COMPACT UWB FREQUENCY NOTCHED ANTENNA

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ABSTRACT

COMPACT UWB FREQUENCY NOTCHED ANTENNA

The designed antenna will be a patch antenna which consists of a conductive sheet of metal mounted over a large sheet of metal called the ground plane with a substrate separating the two. Notched bands are WLAN and WiMAX.

V shaped patch was then chosen and modified to an arrow shaped patch to give the optimized results operating on the entire UWB region with considerable return loss.

The frequency notch prevents the operation of the antenna at a particular range of frequency, hence minimizing interference from other systems. There are numerous methods for introducing the notch but most common is inverted C-shaped slots in the UWB patch to get the notch features as output and also wavelength resonators to introduce notch in UWB band.

The designed antenna is simulated on a software High Frequency Structural Simulator 13.0 simulation software by Ansoft.

CERTIFICATE FOR CORRECTNESS AND APPROVAL

It is hereby certified that the form of the report and the contents of the project "Compact UWB frequency notched antenna" being submitted by the syndicate of students

1. GC Fahad Nawaz
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Have been written well and found satisfactory as per the requirements of the B.E Degree in Electrical (Telecom) Engineering.

Project Supervisor:

____

Dated: ___June,17

Lec. Maryam Rasool

MCS, NUST

DECLARATION

We hereby declare that none of the content of our work presented in this thesis has been submitted for some other award of qualification or degree either in this or anywhere else in another institution.

DEDICATED TO

Allah Almighty and Prophet Muhammad (S.A.W)

And our Parents and Family

Without whose unflinching support, a work of this

magnitude would not have been possible.

ACKNOWLEDGEMENT

We thank Allah Almighty for bestowing his countless blessings upon us without which nothing could have been achieved.

We would like to specially thank our supervisor, Lec. Maryam Rasool, for her support and encouragement was the inspiration without which it would never have been possible to achieve the goals.

We would also like to thank the faculty for being there for us whenever we needed help of any kind as well as the colleagues and other people willingly helping with their abilities us for their support and aid in the development of this project.

We are also most thankful to our parents who bore with us in times of difficulty and hardship and were such a support. Without their consistent support and encouragement, we would never have achieved the targets successfully.

At the end, we would also like to acknowledge Real Madrid CF., FC Barcelona and Arsenal FC for being a source of motivation, hard work and team work for us.

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List of Abbreviations

Abbreviation	Word in Full
UWB	Ultrawide Band
WLAN	Wireless Local Area Network
WiMAX	Worldwide Interoperability for Microwave Access
HFSS	High Frequency Structural Simulator
FCC	Federal Communication Commission
CPW	Coplanar Waveguide
DSRC	Dedicated Short Range Communication
SRR	Split Ring Resonator
HPRLAN	High Performance Radio Local Area Network
PCB	Printed Circuit Board
ISM	Industrial Scientific Medical
FPV	First Person View

1. CHAPTER 1

1.1 Introduction

1.1.1 Overview

In this report, design and implementation of an Ultra-Wideband (UWB) frequency notched patch antenna is presented. Proposed and simulated antenna operates efficiently at frequency range of Ultra-Wideband (3.1-10.6 GHz) with the exception of two specific frequencies (3.5 and 5.0 GHz) to avoid interference from already existing high power narrow bands. The prototype antenna is designed and fabricated. Initially the Ultra-Wideband antenna is designed. In second phase frequency notches are introduced to avoid interference and finally the designed antenna is fabricated. The main aim to design this antenna is to get high speed communication at short distance without the interference from the existing high power narrow bands (WiMAX and WLAN). Ansoft HFSS is used as design tool because of its closer to reality attribute and user-friendly interface. The design is finalized in HFSS and later on optimized for antenna efficiency and impedance matching over wide band. After the satisfactory results of simulated design the antenna is fabricated and results are tested in the Lab using the antenna chambers. [1] The results are successful and in close proximity to the proposed theoretical results. The S11 plot and radiation pattern is tested by using the antenna chambers.

1.1.2 Problem

The Ultra-Wideband is a low power wide band (3.1-10.6 GHz) and thus interferes with the existing commercial high power narrow bands such as WiMAX (3.5 GHz) and WLAN (5 GHz). [2] This interference causes a lot of noise and distorts the communication of Ultra-Wideband. [3] This is the main problem while dealing with the Ultra-Wideband in spite of the fact that it provides very high data rate for short range communication.

1.1.3 Statement

In order to get high speed communication using the Ultra-Wideband without the interference from the other high power narrow bands, frequency notches are introduced at the narrow bands frequencies. Notch is basically a band stop filter which stops communication at that frequency. So, in this way the interference from the existing bands can be removed [4] and Ultra-Wideband can used for communication without interference from WiMAX and WLAN.

1.1.4 Scope of Work

The work done will be able to cater the demand of ever growing wireless communications industry. Patch antennas in the Ultra-Wide Band are becoming increasingly popular due to their low power, light weight and high data rate capability. [5] Also, the compactness of antenna will allow it to fit in majority of the existing devices.

1.1.5 Academic Objectives

- Understanding the functioning of a patch antenna
- Designing a patch antenna
- Studying notch characteristics of a UWB antenna

1.1.6 Approach

In order to design and develop Ultra-Wideband Antenna, in depth study of antenna theory is required and practically following steps and approach is required to achieve the objective.

Analytical calculations of simple Ultra-wideband antenna and it characteristics, Notch introduction techniques, Software simulations in HFSS, optimization of the final design and fabrication of the simulated final design.

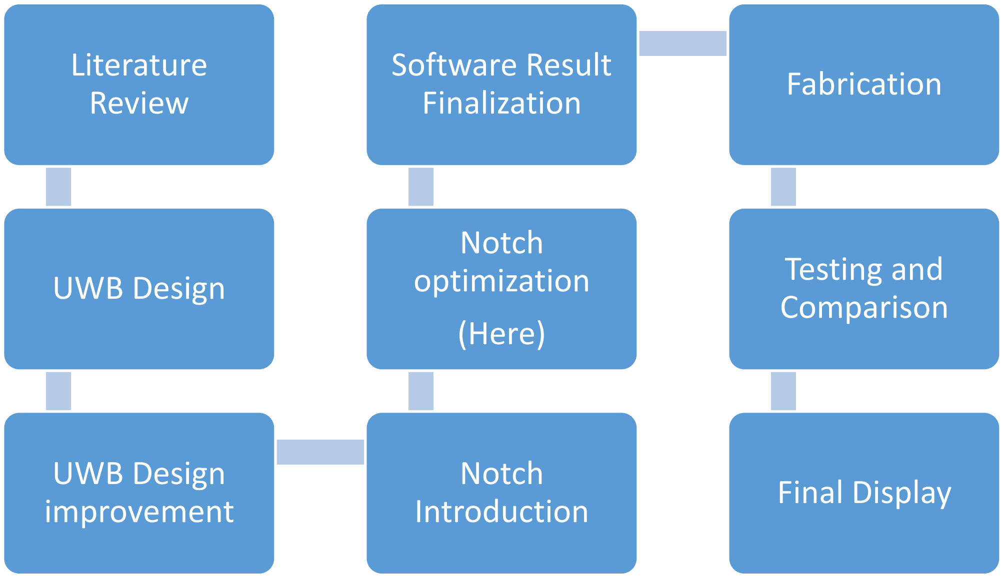

Figure 1 : Approach

1.1.7 Objectives

Understanding the functioning and designing of a patch antenna and Studying notch characteristics of a UWB antenna

The objective of this antenna design is to get high speed short range communication using the Ultra-Wideband without the interference from the existing high-power commercial narrow bands such as WiMAX and WLAN.

The designed antenna will prevent security breach from other systems operating in the spatial region. Interference from surrounding systems will be minimized and smooth functioning of antenna inside the UWB will be achieved.

1.1.8 UWB Applications

The UWB antennas are attaining reputation and becoming very smart in recent and upcoming wireless communication systems. They bring a lot for the future of wireless communications. Some key features are: Operation frequency 3.1 – 10.6 GHz

- Low power
- Low cost
- Secure
- High data rate

UWB systems use small size of impulses which makes them faster as the smaller impulses travel faster than larger ones. [6]

UWB is distinctive in the way that it works. Other wireless tools operate by transmitting persistently at a specific frequency, whereas an UWB transmitter directs out very short - 30 picoseconds - pulses or bursts of information at ultra-low power levels. These pulses discharge outward in a wide band, using an exclusive pulse mark. Rather than using one frequency, UWB uses several frequencies at the same time. [7] One big improvement of UWB's ultra-low power, short bursts and exclusive pulse signatures is the fact that numerous UWB networks can co-exist, without interfering or data safety issues. It is so protected, in fact, that UWB has been in use by the military since the 1960s.

2. CHAPTER 2

2.1 Literature Review

2.1.1 Overview

All wireless technologies use air as medium for communication. Wireless spectrum is divided into number of frequency chunks, called bands, to allow multiple technologies to use it simultaneously. Some of these bands are licensed meaning that companies pay for using them with assurance of no interference. Unlicensed on other hand don't require any payment but are vulnerable to any interference.

In February 2002, the Federal Communications Commission (FCC) has permitted the use of the frequency band of 3.1 to 10.6GHz for unlicensed wireless communication and named this band as ultra-wide band (UWB).

Most commonly used techniques for UWB are modified ground plane and slotted patch.

However, the concern with this band is that it has interference from many existing narrow bands wireless systems i.e. Wireless Local Area Network (WLAN) operated at the frequencies of 2.4 GHz, 5.2 GHz, and 5.8 GHz. WiMAX operates at 3.5 and 5.8 GHz for 802.16d and at 2.3, 2.5 and 3.5 GHz for 802.16e and standard C-band operates at 5.8-6.4 GHz. [8]

To avoid interference from these existing narrow bands, band notching techniques are used while designing the UWB antenna.

The common method to achieve the band-notched function is incorporating slots into the antenna's main radiator, such as a U-shaped slot, a V-shaped slot, an arc-shaped slot, etc. [9]

Other methods that can be used are introduction of simple open-end slits and wavelength resonators, ring resonators which has two strips attached with its patch for resonance. [10]

The antenna reported in consists of a square slot in the radiating patch. The WLAN notch action is attained by vertically placing the quadrilateral coupling strip in the center of the slot patch.

2.1.2 Patch Antenna

Patch antenna also commonly known and termed as micro strip patch antennas. It is small in size having extremely low profile and easily having the capability to be fitted on a smooth and flat surface. Patch consists of a copper sheet etched on a substrate material with a ground plane etched on the opposite side. Fringing effect of the antenna makes the antenna act slightly larger in electrical terms so to make it resonant the length has to be adjusted slightly shorter than one half wavelength. Easy to fabricate, compact and light weight. [11]

Over the last decades, research has been conducted for new techniques to design a good and reliable system for UWB antennas. There are some systems which have their benefits as well as deficiencies. The main focus was on following techniques

2.1.3 Techniques for UWB

There are countless techniques for acquiring UWB system for antenna. Although some of them are most popular and commonly used.

2.1.3.1 Co-Planar Waveguide (CPW)

Basically, Coplanar waveguide is a type of patch antenna which inherently places both conductors (ground and patch) on the same plane leaving one side of the substrate perfectly unused or fully grounded. [12] It has a main metallic strip (feed line) separated by means of a gap or slits from the coplanar ground. The slits are extremely narrow in width as shown in the figure.

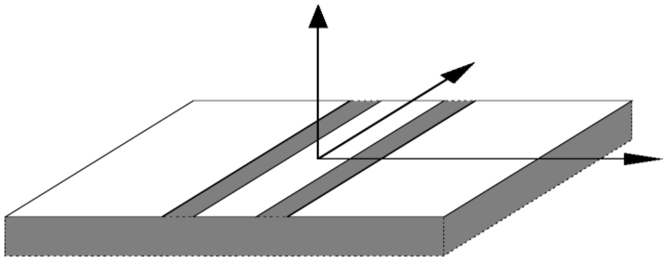

Figure 2: Coplanar Waveguide Patch Antenna

2.1.3.2 Modified Ground Plane

To achieve a UWB antenna the feed line, patch or the ground plane can be amended and modified to enhance the inherently lower bandwidth of patch antennas. [13] Patch and ground plane of patch antennas are basically an unbalanced and asymmetric. The current is flowing evenly through them both. This shows that the performance (gain, bandwidth, radiation patterns etc.) are severely affected by the shape and size of the ground plane. [14]

It has been studied that a patch antenna's performance parameters are heavily dependent on the ground plane shape. By introducing a slot, partial patching, windowing etc. will lower the dependence on the ground plane thus a higher bandwidth can easily be achieved. [15]

Modified ground Plane has two types; Partial Ground Plane in which overall size of ground plane is modified usually reduced than original which increases the bandwidth. Other type is Slotted Ground Plane in which slots are added to the ground plane and can be anywhere in the plane (center or at edge) which usually helps in reduction of cross polarization. [16]

Modified ground plane has many advantages. It improves input impedance characteristics of UWB feed line. High cross polarization between ground plane and feed line can be reduced by modifying ground plane, usually by introducing slots in ground plane. UWB antennas have large bandwidth, their most important feature, bandwidth can be increased by altering or modifying the ground plane. Slotted ground plane gives antenna the UWB character. [17]

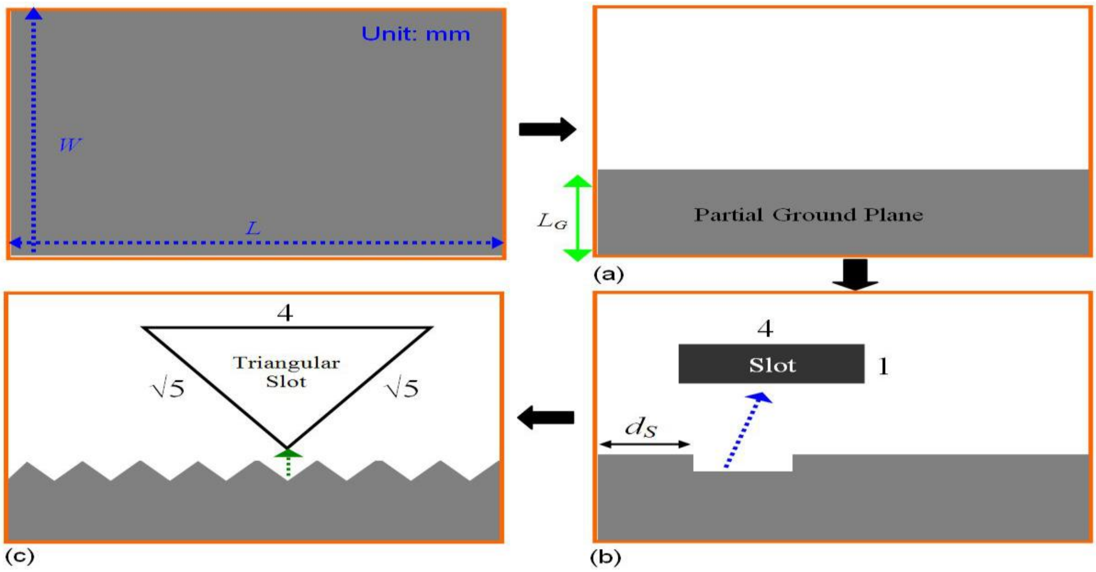

Figure 3: Types of modified ground planes

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2.1.3.3 Tapered Patch

Micro strip patch antenna's patch can be altered to increase its bandwidth and introduce UWB character in it. Sides of the Patch are tapered which causes the inherited narrow bandwidth of the micro strip patch antenna to enhance greatly. [18]

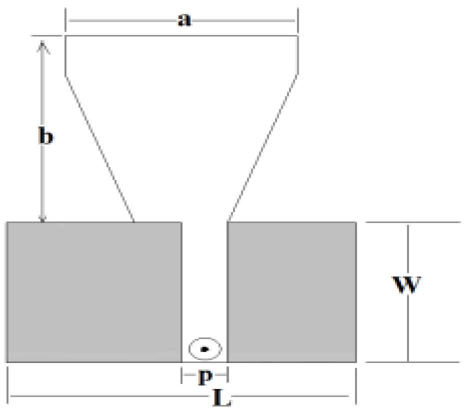

Figure 4: Tapered patch

2.1.4 Techniques for Notch

The frequency notch prevents the operation of the antenna at a particular range of frequency, hence minimizing interference from other systems. It is basically a very narrow and highly attenuated (over a few hertz) stop band. This notch allows the UWB frequencies to pass through with exception of some narrow bands.

There are countless techniques for introducing the notch but some of them are commonly used:

2.1.4.1 Shaped slots

A notch or a frequency notch is a phenomenon in which the working of an antenna is stopped at intended frequency to cancel the interfering effects. It is basically a very narrow and highly attenuated (over a few hertz) stop band. This notch allows the UWB frequencies to pass through with exception of some narrow bands.

Introduction of shaped slots introduce notch in the UWB system. Effective shaped slots are C slot, U slot and V slot. [19] U slot notches the frequency from almost 5 GHz to 6 GHz by varying the parameters it can be studies. It was also studied that two semi U slots cut onto a Y patch changed the current patterns on the patch [20]

C slot can also be utilized to achieve band notch characteristics specifically in WiMAX and WLAN(5GHz) by adjusting the length of the C slot. [21] Hilbert slots can also be used to achieve the same band notched characteristics [22]

There are many advantages of using shaped slots to alter patch for introducing the notch. They bring the least modification to the original antenna patch. And after the patch is altered by slot then by only changing the slot parameters the frequency and bandwidth of the introduced notch can be altered as per requirements. Lastly the slots are applied directly to an existing UWB patch i.e. no additional part it attached or modification is needed.

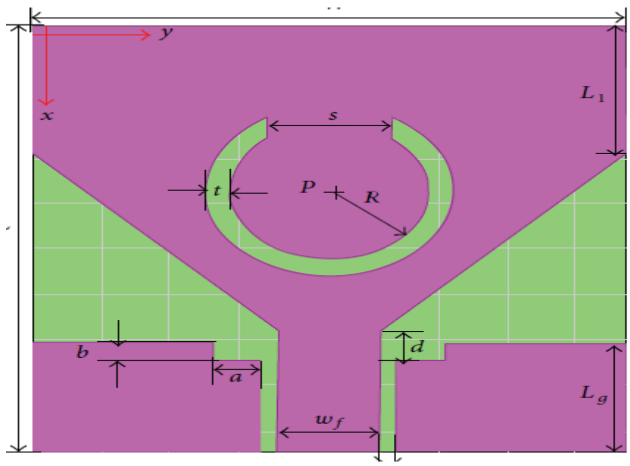

Figure 5: Inverted C shape slot for band notching

Slots can also be introduced in the ground plane for introducing notch in the UWB system. Different shaped slots can be introduced.

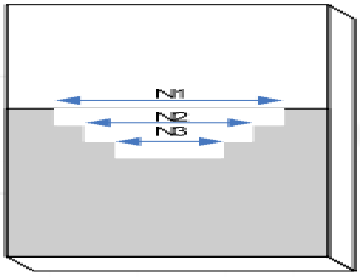

Figure 6: Multiple rectangular slotted ground plane for notch introduction

2.1.4.2 Parasitic patch

A parasitic patch is an element on the antenna (either ground or the patch) which is not electrically connected to any other element on the antenna. Parasitic patches of different shapes are considered to introduce different characteristics on the patch antenna such as improving the gain, notching a specific band of frequencies, improving directivity of the patch antenna etc. [23]

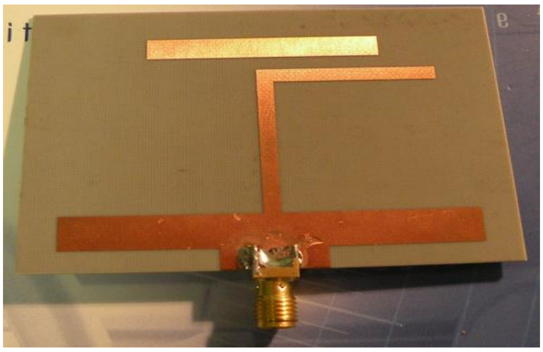

Figure 7: Patch antenna with Parasitic Patch

C or U shaped parasitic patches are said to introduce band notching characteristics in a UWB antenna. An additional advantage would be improvement of gain as the effective aperture would also be increased.

2.1.4.3 Wavelength Resonators

A resonator is essentially a structure which vibrates or experiences resonance at particular frequencies with more enhanced amplitude than at other frequencies

Some strips are connected with the patch that resonate at some particular frequencies. These strips help to produce notch are those frequencies at which it resonates. Therefore, we design or introduce a strip in the patch such that it produces the desired notch. A specific narrow band can be easily notched or stopped by using this wavelength resonators method. [24]

Split ring resonators provide relatively very high impedance to the incident signal of the intended resonant frequency causing it to reflect which in turn causes notching of the frequency band and WLAN frequency. [25]

Different shaped resonating structures can be employed to achieve the band notch characteristics such as L shape resonators, a symmetric resonator etc. [26]

Having wider bandwidth and implementing notch in the mid-band and it has two strips attached with its patch for resonance.

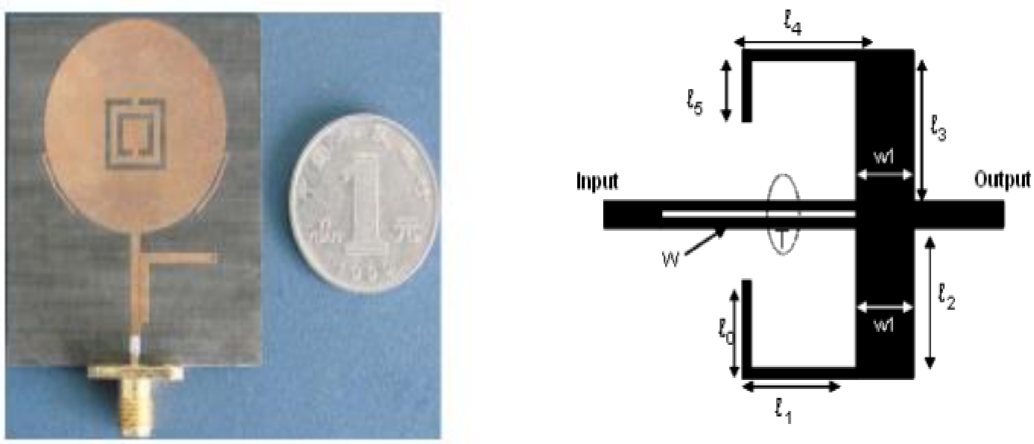

Figure 8: Wavelength Resonators for band notching

3. CHAPTER 3

3.1 Design and Development

3.1.1 Software

The basic design and simulation of antenna is done on software. The designed antenna is simulated on a software which then gives the simulated results the available software's for simulation are High Frequency Structural Simulator and CST studio. For less complex antennas both have similar performance and the main difference comes in the proficiency over a software. The group has proficiency over HFSS software so that will be used.

3.1.1.1 High Frequency Structural Simulator 13.0

HFSS 13.0 is the latest version of the high frequency simulation software by Ansoft. It is a commercial electromagnetic structural simulator and solver. HFSS is a useful tool for antenna design, filters, transmission lines etc. It has an easy to use interface for designing and simulating high frequency structures and antennas. Antenna of any shape and design can easily be simulated. As the antenna being designed in our project will be compact and not complex so there won't be much computational load on the software.

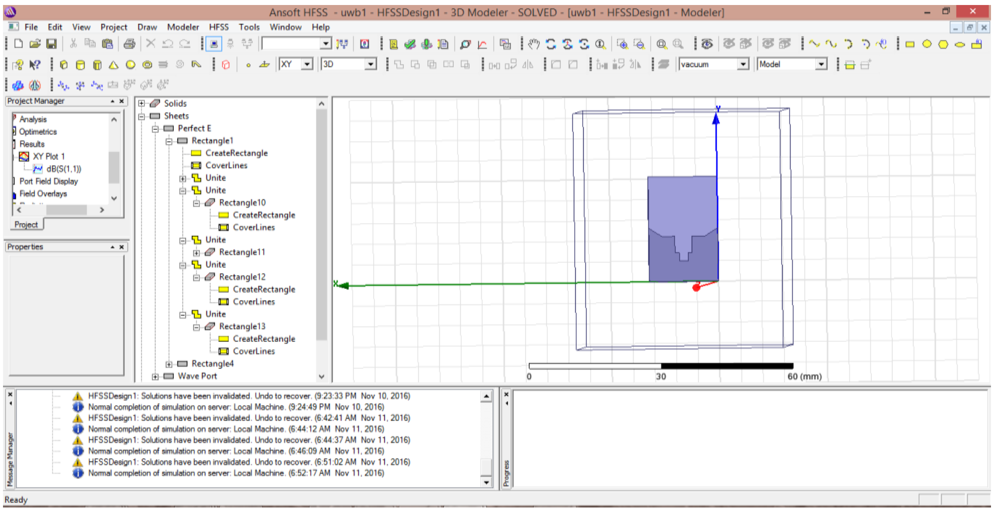

Figure 9: HFSS 13.0 Interface

3.1.2 Fabrication

The designed antenna is fabricated in laboratory on PCB and the selected substrate (FR 4 epoxy). High accuracy fabricator is utilized to get accurate results as even a slight inaccuracy can affect the result drastically. Photo lithography is used to fabricate the antenna.

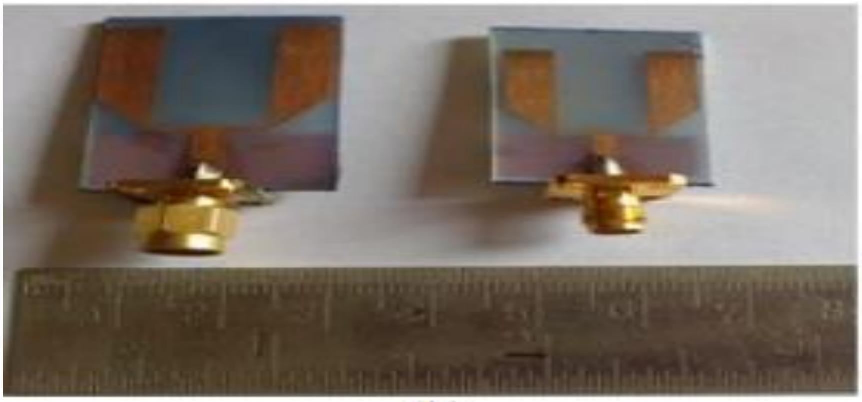

Figure 10: Fabricated patch antenna

3.1.3 Results measurement

The results include the measurement of antenna specification so that to ensure that meet the simulated and aimed results. Usual parameters which characterize are gain, return loss, radiation pattern etc. These parameters are measured after the fabrication of the designed antenna to ensure that the antenna results are similar to the ones simulated. Any error in this stage depicts a design flaw or fabrication error which forces the designer to go back to the previous stage.

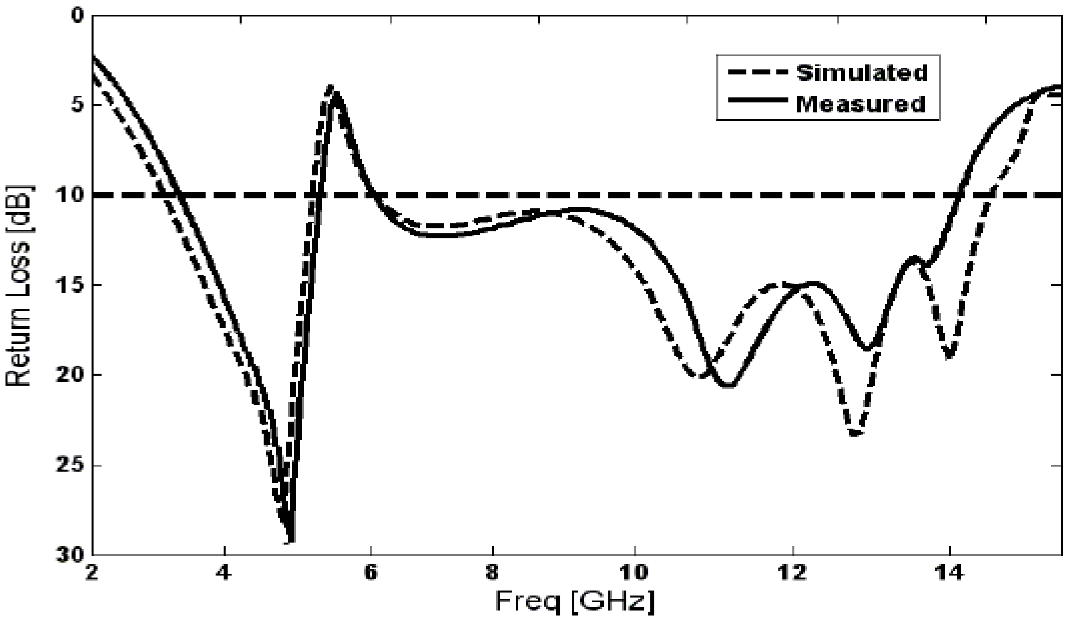

Figure 11: Simulated and measured results of a patch antenna

3.2 HFSS Design Development

The studied techniques in the literature review were thoroughly examined for the implementation of the antenna. The techniques discussed in the literature review section were thus short listed for implementation and experimentation. Techniques with the best results will further be selected for the optimization of the results.

3.2.1 Considered Shapes

Patches of different shapes have different inherent characteristics and advantages. The most commonly used patch is the rectangular shaped patch due to the ease of design and fabrication. The slots which are most common are also rectangular slots. We have also considered the rectangular patch as the basic design of our antenna. Other shapes considered include bevel shaped and bevel and rectangular combined.

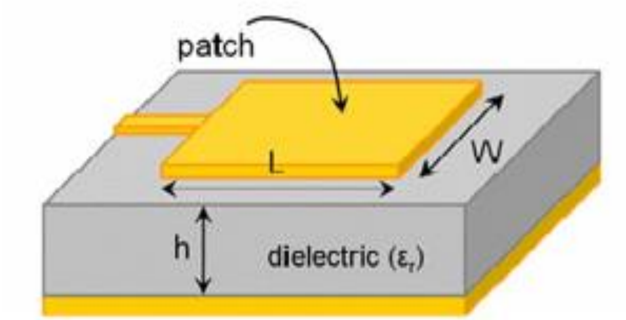

Figure 12: Rectangular patch antenna

3.2.2 Design of UWB

Different techniques used to implement the UWB antenna were individually implemented and their results were examined. Designs with unpromising results were discarded. Some of the results are discussed.

3.2.2.1 Finalized UWB Design

The arrow shaped patch was further modified to give the desired result and the finalized design of the UWB antenna is shown. The techniques employed include Partial / Slotted ground plane and the tapered patch for enhanced bandwidth.

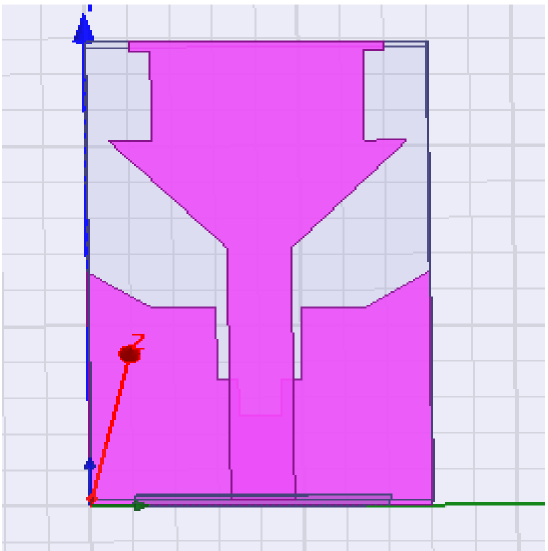

Figure 13: UWB design

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The return loss plot shows the operating region of the antenna,

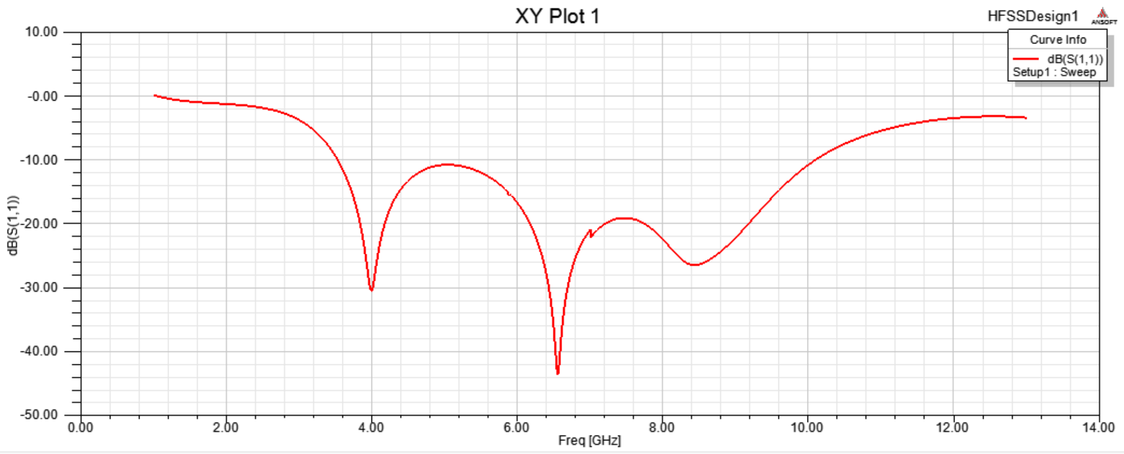

Figure 14: S11 plot of UWB design

Dimension of the antenna are as shown

PATCH	
Parameter	**Dimension(mm)**
Feed Line	14x3
Arrow head	8.139(edge) 14(head) 3(base)
Rectangle 1	5x10
Rectangle 2	0.5 x 12

Table 1: Dimensions of Patch

GROUND	
Parameter	**Dimension(mm)**
Ground	16x13
Slot1	2x2
Slot 2	4x4

Table 2: Dimensions of ground

3.2.3 Notch Design

The frequency notch is introduced in the UWB antenna by cutting an inverted C shaped slot in the UWB patch. The slot introduces a band stop at the WLAN frequency. The design is as shown below.

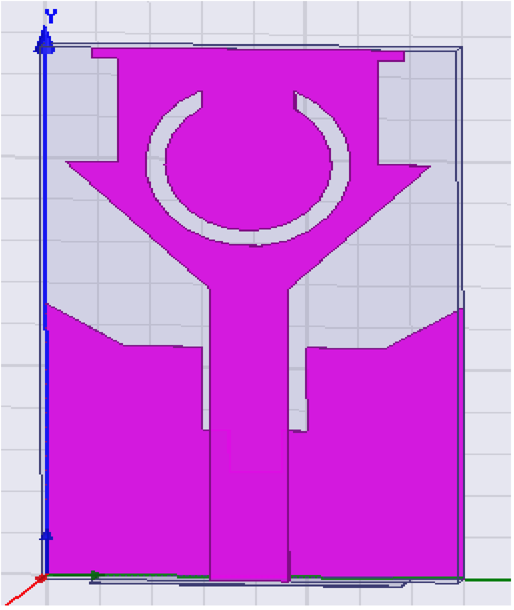

Figure 15: Slotted UWB band notched Design

C SLOT	
Parameter	**Dimension(mm)**
Slot width(t)	.75
Radius (R)	3.2
Connecting patch width (s)	3.6

Table 3: Dimensions of C-slot

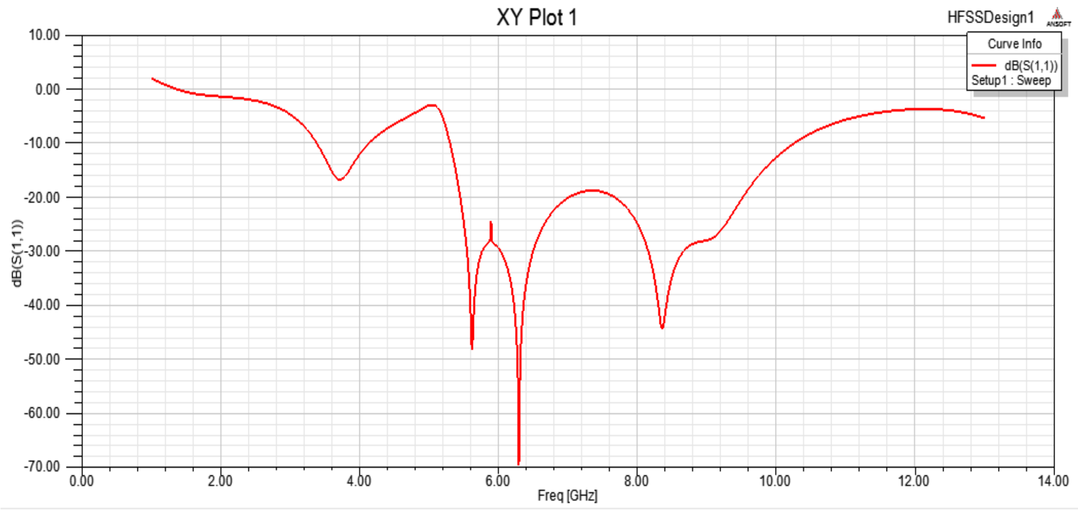

Figure 16: S11 plot of the notched UWB design

NOTCH CHARACTERISTICS	
Parameter	**Value**
Return loss (at center frequency)	-2.92 dB
Center Frequency	5.06GHz
Gain (at center frequency)	-1.9241
Bandwidth	1.2 GHz

Table 4: Characteristics of Notch

The current design will allow the UWB antenna to function in complete UWB region beside the WLAN band (5 GHz) effectively blocking out the interference from this band.

3.2.4 Finalized UWB Notch Design

The finalized UWB and Notch design is as shown below, the previously achieved notch was modified to achieve the notch at 3.5 GHz (WiMAX) and the parasitic technique was used to obtain a notch at 5 GHz (WLAN). The Design is as show below

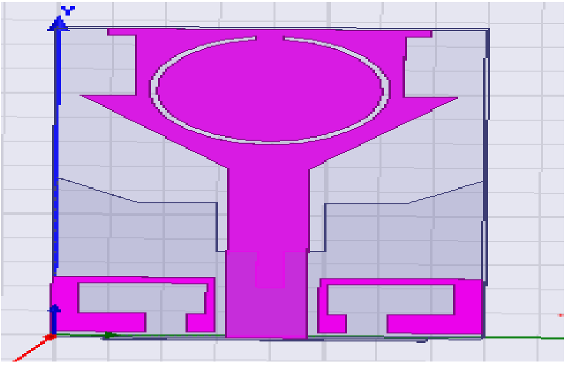

Figure 17: Finalized UWB Design with Notch

C SLOT (WiMAX)	
Parameter	**Dimension(mm)**
Slot width(t)	0.30
Radius (R)	4.2
Connecting Patch Width (s)	1

Table 5: Dimensions of C-slot for WiMAX notching

Parasitic Patch (WLAN)	
Parameter	**Dimensions(mm)**
Length	4.5
Breadth	6.05
Slot Width	2.05
Patch width(average)	0.56

Table 6: Dimensions of Parasitic Patch for WLAN notching

3.2.5 Mathematical Evaluation

The mathematical evaluation of the C shaped slot to calculate the parameters R, s and t respectively is governed by the equation shown below.

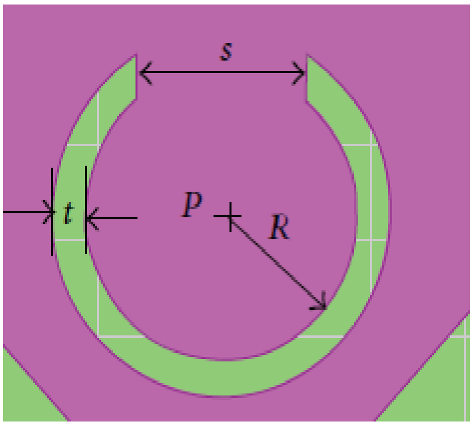

Figure 18: Parameters of the C slot

3.2.5.1 C slot

$$f_{stop} = \frac{C}{2L_s\sqrt{\varepsilon_{eff}}}$$

C=speed of light

ε_{eff} =effective dielectric constant

Ls = total length of the slot

f_{stop}=stop band center frequency

Calculation for effective dielectric constant

ε_r = 4.4 (dielectric constant)

$\varepsilon_{eff} = (\varepsilon_r + 1)/2$

$\varepsilon_{eff} = (4.4 + 1)/2$

$\varepsilon_{eff} = 2.7$

$f_{stop} = 3.5 * 10^9$

3.2.5.2 Calculation for guided wavelength

$\lambda gs = \lambda o / \epsilon^{\ 1/2}$

$\lambda_{gs} =$ guided wavelength

$\lambda o = c / f_{stop}$

$\lambda_o =$ Stop band wavelength

$\lambda_o = (3 * 10^8)/(3.5 * 10^9)$

$\lambda_o = 0.086m$

$\lambda_{gs} = 0.086/1.643$

$\lambda_{gs} = 0.05216m$

3.2.5.3 Calculation for total length of slot

$L_s = \ 0.5 * \lambda_{gs}$ (Condition for band notching)

$L_s = 0.02608m$

$L_s = 0.02608m \rightarrow 26.08mm$

$L_s = (2 * 3.14 * 4.2) + 2 * (0.3) - 1$

(Putting our values of R, s and t)

$L_s = 25.976$

3.2.5.4 Calculation for our parameters of C slot

$f_{stop} = (3 * 10^8)/(2 * 0.02597 * 2.7^{1/2})$

$f_{stop} = 3.515\ GHz$

3.2.5.5 Parasitic patch

$$\boldsymbol{f_{stop}} = \frac{\boldsymbol{C}}{\boldsymbol{2L_s\sqrt{\varepsilon_{eff}}}}$$

C=speed of light

$\varepsilon_{eff} = dielectric\ constant$

$L_s = total\ length\ of\ the\ slot$

$f_{stop} = stop\ band\ frequency$

$\varepsilon_{eff} = 2.7$

$f_{stop} = 5 * 10^9$ Hz

$\lambda_{gs} = \lambda o/\varepsilon^{1/2}$

λ_{gs} = guided wavelength

$\lambda o = c/f_{stop}$

$\lambda o = stop\ band\ wavelength$

$\lambda o = (3 * 10^8)/(5 * 10^9)$

λo = 0.06m

λ_{gs} = 0.06/1.643

λ_{gs} = 0.036

L_s = 0.5 * λ_g (Condition for band notching)

$L_s = 0.5 * (0.036)$

$L_s = 0.0182m \rightarrow 18.25mm$

3.2.5.7 Length of Parasitic patch

$L_{stop} = (4.5 + 6.05 + 4.5 + 3.5 + 1) + (0.56) - 2.05$

$L_{stop} = 18.06mm$

$f_{stop} = (3 * 10^8)/(2 * 0.018 * 2.17^{1/2})$

$f_{stop} = 5.06\ GHz$

3.3 Fabrication

The simulated design was fabricated from the National Institute of Electronics.

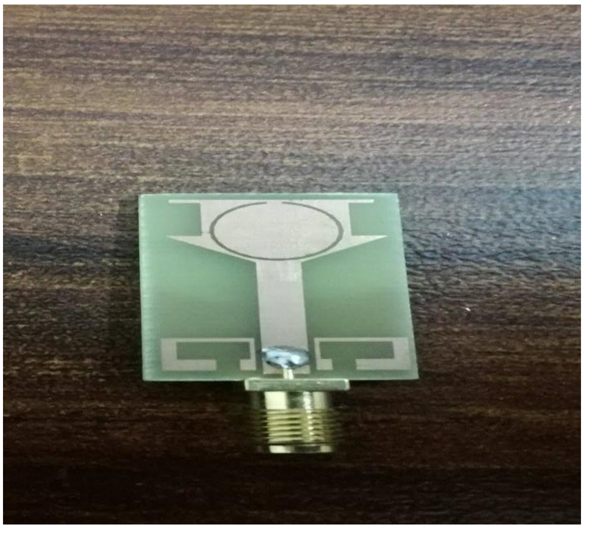

Figure 19: Fabricated Antenna

4. CHAPTER 4

4.1 Testing and Evaluation

The results of the fabricated antenna were tested from NUST H12 Campus and are shown below.

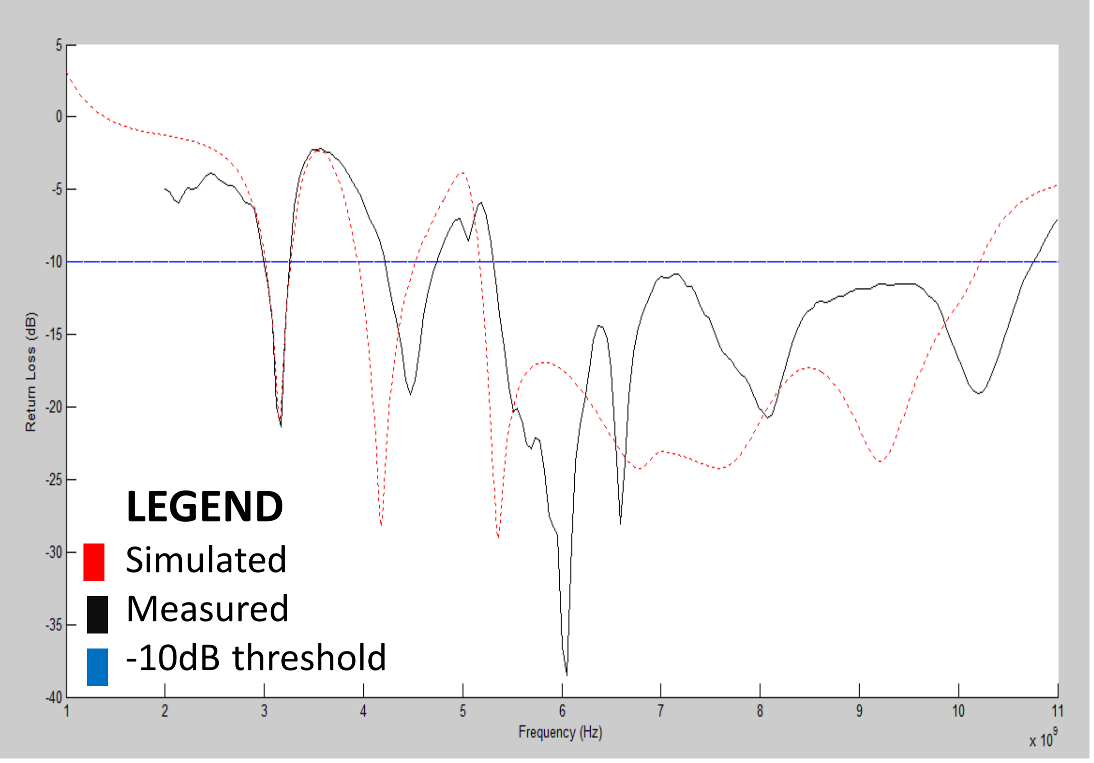

Figure 20: Measured and simulated results

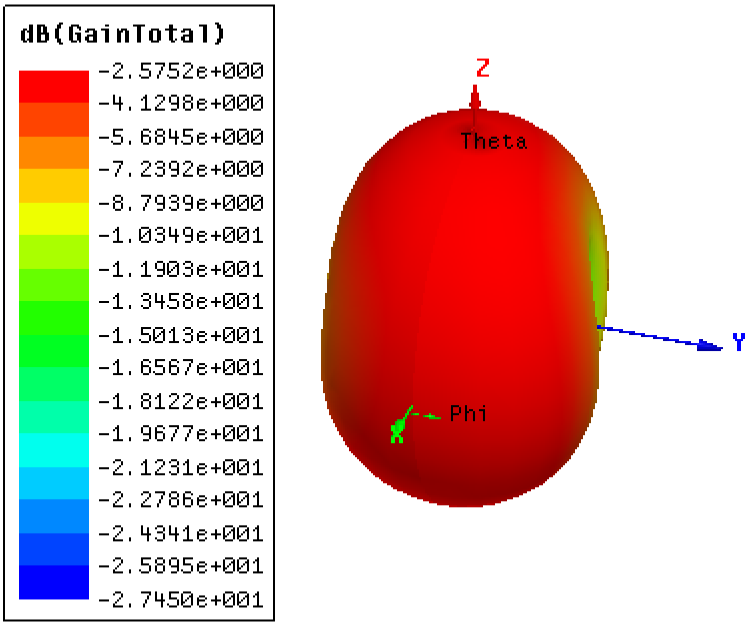

Figure 21:Gain Plot at 3.5GHz

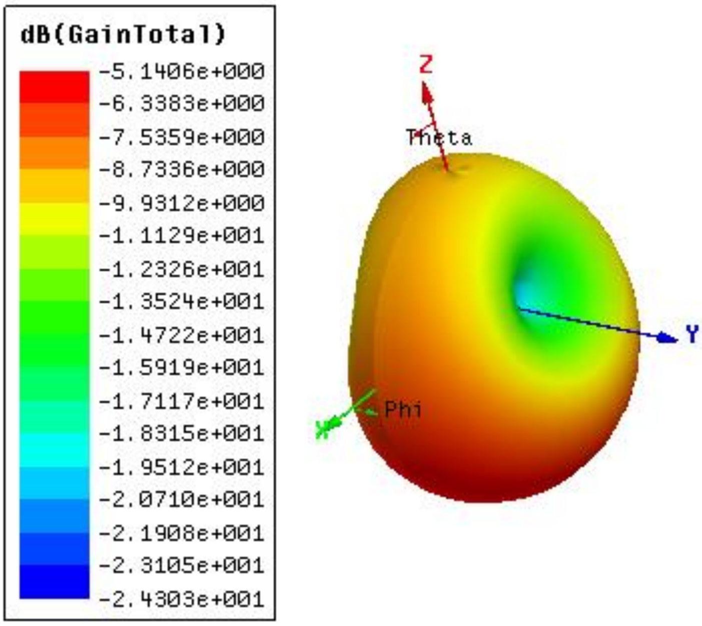

Figure 22:Gain Plot at 5GHz

4.2 Practical Application

For the practical application of our designed antenna we would utilize the ISM (industrial, scientific and medical) radio band which is allocated for the purpose of research, scientific and medical purposes. These are bands on which no commercial operation is done and reserved on a worldwide and local operation depending upon the country's regulatory policy. We would use the 5.8GHz band (5.725-5.875 GHz) band as the return loss is considerably good. The application which we intend to target is FPV (First Person View) drone video transmitted wirelessly through our antenna.

The equipment required for that is

- TS 58200 (5.8 GHz ISM band) Audio Video Transmitter
- RC 305 (5.8 GHz ISM band) Audio Video Receiver
- FPV Drone Camera (2.8 mm Lens)
- Fabricated Antenna

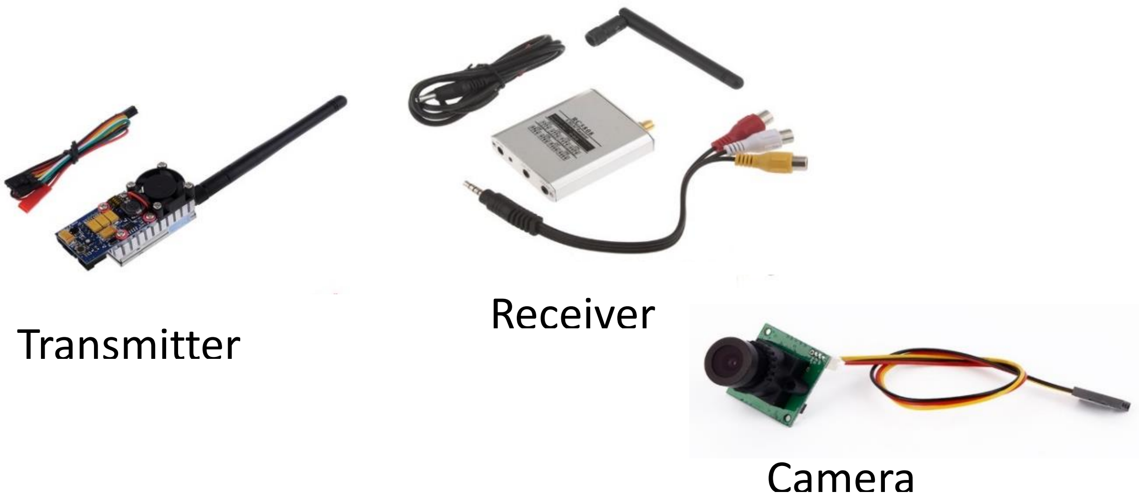

Figure 23: Transmitter and receiver for practical use of fabricated antenna

5. CHAPTER 5

5.1 Future Work

Further improving the gain of the designed patch antenna and making it circularly polarized. Further work can include the following

- Improving the gain
- Improving Directivity
- Switching
- Circular polarization

These improvements will enable better operation of the antenna.

5.2 Conclusion

A compact UWB antenna has been designed and the required specifications and results have been achieved. The frequency notches enable the designed antenna to function without any interference from the commercial WLAN and WiMAX bands. The enhanced bandwidth of the designed antenna will enable it to work adequately well for high data rates. Negative gain has been achieved for the notched frequencies which confirm that the commercial bands would not interfere with the designed antenna. Furthermore, the antenna has been applied and tested on a 5.8 GHz video transmitting and receiving system and works perfectly well. The designed antenna can thus be applied in such audio video receiving systems due to its considerable return loss and gain. The desired goals and objectives have been achieved.

6.CHAPTER 6

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