<u>Development of a Compact UWB MIMO Antenna with WLAN Band Rejection</u>

By

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In The name of Allah the most Beneficent and the most Merciful

DEDICATION

Dedicated to my family who has always been a source of motivation for me and also to my supervisor Dr Farooq Ahmed Bhatti for being forthcoming and helping in fulfillment of this research work.

ABSTRACT

Ultra Wide Band (UWB) technology has become attractive since the U.S. Federal Communications Commission allocated the (3.1-10.6) GHz frequency band for commercial UWB systems, it has become a favorable technology in the wireless communication area. UWB has promising applications in short-range, high-data-rate transmission, medical imaging etc. Another challenge faced by these systems is multipath fading which can severely degrade the transmission quality. The use of multiple-input multiple output (MIMO) and array technology is an effective solution to mitigate this problem and improve the channel capacity and quality of wireless link.

Issues like Multi path effect and reduction in BER are catered with the help of MIMO. This technique ensures high data rate. Therefore, a MIMO antenna operating in the UWB is key technology for next generation. The transmission capacity and reliability of a system can be improved by using diversity techniques without increasing the bandwidth and power. Although UWB is unlicensed band, there is interference due to coexisting narrow frequency bands. To protect WLAN frequency band from interference notch is added which act as filter.

An improved model is proposed to reduce isolation between different antennas which occurs because of neighboring antennas. As a result return losses are increased which are also catered.UWB also introduces interference on other bands which is an important issue to be tackled. For these problems a notch is added to avoid these loopholes.

DECLARATION

No content of work presented in this thesis has been submitted in support of another award of qualification or degree either in this institution or anywhere else.

ACKNOWLEDGEMENTS

With profound humility, I pay my gratitude to Allah Almighty for enabling me to achieve another astounding milestone in my literary career. I would like to extend my special thanks to the faculty and administration of Military College of Signals and NUST, for proffering a commendable research environment at the institute. This arduous work would have not possible without the support of my supervisor Dr. Farooq Ahmed Bhatti and co-supervisor Madam Marayam Rasool who not only provided timely guidance, profound encouragement and positive criticism but also ensured that I complete the assigned tasks in stipulated time. There affectionate and kind consideration towards my research helped me to carry on with my project in odd circumstances. I m also very obliged to my committee members, Dr Abdul Rauf, Dr Imran Rashid and Dr Zeeshan Zahid for their intimate help in fulfillment of this research work.

I am deeply indebted to my great parents, siblings and colleagues for their encouragement and affectionate selfless prayers. Most importantly I would like to thank my dear friends Maida, Soban, Aqib and Sufyan for always appreciating my hard work. Without their continuous support and dialogues of encouragement this would not have been possible.

List of ACRONYMS

UWB	Ultra Wide Band
MIMO	Multiple Input Multiple Output
HFSS	High Frequency Simulated Simulation
VSWR	Voltage Standing Wave Ratio
WLAN	Wireless local area Network
WBAN	Wireless Body area Network
WPAN	Wireless Personal Area Network

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CHAPTER 1

INTRODUCTION

1.1 Background

Different methods are used for wireless communication systems but Ultra Wide Band (UWB) is the basis of all those methods. The first spark gap transmitter was invented by Heinrich Hertz in 1886 after he verified the Maxwell's Equations. The first ever communication system of UWB was established in London in 1896. The task of this system was to connect two post offices which were very far from each other [1]. In 1960 also one UWB system was implemented which basically allows the US armed forces to make use of pulses in order to assure radar and stealth communication [2]. In 2002 Federal Communication Commission (FCC) have introduced the ultra-wide band technology for commercial applications [3] at a limited transmit power of –41 dBm/MHz. The most important aspect of UWB system is that its channel capacity can be considered as bandwidth. Since the bandwidth of UWB system is ultra wide so it has the capability to handle large amount of data rate. UWB after having the capability to handle large amount of bandwidth will be able to cross many license carrier based transmissions. UWB transmissions may result in interference this is one of the biggest assumptions presumed by everyone. UWB systems have the ability to work at extremely low power levels, thus having low power spectral density. This attribute is mainly because of the high bandwidth. It is able to provide reliable and good communication system as due to low energy density the chances of sudden detections are being reduced. The regulatory bodies have strictly limited the power limits on UWB. At few occasions they are so low that even lower than the spurious emissions from electronic apparatus. Keeping in mind this thing it is being assumed that no noticeable interference will be caused by UWB transmission to other licensed users. But besides this the regulatory bodies are trying to make sure that the other users are not being disturbed and their performance is not affected [4].

MIMO is another important and emerging technology. It is having multiple antennas either at the input side or at the output side or at both ends in order to enhance and improve the performance of communication system. For obtaining optimum performance both the sides must have this technology [5].

One important feature that can be added in MIMO is polarization diversity. This approach allows having orthogonal polarization within the same aperture. We need multiple antennas to be placed at a distance of few wavelengths apart in order to enhance results. But this restriction is avoided after the MIMO technology and the antenna size is also reduced which are highly efficient. Significant increase in data throughput will be observed without need for any additional bandwidth. Along with this the cost required for antenna installment will be greatly reduced.

MIMO has these enhanced and improved features.

1. Diversity is greatly increased when dual-polarization is used.
2. Reduced space of antennas.
3. Diversity in polarization.
4. Use of multiple sector antennas to increase coverage.
5. Less signal drop-out in a moving source.

UWB-MIMO is a short range, broad band, high data rate and reliable communication system [6] [7]. Advantages of UWB-MIMO system such as mitigation of interference, high data rate and reliable link make it suitable for the applications high data rate wireless communication systems and radar system.

In past, few years the trend in modern communication system and UWB MIMO system is towards miniaturization. Antenna is an integral part of any wireless communication system. Printed micro strip antennas are widely used in UWB applications due to its compactness and conformity. To introduce MIMO technology in UWB antenna, high isolation between antenna elements is required. Increasing research has been devoted to design an antenna that can provide ultra-wideband impedance bandwidth and good radiation properties with compact size and high isolation between antenna elements.

In literature, one can find multiple techniques to achieve high isolation in UWB-MIMO antennas, like defecting the ground structure [8] [9], spatial and angular variations of antenna elements [6-8] using heterogeneous antenna elements [10]. But using the defecting ground and spatial angular variation techniques increases the size of antenna. While using the heterogeneous antenna elements increases the complexity of antenna design.

There also exists a simple technique inserting stubs between antenna elements to achieve high isolation for UWB-MIMO antenna [11] [12]. However, this tends to large size of antenna and compromise the compactness.

In [13] a compact antenna size of 22 mm × 36 mm was achieved but isolation S21 is less than -15 dB. In [14] two stair case monopoles antennas are separated by comb structure connected to ground plan to achieve compact size of 20 mm × 30 mm but its isolation is less than -20 dB and the comb structure increase the complexity of antenna design.

Planar Monopole antennas from literature are the most effective for UWB communication systems because they provide many benefits like wide impedance matching, simple structure and easy fabrication. The interference between UWB system and other systems which are using the Wireless Local Area Network (WLAN) band operating in the same frequency band need to be avoided. For this purposes various band-rejection techniques need to be used. Many applications like 3.6 GHz IEEE 802.11y Wireless Local Area Network (WLAN) (3.6575-3.69 GHz), 4.9 GHz public safety WLAN (4.94-4.99 GHz) and 5 GHz IEEE 802.11a/h/j/n WLAN (5.15-5.35 GHz), (5.25-5.35 GHz), (5.47-5.725 GHz), (5.725-5.825 GHz) are operating in the FCC UWB 3.1-10.6 GHz band. In order to avoid interference some band-rejection technique is to be implemented [15]. Therefore, a compact simple printed micro strip antenna that can provide high isolation MIMO function for UWB antenna along with WLAN band rejection is the scope of this thesis.

1.2 Research Motivation

1.2.1 Problem Statement

Whenever the number of antennas is increased in MIMO technology this leads to an increase in insertion loss. So this rise in insertion loss calls for isolation. We need to add isolation in order to avoid insertion losses. More the isolation less will be the insertion losses.

UWB systems cause interference in WLAN band which degrades the performance of the system so to tackle this issue a notch is added in antenna which acts as a band stop filter rather than adding a filter at RF front end.

1.2.2 Aims and Objectives

Following are the aims of this thesis.

1. UWB Antenna Design
2. Introduce four-element MIMO technology.
3. Increase isolation to reduce return losses as increasing isolation is a challenging task.
4. To introduce notch on WLAN band is a difficult task as pervious results need to be maintained.

1.3 Applications

There are plenty of applications where we can use UWB technology. They can be categorized among data and voice communications to radar and tagging. Although a lot of hype is made about the use of ultra wideband UWB in commercial applications but these systems are equally important in military applications. Out of many advantages one important benefit is that the pulses are spreaded over a wide range of spectrum so they will be difficult to detect. This makes the idea for use in covert communications [16].

The commercial applications are illustrated below.

1. Radar Avoidance
2. High speed LAN / WAN (>20 Mbps)
3. Tags for intelligent transport systems
4. Altimeter (aviation)
5. Geo-location
6. Intrusion detection

Military applications are

1. Data links
2. Radar
3. Intrusion detection
4. Covert communications
5. Precision geo-location

1.4 Ultra Wide Band Technology

UWB differs well from typical narrowband radio frequency (RF) and spread spectrum technologies. A UWB transmitter works by sending billions of pulses across a wide spectrum of frequency on several GHZ of bandwidth. The corresponding receiver then interprets the pulses into information by demodulating pulse sequence sent by the transmitter. UWB's combination of larger spectrum, lower power and periodic information improves speed and reduces interference with different wireless spectrum. The result's dramatic change short-range communication, data rate and restricted the interference.

1.5 MIMO Technologies

MIMO technology is a wireless technology that uses multiple transmitters and multiple receivers to transfer additional data at constant time and bandwidth. MIMO technology takes advantage of radio wave development referred to multipath wherever transmitted signal bounces off walls, buildings, sign boards ,cars, poles and different objects, reaching the receiving antenna multiple times via totally different angles and at slightly different times. MIMO technology leverages multipath behavior by using multiple “smart” transmitters and receivers. With one more spatial dimension the performance increases dramatically. MIMO permits multiple antennas to send and receive multiple spatial streams at constant time. MIMO makes antennas work smarter by enabling them to mix signal streams coming back from totally different paths and at different times to effectively increase receiver signal-capturing power. Smart high performance antennas are use in spatial diversity technology. If there extra antenna added with spatial streams then it adds receiver diversity, increase data rate and range.

1.6 Ultra wide band MIMO antenna.

Where we transmit billion of pulses per second on wide band which increases the performance of system along with addition of MIMO antenna system capability is further increased. The issues of multipath effect are also reduced due to MIMO. The combination of signal after multipath also reduces the signal to noise ratio. UWB MIMO antenna extends the capability of system to meet the demands of future communication.

1.7 Challenges of UWB MIMO antenna design.

- **Size** Recently, MIMO has been adapted to hand held devices like mobile phone tablets, laptop etc. Which use various communication technologies such as WLAN, WCDMA, Wi-MAX, and UWB in order to realize high speed data transmission. It's obvious that hand held devices requires a compact ultra wide-band MIMO antenna because of the limited space available in devices.
- **Band width** For UWB S11 must be less than -10 dB for band of 3.1 GHz to 10.6 GHz. But in multiple antenna system its one of the most difficult tasks to maintain the S11 values in range.
- **Isolation** One of major concern while designing MIMO systems is mutual coupling between antennas. Mutual coupling affects on both antenna efficiency and correlation. Isolation of operating region of the antenna system throughout better than -16 dB is required.

1.8 Thesis Organization

The remaining part of thesis organized as follows

- **Chapter 2** Literature review of UWB antenna with different shapes. Different techniques to introduce notch on desired frequencies in UWB antennas. Methods and arrangement of MIMO antenna elements. The already existing work available and their performance.
- **Chapter 3** In this chapter design of antenna is implemented step by step. In First step UWB is developed in a single patch. In second step WLAN frequency notch with introducing slot. In third step different arrangements of two elements MIMO antenna is implemented. After getting best results for them in fourth step four element MIMO antennas is constructed. At last selection of final shape is done.
- **Chapter 4** This chapter is based on final shape of antenna along with simulated and measured results. The results are discussed and compared in this chapter.
- **Chapter 5** In last chapter whole thesis is concluded. Improvement required in future is highlighted and future experiment performed with this antenna design is discussed.

CHAPTER 2

LITERATURE REVIEW

2.1 UWB ANTENNAS

UWB technology has been widely used in many applications because of high data transmission rate, increased bandwidth and short-range characteristics. Applications like Wireless Personal Area Network (WPAN), Wireless Body Area Network (WBAN), indoor localization and biomedical imaging make use of UWB. For these applications designing UWB antennas is still a challenging task and has gained the attraction of many researchers. For fulfilling the requirements of different applications UWB antennas are designed in different shapes e.g. rectangular, triangular, circular, elliptical, hexagonal, octagonal, diamond and some random shapes.

2.1.1 Rectangular Shape

A rectangular shaped antenna is presented with compact size and good impedance characteristics in order to fulfill the requirements of UWB applications in Figure 2.1. Antennas parameters are being changed in order to improve impedance bandwidth. As shown in the diagram the ground plane is cut in form of slots so that a symmetrical saw tooth shape is obtained. This design with rectangular shape from the top and saw tooth shaped modified ground was implemented.

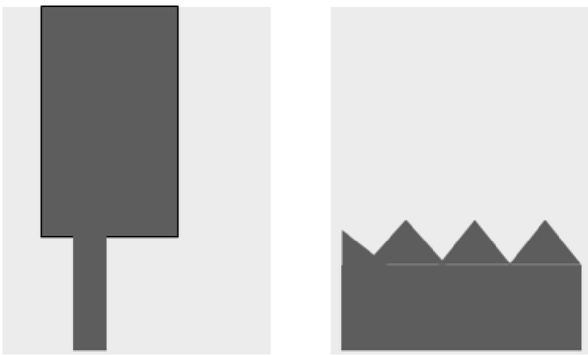


Figure 2.1 Shape of Rectangular Shaped UWB Antenna [17]

Micro strip feed line is directly printed on to the slotted partial ground plane [17]. This antenna design has VSWR less than 2 from 3 GHz to 16 GHz.

2.1.2 Rectangular with Round junction

This simple and low profile antenna was proposed to address the requirements of various UWB applications and cognitive radios. This antenna is designed after making various modifications to the conventional rectangular shaped antenna. The main advantage of these alterations is its increased bandwidth. Basically the ground plane of conventional antenna was truncated to induce reduction in Q factor [18].The impedance between the micro strip antenna and its feed line can also be increased due to truncated ground which further improves the bandwidth. The purpose of round junction was to produce a smooth change in the impedance between transmission line and antenna patch. This smooth change allows to reduce the reflection coefficient hence bandwidth is increased. The last and final step is chamfering the last two corners of antenna radiating element. The figure 2.2 below shows another type of UWB antenna which has a ground plane which is truncated, round junctions and two chamfers. The purpose of chamfers is to provide the impedance matching at 27 and 29 GHz.

Figure2.2 UWB Antenna with round junction [18]

The radiation pattern of antenna at 2 GHz frequency gives us an Omni directional pattern in azimuth plane and a maximum gain of 2.2 dBi can is obtained. Random distributed patterns are being obtained when 14 GHz and 28 GHz frequency bands are used. This randomness in patterns is due to the increasing modes of propagation. The maximum gain obtained of 6.8 dBi and 8.53 dBi [19]. This antenna design have S11 less than -10 dB from 2 GHz to 27 GHz in simulation and S11 less than -10 dB from 2 GHz to 27 GHz in measured.

2.1.3 Two-Rectangles Combined

A UWB antenna was designed by joining two rectangles together is shown in figure 2.3 below. The variation is two rectangular antennas which were further combined to make a single UWB antenna. This antenna range of 1 to 10 GHz the impedance matching is not observed whereas when x = 0 mm then we do not observe any impedance matching and when x = 5 mm then also the matching towards lower and higher frequencies is not realized. In order to see the impedance matching over a wide range of frequencies two rectangular antennas are combined together to make a UWB antenna [20]. The gain variation is over the bandwidth. It is observed that the bandwidth varies from 1 dBi to 3 dBi. This variation results due to the cross polarization levels. Thus it can be seen that without adding any slot or patch in ground we can easily obtain a wide band gain in this type of shape. This type of antenna can be used in applications like WIFI, WIMAX and all other application which operate in 3 GHz to 10 GHz frequency range. This antenna design have S11 less than -10 dB from 2 GHz to 10 GHz in simulation and S11 less than -10 dB from 2 GHz to 10 GHz in measured.

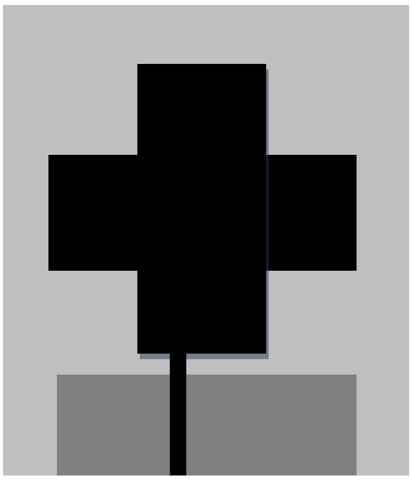


Figure 2.3 UWB antenna with two-rectangles combined [20]

2.1.4 Circular Shape

Circular shape antennas are usually used in application having low profile antennas. There are several shapes in literature when it comes to patch antennas but circular has a lot of more advantages as compared to other shapes. It gives flexibility in design, provides maximum bandwidth, good radiation pattern, better return loss and improved directivity [21]. This antenna consists of a conducting patch and ground plane with FR4 as substrate. Different dimensions are being used for the thickness of substrate, line feeding and the ground plane.

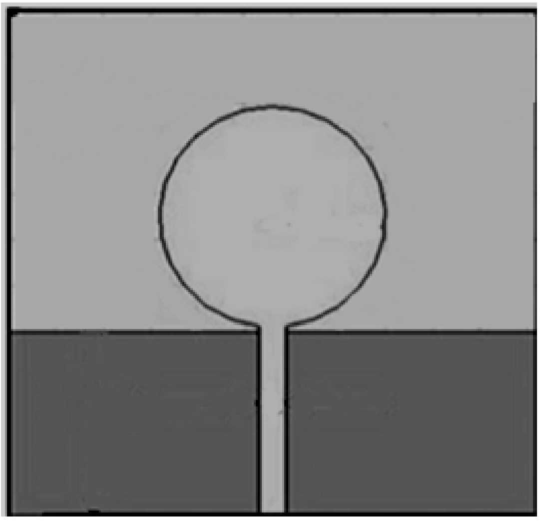


Figure 2.4 Circular Shaped UWB Antenna [21]

Table 1 shows the results of the circular shaped UWB antenna. It highlights that the parameters like gain, VSWR gives satisfactory performance. Due to addition of partial ground in the model the radiation characteristics are further enhanced. Hence this design can be used for multi-band wireless communication [22]. This antenna design has S11 less than -10 dB from 1.58 GHz to 11.58 GHz in simulation and also VSWR less than 2 from 1.58 GHz to 11.58 GHz in measured.

Antenna Parameters	Circular Shape
Resonant Frequency	6.3 10.22
Return Loss (dB)	-19.3391 -24.0508
Gain (dBi)	4.0503 5.5311
VSWR	1.2554 1.1195
Bandwidth (GHz)	1.6-11.6 (10 GHz)

Table 2.1 Results of Circular Shape

2.1.5 Rectangular and Circular Shaped

A unique design is obtained by combining a rectangular and circular shape, hence resulting in a combined shape. Rectangular and circular monopole antennas are implemented individually. The best impedance matching is obtained when the distance of feed line is 5 mm. After this both the shapes were combined to obtain a rectangular and circular shaped UWB antenna as shown in figure 2.5 below.

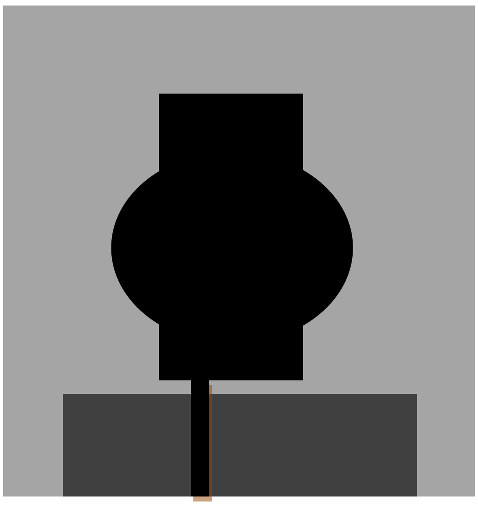


Figure 2.5 Rectangular and Circular Shaped UWB Antennas [23]

This random shaped antenna can be used in applications like personal mobile communication, WIFI and Bluetooth but in the range of 1 GHz to 10 GHz [23]. This antenna design have S11 less than -10 dB from 1.091 GHz to 10 GHz in simulation and S11 less than -10 dB from 1.35 GHz to 8 GHz in measured.

2.1.6 Elliptical Shape

This shape is basically an elliptical shaped monopole antenna with trapezoid ground plane. It is also fed by a tapered modified CPW line. The figure below shows the elliptical shaped antenna. The measurements have shown that a wide impedance bandwidth is obtained. Many wireless services can be supported by this elliptical shaped antenna like GPS, GSM 1800, PCS 1900, GNNS and UWB.

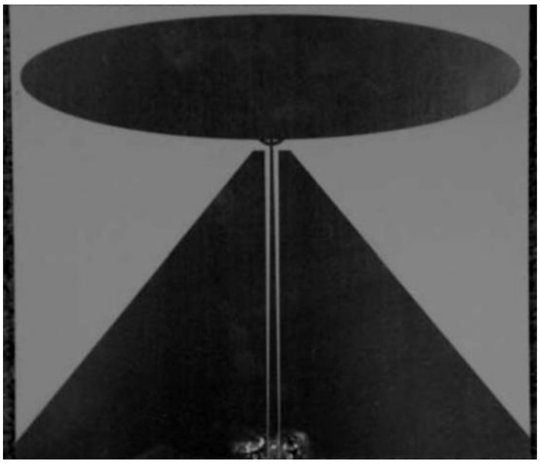


Figure 2.6 Elliptical Shaped UWB Antenna [24]

In order to obtain efficient result two feeding branches are installed. This optimizes the radiating elliptical patch and the ground plane. The antenna and ground plane are attached on same side of the substrate. The graph below shows the gain and efficiency at frequency of 1, 5, 10, 15 and 20 GHz. Few fluctuations are observed in the gain. The gain increases gradually until 15 GHz but a drop is observed after this frequency. The radiation efficiency is approximately constant in low range of frequencies but it drops giving us a value of 76% at 20 GHz. This drop in efficiency and gain is due to the loss of frequency in the RF substrate. When the frequency is increased antenna starts to operate in higher order modes rather than the base mode. As a result the performance of elliptical shaped antenna is severely degraded in far field region and gain also decreases with an increase in frequency [24]. This antenna design have VSWR less than 2 from 0.5 GHz to 25 GHz in simulation and VSWR less than 2 from 1.02 GHz to 24.1 GHz in measured.

2.1.7 Triangular Shape

This antenna consists of a triangular monopole antenna with a CPW tapered feed line. This feed line is used to increase the bandwidth of the CPW-fed. 0.1 mm gap is kept between the ground plane and feed line.

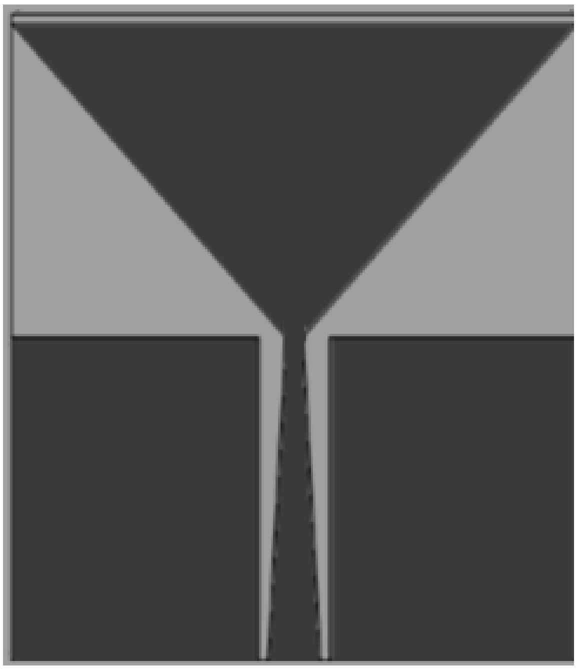


Figure 2.7 Triangular Shaped UWB Antenna [25]

It can be observed that mostly Omni directional radiation patterns are being obtained. The cross-polarization level rises as the frequencies are increased. This antenna can be used in multi-path environments [25]. This antenna design have S11 less than -10 dB from 4.14 GHz to 9.84 GHz in simulation and as well as S11 less than -10 dB from 4.14 GHz to 9.84 GHz in measured.

2.1.8 Hexagonal Shape

A hexagonal shaped antenna with CPW designed. It has WLAN and WIMAX band notch characteristics. The design is initially constructed with a simple hexagonal antenna and then afterwards the band notch characteristics are added [26]. Figure 2.8 below shows the prototype of the hexagonal antenna designed.

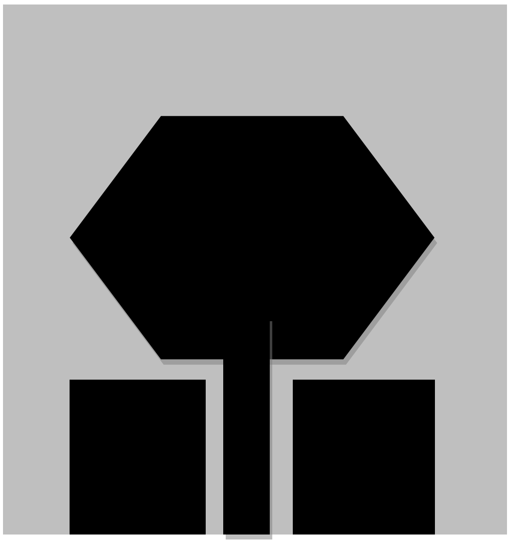


Figure 2.8 Hexagonal Shape UWB Antennas [26]

The simulated and measured result of S-parameter across the frequency satisfied the condition of UWB. This antenna design have S11 less than -10 dB from 3.1 GHz to 13 GHz in simulation and S11 less than -10 dB from 3 GHz to 13 GHz in measured.

2.1.9 Octagonal Shape

This design was basically constructed to achieve a low radar cross-section. Minimum radar cross-section makes it difficult for enemies to see this type of antenna. This design is constructed in two parts. In first part a UWB antenna is made which acts as a reference antenna. Afterwards modification is done in reference antenna so that octagonal shaped UWB antenna with minimum radar cross-section can be obtained. Metal surfaces provide the minimum current distributions so in order to avoid these problem metal surfaces were deleted [27].

Figure 2.9 Octagonal Shaped UWB Antenna [27]

The simulated and measured result of S-parameter across the frequency satisfied the condition of UWB. This antenna design have S11 less than -10 dB from 3.1 GHz to 18 GHz in simulation and also S11 less than -10 dB from 3.1 GHz to 18 GHz in measured.

2.1.10 Diamond Shape

A Diamond shaped UWB antenna is designed for various applications. The bandwidth is greatly increased with the help of radiating patch which is of diamond shape and semi-circular ground plane.

In order to obtain the diamond shape radiating patch a technique is applied which is known as beveling technique. A conventional rectangular antenna is used to apply this technique to its corners so that radiating patch is obtained. When edges are beveled then a smooth transition occurs between different modes due to which bandwidth is enhanced and impedance matching is improved for wide range of frequencies. Micro strip feed line is used to fed the radiating element which further improves the impedance matching. The conventional ground plane is also replaced with semi-circular ground plane so that along with impedance matching bandwidth is also enhanced [28].

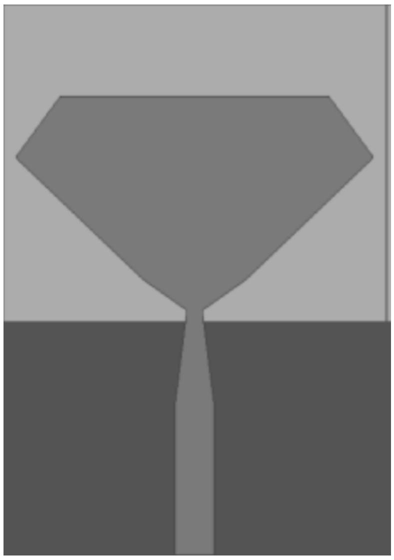


Figure 2.10 Diamond Shaped UWB antenna [28]

The simulated result of S-parameter across the frequency satisfied the condition of UWB. This antenna design has VSWR less than 2 from 0.8409 GHz to 15.5190 GHz and 16.7679 GHz to 18.3753 GHz in measured.

2.1.11 Random Shape

A printed UWB antenna is designed to support various mobile standards like DCS, PCS, UMTS and ISM bands [29]. A spline-based representation is used for the radiator and particle swarm optimization is used to obtain good impedance matching and stable properties of radiation. Shape of the design is shown in figure below.

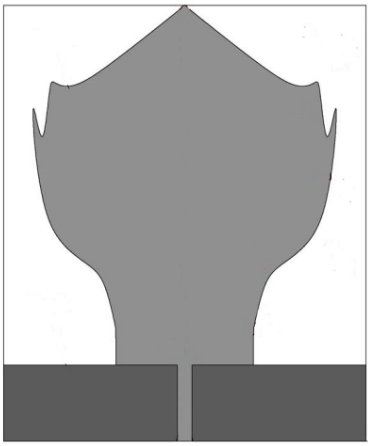


Figure 2.11 Random Shaped UWB Antenna [29]

Random shape antenna design have S11 less than -10 dB from 1.7 GHz to 4 GHz in simulation and S11 less than -10 dB from 1.7 GHz to 4 GHz in measured.

2.2 MIMO

2.2.1 Inverted Shaped MIMO

The designed dual band-notched MIMO antenna with high isolation is shown in figure 2.12 below. There are two symmetric antenna elements in this UWB MIMO antenna. They are titled as element 1 and element 2 and are fed by port 1 and port 2 respectively. U-shaped radiator and rectangular metal strip is the part of every antenna element. The substrate used in FR4. The U-shaped radiator is printed on the front side of this substrate. Main ground part and two protruded ground parts are combined to make ground plane. They are linked by small metal strips. The back area has two overlapping areas of the U-shaped radiator and its corresponding metal strip for each of the element.

Protruded ground part is applied so that lower resonant frequency, better input impedance matching and compact size could be achieved. This ground part produces capacitance which increases the electrical length of radiator. As a result impedance matching is also improved [30].

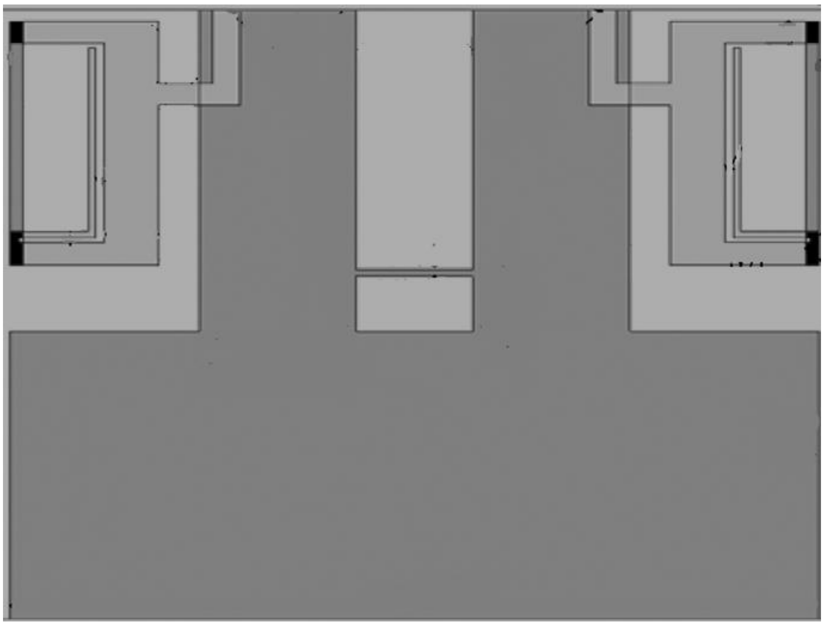


Figure 2.12 Structure of dual-notched band UWB MIMO antenna [30]

This antenna design have S11 less than -10 dB from 3 GHz to 11 GHz excluded 3.3 GHz to 3.7 GHz and 5.15 GHz to 5.85 GHz and S12 less than -20 dB across the whole operation bandwidth. The efficiencies are small due to good impedance matching and high isolation. Total and radiation efficiencies are above 65% for both the elements except at the two notched bands. This is again due to compact size and high isolation. These calculations are good in case of diversity systems.

2.2.2 G-shaped MIMO

Low-profile band notched UWB MIMO antenna having simple geometry is designed. This antenna is suitable for mobile terminals. At first two square elements were used to construct a MIMO system. It operates over a frequency range of 2.2 GHz - 13.3 GHz. For decoupling of antenna elements further a T-shaped strip was designed. After slot loading the square elements of UWB antenna a G-shaped element was constructed. Its purpose was to notch the frequency band of 4.4-6.2 GHz. It was also shown that the notched band can be tuned when parameters of G-shaped element are changed. The structure of MIMO antenna with G-shaped elements is shown below. Square element was slotted in order to create a G-shaped system [31].

Figure 2.13 Structure of G-shaped MIMO [31]

The product of efficiencies which include radiation, mismatch, conduction and dielectric is known as total efficiency of an antenna. When port 2 was terminated by 50 ohm load then these parameters were measured for element 1. Variations are observed in peak gain from 2.44 to 4.78 dBi levels across the frequency of 2.15-4.40 and 6.20 GHz - 13.65 GHz. At 4.8 GHz we can see the minimum gain of 1.2 dBi. The total efficiency is above 60% over the bands of interest. At 4.8 GHz we have the lowest efficiency achieved of 30% in the rejected bands. The simulated and measured result of S-parameter across the frequency shows good isolation result between antennas. This antenna design have S11 and S22 less than -10 dB from 2.2 GHz to 13.3 GHz and S12 and S21 less than -20 dB across the bandwidth.

2.2.3 Orthogonally Placed MIMO

A compact size MIMO antenna is designed which provides band notched features for WIMAX and WLAN band. This antenna compared with others is very compatible and provides isolation of >15 dB throughout the UWB. The design is shown in figure below with top layer on left and bottom layer on right.

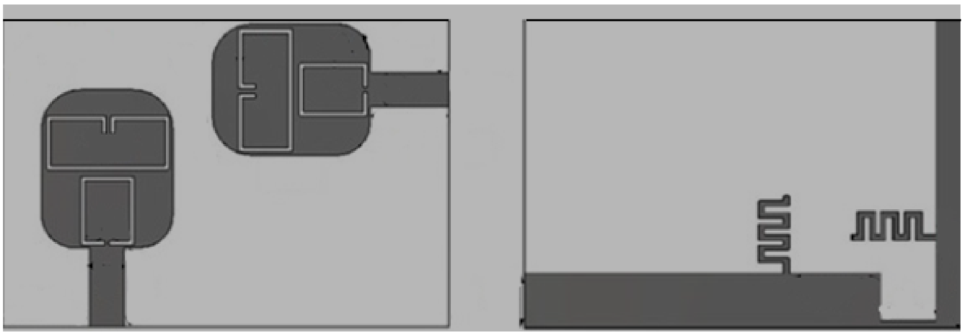


Figure 2.14 MIMO Antenna a) Top Layer b) Bottom Layer [32]

The substrate used for fabrication was FR4. It has thickness of 1.6 mm and permittivity of 4.4 There are two micro strip line fed rectangular monopole antenna. Its edges are curved so that better impedance matching can be achieved. Radius of curved edges is 2.5 mm. For achieving band notch at WIMAX and WLAN two slots are used. For improving isolation between the ports two meander shaped ground stubs or isolating structure are installed [32].

At 4.5 GHz the length is considers as half of guided wavelength. Current coupling to orthogonally placed monopole antenna elements is reduced because of the meander shaped ground stubs. They have length of 16.3 mm. This further reduces the mutual coupling > 15 dB in whole UWB antenna. The simulated and measured result of S-parameter across the frequency shows good isolation result between antennas. This antenna design have S11 and S22 less than -10 dB from 3 GHz to 10.7 GHz and S12 and S21 less than -15 dB across the bandwidth.

2.2.4 Compact Printed MIMO

A compact size band notched MIMO antenna is constructed. The size of antenna is much smaller as compared to other antennas in literature. It is approximately 28.5 % less in electric size when compared with works in past. This antenna covers the band from 3.7-11 GHz. It will band notch the WLAN band. It does not require a separate structure for band notched since its frequency band starts from 3.7 GHz. Besides this it also has better isolation i.e. more than – 17.5 dB [33].

The figure below shows the geometry of the antenna designed. It can be seen that there are two monopole planar elements of some specific size. Impedance matching can be achieved by this antenna by adjusting the slot in the back as shown in figure 2.15

Figure 2.15 Designed MIMO Antenna [33]

Band notched feature is introduced in this UWB antenna so that interference from WLAN band can be avoided. A frequency band notch is created with the help of a C-shaped slot in the radiator. The length of C-shaped slot needs to be approximately half of the wavelength of required notched frequency.

A meander line is added between antennas. It can be seen in the figure above. There are two main reasons behind addition of these meander lines. It provides impedance matching and high isolation. This is due to the reflections of radiations from radiator. The graph clearly indicates that poor impedance matching is obtained from 3.7 to 4 GHz. S11is also known as mutual coupling. It is almost above -15 dB between the two input ports as shown in plot. The meander lines help to achieve high isolation. When it comes to working frequency then S21has a lower value than -17.5 dB. It can also be observed that mutual coupling is less than -21 dB for 91% of time. Due to addition of meander line isolation is enhanced and this antenna becomes highly suitable for communication systems. The simulated and measured result of S-parameter across the frequency shows good isolation result between antennas. This antenna design have S11 less than -10 dB from 3.7 GHz to 12 GHz excluded WLAN (5.1 GHz to 5.8 GHz) and S21 less than -17.5 dB across the bandwidth.

2.3 Notch

2.3.1 Patch Modified Notch

A base antenna is constructed with the help of a printed monopole and modified trapezoid ground plane. The substrate used is TACONIC TLX-0.The ground plane and monopole is etched on the top and back of this substrate. Ground plane can be said as a part of impedance matching network. Sensitivity to fabrication and better impedance matching is provided with the help of this ground plane [34].

To avoid interference with 802.11a/b/g /n WLAN system and downlink of X-band satellite communication systems a notch is added in this base antenna. This feature of interference avoidance is introduced by adding slots which are of arc shape. These slots resonate around notched band resulting into collision avoidance. The diagram of antenna with band notch feature as shown in Fig 2.16.

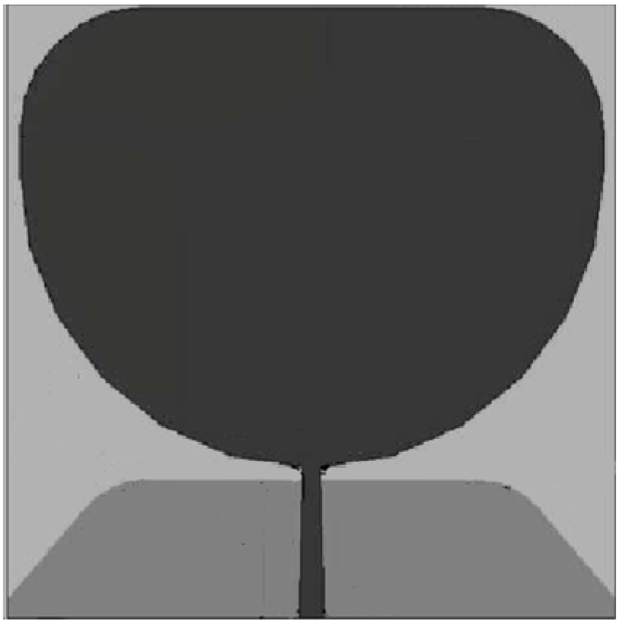


Figure 2.16 Triple band-notched antenna [34]

Two arc shaped slots are placed symmetrically on the radiation patch. This will help to have notched band in the frequency range of 2.4 GHz and 7.5 GHz. Basically patch is modified to get notch and reach the desired results. The simulated and measured result of S-parameter across the frequency shows good result. This antenna design have VSWR less than 2 from 0.72 GHz to 25 GHz excluded notched frequencies (2.4-2.484) GHz,(5.15-5.85) GHz and (7.25-7.75) GHz.

2.3.2 Slotted Notch

In this design two elliptical monopole antennas are designed with band notch characteristics. The two antennas make use of C-shaped and U-shaped slots respectively. The purpose of slot is to cause frequency notch whereas it does not affect the radiation pattern. The designed antenna with C-shaped slot and U-shaped slots are in Fig 2.17.

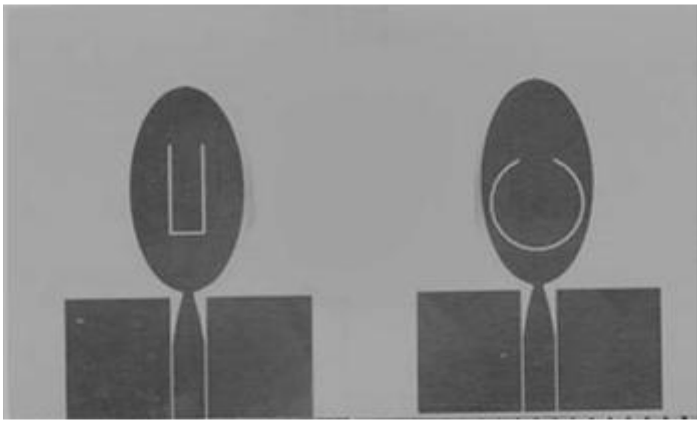


Figure 2.17 Monopole antennas with C-shaped and U-shaped slots [35]

A CPW line to use to fed the antenna. The inner width of conductor is represented by W where W = 2.75 mm. There also exists a gap between the ground and inner conductor whose value is 0.18 mm. The size of ground is very important when it comes to efficient antenna performance. The ground patches used in this design are of very compact size. Out of the two slots U-shaped slot is at a distance of 4.97 mm from the end of the feed line. It also comprises of two parallel segments. The C-shaped slot is at a radius of 3.85 mm since it’s a circular arc [35].

The total length of two slots is same but the results in terms of return loss are different. A more broadband frequency notch is created when C-shaped slot is used rather than U-shaped slot. C-shaped slot results in an increased bandwidth. Besides these both the type of slots does not compromise on radiation pattern. Both slots provide Omni-directional patterns with the required gain and shape. The simulated and measured result of S-parameter across the frequency shows good result. This antenna design has VSWR less than 2 from 2.3 GHz to 12 GHz excluded notched frequencies 5.8 GHz.

2.3.3 Fractal Shape Notch

A circular CPW-fed monopole antenna is designed. In this antenna the radiator comprises of Sierpinski fractal. UWB bandwidth is increased with the help of this. The fractal applied on antenna determines about the benefits of fractal zing. Different geometries of fractal may be joined together in order achieve higher benefits like more frequencies to appear in the bandwidth [36]. Fractal shape notch allows us to improve impedance matching at lower frequencies. When we want to achieve notched band centered at 2.5 GHz for WLAN rejection then elliptical type of slots are very useful. U-shaped fractal at feed line is used for RFID based band centered at 7 GHz. This antenna shown in figure below has a bandwidth range of 1.8 GHz -11.5 GHz. Figure 2.23(a) shows the fractal monopole antenna with slot, Figure 2.23(b) and 2.23(c) gives the top and side view respectively whereas 2.23(d) highlights the enlarged view of elliptical notch.

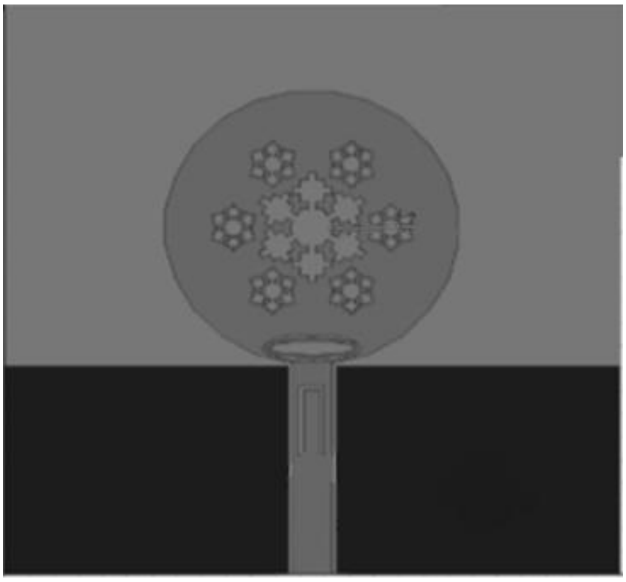


Figure 2.18 Schematic of fractal monopole antenna [36]

This antenna is supposed to give Omni-directional radiation patterns for UWB applications. It fulfils our requirement and provides Omni-directional patterns along with cross-polarization and co-polarization levels [37]. The simulated and measured result of S-parameter across the frequency shows good result. This antenna design have VSWR less than 2 from 2 GHz to 11 GHz excluded notched frequencies 5.2 GHz and 7 GHz.

Chapter 3

Design of compact UWB-MIMO antenna with WLAN band rejection

In this chapter, the design and analysis of UWB-MIMO and WLAN band rejection techniques are discussed. The design process of the proposed antenna is divided into three parts. First part consists of the design of a single element UWB antenna. In second part, the notch is introduced on the WLAN band. In the third part, MIMO system is designed of the second part antenna with the reduced isolation. The aim of the design process of this antenna is to come up with the compact UWB-MIMO antenna with maximum isolation between antenna elements and to produce notch on WLAN band for the purpose of filtration. In the next chapter, measured results are discussed for the verification of the design.

3.1 UWB Monopole Antenna

As discussed earlier, the monopole antennas have dual benefits as it offers larger impedance bandwidth as well as the size compactness. Monopole antennas consist of three parts; radiation patch, ground and the feed line. Partial ground is the major factor to achieve UWB, it covers 3.1-10.6 GHz band of frequencies. All calculations are done on the resonant frequency of the antenna. Optimization of different parameters is carried out to get the better results.

3.1.1 Basic requirement for the design

The design process of any antenna starts with the selection of the dielectric substrate. The selection is based on the material that is suitable for the design and its availability. In this case, FR4 is chosen as a substrate, it has a dielectric constant of 4.4, thickness of 1 mm and loss tangent of 0.02. Reason for the selection of FR4 is that, it is readily available in the market, low cost and it can be modified in any shape. The aim of this design is to achieve the overall UWB impedance bandwidth, while keeping the antenna's size as small as possible, so monopole antenna is chosen for the design. The dimensions of the antenna are calculated by using the following formulas from Balanis:

Step 1: Calculation of the Width.

$$W = \frac{c}{2f_0\sqrt{\frac{\varepsilon_r+1}{2}}}$$

Step 2: Calculation of the Effective Dielectric Constant.

This is based on the height and dielectric constant value of the material and the calculated width of the patch antenna.

$$\epsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-\frac{1}{2}}$$

Step 3: Calculation of the Effective length.

$$\mathrm{L_{eff}} = \frac{\mathrm{c}}{2\mathrm{f_0}\sqrt{\varepsilon_{\mathrm{eff}}}}$$

Step 4: Calculation of the length extension ΔL.

$$\Delta L = 0.412h\frac{(\varepsilon_{eff})\left(\frac{w}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{w}{h} + 0.8\right)}$$

Step 5: Calculation of actual length of the patch.

$$\mathrm{L} = \mathrm{L_{eff}} - 2\Delta\mathrm{L}$$

The following parameter represents:

f_0 = Resonance Frequency.

W = Width of the Patch.

L = Length of the Patch.

h = thickness.

ε_r = Relative Permittivity of the dielectric substrate.

c = Speed of light: 3×10^8m/s.

3.1.2 Design of a single element

Rectangular patch is initially selected as a radiating element of monopole antenna with the size of 16.5 × 15 mm. All the measurements are done by using the formulas. The radiation patch of antenna limits the size of antenna. For the impedance matching of antenna with the 50 Ω SMA connecter, the antenna is fed by the transmission line of a length 11.5 mm and width of 3 mm. To achieve the UWB, design of a rectangular patch is modified by using the stair case technique. Ground plane of antenna is also modified. The final shape of this antenna is shown in the figure 3.1

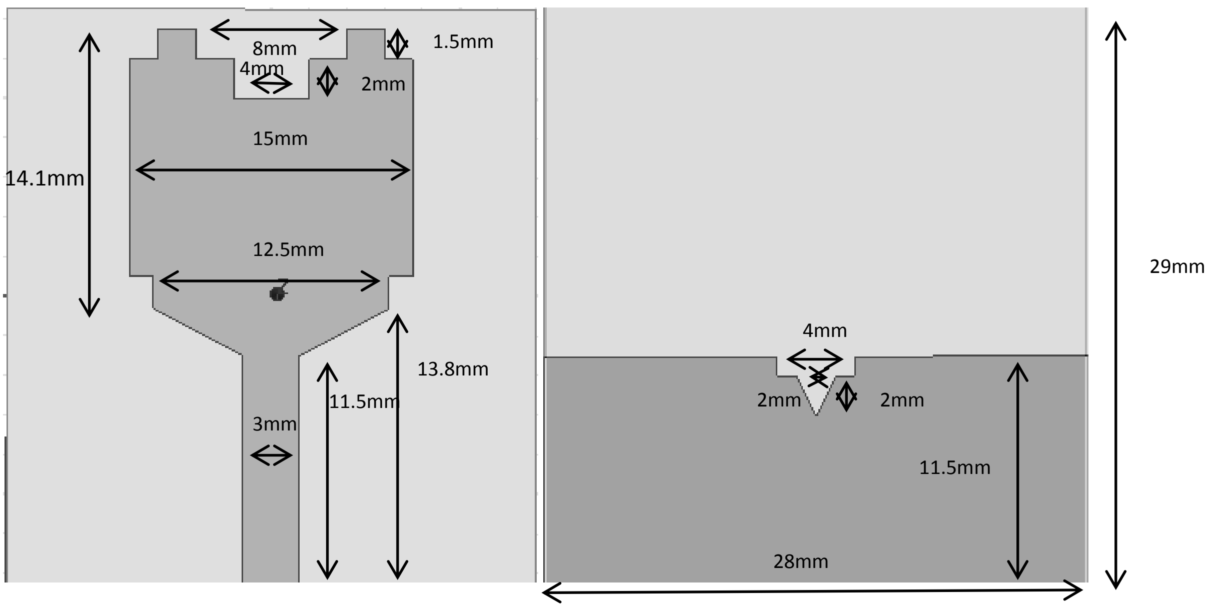


Figure 3.1 Single element monopole antenna

Figure 3.2 S-Parameter

From the figure 3.2, it is shown that the antenna is covering the band from 3.3-20 GHz with the return loss of -22 dB to -47 dB. For achieving UWB, S11 must be less than -10 dB. After simulation of antenna using HFSS, result shows that the S-parameter is less than -10 dB from 3.3 GHz to 20 GHz. So, overall antenna design fulfills the condition of UWB. As well as covers 10 GHz more so this design cover 130% more band, design seems to be effective in terms of S11.

3.1.3 Band Notch

U shape slot is added into patch of a single element monopole antenna, number of optimizations is performed to get the desired results. For the band notch to be effective, the desired S-parameter results must be greater than -5 dB. To get the notch at WLAN, different shapes are added into the patch of antenna according to the current distribution of the patch but the U shaped notch gives the better result. Optimization is done on the value of z, the value is varied from 5 mm to 7 mm with difference of 0.5 mm. As value of z changes it shifts the notch from 5.5 GHz to 7.3 GHz.

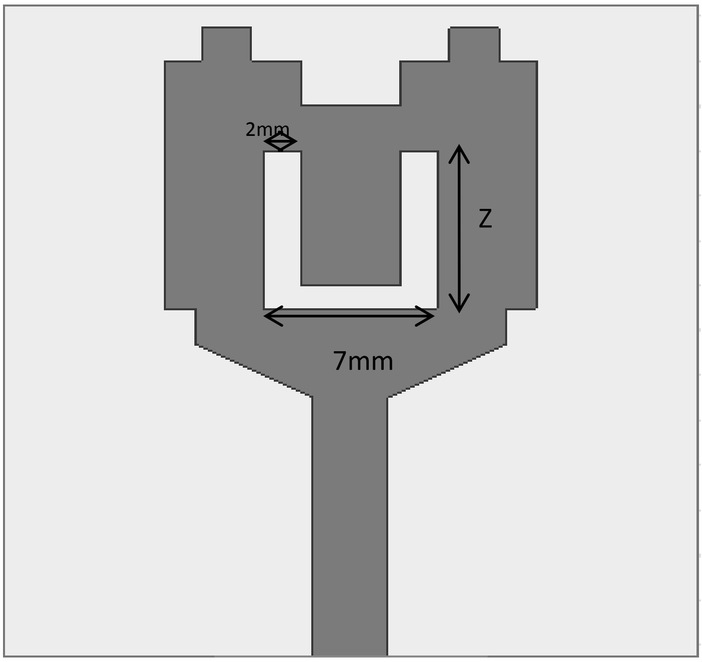


Figure 3.3 Band notch in a monopole Antenna

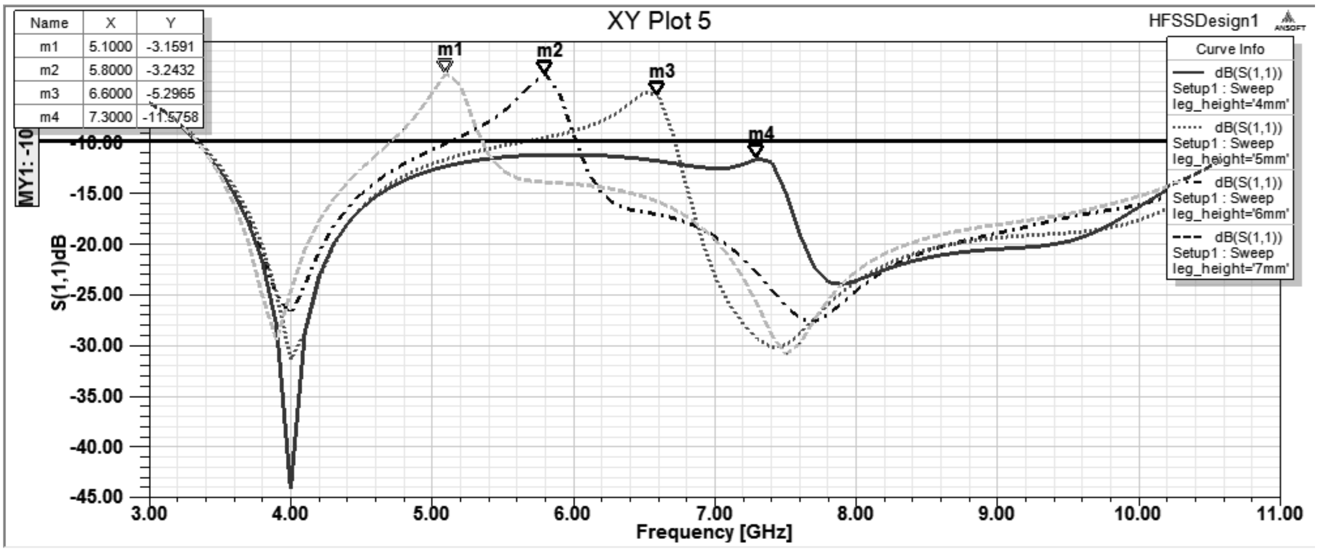


Figure 3.4 S-Parameter

The S-parameter shows that the graph rises at 5.5 GHz when the notch is introduced. By performing the optimization when the value of z=7 mm the peak of notch is on the WLAN band on frequency of 5.5 GHz which is required.

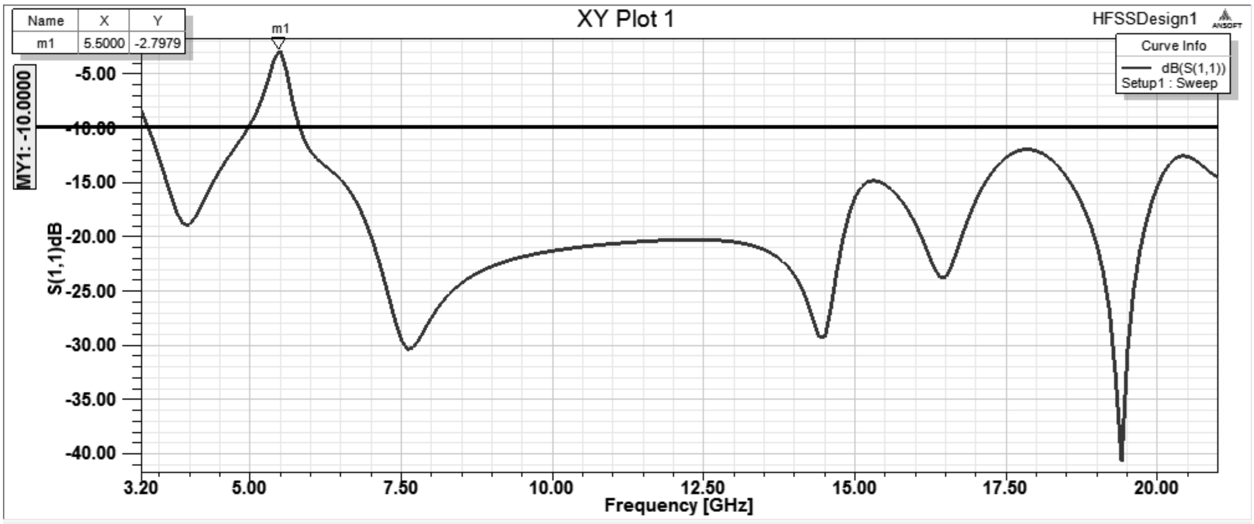


Figure 3.5 S-Parameter

After value of z=7 mm graph of S11 cover 3.2 GHz to 21 GHz with value of less -10 dB. Antenna get notch on 5.5 GHz.

3.2 MIMO System of two Antennas

MIMO system is formed of a single element monopole antenna with a band notch. The two antennas are placed in a multiple orientations in order to achieve the minimum return loss and greater isolation. Each possible orientation with the results is given below:

3.2.1 First possible alignment of antennas in MIMO system

The two antennas are aligned in such a way that there ports are 180˚ apart and the patch of both antennas head is towards each other.

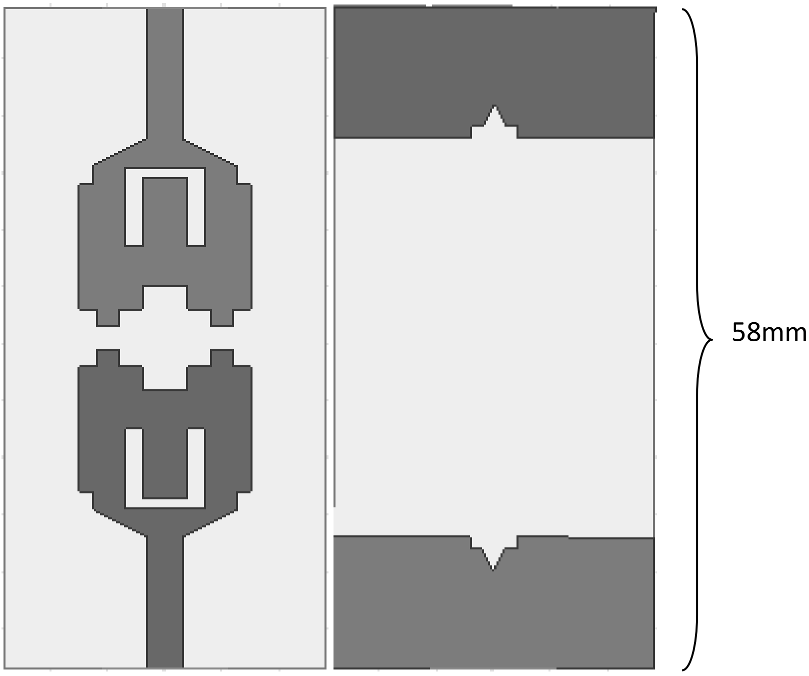


Figure 3.6 First alignments of antennas

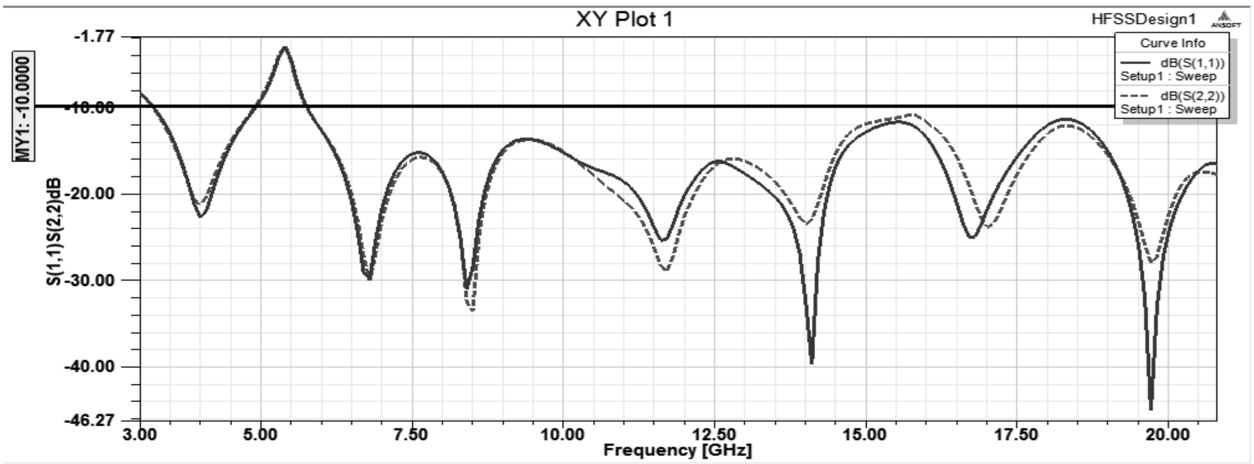


Figure 3.7 S-Parameters (Reflection Coefficients)

The result shows that the S-parameter (i.e. S11 and S22) remain same as that of a single element antenna. However, in MIMO system when there is more than one antenna a factor known as isolation plays an important role.

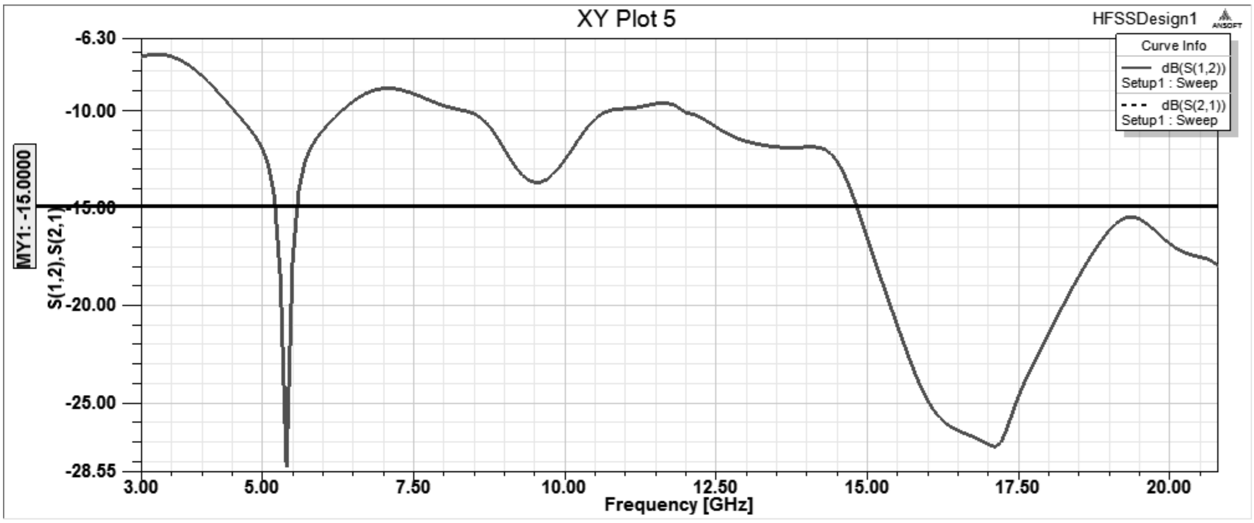


Figure 3.8 S-Parameters (Transmission Coefficients)

The isolation for the transmission coefficients (i.e. S12 and S21) should be less than -15 dB. But in this alignment the transmission coefficient is greater than -15 dB, this orientation is not suitable for the MIMO design.

3.2.2 Second possible alignment of antennas in MIMO system

In the second alignment the two antennas are placed 270 degrees (CW) apart.

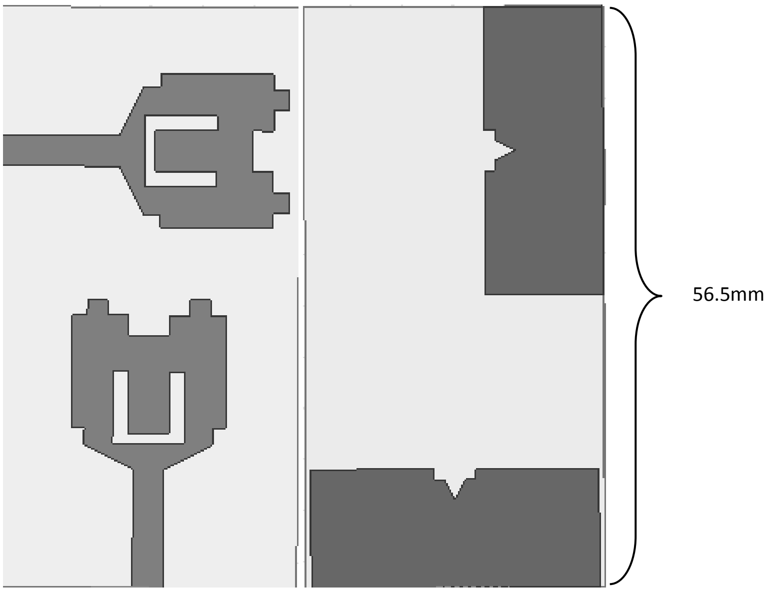


Figure 3.9 Second alignments of antennas

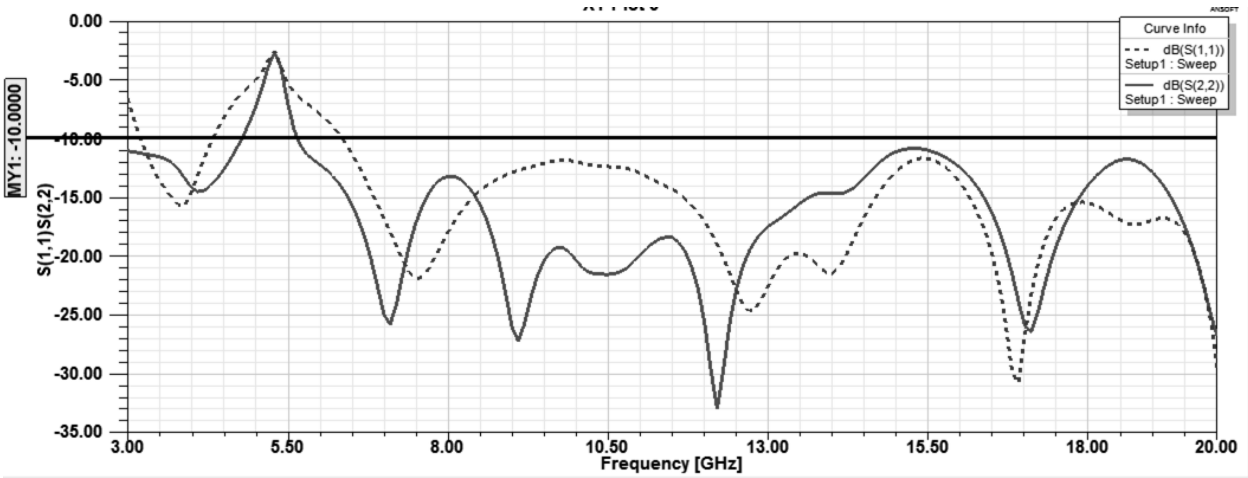


Figure 3.10 S-parameter (Reflection Coefficient)

Figure 3.10 results shows that the reflection coefficient is shifted as compared to the single element monopole antenna. Notch on 5.5 GHz is also shifted. Result shows that the S11 is more than -10 dB from 4 GHz to 6 GHz. The signal is shifted by 2 GHz that is not suitable for the thesis proposed MIMO systems.

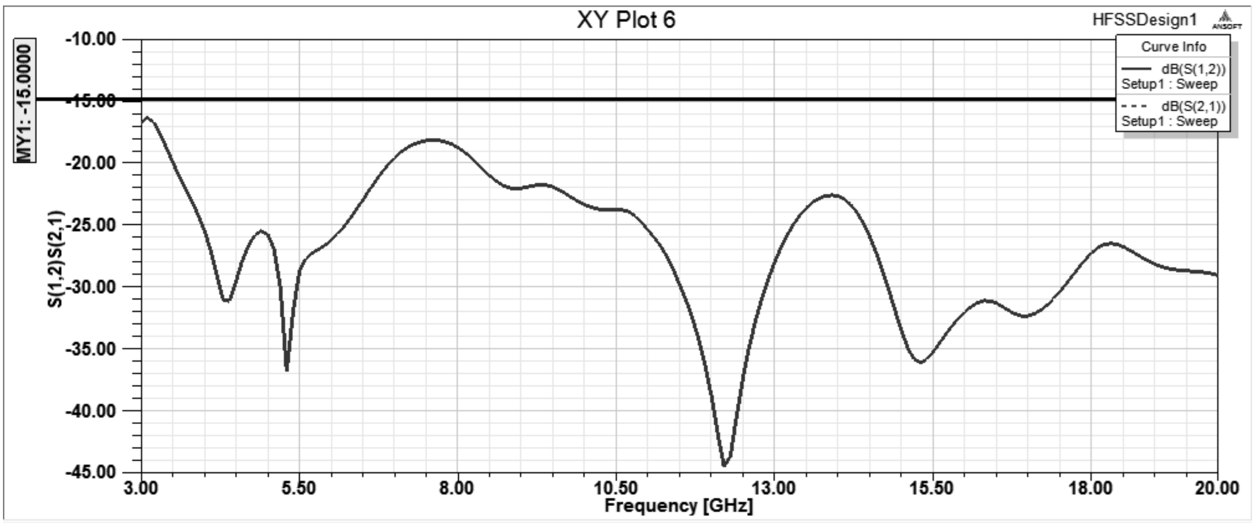


Figure 3.11S-Parameter (Transmission Coefficient)

Figure 3.10 results shows that the isolation between antennas is much more less than -15 dB. Most of the portion of signal lies below the -20 dB. So in terms of isolation this antennas alignment for MIMO has good result.

3.2.3 Third possible alignment of antennas in MIMO system

In this arrangement antennas are placed parallel to each other. Port of both antennas is placed on the same line. In this alignment of antennas the MIMO system has a compact size but the S12 and S21 in the S-parameter graphs are shifted abruptly.

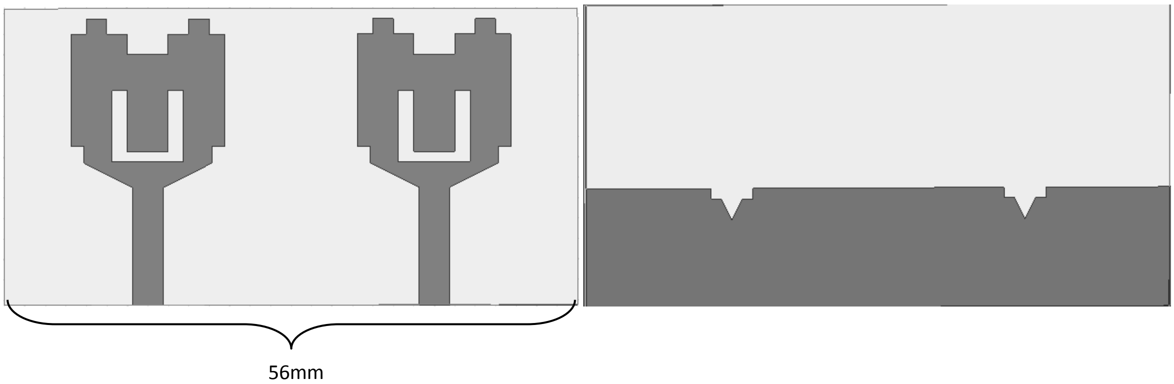


Figure 3.12 Third alignment of Antennas

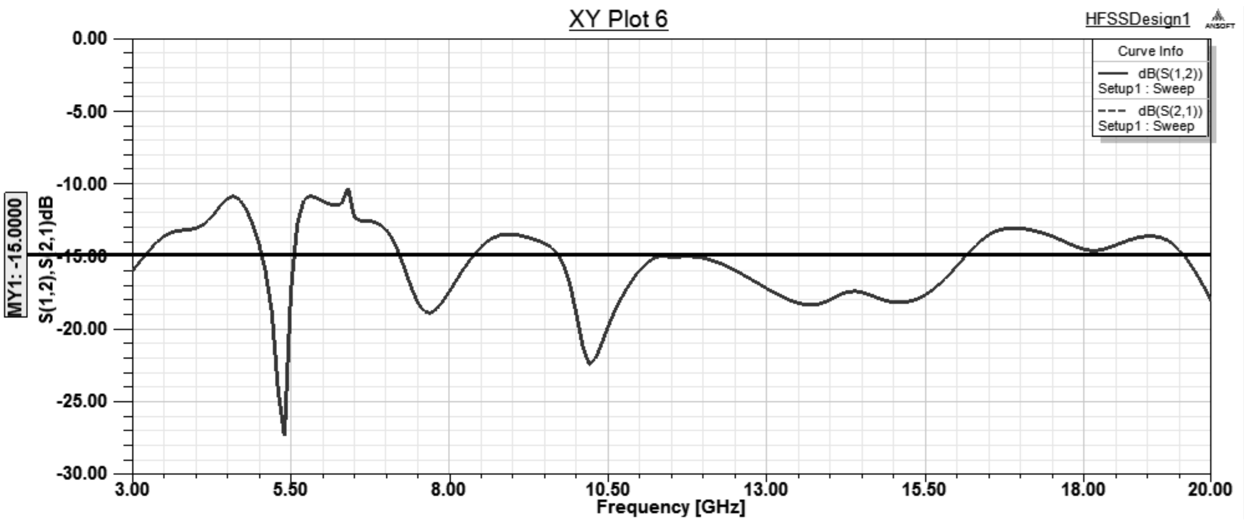


Figure 3.13 S-Parameter (Reflection Coefficients)

In terms of reflection coefficients, this alignment has good results. The whole signal lies below the -10 dB, the notch is little bit shifted but it is still performing its function.

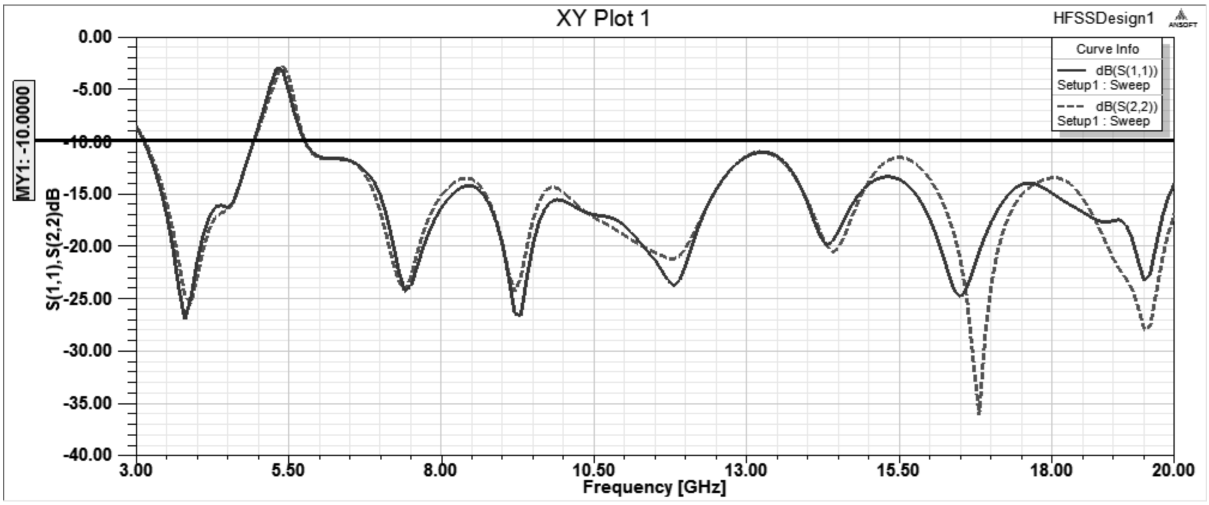


Figure 3.14 S-parameter (Transmission Coefficient)

In terms of isolation, the signal of the transmission coefficient is not less than the -15 dB. So, this alignment is not suitable for the MIMO systems.

3.2.4 Fourth possible alignment of antennas in MIMO system

In this arrangement, antennas are placed parallel to each other but one antenna is inverted, the ports of the antennas are 180 degrees apart. This arrangement has a considerable size and has a good isolation.

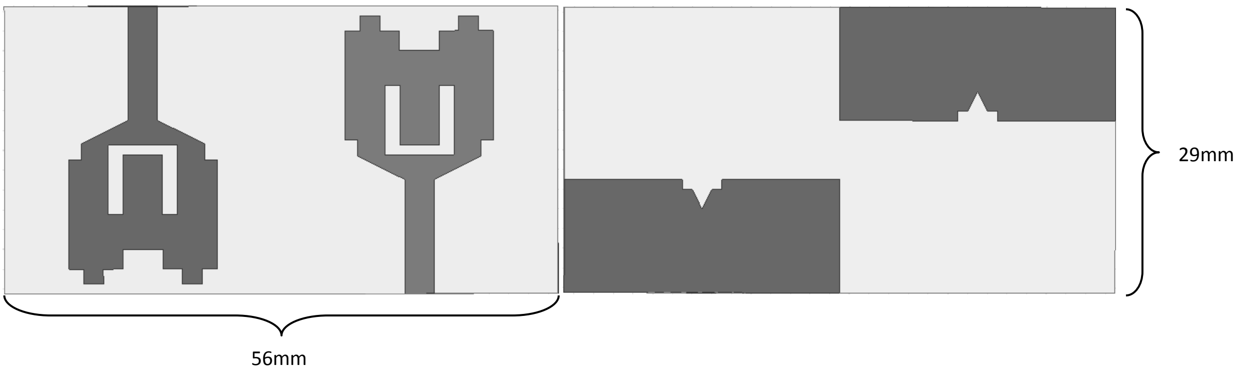


Figure 3.15 Fourth alignment of Antennas

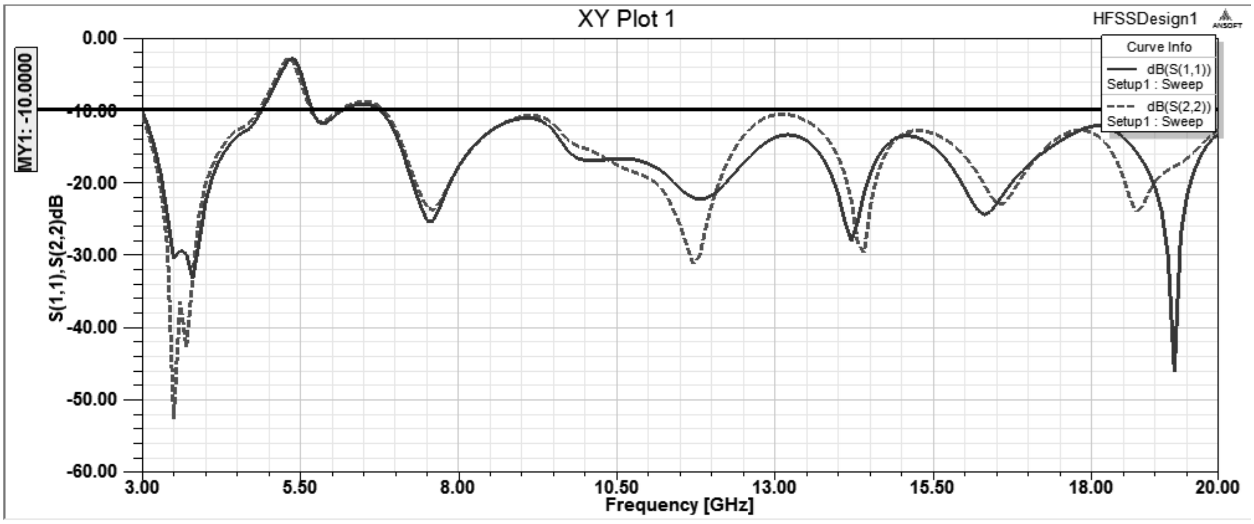


Figure 3.16 S-Parameter (Reflection Coefficient)

In this arrangement of antennas, the result of signals in terms of reflection coefficients is very close to the single element monopole antenna. But at 6 GHz the signal of the reflection coefficient is above -10 dB.

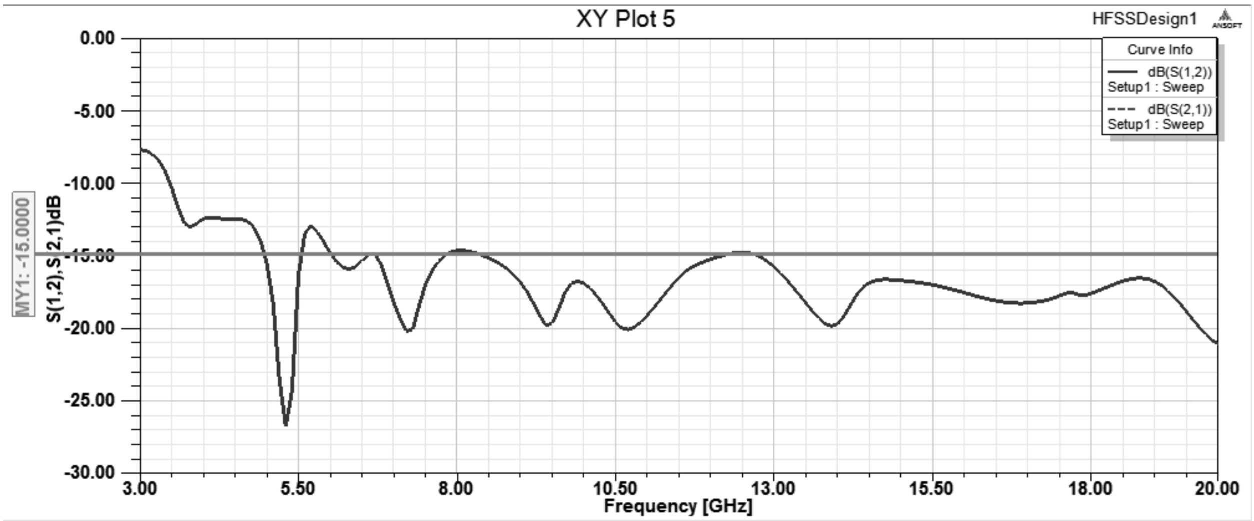


Figure 3.17 S-Parameter (Transmission Coefficient)

In terms of transmission coefficient the results are not satisfactory, from 3 GHz to 5 GHz the signal is below -15 dB which results in the disturbance of the isolation.

3.3 MIMO System Of Four Antennas

3.3.1 First possible alignment

In the first arrangement, four single monopole antennas are placed side by side and in front of each other, two antennas are placed side by side while other in front of each other forming the square shape. To increase the isolation between MIMO antenna one method is introduce the strip line between antennas ground. In this arrangement strip line in plus shape is added in ground. This strip line configuration inspired by [38].

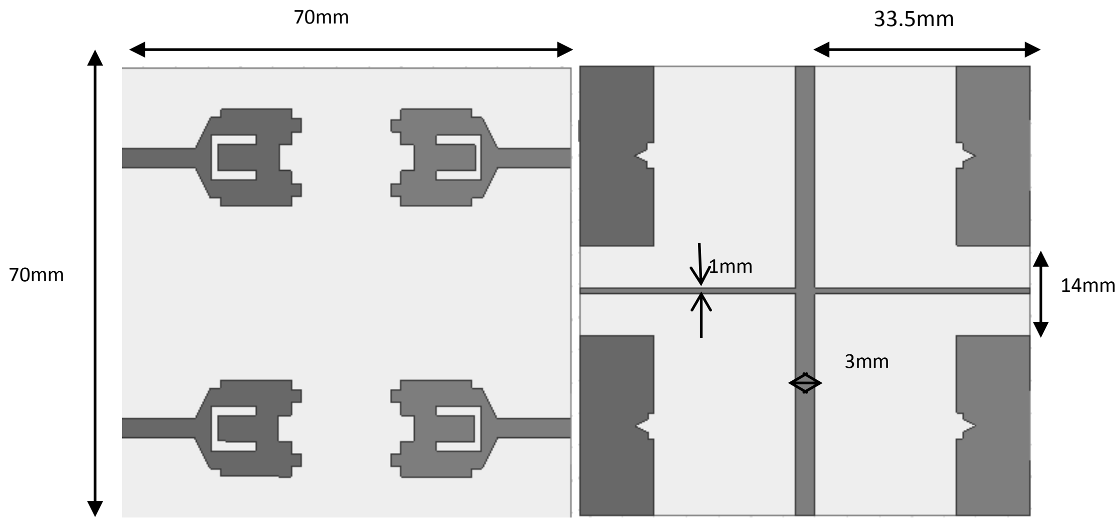


Figure 3.18 First arrangement of Antennas

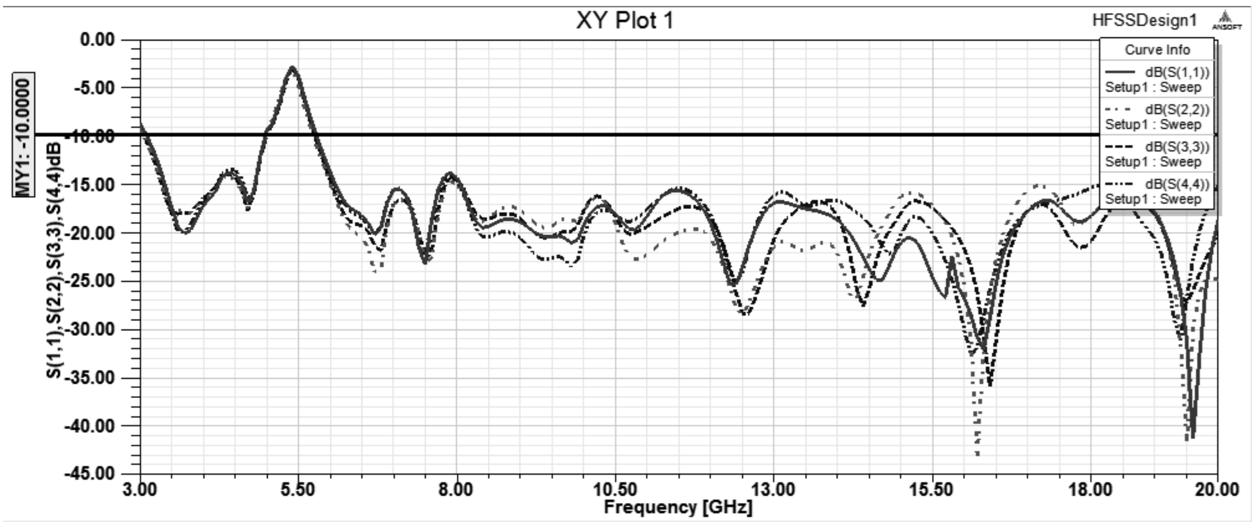


Figure 3.19 S-parameter (Reflection Coefficient)

In terms of reflection coefficient (i.e. S11 S22 S33 S44) the results of the MIMO and a single element monopole antenna are same, the return loss result graph is not distorted by increasing the number of antennas.

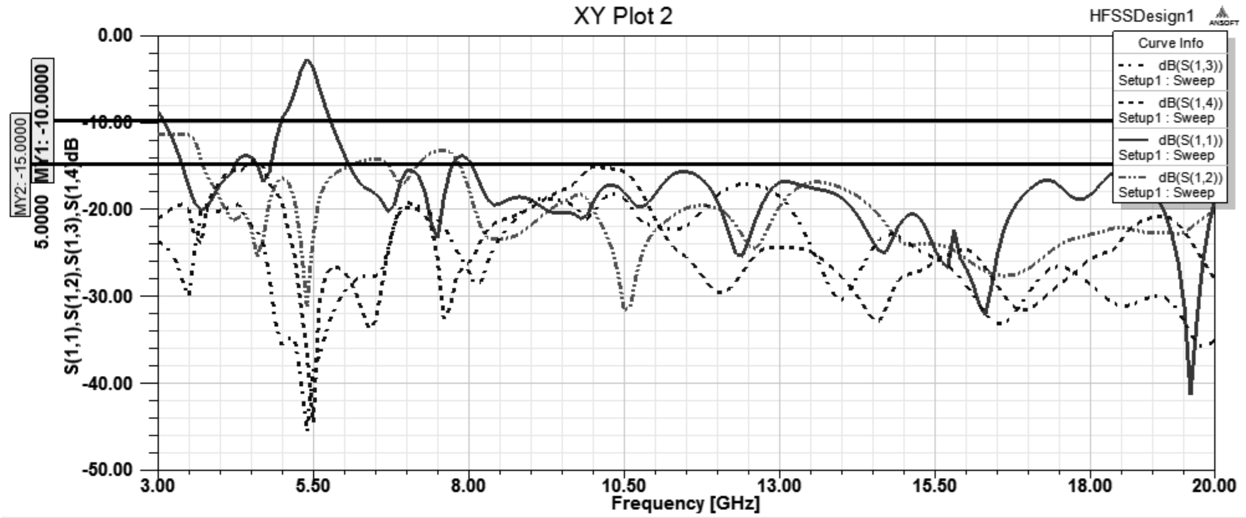
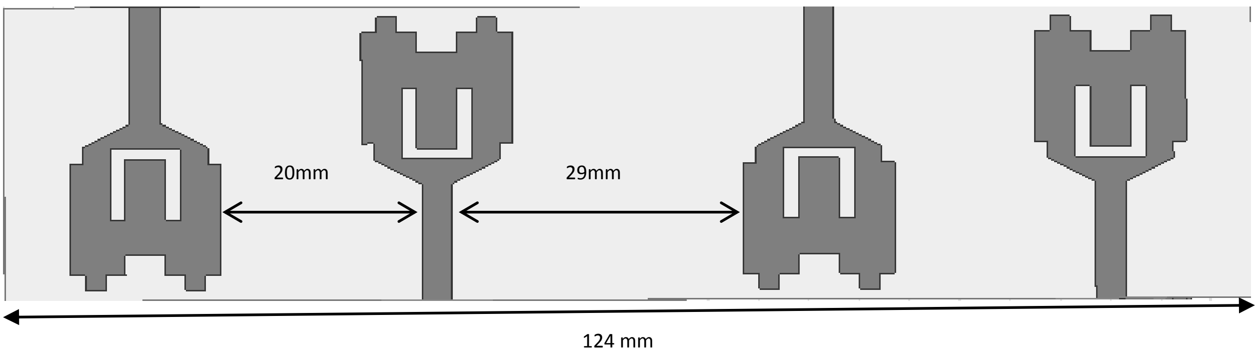


Figure 3.20 S-Parameter (Transmission Coefficient)

In terms of reflection coefficient this alignment produces good results but in case of transmission coefficient the resultant graph line is distorted and isolation between antennas is also improved due strip line but not give satisfactory result.

3.3.2 Second possible alignment

In this orientation all the antennas are placed parallel to each other. Strip line also added to improve the isolation between antenna. Each nearby antenna are flipped of the previous ones But the drawback of this arrangement is that the size of the antenna increases to 120 mm, which is not suitable for the small devices.



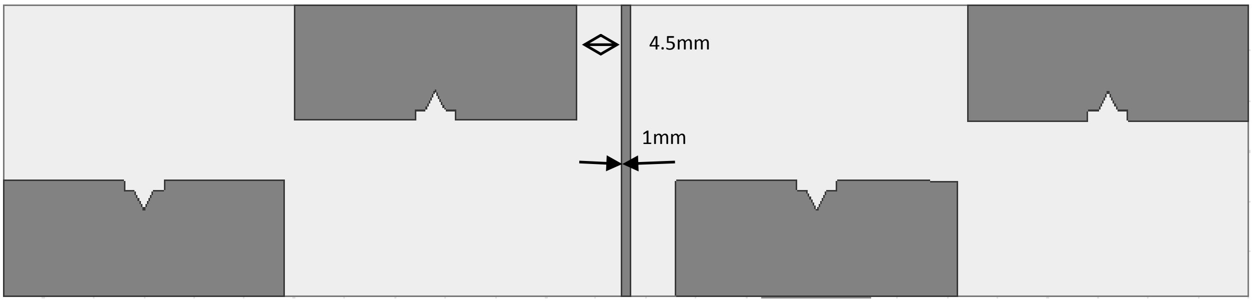


Figure 3.21 Second possible alignment

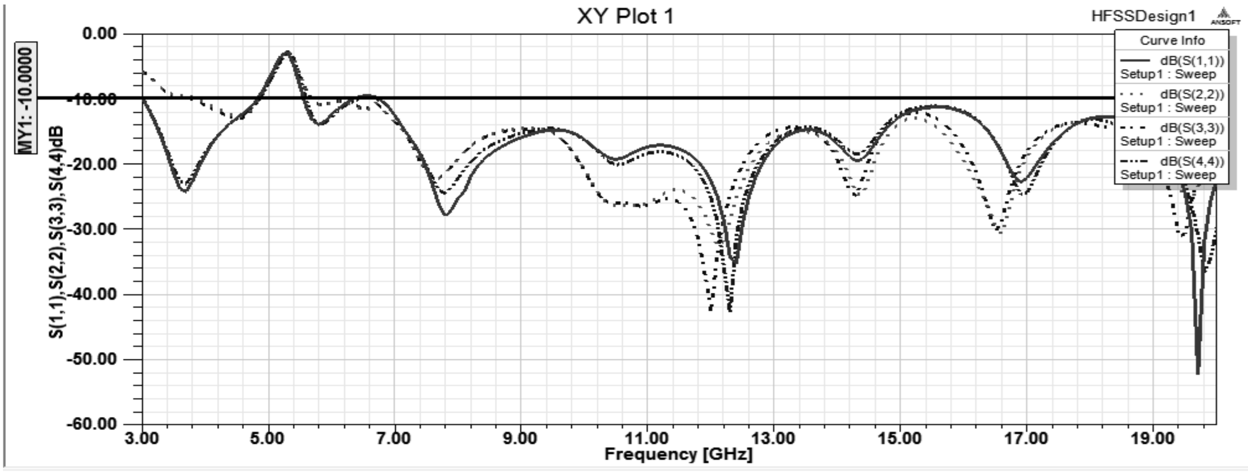


Figure 3.22 S-Parameter (Reflection coefficients)

In terms of reflection coefficient the MIMO system produces good results as compared to the single element monopole antenna. But for the reflection coefficient at port three the resultant signal is disturbed from 3 GHz to 4 GHz.

Figure 3.23 S-Parameter (Transmission coefficient)

In terms of isolation, S13 and S14 produces good results as most of the signal lies below -20 dB, but S12 is disturbed and signal is above -15 dB from 3 GHz to 4 GHz.

3.4 Final design

In this arrangement all the antennas are placed in such a way that they are 90˚ apart. This arrangement resulted in attaining the good isolation. The overall size of the antenna is reduced considerably. For further improvement of isolation four wings fan shape is added in the ground center for attaining more isolation. In previous antennas geometry fan wing extended to edge of board but result are not satisfactory. So in final shape after optimization fan wing values take as to get good possible result. The configuration of the implemented design has been inspired from [38].

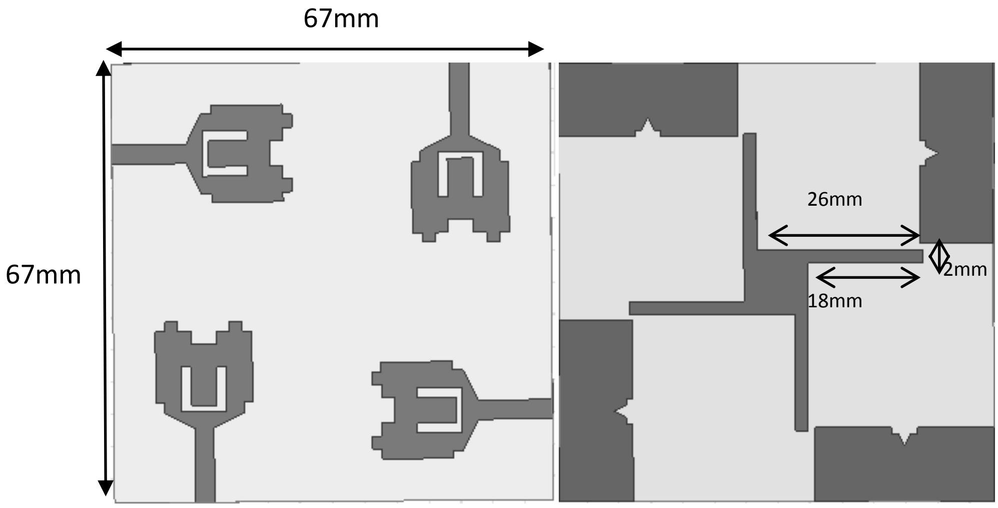


Figure 3.24 Final design of antenna

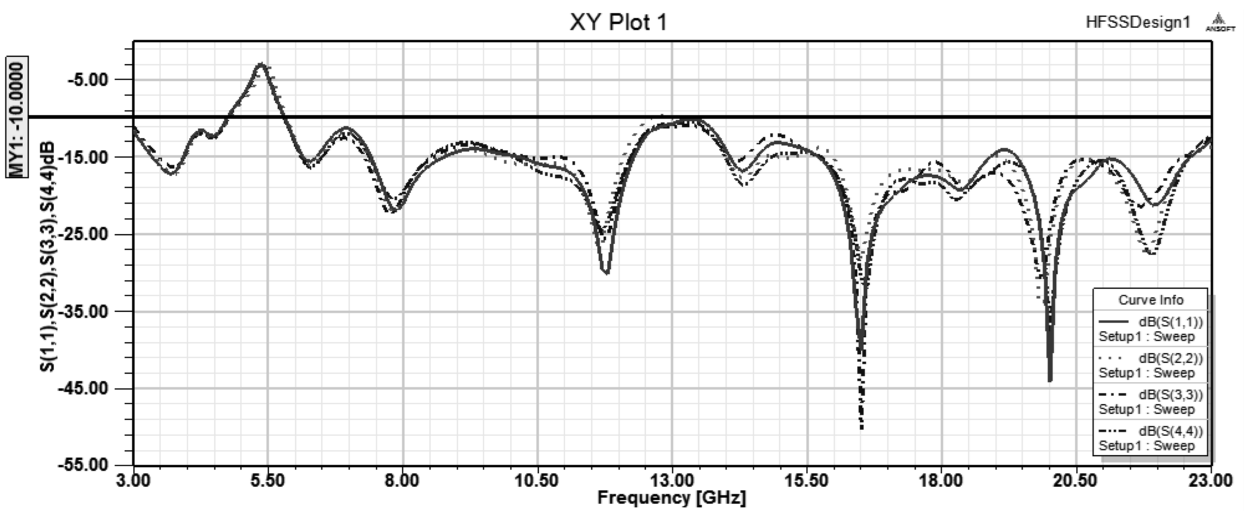


Figure 3.25 S-Parameter (Reflection coefficient)

In terms of reflection coefficient (i.e. S11 S22 S33 S44) antennas have good results and are similar to the single element monopole antenna, it also indicates the correct position of notch.

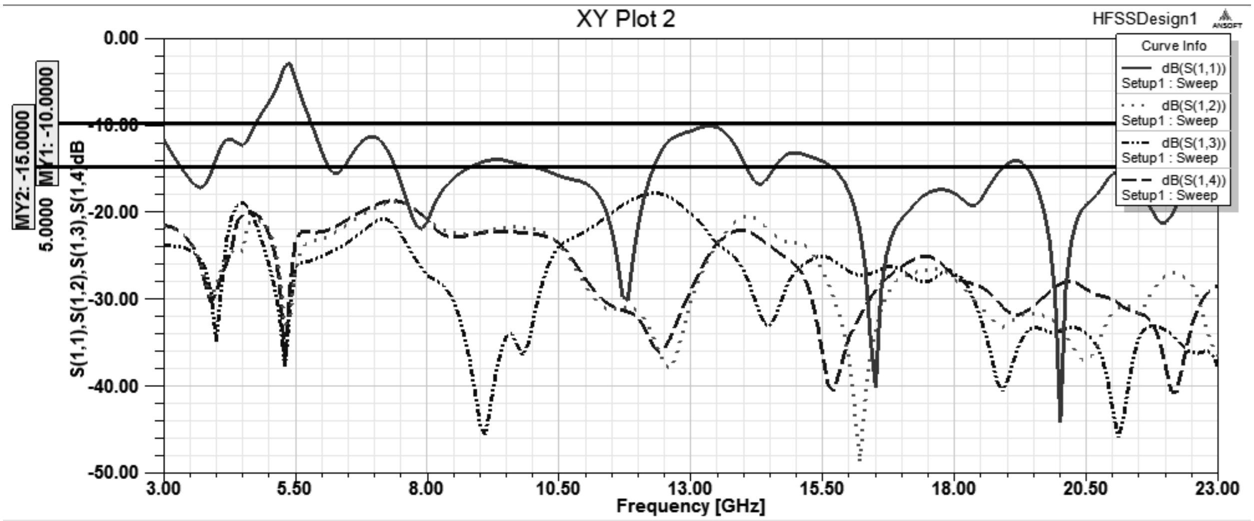


Figure 3.26 S-Parameter (Transmission coefficient)

In terms of isolation, the resultant signal shows that the arrangement produces the good isolation. Requirement for the isolation is to be less than -15 dB, but this orientation produces most of the signal below -20 dB which fulfills the demand compare to all other possible orientation. The fan like structure is parasitic decoupler which help to increase isolation between the antennas.

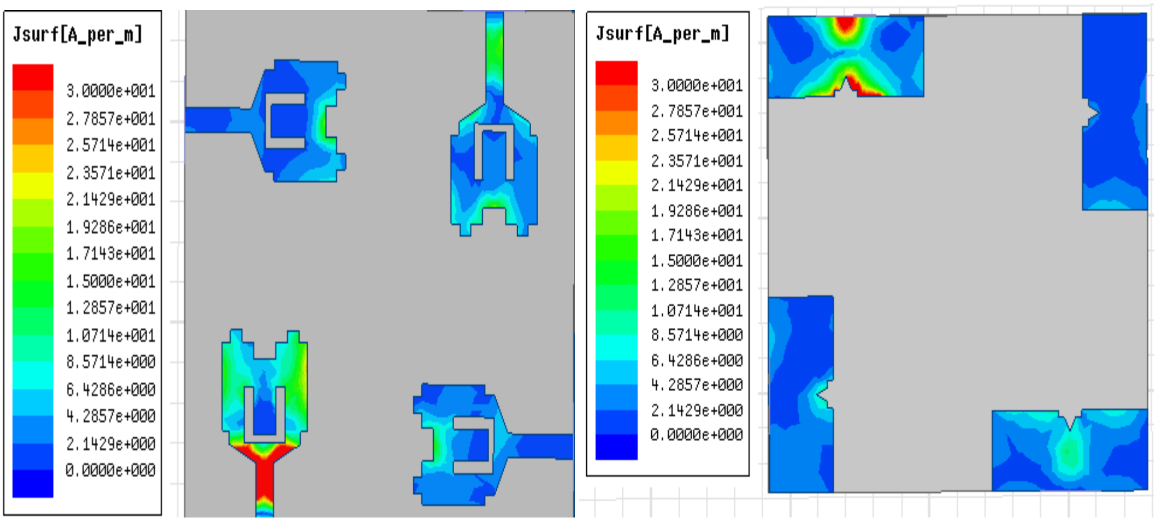


Figure 3.27 Surface Current Before adding of fan structure

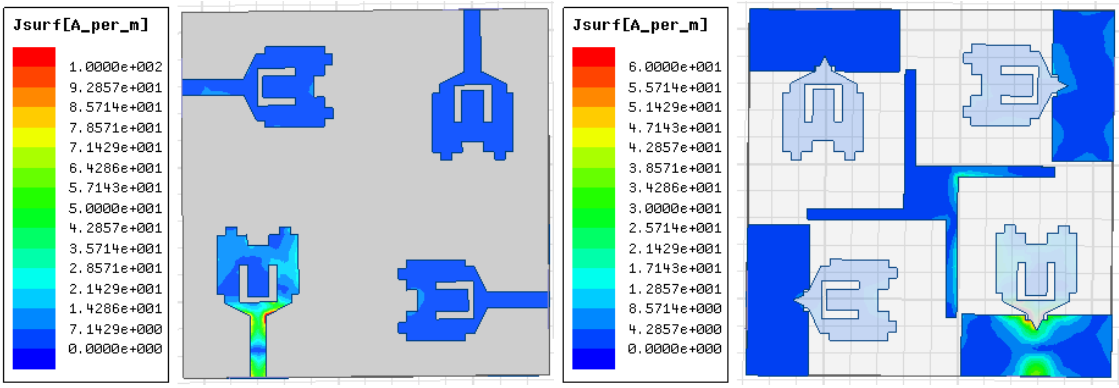


Figure 3.28 Surface Current After adding of fan structure

In figure 3.27 shows that before fan shape parasitic decoupler radiate other antenna patch and ground while only one port is connected. In figure 3.28 after adding fan shape parasitic decoupler when only one port radiate it have no effect on other antenna ground and patch.

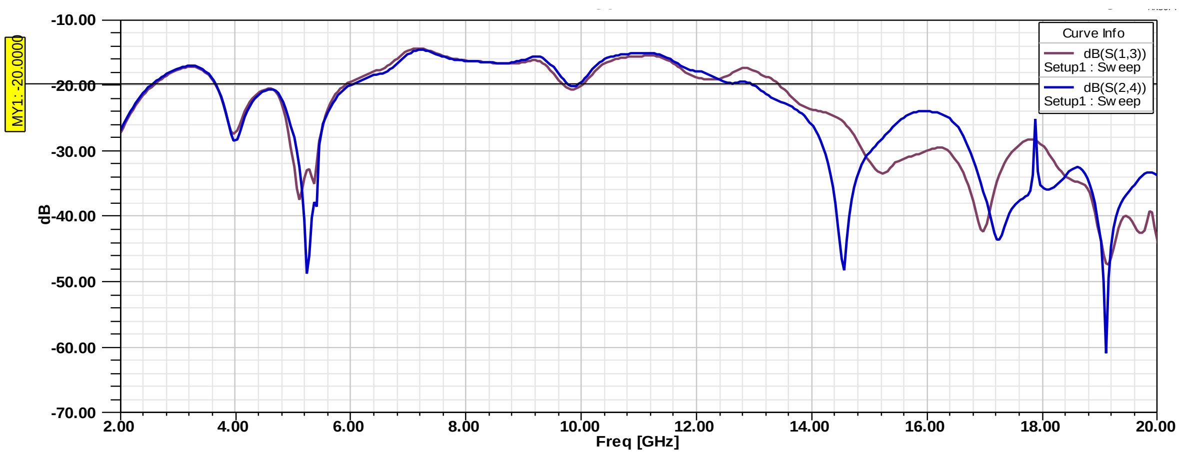


Figure 3.29 S-Parameter before adding of fan structure

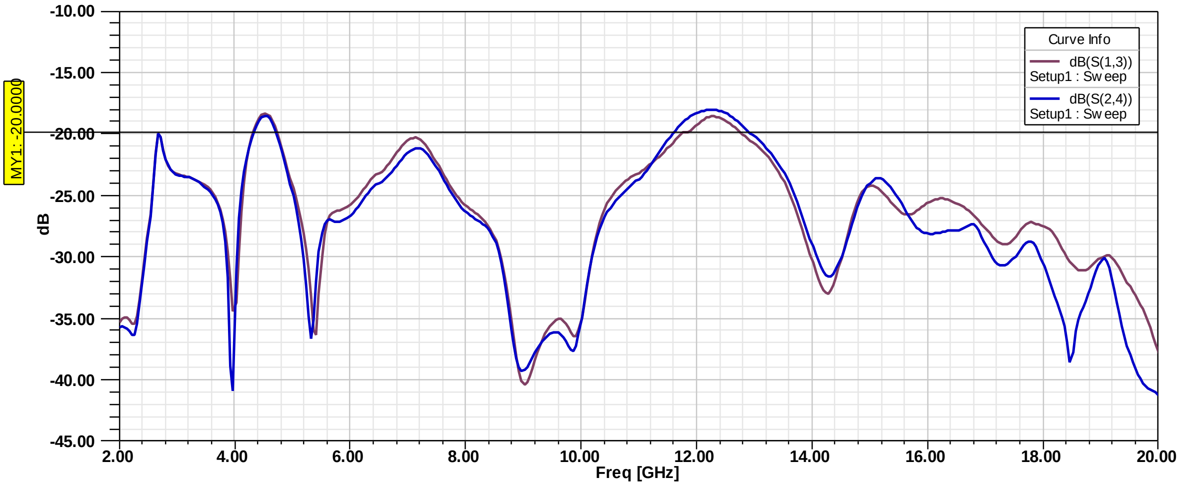


Figure 3.30 S-parameter after adding of fan structure

In figure 3.29 and figure 3.30 show that isolation between antennas improve by 5 dB after adding fan shape parasitic decoupler. So antennas which heads are face each other isolation increase.

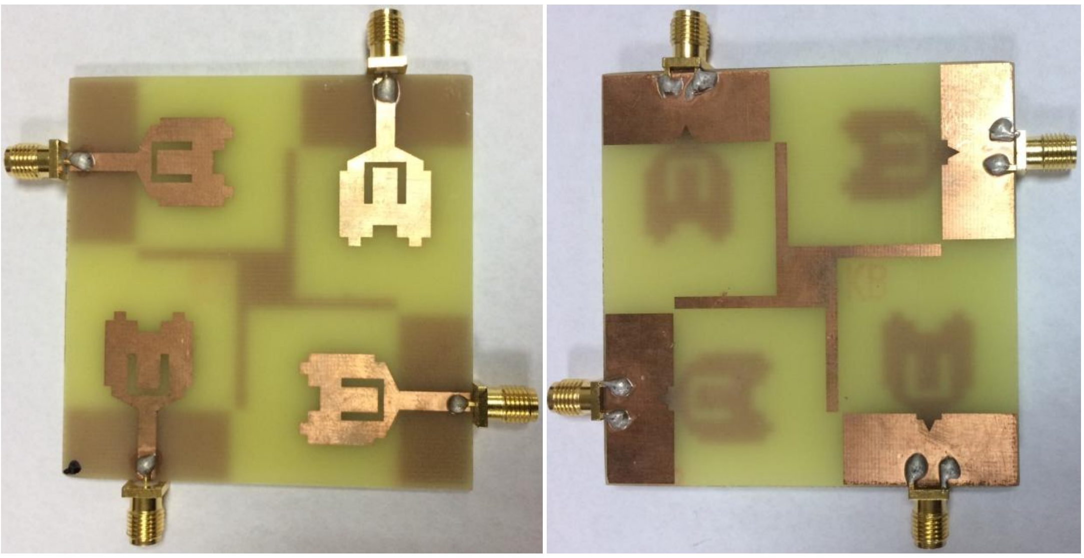


Fig 3.31 Proposed UWB MIMO Antenna

Chapter 4

RESULTS AND DISCUSSION

4.1 Simulated Result & Discussion

Simulated results of single element patch antenna are shown in previous chapter 3 Fig 3.2. After adding notch in single element antenna simulated results are shown in Fig 3.5. Simulated results of possible two element antenna are shown in Fig 3.7, Fig 3.8, Fig 3.10, Fig 3.11, Fig 3.13, Fig 3.14, Fig 3.16, and Fig 3.17. After two elements MIMO antenna four element MIMO possible arrangements is simulated and results are shown in Fig 3.19, Fig 3.20, Fig 3.22, Fig 3.23. So, simulated results of final antenna are shown below.

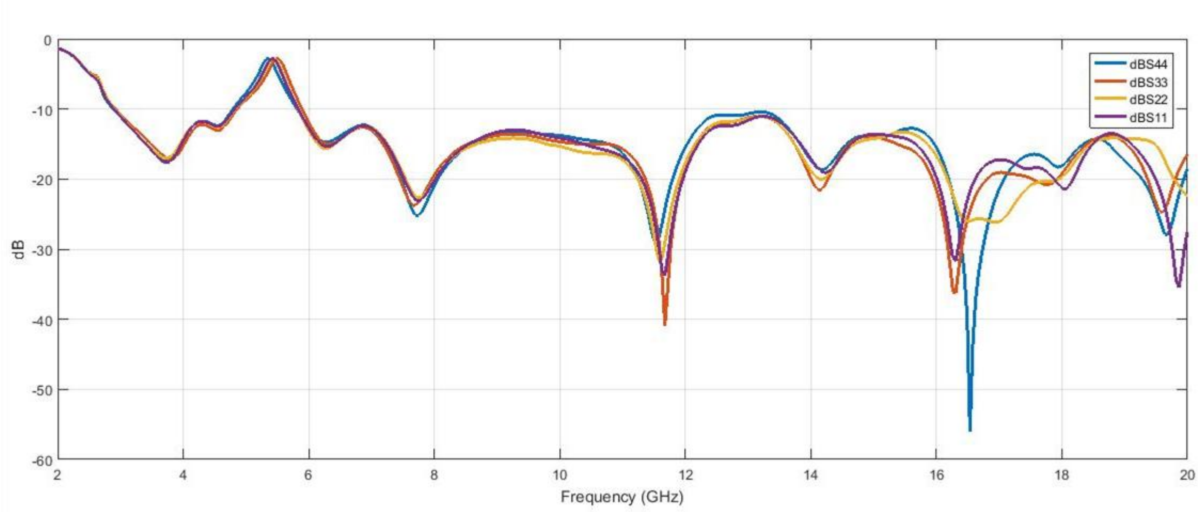


Figure 4.1 Simulated results

Figure 4.1 above shows S11, S22, S22 and S44. The graph is less than -10 dB from 3 GHz to 20 GHz. Only at 5.5 GHz the graph gets highest value which is notch frequency of WLAN. On dips of S-parameter gain plots and radiation patterns on E and H plane are simulated. First gain plot is simulated on 7.7 GHz.

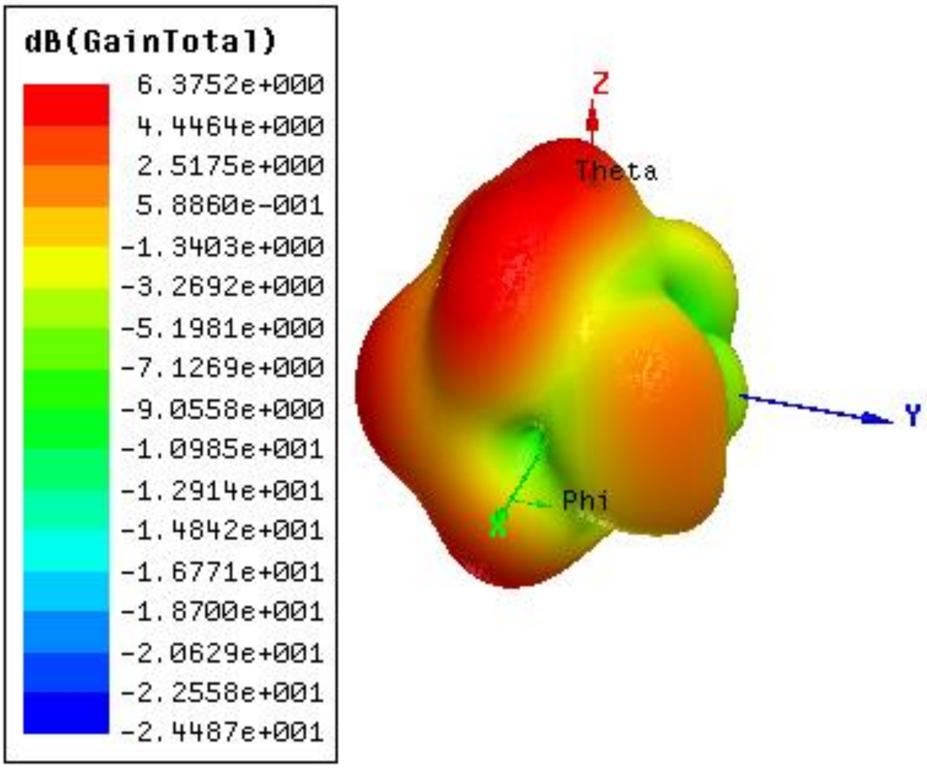


Figure 4.2 3D Gain Plot at 7.7 GHz.

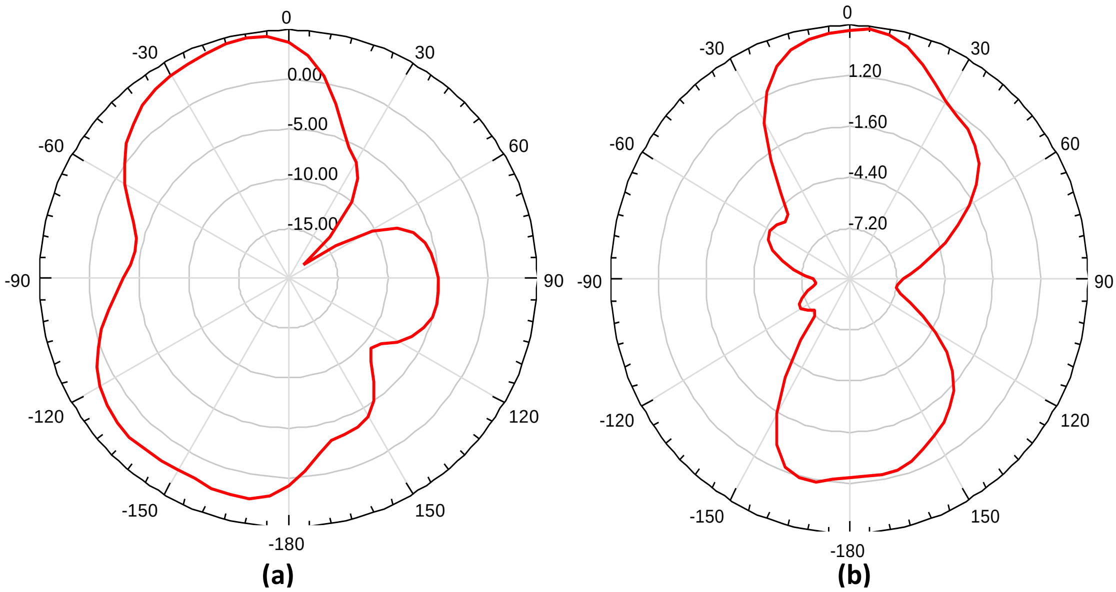


Figure 4.3 2D Radiation pattern at 7.7 GHz

(a)H-plane (b) E-plane

In Figure 4.2 the 3D radiation pattern of proposed final antenna design is shown. The plot shows that gain goes up to 6.35 dB at 7.7 GHz frequency. While in Figure 4.3 a 2D plot of radiation pattern in H-plane and E-plane is demonstrated which helps to understand how patterns are generated in E-plane and H-plane.

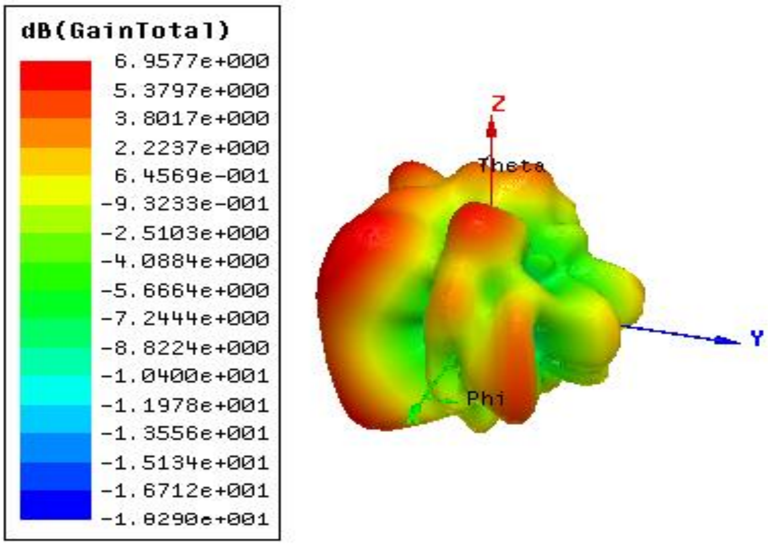
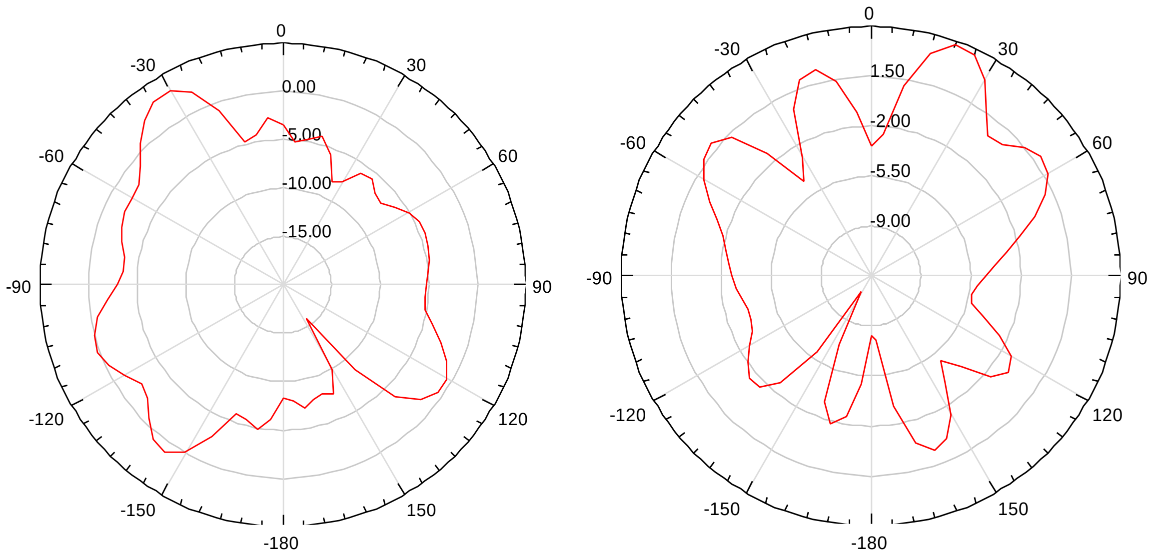


Figure 4.4 3D gains Plot at 11.6 GHz of Proposed antenna



(a) (b)

Figure 4.5 2D Radiation pattern at 11.6 GHz of Proposed antenna

(a)H-plane (b) E-plane

Figure 4.4 shows the 3D radiation pattern of proposed final antenna design. The plot shows that gain goes up to 6.95 dB at 11.6 GHz frequency. While in Figure 4.5 a 2D plot of radiation pattern in H-plane and E-plane is demonstrated which help to understand how patterns generate in E-plane and H-plane at frequency 11.6 GHz through simulation.

4.2 Measured Result & Discussion

After fabrication the antenna is tested on vector network analyzer. After that measured and simulated results are compared in order to examine the results similarity.

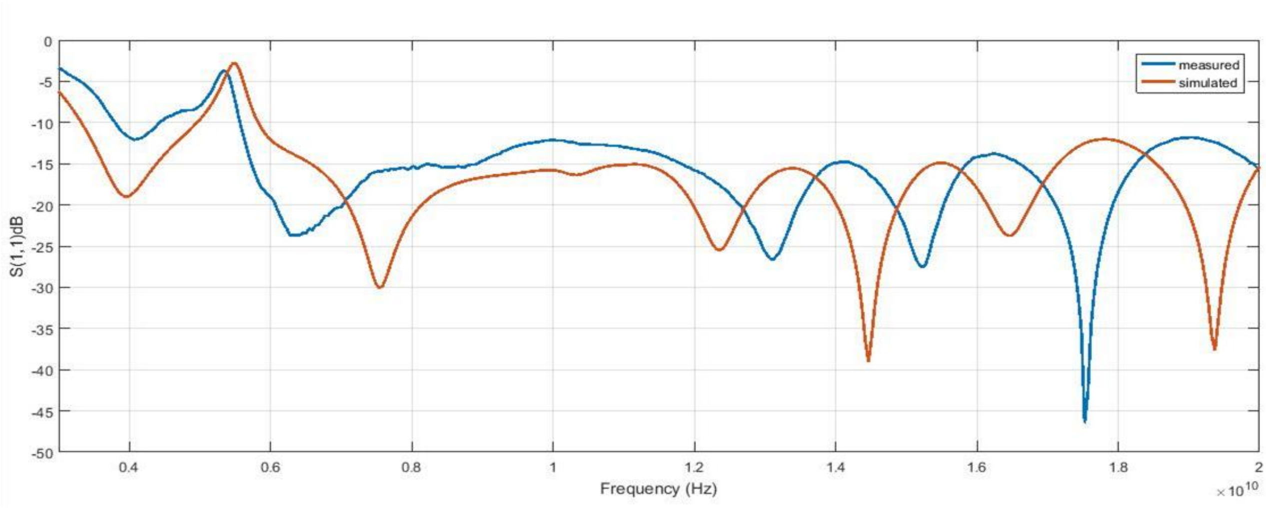


Figure 4.6 S11 of Single element.

In Fig 4.6 the measured results of single patch are compared with simulated results. Both graphs are less than -10 dB from 3 GHz to 20 GHz. But notch is available at frequency of WLAN as they show a peak at this frequency.

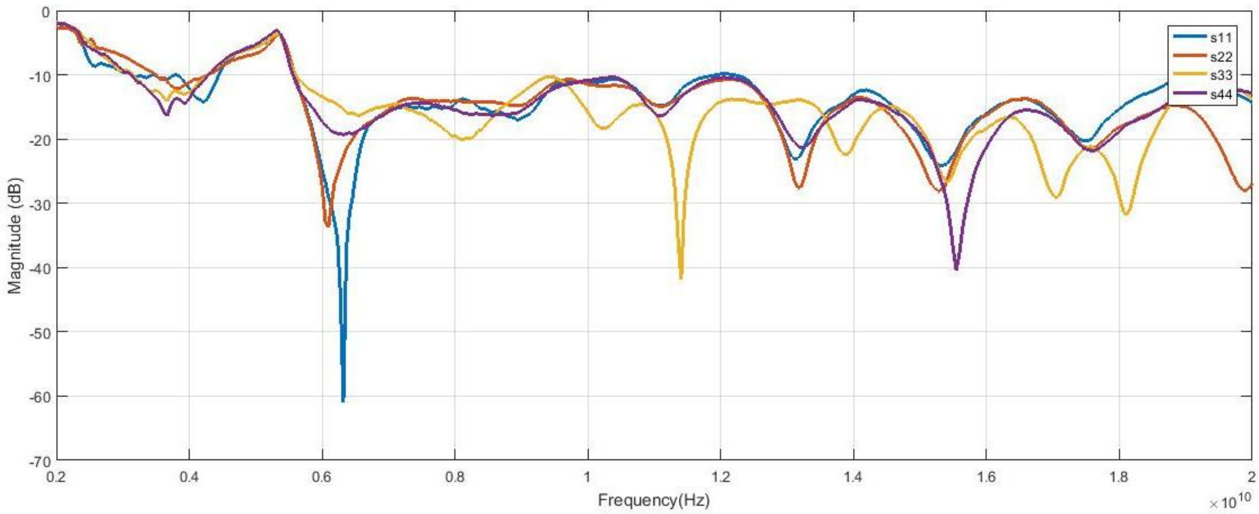


Figure 4.7 S-parameter of MIMO antenna.

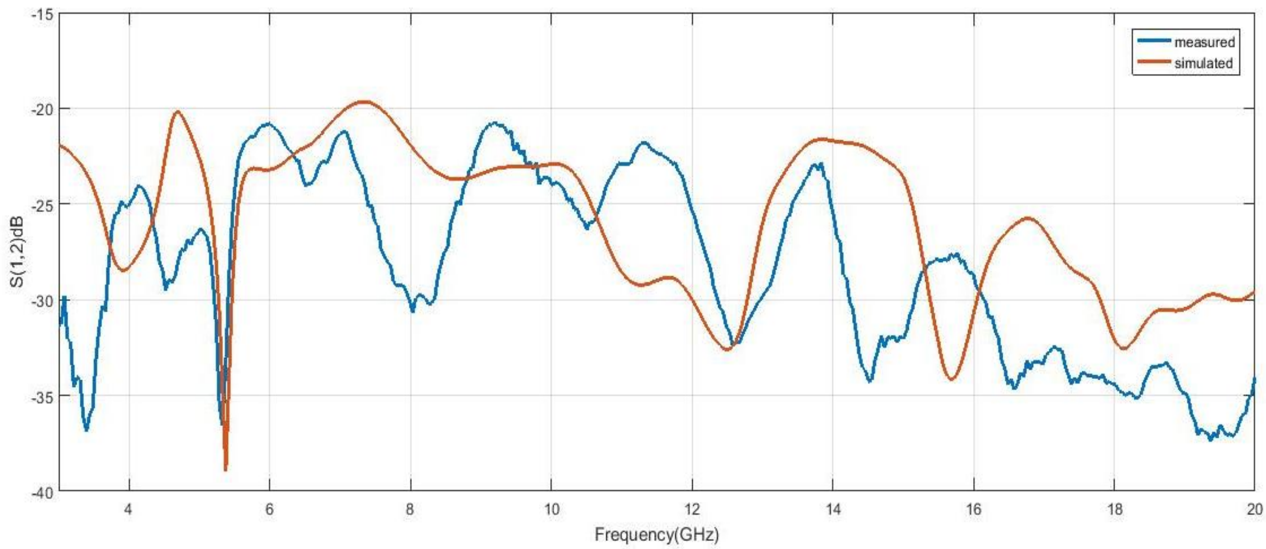


Fig 4.8 S-parameter of MIMO antenna

In figure 4.8 measured and simulated result of S12 are compared. Both graph show isolation between the antennas is less than -20 dB. So it fulfills the case of high isolated antenna.

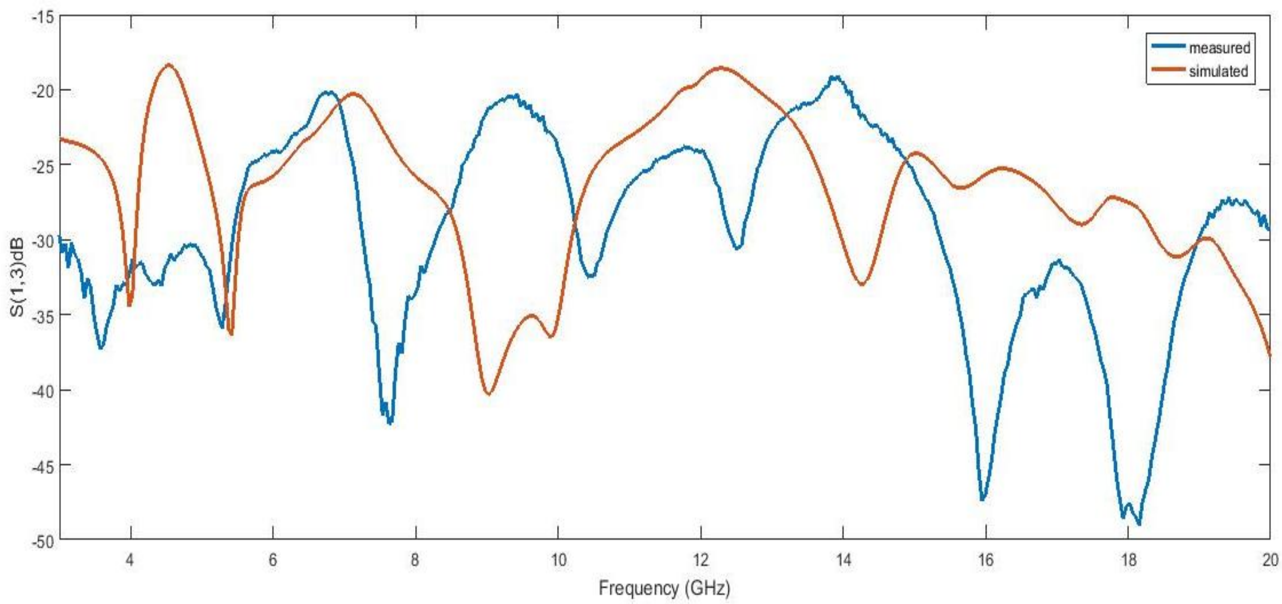


Fig 4.9 S-parameter of MIMO antenna

In figure 4.9 measured and simulated result of S13 are compared. Both graph show isolation between the antennas 1 and antenna 3 is less than -20 dB. So it fulfills expression of high isolation antenna.

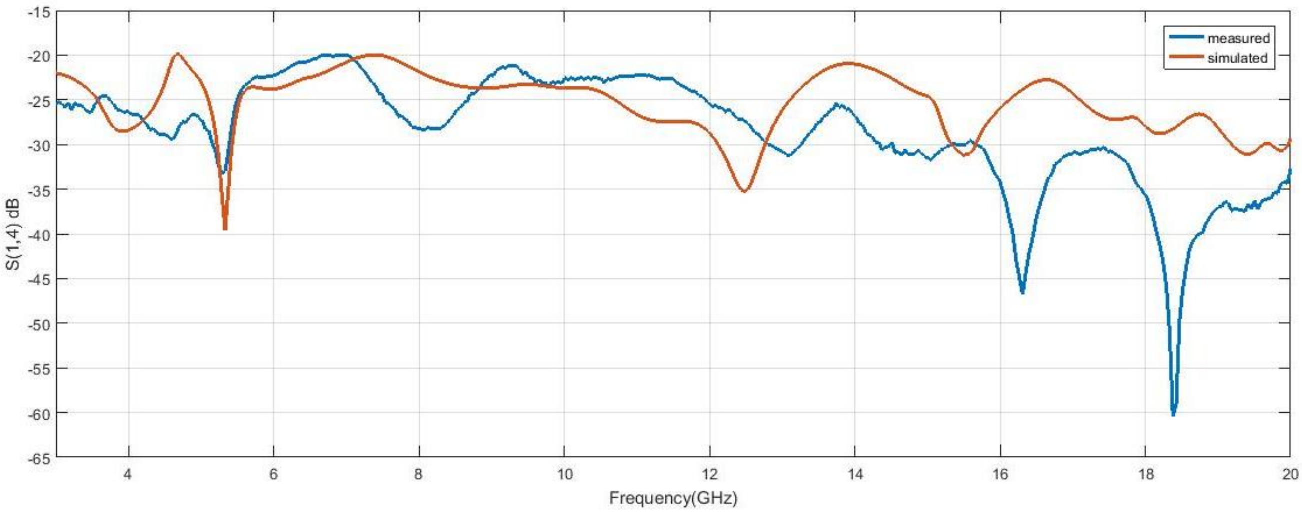


Fig4.10 Return loss of MIMO antenna

Above graphs show the comparison between measured and simulated results of the proposed antenna, which shows that the proposed antenna fulfills the desired requirement. As result of S-parameter of simulated and measured are less than -20 dB so it come in category of highly isolated MIMO antenna.

Chapter 5

Conclusion and Future work

5.1 Conclusion

The proposed antenna in this thesis covers the band from 3.1 to 20 GHz i.e. coverage is 126% more than band coverage of UWB. It has the maximum gain of 6.37 dB at 7.7 GHz and gain 6.95 dB at 11.6 GHz. Also protects WLAN band from interference with the help of a U shaped notch. The four elements of antenna make it a MIMO which helps to tackle the issue of multipath effect. The structure introduced in ground acts as a decouple resonance. Due to this high isolation of -20 dB can be obtained on most of the spectrum. Dimensions of antenna are 67 × 67 mm and proposed antenna has applications of short-range, high-data-rate transmission, medical imaging etc.

5.2 Contribution

The main objective of thesis is to design four element UWB-MIMO antennas with notch on WLAN and high isolation. After throughout literature review, antenna designing and results and discussion for proof of concept, it is concluded that the proposed antenna is significant performance in isolation, gain and band coverage.

Table 5.1 Comparison of Proposed Antenna

Ref No.	Bandwidth (GHz)	Isolation (dB)	Elements	Notch	Dimension (mm)
Lin [38]	1.6-6.5	<-20	4	0	122 × 122
Kayabasi [39]	3.1-17.3	<-15	4	0	75.19 × 75.19
Dhar [40]	1.85-10.6	-15	2	0	50 × 90
Thesis	3.1-20	<-20	4	WLAN	67 × 67

In terms of band width if we compare proposed antenna with other referenced antenna covered double band width. Isolation result make antenna highly isolated antenna. So overall antenna gets better result related to previous designs.

5.3 Future work

- The results obtained in this project are much satisfactory. But there always exists a room for advancement and melioration, therefore, still, several modifications can bring fruitful output in this project.
- In future the size of antenna can be made more compact with the same results.
- On other side band notch can be added at 3.5 GHz and 7.5 GHz to protect them from interference.
- Making a reconfigurable notch antenna which will give the liberty to choose notch characteristics on demand for some desired frequency.
- For operation in UWB band range several other feeding techniques can also be introduced like aperture couple feed technique, inset feed, coaxial probe, proximity coupled feed etc.
- For using antenna in wearable applications substrate and design on fabric material can be changed.
- To reduce SAR (Specific Absorption Rate) with good gain directional antenna can be designed.

Reference

1. H.Nikookar and R. Prasad, "Introduction to ultra wideband for wireless communications" Vol no 200, Springer, 2009.

2. H. G. Schantz, "A brief history of UWB antennas", IEEE Aerospace and Electronic Systems Magazine, Vol no 19, pp. 22-26, 2004.

3. Federal Communication Commission, Washington, DC, USA, "Revision of part 15 of the Commissions rule regarding ultra-wideband transmission systems FCC 0248," First Report and Order, Feb. 2002

4. T.K.Tsang and M. N. El-Gamal, "Ultra-wideband (UWB) communications systems: an overview," *The 3rd International IEEE-NEWCAS Conference, 200*, Quebec City, Que, pp. 381-386, 2005.

5. P. R. Kurekar and S. S. Khade, "Design and implementation of MIMO antenna for WLAN application," *2017 International Conference on Communication and Signal Processing (ICCSP)*, Chennai, pp. 0477-0480, 2017.

6. Kupferschmidt, Claus, Emil Dimitrov, and Thomas Kaiser. "Multiple antenna UWB systems WP3 of the EUWB-Project." In *Advanced Technologies for Communications, 2009. ATC'09. International Conference on*, IEEE, pp. 295-299, 2009

7. C.Abou-Rjeily, N.Daniele, J-C.Belfiore, "Space-time coding for multiuser Ultra-wideband communications." IEEE Trans. Communications 2006,Vol 54 (11),pp. 1960-1972, 2006.

8. L.Liu, H.Zhao H, T.S.P See, Chen Z.N. A printed ultra-wideband diversity antenna. Proceedings of IEEE International Conf. Ultra-Wideband, Vol. 2, pp. 351-356, Sept. 2006.

9. S.Y Lin, H.R.Huang, "Ultra-wideband MIMO antenna with enhanced isolation. " Microwave and Optical Technologies Let. 2009,Vol no 51 (2), pp. 570-573, 2009.

10. A.Rajagopalan, G.Gupta, A.S.Konanur, B.Hughes , G.Lazzi, "Increasing channel capacity of an ultrawideband MIMO system using vector antennas." IEEE Trans. Antennas and Propagation 2007, Vol 55 (10), pp. 2880-2887, 2007.

11. S.Hong , J.Lee , J.Choi, Design of UWB diversity antenna for PDA applications. Proceedings of 11th International Conf. Advanced Communication Technology, pp. 583-585, Feb. 2008.

12. Chen Y, Lu W.J, Cheng C.H, Cao W, Li Y, "Printed diversity antenna with cross shape stub for ultra-wideband applications." Proceedings of 11th IEEE International Conf. Communication Systems, pp. 813-816, Nov. 2008.

13. L. Liu, S. W. Cheung, and T. I. Yuk, “Compact MIMO antenna for portable UWB applications with band-notched characteristic,” IEEE Trans. Antennas Propag., Vol no 63, pp. 1917–1924, 2015.

14. Malekpour, Narges, and Mohammad Amin Honarvar. "Design of high-isolation compact MIMO antenna for UWB application." *Progress In Electromagnetics Research* 62, pp. 119-129, 2016.

15. S. Hussain, M. Zafar, S. Saleem and M. U. Tariq, "Microstrip antenna for UWB with WLAN band rejection," *2015 IEEE 6th International Symposium on Microwave, Antenna, Propagation, and EMC Technologies (MAPE)*, Shanghai, pp. 95-98, 2015.

16. Y. Rahayu, T. A. Rahman, R. Ngah and P. S. Hall, "Ultra wideband technology and its applications," *2008 5th IFIP International Conference on Wireless and Optical Communications Networks (WOCN '08)*, Surabaya, pp. 1-5, 2008.

17. Islam, Mohammad Tariqul, Rezaul Azim, and Ahmed Toaha Mobashsher. "Triple band-notched planar UWB antenna using parasitic strips." *Progress In Electromagnetics Research* 129, pp.161-179, 2012.

18. K. P. Ray, “Design Aspects of Printed Monopole Antennas for Ultra-Wide Band Applications,” International Journal of Antennas and Propagation, vol. 2008, Article ID 713858, 8 pages, 2008.

19. Santos, R. A., and S. Cerqueira Jr. "A low-profile and ultra-wideband printed antenna with a 176% bandwidth." *Journal of Microwaves, Optoelectronics and Electromagnetic Applications* 16, Vol no 1, pp. 59-69, 2017.

20. Deshmukh, Amit A., Payal Mohadikar, Priyanka Verma, and Priyal Zaveri. "Ultra-wideband plus shaped microstrip antenna." In *Information Communication and Embedded Systems (ICICES), 2016 International Conference on*, IEEE, pp. 1-5, 2016.

21. Rakhi, Sonam Thakur, and Ms Sonam Thakur. "Performance Analysis of Different Shapes Patch Antennas At 2.45 Ghz." *Electronics and communication Engineering IGIT (GGSIPU) Kashmiri Gate, Delhi, India, Department of Electronics & Communication Engineering IGIT (GGSIPU) Kashmiri Gate, Delhi, India, International Journal of Engineering Research & Technology (IJERT)*,pp. 2278-0181, 2014.

22. Anusudha, K., and M. Karmugil. "Design of circular microstip patch antenna for ultra wide band applications." In *Control, Instrumentation, Communication and Computational Technologies (ICCICCT), 2016 International Conference*, IEEE, pp. 304-308, 2016.

23. Deshmukh, Amit A., Payal Mohadikar, Priyal Zaveri, Kshitij Lele, Adil Parvez, and Gaurav Panchal. "Ultra-wideband modified rectangular microstrip antenna." In *Green Engineering and Technologies (IC-GET), 2016 Online International Conferenc* , pp. 1-4, IEEE, 2016.

24. Liu, Jianjun, ShunshiZhong, and Karu P. Esselle. "A printed elliptical monopole antenna with modified feeding structure for bandwidth enhancement." *IEEE Transactions on Antennas and Propagation* 59,Vol no 2, pp. 667-670, 2011.

25. Abegaonkar, Mahesh P., Yatinder Chhikara, Ananjan Basu, and Shiban K. Koul. "Tapered-CPW fed printed triangular monopole antenna." In *Antennas and Propagation, 2006. Eu CAP 2006. First European Conference,* pp. 1-4. IEEE, 2006.

26. Mandal, Tapan, and Santanu Das. "A coplanar waveguide fed hexagonal shape ultra wide band antenna with WiMAX and WLAN band rejection." *Radio engineering Journal* 23, Vol no 4, pp. 1077-1085, 2014

27. Dikmen, Cengizhan M., SibelCimen, and GoncaCakir. "Planar octagonal-shaped UWB antenna with reduced radar cross section." *IEEE Trans. Antennas Propag* 62,Vol no 6, pp. 2946-2953, 2014.

28. Singhal, Sarthak, Tushar Goel, and Amit Kumar Singh. "Novel diamond shaped UWB monopole antenna." In *India Conference (INDICON), 2013 Annual IEEE*, pp. 1-6. IEEE, 2013.

29. Lizzi, Leonardo, et al. "Printed UWB antenna operating over multiple mobile wireless standards." *IEEE Antennas and Wireless Propagation Letters* 10, pp. 1429-1432, 2011.

30. Li, Jian-Feng, Qing-Xin Chu, Zhi-Hui Li, and Xing-Xing Xia. "Compact dual band-notched UWB MIMO antenna with high isolation." *IEEE Transactions on Antennas and Propagation*61,Vol no. 9, pp. 4759-4766, 2013.

31. Toktas, Abdurrahim. "G-shaped band-notched ultra-wideband MIMO antenna system for mobile terminals." *IET Microwaves, Antennas & Propagation* 11,Vol no. 5, 718-725, 2016.

32. Chhabilwad, Kaustubh, G. S. Reddy, Anil Kamma, Basudev Majumder, and Jayanta Mukherjee. "Compact dual band notched printed UWB MIMO antenna with

pattern diversity." In *Antennas and Propagation & USNC/URSI National Radio Science Meeting, 2015 IEEE International Symposium*, IEEE, pp. 2307-2308, 2015.

33. Liu, Yao, and ChunWei Sun. "A compact printed MIMO antenna for UWB application with WLAN band-rejected." In *Antennas, Propagation and EM Theory (ISAPE), 2016 11th International Symposium*, IEEE, pp. 95-97, 2016.

34. Liu, Jianjun, et al. "Study of an extremely wideband monopole antenna with triple band-notched charactersistics." *Progress In Electromagnetics Research* 123, pp. 143-158, 2012.

35. Nikolaou, Symeon, Boyon Kim, Y-S. Kim, John Papapolymerou, and Manos M. Tentzeris. "CPW-fed ultra wideband (UWB) monopoles with band rejection characteristic on ultra thin organic substrate." In *Microwave Conference, 2006. APMC 2006. Asia-Pacific*, pp. 2010-2013, IEEE, 2006.

36. Arriola, Aitor, Ezzeldin A. Soliman, Steven Brebels, and Walter De Raedt. "Single and dual band-notched UWB antennas with U-shaped structures." In *Microwave Conference, 2009. EuMC 2009. European*, IEEE, pp. 89-92, 2009.

37. Sahoo, Manaswinee, and Sudhakar Sahu. "Design & development of UWB notch antenna with fractal geometry." In *Circuit, Power and Computing Technologies (ICCPCT), 2015 International Conference on, IEEE*, pp. 1-5, 2015.

38. Lin, Shun Yun, and Hong Ren Huang. "Ultra wideband MIMO antenna with enhanced isolation." Microwave and Optical Technology Letters 51, Vol no 2, pp. 570-573, 2009.

39. Kayabasi, Ahmet, Abdurrahim Toktas, Enes Yigit, and Kadir Sabanci. "Triangular quad-port multi-polarized UWB MIMO antenna with enhanced isolation using neutralization ring." AEU-International Journal of Electronics and Communications 85, pp.47-53, 2018.

40. Dhar, Sagar K., and Mohammad S. Sharawi. "A UWB semi-ring MIMO antenna with isolation enhancement." Microwave and Optical Technology Letters 57, Vol no. 8, pp.1941-1946, 2015.