COMPACT FOUR ELEMENT UWB MIMO ANTENNA

FINAL YEAR PROJECT

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ABSTRACT

COMPACT FOUR ELEMENT UWB MIMO ANTENNA

With advent of multiple input multiple output (MIMO) techniques, considerable reliance on wireless data communication services has been seen that too especially with regards to ultra-wideband technology (UWB). Significant throughput is ensured by a combination of MIMO and UWB systems. These systems consist of antenna elements closely placed. As the number of antenna elements increases, spatial multiplexing also increases with throughput but with an allied problem of mutual coupling. Inter-channel correlation due to coupling effects MIMO system's efficiency adversely. Several techniques can be applied to reduce the mutual coupling to our requirements which can be consulted from large literature in and around the globe.

CERTIFICATE OF CORRECTNESS AND APPROVAL

It is hereby certified that information in this thesis, titled "**Compact Four Element UWB MIMO Antenna**" carried out by Capt Muhammad Sayyam Saddique, Major Muhammad Abdul Rehman Niazi, Major Usman Tahir Khawaja and Capt Moseb Shah under the supervision of Lec Maryam Rasool in partial fulfillment of degree of Bachelors of Telecommunication (Electrical) Engineering is correct and approved.

Approved By

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Dated:

DECLARATION

We hereby declare that no content and form 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.

Dedicated to

The Creator

and

The Created

ACKNOWLEDGEMENT

By the Grace and Mercy of Allah Almighty, the most Exalted and the most Knowledgeable, we the humble servants were able to put in our bit of contribution in that what has been bestowed upon His creation as knowledge.

We are thankful to our supervisor Lec Ms Maryam Rasool for her continuous guidance and supervision as well as other faculty and staff who taught and helped us during our entire degree and project. Without them we would have never explored the world's horizon from engineering or scientific perspectives.

We are grateful to our parents, whose prayers and shadow led us through thick and thins of life unharmed. Also, we are thankful to our better halves for their continuous support and dutifulness.

And to our colleagues we extend our gratitude for being there with us.

ABBREVIATIONS

1. **MIMO** > MULTIPLE INPUT MULTIPLE OUTPUT
2. **HFSS** > HIGH FREQUENCY STRUCTURE SIMULATOR
3. **PIFA** > PRINTED INVERTED F ANTENNA
4. **IEEE** > INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS
5. **Wi-Fi** > WIRELESS FIDELITY
6. **WiMAX** > WORLDWIDE INTEROPERABILITY FOR MICROWAVE ACCESS
7. **MSA** > MICROSTRIP PATCH ANTENNA
8. **dB** > DECIBEL
9. **PSD** > POWER SPECTRAL DENSITY

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CHAPTER 1

INTRODUCTION TO ANTENNA

1.1 Introduction

1.1.1 Overview

As a result of varying voltages, propagation of Electric and Magnetic waves come into existence.

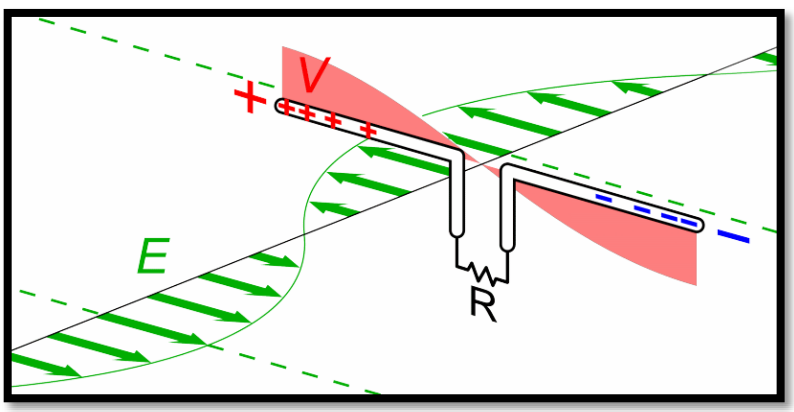


Figure 1- 1 Electromagnetic Waves

Requirements of compact sizes in wireless systems posed a challenge for their integration with multi-component printed circuit boards as well as other devices. Apart from that, social interactive technologies such as WiMax, Wi-Fi, Bluetooth, UWB, 3G/4G/5G etc too have narrowed the choice to research and develop efficient modern wireless technologies. Antennas are the front-end of these integrated devices and electronic modules. A remarkable innovation in this field is the design of Ultra Wide Band (MIMO) antennas with large throughput [1][2]. A lot of emphasis has been laid to design compact antennas with large data rate.

1.1.2 Definitions

Antenna

"In radio engineering, an antenna is the interface between radio waves propagating through space and electric currents moving in metal conductors, used with a transmitter or receiver".

Bandwidth

"Bandwidth is the range of frequencies over which an antenna works efficiently. For some classes of antenna, bandwidth is taken as ratio of upper to lower frequencies of acceptable operation"

Polarization

"It is orientation of oscillations of electromagnetic waves in space. Polarization is the property of electromagnetic waves which describes the time varying direction and magnitude of the electric field vector".

Polarization phenomenon is categorized into

- ✓ Linear polarization.
- ✓ Circular polarization.
- ✓ Elliptical polarization.

Linear polarization is further classified into

- ✓ Horizontal polarization
- ✓ Vertical polarization.

Beam Efficiency

"Beam efficiency of minor lobe is the ratio of the beam area of the minor lobe to the beam area of the antenna. It is also known as stray factor".

Voltage Standing Wave Ratio (VSWR)

"Voltage standing wave ratio is the measure of how well the impedance of the antenna is matched with the transmission line to which it is connected or it shows how well the load impedance is connected to the source impedance if the VSWR is smaller than maximum power is transmitted to the antenna".

Return Loss

"These are merely the reflections in signal power caused by the insertion of a device in transmission line. It is the magnitude of reflection coefficient given in dB".

1.1.3 Importance of Antenna in Wireless Communication

As the terminology itself explains, the Antennas play a vital role in the transmission and reception of signals and waves propagated in the surroundings. A wide range of utilities and devices use antennas to connect to the base stations, satellite terminals, beyond visual range sites and hubs; all of that making the effective and efficient use of wireless mode of transmissions using air as a medium.

1.2 Types of antennas

1.2.1 Line Antennas

The simplest form of an antenna is a straight line, pole or dipole antenna radiating omnidirectionally. It mainly consists of a strip or wire of a wavelength or requisite measurements for transmission and reception of propagated waves.

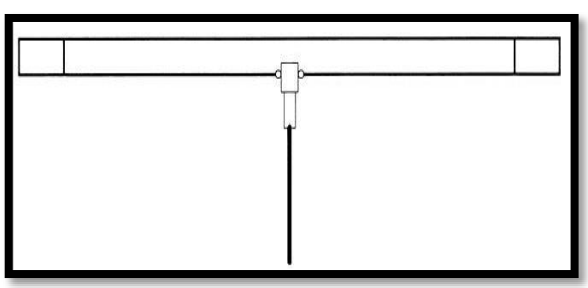


Figure 1- 2 Simple Dipole Antenna

1.2.2 Horn Antennas

As the name portrays, directional horn antennas are used to propagate UHF and micro waves at frequencies of more than 300 MHz. Horn antennas are metal waveguides, structured into the form of public address equipment loudspeakers. The best results are achieved with help of this construction as the radio waves are directed in beams.

Figure 1- 3: Horn Antenna

1.2.3 Patch Antennas

If you mount an antenna onto a flat rectangular sheet or surface, basically made of metal, the resulting antenna is a patch antenna. This metal patch is mounted on top of another sheet that acts as the ground plane. With a wavelength nearly of one-half of radio waves, these metal pieces are combined together as a resonating microstrip transmission-lines.

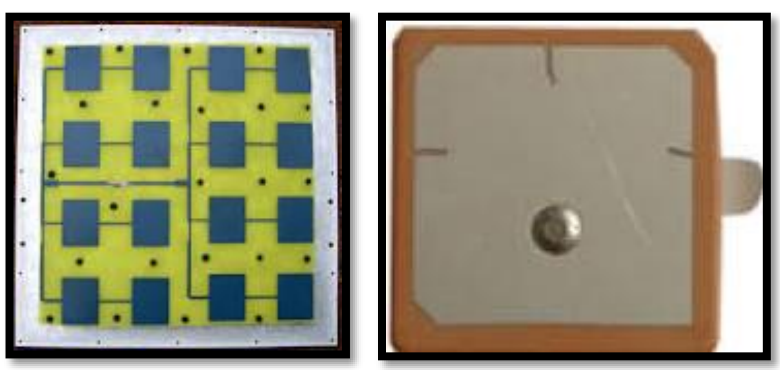


Figure 1- 4: Patch Antennas

1.2.4 Parabolic Antennas

The layman term of dish may describe the parabolic antennas. Parabolic antenna mainly utilize parabolic reverberator/reflectors that are curvy dishes of parabolic cross-sections. Used in satellite communication mainly parabolic antennas are used to direct radio waves into the space.

Figure 1- 5: Parabolic Antenna

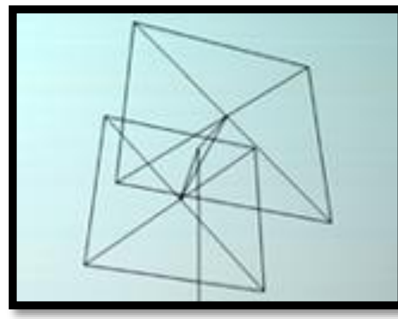


Figure 1- 6: Loop Antenna

1.2.5 Loop Antennas

Loop antennas are are coils or loops of wire that are joint to form any of the closed shape of, rectangle, circle, square or any such other configuration. Magnetic field components are of the major interest when it comes to Loop antennas. Loop antenna is categorized into full wave loop antenna and small loop antenna.

1.2.6 Array Antennas

Array are combination of various elements of one larger antenna. Various combinations are used to form arrays of antennas for transmission or reception of signals, examples being circular array antennas, linear array antennas etc. the most common being the Yagi-Uda antenna (mostly seen with television receptors) [3].

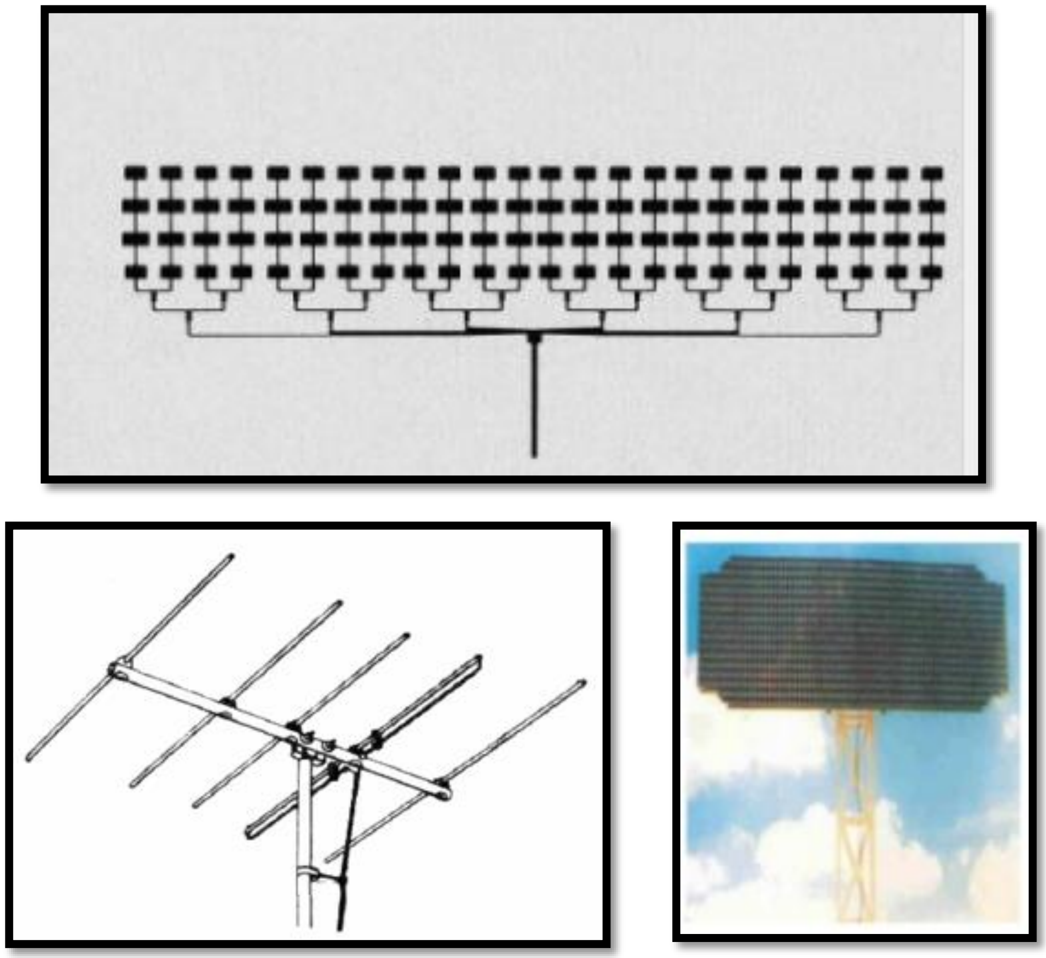


Figure 1- 7: Antenna Arrays

1.2.7 UWB and MIMO antennas

The two terms UWB and MIMO have enhanced the capabilities of the transmission and reception devices in the recent years. A huge amount of research is being carried out in these fields. Covering large radio spectrum; UWB antenna technology covers short range, high bandwidth using its lower energy levels. Whereas, MIMO term refers to enhancing the multiplexing capability of radio transceivers using multiple input and output ports/antennas keeping in view the multipath radio propagation. Today MIMO technology is an important part of wireless communication.

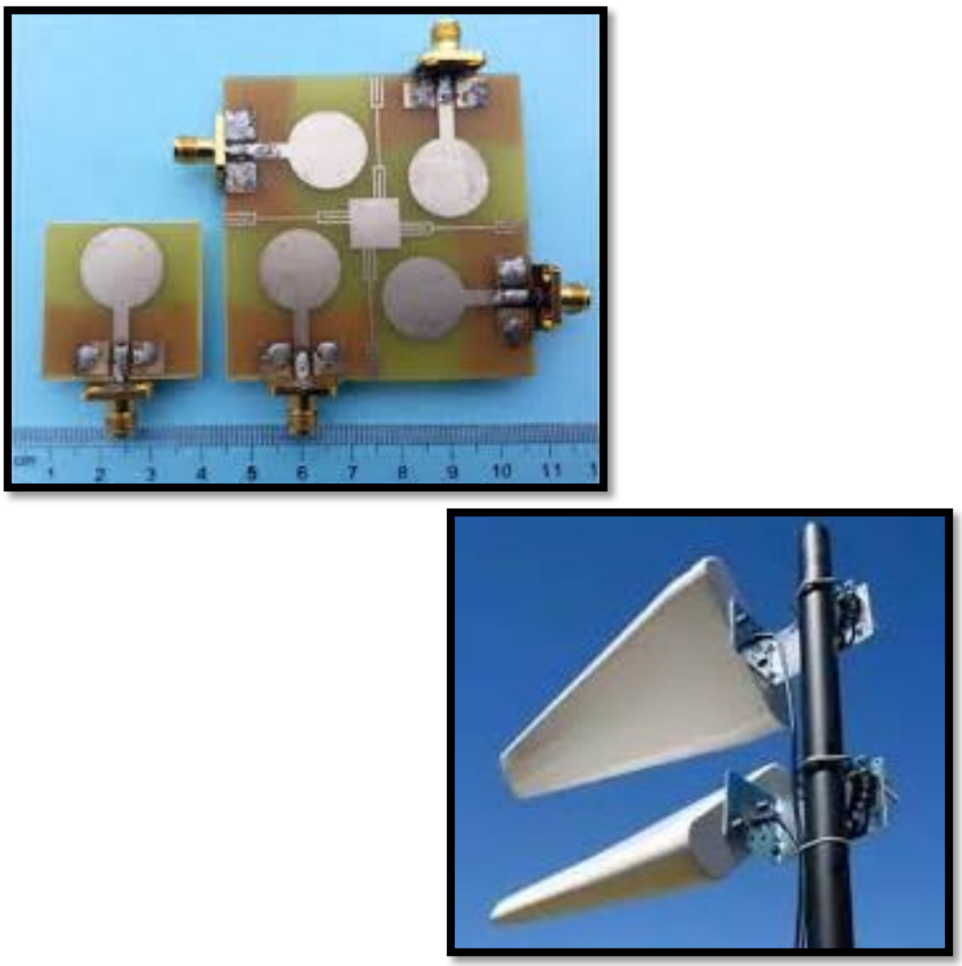


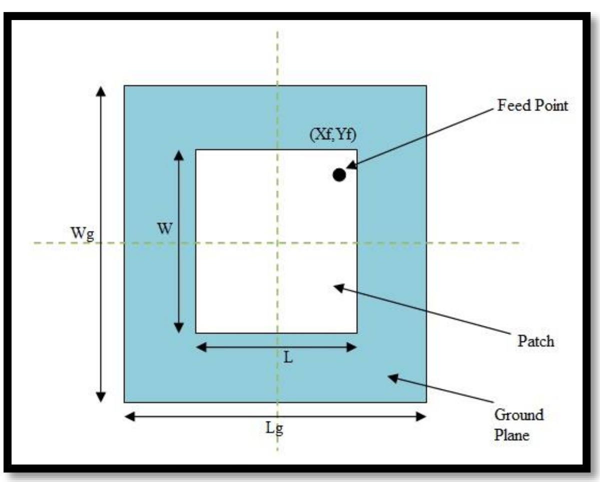
Figure 1- 8: MIMO Antennas

1.3 Microstrip Patch Antennas

1.3.1 History of Patch Antennas

Advancement in printed circuit board (PCB) technology and patching techniques, Patched antennas have taken a leap where microstrip antennas are fabricated onto PCBs. Mostly, these patch antennas consist of different patches in a multi-dimensional array, also referred to as printed antennas.

First introduced in mid-20th century, Microstrip antennas were realized into existence after development of PCB Techology [4]. Since then, the most commonly used antennas include microstrip antennas with a wide range and variety of applications [5]. Factually the weight, cost, easy conformal and configuration, portable nature and suitability for using in array antennas make them the most efficient and useful tool in the field of antennas/telecommunications. As an add-on their integration with "Monolithic Microwave Integrated Circuits" makes usage of applications in 300Mhz to 300 GHz (MMICs) possible. Wide range of applications, civil as well as military, like radio-frequency identification (RFID), global positioning system (GPS), television and broadcast radio, MIMO systems, satcomm, vehicle accident-avoidance system, surveillance and direction finding radars, remote sensing and missile guidance systems make use of microstrip patch antennas.



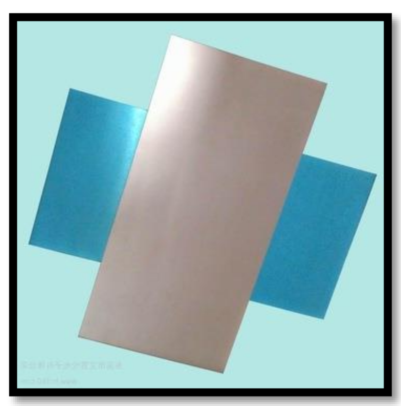


Figure 1- 9: Microstrip Patch Antenna

1.3.2 Components

Substrate

"Substrate is any material used for depositing a metallic or nonmetallic layer on its surface". Similarly in telecommunication various substrates are used for making antennas (antenna metal is deposited in layers on the substrate e.g a PCB). FR4 epoxy glass substrate is the most commonly used material for antenna fabrication. Others include honey comb, duroid quartz and alumina. The thicker the substrate the increased is the radiation power, lower is the conductor loss and improved bandwidth is achieved.

Table 1: Comparison Profile Printed Antennas

Comparison of various types of flat profile printed antennas:

Charaterstics	Microstrip patch antenna	Microstrip slot antenna	Printed diploe antenna
Profile	Thin	Thin	Thin
Fabrication	Very easy	Easy	Easy
Polarization	Both linear& circular	Both linear& circular	Linear
Dual freq operation	Possible	Possible	Possible
Shape	Any shape	Rec &circle	Rec &tiangular
Spurious radiation	Exists	Exists	exists

Ground

A conducting surface larger in comparison with antenna's wavelength, and serves as a reflecting surface for transmitted or received radio waves. In PCB, it plane is the larger area of copper foil on the PCB, connected to the power supply. It is used as a return path for current coming from different components.

Patch

Patch is the configuration in a radio antenna that is used to transmit and receive the radio signals.

Feed

A component in the antenna that is responsible for conveying the RF electrical currents to the antenna where it is radiated into the space/air

Port

Antenna's port is a same signal transmission path under identical channel characteristics and conditions.

1.3.3 Advantages

Following are few of the many advantages of microstrip patch antennas:-

- ✓ Robust design.
- ✓ Smaller antenna size provide small end user devices
- ✓ Easy to fabricate and etch on PCB
- ✓ Uses in Mobile and satellite communication application
- ✓ Broadband microstrip antenna for wireless communication
- ✓ Bluetooth applications
- ✓ Global positioning system applications
- ✓ Interoperability for microwave access (WiMax)
- ✓ Radar, Rockets and aircraft applications

1.3.4 Disadvantages

Following are the disadvantages of Microstrip Antenna:

- ✓ Unnecessary radiation exists in various microstrip based antennas such as microstrip patch and slot as well as printed dipole antennas.
- ✓ Low efficiency due to dielectric and conductor losses with a lower gain.

- ✓ The high cross polarization level renders a serious problem.
- ✓ Lower power handling capability.
- ✓ These inherent, low impedance bandwidths.

1.3.5 Commonly Used Shapes

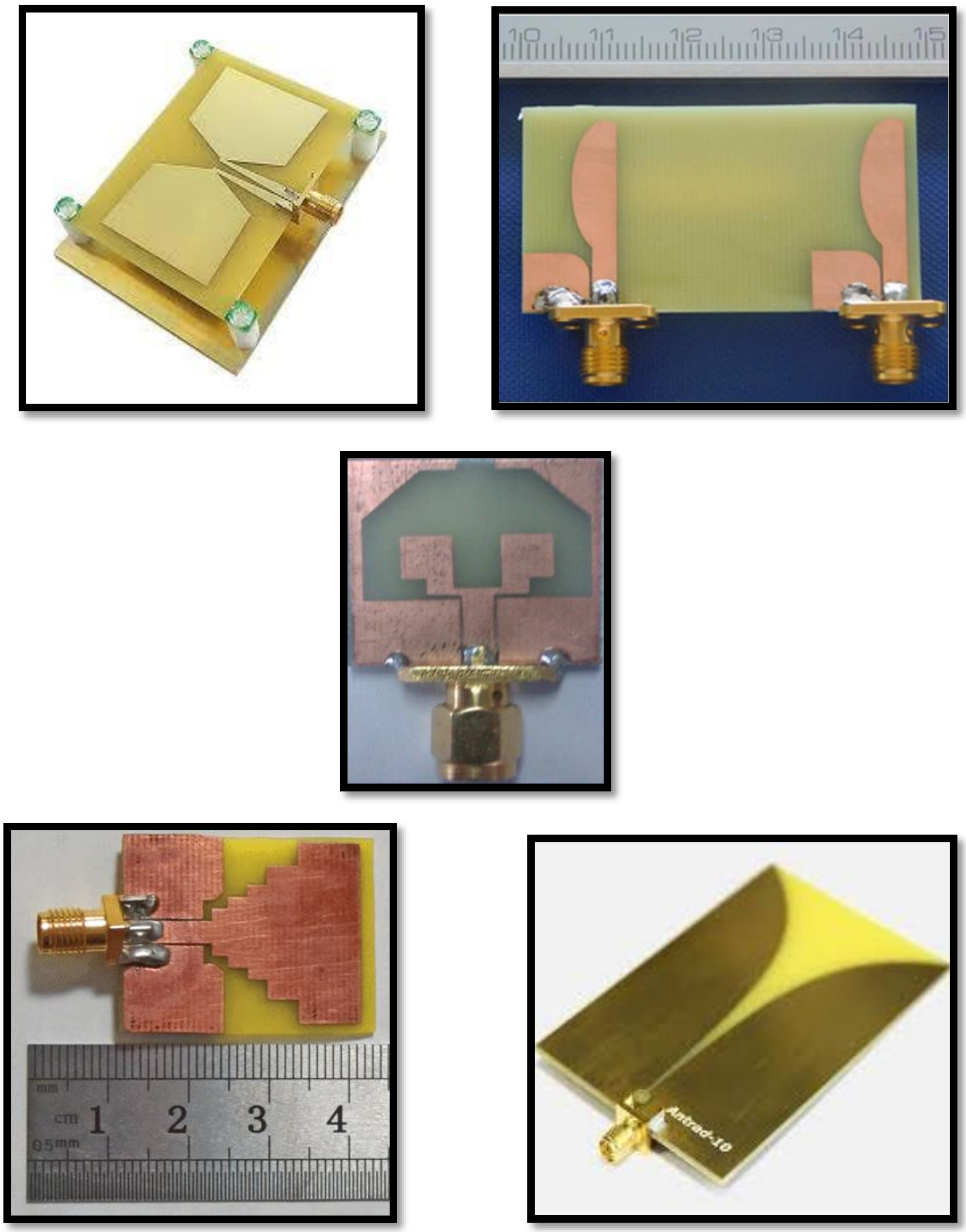


Figure 1- 10: Common Antennas

1.3.6 MIMO Technology

Fast pace changings in technology are letting Compact MIMO Antennas make their way into the field by providing high data rates. The day by day shrinking devices as required by the users directed our focus to design a MIMO UWB antenna with reduced mutual coupling, without compromising compactness.

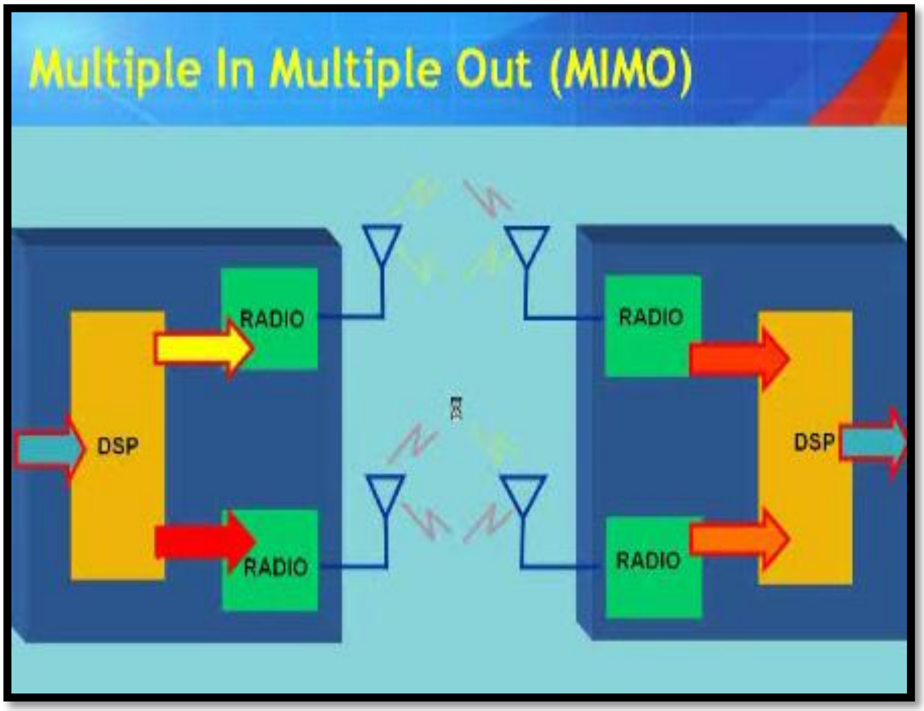


Figure 1- 11: MIMO Block Diagram

Importance of MIMO Tech (Why MIMO)

- ✓ UWB MIMO antennas have high data rate for various applications.
- ✓ Wireless applications like WIMAX [6]
- ✓ Military purposes
- ✓ Medical applications
- ✓ Radio Frequency Identification (RFID)
- ✓ High Data Rate Home Network Applications
- ✓ Ground penetration radar (GPR)

- ✓ Search and rescue radar to detect human avalanche/earthquake victims
- ✓ Wireless applications like wireless monitors, camcorders and printers etc

1.4 UWB Antennas

1.4.1 Importance of UWB Antennas

The widespread commercial usage of UWB antenna systems has attracted the interest of technical populace towards the maxim “every dB counts in UWB than in narrowband systems”. Thus an effective and efficient UWB antenna plays a critical part in UWB design.

1.4.2 Frequencies of UWB Antennas

In February 2002 an FCC Report authorized the use of UWB in range of 3.1 to 10.6 GHz frequency with PSD limit of -41.3 dBm for every MHZ on a transmitter.

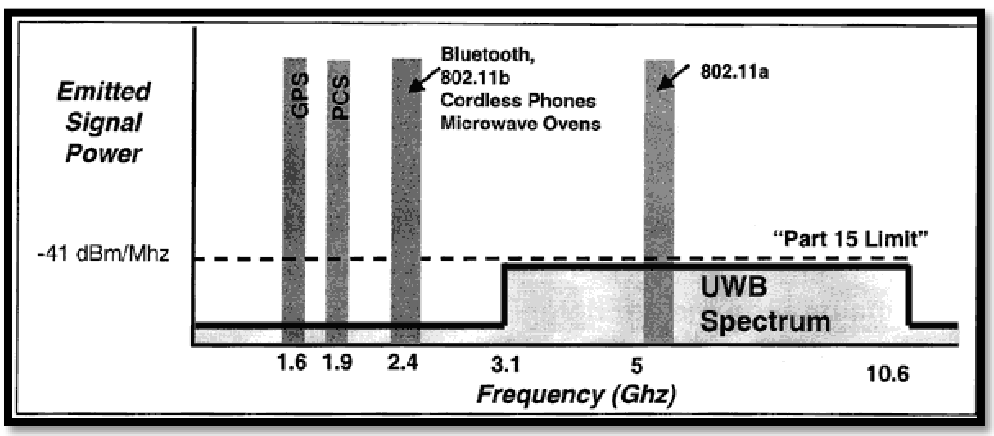


Figure 1- 12: UWB Frequency Band

1.5 Objectives

To design compact antenna array that has a very tolerable mutual coupling and radiation efficiency keeping the MIMO channel capacity intact [7]. The projected system will address following issues in present antennas:

- ✓ To design MIMO antenna for UWB applications.
- ✓ To design MIMO 4x4 array for UWB applications.
- ✓ To design a method for Reduced Mutual Coupling between antenna elements of array.
- ✓ To perform and analyze the result by simulating using High Frequency Structure Simulator software (HFSS).
- ✓ To analyze performance of the designed antennas and fabricate the structure of the antenna.

1.6 Conclusion of Chapter 1

Our project envisages the design and fabrication of UWB-MIMO system consisting of four multiple antenna elements placed closely (figure below). After the fabrication of antenna, we shall be able to achieve high throughput with low mutual coupling.

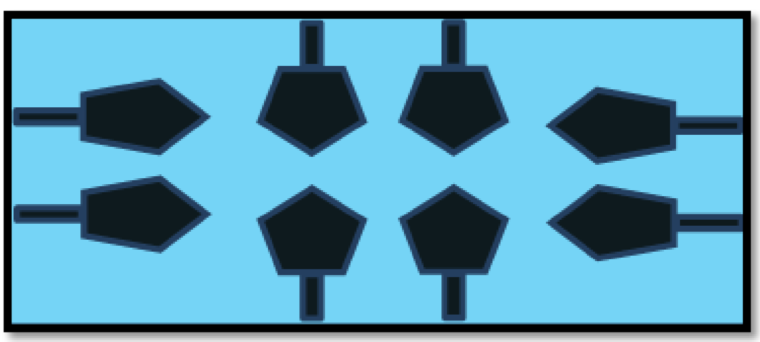


Figure 1- 13: Closely Placed MIMO Antennas

CHAPTER 2

LITERATURE REVIEW

2.1 Analysis of Implemented Antenna Designs

A variety of UWB antenna designs were studied. In the study their design techniques, applications, problems and challenges faced in those designs were reviewed. The facts/important aspects of each antenna have been congregated in the following sub-headings under each antenna type:-

2.1.1 Design 1 - Easily Extendable Compact Planar UWB MIMO Antenna Array

The design shows highly isolated MIMO UWB compact 4 element antenna array [8]. The design was chosen as it required no isolation and its configuration was easy to be extended on a larger size. In the figure shown aside the design is an extension i.e 8 elements array.of 38x90 mm^2 size. Size of each UWB antenna is 18×18x0.762 mm^3, substrate being Neltec. Its relative-permittivity and loss-tangent are 3.2 and 0.0024 respectively.

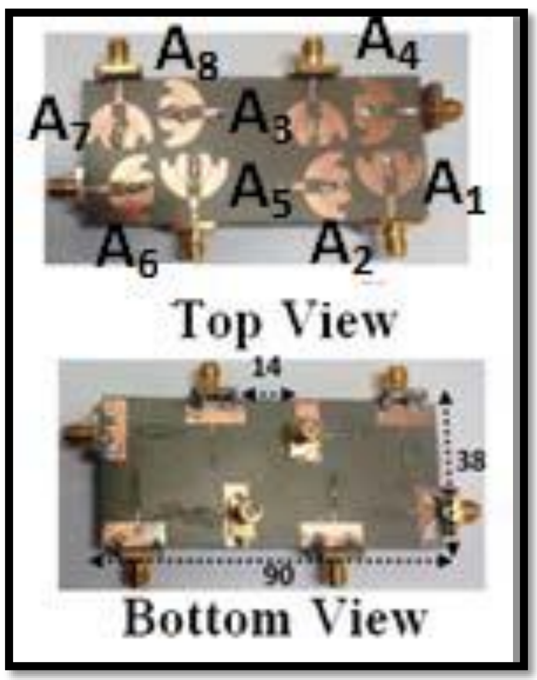


Figure 2- 1: Top & Bottom View of Compact Planar MIMO Antenna

Results. As show below, a gain of 5 dB has been achieved at a frequency of 8 GHz. S11 parameter shows a return loss of -24 dB. In comparison to these results our results show that we can achieve 7dB gain and S11 parameter with -30 dB return loss.

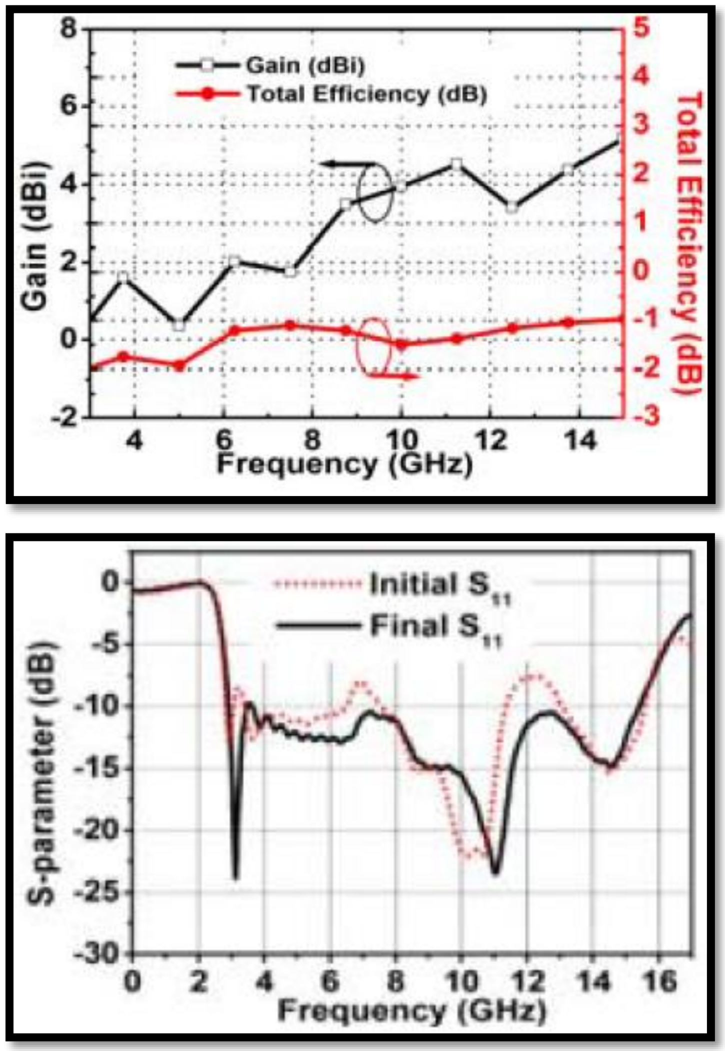


Figure 2- 2: Gain & S-11 Plots

2.1.2 Design 2 - A 4xElements Performance Analysis of Compact UWB Antenna for MIMO-OFDM Systems

Study of above-mentioned design reveals that an UWB MIMO array antenna of 40x40 mm^2 size has been printed using FR4 epoxy substrate but with a thickness of 1.5 mm. The results showed that an undesirable notch was found in the upper region (as in figure below) since it does not cover UWB as simulated and therefore the results went up as against the simulated return loss values/graph. However, in our modified antenna design the ground concept of this paper has been incorporated.

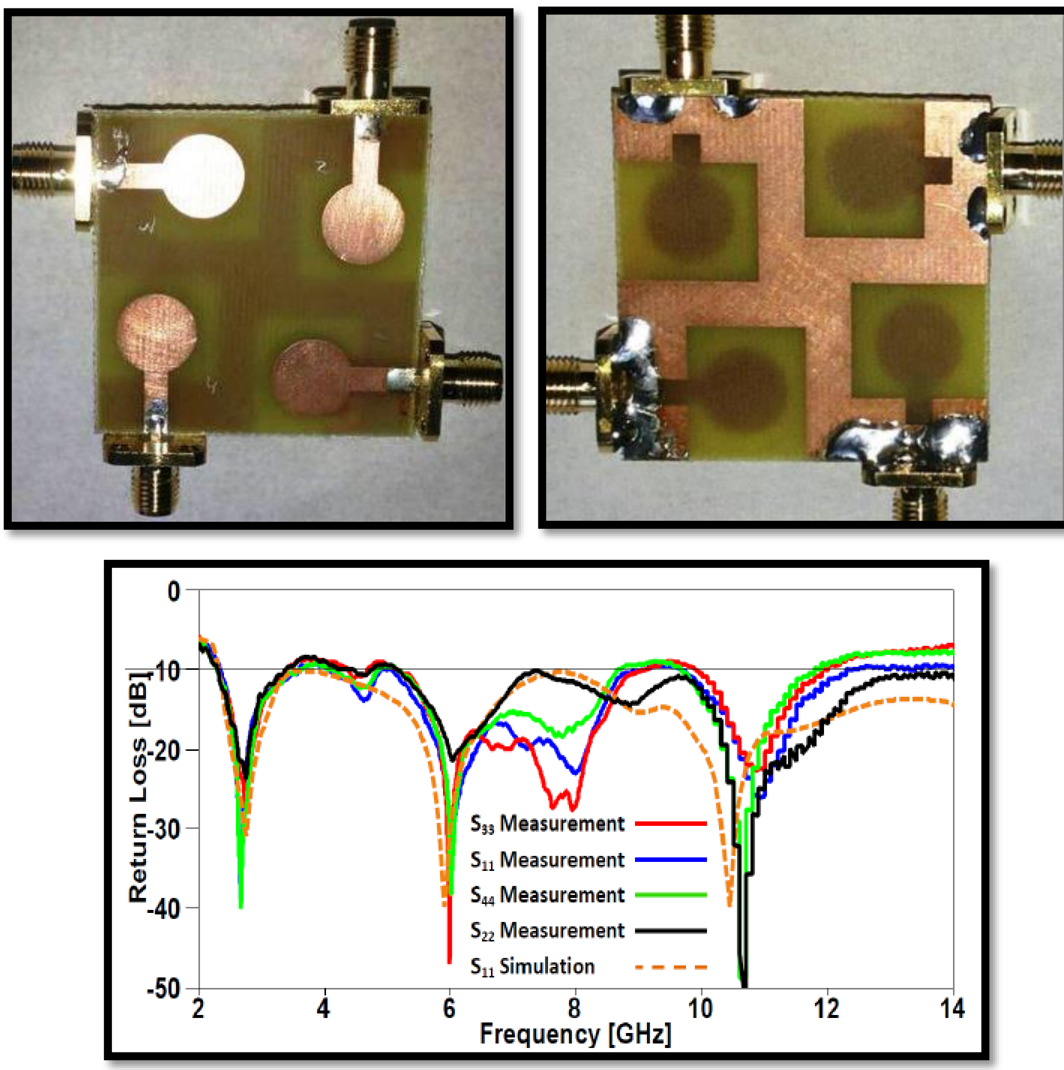
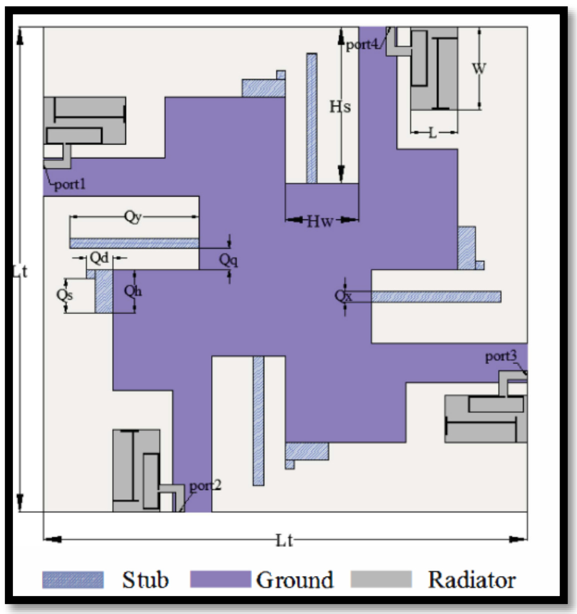


Figure 2- 3 : Four Element MIMO for OFDM Systems

2.1.3 Design 3 - A Compact 4 x 4 Dual Band-notched UWB MIMO Antenna with High Isolation

With notch characteristics for WiMax (3.3-3.8 GHz) and WLAN (5.15-5.35 GHz) the design was implemented [9]. In our work we have tried to modify the notch and use its ground concept to implement in our proposed antenna design. Also, this antenna has larger dimensions of 56x56x0.8 mm^3 as compared to our 44x44x1 mm^3. The return loss is shown in the figure below.



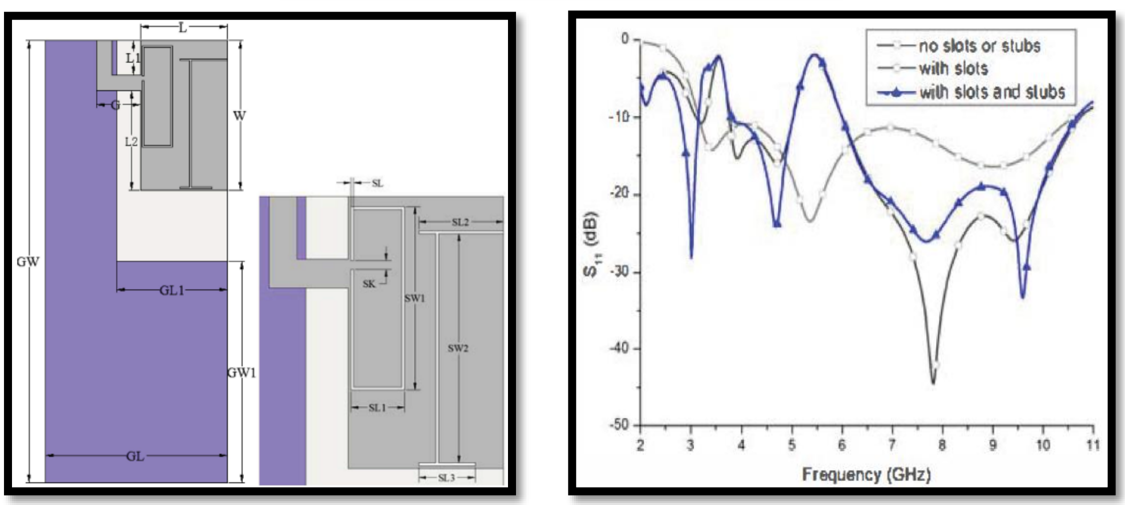


Figure 2- 4: Design 3 Antenna Elements and S11

2.1.4 Design 4 - A Compact Koch Fractal UWB MIMO Antenna with WLAN Band-Rejection

This unique orthogonal fractal design antenna provides desired miniaturization, implemented on a 45x45x1.6 mm^3 dimensions, this antenna achieves better S11 results as compared to the above discussed antennas. However, the notch characteristics renders its efficacy to few limitations which is why our implemented antenna on 44x44x1 mm^3 dimensions gives better results [10][11].

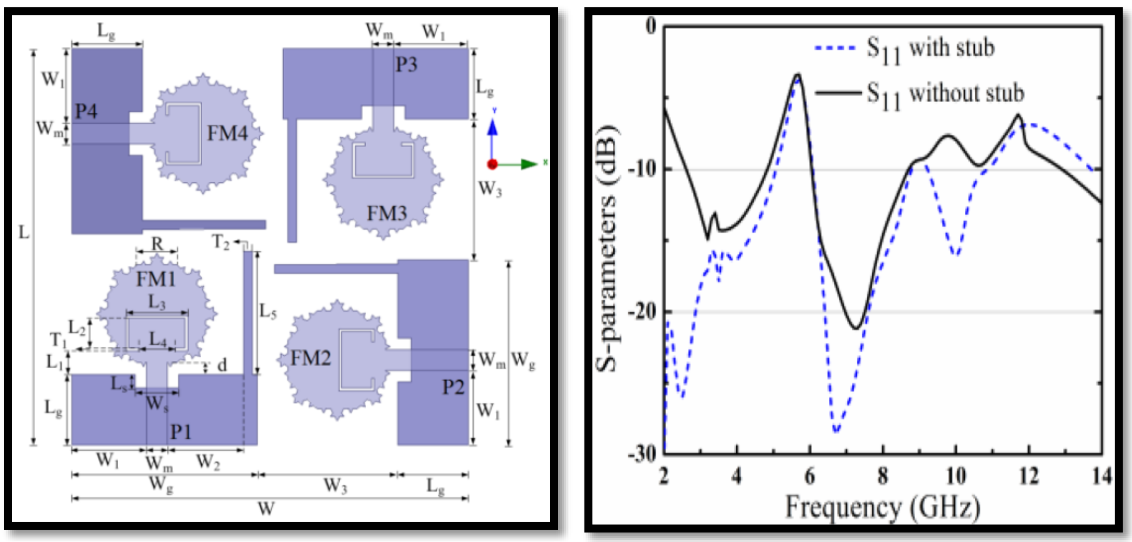


Figure 2- 5: Design 4 Antenna Elements and S11

2.1.5 Design 5 - A Quasi Self-Complementary (QSC) UWB MIMO Antenna having WLAN-band Notched Characteristics

When four element QSC UWB MIMO antenna was studied [12], S11 simulated a band notch in the range of 5.15-5.85 GHz. Problem with this antenna design was that its 4-dB gain is less even with 4 elements as shown in 3D radiation pattern figure.

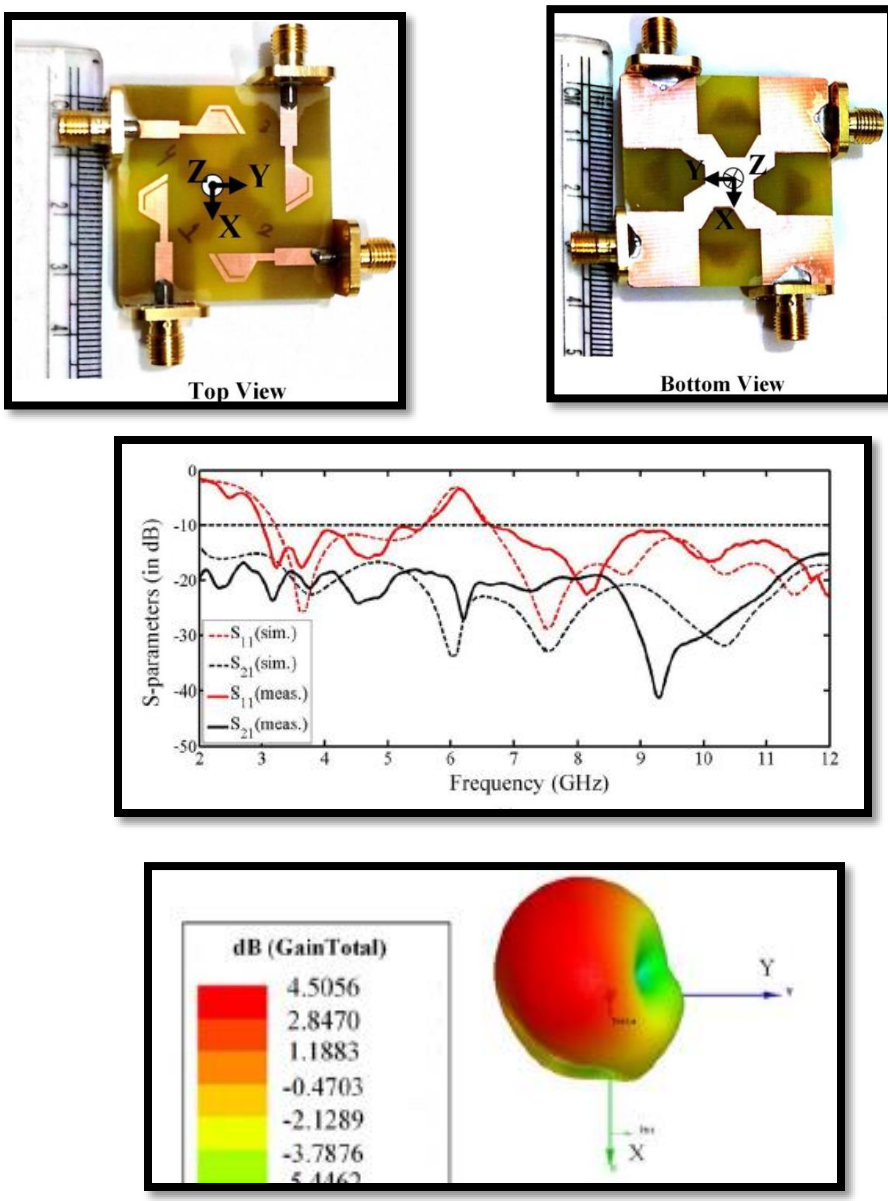


Figure 2- 6: Design 5 Antenna Elements and S11

CHAPTER 3

ANTENNA DESIGN AND DEVELOPMENT

The chapter guides our readers through the various design and development stages of our antenna. MIMO antennas are basically based on the arrays of atleast two antenna elements, however, initially single element antenna was designed and fabricated before forming the array. HFSS software has been used for simulating our antenna designs. Our antennas have been designed on widely available FR4 Epoxy substrate [13][14]. With the loss tangents between 0.017-0.025, our antennas give desired results as shall be shown in the undermentioned paragraphs. About the design it is pertinent to mention aforehand that by adding L-shaped ground stubs our Return losses reduced and mutual coupling improved.

3.1 HFSS Designs

3.1.1 Single Element With Slot Only Antenna

A 'Single Element UWB Antenna' was developed using HFSS software. With the slots only design the 3D polar plot gave a maximum of 7 dB gain.

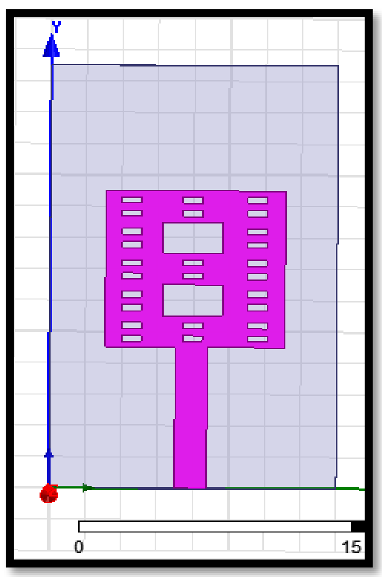


Figure 3- 1: Single Element

3.1.2 Single Element With Stub and Slot Antenna

The design was improved by reflecting radiations as we changed the design by adding an L-shaped ground stub. Ground stubs are helpful in achieving better matching with enhanced isolation. The design in HFSS looks like as in figure below.

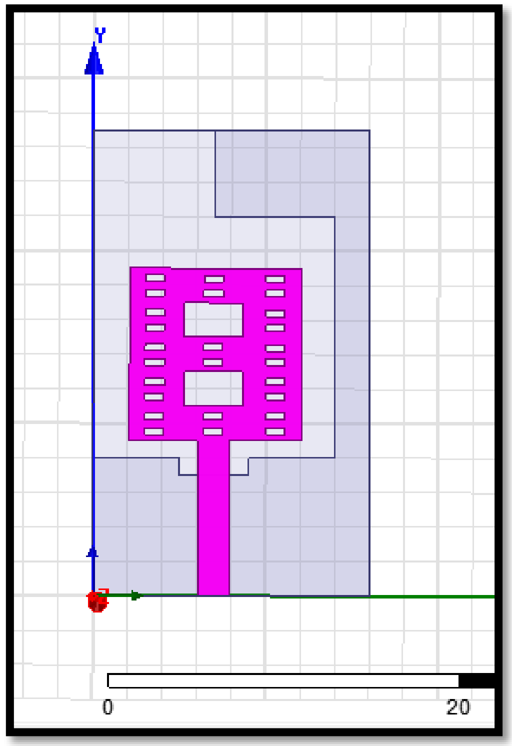


Figure 3- 2: Single Element with Stub and Slot

3.1.3 Dual Element MIMO Antenna Design Implementation

1 x 2 MIMO was implemented by taking lead from single element antenna's geometry. The partial L-shaped ground stubs and rectangular patch helps reduce the mutual coupling as well as due to the addition of second antenna a shift in frequencies was observed as will be shown in the Chapter 4 'Antenna Measurements and Results'. HFSS design of antennas are shown in figure below.

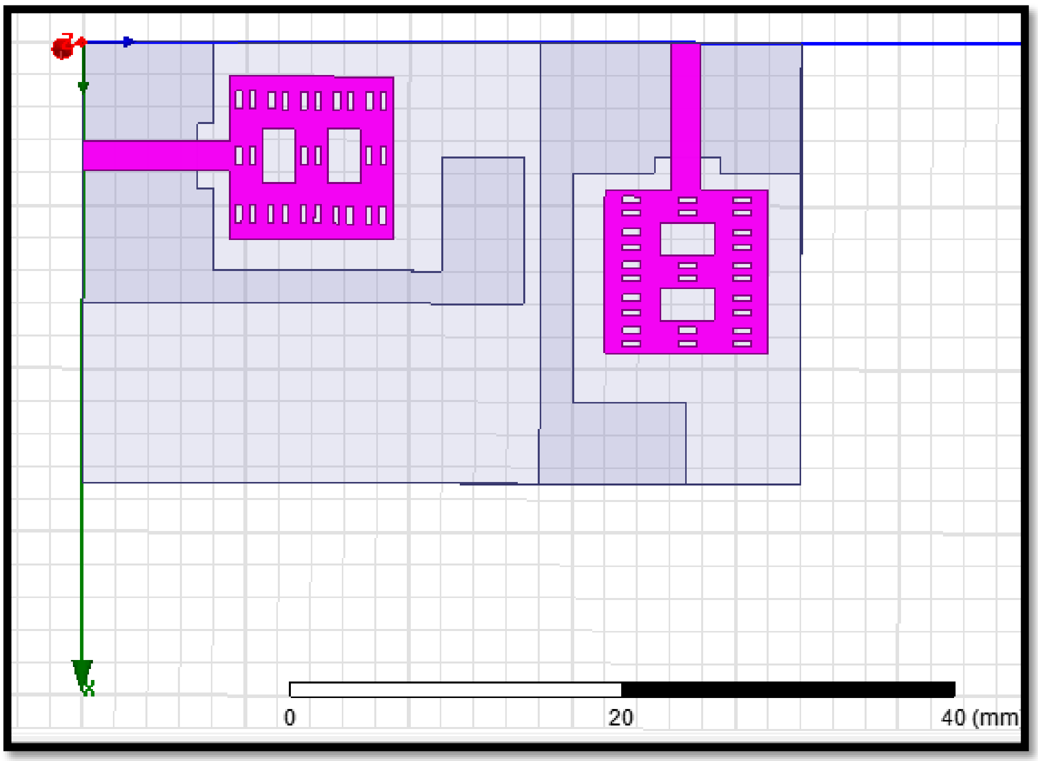


Figure 3- 3: Dual Element Design

3.1.4 Four Element Array UWB MIMO Antenna Design Implementation.

As a spur to the above experimented designs; Two elements MIMO was upscaled to four element MIMO antenna array. Addition of the two more antennas has resulted in the better gain and this addition of two additional elements will further increase the results achieved by array elements. Various isolation enhancing and miniaturization techniques have been used to get a compact size. Stubs designs were varied during the process and with the final design using reflecting radiations better matching along enhanced isolation could be observed. Also, studies show that stubs also perform the function of reflectors which can be used to separate electromagnetic radiations of various patches which is helpful in achieving low mutual coupling [15].

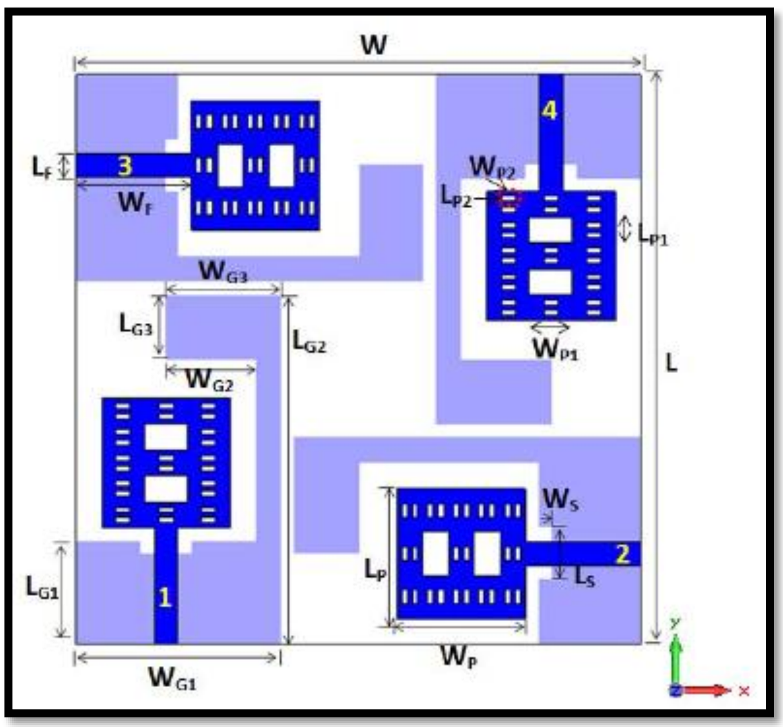


Figure 3- 4: Four Element Array

The dimensions (in mm)of the designed antenna array is given in Table 2.

Table 2: Implemented Antenna Design Dimensions

L	44	**W**	44
L_P	10	W_P	10
L_{P1}	2	W_{P1}	3.33
L_{P2}	0.4	W_{P2}	1.11
L_F	1.8	W_F	9
L_S	4	W_S	1
L_{G1}	8	W_{G1}	16
L_{G2}	27	W_{G2}	7
L_{G3}	5	W_{G3}	9

3.2 Fabricated Antennas

3.2.1 Single Element With Stub and Slot Antenna

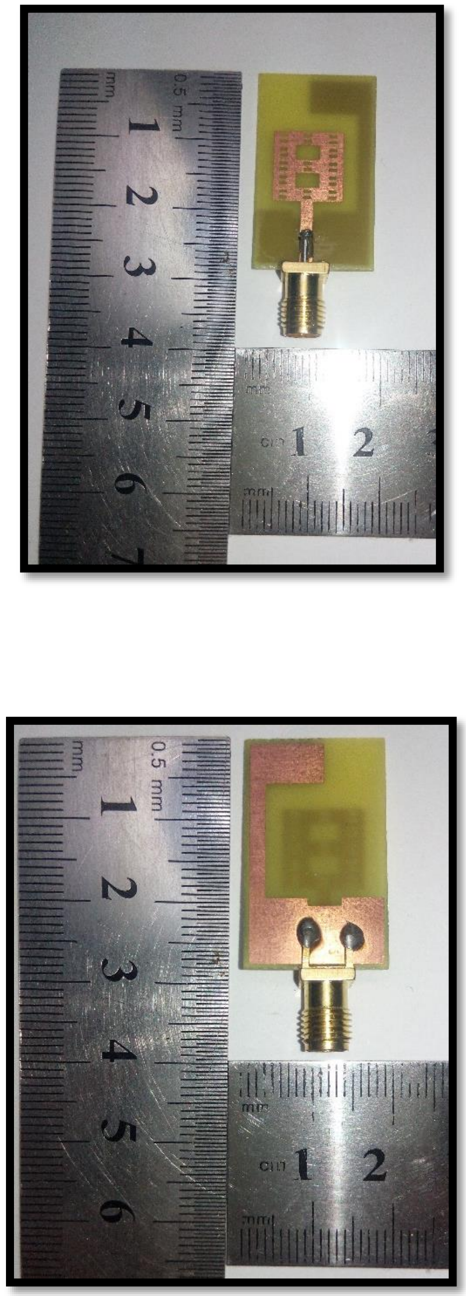


Figure 3- 5:Fabricated Single Element

3.2.2 Dual Element MIMO Antenna Design Implementation

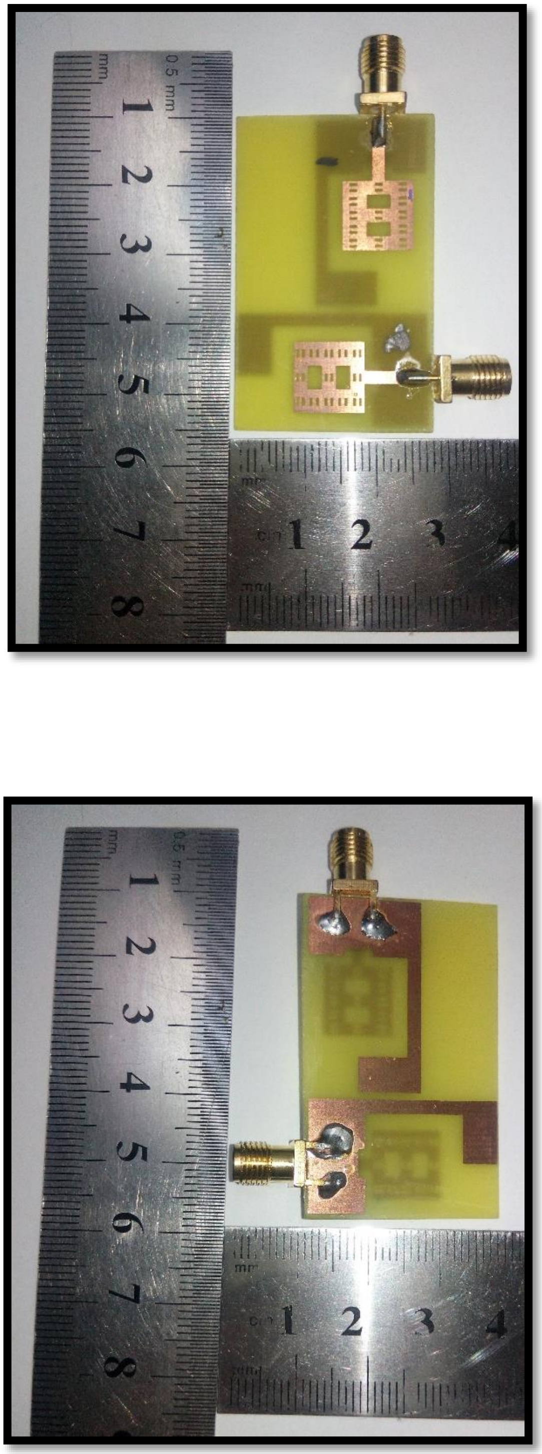


Figure 3- 6: Fabricated Dual Element

3.2.3 Four Element UWB MIMO Antenna Array Design Implementation.

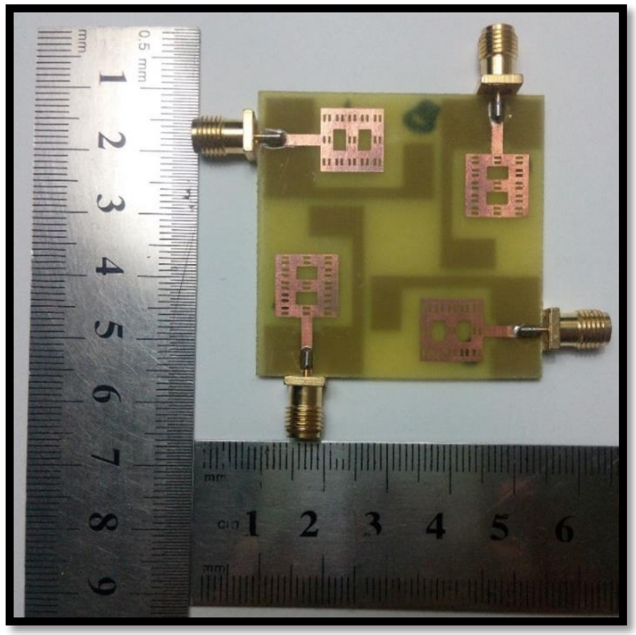


Figure 3- 7: Fabricated Four Element (Front View)

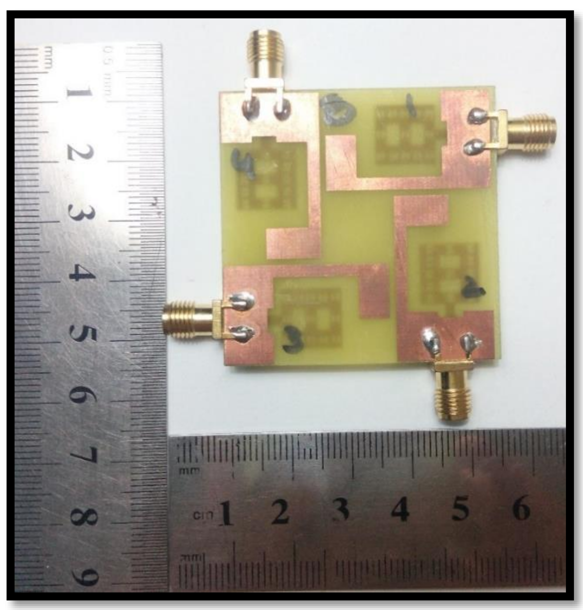


Figure 3- 8: Fabricated Four Element (Back View)

CHAPTER 4

ANTENNA MEASUREMENTS AND RESULTS

4.1 Single Element with Slot Only Antenna

A ‘Single Element UWB Antenna’ with 16 x 27 mm^2 dimensions was developed using HFSS software. With the slots only design the 3D polar plot gave a maximum of 7 dB gain. 3D polar plot and the radiation pattern are shown in figures below [16][17].

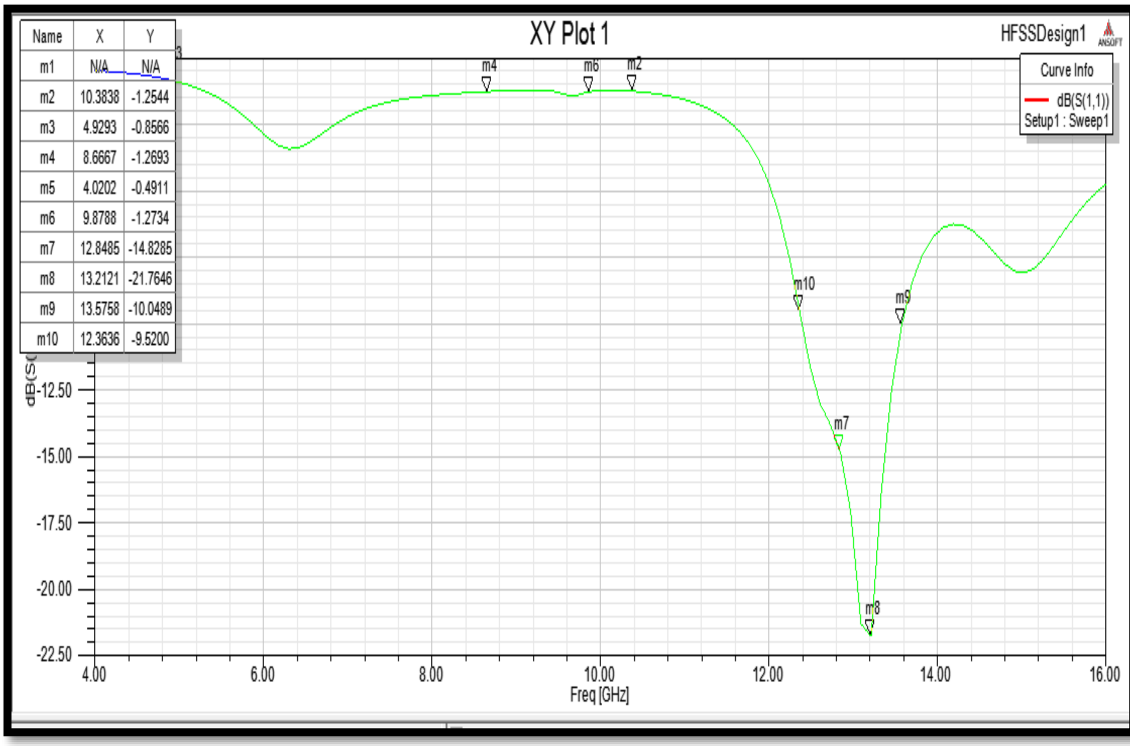


Figure 4- 1: Single Element

Figure above shows that antenna has limited bandwidth from 12.2 GHz to 12.9 GHz which is not even in UWB

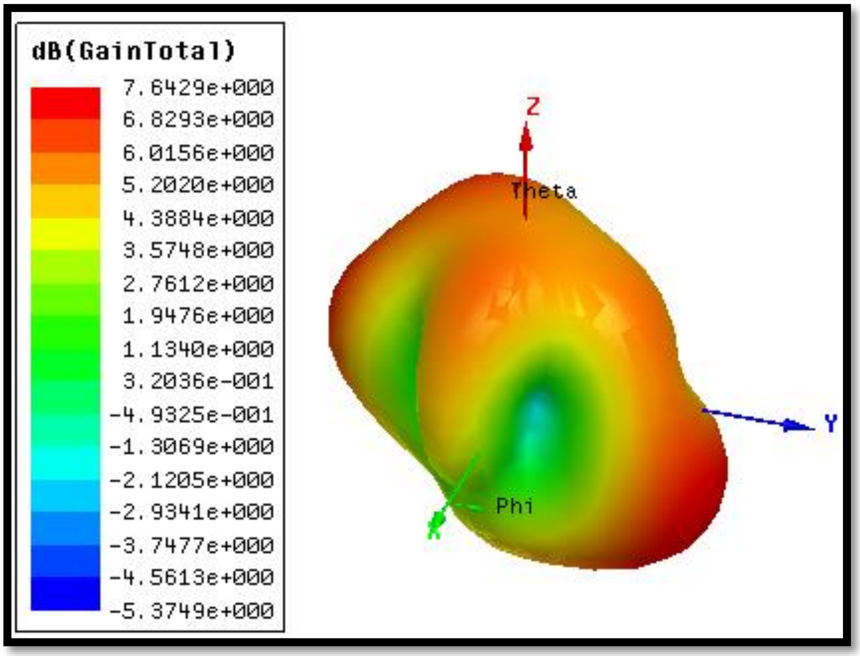


Figure 4- 2: Gain Single Element

Figure above shows the gain we are getting throughout the spectrum is around 7dB.

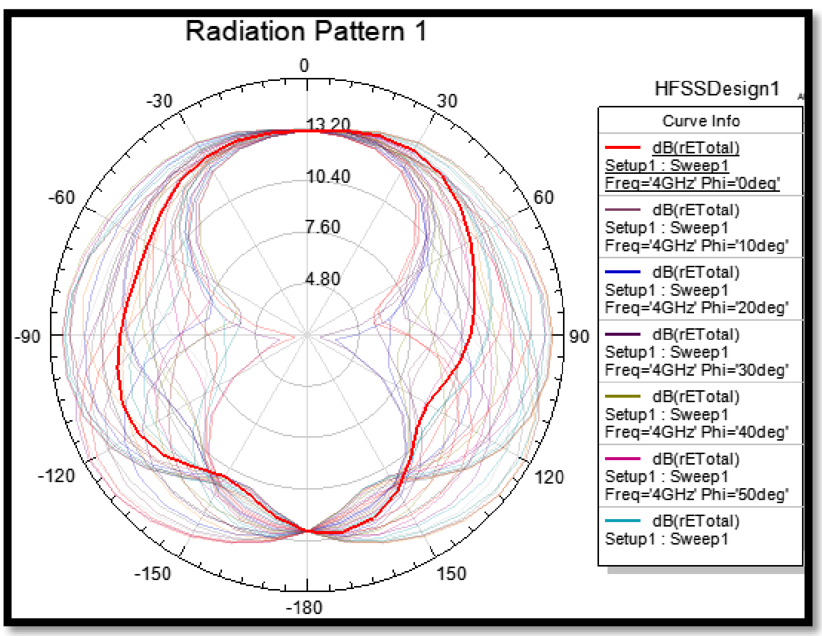


Figure 4- 3: Rad Pattern Single Element

Figure above shows the omni directional radiation pattern of antenna at 0 degree phi

4.2 Single Element With Stub and Slot Antenna

S parameters values are shown in Fig below. Antenna has an impedance bandwidth ranging between 4 and 10.6 GHz. Return loss is below -10dB for entire bandwidth and gain of antenna is between 3.37dB to 6.44dB. Isolation is greater than 20 dB between UWB elements for this frequency range that too without using separate decoupling, reason being orthogonal feeding and mutually non - overlapping directional pattern of each element [18].

4.2.1 Return Loss (S11) Plot

Simulated

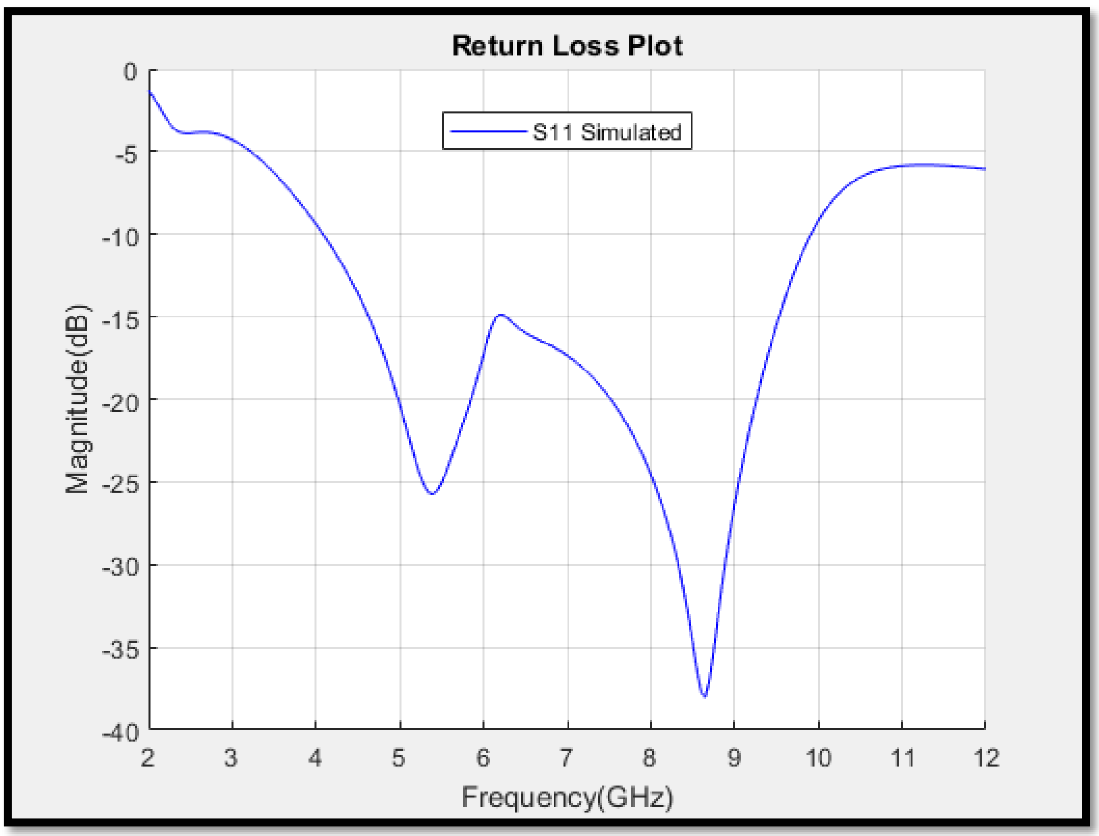


Figure 4- 4: Single Element with Stub and Slot

Figure shows the antenna has the bandwidth from 4 GHz to 10 GHz with return loss below -35 dB.

Measured

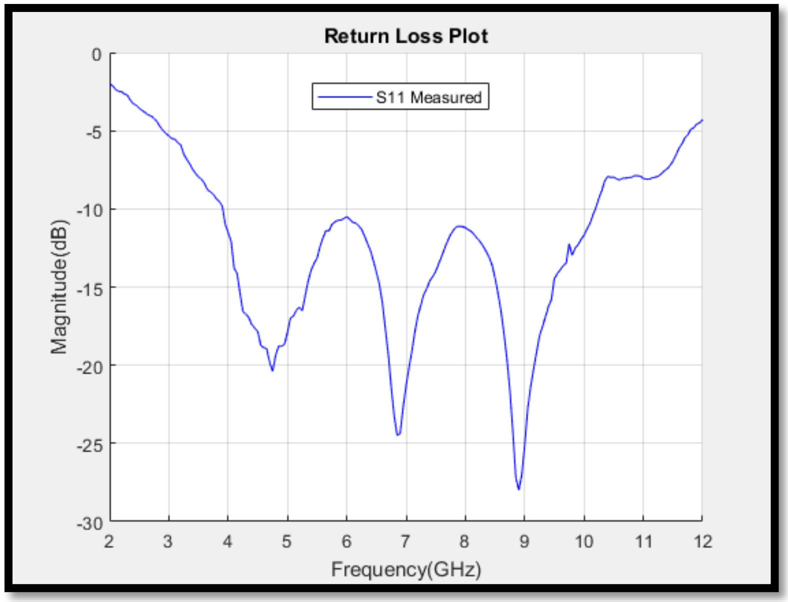


Figure 4- 5: Single Element with Stub and Slot (Measured)

Figure shows the measured S11 plot of antenna with bandwidth from 3.9 GHz to 10.2 GHz with return loss below -25 dB.

Combined Results S11

Figure 4- 6: Single Element with Stub and Slot (Combined Result S11)

4.2.2 Gain

Figures below shows the gain of antenna with bandwidth from 3.9 GHz to 10.2 GHz and a positive gain of around 6dB at 9.21 GHz, 5.11 dB at 8.67 GHz and 3.37 dB at 5.02 GHz.

9.21 GHz(max gain freq)

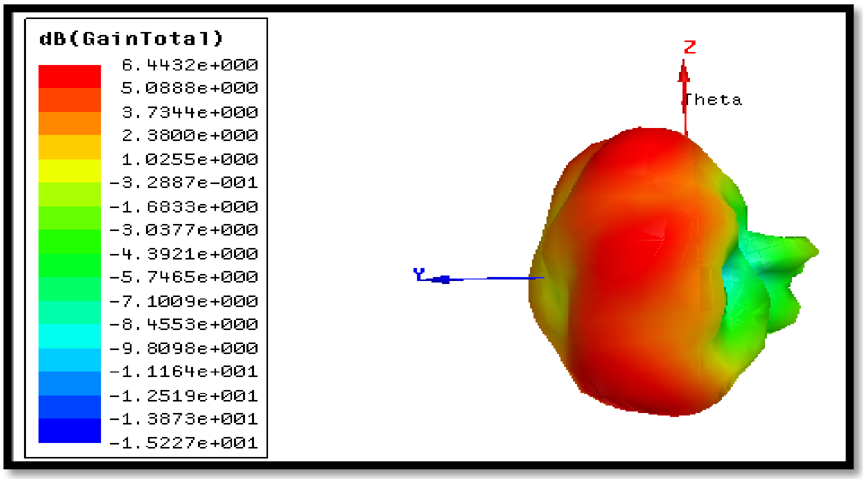


Figure 4- 7: Gain Single Element with Stub and Slot (9.21 GHz)

8.67 GHz(max dip freq gain)

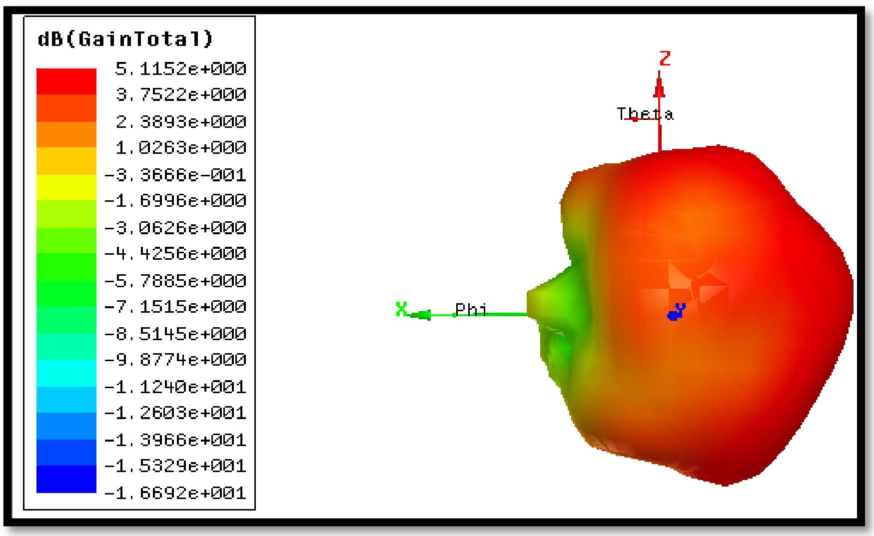


Figure 4- 8: Gain Single Element with Stub and Slot (8.67 GHz)

5.02 GHz(min gain freq)

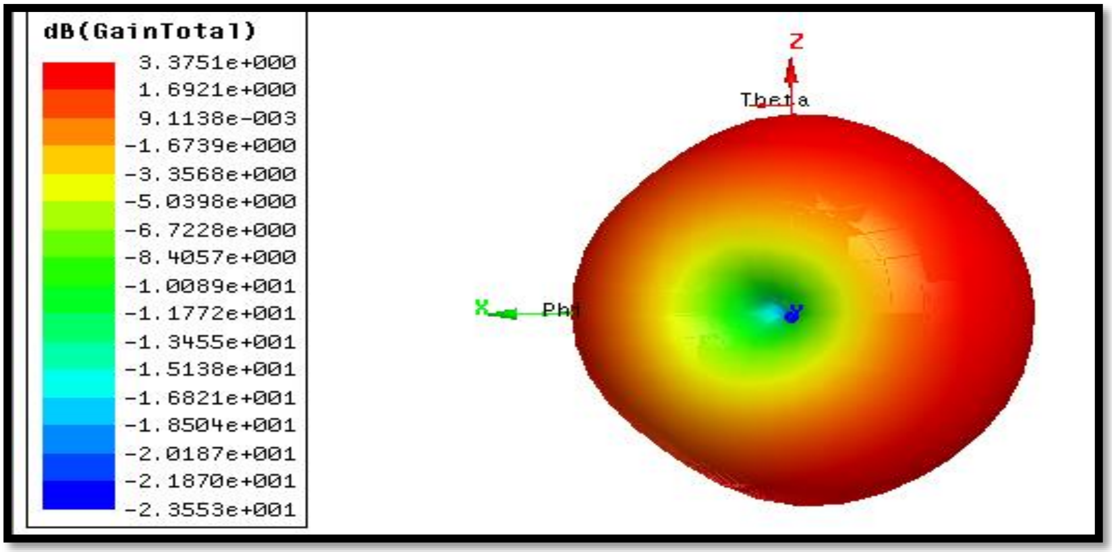


Figure 4- 9: Gain Single Element with Stub and Slot (5.02 GHz)

4.2.3 Radiation Pattern

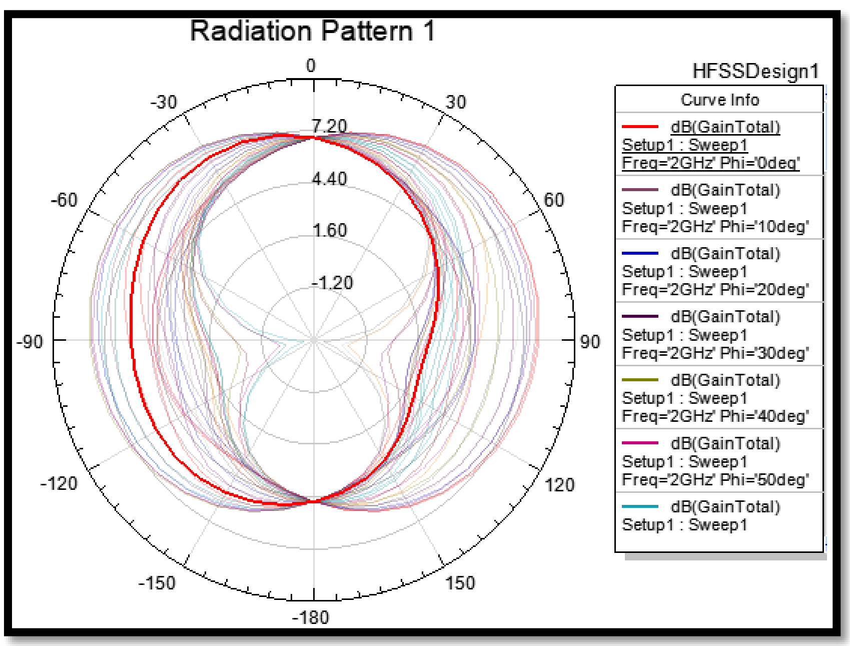


Figure 4- 10: Rad Pattern Single Element with Stub and Slot

Figure above shows radiation pattern of antenna at 0 deg phi.

4.3 Dual Element with Stub and Slots

Simulated and measured values of S parameters are depicted in Fig. 4-11 & 4-12 below. Impedance bandwidth ranges from 3-11 GHz, the Return loss being less than -10dB with gain of antenna ranging from 3.8dB to 8.0dB [19]. As stated in preceding paragraph, here too the isolation is over 20 dB as obtained due to the orthogonal feeding and non-overlapping directional patterns of individual elements.

4.3.1 Return Loss (S11, S22) Plots

Simulated results (S11,S22)

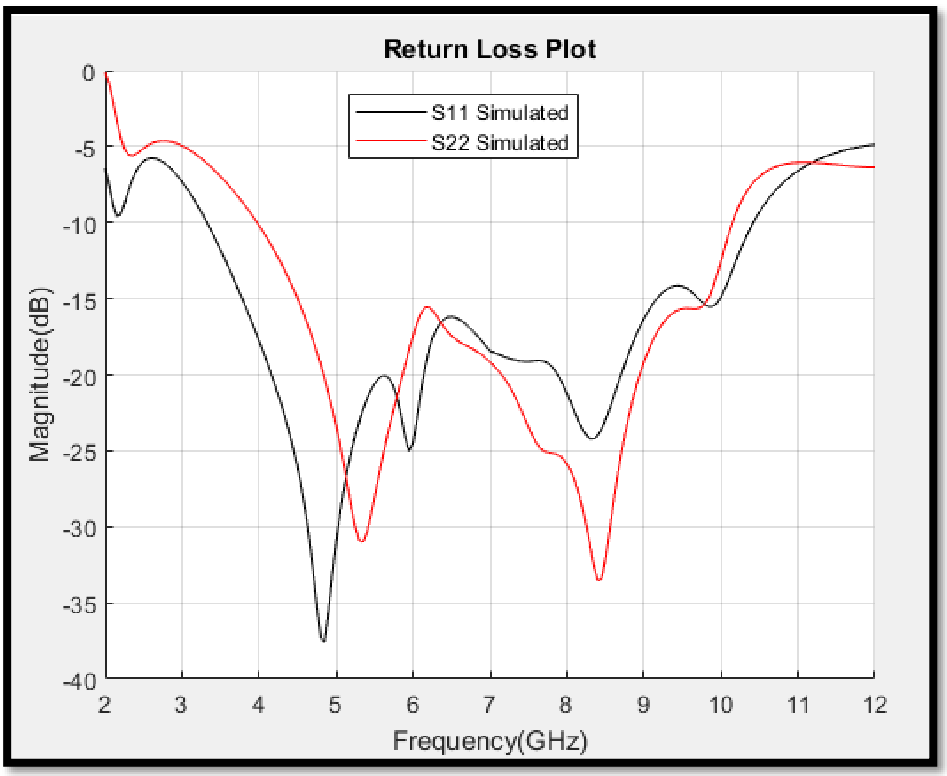


Figure 4- 11: Dual Element with Stub and Slot (Simulated)

Figure shows antenna has bandwidth of 3.4 GHz to 10 Ghz with a return loss below -35 dB.

Measured Results(S11,S22)

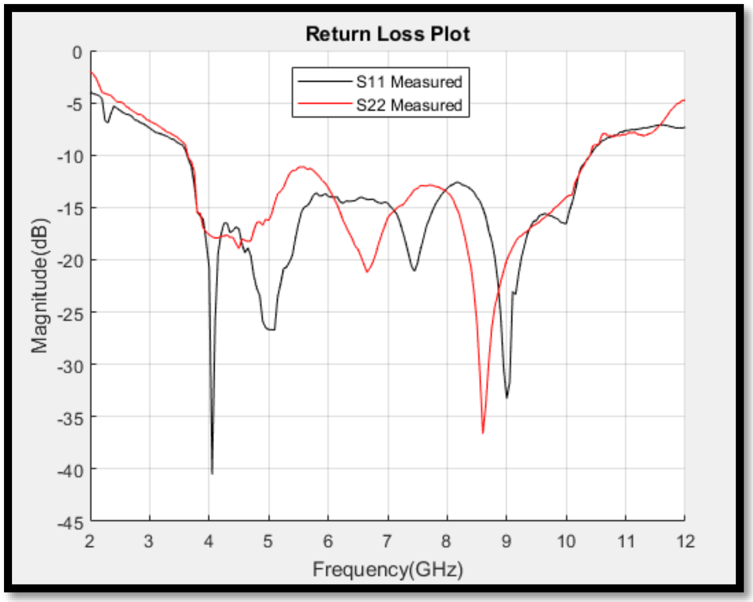


Figure 4- 12: Dual Element with Stub and Slot (Measured)

Measured result shows that bandwidth is increased 2.8 GHz to 10.1 GHz with improved return loss below -40 dB.

Combined results

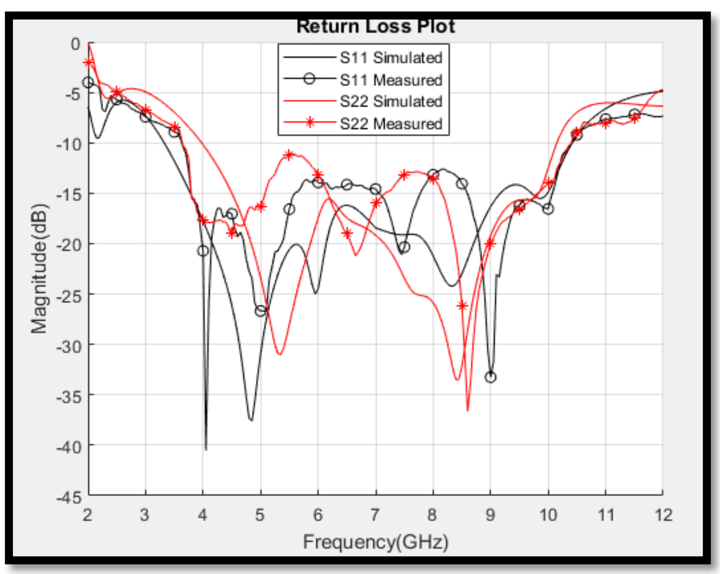


Figure 4- 13: Dual Element with Stub and Slot (Combined)

4.3.2 Gain

Figure below shows the gain of antenna with bandwidth from 3.9 GHz to 10.2 GHz and a positive gain of around 8 dB at 3.71 GHz, and 3.84 dB at 4.82 GHz.

3.71 GHz(max gain freq)

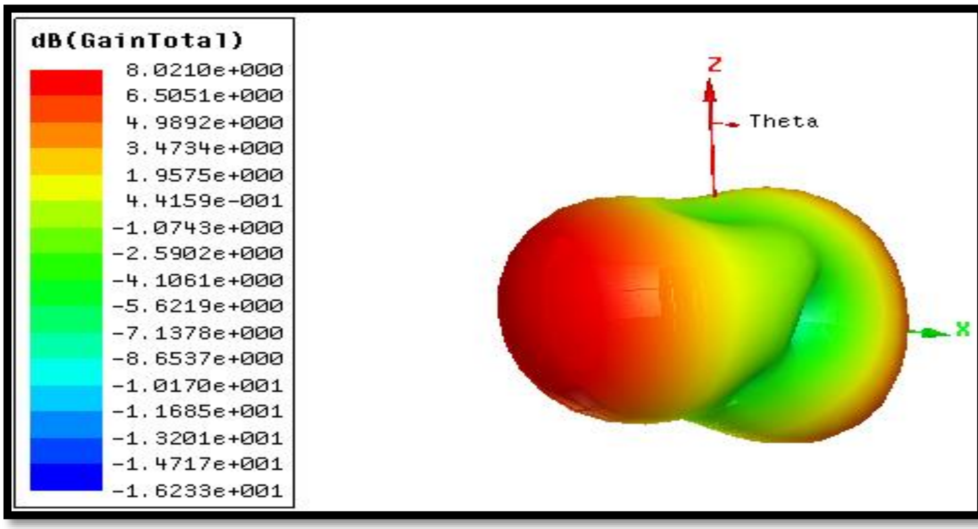


Figure 4- 14: Gain Dual Element with Stub and Slot (3.71 GHZ)

4.82 GHz(max dip freq gain and same as min gain freq)

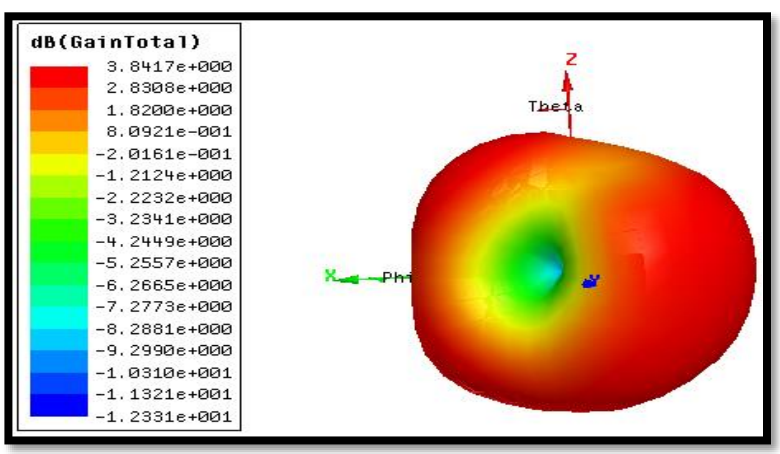


Figure 4- 15: : Gain Dual Element with Stub and Slot (4.82 GHZ)

4.3.3 Radiation Pattern

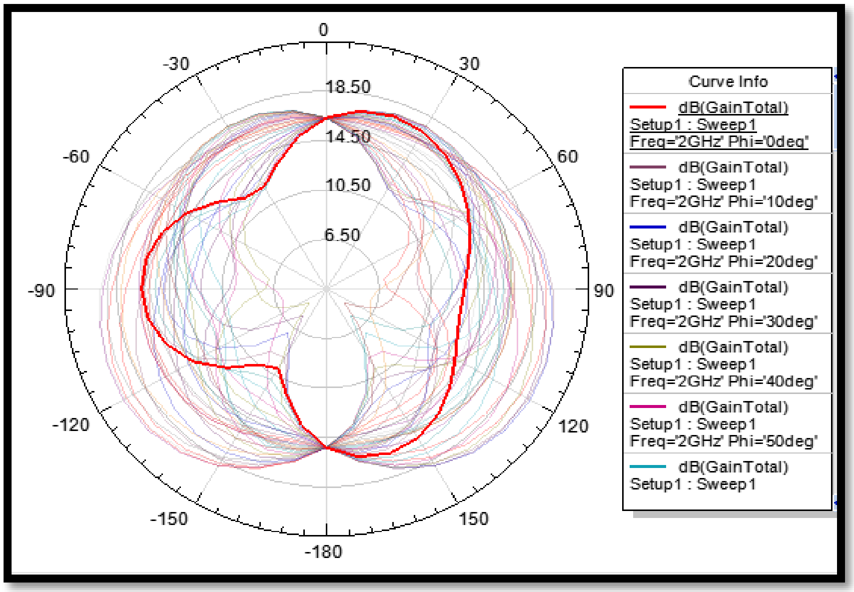


Figure 4- 16: Rad Pattern Dual Element with Stub and Slot

Radiation pattern shows omni directional characterristics of antenna at 0 deg phi

4.3.4 Isolation

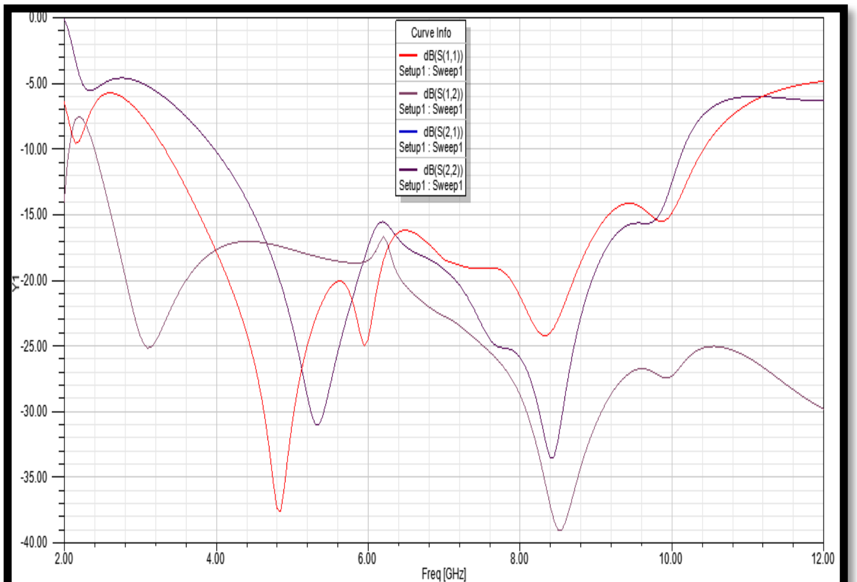


Figure 4- 17: Isolation Dual Element with Stub and Slot

4.4 Four Element with Stub and Slots

Entire procedures followed above were carried out on final design where simulated and measured results showed a wide impedance bandwidth (Sll<-10 dB) ranging between 2.8 GHz to 10.7 GHz [20]. Also, its S21, S31, S41 isolations were found to be better than 20 dB at frequencies between 3.2 - 11 GHz. In H-plane, Radiation patterns were quasi-omnidirectional. Gain of antenna is between 4.76 dB to 12 dB in entire operating band. Orthogonal feeding, directional patterns of individual elements were helpful in obtaining these results. An antenna having high isolation in-between 3.2 and 10.7 GHz can be considered to be a fruitful selection in UWB, MIMO system [21].

4.4.1 Return Loss (S11, S22, S33, S44) Plots

Figures 4-18 and 4-19 show simulated and measured results respectively, showing a wide impedance bandwidth (Sll<-10 dB) ranging between 2.8 GHz to 10.7 GHz with return loss below -35 dB for simulated results and an improved return loss below -40dB for measured results.

Simulated Results(S11,S22,S33,S44)

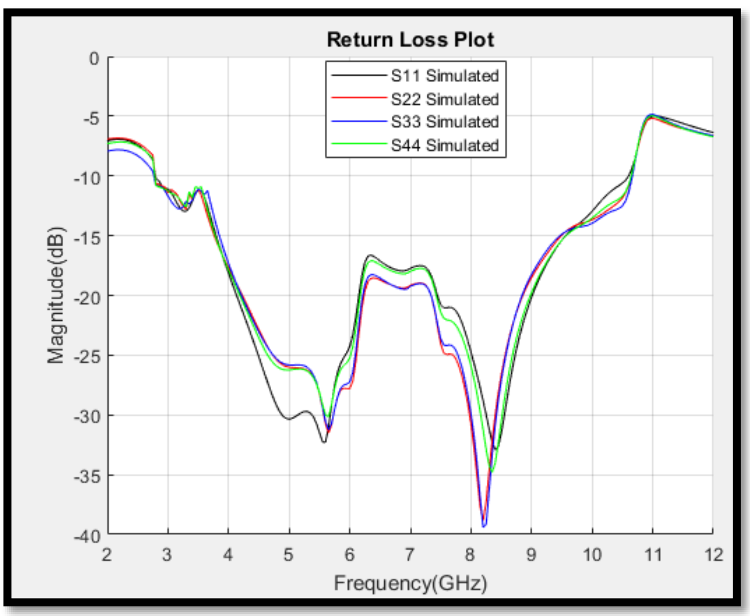


Figure 4- 18: S11 Four Element with Stub and Slot (Simulated)

Measured Results(S11,S22,S33,S44)

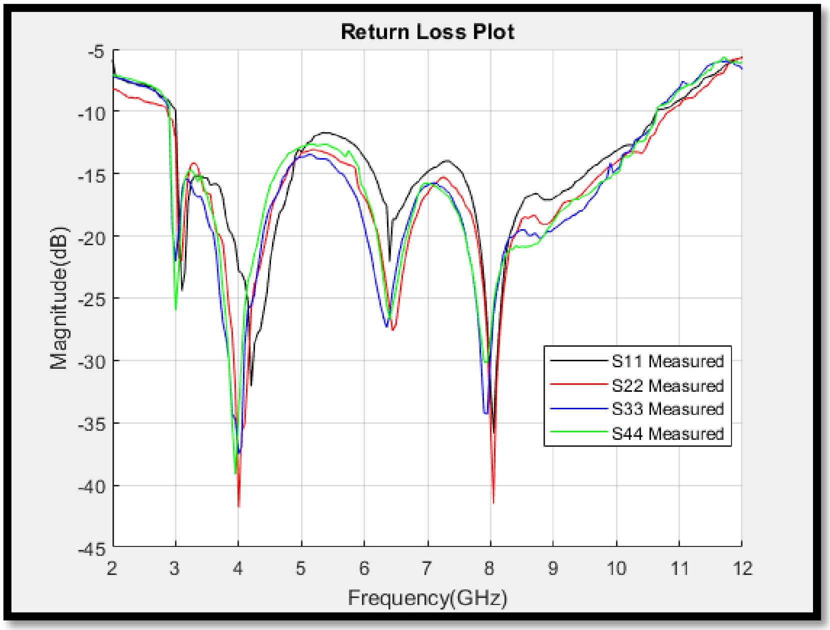


Figure 4- 19: S11 Four Element with Stub and Slot (Measured)

Combined results

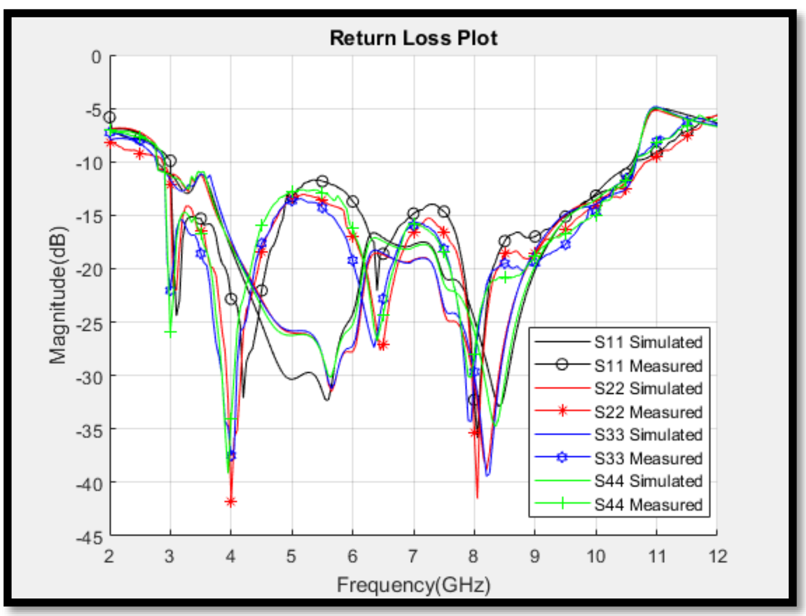


Figure 4- 20: S11 Four Element with Stub and Slot (Combined)

4.4.2 Gain

Figure below shows the gain of antenna with bandwidth from 3.9 GHz to 10.2 GHz and a positive gain of around 12 dB at 4.12 GHz, 7 dB at 4.91 GHz and 4.67 dB at 7.02 GHz

4.12 GHz(max gain freq)

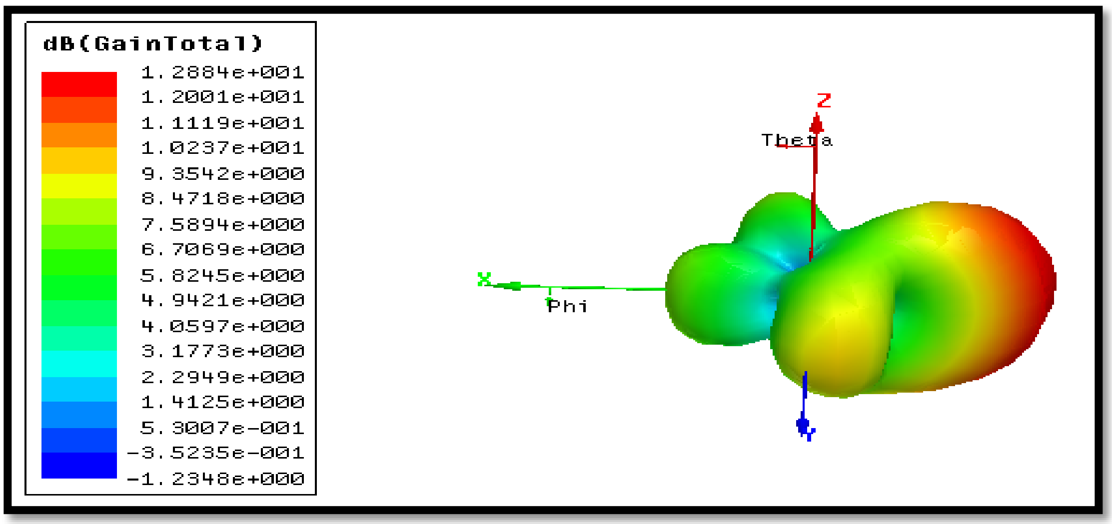


Figure 4- 21: Gain Four Element with Stub and Slot (4.12 GHz)

4.92 GHz(max dip freq gain)

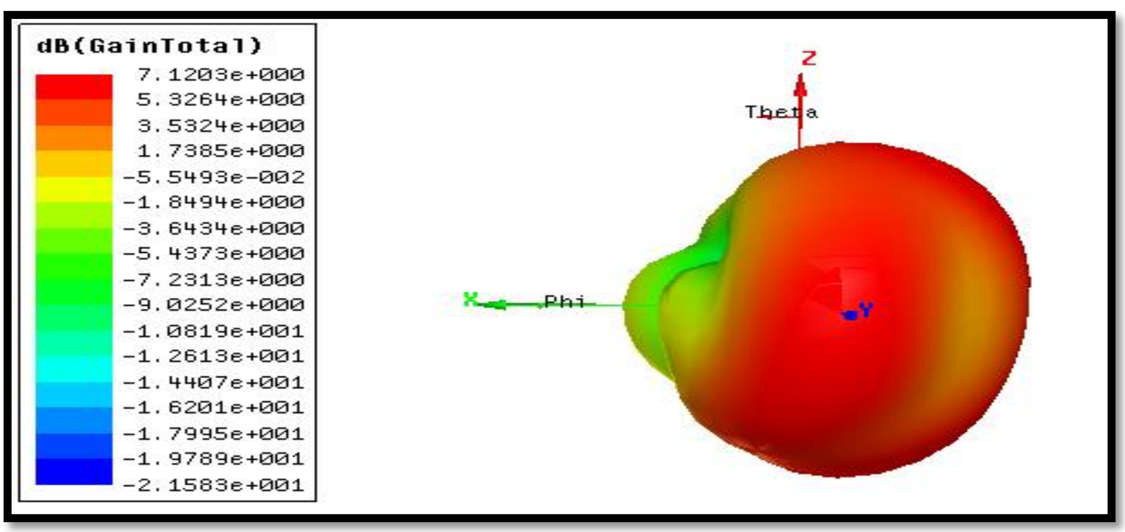


Figure 4- 22: Gain Four Element with Stub and Slot (4.92 GHz)

7.02 GHz(min gain freq)

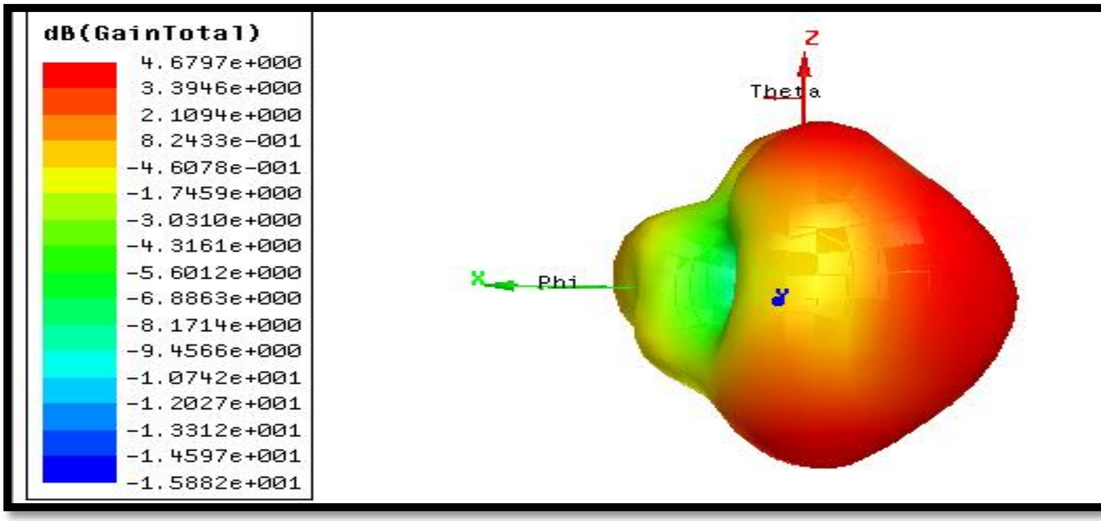


Figure 4- 23: Gain Four Element with Stub and Slot (7.02 GHz)

4.4.3 Radiation Pattern

Figure below shows antenna display an omnidirectional characteristics.

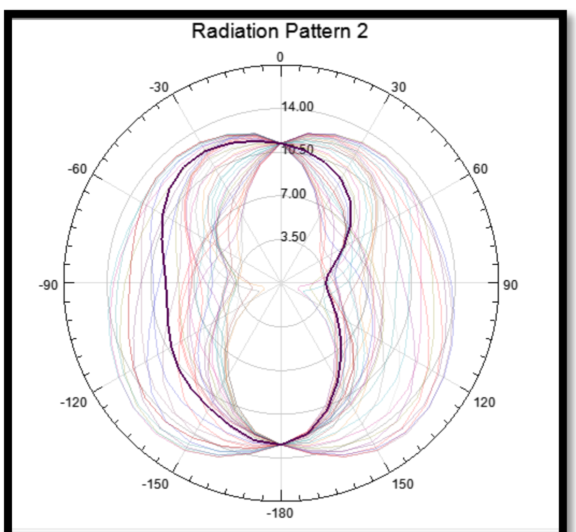


Figure 4- 24: Rad Patten Four Element with Stub and Slot

4.4.4 Isolation

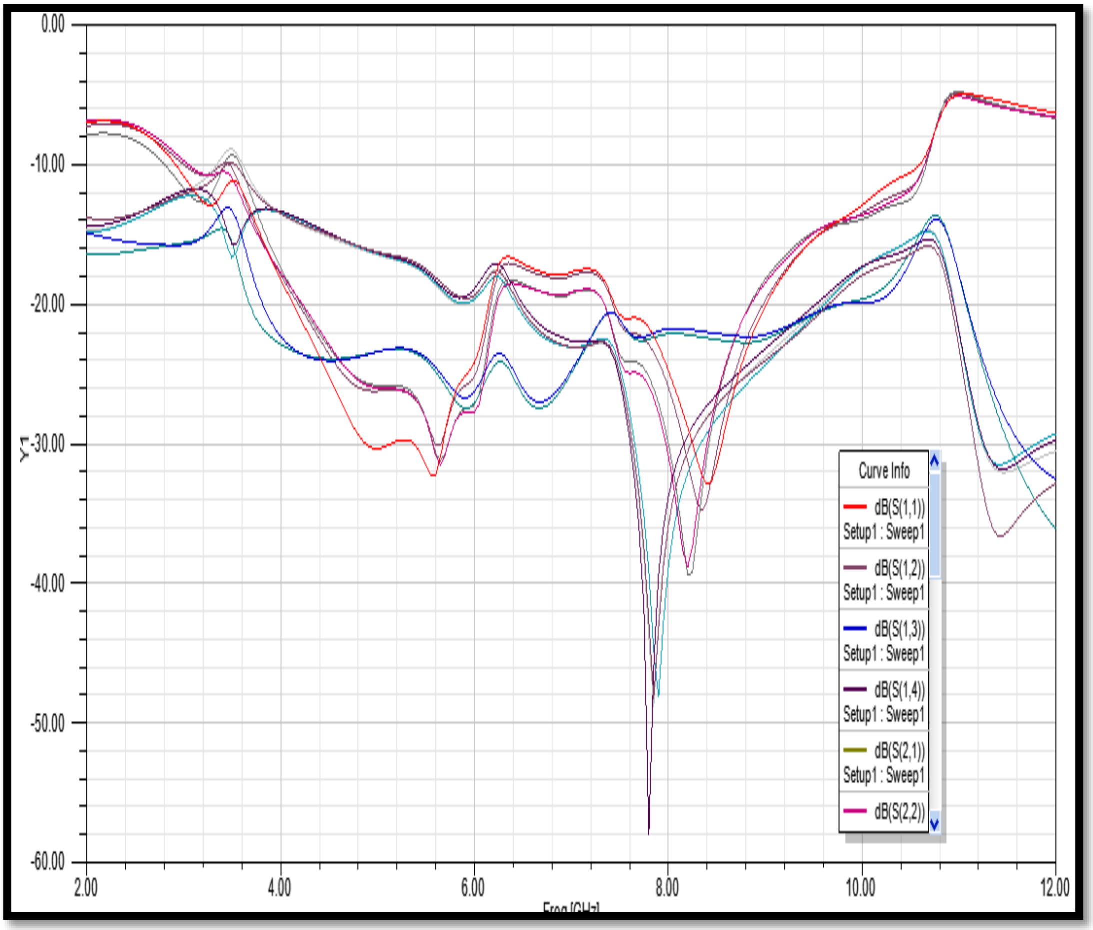


Figure 4- 25: Isolation Four Element with Stub and Slot

Figure shows S21, S31, S41 isolations were found to be better than -20 dB at frequencies between 3.2 - 11 GHz.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Future Work

As a wise man once said, “Your eagerness to knowledge is reflected by your will to learn and experience more”. Future work to modify our project by incorporating various changes will be taken up in following areas:-

- ✓ Design changes with different dimensions of slots and stubs.
- ✓ UWB works in between 3.1 to 10.6 GHz, however, future work on lower frequencies can be carried [22][23].
- ✓ Much smaller sized antennas are an important avenue in the future work.
- ✓ Substrate other than FR4 epoxy can be used to test the same antennas for results comparison.
- ✓ As part of future work, anechoic chamber will be used to test the antennas in field conditions.
- ✓ Study on UWB antennas application in Medical Field can be carried out in the future using the above designs.
- ✓ Due to their small sizes, UWB antennas can be used in avionics industry. As a kick start, implementation on Drone UAVs/Quadcopters can be experimented [24].

5.2 Conclusion

This chapter marks the end of our work on “Compact Four Element UWB MIMO Antenna” project. UWB offers a wide portion of the frequency spectrum where many frequencies are useable in multi-purpose application. In our earnest endeavor we shall be working on and studying lower and higher frequencies of this band, analyzing their band notches, gains, radiation patterns and isolations etc to improve this project further [25].

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Anx A

ABSTRACT

The multiple-input–multiple-output (MIMO) technique has established its significance in wireless data communication services, especially in association with ultra-wideband (UWB) technology. Large throughput can be ensured by combining MIMO technology with UWB systems. The UWB-MIMO system consists of multiple antenna elements placed in close proximity. Since the spatial multiplexing is directly related to the number of antenna elements, so the larger the element counts the higher will be the throughput. Closely placed antennas, however, develop undesired mutual coupling with other elements. Various techniques can used to reduce mutual coupling. This coupling reduces the effectiveness of the MIMO system due to larger correlation between channels.

Anx B

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