MINIATURIZED TRIPLE-BAND MICROSTRIP ANTENNA FOR 5G WIRELESS APPLICATIONS

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ABSTRACT

MINIATURIZED TRIPLE-BAND MICROSTRIP ANTENNA FOR 5G WIRELESS APPLICATIONS

With the invention of new technologies and rapid advancement in the field of wireless applications, there is an increased demand of wireless module capable of handling higher data rates. With the evolution of 5G technology, there comes many designs of antennas that supported this revolutionary wireless transmission/ reception technology. With more advancement in this field and innovative smart gadgets, integration of these wireless modules in to new-age advance gadgets became a problem. Due to the size constraint of these devices and demand of high data rates for 5G, new space for research and development emerges. An effort has been made in this paper to present a Microstrip Antenna For 5G Wireless Applications which works on Triple-Band and Miniaturized in size to meet the size constraint of modern age devices. The developed Antenna design consists of a diamond shape microstrip path that operates within 4.1 GHz to 8.1 GHz giving a triple band operation. Two thin rectangular slots are introduced at the bottom to support desired polarization. This helps in reducing axial ratio of the developed design. To improve the design slotted ground design has been introduced which support the antenna to radiate at 3 different frequencies. Antenna delivers an average high gain of **9 dBi** and return loss of **-17 dB**. Results of simulations in **HFSS** software and that of measured on **VNA Network Analyzer** in Communication laboratory **NIE** Islamabad depicts that this antenna is suitable for use in Wireless Transmission applications for 5G.

ENDORSEMENT OF CORRECTNESS AND APPROVAL

It is affirmed that data presented in this thesis "**MINIATURIZED TRIPLE-BAND MICROSTRIP ANTENNA FOR 5G WIRELESS APPLICATIONS**" carried out by 1) Maj. Muhammad Bilal Khan Khaleel 2) Maj. Muhammad Saqib 3) Capt. Saim Bajwa 4) Capt. Junaid Fareed under the direction of Asst. Prof. Dr. Zeeshan is in complete satisfaction of our level of Bachelor of Telecommunication Engineering, is right and endorsed. Percentage of plagiarism found in document as per software Turnitin available on LMS NUST comes out to be ____

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DECLARATION

We hereby declare that no content and variety of work bestowed during this thesis has been submitted in support of another award of qualification or degree either during this course or anyplace else.

DEDICATION

This proposition is devoted in thanks to **ALLAH ALMIGHTY,** our Creator, who has blessed us with wisdom, knowledge and understanding, then to our parents for their direction and their endless support. I would also like to thank our faculty for their guidance and supervision. Without their help and supervision this project would not have been made possible.

ACKNOWLEDGEMENT

The accomplishment of this project would not have been possible without the contribution of different people the names of which cannot be reckoned with. Their assistances are sincerely respected and thankfully recognized. I would like to thank **Allah Almighty** who is the most Powerful and Merciful and everything is in His obedience, **Asst. Prof. Dr. Zeeshan Zahid** and **Lec. Maryam Rasool** for their support and guidance during the entire project and all the relatives and friends.

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ABBREVIATIONS

1.	**dBi**	>	DECIBELS RELATIVE TO ISOTROPIC
2.	**WT**	>	WIRELESS TRANSMISSION
3.	**IOT**	>	THE INTERNET OF THINGS
4.	**NIE**	>	NATIONAL INSTITUTE OF ELECTRONICS
5.	**HFSS**	>	HIGH-FREQUENCY STRUCTURE SIMULATOR
6.	**IEEE**	>	INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS
7.	**CP**	>	CIRCULARLY POLARIZED
8.	**mm**	>	MILLI METER
9.	**mm Wave**	>	MILLIMETER WAVE
10.	**dB**	>	DECIBEL
11.	**BW**	>	BANDWIDTH
12.	**TX**	>	TRANSMITTING
13.	**RX**	>	RECEPTION
14.	**PCB**	>	PRINTED CIRCUIT BOARD
15.	**EM**	>	ELECTRO MAGNETIC
16.	**BW**	>	BANDWIDTH
17.	**R&D**	>	RESEARCH AND DEPELOPMENT

CHAPTER 1

1. INTRODUCTION

Antenna is an apparatus or a device, which consists of mostly metallic conductors that provides an interface between electromagnetic waves, propagating in to the space and the current moving through metallic conductors. During transmission, Antenna converts the current applied through its terminals and moving through conductors into the electromagnetic waves and upon reception, process converts the electromagnetic waves in contact with antenna into to electric current and directs it towards its terminals.

The type of Antenna which is fabricated using microstrip techniques on a PCB is known as Microstrip Antenna. Such Antennas are also known as Printed Antennas (because it is printed on PCB). In most cases, these are compatible with microwave frequencies. A common type of Microstrip Antenna is Microstrip Patch Antenna. These Antennas are widely used in wireless technologies for being relatively inexpensive and simple to design and fabricate. Simulation of such Antennas is simpler as compared to other complex techniques. They support wide range of frequencies and can be of any shape. Most commonly used are Circular Patch, Triangular Patch, Rectangular Patch and Diamond shape Patch.

1.1 PROJECT OVERVIEW

In this developed design, "**Diamond shaped Microstrip Antenna Patch Antenna for Triple band operation and 5G applications"** is used. Project includes design and fabrication of microstrip patch antenna with modified ground containing slots at the front and back.

Why Diamond shaped Microstrip Patch?

To make antenna resonate at targeted frequencies with triple band operation, a diamond shape Patch is inserted at the top of the antenna. This provides antenna with better result as compared to circular patch and square /polygon patch.

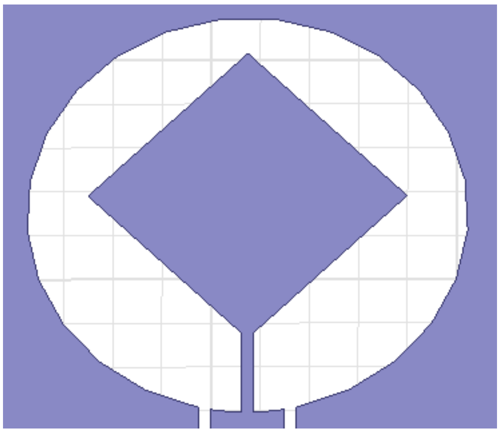

Figure 1: MICROSTRIP DIAMOND PATCH

Why Slotted Ground?

The Modified ground half of which is conductor backed and half having slots, helps the developed design with improved gain and better S11 plot. It also supports the triple band operation of the antenna. This provide antenna with low radiation and dispersion loss.

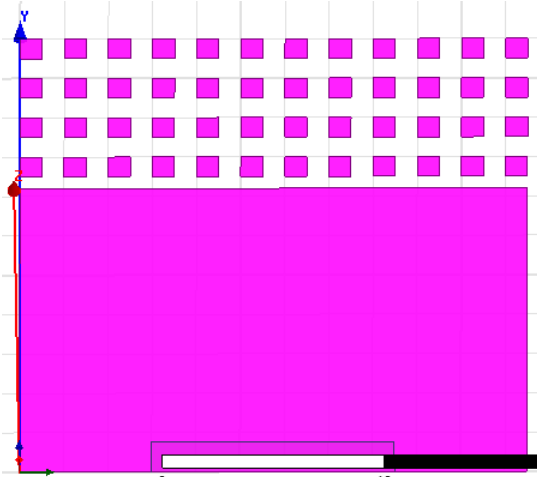

Figure 2: ANTENNNA GROUND

1.2 PROBLEM STATEMENT

1. Proposing a compact antenna design for 5G applications which allows it to function in frequency with its range from 4.1 GHz to 8.1 GHz with following characteristics:
   a. Miniaturized size
   b. Low-cost
   c. Ease of fabrication
   d. Ease of integration for multi-band operation

1.3 APPROACH

1. Design a simple Microstrip patch antenna
2. Achieve CP through induction of slots in the developed design
3. Achieve Triple band operation with introduction of diamond path and slotted ground
4. Enhance gain by changing dimensions of design
5. Discover dimensions and shape of Patch with best possible results

6. Fabrication
7. Test the hardware

1.4 OBJECTIVES

Objectives of our work in the order of priority are as follows:

1. To design Miniaturized Triple-Band Microstrip Antenna For 5G Wireless applications
2. To reduce the surface wave losses
3. Reduced Return Loss
4. To reduce effect of high radiation (at the feed)
5. Improved gain
6. Good radiation pattern
7. To perform and analyze the results using High Frequency Structure Simulator software (HFSS)
8. To analyze performance of the designed antenna and fabricate the structure of the antenna

1.5 ORGANIZATION

We introduce the main details of our work in the start of this document which included **Microstrip patch, Modified Ground with slots, Triple-band operation**. After brief introduction problem statement is given, brief introduction of approach we followed for our work, the scope of our work followed by the objectives & limitations of developed design. In literature review we define several resources we read online as part of our extensive research in form of papers and books. This enhanced our knowledge about antenna basic parameters. Results of simulations in **HFSS** software and that of measured on **VNA Network Analyzer** in Communication laboratory **NIE** Islamabad depicts that this antenna is suitable for use in Wireless Transmission applications for 5G.

1.6 LIMITATIONS

This project has few limitations.

1. Due to limited literature available on 5G Antenna designs, we had to undergo an extensive research to be able to design a miniatured Antenna for 5G applications
2. Achieving triple band operation resonating at frequencies supporting 5G operation was the biggest challenge
3. After achieving targeted results, focus was to improve Antenna gain maintaining same small size of Antenna
4. FR4 substrate is a lossy material, having its own disadvantages was the only option available to be used as substrate
5. Location of vertical slots in the designs and adjusting their effects on overall results of Antenna

CHAPTER 2

2. BASIC ANTENNA PARAMETERS

G.A. Deschamps first presented patch antenna in year 1953. High frequency operation of the patch antenna became a reality due to the fact that frequency is inversely of antenna is inversely proportional to its size, hence for a relatively smaller size antenna frequency starts increasing. Due to their smaller size and radiating properties, these are very popular for use in cell phones as Bluetooth and WIFI transmission reception modules. They have low cost and easy to fabricate as compared to other antennas. Few basic properties of patch antenna are as follows.

2.1 RADIATING NEAR-FIELD, FAR-FIELD AND REACTIVE NEAR-FIELD

When Antenna source radiates, different types of fields are formed around an antenna. These fields are divided into 3 main areas. The immediate area surrounding the source is known as reactive near field. The outermost or farthest area is known as far field, whereas the area between reactive near field and far field is known as radiating near field.

If D is the diameter of an antenna and here λ represents wavelength at the operating frequency, then the far field condition would be.

$$\text{Far Field} \geq \frac{2D^2}{\lambda}$$

EQUATION: 1

The inner area relative to far field is called near field. Near field is further divided in two sub-fields reactive and radiating near-field. Following equation describes the outer limit of the reactive near field.

$$Reactive\ Near\ Field \leq 0.62 \times \sqrt{\frac{D^3}{\lambda}}$$

EQUATION: 2

here D is the diameter of an antenna and here λ represents wavelength at the operating frequency

2.2 RADIATION PATTERN OF ANTENNA

There are three major types of Antennas with respect to radiation pattern

a. Isotropic Antennas

b. Directional Antennas

c. Omni-directional Antennas

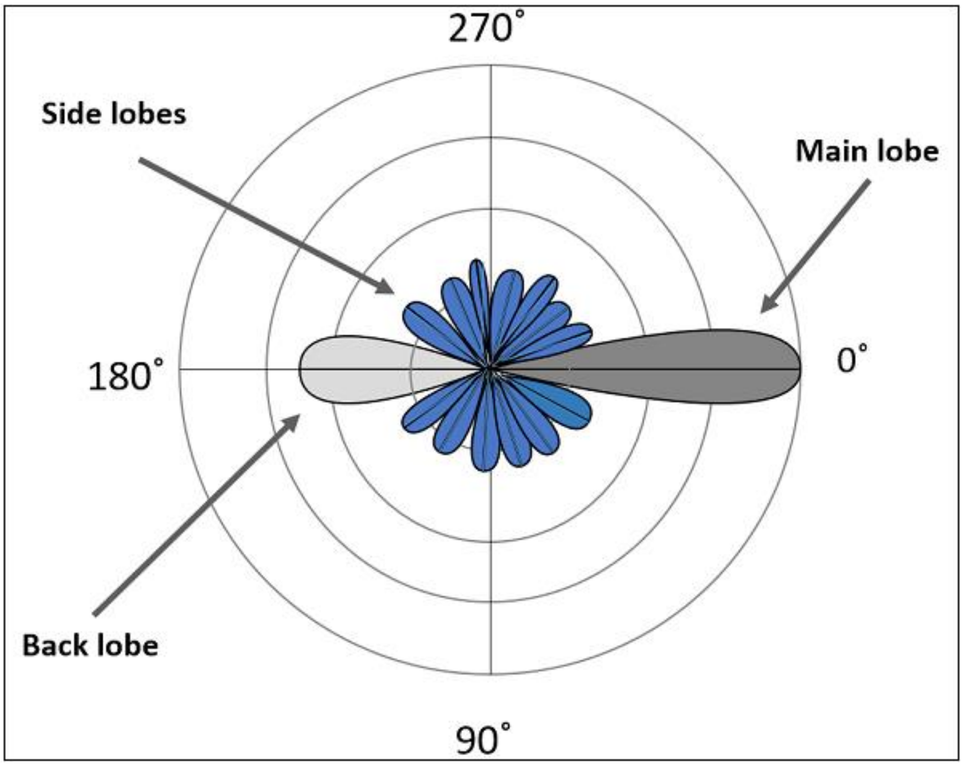

Figure 3: RADIATION PATTERN OF ANTENNA

2.3 ANTENNA DIRECTIVITY

Directivity is taken as one of the most important antenna parameter. Direction and Directivity of an antenna are related terms. This term indicates at some given direction with what power an antenna radiates with respect to some other direction. Usually we only consider only that direction where antenna radiates its maximum. Directivity can be represented as follows

$$D = \frac{U}{U_0} = \frac{4\pi U}{P_{rad}} = \frac{4\pi}{\Omega_A}$$

EQUATION: 3

Where P_{rad} depicts the Total Power in watts and U represents radiation intensity.

2.4 ANTENNA REFLECTION COEFFICIENT

Antenna performance can be measured as value of its reflection coefficient. It tells us how good the Tx line and load are matched. Following relation can be considered to determine value of reflection coefficient

$$\tau_A = \frac{Z_L - Z_A}{Z_L + Z_A}$$

EQUATION: 4

2.5 GAIN

Gain is the considered as most important antenna. It includes efficiency as well as the directionality of an antenna. Gain determines that how well electric power (current) is converted to electromagnetic waves by the particular antenna in a given direction with respect to the isotropic Antenna. It is considered in the direction of maximum radiation unless it is specifically mentioned. It is written as follows

$$G = \frac{4\pi U(\theta, \emptyset)}{P_{in}\ (lossless\ isotropic\ source)}$$

EQUATION: 5

Where P_{in} is the Input power in watt and by U is Antenna Radiation intensity. Gain is also the product of efficiency and Directivity of an antenna.

2.6 BANDWIDTH

Another important factor for estimating performance of antenna is its BW. It consists of a set of frequencies at which the antenna converts its input electric power into output radiated power. It is also known as the resonant frequency or resonant frequencies of a particular antenna.

2.7 POLARIZATION OF AN ANTENNA

This orientation of the radiated wave is known as polarization. To calculate and draw polarization of electromagnetic waves, an electric field plane is considered in the direction of the propagation of waves. The polarization can also be shown as the orientation of vector of E-field. It is also described as position and direction of electric field relative to the normal.

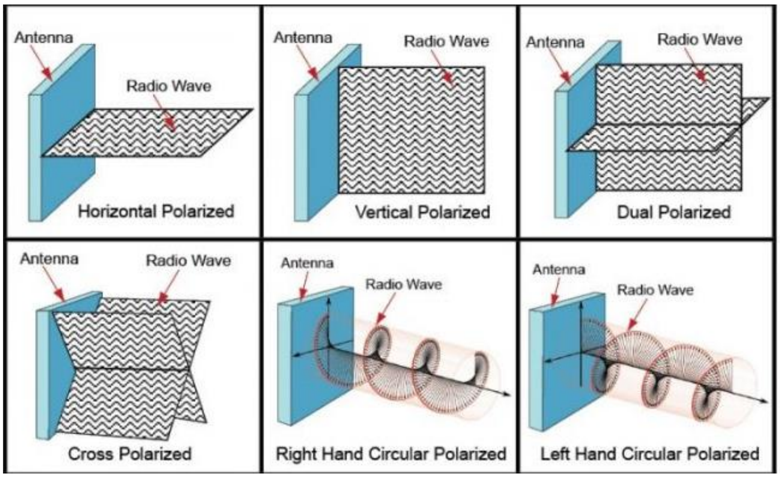

Figure 4: POLARIZATION OF EM WAVES

CHAPTER 3

3.1 BACKGROUND STUDY

A lot of work in the field of microstrip patch antenna has been done. Making a microstrip patch antenna to resonate at frequencies supporting 5G operation is relatively a new concept. The aim of this research was to undergo study material that provides us with the basic knowledge that enables us to design an antenna to support 5G operation. There has been quite a lot of advancement in this field in last few years. Extensive research has been made on our part in the following fields.

a. Downsizing of antenna sizes

b. 5G application

c. Triple-band operation

d. Simple design for ease of fabrication

c. Integration in modern devices cellphones etc

3.2 LITERATURE REVIEW

Extensive research has been made by reviewing literature that included IEEE research papers and books references to which are included at the end of this paper.

3.2.1 5G FREQUENCY BAND SELECTION

First problem in our work was to identify the frequency that supports the 5G operation for our design. 5G is still to be defined officially by the standardization bodies [1]. R&D of many renowned companies like QUALCOMM and ZTE have made modules commercially that support 5G operation.

Figure 5: QUALCOMM 5G MODULE USING 6 GHz **[2]**

3 GHz band is already a congested one. In China efforts has been made to utilize the same band for 5G operation (3.4 GHz to 3.8 GHz). Many IOT (The Internet of Things) devices are also using this band. So using this band for your work was discarded.

5G also utilizes mm Wave **Millimeter Wave above 27 GHz** for its operation. According to our research, this band is very much susceptible to even minor environmental changes such as rain, snow, polarity of ground and even wind. No remarkable work has been found at these frequency bands.

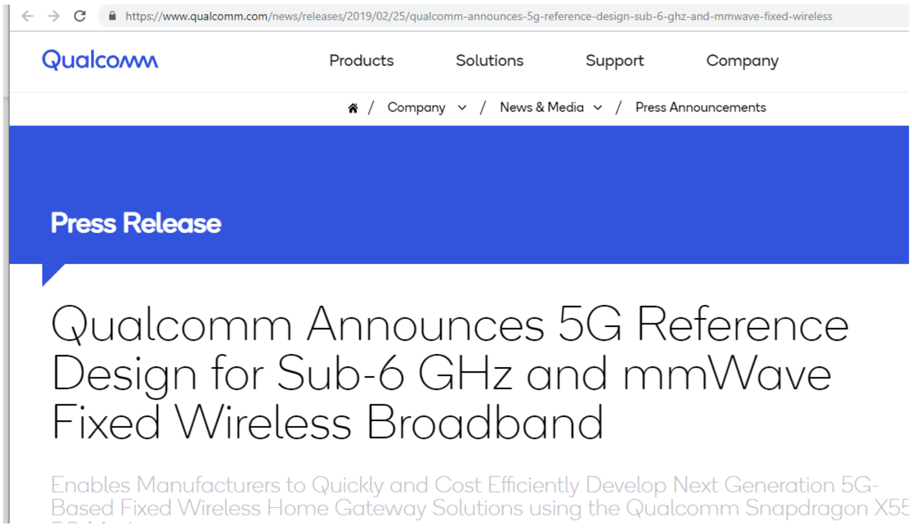

Figure 6: QUALCOMM OFFCIAL 5G MODULE USING 6 GHz [3]

Considering above factors we narrowed our research to select frequency band for triple band operation between **4.1 GHz to 8.1 GHz**. This solves our first problem of selection of the frequency on which we want our developed design to resonate at.

3.2.2 MINITERISATION GAIN AND TRIPLE BAND OPERATION

During the course of our research and library search we had to find out answers for our problem statement. This included downsizing of our developed design, more gain with same small size and achieving triple band operation. We have undergone many research papers and compared their results that were best suited for our research.

3.2.2.1 EXISTING ANTENNNA DESIGNS

Author	Triple Frequency (GHz)	Gain (dBi)	Size of antenna (mm^2)	Average Gain (dBi)
Maryam Rahimi [4]	1.76	2.1	30 x 30	0.23
	2.55	-3.9		
	3.85	2.5		
R. Sujith [5]	0.9	-1.25	32 x 31	1.38
	1.74	1.94		
	2.44	1.11		
	5.5	3.71		
C. H. See [6]	1.8	-1.7	50 x 100	1.92
	2.0	2.34		
	2.2	5.12		
C. M. Wu [7]	2.4	1.48	120 x 40	2.28
	5.2	2.30		
	5.8	3.05		
Y. Joong Han [8]	5.7	5.06	26.9 x 25.9	2.32
	2.44	0.85		
	5.25	1.05		
Y. Jee [9]	0.85	3.25	29 x 28	2.77
	1.8	2.25		
	2.1	2.8		
W. C Liu [10]	1.86	2.5	47 x 35	3.24
	5.1	3.7		
	5.75	3.51		

Table 1: EXISTING ANTENNA DESIGNS COMPARISION

After going through these papers, one can observe different values of gain with respect to antenna sizes or dimension. Increasing antenna size is in-turn increasing gain. Our aim is to achieve better gain with reduction of an antenna size.

Design improvements and more innovative design also resulted in better results example of which is as follows.

3.2.2.2 R. SUJITH'S ANTENNA DESIGNS PARAMETERS

Design parameters used by R. Sujith in his paper are defined in Table 2.

Author	**Triple Frequency (GHz)**	**Gain (dBi)**	**Size of the antenna (mm^2)**	**Average Gain (dBi)**
R. Sujith [5]	0.9	-1.25	32 x 31	1.38
	1.74	1.94		
	2.44	1.11		
	5.5	3.71		

Table 2: R. SUJITH'S ANTENNA DESIGNS PARAMETERS

Key to achieve better results are innovative design used by R. Sujith is shown as under.

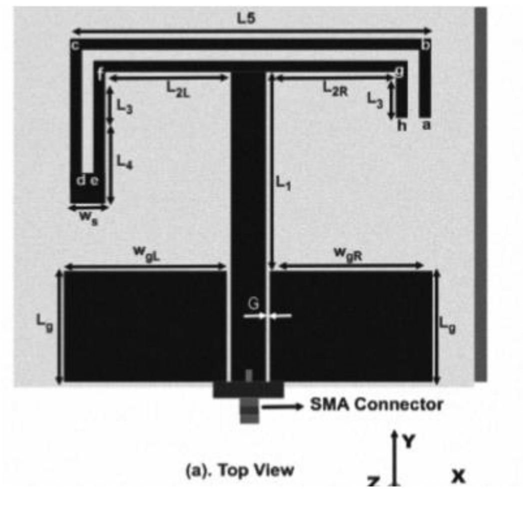

Figure 7: ANTENNA DESIGN R. SUJITH

S11 plot showing values of return loss shows that improving design, results in better antenna output. Return Loss characteristic R. Sujith Design are as under.

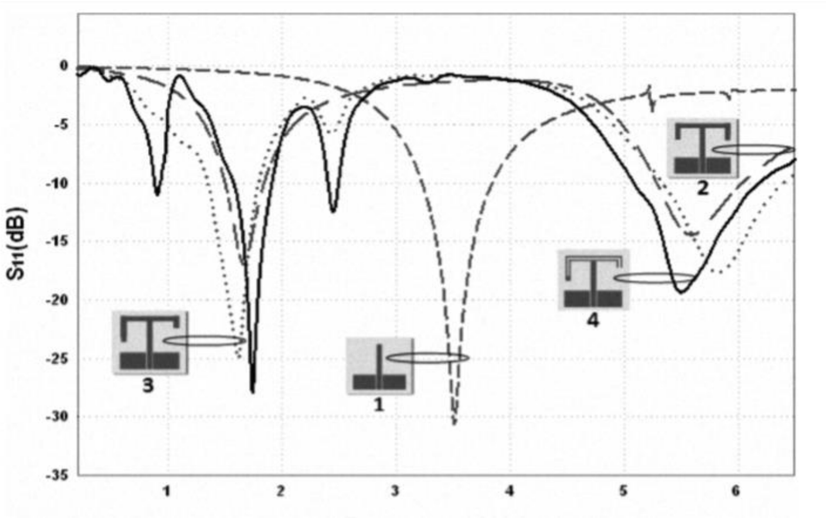

Figure 8: RETURN LOSS CHARACTRISTIC R. SUJITH DESIGN

3.2.2.3 Y. Lee ANTENNA DESIGNS PARAMETERS

Design parameters used by Y. Lee in his paper are as under.

Author	Triple Frequency (GHz)	Gain (dBi)	Size of the antenna (mm^2)	Average Gain (dBi)
Y. Jee [9]	0.85	3.25	29 x 28	2.77
	1.8	2.25		
	2.1	2.8		

Table 3: Y. JEE ANTENNA DESIGNS PARAMETERS

S11 plot showing values of return loss shows that improving design results in better antenna output. Return Loss characteristic of Y. Lee are as under.

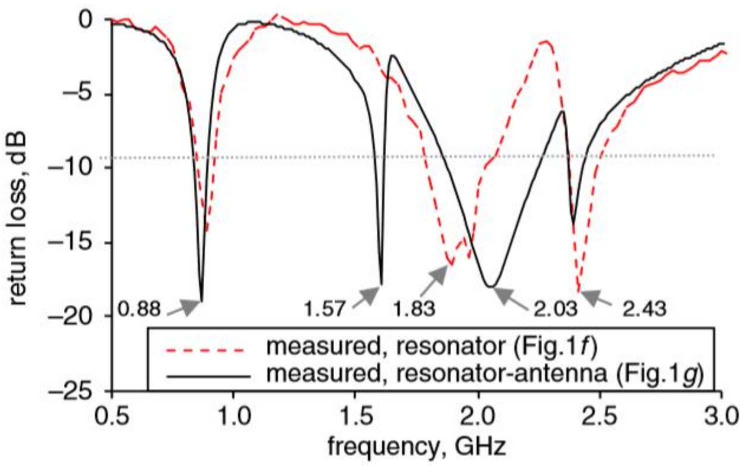

Figure 9: RETURN LOSS CHARACTRISTIC Y. JEE

3.3 DELIVERABLES

After going through all these designs, their dimensions, their effect on the gain and triple band operation keeping within the desired frequency range supporting 5G utilization, enough knowledge has been gained to start with our own design with better results from above mentioned existing designs.

CHAPTER 4

4.1 DESIGN EVOLUTION

To obtain the desired BW and operating frequencies, a methodical approach has been followed in its design development. The developed design required to resonate at triple band within the frequency range of 5G discussed earlier in this paper. Antenna downsizing from already available designs and improved gain are other important considerations while designing this Antenna.

To start with, a simple antenna was designed by subtracting a circular shape hole on the top of the rectangular microstrip patch. Following dimensions were used

a. Length of the rectangular patch → 22 mm

b. Width of the rectangular patch → 23 mm

c. Radius of the circle subtracted → 7.5 mm

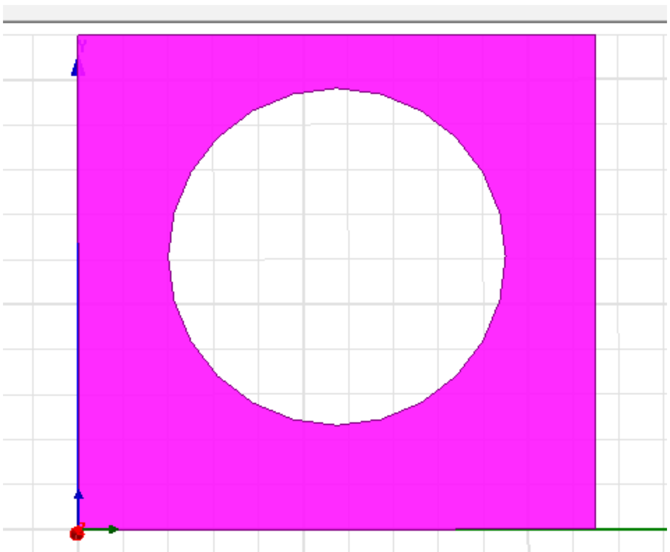

Figure 10: FRONT SIDE OF ANTENNA 1

As per our research, to make it resonate at more than one frequency we needed to modify the design. To obtain the desired polarization, two rectangular vertical slots were cut from the design. Specifications of the slots are as follows.

a. Width of slot → 0.4 mm

b. Height of slots → 4 mm

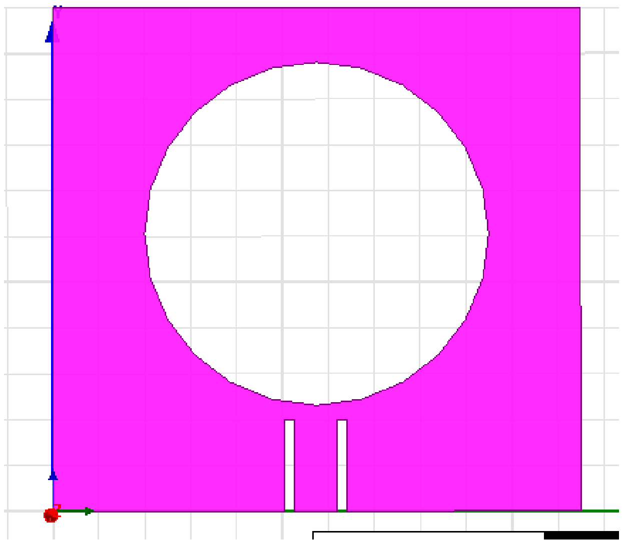

Figure 11: FRONT SIDE OF ANTENNA 2

A diamond shape monopole is inserted inside the circle already cut through the rectangular patch along with the feeder. Prior to the selection of diamond shape patch, we also tried triangular patch, circular path and square monopole. Best results were achieved by diamond shape monopole which is discussed in this paper in detail. Dimensions of monopole and feeder are

a. Sides of Diamond patch → 5.7 mm

b. Height of Feeder → 3.4 mm

c. Width of Feed → 0.5 mm

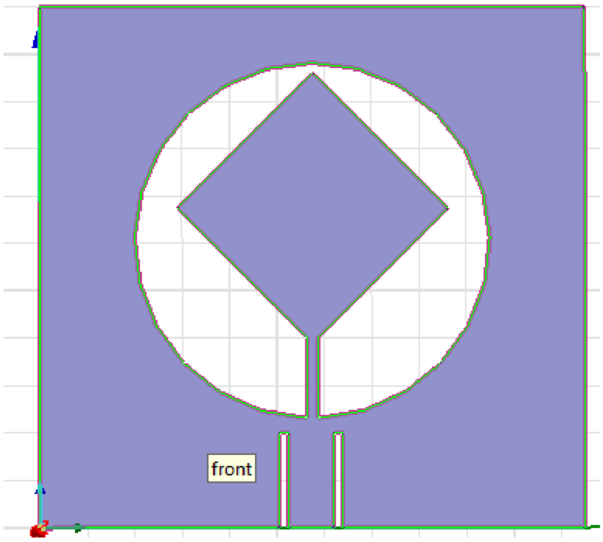

Figure 12: FRONT SIDE OF ANTENNA 3

Screenshots of different monopoles tried to achieve desired results are as under.

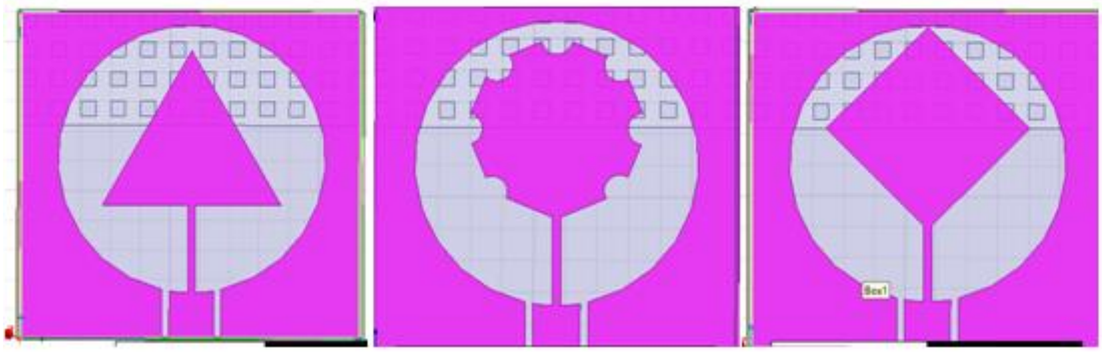

Figure 13: DEVELOPMENT PROCESS FRONT SIDE OF ANTENNA

Diamond shape monopole was selected for giving best results among other shapes inserted as radiating monopole. Length and width of the feeder as well as the dimensions of the monopole are also adjusted for achieving optimum results.

After completion of the front side of the antenna we designed a modified ground plan for our antenna. First a simple rectangular patch was selected as ground plan having same dimensions as of the front side of an antenna.

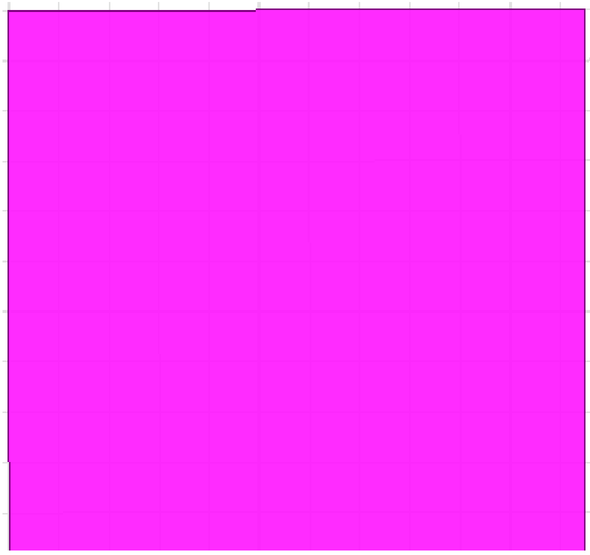

Figure 14: SIMPLE GROUND

Simple ground sheet did not provide us with the triple band operation and desired frequency range. Major innovative modifications were carried out in antenna ground design after having gone through literature and simulations of different designs. Best possible solution to the problem was to divide ground plan in two halves. Introduce one half with slots of 1 mm after every millimeter. The final design of ground is as under.

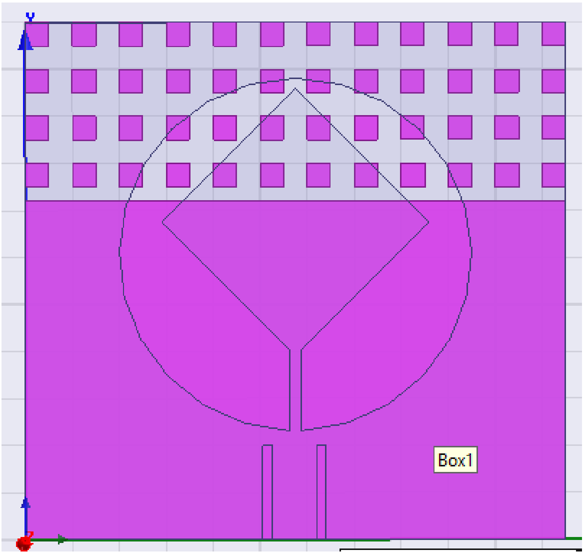

Figure 15: MODIFIED GROUND DESIGN

Dimensions of the slots used in the above design are as under.

a. Width of introduced slot → 1 mm

b. Gap between consecutive slots → 1 mm

We did not have much choice with the kind of substrate which can be used in our design. Keeping in view the limitations of fabrication, FR4 epoxy was selected as substrate despite being a lossy material. To obtain desired results best suited for our design, 1.6 mm width of substrate was placed between the front and ground.

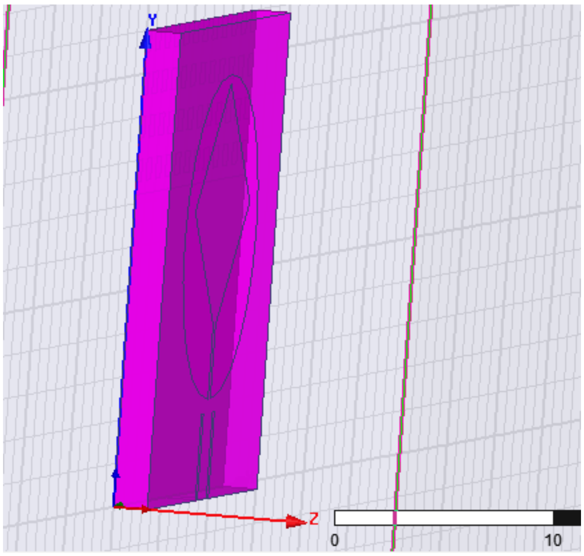

Figure 16: SIDEVIEW OF ANTTENNA

For simulations Lumped port is used as feed. Dimensions are as under

a. Length of Port → 1.9 mm

b. Height of Port → 1.6 mm

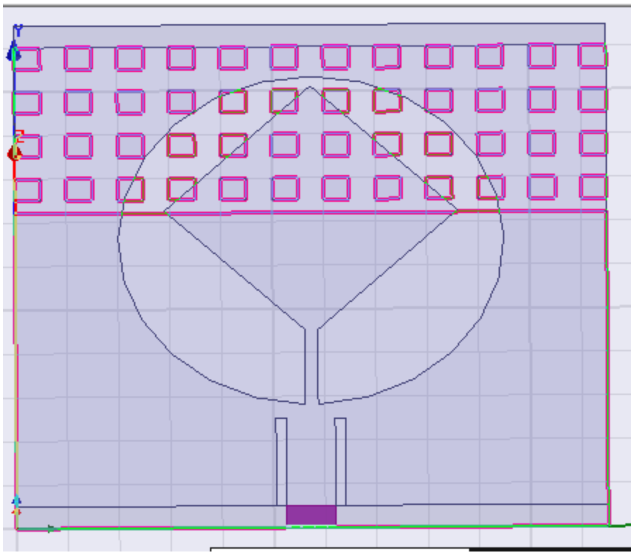

Figure 17: LUMPED PORT ANTENNA DESIGN EVOLUTION

4.2 ANTENNA GEOMATRY SUMMERY

Following figure along with table shows in detail the summary of dimensions used in developed antenna design.

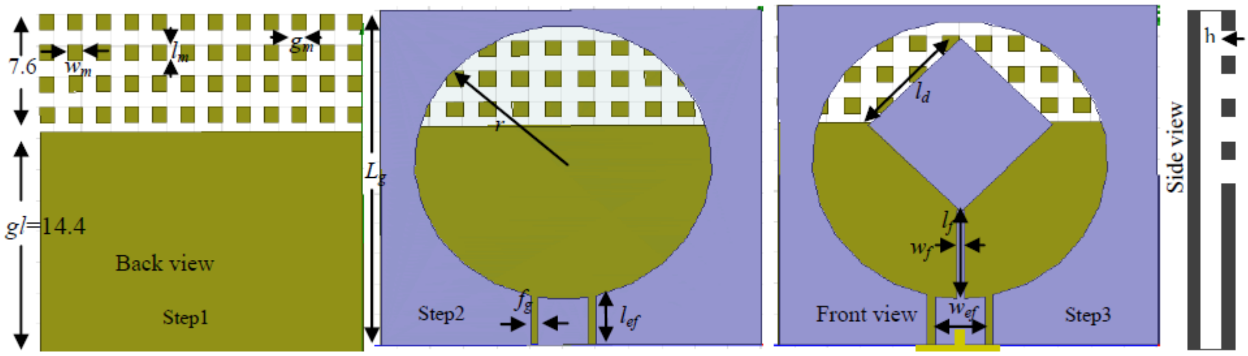

Figure 18: ANTENNA PARAMETERS

Symbol	**Quantity**	**Value (mm)**
L_g	Length of ground plane	22
W_g	Width of ground plane	23
g_l	Finite ground plane length	14.4
l_m	Length of ground slots	1
w_m	Width of ground slots	1
g_m	Gap between the slots	1
r	Radius of circle	9
l_{ef}	Length of feed slot	3.4
f_g	Width of feed slot	0.5
w_{ef}	Width of edge feed	1.9
l_f	Length of the feed	5.7
w_f	Width of the feed	0.5
l_d	Length of the diamond patch	5.7
h	Height of the substrate	1.6

Table 4: DEVELOPED DESIGN PARAMETRES VALUES

4.3 ANTENNA FRABRICATTION

Antenna was fabricated at **NIE** Islamabad. Material selected as substrate was FR4 epoxy. Fabrication process took 4 days. Eight different antenna designs were submitted along with our selected design for future research purpose and as of proof of work. Pictures of developed Antenna design after fabrication are as follows.

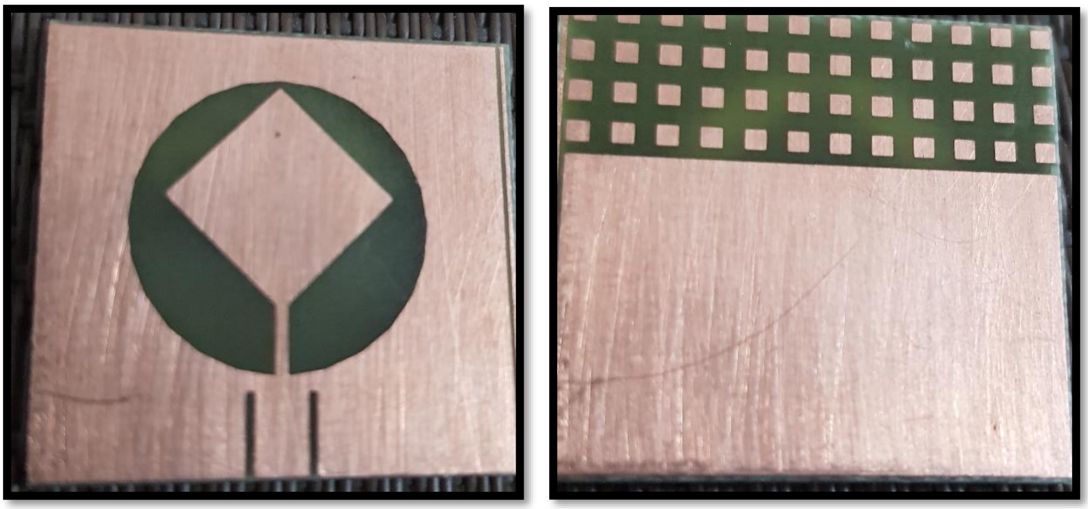

Figure 19 FABRICATED ANTENNA (FRONT AND GROUND)

CHAPTER 5

5.1 MEASUREMENTS AND RESULTS

Design improvement and running simulation was a parallel progress with continued throughout the course of this project. After the selection of our objectives for this project, emphasis was to develop an improved innovative design that is smaller in size as compared to antenna designs already available with improved gain, thus allowing it to resonate at three different frequencies within 5G band. In this section different results recorded by the simulation process during the evolution of Antenna designs are discussed.

5.2 SINGLE FREQUENCY BAND RESULTS

After extensive research and selection of desired objectives for our antenna, first step was to make an antenna that resonates with in 5G band. A simple monopole design with plan ground was designed and its results were measured.

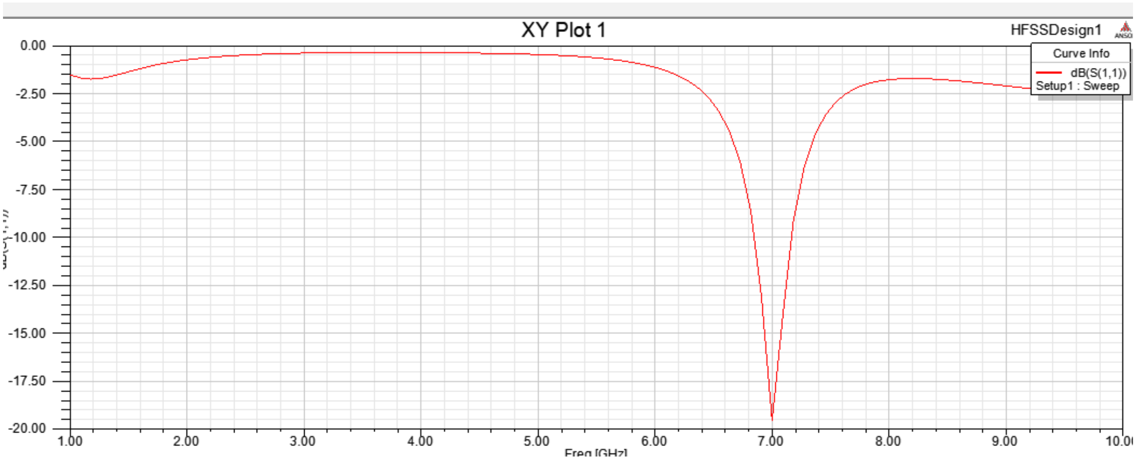

Figure 20: S11 PLOT SINGLE BAND OPERATION

Dimension we selected for our designs were 22 mm x 23 mm. Keeping in consideration the size constraints, an effort has been made to improve the results by more innovative designs. The space of the monopole was replaced by other geometric figures and pattern of their radiation is recorded. With a Triangular monopole radiating path following results were obtained.

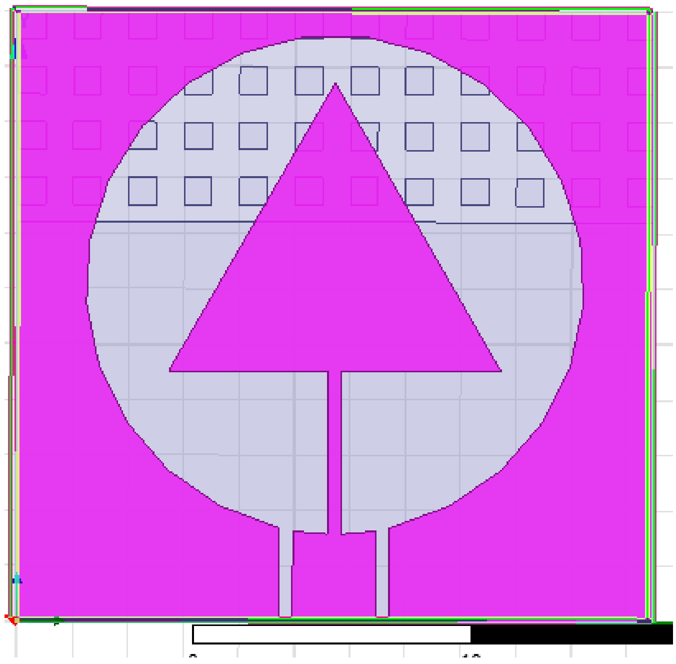

Figure 21: TRIANGULAR MONOPOLE

S11 plot showing return loss of and single band operation of above antenna.

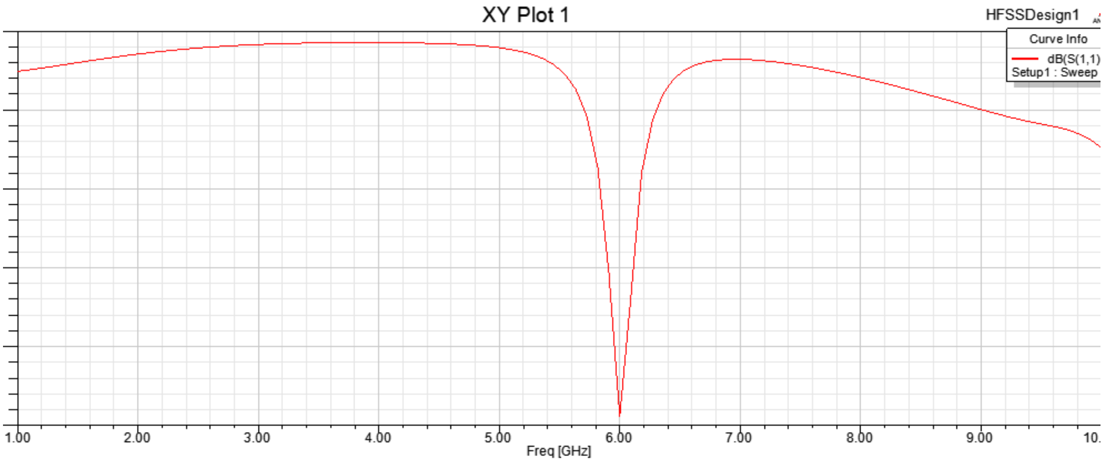

Figure 22: S11 PLOT OF TRIANGULAR MONOPOLE

There was no significant change from the previous results. More designs were discussed in group and were implemented. Circular patch was introduced in the design but this deteriorated our results. Efforts were made to circularly polarize the circular path. Following results were obtained.

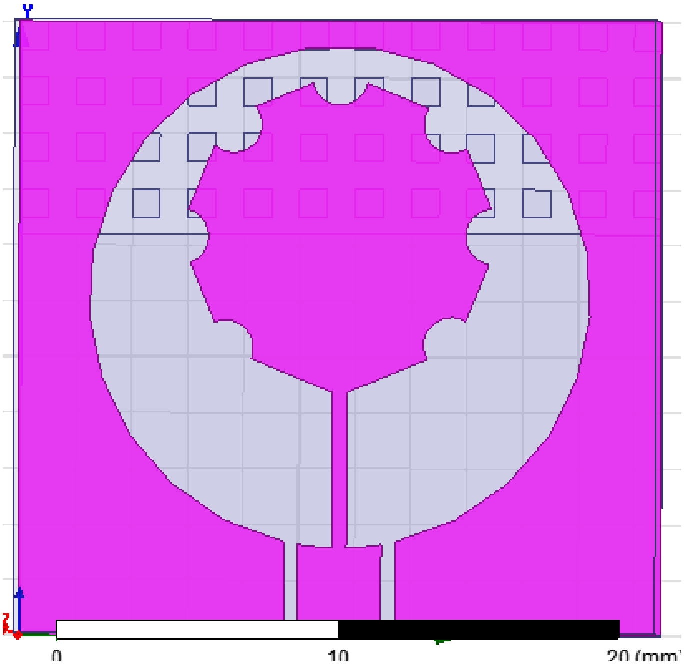

Figure 23: MODIFIED CIRCULAR MONOPOLE

S11 plot showing return loss of and single band operation at different frequency.

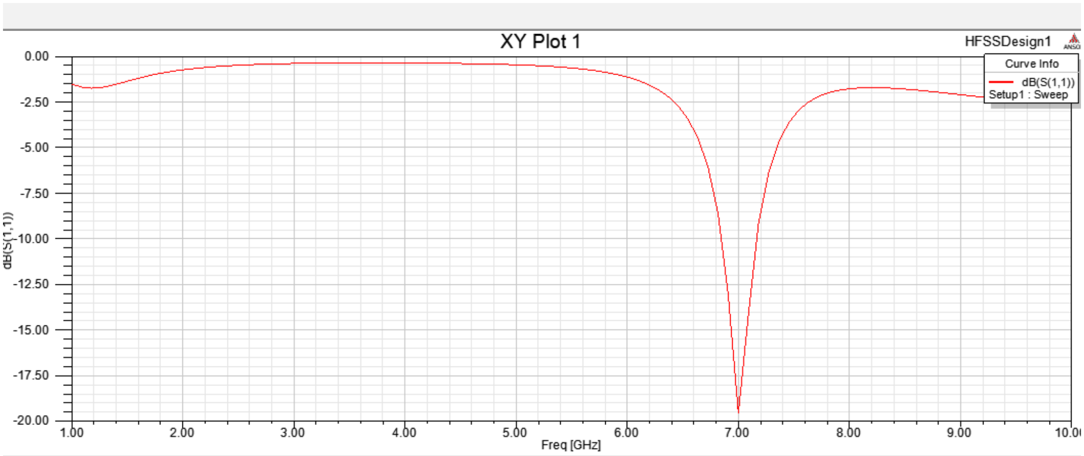

Figure 24: S11 PLOT MODIFIED CIRCULAR MONOPOLE

Diamond shape monopole was selected, and other geometric shapes were discarded for giving inferior results. Better radiation pattern was observed with diamond shape monopole.

5.3 DOUBLE FREQUENCY BAND RESULTS

The objective of our work was to achieve the triple band operation within 5G band limitations. To achieve that further modification were carried out in the design. Introduction of two vertical rectangular slots at the bottom of the front side of antenna and diamond shape monopole radiating patch helped us to achieve double band operation. Few results recorded are shown here.

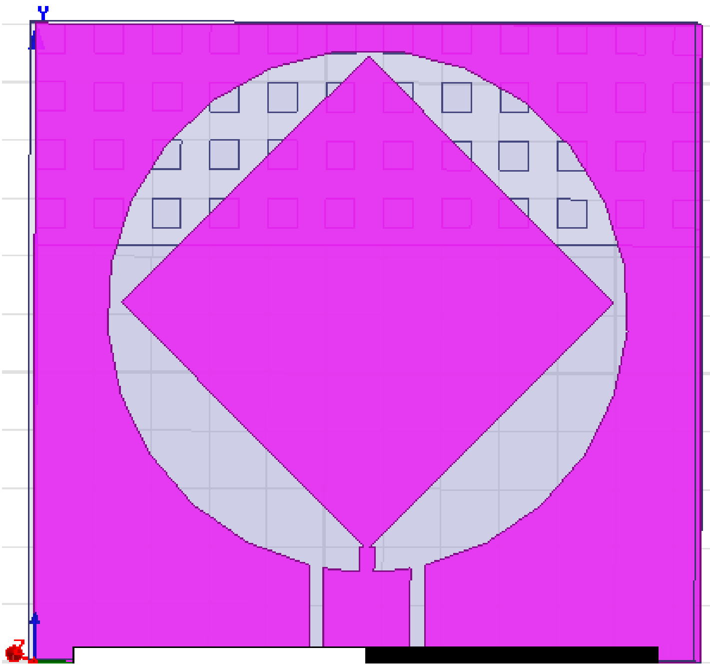

Figure 25: DIAMOND SHAPE MONOPOLE

S11 plot showing return loss and double frequency band operation.

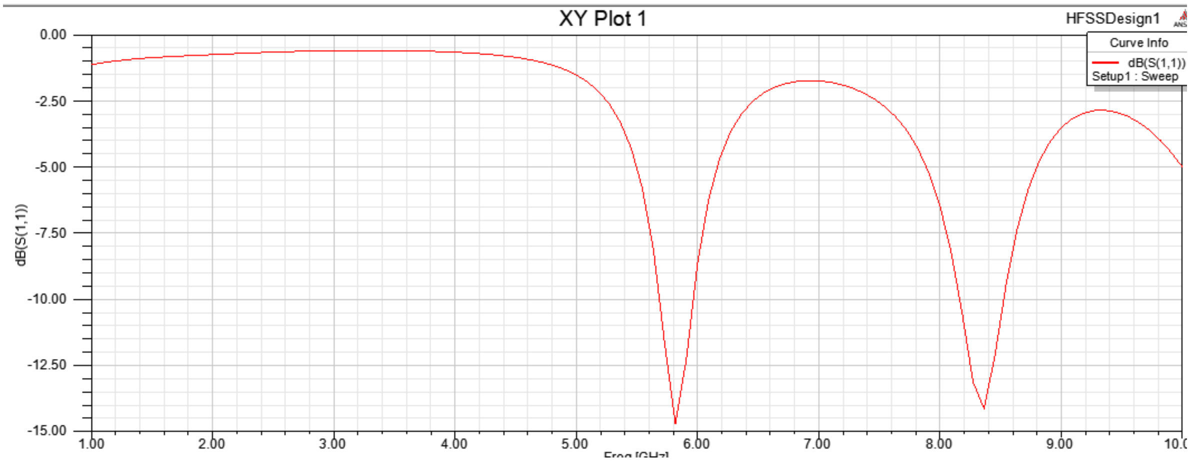

Figure 26: S11 PLOT DOUBLE BAND OPERATION

Axial Ratio of the above-mentioned design is as under.

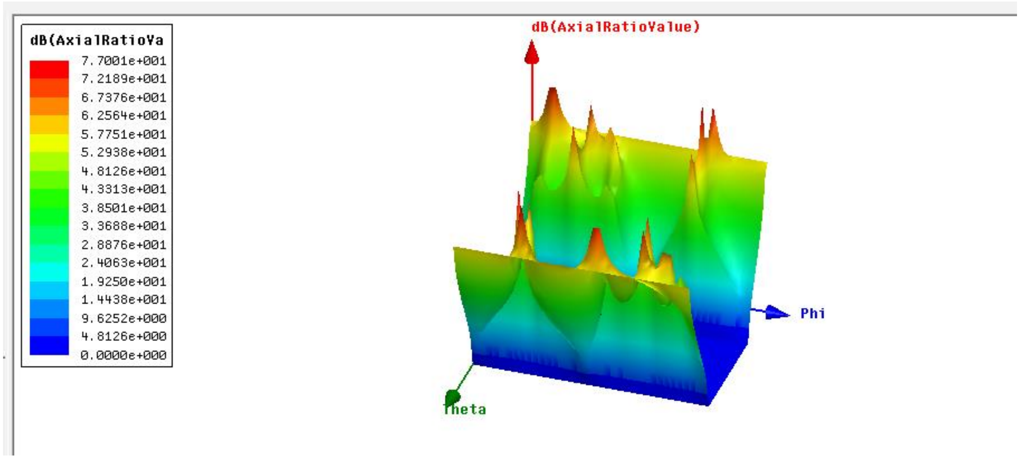

Figure 27: AXIAL RATIO DOUBLE BAND DESIGN

5.3 TRIPLE BAND RESULTS

More innovation in the design backed by the literature we reviewed was required to improve the results. Objective was to obtain triple band operation within 5G band. To achieve this, ground plan was modified by introducing slots of 1 mm in size and 1 mm apart from each other. Slots were made at almost half of the ground plan. This along with the modification in the dimension of the monopole, feeder length and width, reduction of the input slot helped us to achieve the triple band operation.

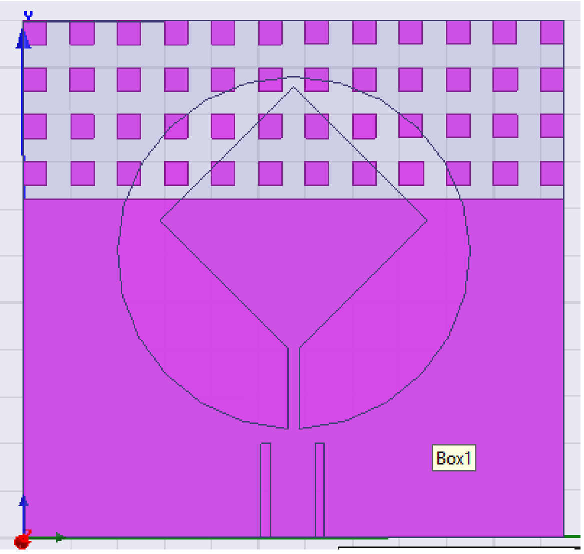

Figure 28: MODIFIED GROUND DESIGN

S11 plot showing triple band frequency operation by using modified Antenna design discussed above.

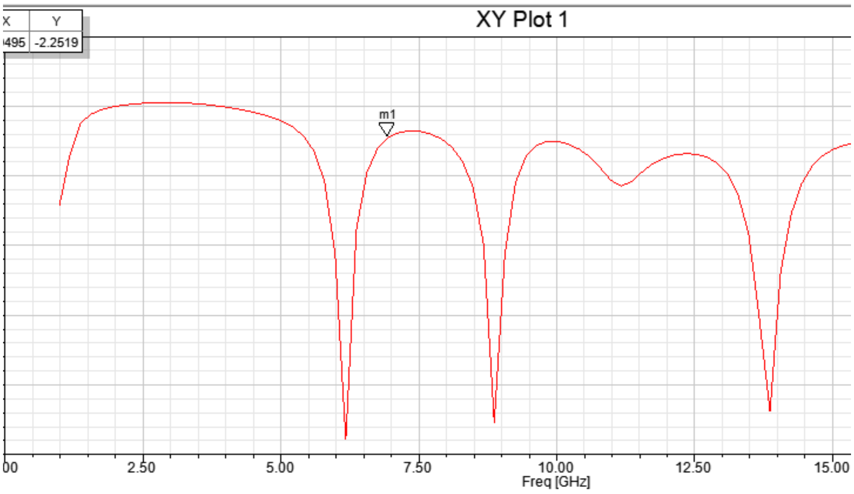

Figure 29: S11 PLOT TRIPLE BAND OPERATION

5.4 FINALISATION OF RESULTS

After achieving the triple band operation, next step was to improve the design in way that produces desired results. This was done by shifting the resonating frequency at the lower side and make antenna resonate at three frequencies with in 5G cellular band. More modifications were carried out in the design. After hundreds of simulations and minor changes in the design, following results were recorded and selected as presentation of our developed design.

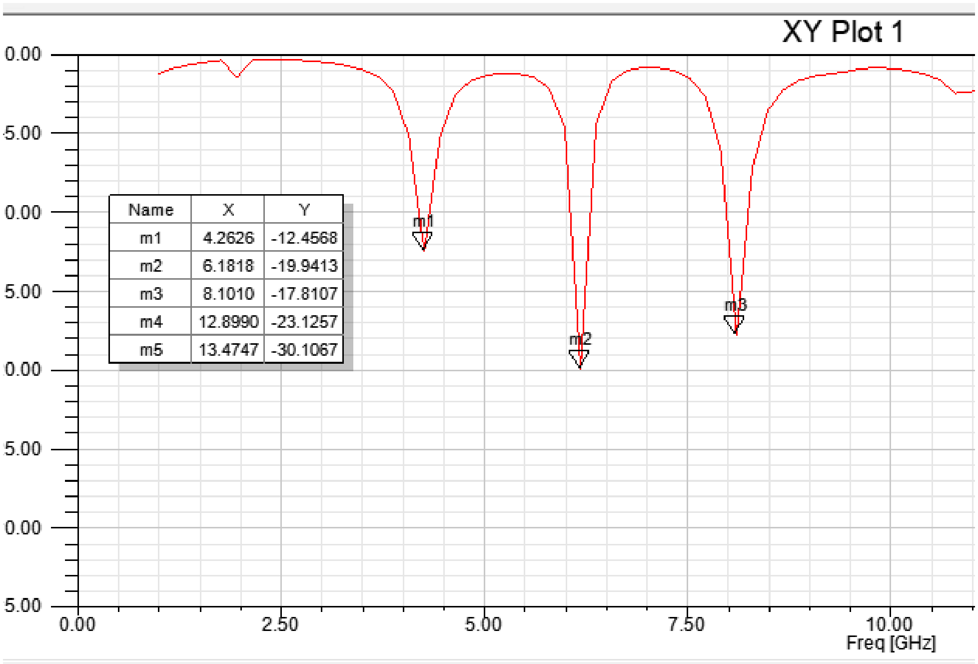

Figure 30: S11 PLOT SELECTED DESIGN

5.5 GAIN

Our developed design provided better gain as compared to the designs discussed in the literature review at all the three frequencies. At 4.1 GHz simulated value of gain is almost -15 dB which better than any other design discussed above in literature review.

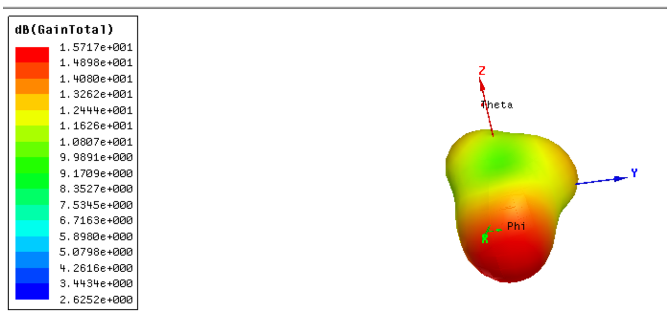

Figure 31: GAIN AT 4.2 GHz

Improved value of gain was observed at 6.1 GHz after simulations.

Figure 32: GAIN AT 6.1 GHz

At the third operating frequency 8.1 GHz value of gain observed was – 2.11 dB.

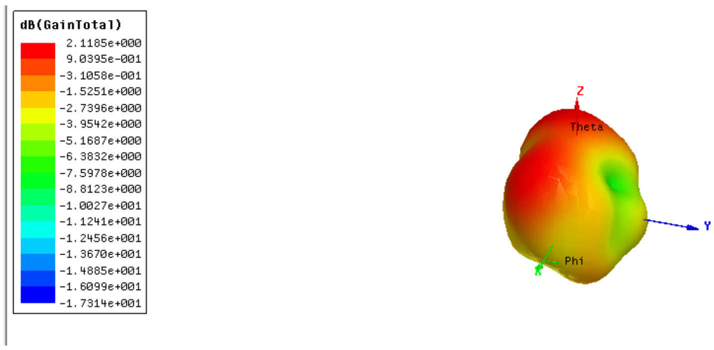

Figure 33: GAIN AT 8.1 GHz

It can be clearly seen from the figure that the triple band operation has been achieved. All three bands lie within future 5G cellular applications range. Downsizing of the antenna is also achieved as size of this design is 22 mm x 23 mm. This developed design gives us improved gain from the models discussed in literature review. The gains are improved individually, and average gain is also improved.

5.6 MEASURED RESULTS

Fabricated antenna was tested in Communication lab NIE Islamabad on VNA Network Analyzer **E5071C**.

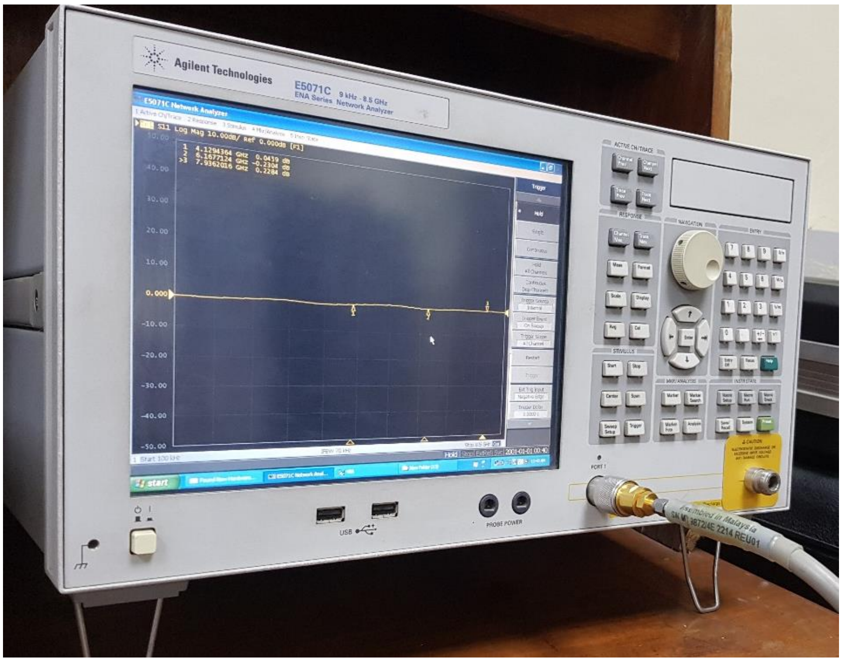

Figure 34: VNA Network Analyzer E5071C

Results received from communication lab NIE complemented simulated results obtained from HFSS.

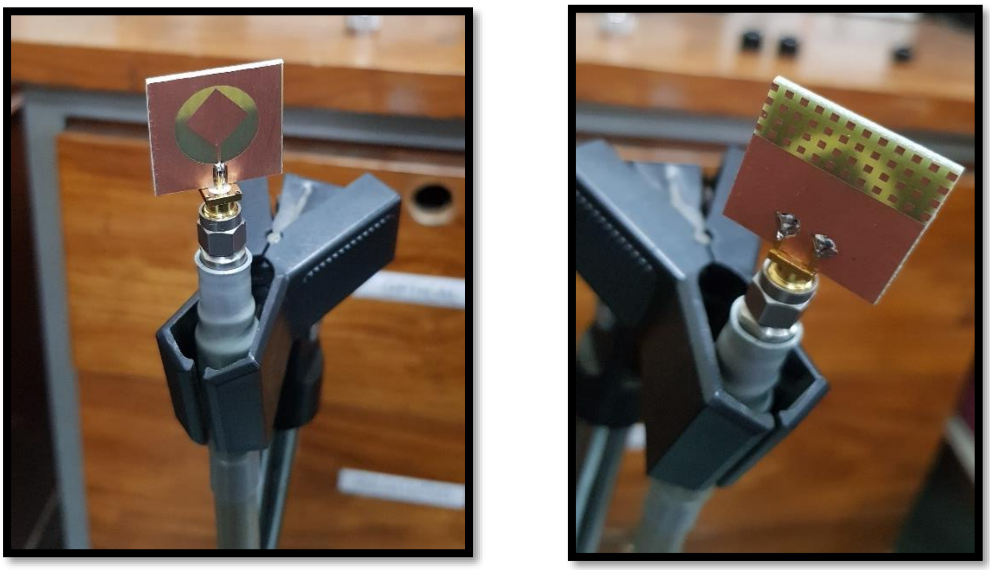

Figure 35: MEASUREMENT PROCESS AT NIE

Results are in conformity with simulated HFSS results with slight shift in third frequency. Results measured from ENA network analyzer communication lab NIE Islamabad are as under.

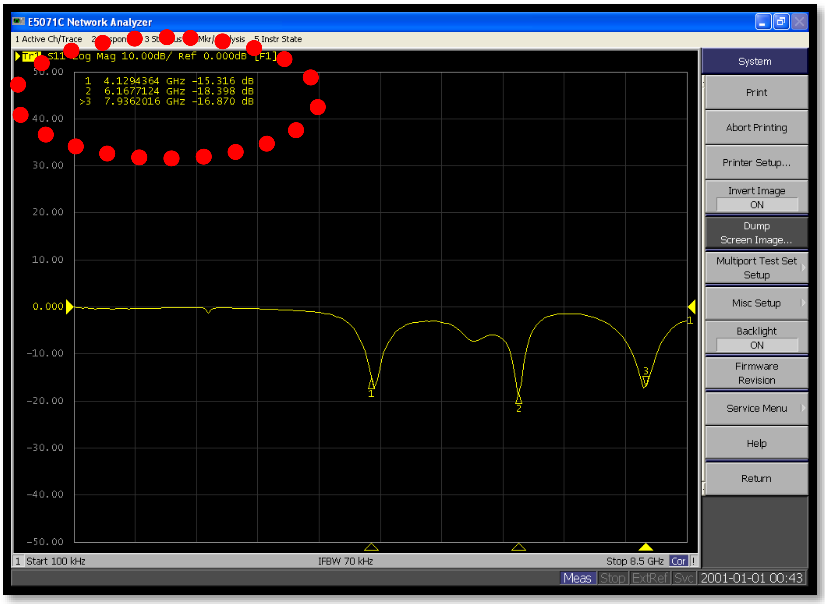

Figure 36: VNA NETWORK ANALYZER MEASUREMENT RESULTS OF FABRECATED ANTENNA

SnP files received from NIE were then further analyzed using **MATLAB**. Using **S-parameter plot** on MATLAB. S-Parameter plot shown by MATLAB further completed our work and was in conformity with simulated HFSS results. S-Parameter Graph in MATLAB is shown below.

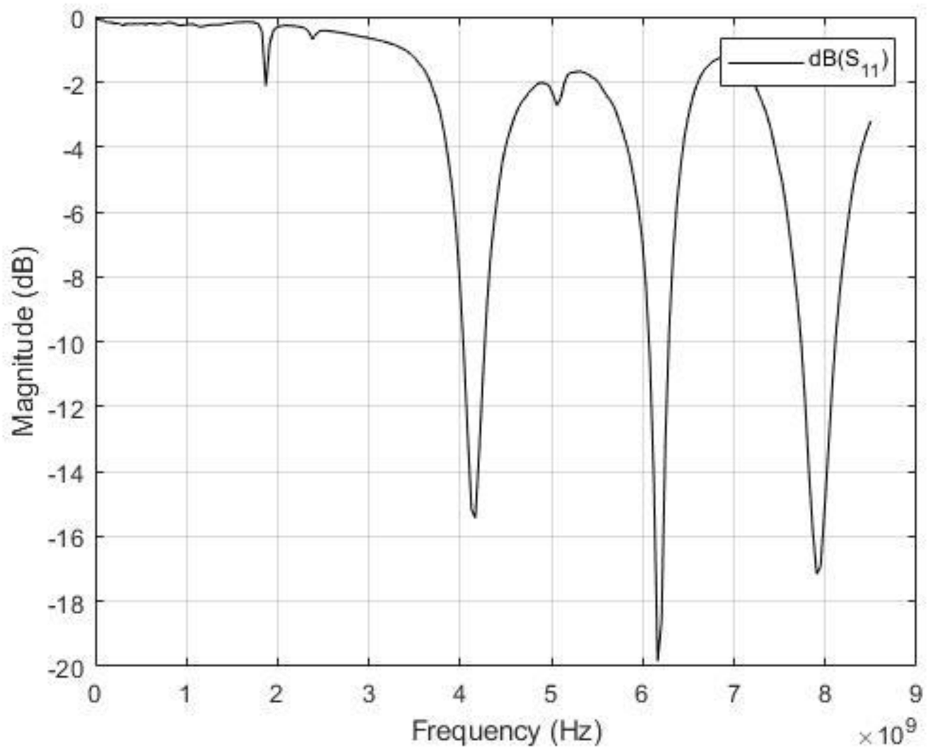

Figure 37 S-PARAMETER PLOT MATLAB

Measured return loss of fabricated antenna at the frequency of 4.1 GHz is found to be -15 dB, at 6.1 GHz, it is -19 dB and at 8 GHz its is found to be about -17 dB as shown in figure 34. It can be clearly seen from the figure that the miniaturized antenna achieved triple band operation. All three bands lie within future 5G cellular applications range.

5.7 RESULTS AT DIFFERENT OPERATING FREQUENCIES

Operating Frequency	Return Loss	Gain (dBi)
4.1 GHz	-15 dB	15
6.1 GHz	-19 dB	4.6
8 GHz	-17 dB	2.1

Table 5: VARIOUS PARAMETRES VALUES

CHAPTER 6

6.1 FURTHER RESEARCH

During research and design development it is observed that the performance of a particular antenna can be improved by simple yet innovative design innovations. A single Microstrip patch antenna with small modifications in design was able to achieve triple band 5G supported operation. Similar designs, if given multiple inputs can achieve better results in-terms of enhanced gain and return loss. Changing the substrate to less lossy material as FR4 epoxy will improve results too. More innovative designs can be further achieved by downsizing of antenna for easy integration in modern devices.

6.2 CONCLUSION

The project provided the guide line for triple band operation supporting 5G operation remaining within the limitations of size constraints using a simple yet innovative antenna design. Both triple band operation with high gain makes it a better and a flexible choice for future 5G wireless power transmission applications.

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