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MASTER

In **Telecommunication**

Option:**Telecommunications**

Title:

A Compact MIMO UWB Antenna with Band Notched Characteristicsat WLAN Frequency Band

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DEDICATION

To

MyMother&MyFather

A special feeling of gratitude to my parents who always supportedmeon time andencouragedmetogooneveryadventure.Theyturnedmymomentsofweaknessandfailureintom

omentsofstrengthandjoy.

Thankyou!

MySisters &MyBrothers

Mysweetlittlesistersoumia,youarethecarrierofhappinessforme,mybrothersAbdelkaderNasrEldineandYahiayouaremyhappiness, myaudience, mybest friends.

Thankyou!

MyHusband

A special person in my life who was always here for me and pushed me toworkhard,makemestrong,andbeenasourceofencouragementandinspirationforme.

Thankyou!

MyChildren

To my lovely children Yacine; Israa; Maria; and Youcef
you are my source of happiness.

Nadjet

Acknowledgement

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A special thanks to my supervisor, Msr.MOUHOUCHE FAIZA, for her patience andencouragement along the route, as well as for her helpful comments, remarks, andengagementduringthecompletionofthismasterthesis.Youwereanexcellentprojectmanager.

I would like to express my gratitude to the lecturers, employees, and technicians fortheir collaboration and direct or indirect contributions to the completion of my project in particularlyLte. LACHEHAB HOUDA and all the stuff ofhigher school of territorial air defense

Abstract

This work presents a compact UWB MIMO antenna with band notch characteristics for WLAN application is designed and investigated. The proposed MIMO antenna consists of two unit cell antennas, being comprised of a Microstrip feed line and a partial ground plane, and these radiators are placed parallel to each other. A single antenna comprises an inverted Christmas tree shaped patch fed by a 50 ΩMicrostrip line and partial ground plane is designed for achieving UWB application. The operating frequency of the proposed single antenna is 3.5–14.5 GHz with a return loss of less than −10 dB. Subsequently, a circular split ring shaped slot is implemented in the radiating element to optimize the antenna for WLAN band rejection at 5.6-6.2GHz .

Furthermore, a 2 × 1 MIMO antenna is designed by utilizing the polarization diversity technique. The two radiating elements are placed parallel and decoupling structure is placed between them to improve the isolation performance. Finally, the compact UWB MIMO antenna prototype is designed on the FR4 substrate with the overall dimensions of 20 × 39 × 1.63 mm3.The proposed UWB MIMO antenna design provides an impedance bandwidth (S 11 less then −10 dB) of 130% (3.3–16 GHz) with band notch centered at 5.8GHz.The isolation of the

proposed MIMO antenna is higher than −17 dB,. Results show that the proposed MIMO antenna is a good candidate for handheld devices for wireless personal-area networks application.

General Introduction

An antenna is a device designed to transmit or receive electromagnetic waves. These waves can be in various forms, such as radio waves, microwaves, or light waves. Antennas are fundamental components in many modern technologies, including radio and television broadcasting, wireless communication systems, radar systems, satellite communication, and even RFID (Radio Frequency Identification) systems.

The primary function of an antenna is to convert electrical signals into electromagnetic waves for transmission, or to convert electromagnetic waves into electrical signals for reception. Antennas come in various shapes and sizes, depending on the application and frequency range they are designed for. Some common types of antennas include dipole antennas, Yagi antennas, patch antennas, helical antennas, and parabolic antennas.

An Ultra-Wideband (UWB) antenna is a type of antenna designed to operate over a very large frequency range, typically spanning several gigahertz (GHz) or more. UWB technology enables high data transfer rates over short distances and is used in various applications such as wireless USB, radar systems, precision location systems, and wireless sensor networks.

The design of an antenna depends on factors such as the desired radiation pattern, gain, polarization, bandwidth, and impedance matching. Antenna engineers employ various techniques and principles from electromagnetics and antenna theory to optimize the performance of antennas for specific applications.

A microstrip antenna is a type of antenna that operates at microwave frequencies and is commonly used in various wireless communication systems, including mobile phones, Wi-Fi routers, satellite communication, and radar systems. It is known for its low profile, lightweight, ease of fabrication, and compatibility with printed circuit board (PCB) technology.

microstrip antennas are a popular choice for many wireless communication applications due to their compact size, ease of integration, and compatibility with modern manufacturing techniques.

MIMO (Multiple Input Multiple Output) antenna systems are a key technology in modern wireless communication systems. These systems utilize multiple antennas at both the transmitter and receiver ends to improve communication performance by exploiting spatial diversity and multiplexing capabilities.

This report contains three chapters as follows:

Chapter1: review of basic concepts of microstrip antenna theories and MIMO system

Chapter2: provides the steps of designing an Ultra-Wideband (UWB) monopole patch antenna .In addition, an extensive parametric study for the proposed structure is carried out in order to have a better understanding of operating mechanism.

Chapter 3: we will present the design and simulation the MIMO system by using the two identical parallel antennas ultra-Wideband (UWB) antenna

The performances of this MIMO antenna will be discussed in details

Finally, a conclusion and some suggestions for future scope are presented.

Chapter 1

Generalities of Microstrip Antennas.

1.1 Introduction

In this chapter, some useful concepts on Microstrip antenna, its behavior and the theory behind are described in details.
Microstrip antennas are a type of printed antenna widely used in various wireless communication systems due to their compact size, low profile, lightweight, and ease of integration with printed circuit boards (PCBs).

The Microstrip antenna will absolutely continue to find many uses in the future due to its numerous distinctive and attractive qualities (e.g., lightweight, cheap cost, ease of fabrication, and compatibility with integrated circuits) [1].

1.2 Microstrip antenna

1.2.1 History

The history of microstrip antennas dates back to the 1950s when researchers began exploring various types of printed antennas for microwave applications. However, the development and widespread adoption of microstrip antennas as we know them today can be traced to the late 1960s and early 1970s [1].

research and development in microstrip antennas have focused on improving bandwidth, efficiency, radiation patterns, and integration with other components for multi-functionality. Advanced techniques such as metamaterial-inspired designs, fractal geometries, and reconfigurable antennas are being explored to address emerging challenges in wireless communication systems[2].

1.2.2 Basic structure

The basic structure of a microstrip antenna consists of a thin metallic patch mounted on a dielectric substrate, such as fiberglass or ceramic. The metallic patch acts as the radiating element, while the dielectric substrate provides mechanical support and insulation. Below the substrate, a ground plane is typically placed to enhance the antenna's performance and provide a reference for radiation as shown in **Figure 1.1**

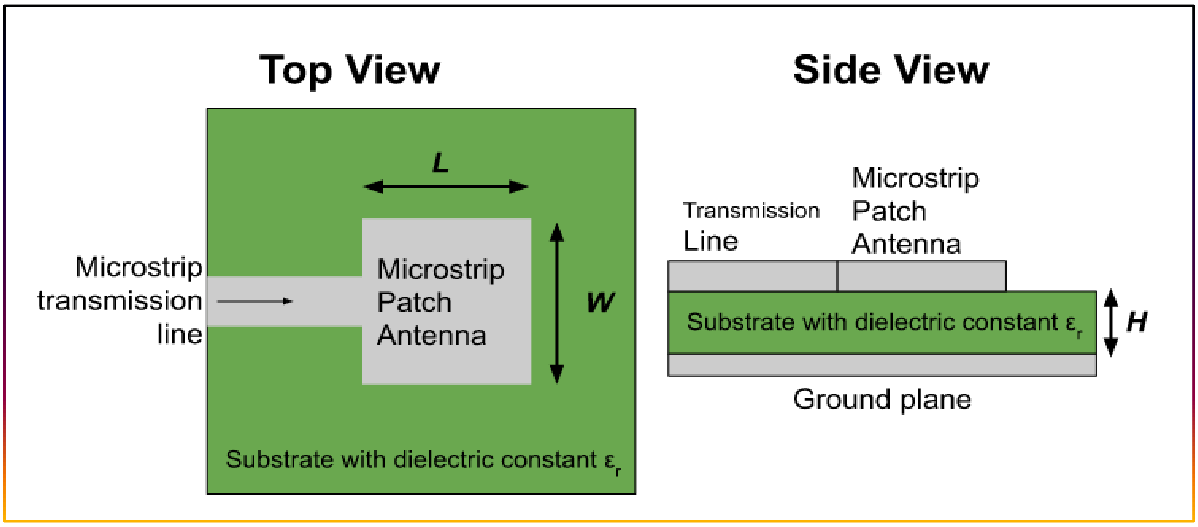


Figure 1.1 Basic microstrip patch antenna structure [2].

Microstrip antennas can take various shapes and configurations, including rectangular, circular, or triangular patches. They can also be designed to have different feeding mechanisms, such as coaxial probe feeding, microstrip line feeding, or aperture coupling Some of the common types are shown in **Figure1.2**

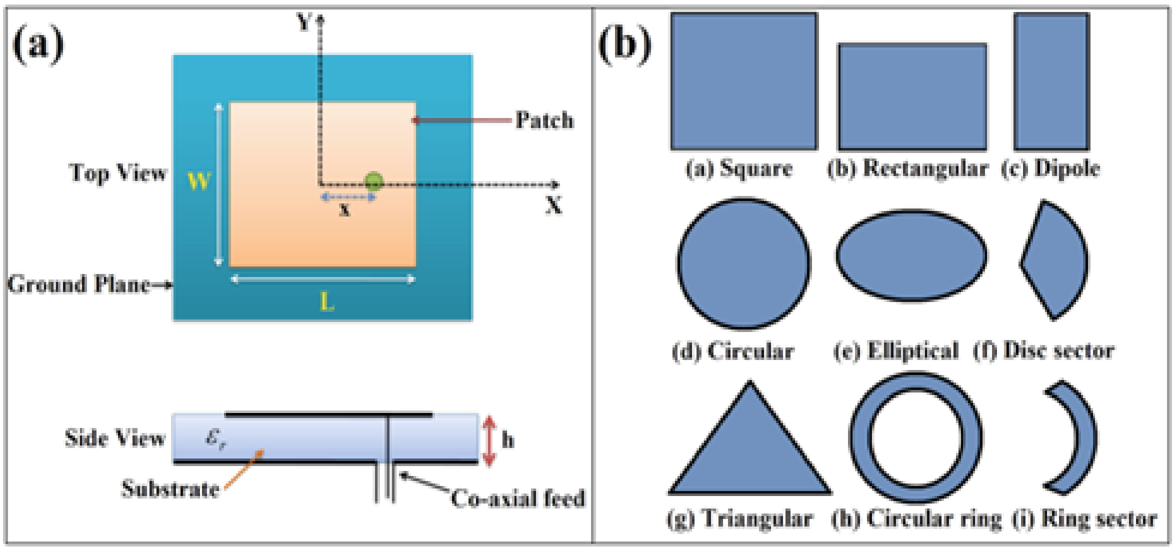


Figure1.2 Basic microstrip antenna configurations [3].

1.2.3 Principle of Operation

The fringing fields around the microstrip antenna are responsible for the radiation. This is due to the fringing E-fields on the edge of the patch antenna which are in phase. This causes them to add up and produce electromagnetic wave radiation. The current also adds up in phase;

however, in the ground plane an equal current but with opposite direction, which cancels the radiation therefore, the microstrip patch antenna is considered as a "voltage radiator”[4].

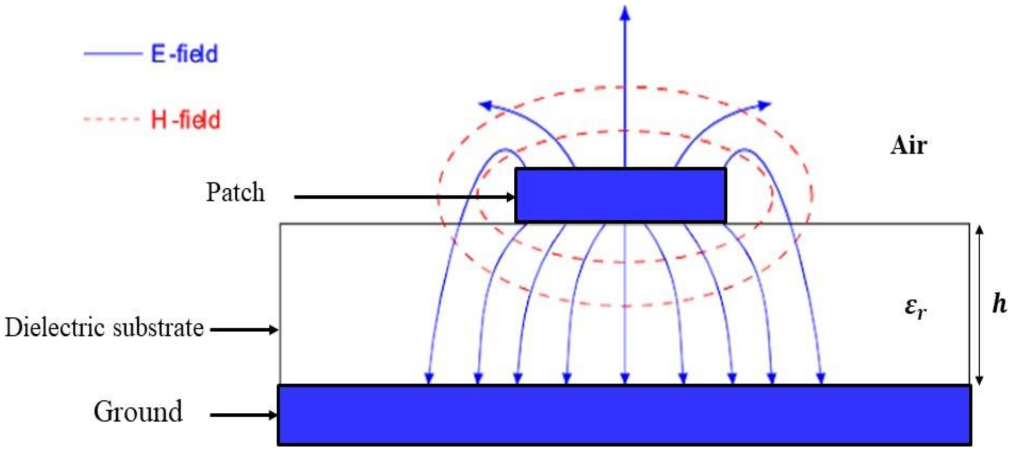


Figure 1.3 Fringing fields in patch antennas [5].

1.2.4 Microstrip Antenna Feeding Methods

Feeding the microstrip antenna is very important to improve the antenna input impedance matching. The feeding techniques used in the patch antenna are divided into two important classes [6].

1.2.4.1Contacting feed

In this method, the power is directly fed to the radiating element. The most commonly used methods of this class are Microstrip and Coaxial Feed line.

a. Microstrip Line Feed

In this type of feed technique, a conducting strip is connected directly to the microstrip patch's edge, as shown in Figure 1.3. The conducting strip is smaller in width than the patch, and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure [6].

b. Co-axial Feed

The co-axial feed is a non-planar feeding technique in which z co-axial cable is used to feed the patch. The inner conductor of the co-axial connector extends through the dielectric, making a metal contact with the patch, and the outer conductor of the cable is connected to the ground plane

The inner conductor extends through the dielectric and is soldered to the patch, while the outer conductor of the coaxial connector is connected to the ground plane as shown in figure 1.5. To obtain better input impedance matching the feed line position can be altered to any desired location on the patch [7].

1.2.4.2Non-Contacting Feed

The power is not fed directly to the patch but is instead transferred from the feed line through electromagnetic coupling. This is done using Aperture or Proximity Coupled Feed [7].

a. Aperture Coupled Feed

A microstrip feed line printed on the lower substrate is electromagnetically coupled to the patch through a slot printed in the common ground plane [7].

b. Proximity Coupled Feed

In this feeding mechanism, two dielectric substrates are used and the feed line is between the two substrates. The radiating patch is on top of the upper substrate. This feed technique eliminates spurious feed radiation and provides very high bandwidth due to the increase in the thickness of the microstrip patch antenna [7].

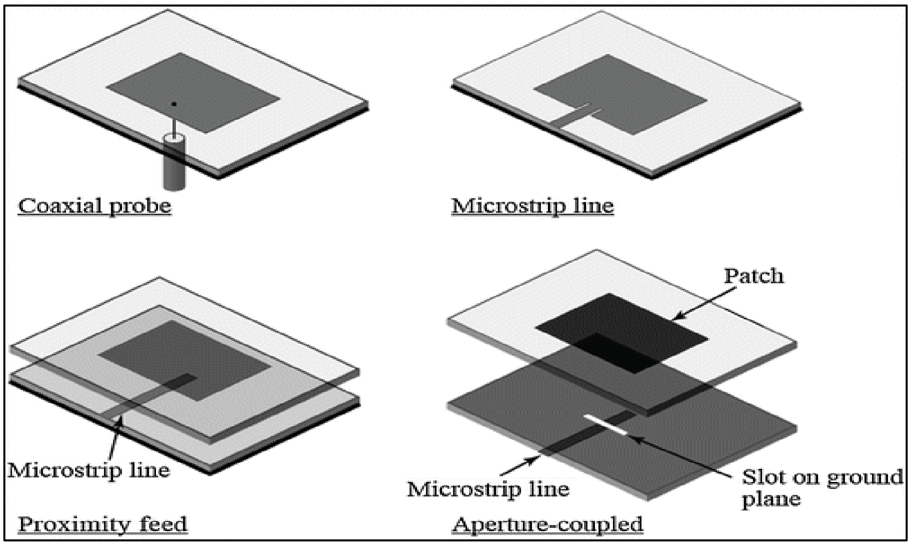


Figure 1.4 Four common feeding methods of microstrip patch antenna.

Table 1 shows a comparison between the different feeding techniques mentioned in the previous unit.

Table1: Comparison between different patch antenna feeding techniques [10].

Characteristic	Microstrip line feed	Coaxial probe feed	Aperture coupled feed	Proximity coupled feed
Spurious feed radiation	More	More	less	minimum
Impedance matching	Easy	Easy	easy	easy
Reliability	Better	Poor	Good	Good
Bandwidth	2 - 5%	2 - 5%	2 - 5%	2 - 5%

1.2.5 Method Analysis

Methods of analysis the most well-known method for the analysis of microstrip patch antenna are divided into two groups of methods:

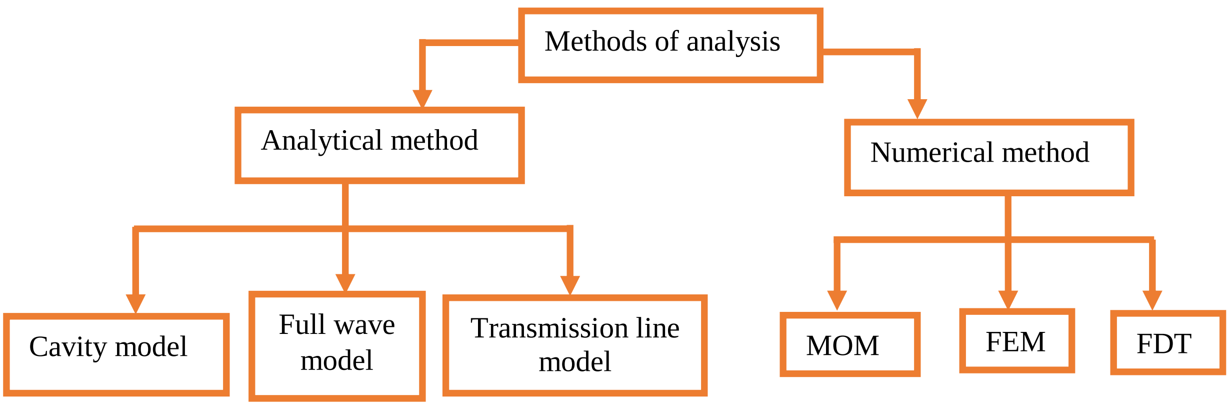


Figure 1.5 Methods of analysis

1.2.6 Antenna Parameters

1.2.6.1 Input Impedance

It is the impedance offered by the antenna at its terminals. It can be also defined as "the ratio of the voltage to the current across the input terminals" or "the ratio of the appropriate components of the electric to magnetic fields at a point [12]. It is defined as:

$$Z_{in} = Z_0 \frac{1+\Gamma}{1-\Gamma} \quad (1\text{-}1)$$

Where

- Z_0 is the characteristic impedance
- Γ is input reflection coefficient.

1.2.6.2 Directivity

Directivity is the increase in power density in a given direction at a fixed distance from the antenna, relative to the power density averaged over all directions. Usually, the maximum value of directivity is of primary interest, and here we use directivity to mean maximum directivity. Hence, directivity is a measure of the increase in maximum power density at a fixed distance compared to that from a hypothetical isotropic radiator. Directivity, D, is a unit-less power ratio, usually expressed in dB [12].

$$\boldsymbol{D(\theta,\varphi) = 4\pi \frac{U(\theta,\varphi)}{P_{rad}}} \quad (1\text{-}2)$$

Where D($\boldsymbol{\theta,\varphi}$) is the antenna directivity, U($\boldsymbol{\theta,\varphi}$) is the radiation intensity and P_{rad} is the total radiated power.

1.2.6.3Efficiency

The total antenna efficiency is used to take into account losses within the antenna and at the input terminals. These losses occur due to the mismatch between the antenna and transmission line which causes reflections and the conductor and dielectric losses [12]. The total efficiency is given by the equation:

$$e_0 = e_r e_c e_d \quad (1\text{-}3)$$

Where

- e_0 is the total efficiency,
- e_r is the reflection (mismatch) efficiency,
- e_c is the conductor efficiency
- e_d is the dielectric efficiency.

1.2.6.4Gain

Antenna gain is closely related to the directivity, but it also takes into account the efficiency of the antenna. The gain of an antenna in a given direction is defined as the ratio of the intensity, in a given direction, and the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotopically. This is called the absolute gain. The radiation intensity corresponding to the isotopically radiated power is equal to the power input by the antenna divided by 4π. Thus,

$$\boldsymbol{G(\phi,\theta) = 4\pi \frac{U(\phi,\theta)}{P_{in}}} \quad (1\text{-}4)$$

where G is the gain. P_{in} is the total input power and U is the radiation intensity. In many applications, partial gains G_{ϕ} and G_{θ} are used. These partial gains are defined as:

$$\boldsymbol{G_{\phi} = 4\pi \frac{U_{\phi}}{P_{in}}} \quad (1\text{-}5)$$

$$\boldsymbol{G_{\theta} = 4\pi \frac{U_{\theta}}{P_{in}}} \quad (1\text{-}6)$$

Where $U\phi$ is the radiation intensity in a given direction contained in the ϕ-field component, $U\theta$ is the radiation intensity in a given direction contained in the θ-field component.

The realized gain of an antenna is calculated by considering the total efficiency of the antenna, along with its directivity. In a simple way, the realized gain is what you actually get with the actual mismatch. It takes into account total antenna efficiency not radiation efficiency.

1.2.6.5 Radiation Pattern

The antenna radiation pattern is defined as a mathematical function or graphical representation of the radiation properties of the antenna as a function of the space parameters. This pattern is usually determined in the far field region. It has various properties such as power flux density, radiation intensity, field strength, directivity phase or polarization. The performance of the antenna is often described in terms of its principal E- and H- plane patterns [8].

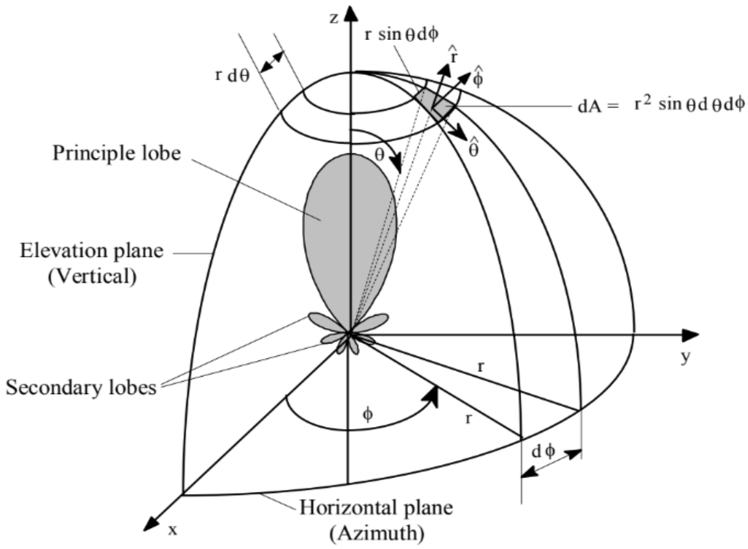


Figure 1.6 Radiation pattern in spherical coordinates.

1.2.6 Advantages and disadvantages of Microstrip antenna

Microstrip antenna has several advantages compared to other microwave antennas, some advantages are:

- Light weight and low volume.
- Low profile planar configuration which can be easily made conformal to host surface.
- Low fabrication cost, hence can be manufactured in large quantities.
- Supports both, linear as well as circular polarization.
- Can be easily integrated with microwave integrated circuits (MICs).
- Capable of dual and triple frequency operations.
- Mechanically robust when mounted on rigid surfaces.

Microstrip antenna has also some disadvantages compared to conventional microwave antennas they are some:

- Narrow bandwidth.
- Low efficiency.
- Low Gain.
- Low power handling capacity.
- Extraneous radiation from feeds and junctions.
- Surface wave excitation.

1.3 Introduction to Multiple Input Multiple Output Systems (MIMO)

1.3.1 introduction

Multiple Input Multiple Output (MIMO) systems are a key technology in modern wireless communication systems. In traditional communication systems, there is typically one antenna at both the transmitter and receiver, leading to a single-input single-output (SISO) configuration. However, with MIMO systems, there are multiple antennas at both the transmitter and receiver, enabling enhanced performance in terms of data rate, reliability, and range[9]

MIMO system improves the communication performance by utilizing multiple antennas at both the transmitter and receiver ends. The communication range and throughout of the communication system is increased significantly using MIMO. to describe the performance of antenna there are several commonly used antenna parameters, including impedance bandwidth, radiation pattern, directivity, gain, and polarization [10].

1.3.2 Techniques of isolation

1.3.2.a Frequency diversity

is a technique used in wireless communication to transmit the same information over multiple frequency channels simultaneously or sequentially. By exploiting the fact that different frequencies experience independent fading, frequency diversity improves reliability, combats interference, and enhances overall communication performance, particularly in environments prone to frequency-selective fading. [11].

1.3.2.b Time diversity

is a method used in wireless communication to improve reliability by transmitting the same information over multiple time instances. By sending redundant copies of the data at different time intervals, it exploits the variations in fading over time to ensure that at least one transmission experiences favorable conditions, thereby reducing the likelihood of communication errors or outages[11].

1.3.2.c Space diversity

Space diversity in wireless communication involves using multiple antennas placed in different spatial locations to improve signal reliability by mitigating the effects of fading. This technique exploits the fact that signals received at different antennas experience independent fading, reducing the probability of all antennas experiencing deep fades simultaneously and thus enhancing communication performance [11].

1.3.3 Mutual Coupling

in MIMO antennas refers to electromagnetic interaction between antenna elements within the same array. It can degrade system performance by increasing channel correlation, reducing diversity gain, causing channel imbalance, and introducing errors in beam steering. Techniques to mitigate mutual coupling include antenna decoupling methods, design optimization, and system calibration. Managing mutual coupling is crucial for optimizing MIMO system performance [11].

1.3.4 MIMO Application

MIMO antennas find applications in various wireless communication systems where increased data rates, improved reliability, and enhanced spectralefficiency.

1.3.4.a Data Rate Extension

MIMO with low bandwidth and high spectral efficiency solves the problem of high speed and low speed users. In MIMO 1 Gbps data rate is achieved with 20 MHz bandwidth only. MIMO with different modulation like binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), and quadrature amplitude modulation (QAM), offers variable data rates [12].

1.3.4.b Power Saving

MIMO systems can achieve higher energy efficiency by optimizing the use of transmit power and reducing the need for retransmissions due to improved reliability. This efficiency is beneficial for prolonging battery life in mobile devices and reducing overall power consumption in wireless networks [12].

1.3.4.c Spectral Efficiency Enhancement: By exploiting spatial diversity, MIMO systems achieve better spectral efficiency, transmitting more bits per second per hertz of bandwidth. This efficiency is crucial for accommodating the growing demand for wireless data services without requiring additional spectrum allocations

References

[1] The McGraw-Hill Companies 2007 under license agreement with Books24x7

[2] Punit S. Nakar. Design of a compact microstrip patch antenna for use in wireless/cellular devices. Master's thesis, The Florida State University, 2004.

[3] Balanis, C. A. (2005). Antenna Theory Analysis and Design Third Edition. New Jersey: John Wiley & Sons, Inc.

[6] ParwinderKaur, "Gain Enhancement of Microstrip Patch Antenna with Slotting Techniques" International Journal Of Advanced Research in Engineering & Management (IJAREM)-Volume 03, issue 01, PP.13-19, ISSN:2456-2033, Feb 2017

[7] A. S. Mohammed, A, R Yauri and A. Kabir, " Review of feeding technique for microstrip patch antenna " International jornal of computer application, vol. 178, pp. 97-887, 2019

[8] C. A Balanis, antenna theory: analysis and design: jhon wiley & sons, 2015

[9] Ramesh Garg, Prakash Bhartia, Inder J Bahl, and Apisak Ittipiboon. Microstrip antenna design handbook. Artech house, 2001.

[12] Malviya, L., Panigrahi, R. K., & Kartikeyan, M. V. Mimo antennas for Wireless Communication: Theory and Design. CRC Press, 2021.

[10]] Kshetrimayum. Fundamentals of Mimo Wireless Communications. Cambridge University Press, 2017.

[11] Malviya, L., Panigrahi, R. K., & Kartikeyan, M. V. Mimo antennas for Wireless Communication: Theory and Design. CRC Press, 2021.

Chapter 2

A Compact Ultra Wide Band Printed Antenna with Band Notch Characteristics at WLAN Frequency Band

2.1 Introduction

In this chapter, a compact UWB printed monopole antenna with band rejection characteristics for WLAN application is proposed. The antenna provides an ultra-wide impedance bandwidth ranging from 3.5 GHz to 15 GHz. Furthermore, A circular split ring slot is introduced on the radiating patch to get a band notched at WLAN . The design and simulations procedures are carried out using CST Microwave studio(MWS)software.

2.2 UWB Antenna Design

The configuration of the proposed Ultra wide band printed monopole antenna is presented in figure 2.1 . The proposed structure comprises of new shape of inverted Christmas tree shaped as a radiating element which is inspired from literature[1 ,2] and it is fed by a 50Ω microstrip feed line. The proposed structure is printed on FR4 substrate of thickness h=1 .6 mm, loss tangent of 0.02 and dielectric constant εr =4.3. It has a compact physical size of 20x20x1.63mm^3 .

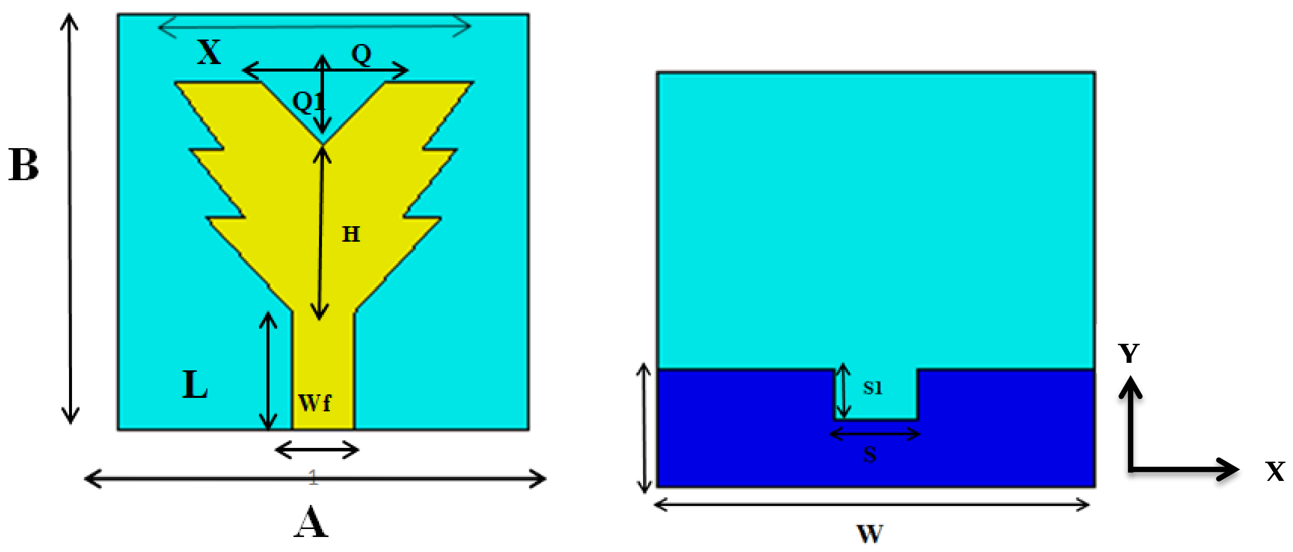


Figure 2.1: Proposed antenna geometry.

Table 2.1 : Detailed parameters antenna.

Parameter	A	B	h	W	Wf	X	R	S	S1	L	Q	Q1	H
Value(mm)	20	20	1.63	20	3.1	14.5	5.7	3.7	2.2	3	3	3	11

The proposed UWB antenna design is developed to the final structure as shown in Figure 2.2 through five evolution stages. First, it is starting with a small inverted triangle shaped patch as Ant-1 as shown in figure 2.2. The second stage of the design is achieved by adding another inverted triangle shaped on the top of radiating element of Ant-1 as illustrated in Figure 2.2.The third stage, Ant-3 is formed by introducing a third inverted triangle shaped on the top of Ant-2 as depicted in figure 2.2.To increase the bandwidth of antenna a triangular slot is introduced on the top of Ant-3 to form Ant-4 as shown in figure 2.2.Finally,a rectangular slot is added in the ground to achieve UWB application(Ant-5).

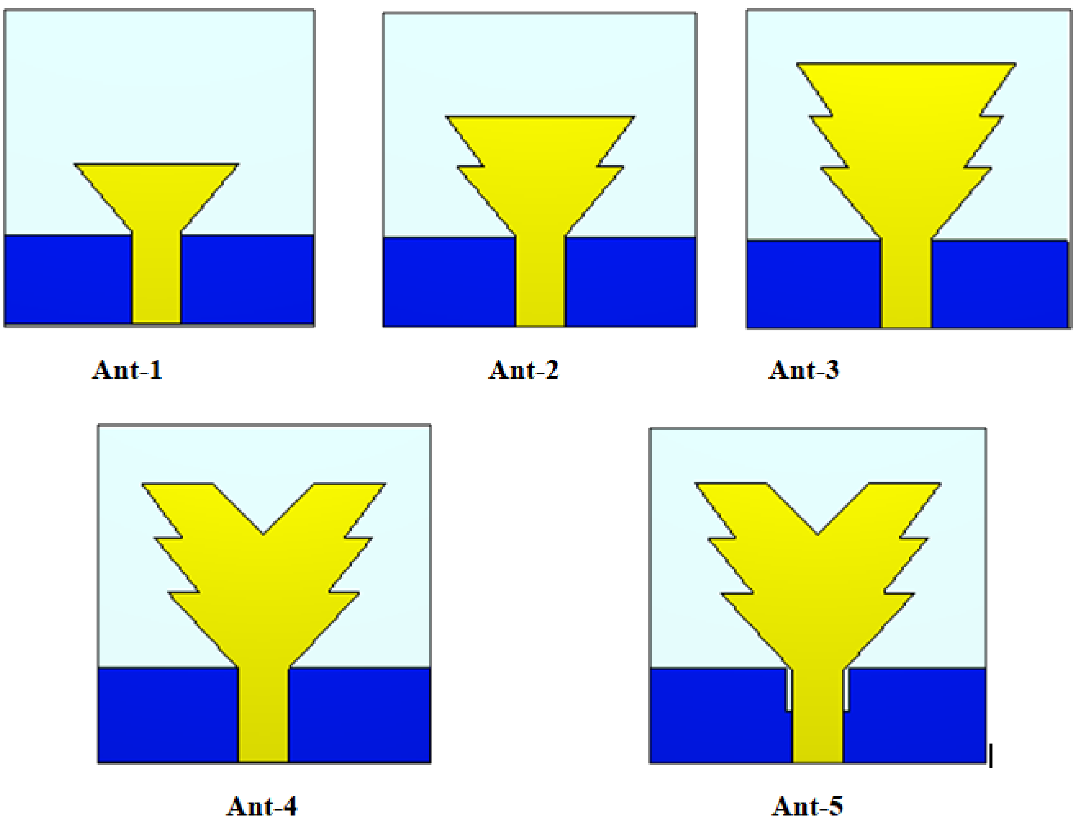


Figure 2.2: The design stages of the proposed UWB antenna

2.2.1 . Result and discussion

Figure 2.3 depicts the simulated results of return loss of the five Antennas, respectively. From the figure, it noticed that the Ant-1 operates at resonant frequency of 8.8GHz with wideband characteristic .By introducing a second triangle shaped a wideband is increased in bandwidth and is shifted to lower frequencies from 4.3-9.2GHz as illustrated in figure 2.3. From the plot, it is also observed that the inverted Christmas tree shaped (ANT-3) gives a larger band ranging from 3.2 to 12GHz which is suitable for UWB application. Ant-4 improves the matching of Ant-3 as depicted in figure 2.3.Finally as introducing a slot on the ground plane the bandwidth is increased to achieve 11GHz ranging from 3.5 to 15GHz which include the UWB application.

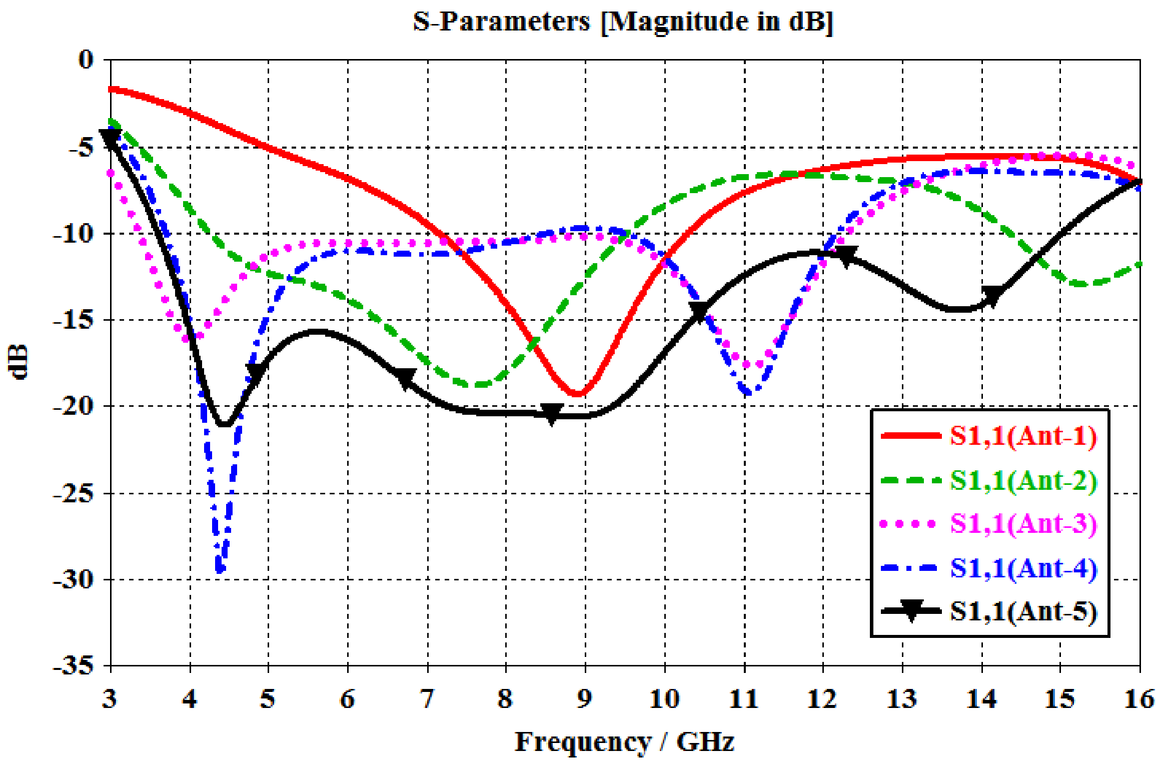


Figure 2.3: Simulated input reflection coefficient of different stages of the proposed antenna.

2.2.2 Parametric study

To further investigate the proposed antenna performance, a parametric study is carried out and discussed.

- **Effect of X:**

Figure 2.4 shows the input reflection coefficient for different values of X (is the length of the base of the triangle)whereas the other parameters are kept constant. From the graph, it is clear that as X is increasing the bandwidth is decreased . For X equals to 14.5 mm, good impedance matching and a large bandwidth are obtained.

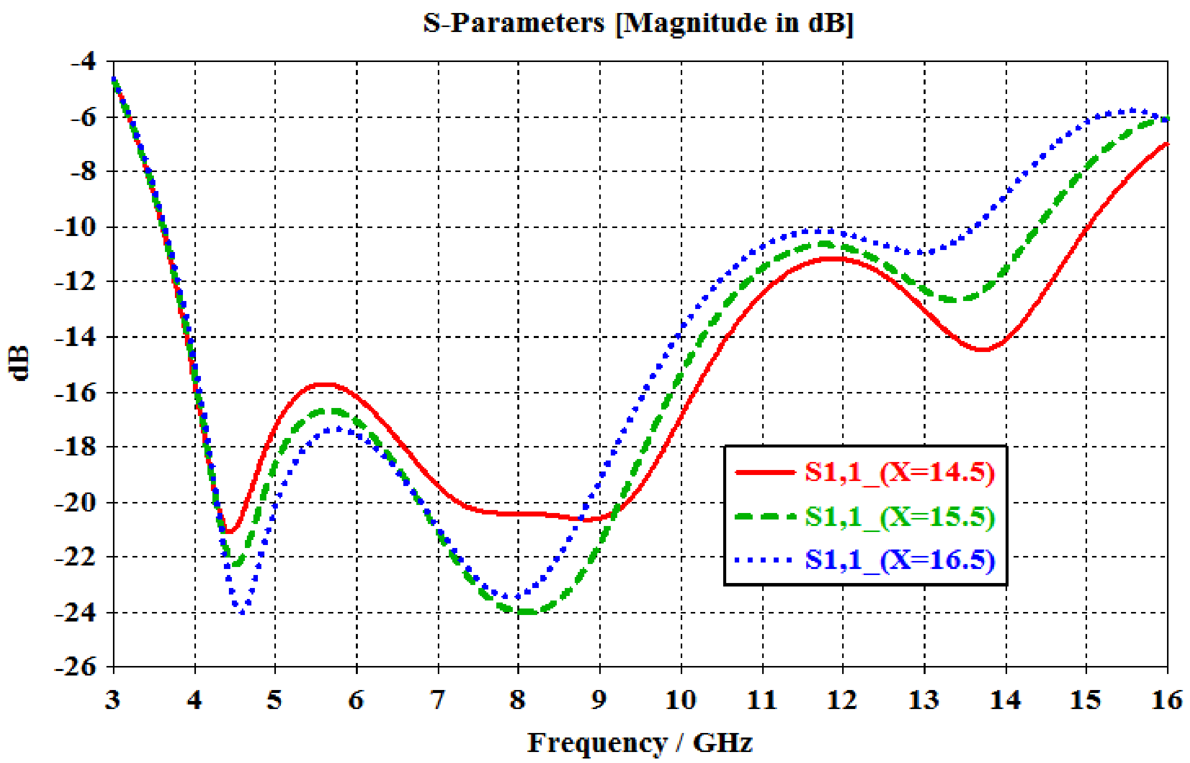


Figure 2.4 : Simulated input reflection coefficient for different values X

- **Effect of Q1:**

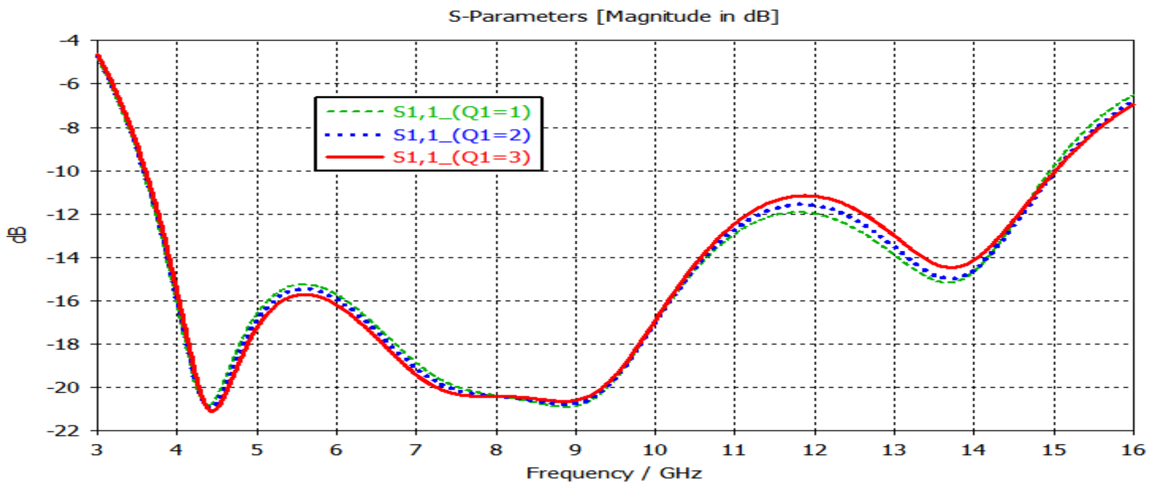


Figure 2.5: Simulated input reflection coefficient for different values Q1

Figure 2.5 shows the input reflection coefficient for different values of Q1 (the height of triangular slot) with other parameters are kept constant. From the plot, it is observed that as increasing Q1 the bandwidth also increases ; For Q1 equals to 3 mm, gives best results .

- **Effect of S1:**

Figure 2.6 displays the antenna input reflection coefficient for different values of S1.It is seen that by increasing S1, the bandwidth is enhanced. For S1 equal 2.5mm, gives the best results as illustrated in figure 2.6.

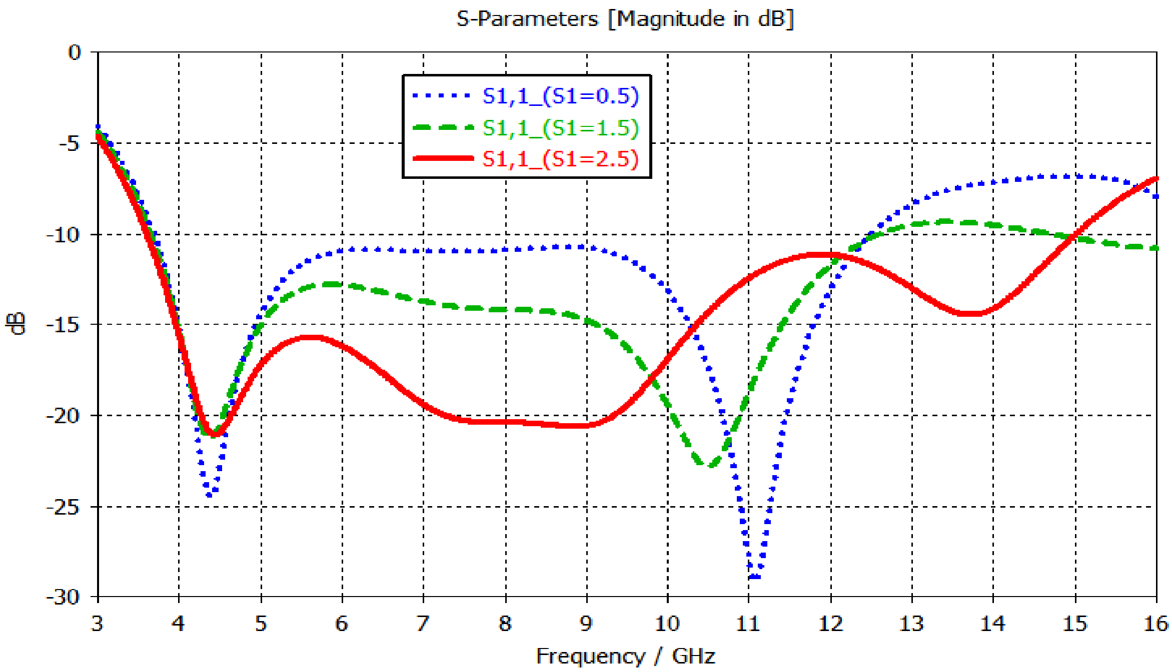


Figure 2.6: Simulated input reflection coefficient for different values S1

- **Effect of S:**

The effect of changing the parameter S on the antenna input reflection coefficient characteristics is depicted in Figure 2.7. It can be observed from the graph that by increasing the value of S the bandwidth decreases. Hence, it can be concluded that a good results are obtained for S=3.7mm.

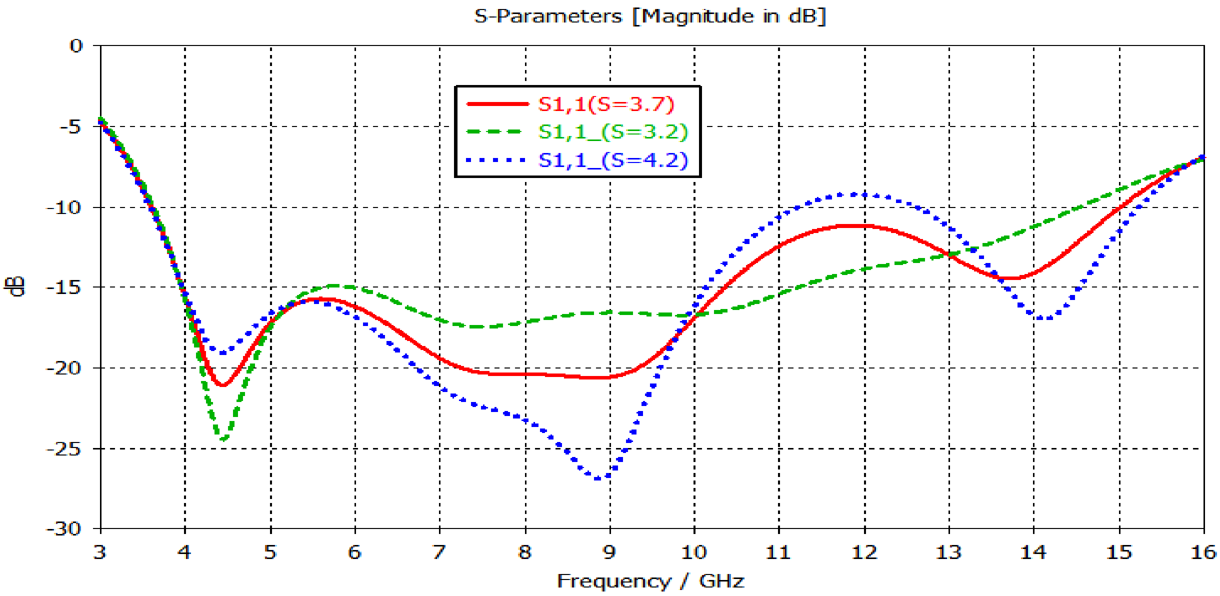


Figure 2.7: Simulated input reflection coefficient for different values S1

The final proposed antenna's geometry is depicted in Figure 2.1. The optimal dimensions of the proposed antenna are displayed in Table 2.1. The proposed structure's simulated input reflection coefficient is shown in Figure 2.8

The bandwidth (BW) of the antenna using the equation below is:

$$BW(\%) = \frac{15 - 3.5}{15 + 3.5} \times 200 = 124.35\%$$

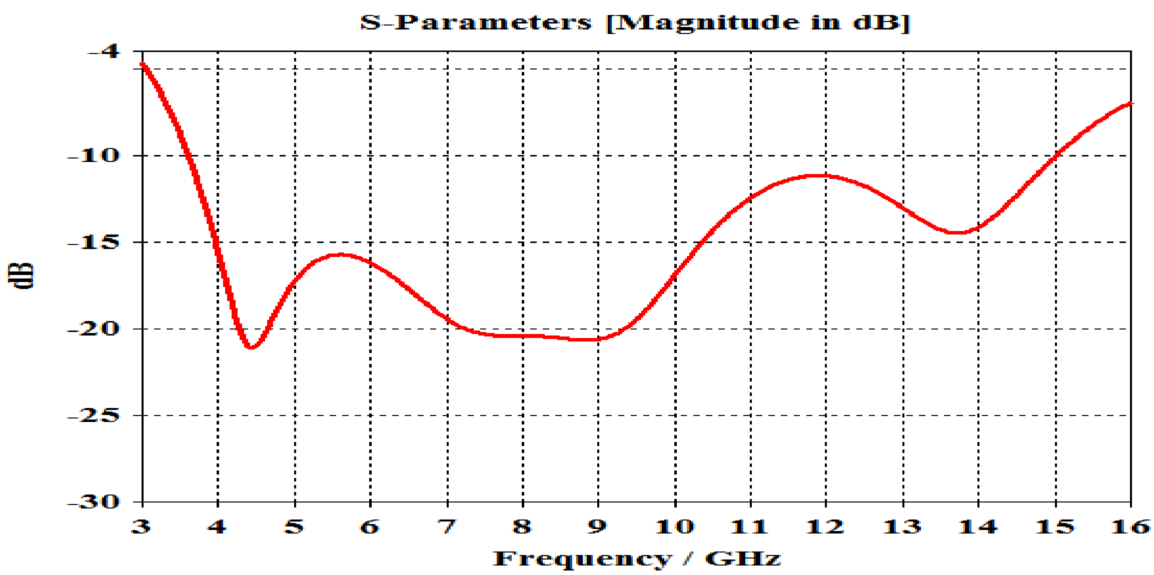


Figure 2.8: Simulated the input reflection coefficient of the final structure.

2.2.3 Current Distribution of UWB Antenna

The current distribution is also an important factor that should be taken into consideration as it shows how the current moves across the patch after feeding the antenna. Figure 2.9 illustrates the simulated surface current distribution on the antenna at 4.4 GHz, 9.06GHz and 123.71GHz ;respectively. From the plot it is observed that the strong surface current occurs on the feeding line and the bottom edges (left and right sides) of the inverted Christmas tree shaped patch and decreases gradually when moving to the top of the patch and in the center of the patch.

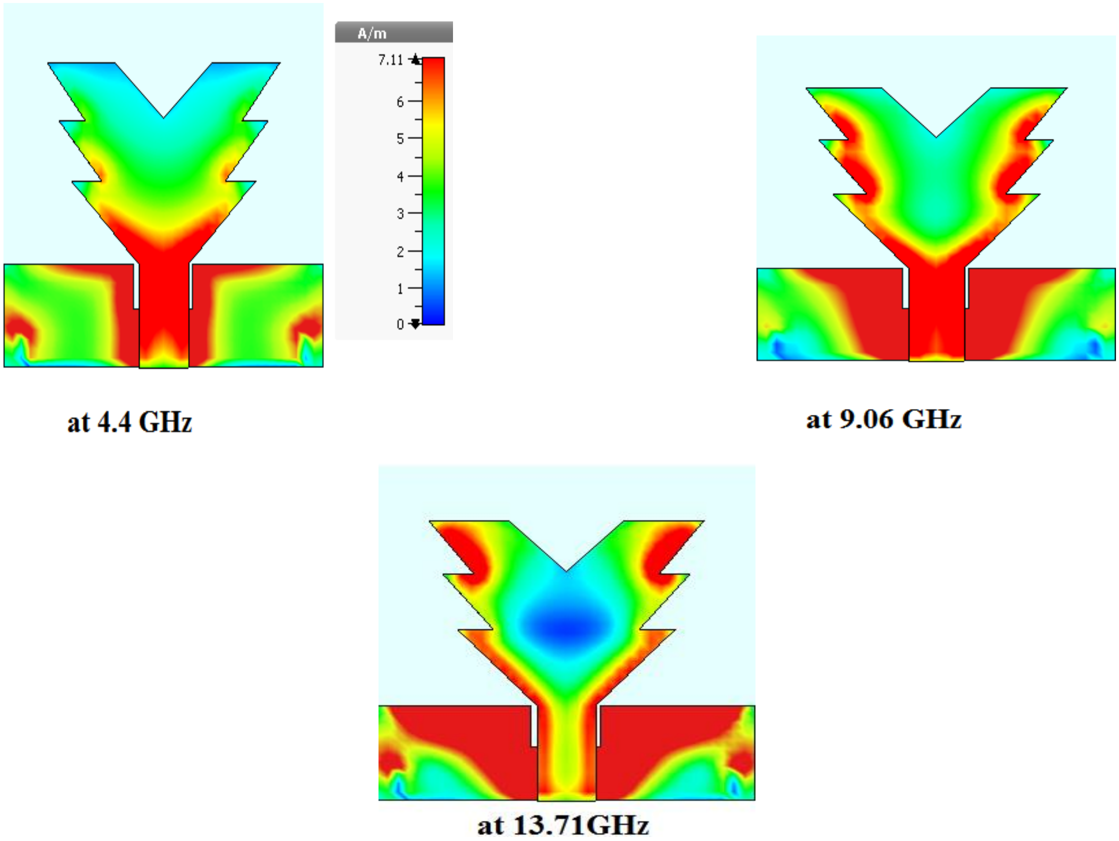


Figure 2.9: Surface current distribution of the proposed UWB antenna without a notch at 4.4 GHz, 9.06 GHz, 13.71 GHz .

2.2.4 Radiation Pattern

The far zone fields of the proposed antenna at three distinct frequencies (4.4 GHz, 9.06 GHz, and 13.71 GHz) in H-plane and E-plane ($\varphi = 0°$and $\varphi = 90°$planes) are shown in Figure 2.10. As observed, the radiation patterns are nearly bidirectional in the E-plane and almost omnidirectional in the H-plane at all frequency points except at f=13.71GHz which has some distortion because the higher modes. The simulated gain of the proposed antenna is shown in Figure 2.11 with gain varies between 1 and 5.1dBi for the whole frequency band.

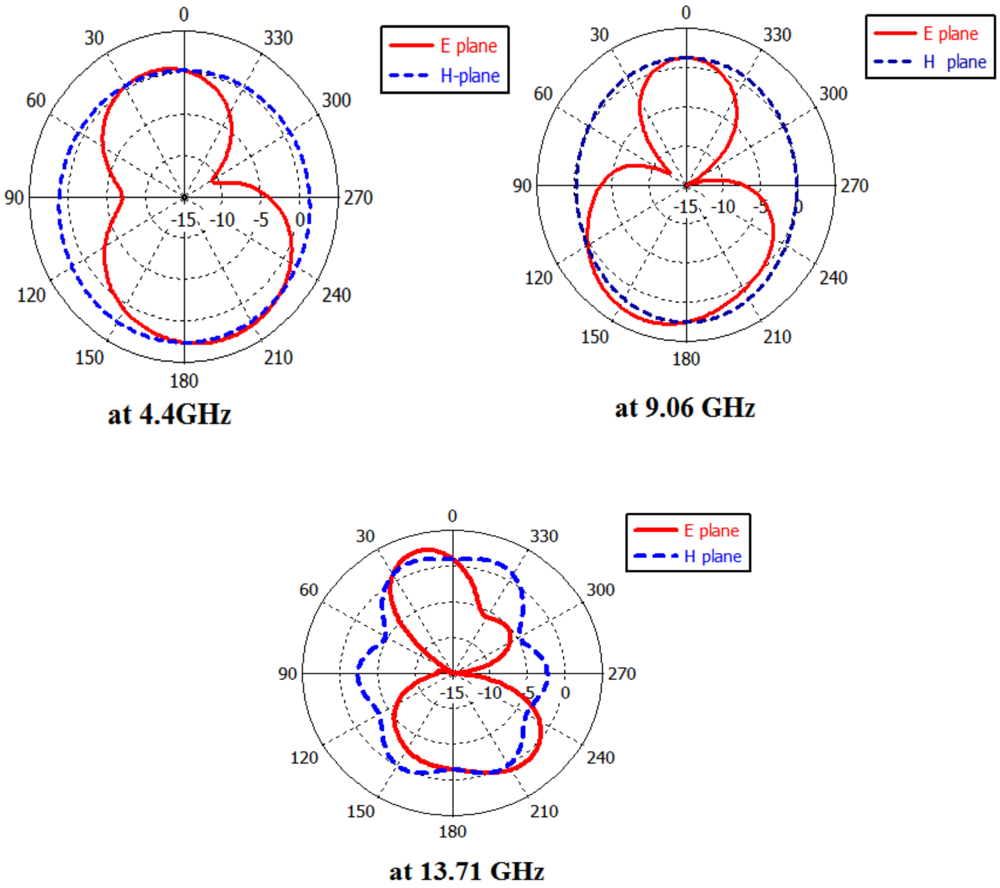


Figure 2.10: Simulated radiation patterns of the proposed UWB antenna without a notch.

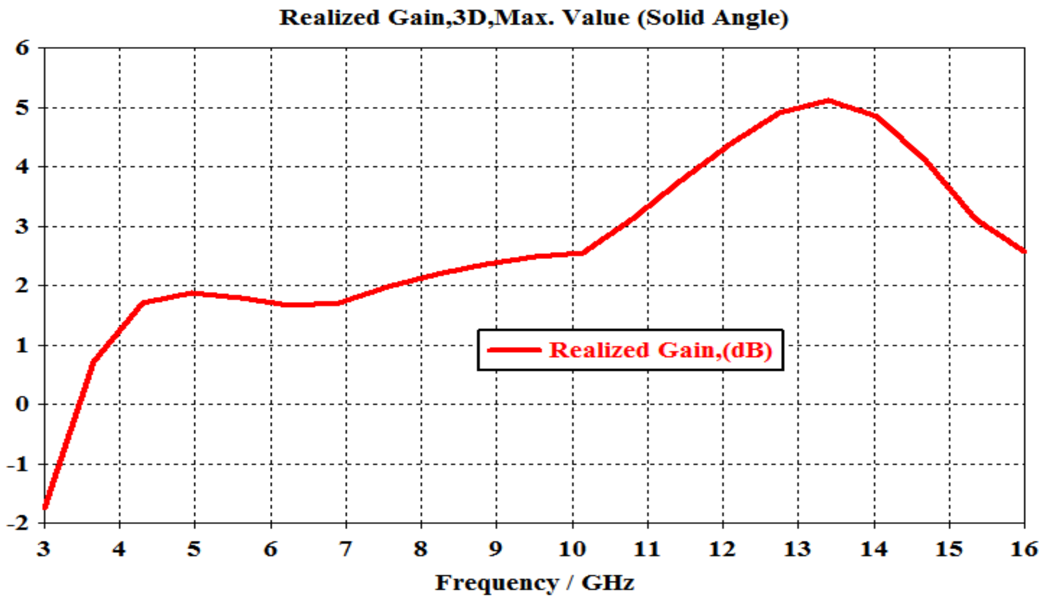


Figure 2.11: Gain of the proposed antenna as a function of the frequency

2.3 UWB Antenna with a notched band

After the designing of the antenna to cover UWB application, the next step is to introduce the band rejection feature. In order to avoid the interference of WLAN (5.15 GHz-5.825 GHz) signals to the UWB system, an UWB antenna with a notched band from 5.5 GHz to 6.2 GHz is required. A band notched is achieved by introducing split ring slot on the patch surface .The 2-D design of the UWB antenna with notched band is shown in Figure 2.12.

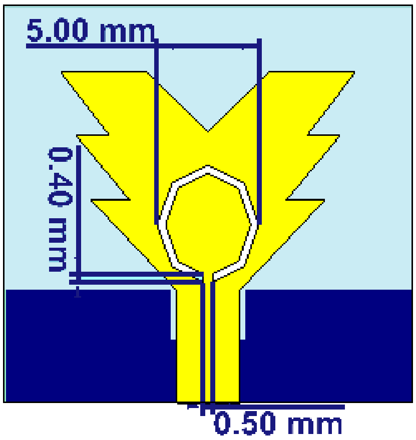


Figure 2.12: The geometry of UWB antenna with notch

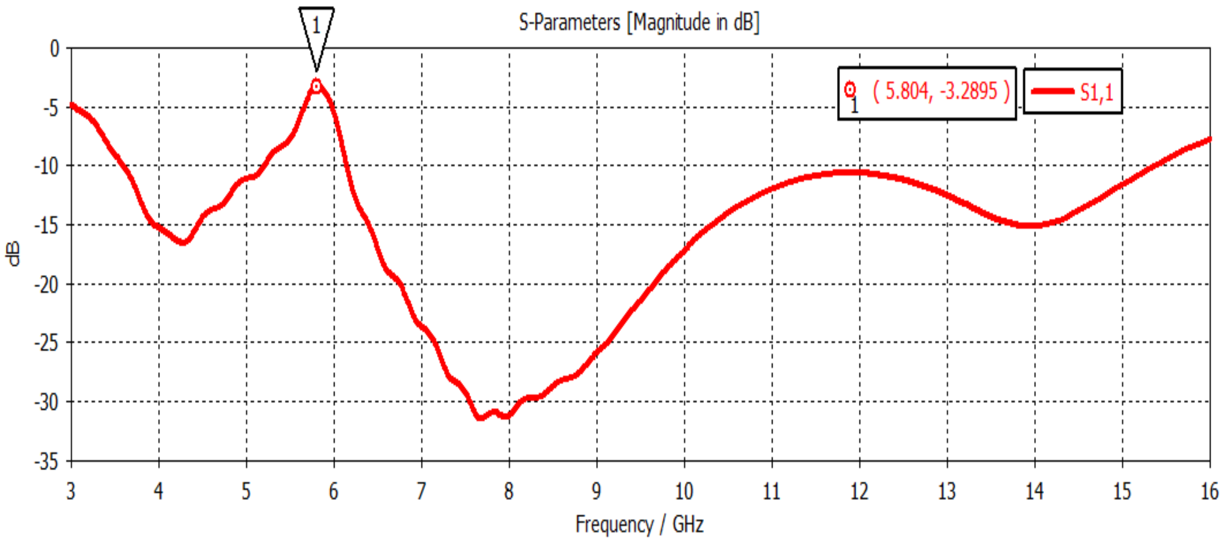


Figure2.13 : The Simulated input reflection coefficient of the final structure.

Figure 2.13 presents the reflection coefficient of the proposed antenna with notched band in the frequency band of WLAN applications. It can be noticed from the plot that the S11 is lower than -10dB except at the notched frequency centered at 5.8 GHz.

2.3.1 Current Distribution of UWB antenna with a notch:

Among the most important parameters used to demonstrate the effectiveness of the notch structures is the analysis of the current surface distribution as shown in Figure2.14. As revealed from the plot ,the current is concentrated around the split ring slot and practically no current passes through the patch. This confirms the fact that the split ring slot acts as a band-stop filter and the antenna does not radiate at this frequency band.

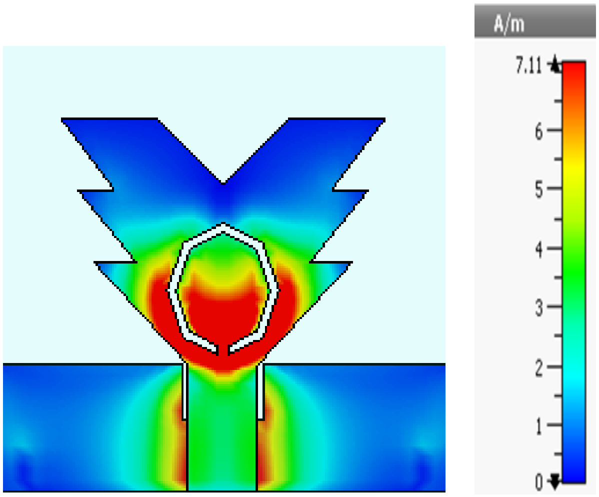


Figure 2.14: Surface current distribution of the proposed antenna at notch frequency 5.80 GHz

Figure2.15 presents the simulated gain for antenna structures with a notch. From the results the gain of the antenna is within the acceptable range, the gain increases with the frequency in the range of [0-6 dB]and, as expected, it decreases considerably at the notched bands .

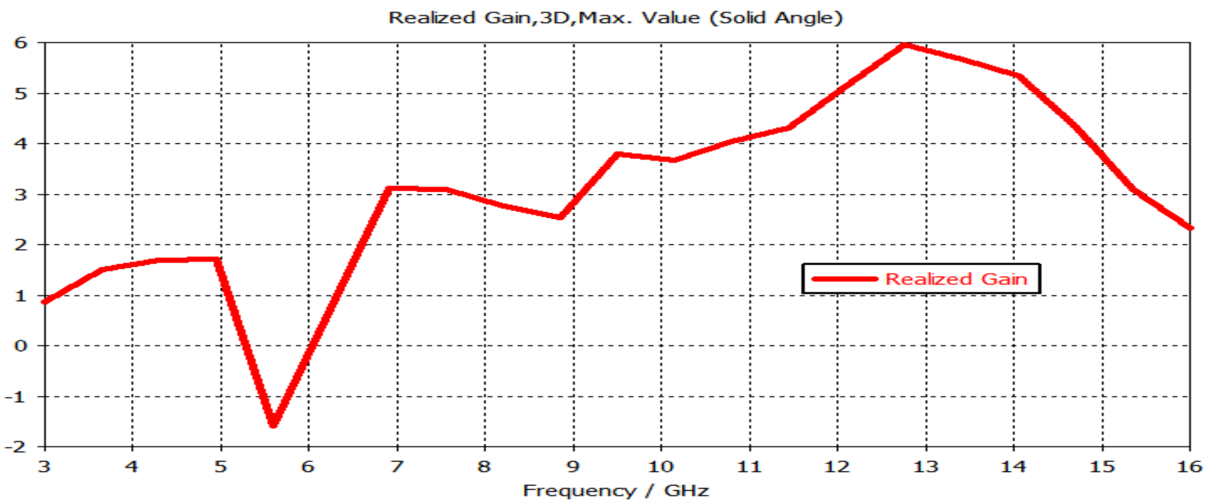


Figure 2.15: The simulated gain of the proposed antenna with a notch.

2.4 Conclusion

In this chapter, a compact UWB antenna with a band notch characteristics is proposed and investigated. To prevent interference with WLAN, the DMS band stop filter (circular split ring slot) introduced on the radiating element is used to reject the frequency band. The simulated and measured return losses show a good agreement and the proposed antenna can be a good candidate for UWB wireless communication systems.

References

[1] Pandey, D. and Kundu, S. (2023) 'A Christmas Tree-Shaped Quadband Compact Antenna with Triple Slots for Various Wireless Technologies', *IETE Journal of Research,* 70(2), pp. 1209–1218. doi: 10.1080/03772063.2023.2171914.

[2] Pandey, D., & Kundu, S. (2023). A Christmas Tree-Shaped Quadband Compact Antenna with Triple Slots for Various Wireless Technologies. *IETE Journal of Research*, *70*(2), 1209–1218. https://doi.org/10.1080/03772063.2023.2171914

Chapter 3

A Compact UWB MIMO Antenna with Band Notched at WLAN Frequency Band

3.1 Introduction

In this chapter, a compact UWB MIMO antenna with band notched characteristics is presented. the antenna element is the same as the antenna that is discussed in chapter 2. In order to minimize the overall size of the MIMO antenna with high isolation, an inverted T-shaped bar is inserted between the antenna elements at the ground side and a rectangular split ring resonator is added in the top of MIMO structure between the two antennas. The proposed design printed on an FR-4 substrate with dielectric constant 4.3, a thickness of about 1.63 mm and a loss tangent of 0.02.a detailed study of the proposed compact MIMO antenna will be presented.

3.2 Design of MIMO Antenna

The geometry of the proposed UWB MIMO antenna with band notched for WLAN applications is shown in Figure 3.1. The design involves two identical planar monopole elements placed in parallel to each other and constructed on the top side of the dielectric substrate and backed by the partial ground. An inverted T shaped stub is inserted in the middle of shared ground plane and a rectangular split ring resonator is introduced in the top of substrate between the two identical antennas to improve the isolation between them. The radiators are the same as the single UWB monopole antenna that is discussed in chapter 2. The overall size of the proposed structure is $20\times39\times1.63\ mm^3$.

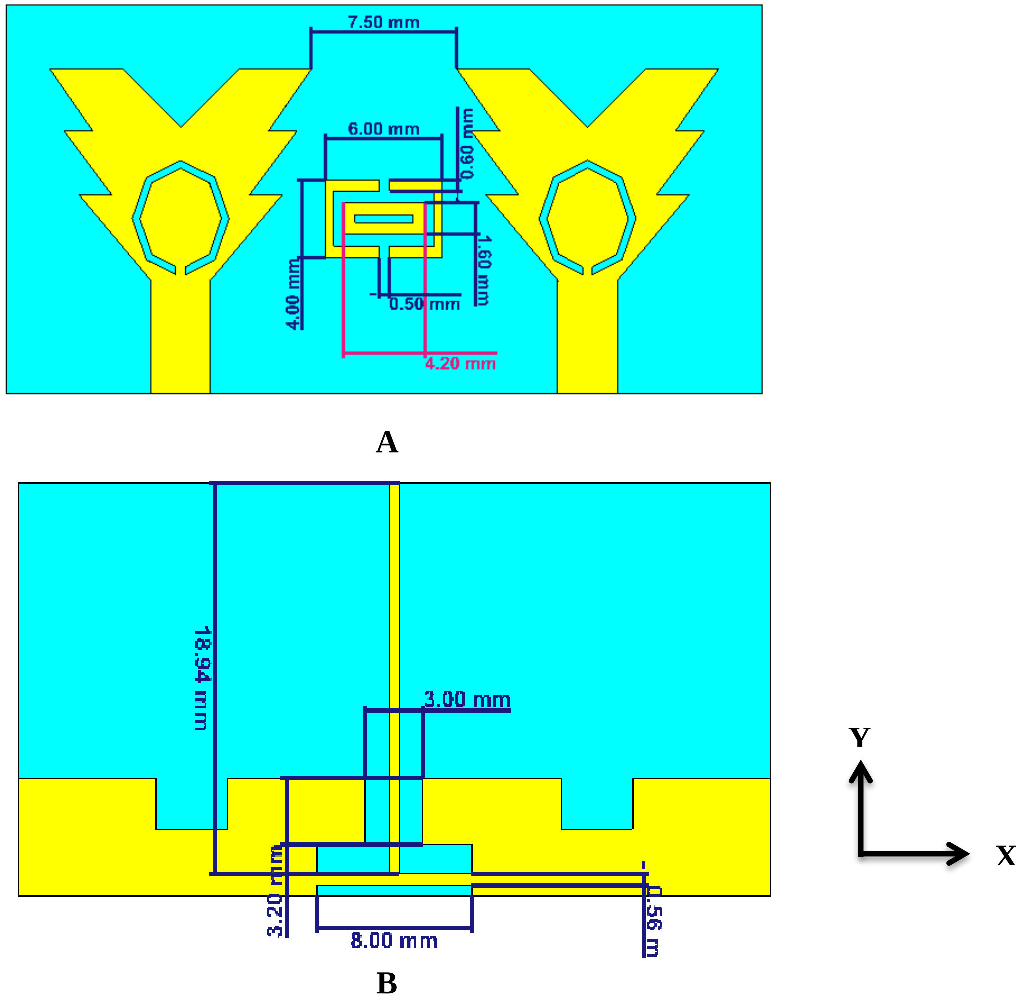


Figure 3.1: Geometry of the proposed antenna (A) front view(B) back view.

Usually, the design of a MIMO antenna needs to consider the issue of isolation. Several methods have been used to improve the isolation, such as increasing the distance between the antenna units, adding a decoupling structure or a metal isolation bar. However, the parallel placement is used in this work to improve the isolation of the designed MIMO antenna. Compared with other methods, this method can achieve a more compact structure without enlarging antenna size, reducing antenna performance, and affecting the impedance matching of the antenna.

Defected ground structure (DGS) is used to reduce mutual coupling between radiating elements of MIMO antennas. It disturbs and diverts the surface current distribution and suppresses the coupled fields between the radiating elements of the MIMO antenna.

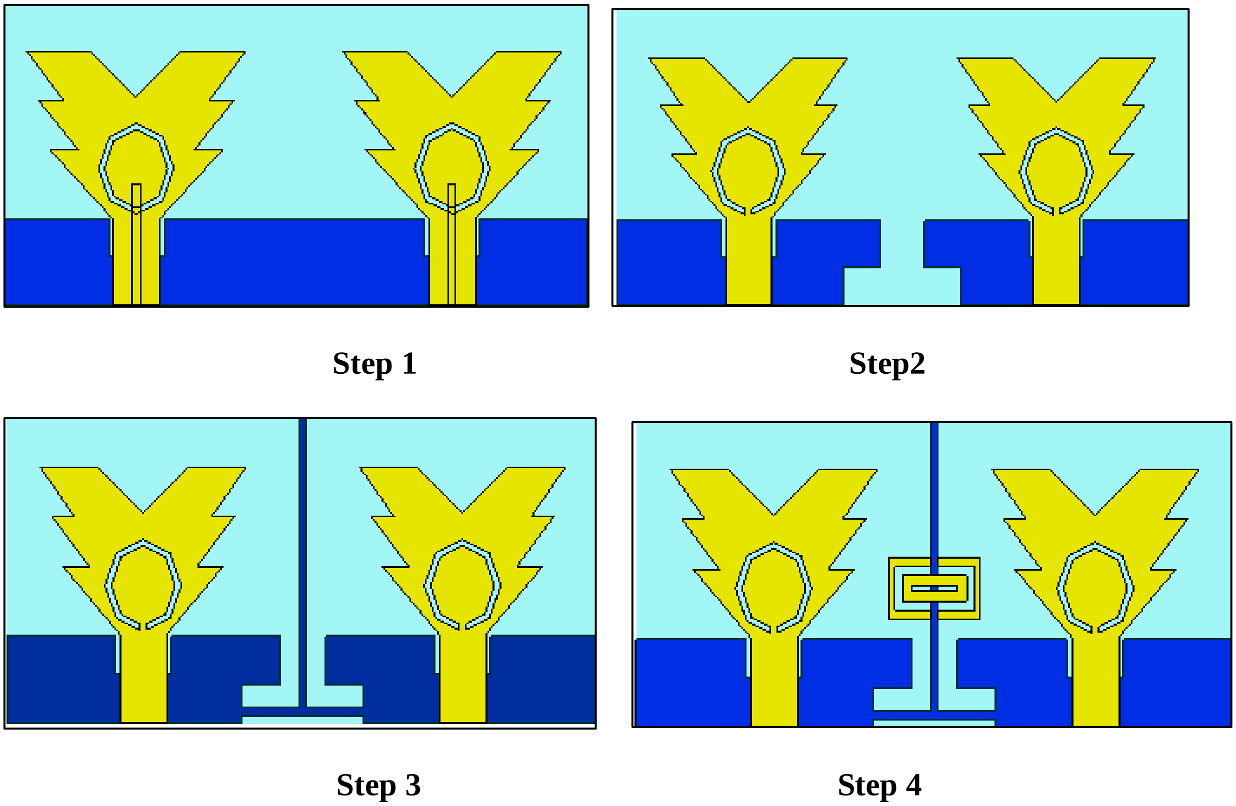


Figure 3.2: Evolution structures of the proposed UWB-MIMO antenna.

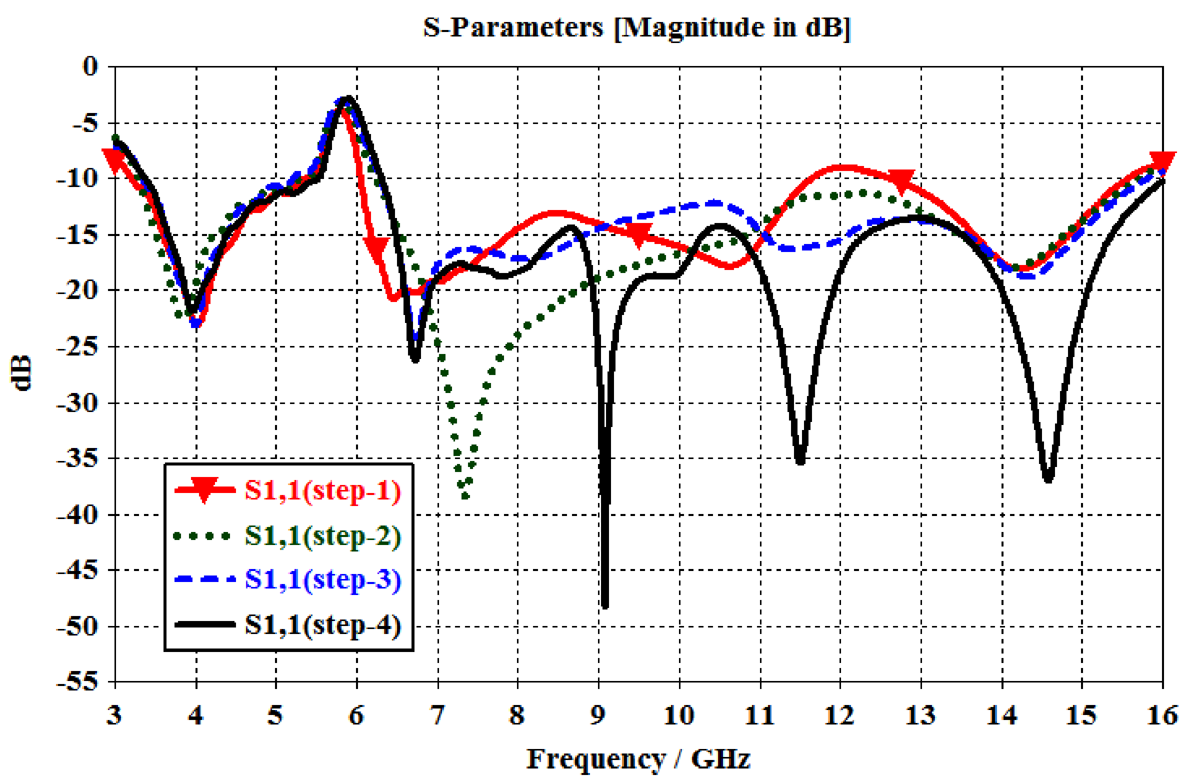
The evolution process of the design UWB MIMO antenna is shown in Figure 3.2. Initially, two identical UWB inverted Christmas tree shaped monopole antenna elements are placed parallel to each other with a simple shared ground plane as illustrated in step 1 in Figure 3.2. Then, the ground is modified by introducing an inverted T shaped slot as illustrated in Figure 3.2(Step-2). Next, an inverted T shaped bar is placed in the middle of the T shaped slot in the ground plane between two antennas (Step-3) as depicted in Figure 3.2. Finally, in the last stage to ensure more isolation conditions a rectangular split ring resonator shape is placed between the two antennas on the top of substrate as presented in (Step-4) Figure 3.2

3.2.1 Result and discussion

Figure 3.3 shows the respective S11 and S21 responses (versus frequency) for the different stages of the proposed MIMO antenna. .From the plot; in step 1 the design exhibits the large impedance bandwidth ranging 3.4-15.7GHz with mismatch at 12GHz with a very poor isolation through the operating bandwidth. In the next step, the antenna covers the whole UWB range with slight increasing in the band notch, also the mutual coupling (|S 12 |) decreased noticeably to less than

15 dB except at the lower frequencies. The antenna provides a wide band ranging from 3.4 - 16GHz with WLAN band notch and mutual coupling reduction is obtained (<-15dB).Finally, step 4 and 5 the antenna covers the whole UWB range (3.4-16GHz) with good matching and the mutual coupling is less than (<-17dB) .

The input reflection coefficient and the transmission coefficient of the optimum final structure is presented in Figure 3.4. The antenna exhibits an UWB range with a notched band in (5.51-6.28GHz) centered at 5.8GHz for WLAN application. .It is also clearly seen from the figure that the isolation between the two antennas is high approximately (≤-17dB) and covers the whole band of UWB.



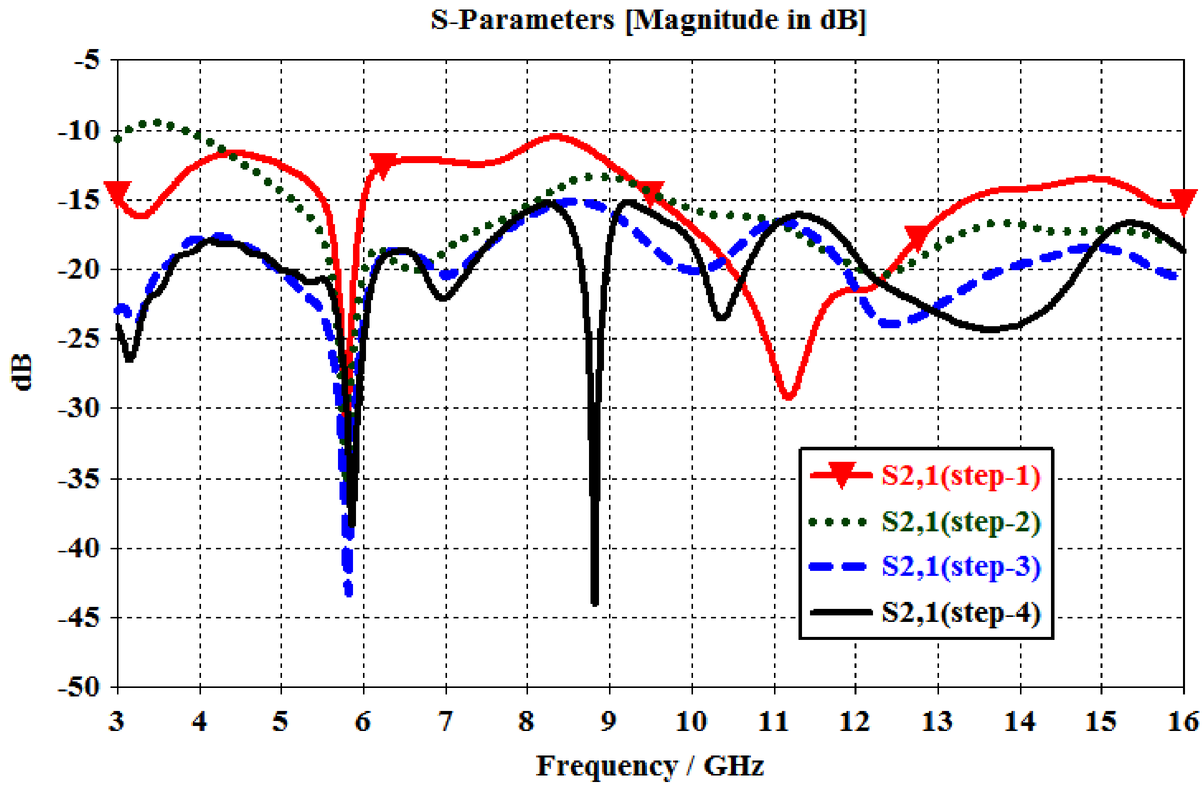


Figure 3.3: Simulated S11 (dB) and S21 (dB) response for different steps of the proposed UWB MIMO antenna.

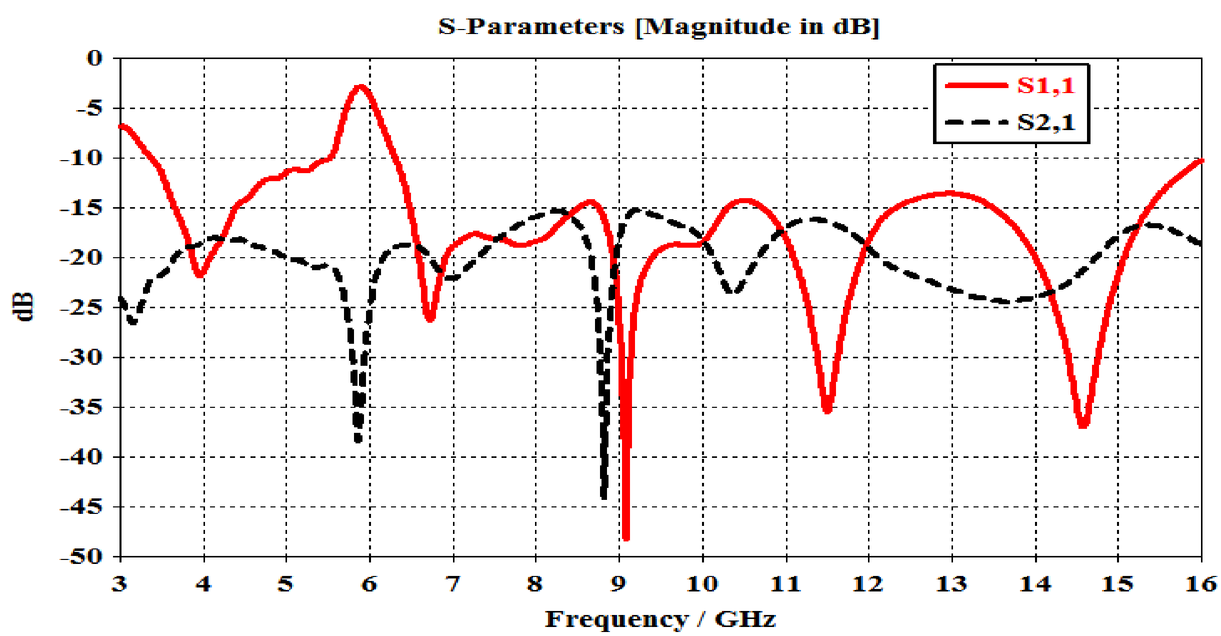


Figure 3.4: Simulated S1.1 &S2.1 of the final structure**.**

3.2.2 The current distribution

To further understand the decoupling effect between antenna elements, the surface current distributions at the three bands are depicted in Figure 3.7. When port 1 is excited and port 2 is matched by 50 Ω load (vice-versa when port 2 is excited).

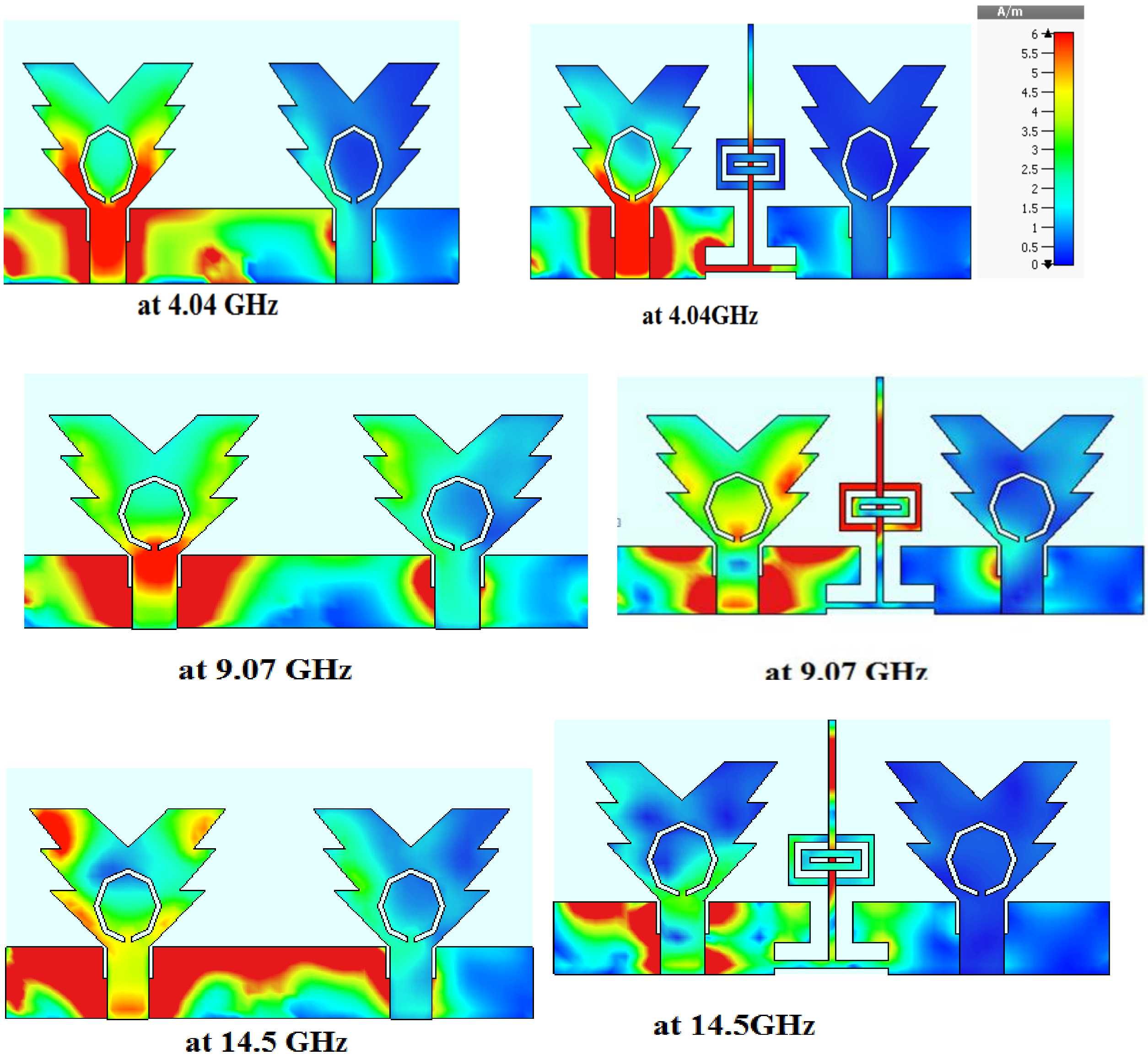


Figure 3.5:Surface current distribution of the proposed MIMO Antennaat with and without isolation at 4.04 GHz, 9.07 GHz, 14.5 GHz**.**

When the MIMO antenna is excited at port 1 without isolation , the surface current of port 1 has high tendency to couple with port 2 through the common ground plane (vice- versa when port 2 is excited).It is also observed that with isolation technics, the surface current is strongly excited in the inverted T-shaped stubs and a rectangular split ring resonator port which results in better inter-port isolation and there by significantly improves the diversity performance of the UWB MIMO antenna.

3.2.3 The radiation pattern

Figure3.8 shows the simulated radiation patterns containing E-plane and H-plane (x-z plane) and E-plane y-z plane) at the 4.04, 9.07, and14.5GHz. One of the two ports is excited and the other port terminated with 50-Ω matched load.

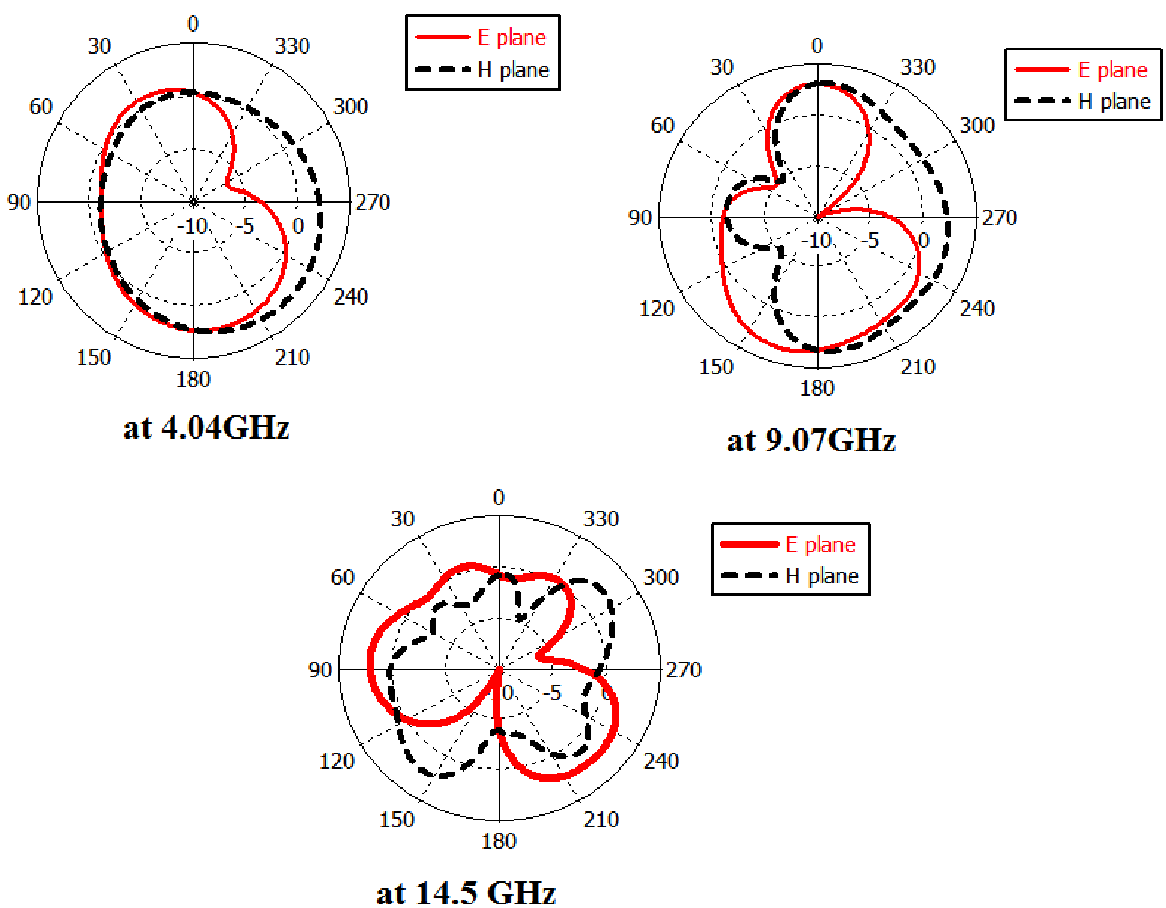


Figure 3.6: Simulated radiation patterns of the proposed UWB MIMO Antennafor port-1.

From the graph, it is observed that the radiation patterns are almost Omni-directional at the three frequencies and bidirectional in E-plane was observed at all frequency bands. It is noted also that as the frequency increases, the shape of the pattern becomes distorted.

Envelope Correlation Coefficient is an important parameter which indicates the diversity performance and pattern independence of the elements of the antenna. For the two port MIMO antenna, ECC can be obtained from the following equation using S-parameters [1].

$$ECC = \frac{\left|S_{11}^{*}S_{12} + S_{21}^{*}S_{22}\right|^{2}}{\left(1-\left(|S_{11}|^{2}+|S_{21}|^{2}\right)\right)\left(1-\left(|S_{22}|^{2}+|S_{12}|^{2}\right)\right)}$$

The value of ECC should ideally be zero for an uncorrelated MIMO antenna. However, for practical circumstances, the preferred limit is ECC < 0.5. Figure 3.7 presents the graph of ECC versus frequency of the proposed quad band MIMO antenna. From the figure it is observed that the ECC < 0.01 over the four operating bands of the proposed MIMO antenna, which is so far below the accepted value 0.5.

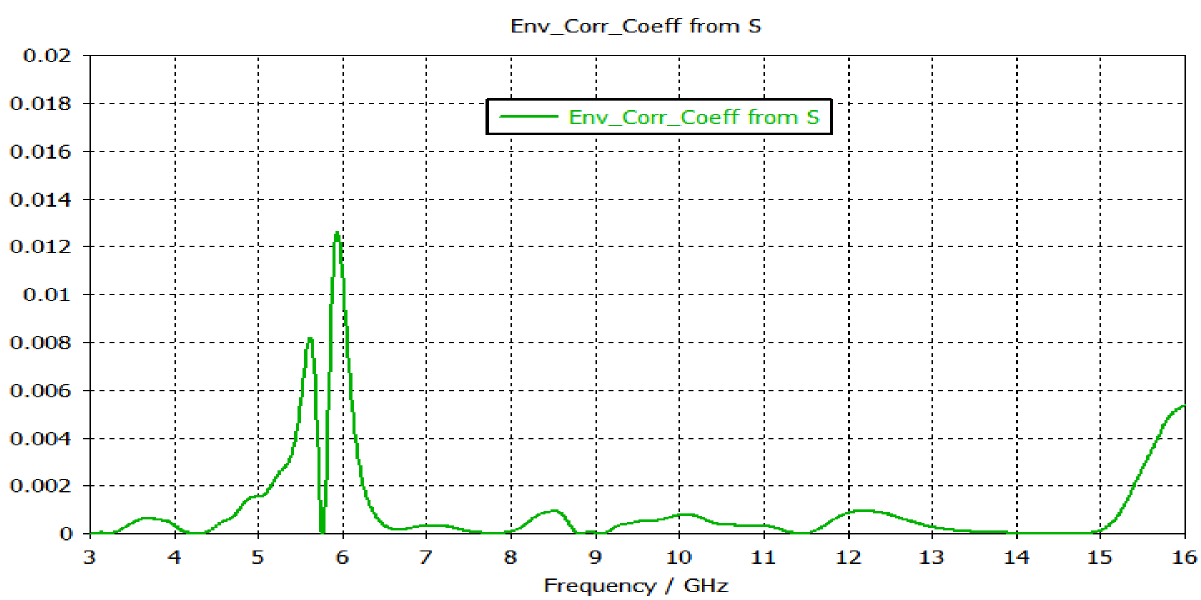


Figure 3.7: Simulated ECC for the proposed MIMO antenna

Diversity gain is also an important parameter to evaluate the diversity performance of the antenna. The relation to calculate DG of the MIMO antenna is as given below[2]:

$$DG = 10\sqrt{1-(ECC)^2}$$

The diversity gain is also simulated and it is varying around 10 dB over operating band of the MIMO as observed in Figure 3.8.

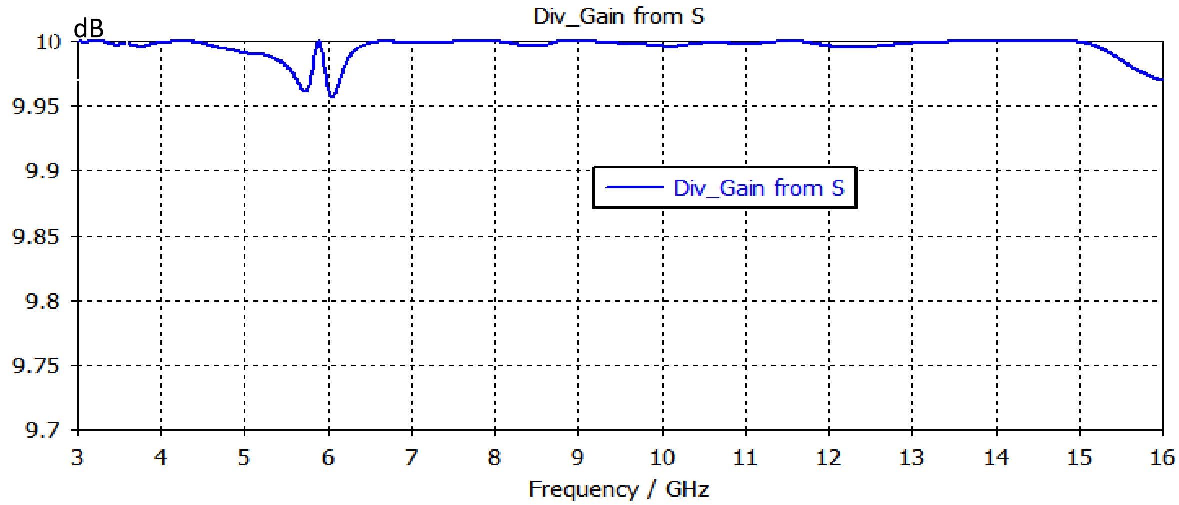


Figure 3.8. Diversity gain of the proposed MIMO antenna.

3.3 Conclusion

In this chapter, a compact two-element band-notched UWB MIMO antenna is proposed. The proposed MIMO antenna is fabricated and tested. The antenna offers a wide impedance bandwidth with one notched band. An inverted T-shaped stub in the common ground plane and a rectangular split ring resonator in the top of substrate of the MIMO antenna help in improving the isolation between MIMO elements. The MIMO antenna also exhibits good diversity performance with value of ECC < 0.01, and DG ≈ 10 dB for the whole UWB band.

[1] H. S. Singh, G. K. Pandey, P. K. Bharti, and M. K. Meshram, "Design and performance investigation of a low profile MIMO/Diversity antenna for WLAN/WiMAX/HIPERLAN applications with high isolation," *International Journal of RF and Microwave Computer-Aided Engineering*, vol. 25, pp. 510-521, 2015.
[2] M. S. Sharawi, *Printed MIMO antenna engineering*: Artech House, 2014.

General Conclusion

This work focuses on study, design, fabrication and measurement of compact UWB MIMO monopole antenna with notched band characteristics. The MIMO system contains two elements are placed adjacently.

In the first part, an UWB Iverted crismas tree shaped patch antenna with notched bands have been proposed .The proposed UWB exhibits a large functional bandwidth ranging from 3.5 to 15 GHz. a compact UWB printed monopole antenna with band rejection characteristics for WLAN application is proposed. The antenna provides an ultra-wide impedance bandwidth ranging from 3.5 GHz to 15 GHz. Furthermore, A circular split ring slot is introduced on the radiating patch to get a band notched at WLAN . The design and simulations procedures are carried out using CST Microwave studio(MWS)software.

The proposed antenna also provides a good radiation characteristic as well as stable gain (0-3.9 dB) throughout the UWB range except for the two rectangular notches, where it decreases to negative values.

The work is extended to design and analysis of compact UWB MIMO antenna with band notched characteristics. The proposed design has a compact dimension of 20 mm ×39 mm. Isolation between two ports is enhanced by the addition of an iverted T line on the partial ground plane and a split ring resonator between antenna elements. The obtained results show that the UWB MIMO antenna has a large functional bandwidth covering from 3.4 to

The antenna port envelope correlation coefficients are observed to be less than 0.02 with diversity gain better than 10 dB. However, the gain curve for the suggested antenna is exponentially increasing with a sharp decrease at the notched frequencies. The measured results show good resemblance to the simulated ones.

The suggested future work on this subject is:

- Design a compact 4×4 UWB MIMO antenna with notched band characteristics.