DESIGN OF MULTI-BAND ANTENNA FOR WLAN/WIMAX AND C-BAND APPLICATIONS

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ABSTRACT

Our paper presents a small, low profile, planar multi-band patch antenna for WLAN, WIMAX and C-band applications. The proposed antenna consists of two F-shaped fractal slots that are etched on either sides of the line feed and a defected ground plane. It is therefore compact in size and simple in structure. The measured bandwidths for 10 dB return loss are 98.1MHz, 237.6MHz, 289.3MHz and 1090.1 MHz with center frequencies 2.5GHz, 3.69GHz, 4.25GHz and 5.65GHz respectively, effectively covering S & C bands. Accessing the internet by simultaneously using WLAN&WIMAX standards and getting the satellite and mobile services have been the hallmarks of this design. To validate the proposed design, an experimental prototype has been fabricated and tested. Good agreement between measured and simulated results has been found.

The designed antenna has been simulated in High Frequency Structural Simulator (HFSS) 13.0 by Ansoft.

DECLARATION

No portion of the work presented in this dissertation has been submitted in support of another award or qualification either at this institute or elsewhere.

DEDICATION

We dedicate our work to Hazrat Awais Qarni (May Allah be pleased with him).

ACKNOWLEDGEMENTS

Our teachers have been very kind in making us explore new horizons of knowledge. We owe them a lot for their each and every second and for the worthwhile services that left no stone unturned in molding us into successful engineers-more aware than before.

We would like to thank our project supervisor Assoc Prof Dr Farooq Ahmed Bhatti who guided us throughout the year so that today we stand successful in bringing our FYP into reality. He steered us in the right direction whenever he thought we needed it.We would also like to thank our co-supervisor Lec Maryam Rasool without whose assistance and input, this work wouldn't have been possible. She can rightly be credited to have taught us the abc of antenna and HFSS software.

Brig Tariq Saeed, Mr Moiz Ahmed Pirkani, Mr Intisar Rizwan i Haque, Gp Capt Umer Farooq and Lec Alia Razia Malik will long be remembered for their untiring efforts in our grooming.

Mr Farhan Munir and his groupmates merit a special mention for their coursemate spirit with special reference to their support in antenna design and fabrication. The staff of RF& Microwave lab of MCS and NIE especially Engr Babar Ali (an MCS alumnus) also deserve appreciation who rendered their services at our disposal. Hat tip to our parents for providing us with unfailing support and continuous encouragement throughout the years of study.

Finally, we express our profound gratitude to Allah Almighty our creator, our source of inspiration, wisdom, knowledge and understanding. He has been the source of our strength throughout this program and on His wings only have we soared.

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1. INTRODUCTION:

1.1 Background Study:

The development of wireless communications has seen a very rapid progress in the last decades. An integral and a crucial part of any wireless communication system is the antenna.

The antenna is a system component that is designed to transmit or receive waves. Other definition, an antenna is a type of transducer which is used to convert guided waves from transmitted antenna transmission line to radiated free-space waves and vice versa. In modern wireless technology, the antenna act as a directional device to improve the energy in some directions while suppressing it in other directions. A good and optimized antenna design can greatly benefit the performance and ease of some of the system's requirements.

Hence we moved on for selecting antenna design as our FYP.

1.2 Problem Statement:

The ultimate goal of our FYP is to design an antenna that can excite triple-band operation combining WIMAX and WLAN communication technology at the same time into a single device. It requires Ansoft HFSS for simulation. The final product is an antenna that is operating within the range of 2 to 6.5 GHz.

The suggested antenna presents three different resonances in bands of 2.0–2.76 GHz, 3.04–4.0 GHz, and 5.2–6.0 GHz.

1.3. Proposed Application:

With the rapid advancement in modern wireless communications, such as wireless local area network (WLAN) and worldwide interoperability for microwave access (WiMAX), for multiple functions there is a requirement to merge different frequency bands into a single design. Moreover, such as low-profile, lightweight and line-feed is also desired as compactness of system to fit the small size of WiMAX and WLAN devices. In order to achieve all above specifications, this antenna has been designed.

Nowadays, more people use wireless devices to surf the Internet through Wi-Fi. So, applications of WIFI must be able to operate at high data rates. Multiple-Input Multiple-Output technology (MIMO), which transmit and receive data by using multiple antennas. Owing to its small size and performance, the planar inverted F antenna (PIFA) is mostly used in wireless devices.

1.3.1 MIMO:

MIMO (multiple input multiple output) is technique for wireless communication in which the transmission (at source) and reception (at destination) occur with the help of multiple antennas. The antennas grouped to reduce errors and optimize data speed at each end of communications.

1.3.2 Why MIMO:

MIMO has become important in wireless communication standards including IEEE 802.11n (Wi-Fi), IEEE802.11ac (Wi-Fi), HSPA+ (3G), WiMAX (4G), and LTE (4G).

In future, data rate desire for mobile services will be high .In compact devices such as wireless modems there is the demand of small antennas. This requirement is satisfied by the microstrip antenna.

In MIMO antennas, two or more patches are placed at the common ground plane and dielectric material.

All Wireless mobile devices with compact size has to provide faster access, higher resolution screens, additional connectivity. The idea of improving the channel capacity by using more than one antennas at the transmitter and receiver was first predicted by Foschini.

All wireless devices face Problems of fading, multiple-path, enhance interference and limited frequency band. MIMO (multiple-input-multiple-output) technology used multi-path to provide higher data throughput, and increase in range and reliability. It provides solution for two problems of wireless technology, speed and range. MIMO technology has find applications in television, wireless local area networks (WLANs), metropolitan area networks (MANs), and mobile communications.

1.4 Methodology:

The proposed antenna consists of same size two F-shaped slots that are etched on patch of rectangular shape for multiband operation. By gap-coupling of circular shape with rectangular ground plane (defected ground plane) on the one side of dielectric substrate impedance matching can be achieved.

1.5 Fractal Technique:

A fractal is a technique of antenna that uses a self-similar design to expand the length of material that can receive or transmit radiation within a given total surface area.

Such antennas are also called as multilevel and space filling curves, but the key concept lies in the repetition of a pattern over scale sizes. For this reason, fractal antennas are very short, wideband and useful in telephone and microwave communications.

2. PROPOSED ANTENNA FEATURES:

The proposed system will have features like:

Compact Size, Novel Design, Covers WLAN and WiMAX Bands simultaneously

Improved Gain, Simple Structure, easy to Fabricate and Omni directional radiation properties.

2.1 Analytical Treatment:

$$\in \boldsymbol{eff} = {(\in \boldsymbol{r}+\mathbf{1})}/_{\mathbf{2}} + {(\in \boldsymbol{r}-\mathbf{1})}/_{\mathbf{2}}\,[\mathbf{1}+\tfrac{\boldsymbol{h}}{\boldsymbol{w}}]^\wedge\mathbf{2}$$

$$\Delta\boldsymbol{L} = \mathbf{0.412}\boldsymbol{h} * \frac{(\in \boldsymbol{eff}+\mathbf{0.3})(\mathbf{0.264}+\frac{\boldsymbol{W}}{\boldsymbol{h}})}{(\in \boldsymbol{eff}-\mathbf{0.258})(\mathbf{0.8}+\frac{\boldsymbol{W}}{\boldsymbol{h}})}$$

$$\boldsymbol{L} = \boldsymbol{Leff} - \mathbf{2}\Delta\boldsymbol{L}$$

$$\boldsymbol{Leff} = \frac{\boldsymbol{c}}{\mathbf{2} * \boldsymbol{f}\mathbf{0}\sqrt{\in \boldsymbol{eff}}}$$

$$W = \frac{c}{2 * f0\sqrt{\frac{\in r + 1}{2}}}$$

2.2 Substrate Selection:

The use of a good substrate in this microwave strip antenna design is a science in itself. Thin boards with high dielectric constants are desirable in microwave circuits because they reduce unwanted crosstalk, higher order modes and surface waves, yield smaller circuit sizes (therefore increasing design efficiency), and prevent radiation losses. On the other hand, a lower dielectric constant of around 2.2 with a thicker substrate is preferred for the patch antenna to achieve high gain, larger bandwidth and overall greater efficiency. FR-4, possibly the most popular substrate using in the electronics industry today, typically has a permittivity of 4.4 with a certain variance, and comes in various thickness FR4 epoxy glass substrates are the exceptional material for most PCB applications. The material is very low cost and has distinguished mechanical properties, making it exemplary electronic component applications. Since it is cheap and easily available in the market, it became the best choice for us to use it for our design implementation. After studying different designs from the different research papers of IEEE we decided to implement our design using FR4 with 1.6 mm thickness.

3. DETAILED DESIGN:

The proposed design consists of F-shaped slot radiators that are etched on either side of simple line feed that have been further slotted resulting into a fractal antenna patch and a defected ground plane for impedance matching. Dimensions have been explained further.

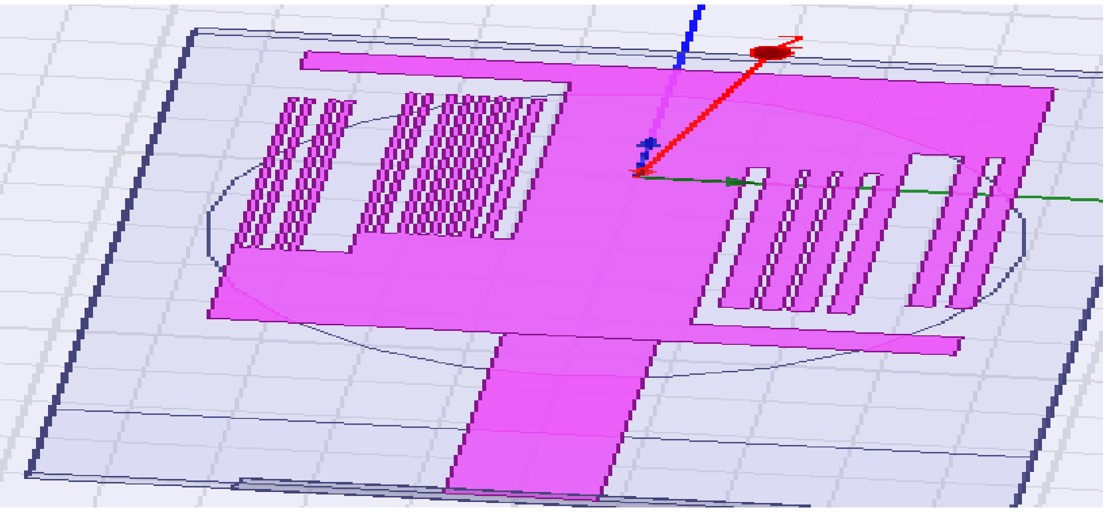

Figure 1: Detailed software design showing fractal patch

3.1 Software Design evolution:

The antenna design evolution process to attain the multi-band operation for WIMAX/WLAN applications is shown. The design starts by convention rectangular patch and ground plane, it can be seen that in this case a single resonant mode seems to form. Due to the modification of the radiating patch by etching two L-shaped slots each on either boundaries of the patch 2 resonant modes are observed. Finally, ground plane is modified by printing circular-shaped patch to improve the impedance matching along with an additional slot on patch (F-shaped) giving multiband operation.

3.1.1 Design for Single band:

A simple rectangular patch without any slot is required to realize single band operation.

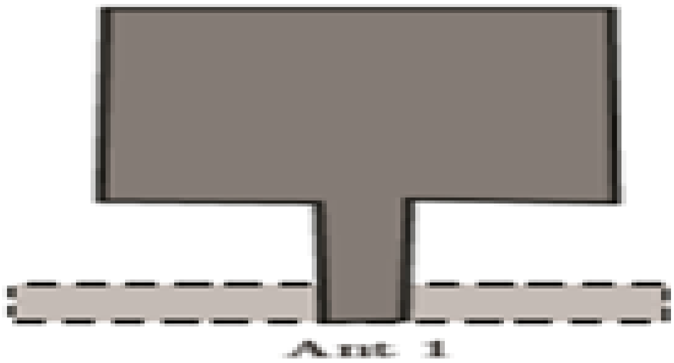

Figure 2: Design for single band

3.1.2 Design for Dual Band:

After introducing 2 L-shaped slots on either side of the line feed, double bands are realized.

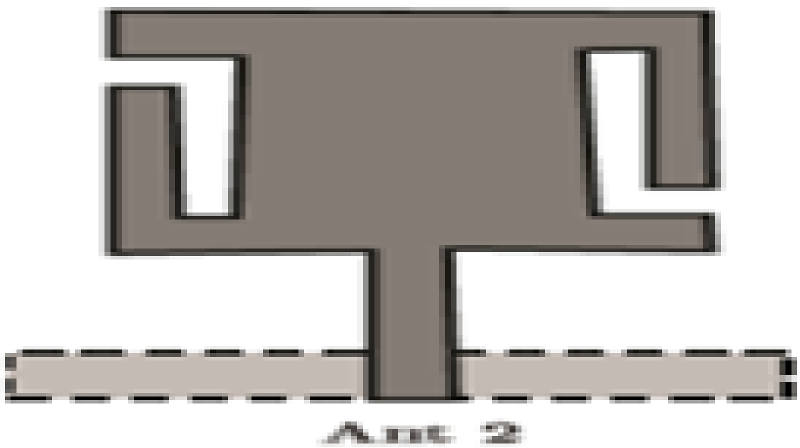

Figure 3: Design for dual band

3.1.3 Design for Triple Band (with Defected Ground):

When further slots are etched on either side of line feed, multiband operation is observed.

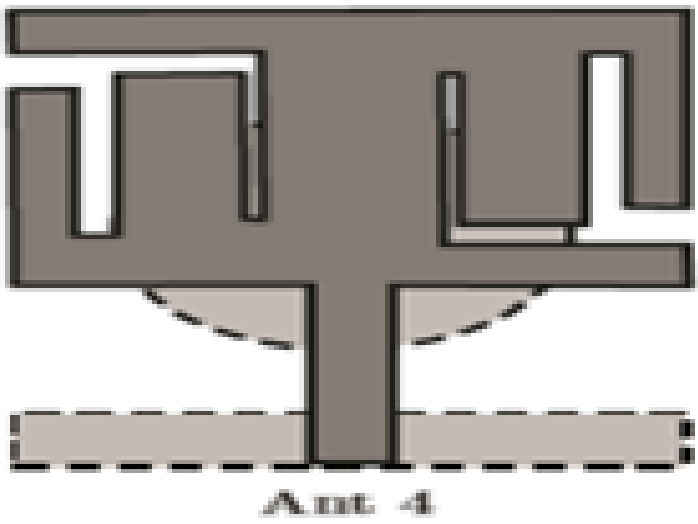

Figure 4: Design for triple band with defected ground

After this point fractal technique was introduced.

4. SOFTWARE RESULTS:

After implementing the design on HFSS and optimizing the parameters we have achieved certain results which will be discussed below.

4.1 HFSS Design:

4.1.1 Design for Single band:

We have selected very simple design which is easy to fabricate. Firstly we have made our design on HFSS software and achieved our desired results in single band. HFSS design is as shown below.

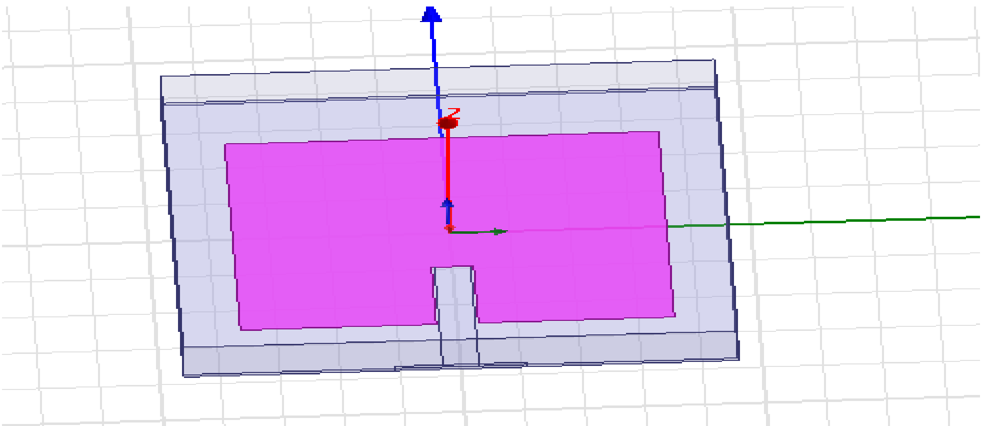

Figure 5: HFSS Design for single band

4.1.2 Design for dual band:

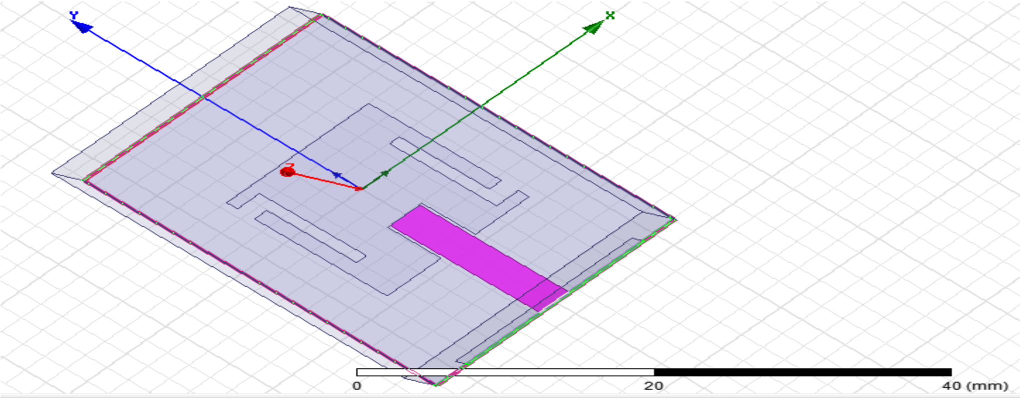

Figure6: HFSS Design for dual band

4.1.3 Design for Triple band with defected ground:

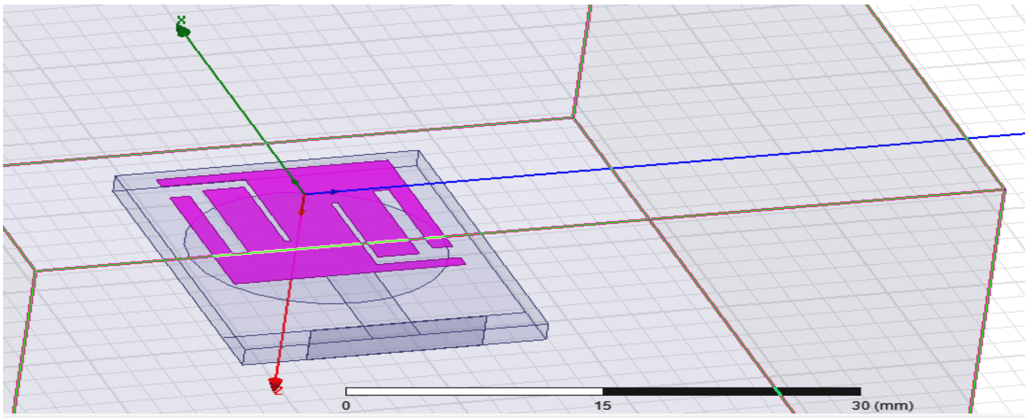

Figure7: HFSS Design for triple band with defected ground

4.1.4 Design for Triple band With Fractal patch (varying no. of iterations):

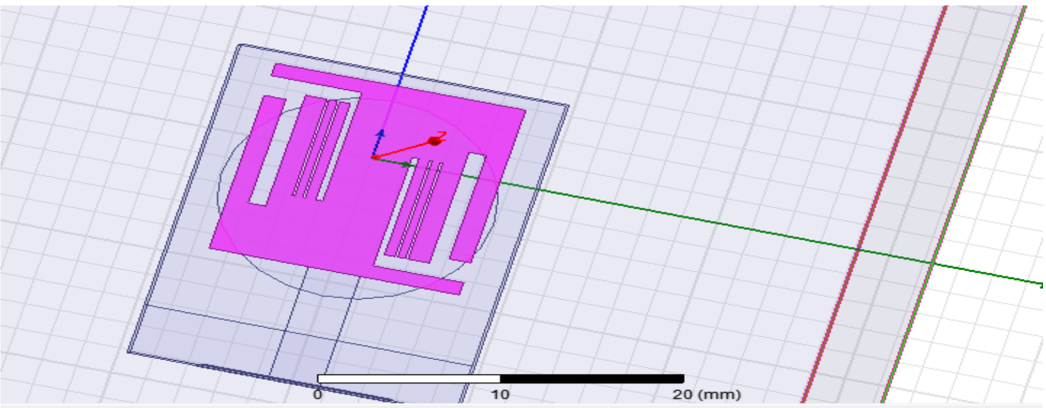

Figure8: HFSS Design for triple band (fractal patch)

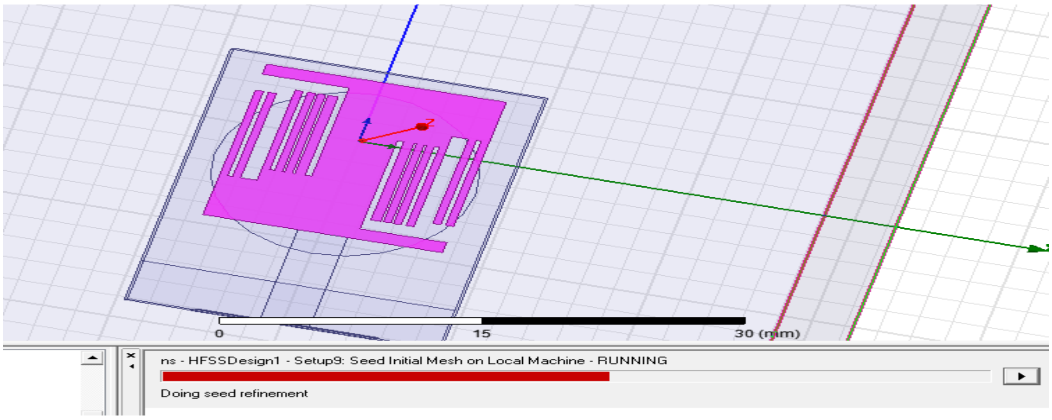

Figure9: HFSS Design for triple band (fractal patch)

4.1.5 Design of MIMO With Same Side Feed:

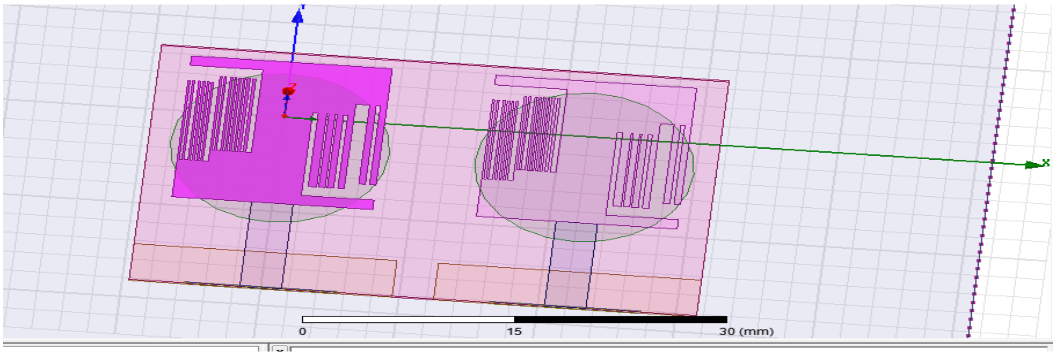

Figure10: HFSS Design of MIMO with same side feed

4.1.6 Design of MIMO with opposite Side Feed:

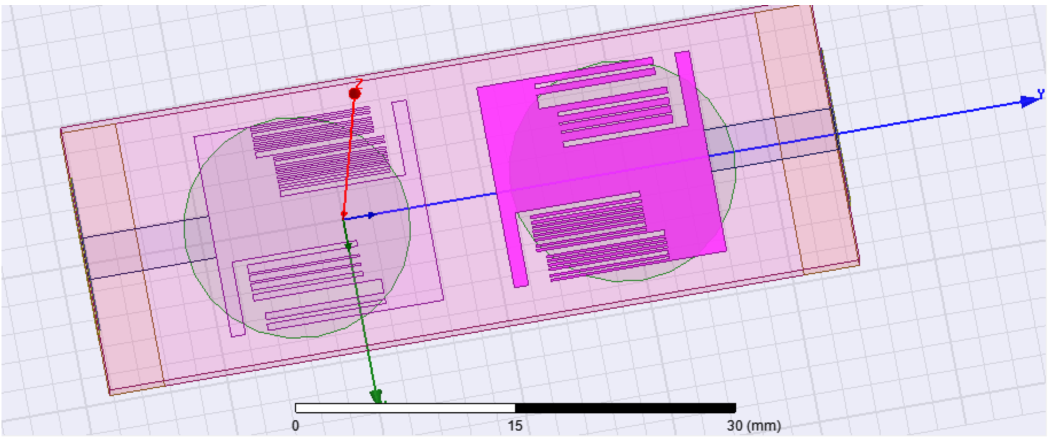

Figure11: HFSS Design of MIMO with opposite side feed

4.2 RESULTS:

4.2.1 Result of Single Band:

Single band result of return loss is as follows:

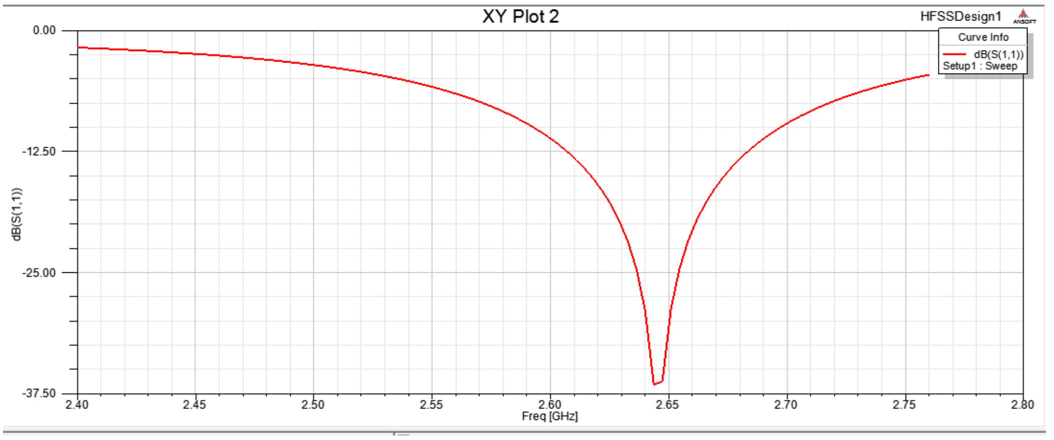

Figure12: S (1,1) Plot of single band

4.2.2 Result of Dual Band:

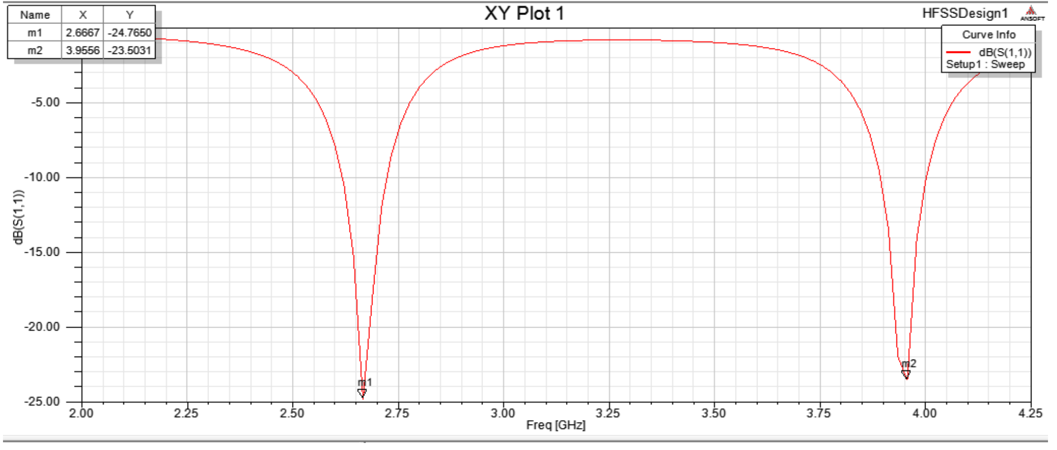

Figure 13: S(1,1) Plot of dual band

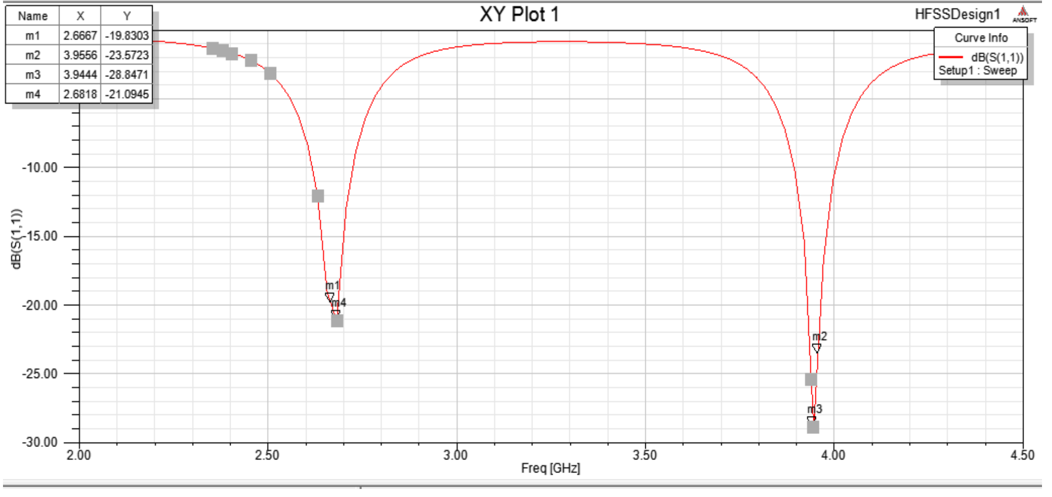

Figure 14: S(1,1) Plot of dual band

4.2.3 Results of Triple Band with Defected Ground:

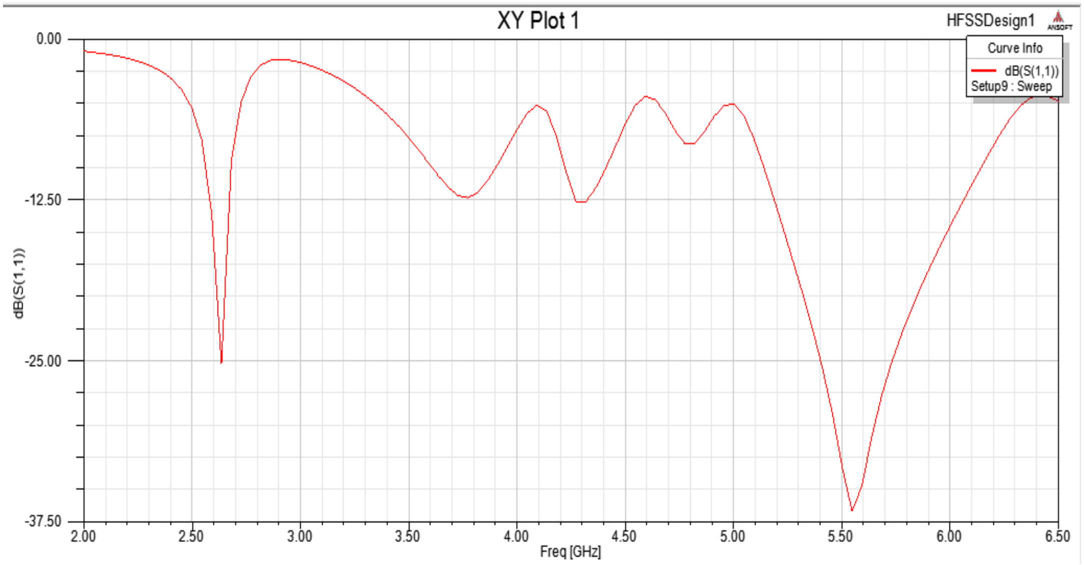

Figure15: S(1,1) Plot of triple band with defected ground

For the purpose of bandwidth enhancement stacking technique was employed whereby one antenna is stacked over the other, but as it results into an antenna that is more of a heavyweight so this goes against our design specifications so this proposal was dropped.

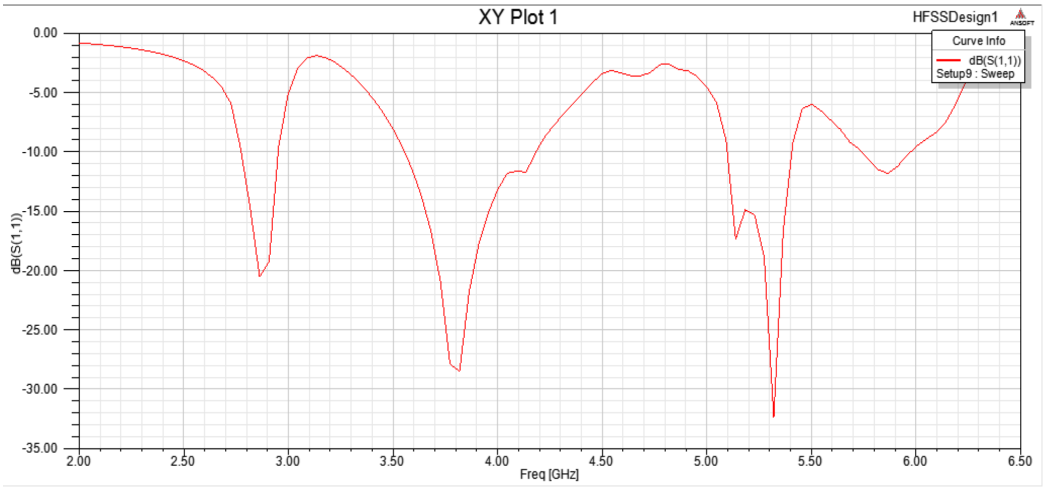

Figure 16: S(1,1) Plot of triple band with defected ground(stacked MSA)

4.2.4 Results of Triple Band (fractal patch):

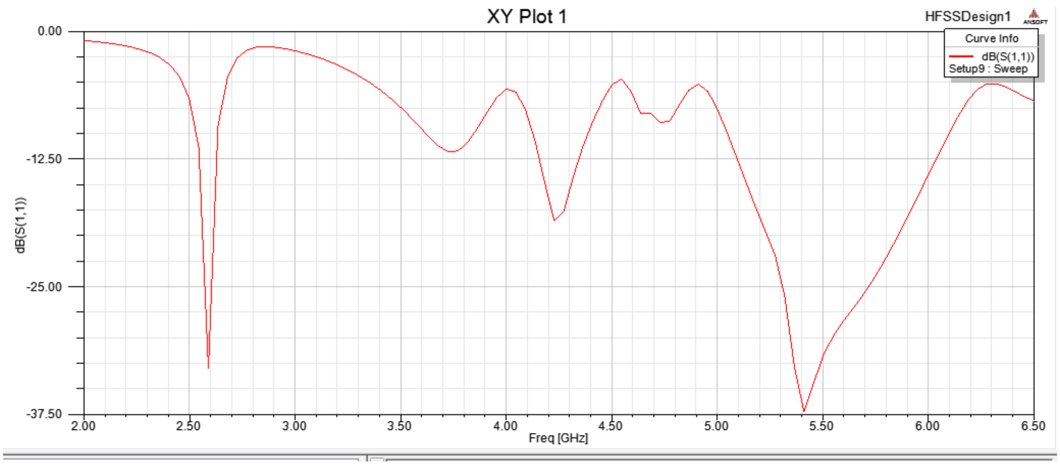

Figure 17: S(1,1) Plot of triple band(fractal patch)

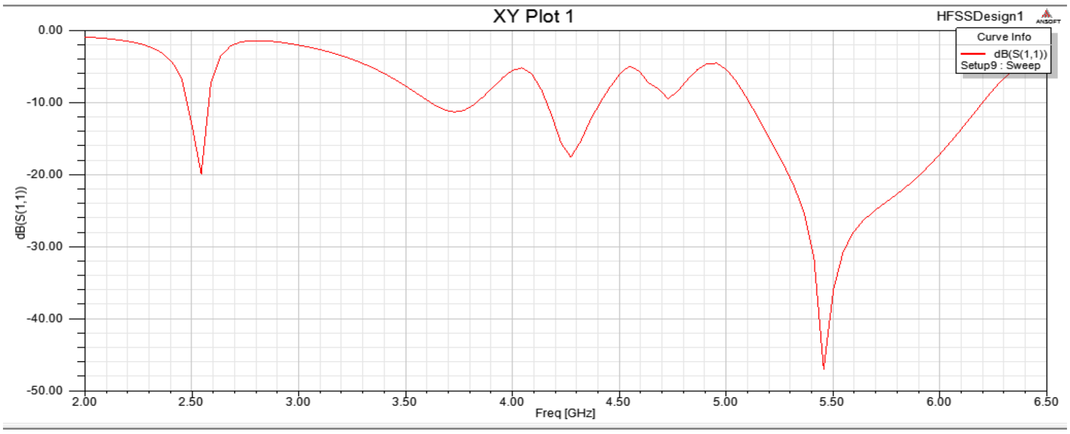

Figure 18: S(1,1) Plot of triple band(fractal patch)

4.2.5 Results of MIMO With Same Side Feed:

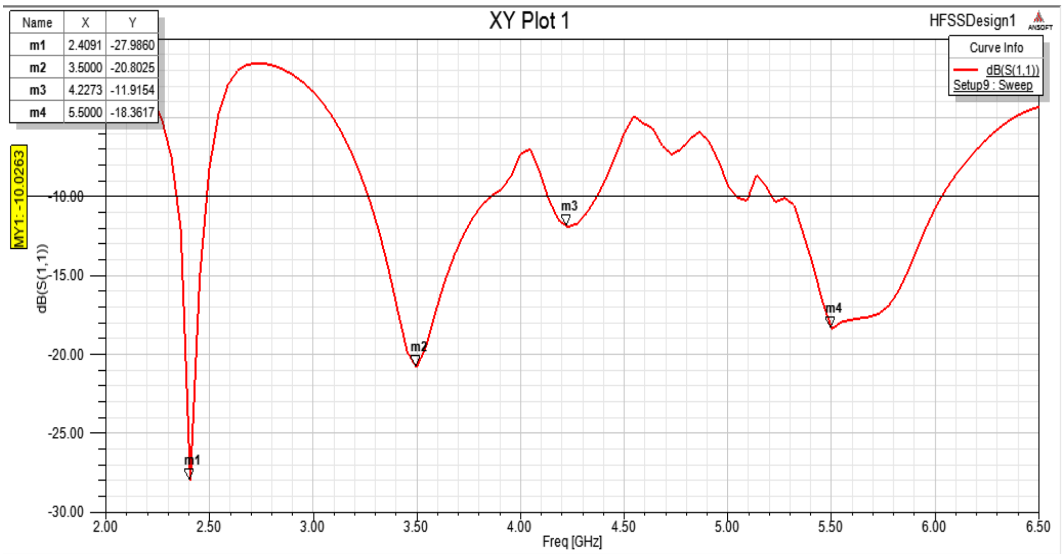

Figure 19: S(1,1) Plot of MIMO with same side feed

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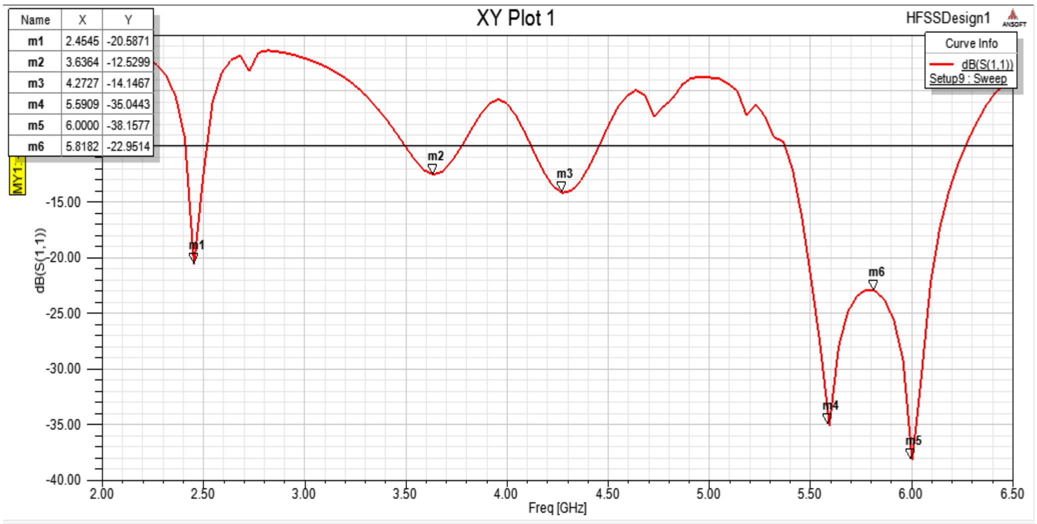

Figure 20:S(1,1) Plot of MIMO with same side feed

4.2.6 Results of MIMO With Opposite Side Feed:

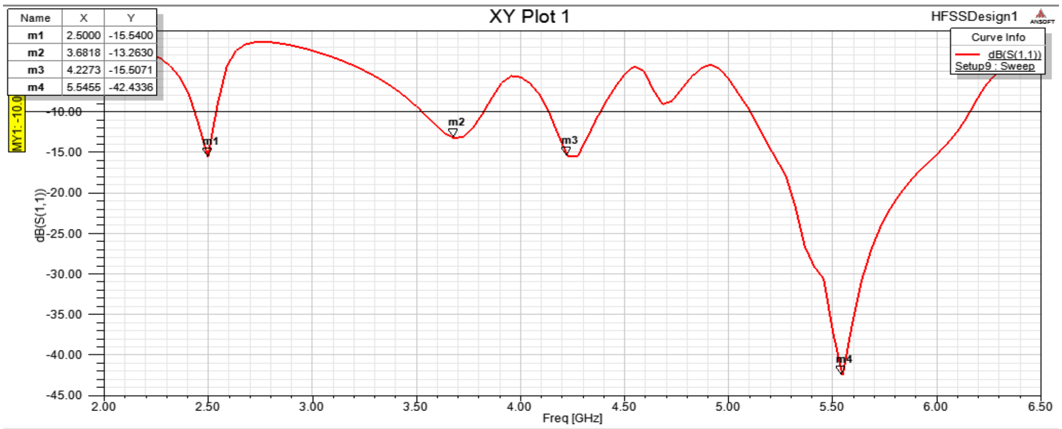

Figure 21: S(1,1) Plot of MIMO with opposite side feed

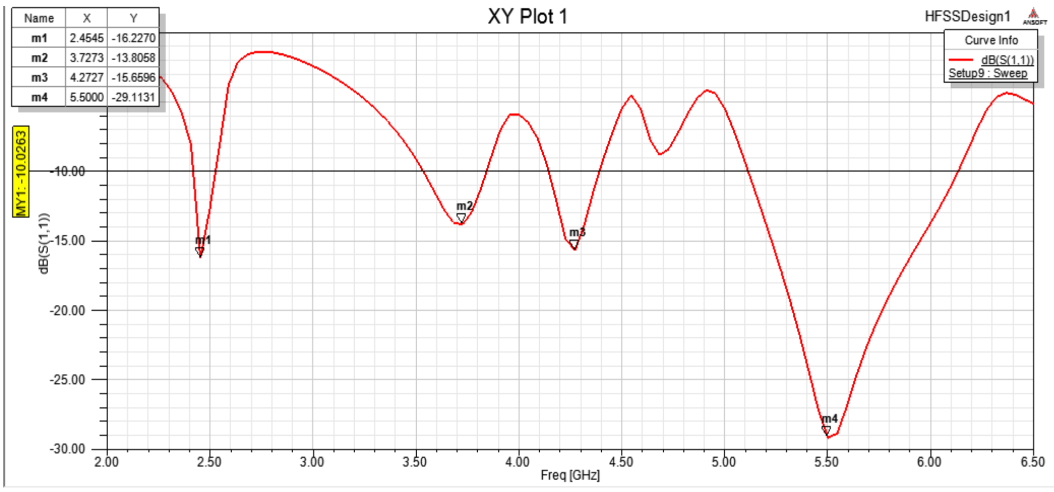

Figure 22: S(1,1) Plot of MIMO with opposite side feed

4.2.7 Results (isolation) of MIMO With same Side Feed:

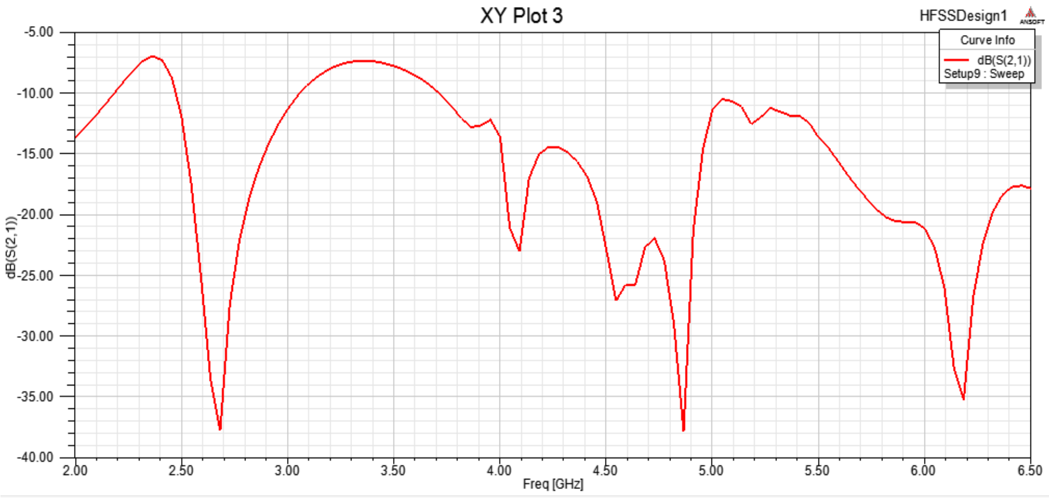

Figure 23: S(2,1) Plot of MIMO with same side feed

4.2.8 Results (isolation) of MIMO With same Side Feed:

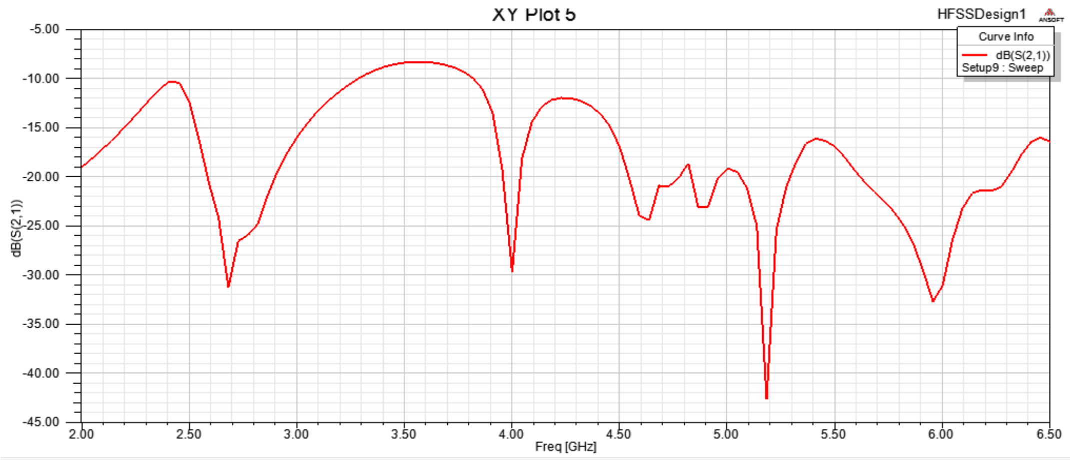

Figure 24: S(2,1) Plot of MIMO with same side feed

4.2.9 Results (isolation) of MIMO with Opposite Side Feed:

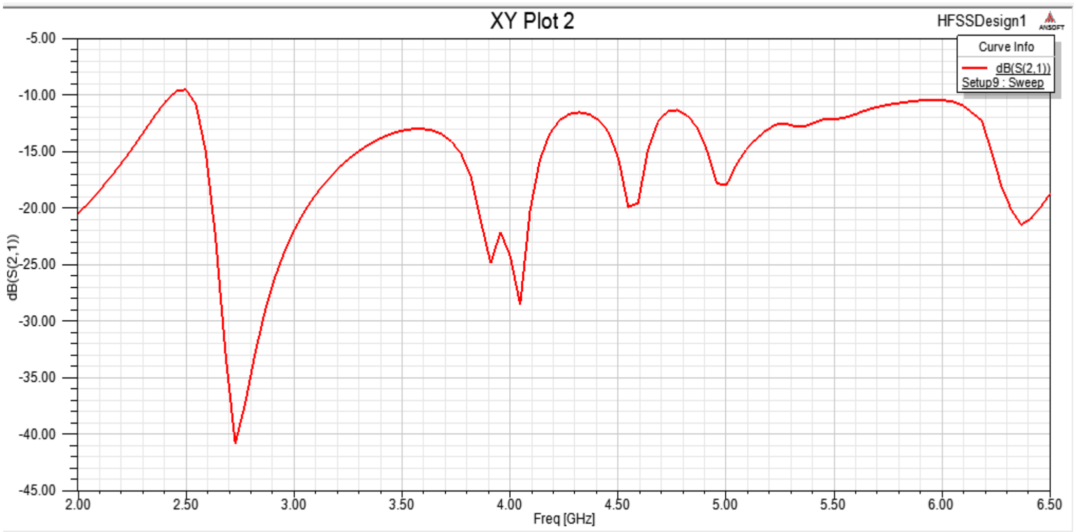

Figure 25: S(2,1) Plot of MIMO with opposite side feed

4.2.10 Results (isolation) of MIMO with Opposite Side Feed:

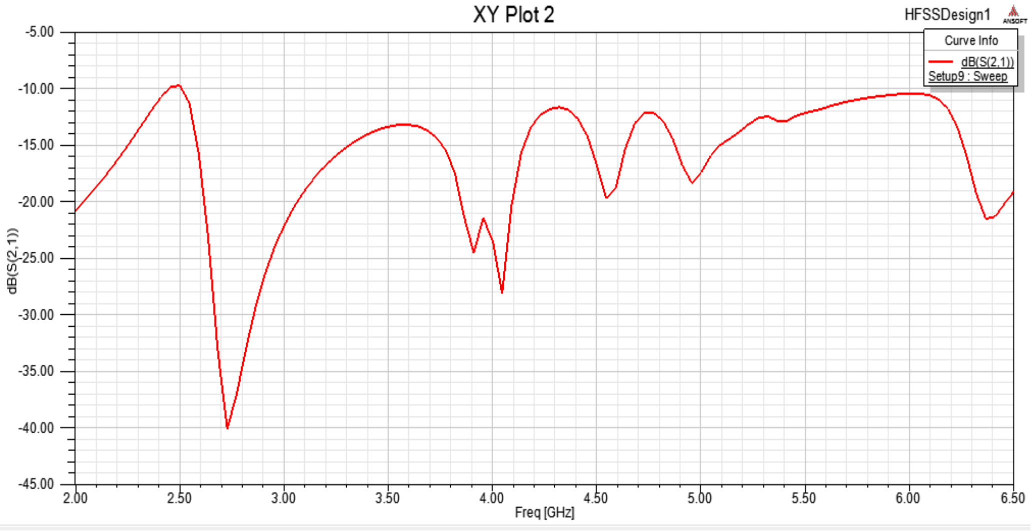

Figure 26: S(2,1) Plot of MIMO with opposite side feed

4.2.11 2-D radiation patterns:

Far field measurements show E&H fields (for single element antenna) as:

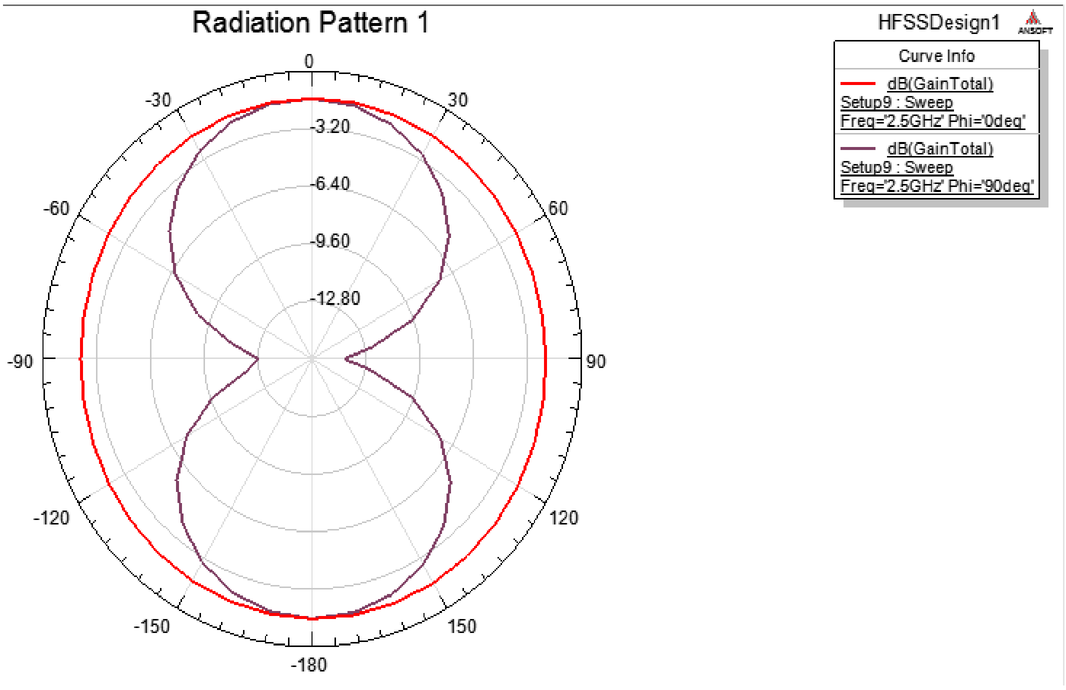

Figure 27: 2-D Radiation pattern (2.5 GHz)

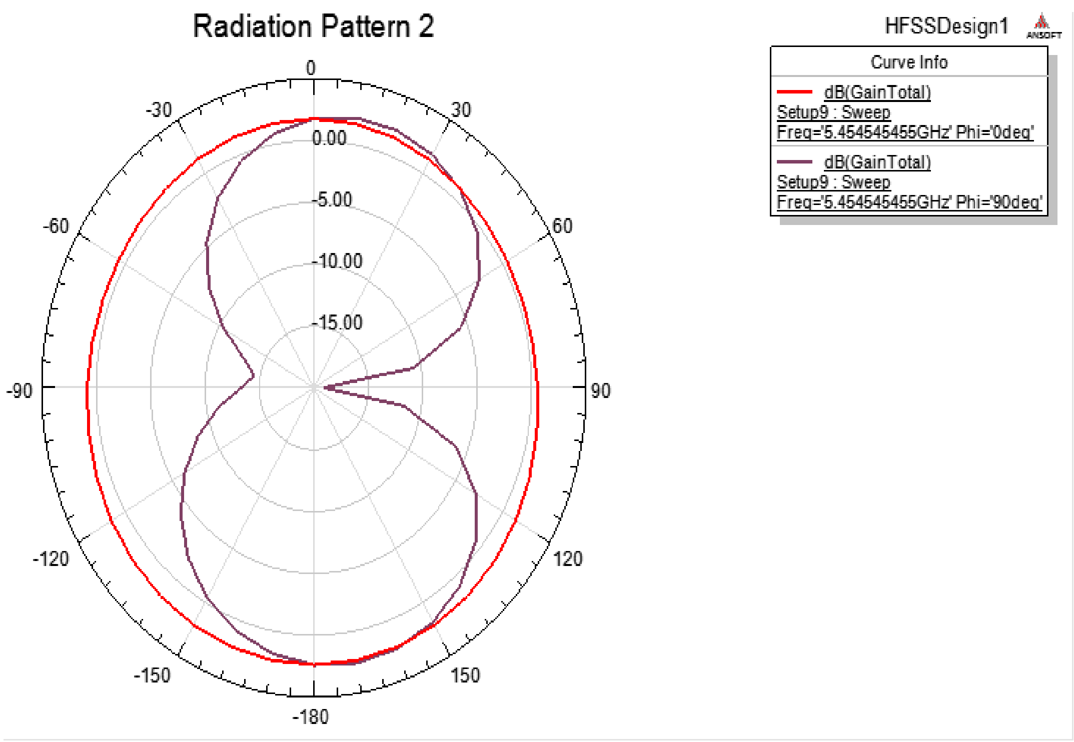

Figure 28: 2-D Radiation pattern (5.5GHz)

Now the same results for opposite side fed MIMO at 2.5GHz WIMAX frequency:

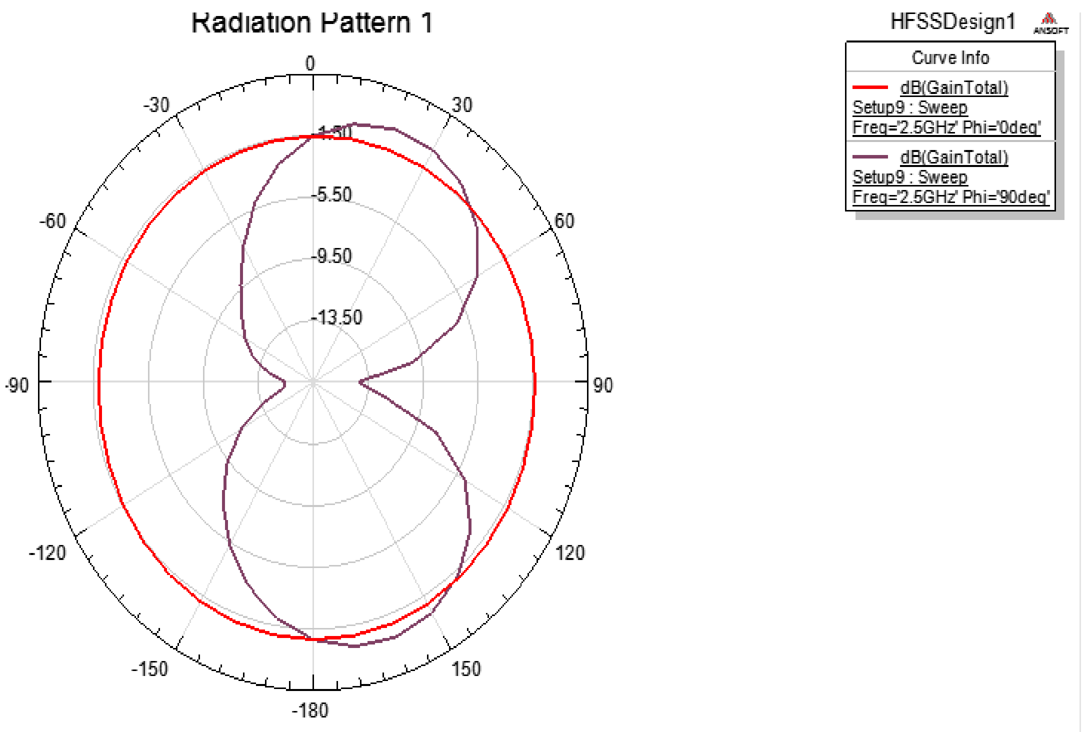

Figure 29: 2-D Radiation pattern (2.5GHz)

Other design for opposite side fed MIMO corresponds to the following radiation pattern:

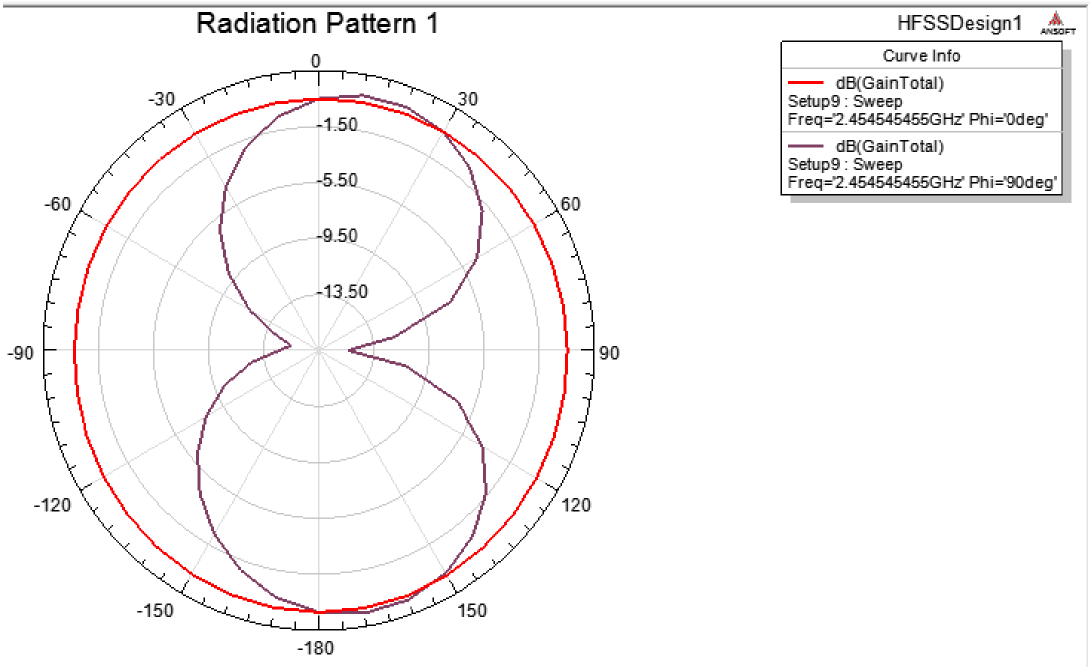

Figure 30: 2-D Radiation pattern (2.5 GHz)

2-D radiation patterns for same side fed MIMO run as under:

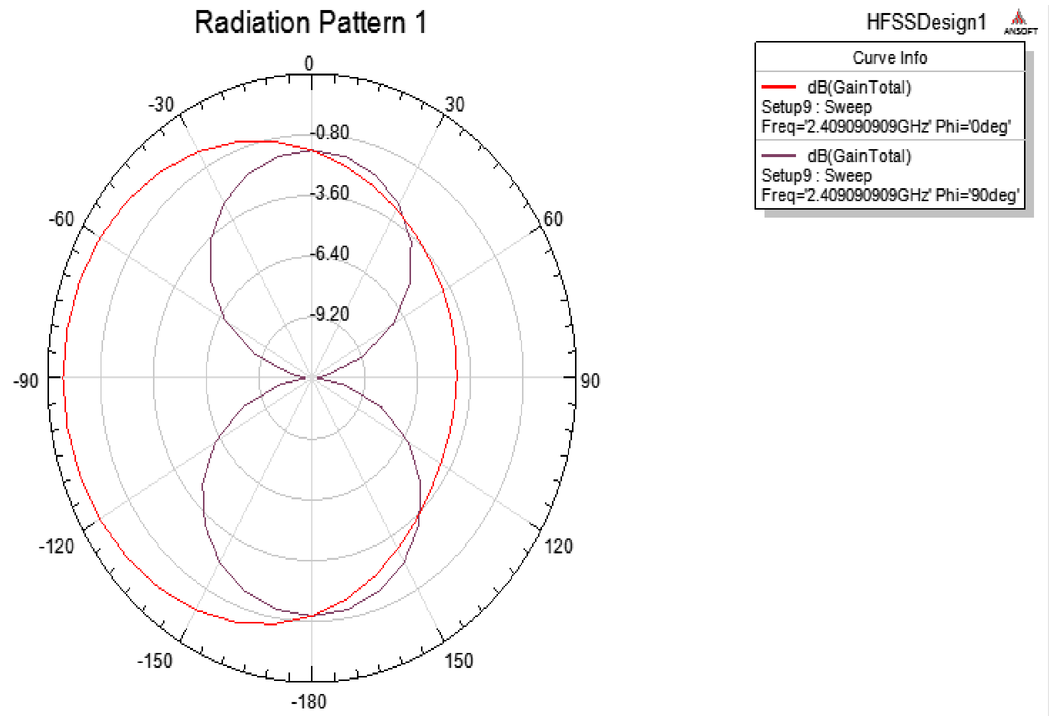

Figure 31: 2-D Radiation pattern (2.4GHz)

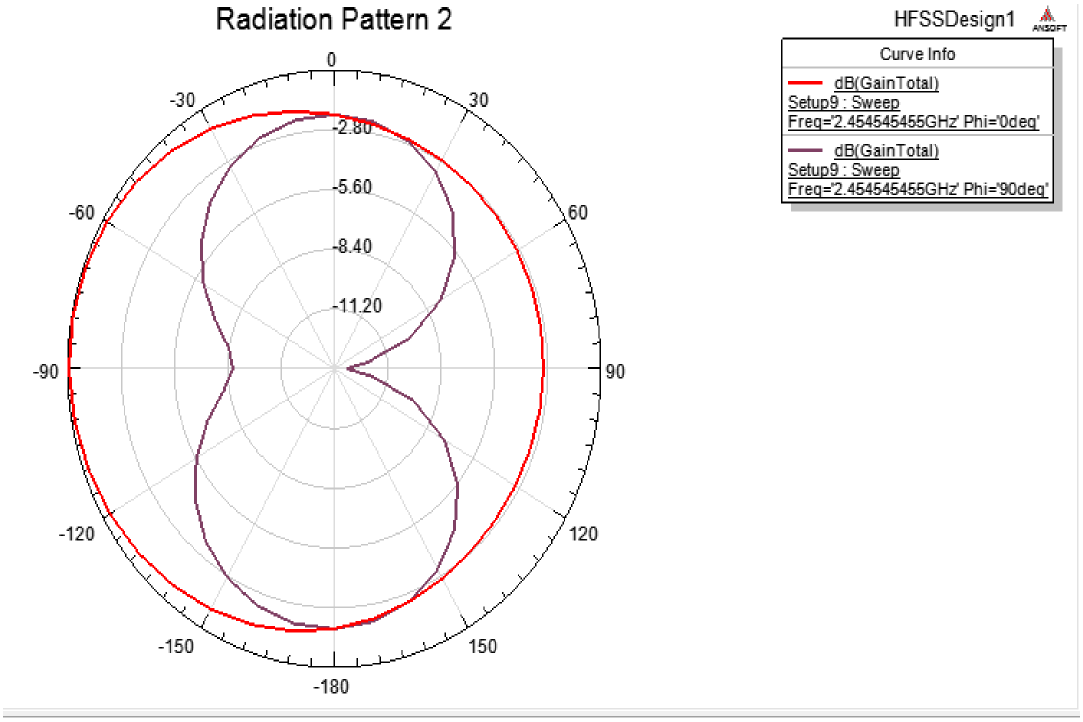

Figure 32: 2-D Radiation pattern (2.5GHz)

3-D polar plots representing the gain and direction of max radiation (here same as omnidirectional) of single element antenna run as under. Note that it is just the view of radiation pattern in 3-D (rest same as far field radiation pattern):

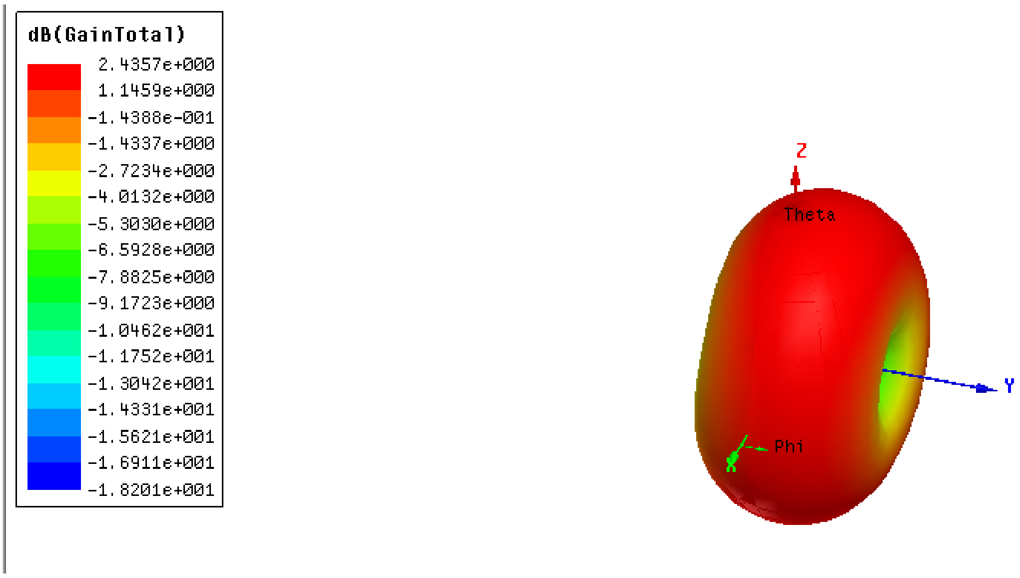

Figure33: Gain at 2.44 GHz (single element antenna)

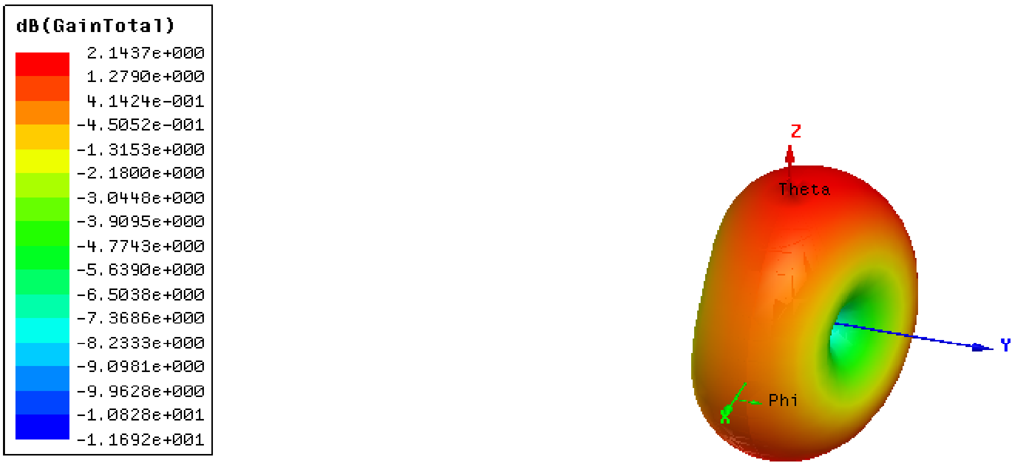

Figure 34: Gain at 4.23 GHz (single element antenna)

5. HARDWARE IMPLEMENTATION ANALYSIS AND RESULTS:

After achieving the simulated results antenna was fabricated from National Institute of Electronics (NIE) and results were tested in RF lab NIE as shown below:

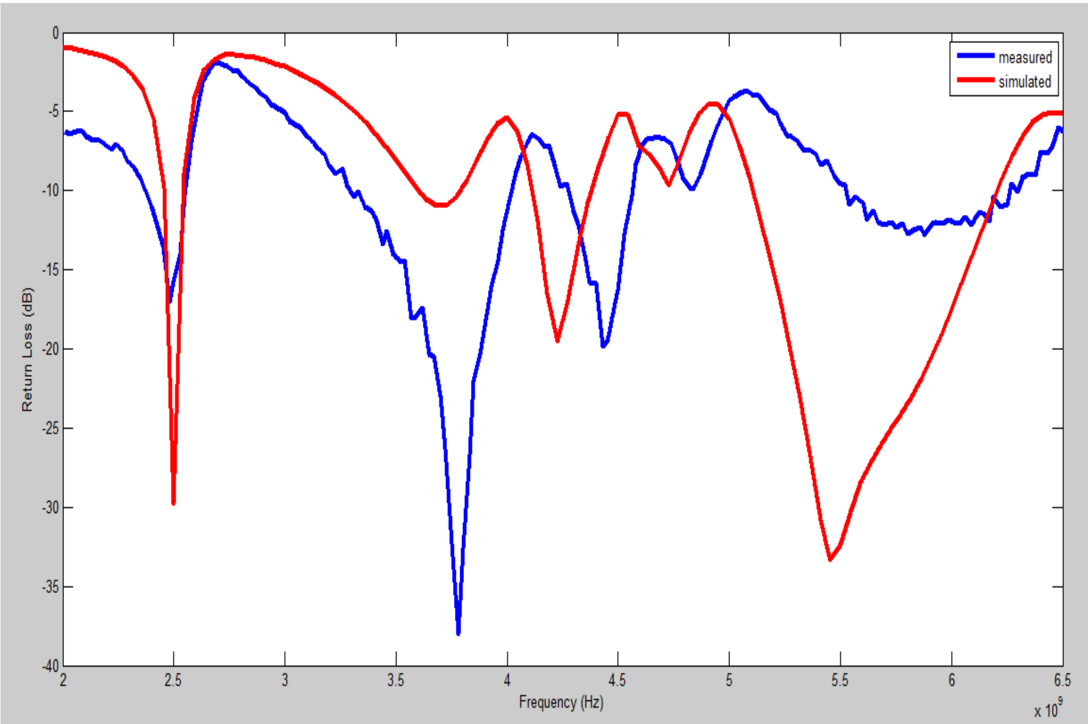

Figure 35: Comparison of simulated and measured results

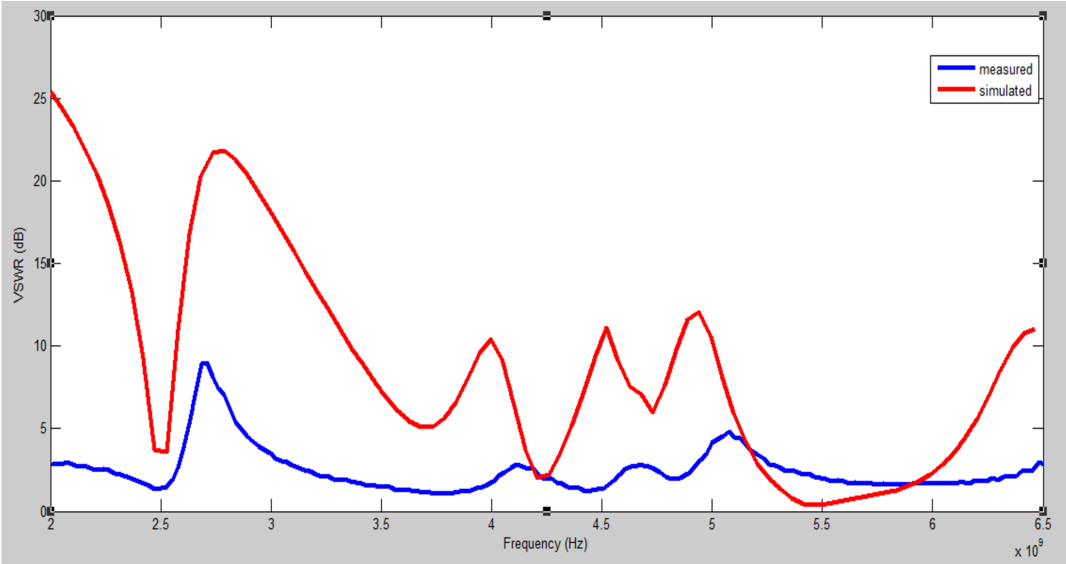

Figure 36: Comparison of simulated and measured results of VSWR

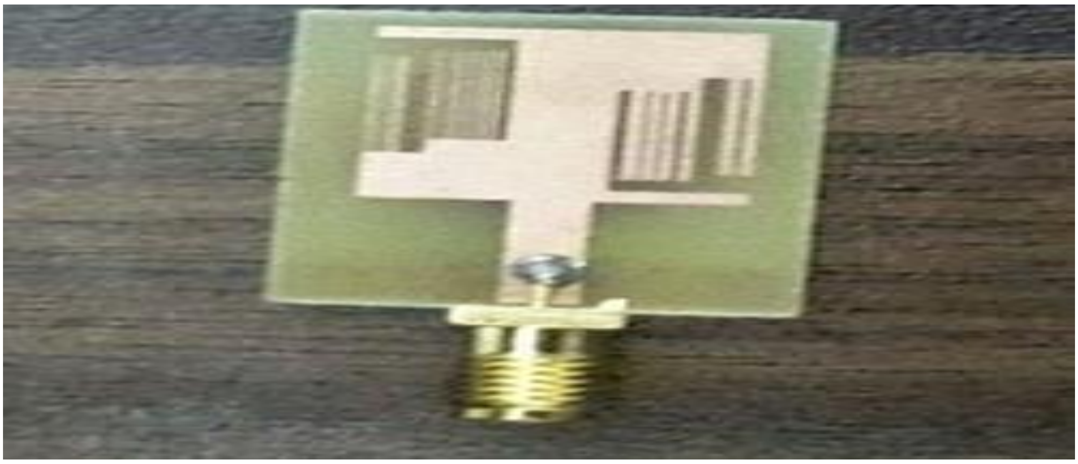

Figure 37: fabricated antenna (front view)

Figure 38: fabricated antenna (back view)

6. DIVERSITY PERFORMANCE:

We converted our single element antenna into a 2x2 planar MIMO antenna for suppressing the demerits of conventional wireless communication system as discussed before.

The higher data rates and improved spectral efficiency are achieved by the use of MIMO antennas. MIMO antennas offer a momentous increase in data throughput and link range without additional bandwidth and transmitter power. So Multiple Input Multiple Input antennas are the new research area for the communication engineers.

Efficient MIMO system is characterized by spatial diversity and channel independence. The spatial diversity and channel independence is achieved by reducing the mutual coupling between elements of antenna. Correlation coefficient is very important parameter to check diversity performance. ECC is calculated using either the radiation patterns or by using the S- parameters as per the method presented.

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

In this paper we used s-parameters to calculate ECC by using equation (1). For practical application ECC value less than 0.5 is acceptable for mobile phones. Fig. 9 shows measured ECC is less than 0.36 over complete operating frequency band, which is all right for mobile phones.

6.1 Designs of MIMO (OPPOSITELY FED):

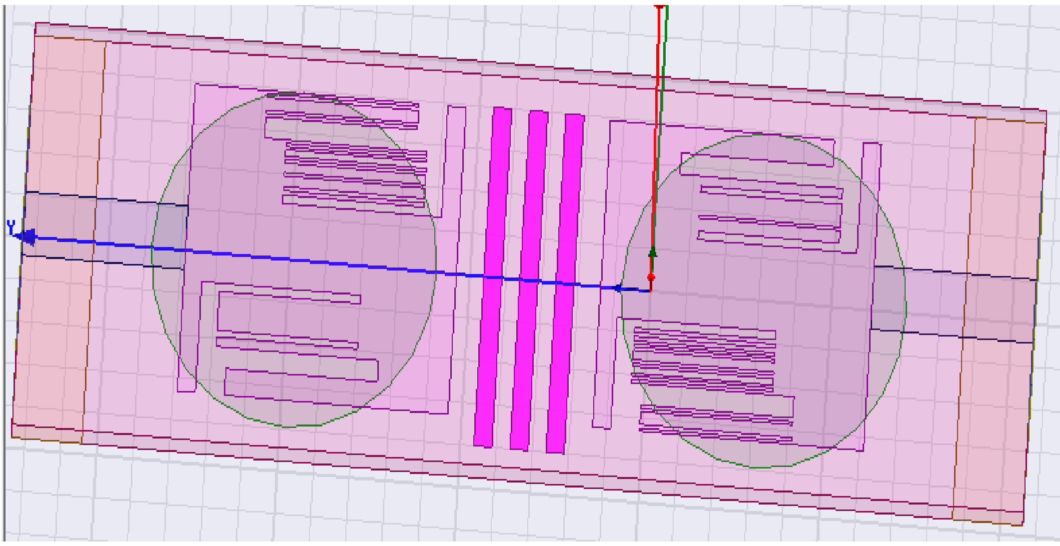

Figure 39: oppositely fed MIMO design 1

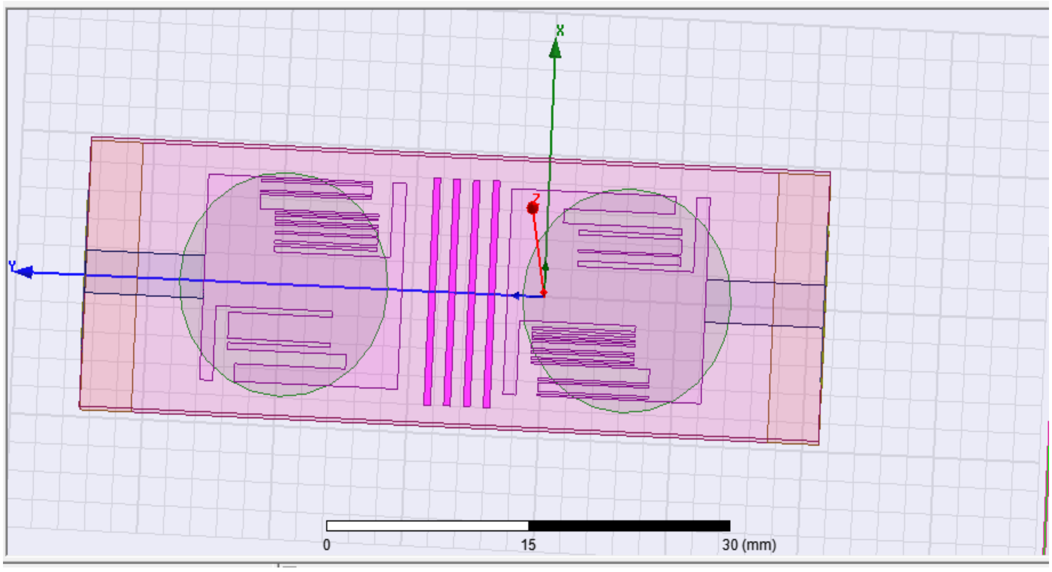

Figure 40: oppositely fed MIMO design 2

6.2 Designs of MIMO (same side fed):

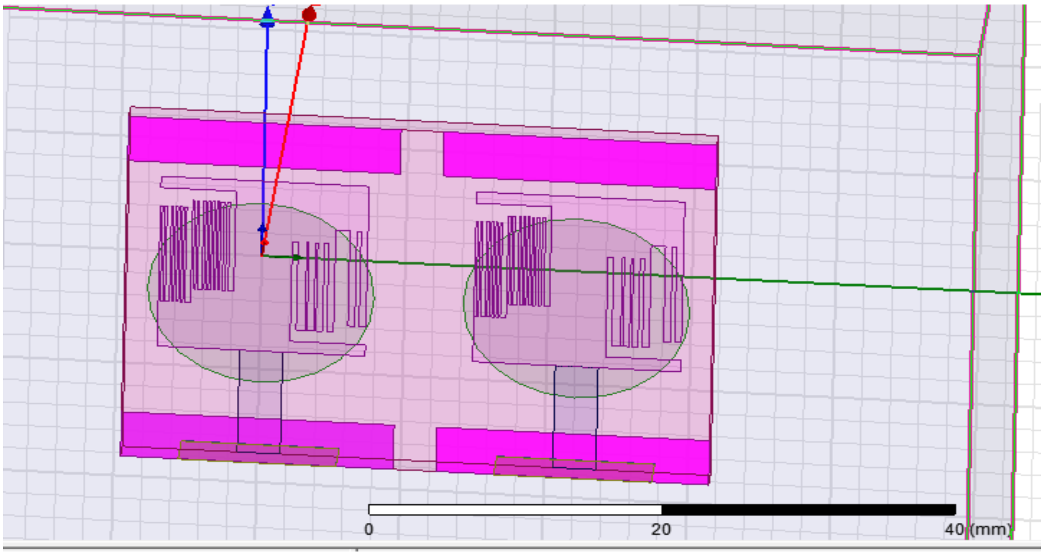

Figure 41: same side fed MIMO design 1

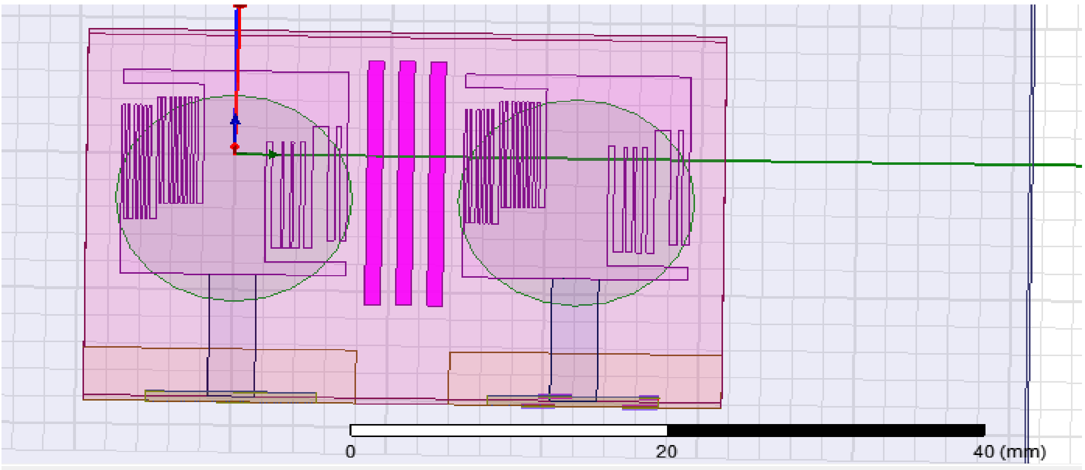

Figure 42: same side fed MIMO design 2

6.3 To improve isolation:

When multiple antennas are brought close to each other, between the multiple signals correlation can be reduced by using MIMO antenna. High mutual coupling resulted in correlation coefficients which affect the transmission capacity of MIMO systems. By increase the distance between adjacent elements of antenna, different methods have been proposed to increase isolation among the elements. In general two theoretical solutions are available for the mutual coupling reduction in MIMO antennas:

By field cancellation and using Electronic Band gap Structure.

Many EBG structures are proposed for different application as interface minimization within multilayer PCB, bandwidth and gain enhancement of patch antenna, mutual coupling reduction etcetera. Other reported techniques in literature include the introduction of the decoupling structures, modifications in the ground plane, lumped component filters, neutralization strips, introduction of resonating structures near the antennas, antenna orientation and the use of metamaterials.

In our case mutual coupling could've been mitigated using increasing the distance method but it results into an overall bigger antenna size so we modified the ground plane and introduced rectangular structures that prevent the coupling of electromagnetic energy from one antenna element to another.

This figure depicts clearly the isolation between the antenna elements:

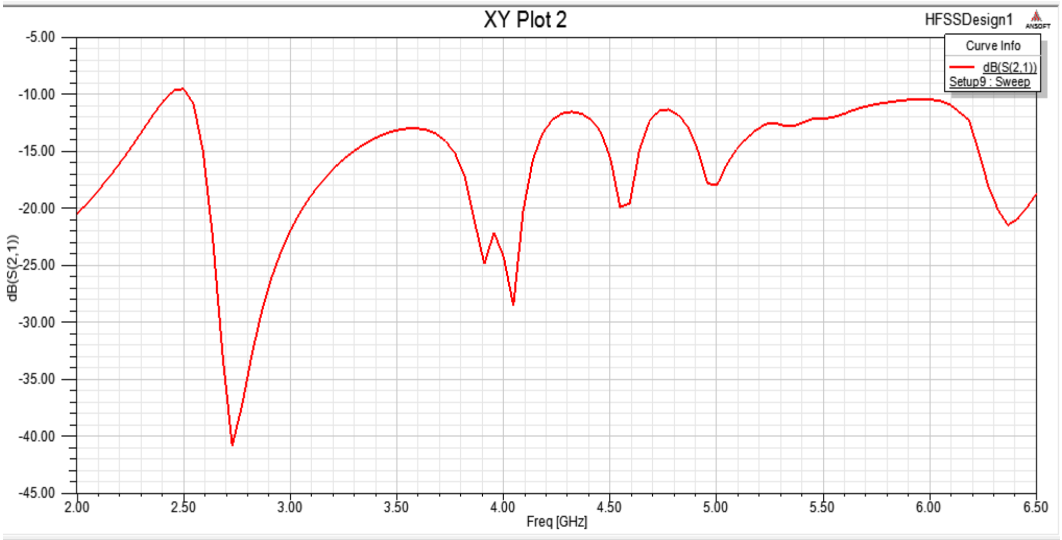

Figure 43: isolation depiction

7. APPLICATIONS:

Wireless and mobile networks are used in multiple areas such as studies, travelling to recover from natural hazard etc.

A wireless LAN (WLAN) is type of communication that is the extension of a wired LAN. The electromagnetic waves transmit and receive data in the air, by reducing wired connection.
Wireless local area network (WLAN) and worldwide interoperability for microwave access (WIMAX) technologies are used in tablets and mobile phones for internet. The WLAN operates at data rates up to 2 Mbps in Wi-Fi frequency. The aim of this standard was to perform the work of wired Ethernet.

802.11g is having best features of 802.11a, b. It will use OFDM as modulation technique in physical layer and operate in 2.4GHz. The standard shows the requirement of one Medium Access Control (MAC) layer and three physical layers: Frequency Hopping, Direct Sequence and diffused infrared. Two standards of operation, a distributed mode (CSMA/CA), and a coordinated mode present in MAC.

This WLAN/WIMAX module is used in these environments. The module is capable of operating at multiple frequency bands. Due to the attractive features, such as simple feeding, easy-to-integrate, the microstrip patch antennas are mostly used in these devices.

In this project, a compact F-shaped planar antenna is designed for wireless communication that can help the multi-band WLAN/WiMAX applications.

8. FUTURE WORK:

Since antenna is operating on WLAN/WIMAX frequencies simultaneously including C-band as novelty for satellite communication. By applying different more accurate techniques available in the literature, size of the antenna can be considerably reduced whereas to affect gain we can convert it into 4X4 MIMO. Yes, there is a space for improvement available as regards to the form of reducing mutual coupling and methods of improving isolation besides those.

We can check for the effectiveness of electronic band gap structure for isolation.

9. CONCLUSION:

Our paper shows a small, planar multi-band patch antenna for WLAN, WIMAX and C-band applications. The idea of size reduction by using fractal geometry and Impedance matching by using defected ground plane have been illustrated. The antenna consists of two F-shaped fractal slots that are etched on either sides of the line feed and a defected ground plane. It is therefore compact in size (19×25 mm^2 (0.152 λ_0 ×0.2λ_0)) and simplicity of structure it becomes a strong candidate for small wireless devices used in telecommunication systems. The maximum return loss of −27.54 dB, −11.356dB and −19.3dB and -41.4 dB is obtained for the four resonant modes. The measured bandwidths for 10 dB return loss are from

2.4495 to 2.5476 GHz (98.1MHz covering the 2.5GHz WIMAX),

3.5758 to 3.8234 GHz (237.6MHz covering WIMAX band from 3.15GHz-3.85GHz),

4.1028 to 4.3921 GHz (289.3MHz for C-band applications especially weather radar& satellite communications),

5.0896 to 6.1797 GHz (1090.1 MHz covering the WLAN from 5.2GHz to 5.8 GHz & 5.5 GHz WIMAX with center frequencies 2.5GHz,3.69GHz,4.25GHz and 5.65GHz respectively, effectively covering 2 – 6.2 GHz frequency range(S&C-bands).

Accessing the internet by simultaneously using WLAN&WIMAX standards and getting the satellite and mobile services have been the hallmarks of this design.

To validate the proposed design, an experimental prototype has been designed on PCB and results measured. Good agreement between measured and software results has been found.

PROJECT SYNOPSIS

Extended Title: Design of Novel Multi-Band Antenna for WLAN/WiMAX and C-band Applications.
Brief Description of The Project / Thesis with Salient Specifications: Small, multi-band microstrip antenna for WLAN/WiMAX applications is designed. The suggested antenna comprises of F-shaped slot radiators and a ground plane. Since just two F-shaped slots are etched on either sides of the radiator for multi-band operation, the radiator is very compact in size and structurally very simple. To validate the proposed design, we shall fabricate the experimental prototype and test it.
Scope of Work: The work done will be able to cater the demand of ever growing wireless communications industry. The designed multiband antenna can be used in devices operating on multiple bands for communication. Also the compactness of antenna will allow it to fit in majority of the existing devices.
Academic Objectives : We will see how by changing certain parameters of antenna like the dimensions we can achieve enhanced bandwidth reducing size improved gain(by employing impedance matching_ conjugate) Decreased return loss. Whereby our antenna will be simultaneously operating over WLAN and WiMAX frequency bands.
Application / End Goal Objectives : The goal is to combine WLAN and WiMAX communication standards together into a single device by designing a single antenna that can excite triple-band operation.
Previous Work Done on The Subject : We have used HFSS for implementing horn, monopole, dipole antennae, circular and Rectangular Waveguides etc
Material Resources Required: Ansoft HFSS

Tools for fabricating the antenna VNA and anechoic chamber to check our results
No of Students Required :4 **Group Members:** CSUO Ahmed Abdullah(Gp Ldr) Sgt Hassan Murtaza GC Muneeb-ur-Rehman GC Qamar Zamir
Special Skills Required: Antenna Design and its improvement as far as size reduction and bandwidth enhancement is concerned.

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