which includes VSWR (voltage standing wave ration),S11,S21(return loss),radiation pattern ,gain of the UWB and with one additional parameter envelope correlation coefficient of UWB MIMO antennas will be shown and discussed in details.

The results and discussions will be bifurcated into two parts

1. UWB antenna (single element).

2. UWB MIMO antennas.

4.1 UWB antenna



(a) Upper shape **(b) Bottom shape**

Fig.4.1 UWB antenna

Configuration

Fig 4.1 shows the configuration of the ultra-wideband antenna, which consist of simple slot antenna. The slot antenna is fed by a 50 Ω microstrip line and is designed on low cost FR4 substrate of thickness o.8 mm, permittivity of 4.4 and loss tangent of 0.02.

Description

A UWB slot antenna is designed. A tapered shape of feed line is designed to enhance the impedance bandwidth. Two slots make on the bottom shape to resonate the frequency from 3.18 GHz to 10.8 GHz.

Simulated results

After going through all the parametric studies and finalizing the design parameters, the verification of the final design takes place using HFSS software. Figure 4.2 shows the return loss of UWB slot antenna which it covers the frequency bandwidth (3.18 – 10.8) GHz.

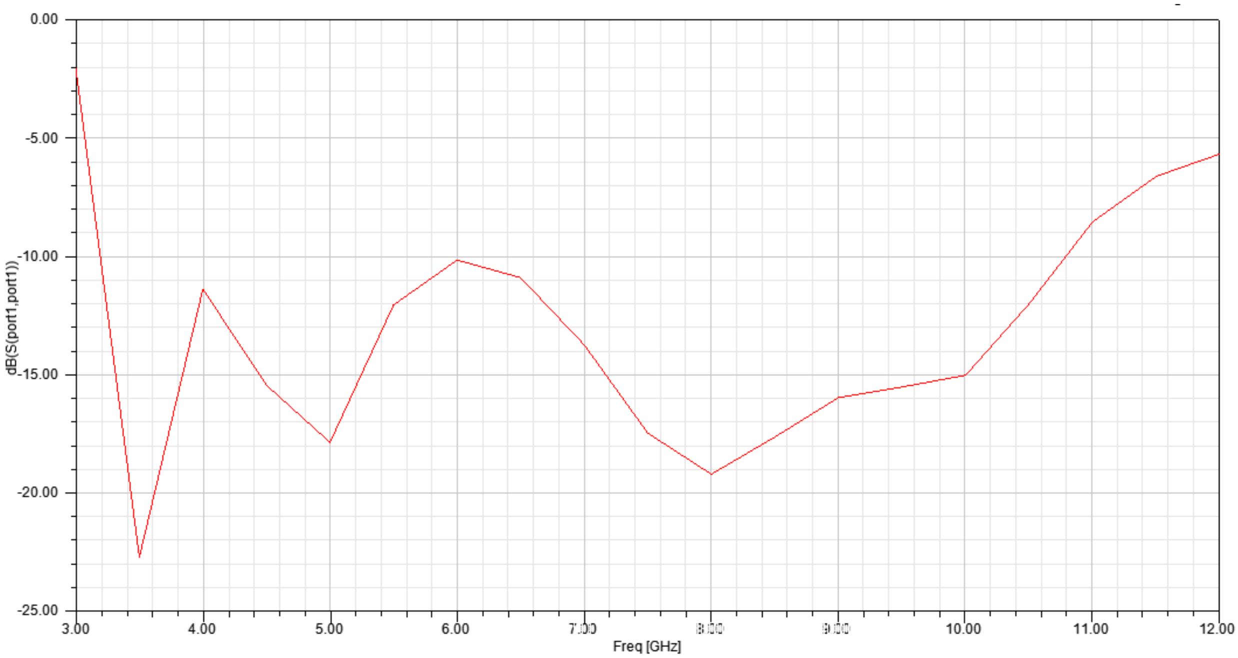


Fig. 4.2 Return Loss

Figure 4.3 shows the (VSWR) for the UWB slot antenna.

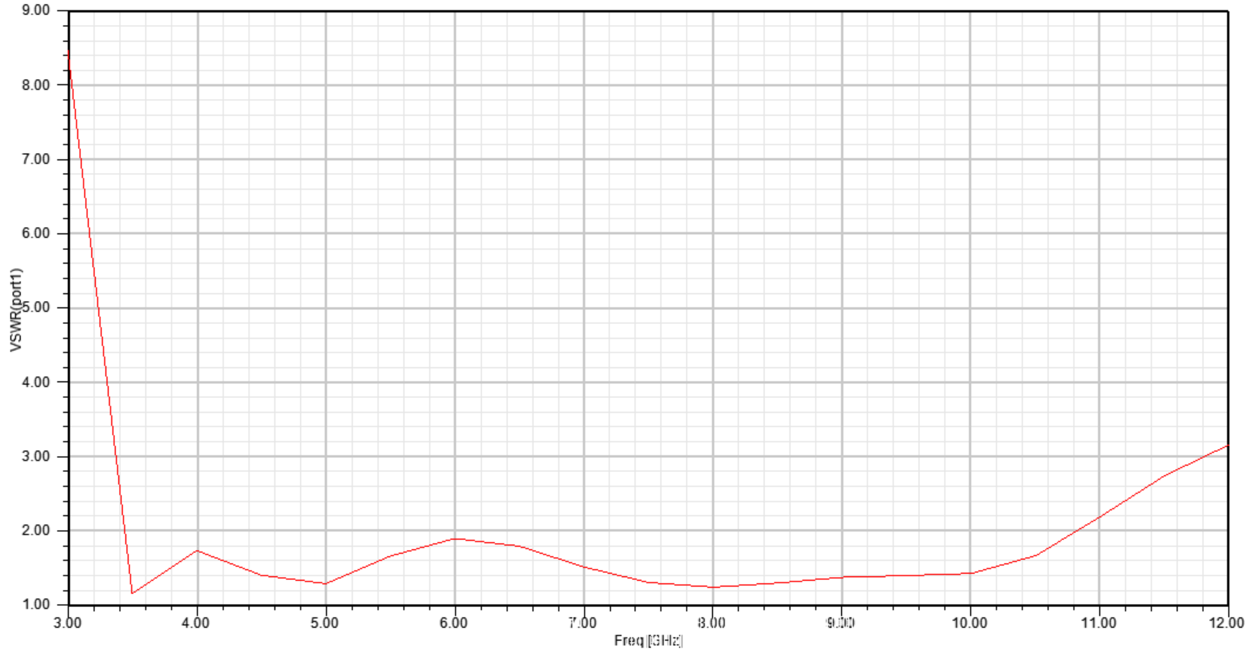


Fig.4.3 VSWR for UWB antenna

Figure 4.4 shows the radiation efficiency for UWB slot antenna varies with the frequency, it is between (81% - 95%).

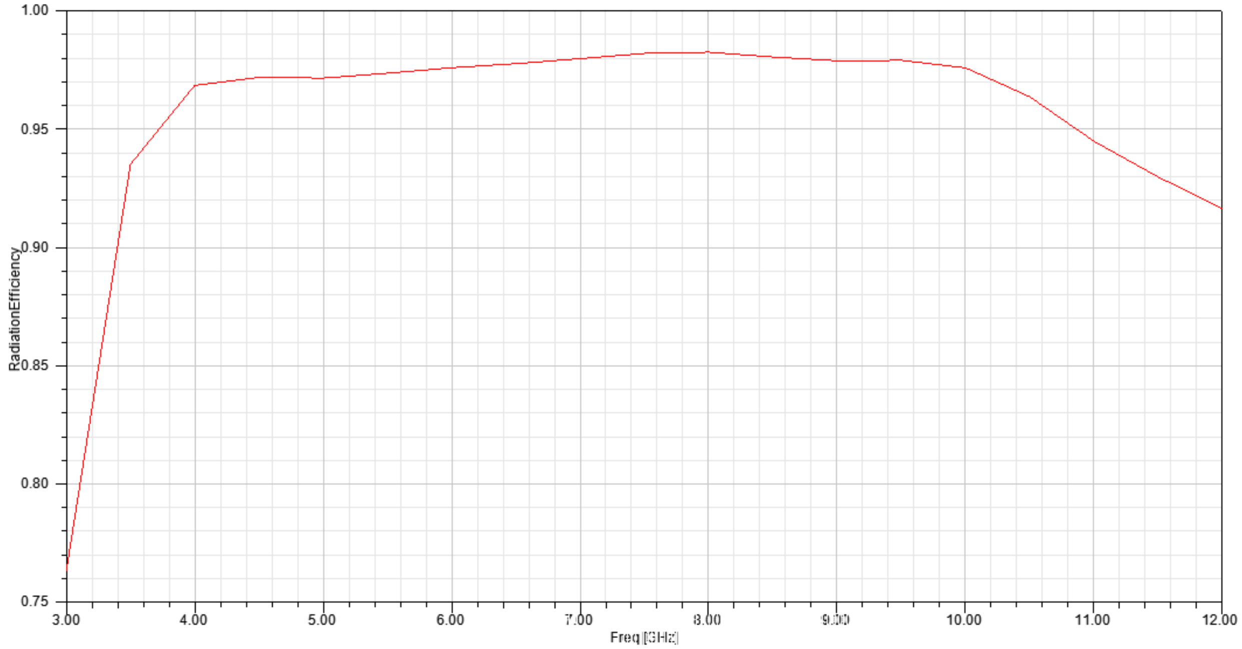


Fig. 4.4 Radiation efficiency for UWB antenna

Figure 4.5 shows the variation Gain with the frequency. The peak gain equal to 5.6 dB at the frequency 10.7 GHz.

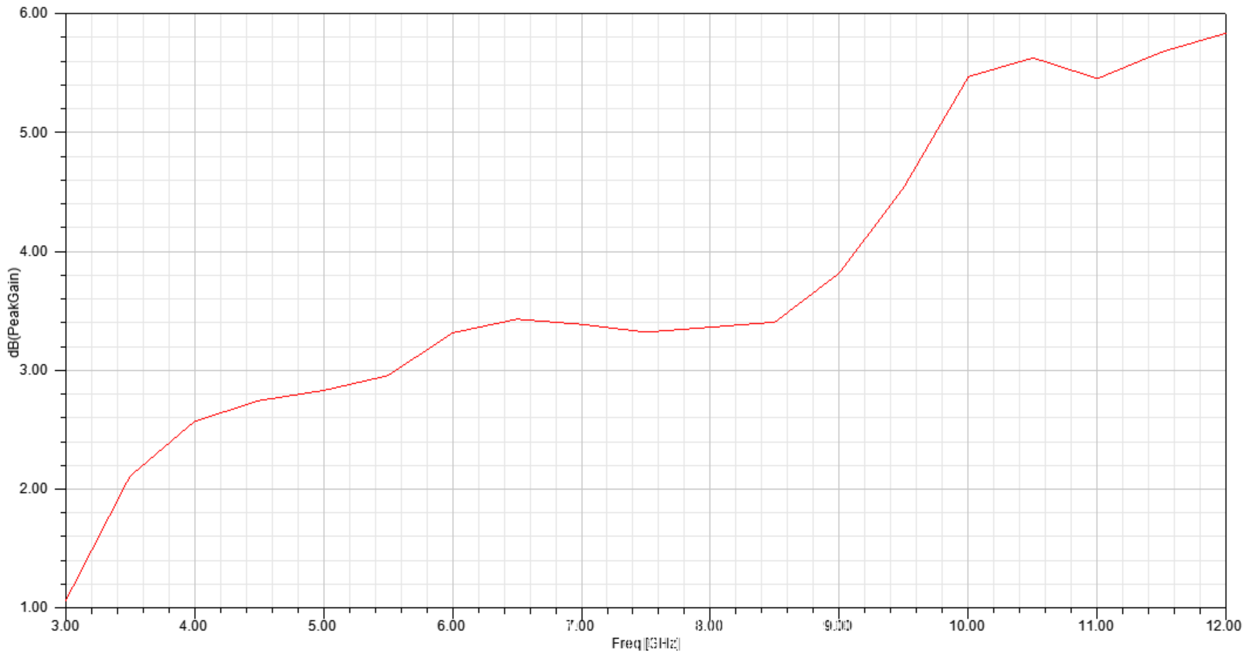


Fig. 4.5 variation Gain with the frequency for UWB antenna

4.2 UWB MIMO ANTENNA

Configuration

The antenna in Fig.4.6 (a) and (b) is designed on inexpensive FR4 substrate of dielectric constant 4.4, loss tangent 0.02 and thickness 0.8 mm. The size of the proposed UWB MIMO antenna is 43 mm × 43 mm.

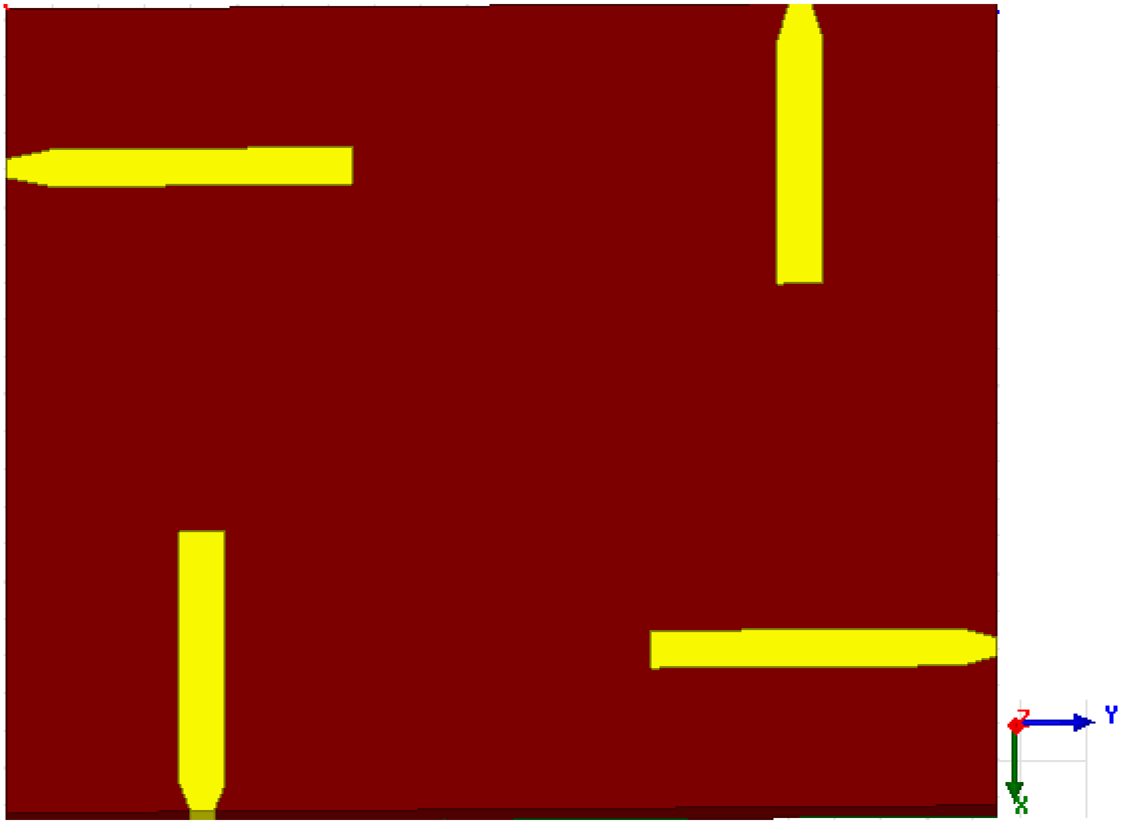


Fig. 4.6 (a) upper shape of UWB MIMO antenna

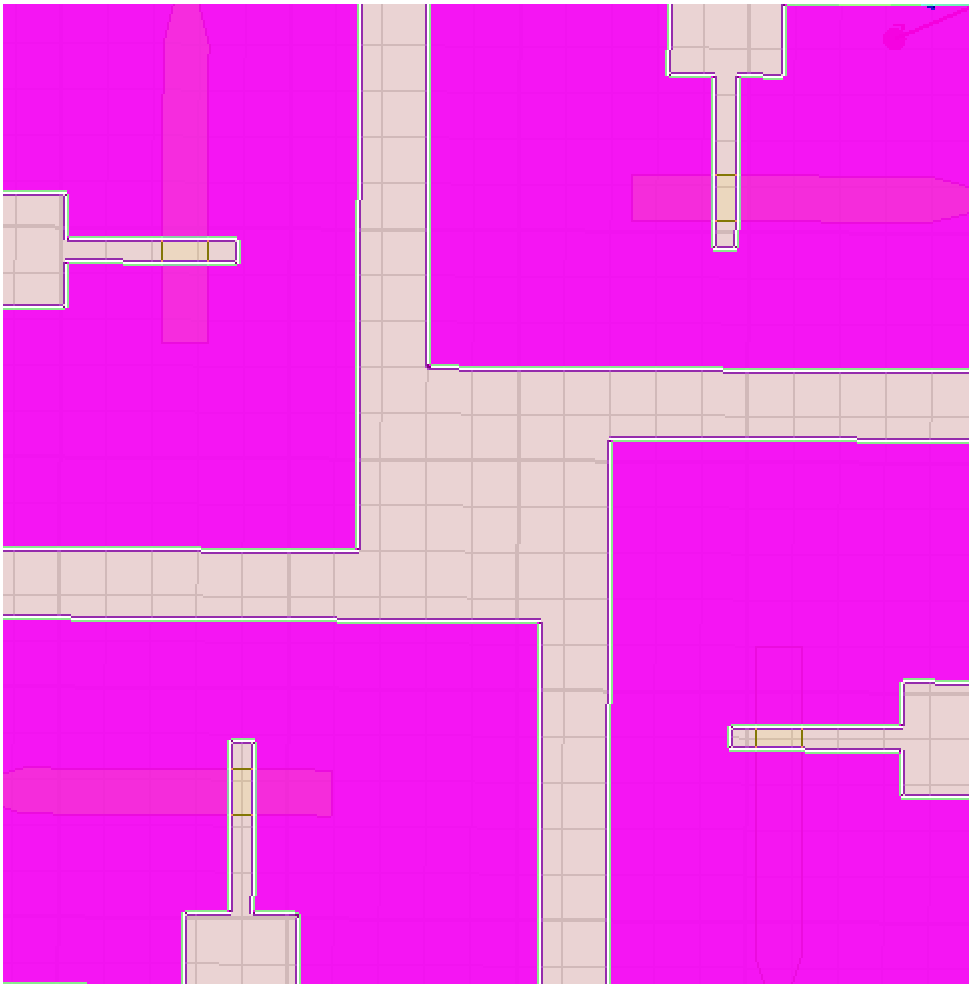


Fig. 4.6 (b) bottom shape of UWB MIMO antenna

This common radiator is fed by four tapered micro strip feed line structures and are designated as Port 1, Port 2, Port 3 and Port 4. The polarization is achieved by four simple orthogonally oriented feeds.

The single common radiator helps to reduce the overall size of the UWB MIMO antenna. The UWB MIMO antenna has two L-shaped slots presented in the ground plane.

Description

The simulated impedance bandwidth of the antenna is 2.6 GHz to 10.8 GHz which covers the overall UWB spectrum. For good diversity performance the isolation must be better than 15 dB in the entire UWB spectrum.

High isolation (≥ 18 dB) between the antenna elements is achieved by creating a rectangular slot of dimensions 27mmX3mm in each side of the ground plane and square slot of dimensions 7mmX7mm in the middle of the ground plan.

Figure 4.7 shows the simulated S-parameters of UWB MIMO antenna which is consists of four ports.

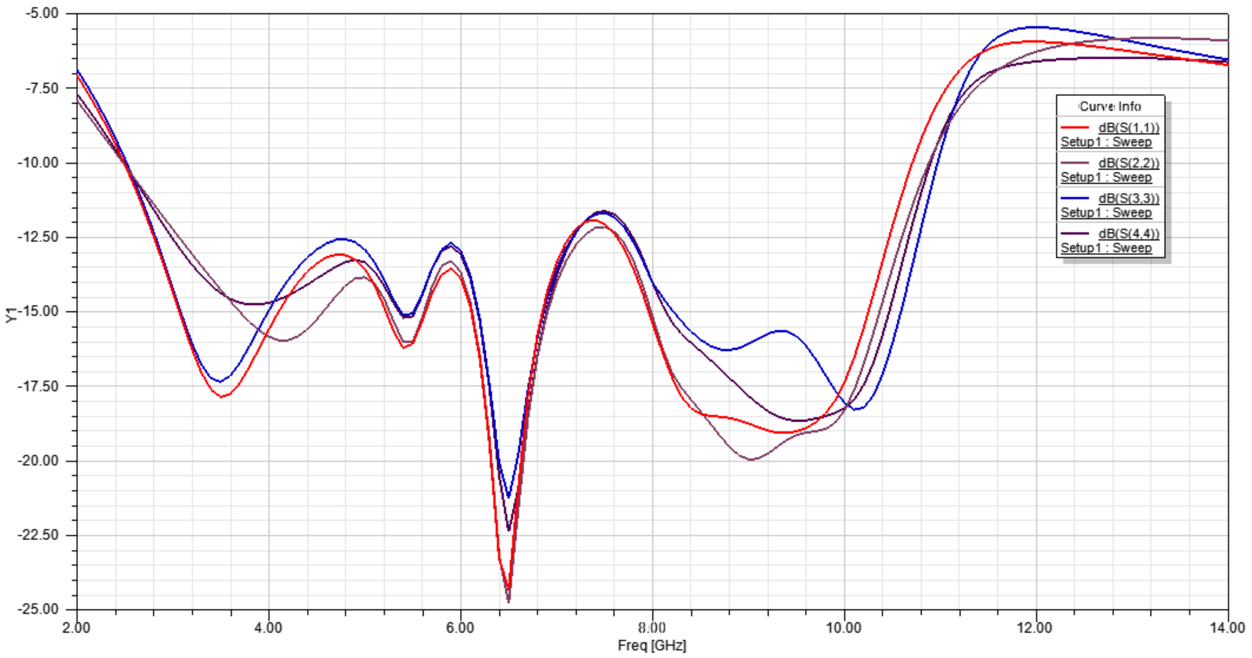


Fig 4.7 s-parameters for UWB MIMO antenna

Figure 4.8 shows the isolation between port 1 and (port2, port3 and port4), by other word S(1,1) and S(1,2) , S(1,3) , S(1.4).

S(1,1) (≥ 24 dB) , S(1,2) (≥ 18 dB) , S(1,3) (≥ 22 dB) , S(1,4) (≥ 22 dB).

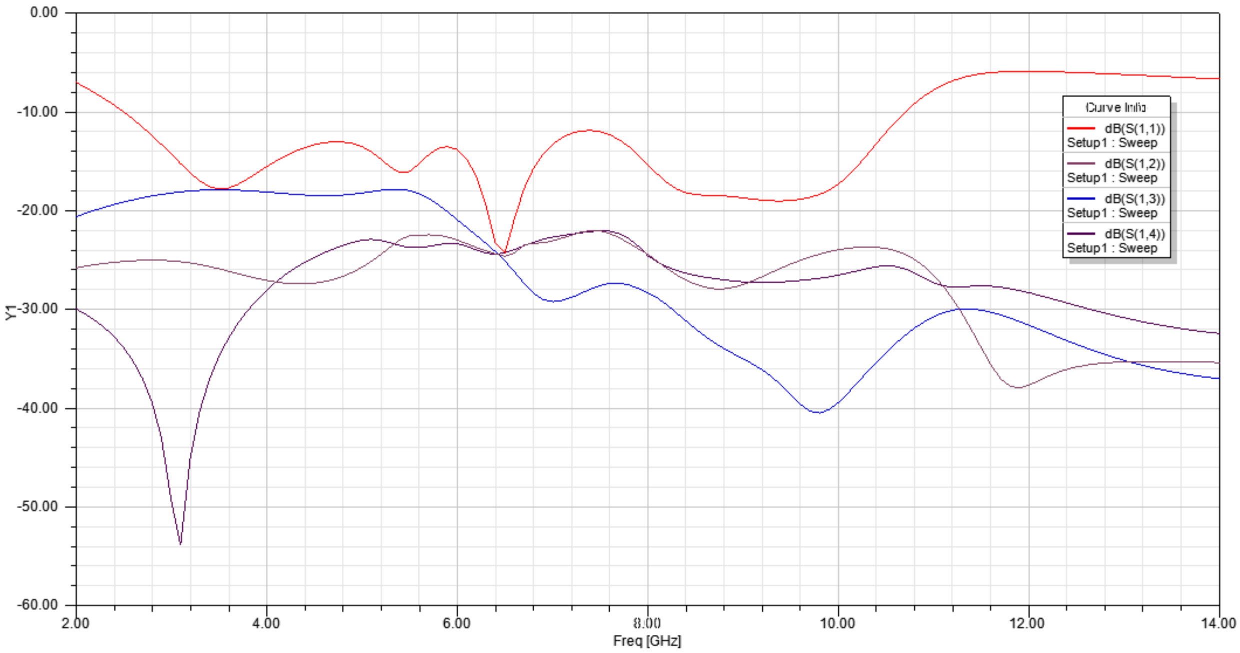


Fig 4.8 isolation between P1and (P2, P3, and P4)

Figure 4.9 shows the isolation between port 2 and (port1, port3 and port4), by other word S(2,2) and S(2,1) , S(2,3) , S(2.4).

S(2,2) (≥ 24 dB) , S(2,1) (≥ 17 dB) , S(2,3) (≥ 22 dB) , S(2,4) (≥ 22 dB).

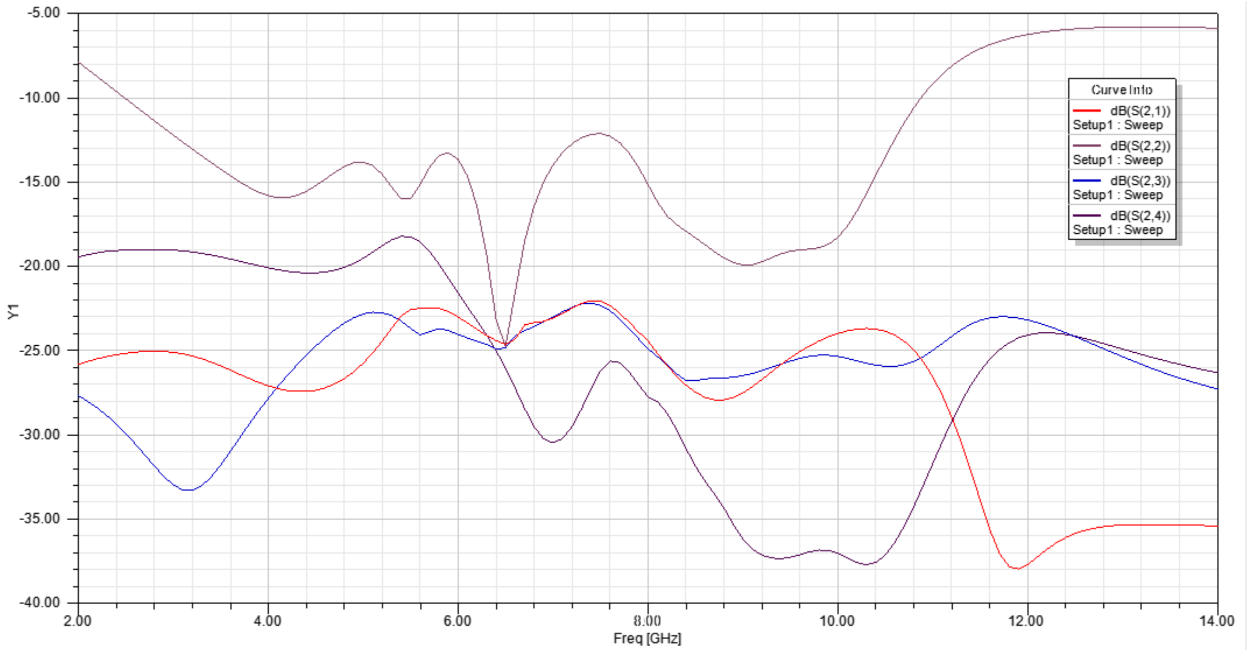


Fig 4.9 isolation between P2and (P1, P3, and P4)

Figure 4.10 shows the isolation between port 3 and (port1, port2 and port4), by other word S(3,3) and S(3,1) , S(3,2) , S(3.4).

S(3,3) (≥ 21 dB) , S(3,1) (≥ 18 dB) , S(3,2) (≥ 22 dB) , S(2,4) (≥ 22 dB).

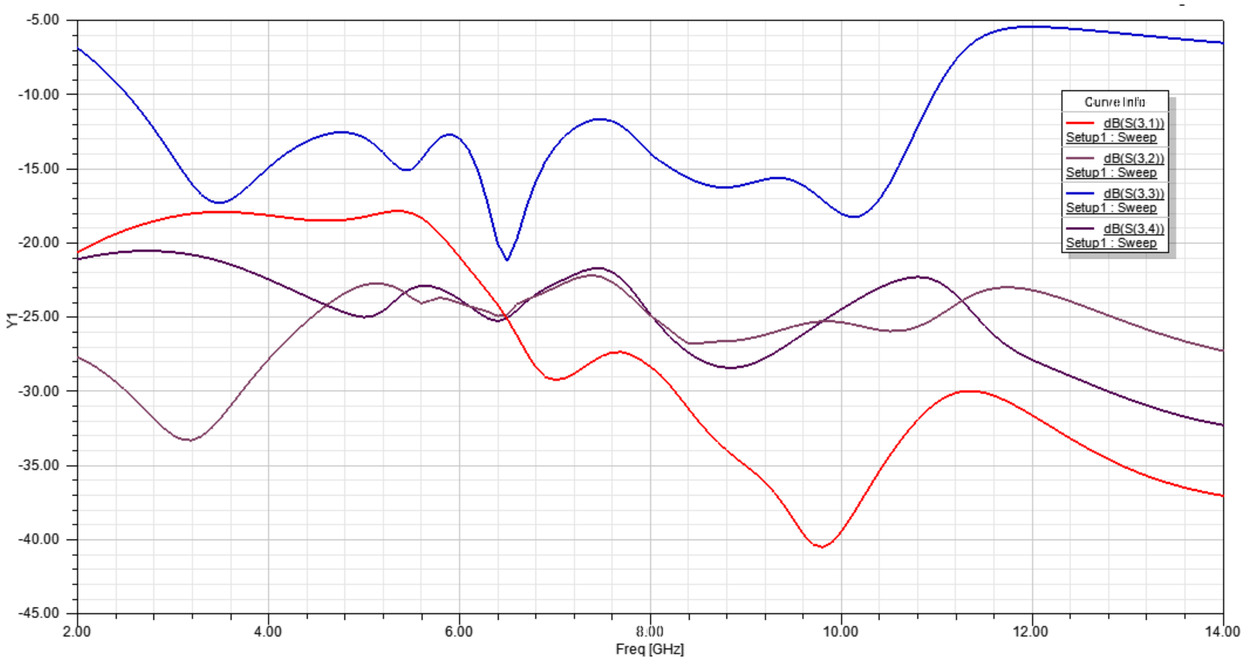


Fig 4.10 isolation between P3and (P1, P2, and P4)

Figure 4.11 shows the isolation between port 4 and (port1, port2 and port3), by other word S(4,4) and S(4,1) , S(4,2) , S(4.3).

S(4,4) (≥ 22 dB) , S(4,1) (≥ 18 dB) , S(4,2) (≥ 18 dB) , S(4,3) (≥ 22 dB).

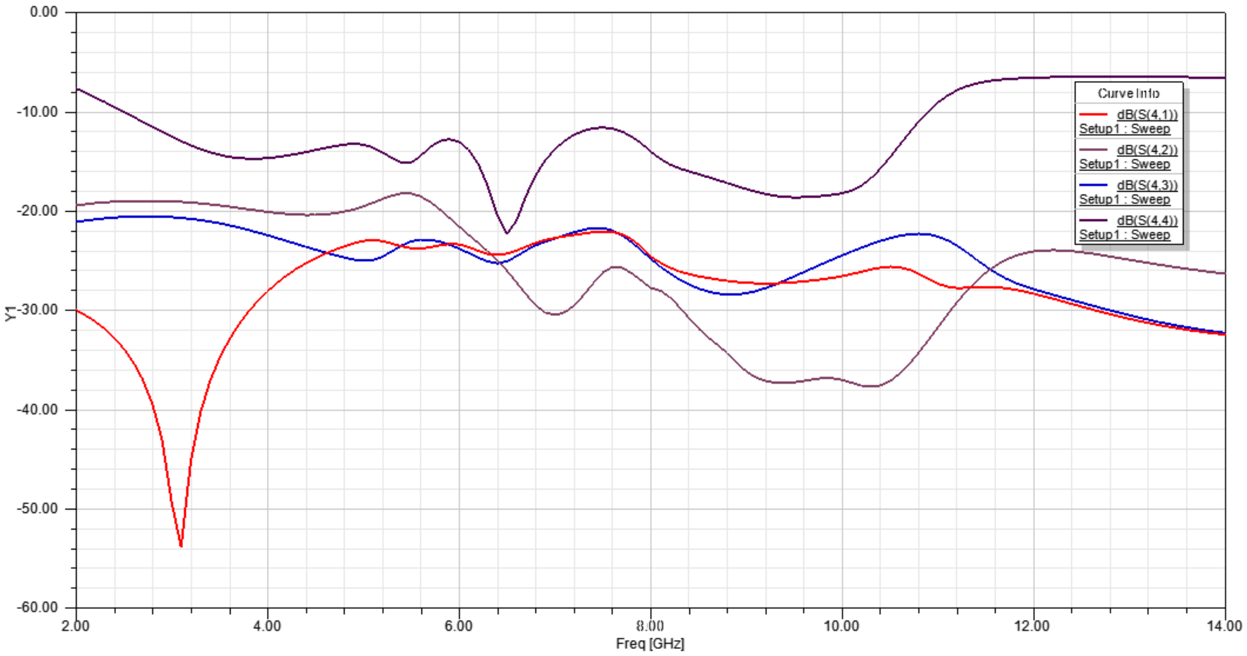


Fig 4.11 isolation between P4and (P1, P2, and P3)

Figure 4.12 shows the total affective reflection coefficient (TARC) for UWB MIMO antenna.

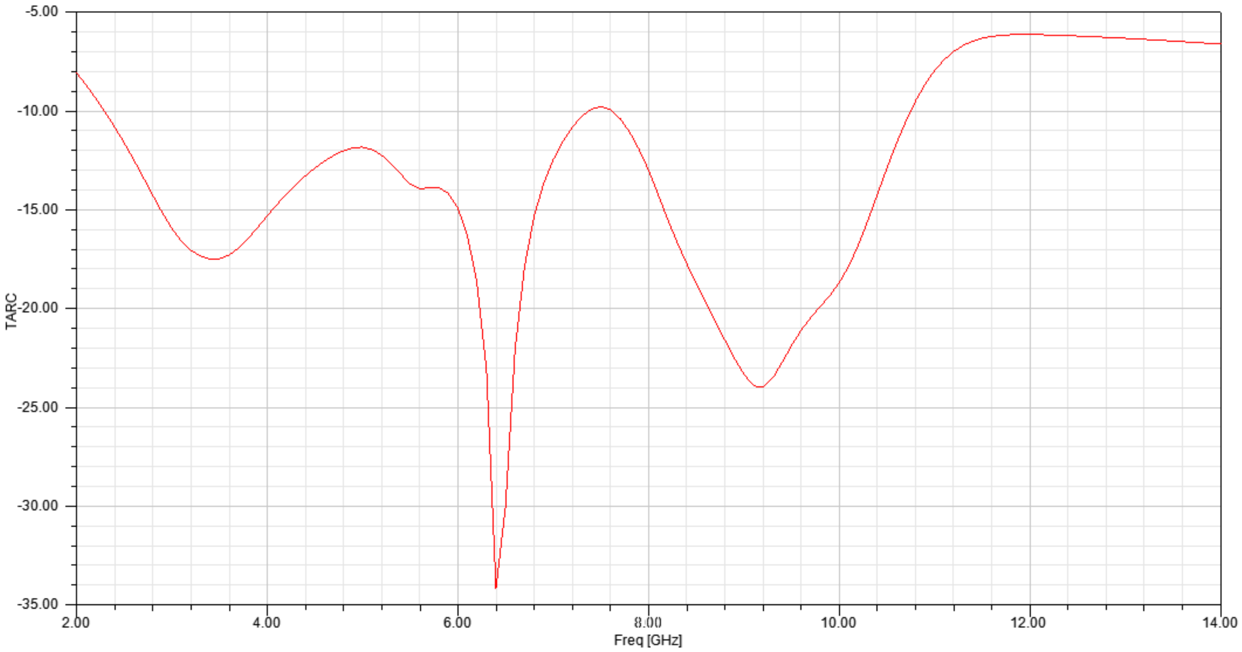


Fig 4.12 TARC

Figure 4.13 shows the axial ratio of UWB MIMO antenna.

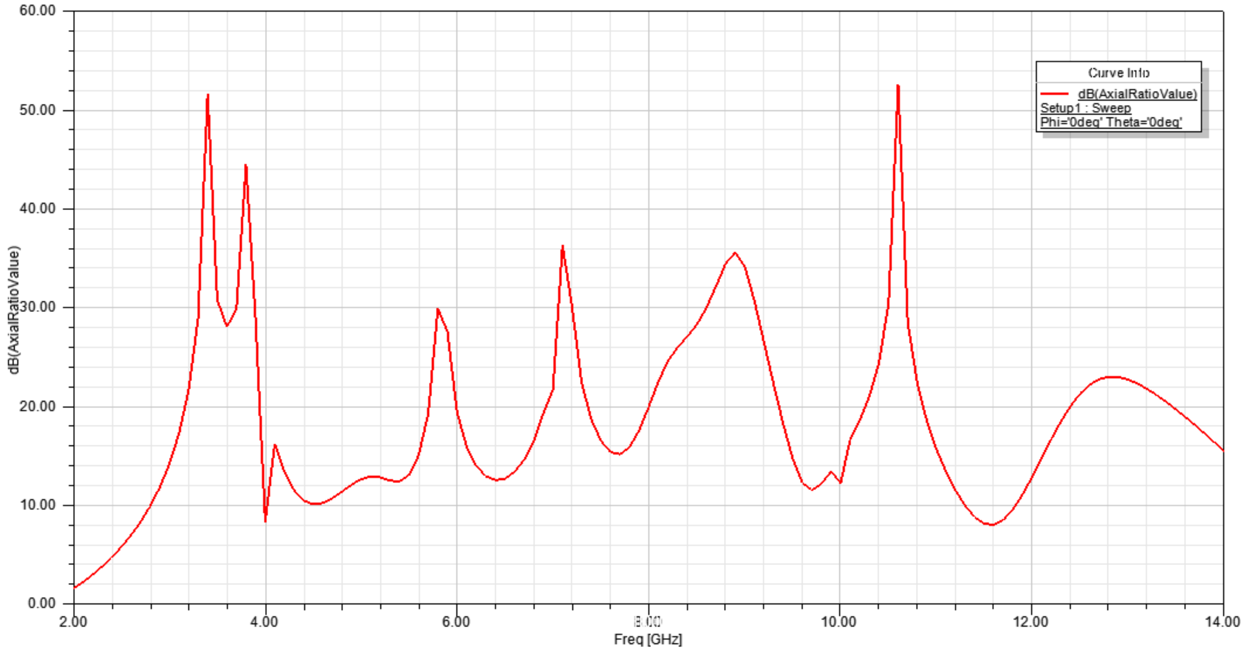


Fig. 4.13 AR for UWB MIMO antenna

Figure 4.14 shows the correlation coefficient of UWB MIMO antenna.

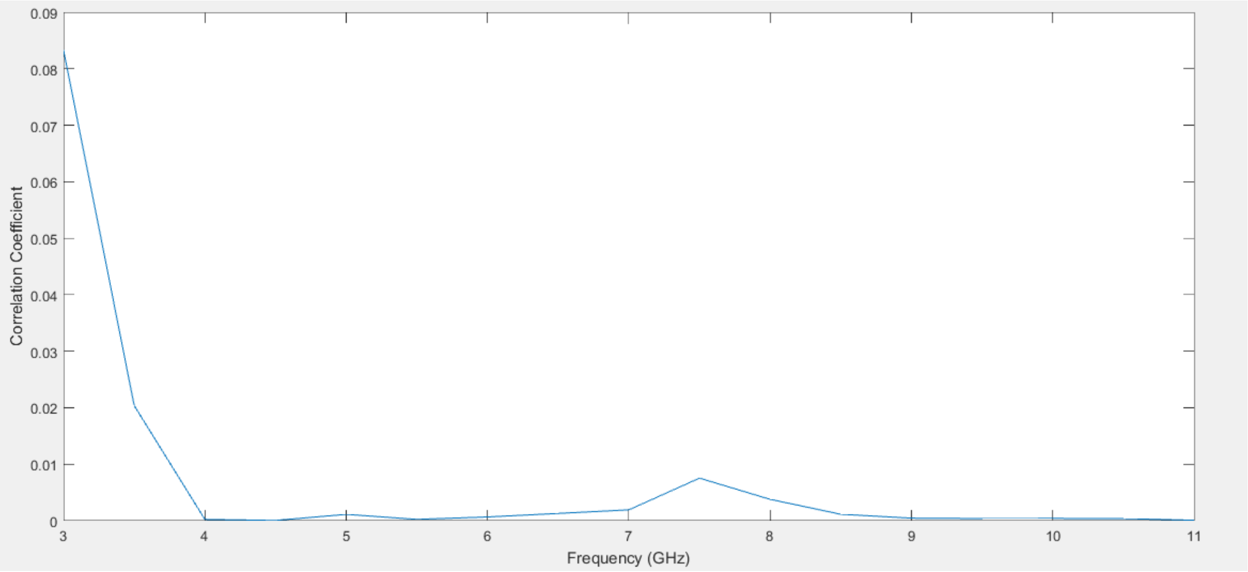


Fig. 4.14 Correlation Coefficient for UWB MIMO antenna

Figure 4.15 shows the envelope correlation coefficient (ECC) of UWB MIMO antenna.

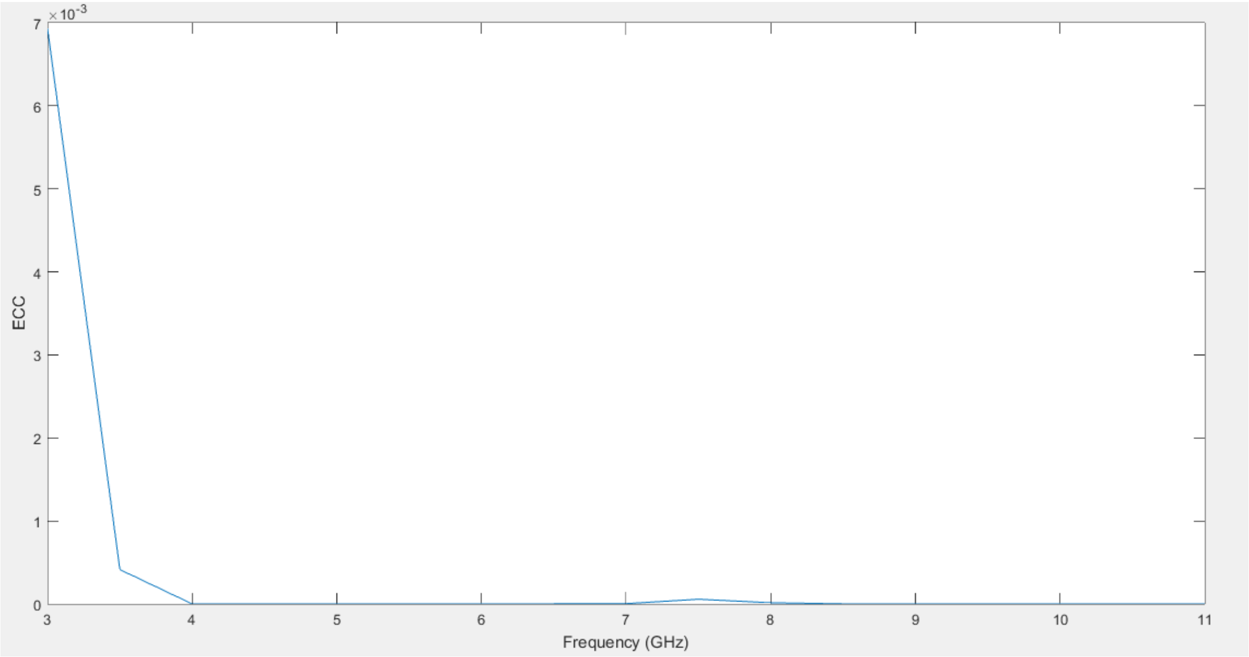


Fig. 4.15 ECC for UWB MIMO antenna

Figure 4.16 shows the diversity gain (DG) of UWB MIMO antenna.

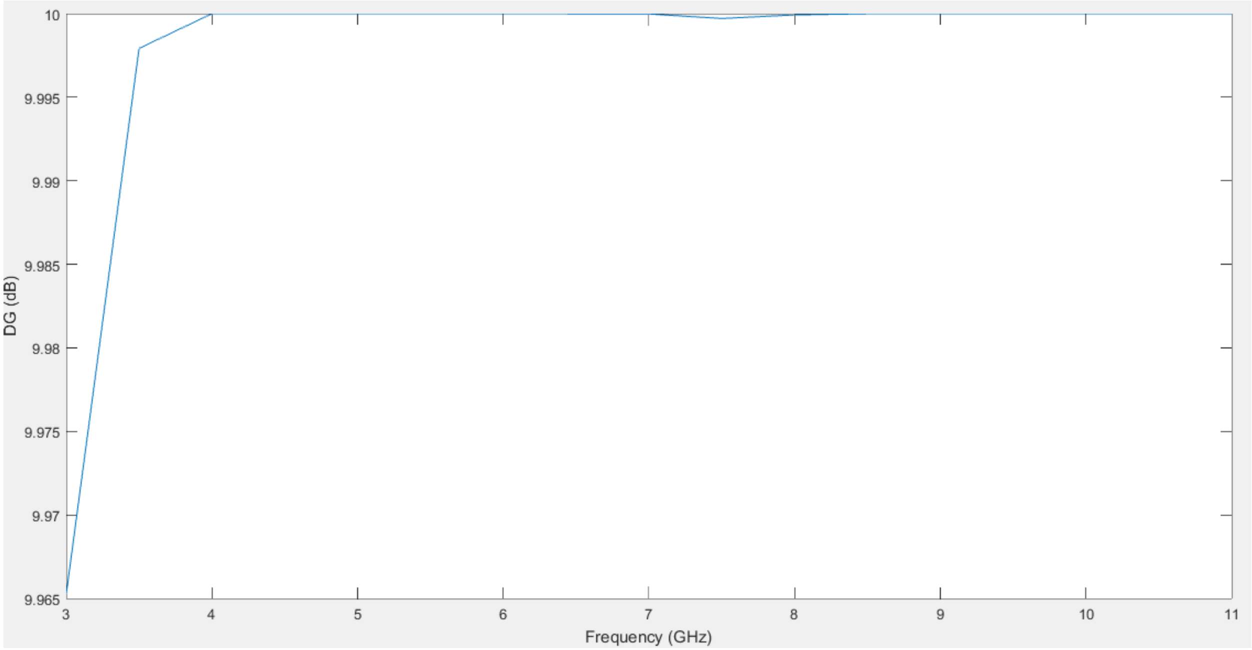


Fig. 4.16 DG for UWB MIMO antenna

Figure 4.17 shows the radiation efficiency of UWB MIMO antenna.

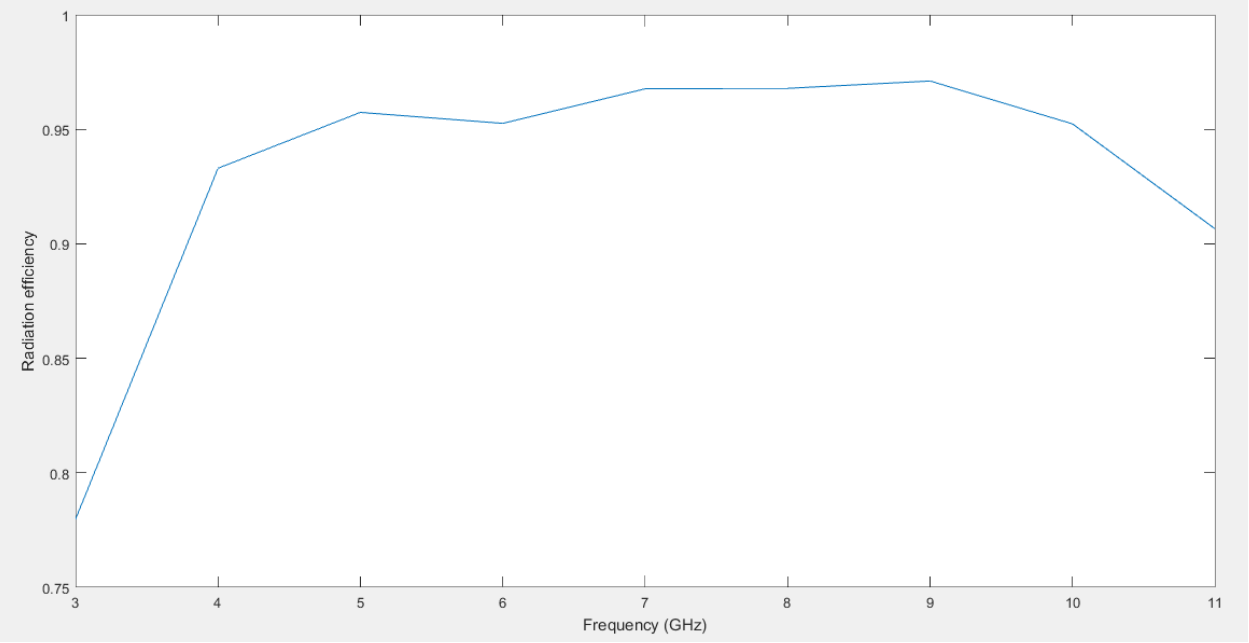


Fig. 4.17 Radiation efficiency for UWB MIMO antenna

Figure 4.18 shows the peak gain of UWB MIMO antenna.

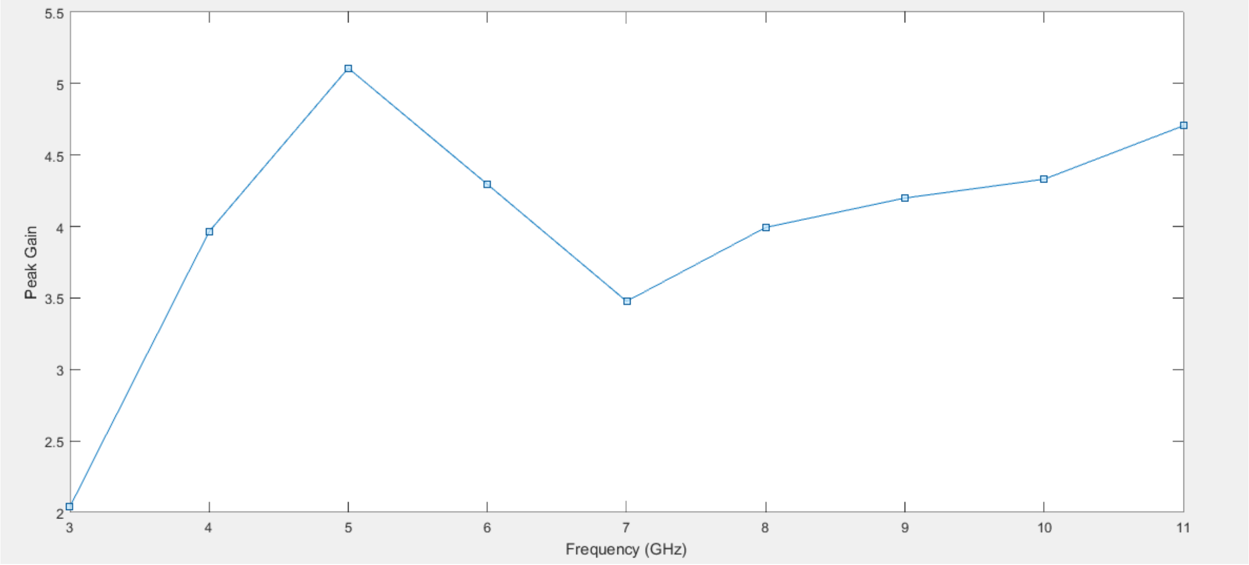


Fig. 4.18 Peak Gain for UWB MIMO antenna

Figure 4.19 shows the radiation pattern (x-y) of UWB MIMO antenna at frequency 6.8GHz

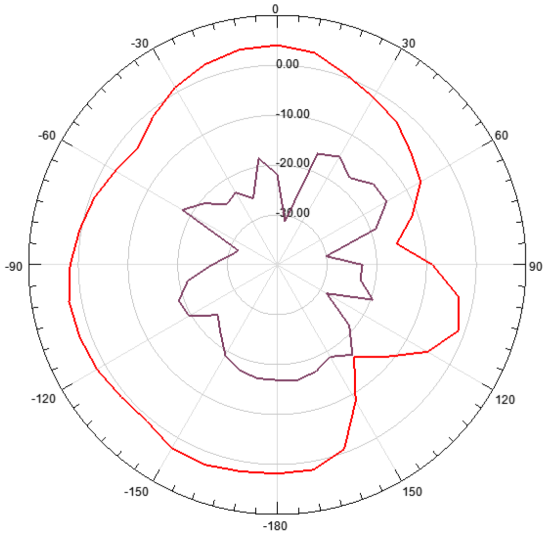


Fig. 4.19 radiation pattern at 6.8 GHz

Table 4.1: Comparison of proposed UWB-MIMO antenna with other designs.

Antenna Size (mm^2)	**Isolation (dB)**	**Frequency (GHz)**	**ECC**	**DG (dB)**	**Material**	**Radiation Efficiency**
50×90 [18]	>12	1.8-5.2	<0.33	>9.50	RO4350B	>0.63
50×40 [19]	>15	2.5-11	<0.02	>9.65	FR-4	>0.692
50×82 [20]	>15	2.15-13.62	<0.04	>9.79	FR-4	0.6-0.85
40×40 [21]	>15	2-6	<0.1	>9.95	FR-4	0.5-0.85
43×43 [**Proposed**]	>18	2.6-10.8	<0.007	>9.96	FR-4	>0.78

CHAPTER FIVE

CONCLUSION AND FUTURE WORK

5.1 Conclusion

This thesis presented the work on the analysis and design and analysis of UWB antenna and UWB MIMO antennas taking into consideration of two major performance characteristics, viz. isolation and bandwidth and further band notched characteristics has been introduced with this MIMO antenna design. The proposed antenna design has been discussed which satisfy the required isolation and bandwidth requirements.

Firstly, the UWB slot antenna has been designed and discussed. It has been observed that the proposed UWB antenna has stable radiation pattern for the entire UWB spectrum approximately.

Secondly, four elements UWB MIMO antenna together are designed and analyzed. The proposed MIMO antenna has the simulated impedance bandwidth of 2.6–10.8 GHz with the isolation better than 18 dB for the entire UWB spectrum. To get better insight of antenna performance, a parametric analysis of different antenna design parameters was performed. The detailed investigation of diversity performance in terms of ECC and diversity gain was presented. Both of them were within their acceptable limits, which make it suitable candidate for ultra wideband applications.

5.2 Future Work

- Fabricate the proposed UWB MIMO antenna and take the measurements of antenna parameters specially isolation, ECC, CCL and MEG.
- Change the material of substrate and compare the results between the two designs.

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