NOTCHED EDGE B SHAPE MICROSTRIP PATCH ARRAY ANTENNA FOR SATELLITE COMMUNICATION

By

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A thesis submitted to the Faculty of Electrical Engineering Department, Military College of Signals, National University of Sciences & Technology, Pakistan in partial fulfillment of the requirements for the degree of MS in Electrical (Telecom)

September, 2019

THESIS ACCEPTANCE CERTIFICATE

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ABSTRACT

Large reflector antennas for satellite communication have many disadvantages like low flexibility, mechanical complexity and high operation and maintenance costs. That's why phased array antennas are being promoted to overcome this problem [1]. Several antenna types have been used to implement this technology among which the microstrip patch antennas are of great importance due to their eye-catching attributes as they are light weight, low profile, inexpensive and top of all, quick and simple to fabricate.

Different microstrip patch antennas are proposed for uplink or downlink satellite communication. Design engineers have also designed dual band antennas that can be used for both uplink and downlink to achieve higher efficiency.

Thesis provides a novel design dual band microstrip patch antenna operating at C band i.e. the most important band for satellite communication, with eye catching features of efficient gain, low return losses and higher efficiency. A novel design B shape microstrip patch antennas operating at two different frequencies of 4 GHz and 7.92 GHz are designed to meet the ITU standard and PTA assigned frequencies for downlink and uplink frequencies. B shape microstrip patch antenna at 4 GHz provides return losses of -40.70 dB and gain of 9.29 dBi with two elements array, while B shape microstrip patch antenna at 7.92 GHz provides return losses of -35.2 dB and gain of 10.8 dBi with two elements array.

Keeping the concept of segment utilization in mind, a dual band B shape antenna is also designed at these two frequencies of 4GHz and 7.92 GHz. It provides the gain of 10 dBi and return loss of -30.8 dB for uplink frequency of 7.92 GHz. Similarly it provides the gain of 9.1 dBi and return loss of -25.2 dB for downlink frequency of 4 GHz.

Cutting edge technique is further used to improve gain of antennas.

DEDICATION

Dedicated to my parents, especially to my elder brother Nasir Hussain Khan and my dear ones for their continuing support and encouragement throughout my Master's course work and research

DECLARATION

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

ACKNOWLEDGEMENT

First of all, I would like to say thanks to my supervisor Associate Professor Dr. Farooq Ahmad Bhatti who helped me and assisted me during my research work. His kindness and encouragements had always been a morale booster whenever I had problems during my research phase. I am impressed by his humble and kind nature. Besides, I would also like to say thanks to my thesis committee members respected Brig Abdul Rauf, PhD, Brig Imran Rashid, PhD and Dr. Zeeshan Zahid.

I can never forget the efforts of my parents and especially my elder brother, Nasir Hussain Khan who brought up me to this stage of my life and without their prayers and support I could never be so much successful in my life. I would like to say thanks to all my friends who helped me in my research work and especially to Hafiz Khawar Hayyat, Tehseen Raza, Ahsan Javid and Adnan Ali for their continuous encouragement, motivation and support.

And above all, Thanks to Allah Almighty for everything.

Table of Contents

List of ACRONYMS

ITU	International Telecommunication Union
PTA	Pakistan Telecommunication Authority
CST	Computer Simulation Technology
LHM	Left Handed Materials
FSS	Frequency Selective Surface
EBG	Electromagnetic Band Gap
ISL	Inter Satellite Link
UBW	Ultra Wide Band
MIMO	Multiple Input Multiple Output
DGS	Defective Ground Surface

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Chapter 1

INTRODUCTION

1.1 Background:

Besides the various advantages of using large reflector antennas for satellite communication, it has many disadvantages like low flexibility, mechanical complexity and high operation and maintenance costs. In place of installing a complex mechanical system which can only track one satellite at a time and reducing the efficiency of the segment, phased array antennas are being promoted to overcome this problem which can work for several satellites [1].

The antenna arrays technology for satellite communications will substitute reflectors by providing a more compact and easy installation, which is an interesting solution.

Several antenna types have been used to implement this technology among which the microstrip patch antennas are of great importance due to their eye-catching attributes as they are light weight, low profile, inexpensive and top of all, quick and simple to fabricate [3].

However, designing the microstrip patch antenna, while meeting the commercial requirement of satellite communication system and other design constraint, is becoming more challenging for design engineers. Different microstrip patch antennas are present in market that can be used for uplink or downlink. Different design engineers have also designed dual band antennas that can be used for both uplink and downlink to achieve higher efficiency. However, it will be good step in research to design a dual band antenna with efficient gain and low losses for C band frequencies i.e the most important band for satellite communication.

1.2 Research Motivations:

1.2.1 Phased array antennas operating at C Band:

In past few years, the trend of antennas used for satellite communication is towards miniaturization. Antenna is an integral part of satellite communication system. Phased array antennas are popular and efficient proposed solution to overcome the problems of large reflector antennas. From the different types of antennas used for phased array technique, microstrip patch antennas are of great importance due to their remarkable features like smaller size, less expensive and easy to fabricate. That's why different researchers proposed different phased array microstrip patch antennas for satellite communication operating at different bands. My interest was to design a novel antenna operating at C band i.e. the most important band for satellite communication for both uplink and downlink frequencies.

1.2.2 Problem statement:

Lot of microstrip patch antennas are proposed for phased array technology operating at different frequencies bands for satellite communications with different techniques and shapes but most of them are designed only for either uplink or downlink applications.

The main thing I noted down in my literature survey was that, these proposed antennas are operating at a single frequency either for downlink or uplink and few of them are operating at dual band frequencies but not in a single band [6]. As C band is most important for satellite communication due to its capacity to severe drastic weather conditions like heavy rain, so there should be a dual band antenna in this band for both uplink and downlink frequencies with efficient gain and low return losses.

1.2.3 Aims and Objectives:

1.2.3.1 A novel design B shape antenna operating at C band:

My aim was to design a novel shape antenna operating at C band i.e. the most important band for satellite communication with both uplink as well as downlink frequencies. The designed antennas provide efficient gain and very low losses at 4 GHz and 7.92 GHz.

1.2.3.1 A dual band B shape antenna operating at C band:

Due to segment utilization, different researchers are designing dual band antennas for uplink as well as downlink applications. That’s why it is necessary to design a dual band antenna at these two frequencies of C band to meet requirements of modern research.

Therefore, thesis provides a novel design dual band B shape microstrip patch antenna for satellite communication operating at C band frequencies of 4 GHz and 7.92 GHz with an efficient gain and low return losses. Dual band antenna at these frequencies of C band with complete utilization of segment is the scope of this thesis. Moreover, frequencies of designed antennas are highly matched to the ITU standard and PTA frequency allocation board for satellite communication.

1.4 Applications:

Antennas designed at C band frequencies can be used for lot of applications due to the better performance of C band in adverse weather conditions [3].

The main purpose of designing a phased array B shape antenna at C band is a proposal for its usage in satellite communication because C band is most important band for satellite communication. The selected frequencies are highly matched to the ITU standard and PTA Frequency Allocation Board assigned frequencies for uplink and downlink satellite communication [15].

Moreover, antennas with these frequencies of C band can be used for radar applications, especially for weather radar system, maritime communication, aviation security, VSAT and different military applications [2]

Chapter 2

LITERATURE REVIEW

2.1 Microstrip Patch Antenna:

2.1.1 Introduction:

"Antenna is known as a sensor or a transition device that converts electromagnetic radiated energy to electric signals. It also transfers electromagnetic energy from guided medium to un-guided medium which means that it can transmit and receive electromagnetic waves". Different types of antennas are available in literature such as wire antennas, aperture antennas, printed antennas and lens antennas and etc. Microstrip antenna is a major type of printed antennas. A common microstrip antenna consists of two metallic conductor layers separated by a dielectric medium, as shown in Figure 2.1. Usually one layer serves as radiator and other as ground. Now a days microstrip technology have become very popular because of their compactness and conformity in metallic gadgets.

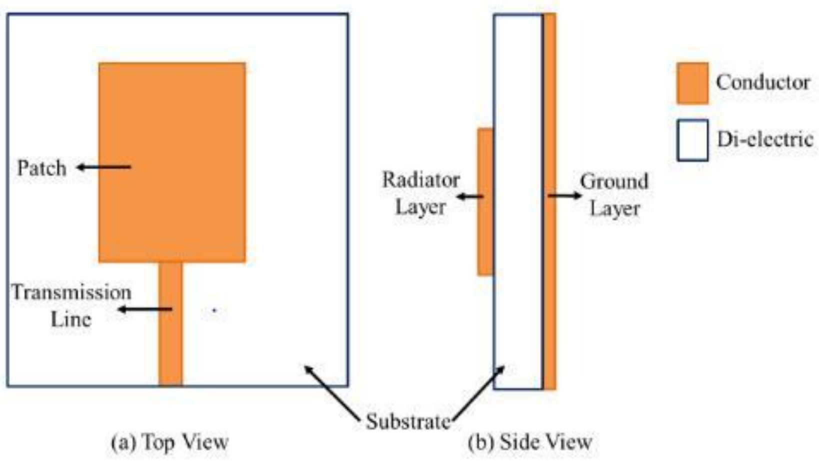


Figure 2.1 Microstrip Patch Antenna

Microstrip patch antenna has lot of applications in different fields of life, but now a days microstrip patch antennas are going to be preferred for phased array technique in satellite communication due to their stunning features. Different shapes of microstrip patch antennas are proposed that can be used for satellite communication by making their phased arrays [1].

2.2 Microstrip patch antennas proposed for satellite communication:

In this section, major types of Microstrip Patch antennas will be presented that can be used for satellite communication in different bands. All the performance parameters like return loss, gain, radiation properties and size of these antennas are discussed.

2.2.1 E-Shape microstrip patch antenna

In this paper a modified E shaped dual band antenna is proposed for C and X band satellite communication. It covers 6 GHz in C band and 9.2 GHz in X band. Separate antennas at 6 GHz and 9 GHz are designed as well as a dual band antenna at these two frequencies is also designed. Its design strategy and values of parameters are shown in figure 2.2

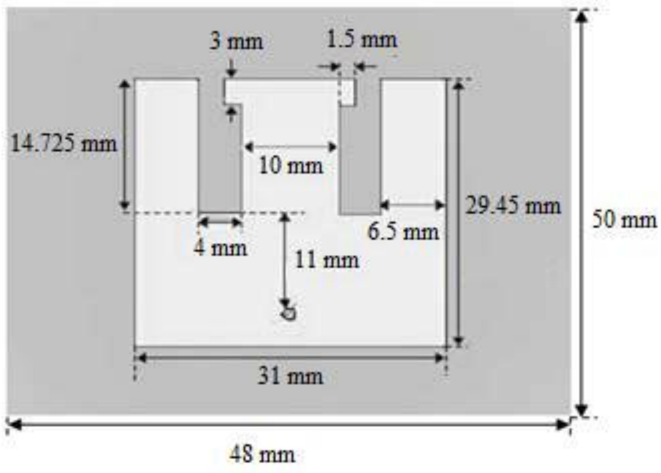


Figure 2.2 E-Shape microstrip patch antenna

It provides gain of 7.5 dBi by using different gain improvements techniques and loss of -26.3 dB with single element [8].

2.2.2 W Shaped Slotted Patch Antenna

In this research work a dual-Port W-shaped slotted microstrip patch antenna is proposed for satellite communication. It covers X-band for uplink satellite communication. W –shaped patch of the antenna is shown in figure 2.3.

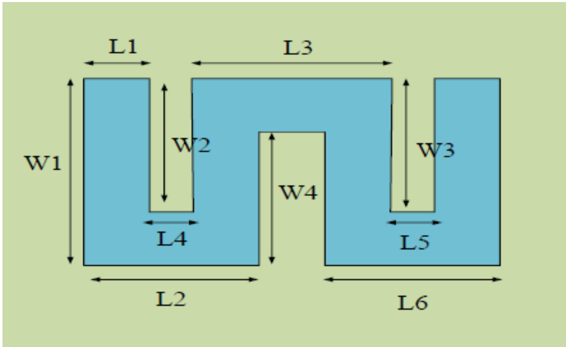


Figure 2.3 Patch of W-shaped Antenna

Overall patch is designed by merging two W-shaped patches to obtain better results. The front view of the W-shaped slotted microstrip patch antenna is shown in Figure 2.3.

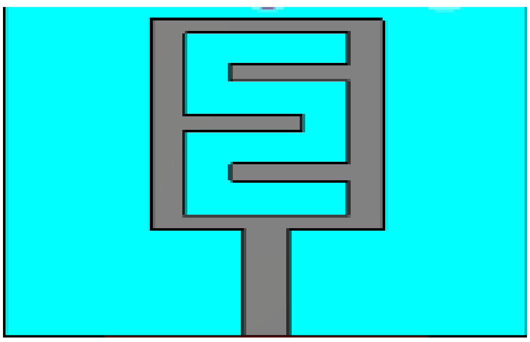


Figure 2.4 W-shaped Microstrip Patch antenna

It provides return losses of -26.945 dB and gain of 6.05 dBi with single element Operating at frequency of 8.26 GHz [2].

2.2.3 Slotted Rook Shaped Patch Antenna

In this research work designer claims to represent a novel slotted rook shape patch antenna. Antenna is proposed for downlink satellite communication and radar applications. Design strategy and values of related parameters are shown in figure 2.5

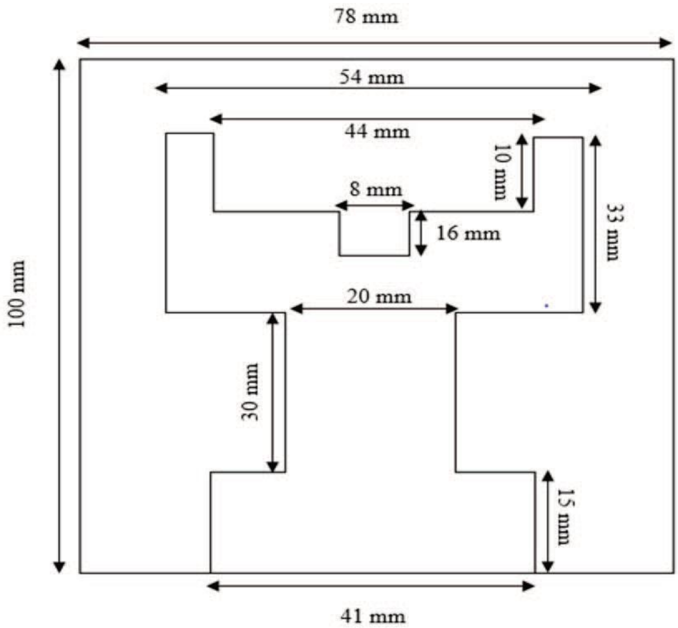


Figure 2.5 Slotted Rook shape Patch Antenna

The antenna is designed using software of CST at frequency 4.29 GHz. Design provides the return loss of -28.8 dB and gain of 5.7 dBi for single element [3].

2.2.4 Inverted L-Slot Patch Antenna

In this research work an inverted L-slot patch antenna is proposed for downlink communication. It consists of inverted L-slot patch with partial ground as shown in figure 2.2. Size of width is 25mm and length is 40mm for single element ground plane.

The antenna is designed using software of HFSS at solution frequency is 4.2 GHz. Design provides the return loss of -25.6 dB and gain of 6.8 dBi for single element.

Design parameters and all the used parameters are shown in figure 2.6 [4].

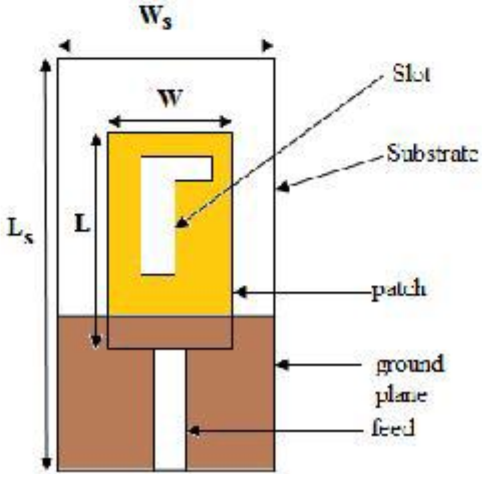
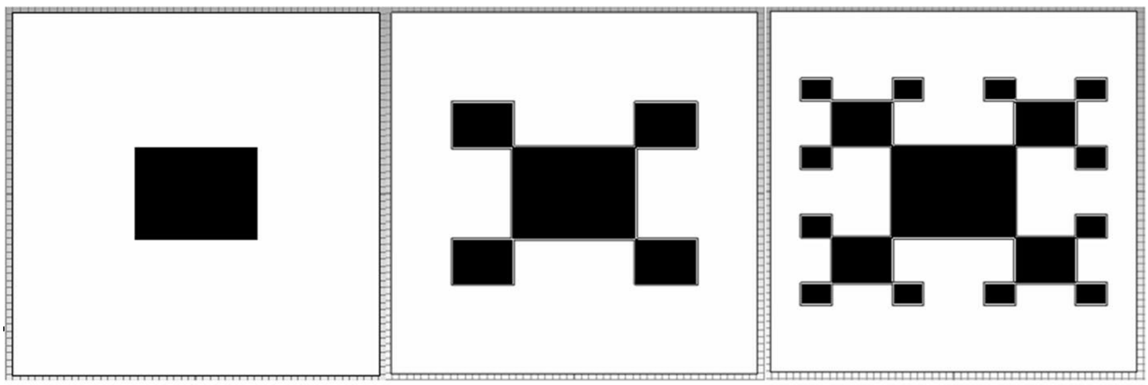


Figure 2.6 Inverted L slot Patch Antenna

2.2.5 A novel fractal geometry approach for patch antenna

In this research work a fractal geometry approach is proposed for microstrip patch antenna. The main patch of antenna is rectangular patch with 16.75 mm × 12.63 mm. These dimensions are the dimensions of base geometry and next iteration is formed from scale down rectangular patches of the main rectangular patch at all the corners of the main geometry. This process is repeated to get the second and third iteration. The final geometry obtained after the result of iteration is shown in figure 2.7(c).



(a) **(b)** **(c)**

Figure 2.7 **(a)** Main rectangular patch, **(b)** first iteration & **(c)** second iteration

The overall patch size reaches to the width of 12.63 mm and length of 16.74 mm for second iteration (c).The antenna is designed using CST. Antenna design provides the gain of 7.2 dBi and 7.22 dBi at these frequencies [5].

2.2.6 Microstrip patch antenna with four circular slots

The proposed design antenna consists of microstrip with four circular slots of radius 1.5 mm. The dimension and design strategy is shown in figure 2.8 (a) and (b) representing top and bottom view of antenna.

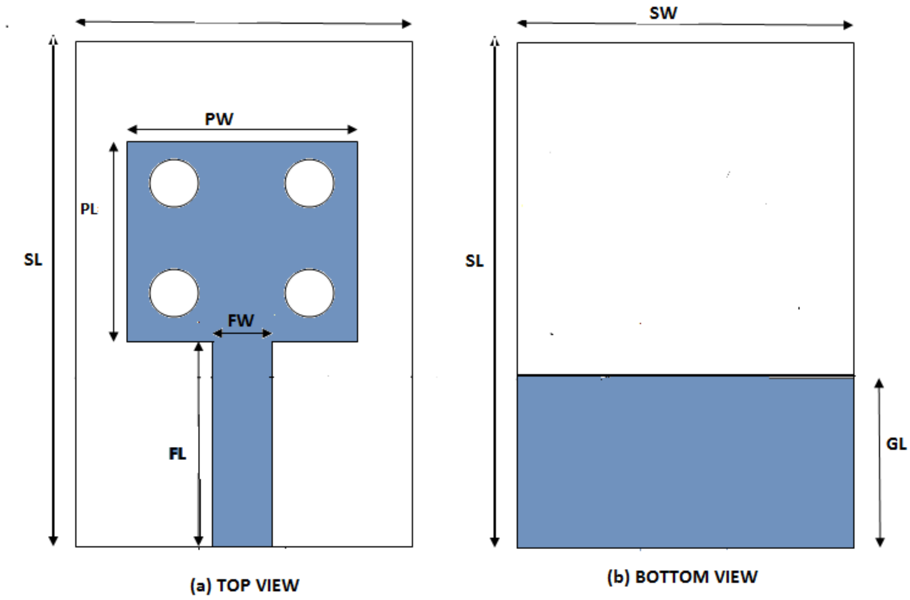


Figure 2.8 (a) Top view and **(b)** Bottom view

The antenna gives the best performance in C band for satellite communication as it provides -32 dB of return loss at 4.4 GHz. Similarly the proposed antenna with modified parameters provides better results for 5 GHz, 6 GHz and 6.8 GHz [6].

2.2.7 A dual band triangular microstrip patch antenna

In this research paper a triangular microstrip patch antenna with size of 80 mm, 55 mm, 39 mm is proposed for maritime applications and satellite communication. The coaxial feed line is used for feeding. Proposed antenna can operates at two modes of (4.9 -5.1) GHz and (5.72 – 5.86) GHz. Antenna configuration is shown in figure 2.9.

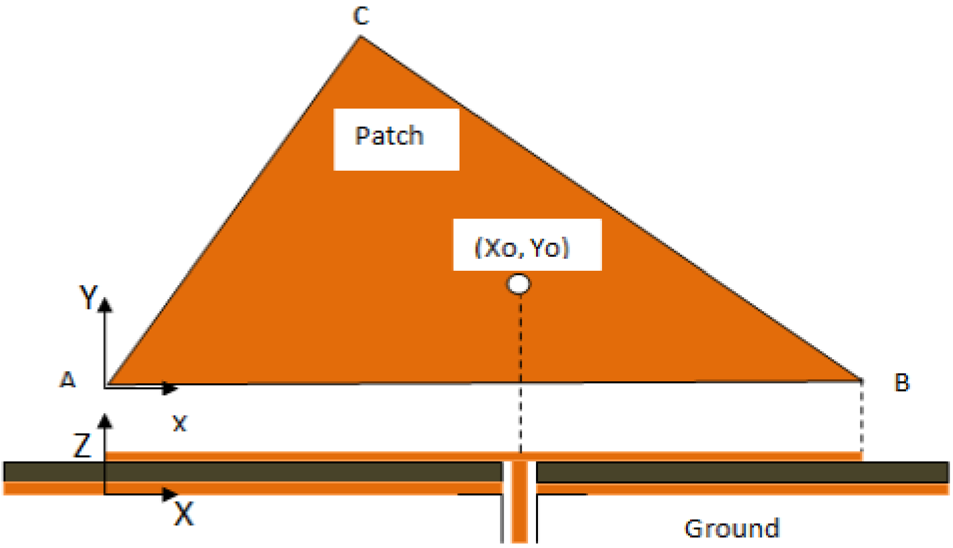


Figure 2.9 Triangular patch antenna

The antenna gives good results using HFSS software. It provides almost -42.5 dB return loss and better gain at given frequencies [7].

2.2.8 Metasurface Superstrate antenna

The proposed antenna consists of planer slot coupling antenna with an array. A metasurface superstrate technique is applied at this planer antenna. This technique is used to improve the gain and to adjust axial ratio for wideband circular polarization. Proposed antenna has compact structure with the size of ground is equal to 34.5 × 28 mm^2. Geometry of proposed antenna is shown in figure 2.10.

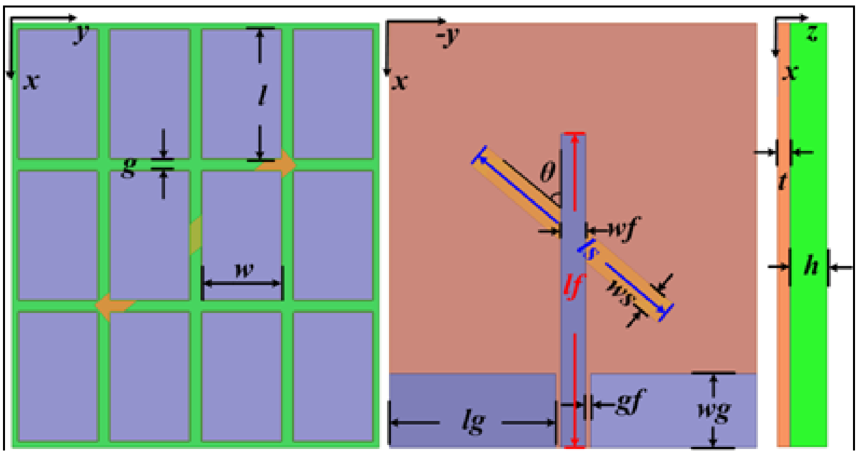


Figure 2.10 (a) top view **(b)** rare view **(c)** side view

The proposed antenna operates at different frequencies in the range of 4.2 to 5.9 GHz. It provides the gain of 5.8 dBi with single element. It has compact size as shown in figure 2.11

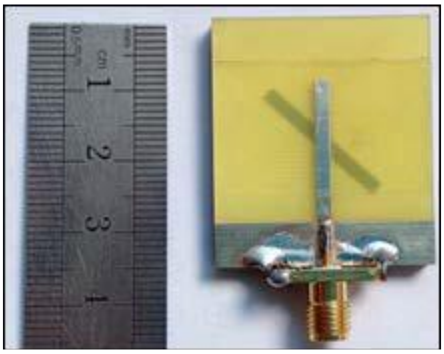


Figure 2.11 Fabricated metasurface superstrate antenna

The basic purpose of including this research paper in my literature survey is that it provides different techniques for the improvement of gain. It elaborates Left handed materials (LHM), Frequency selective Surface (FSS), metasurface and Electromagnetic Band Gap (EBG) techniques [9].

2.2.9 H shape microstrip antenna

The H microstrip patch antenna with I shape slot is proposed for satellite communications and weather radar. Antenna can operate at different frequencies of S, C and X band. Geometry of proposed antenna is shown in figure 2.12.

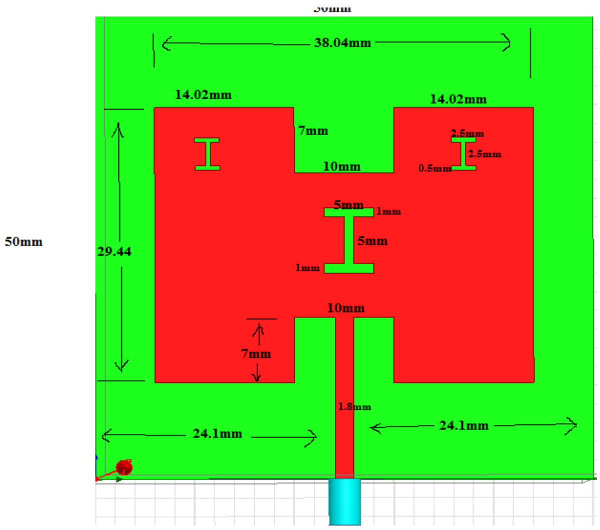


Figure 2.12 H shape microstrip patch antenna

The antenna is designed using HFFS. According to the researcher, there are different purposes of using slots but one of the purposes of using slots in shape is that you can change more parameters to adjust you results.

Moreover, different techniques of feed lines are proposed in this research paper that is helpful in optimization of results. Inset feed line and line feed at different places with different results is the beauty of this research as well [10]. H shape microstrip patch antenna with line feed line moved at the right side of the patch is shown in figure 2.13

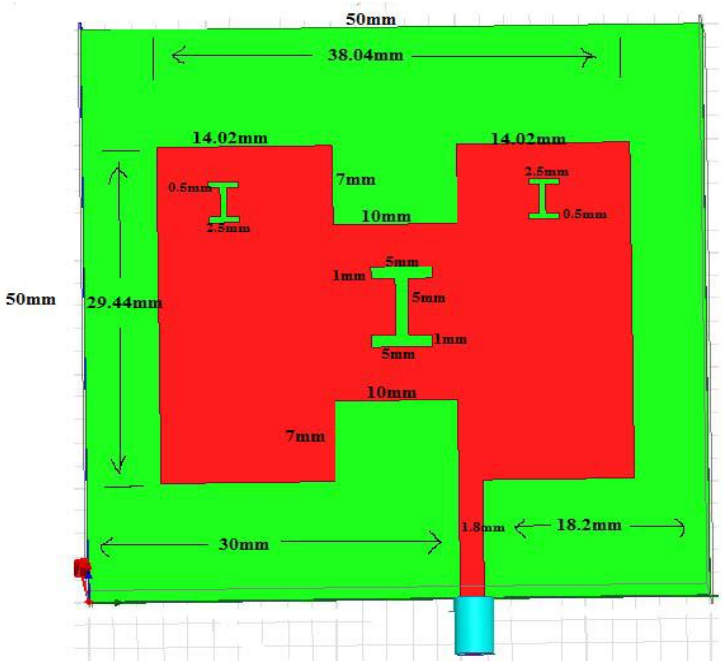


Figure 2.13 H shape microstrip fed off centre

2.2.7 Comparison

The main task of proposed antenna for satellite communication or any other application of C band communication is that you have to maintain efficient gain and minimum losses. For this purpose different design engineers designs different shape antennas to obtain efficient results. Moreover, different techniques are used for the enhancement of gain to fulfill the criteria of satellite communication. That’s why I have chosen different research papers in my literature survey for the implementation of any appropriate technique for the improvement of gain and efficient shape for the design of antenna. Comparison of the different techniques used in different research papers for the improvement of gain and many other required parameters are discussed in table 2.1. Table shows the comparison of gain and return losses of the proposed microstrip patch antennas used for satellite communication.

Table 2.1 Comparison of gain, return loss and techniques used in proposed Patch Antennas

Sr. No	Name of Antenna	Return Loss (S_{11})	Gain	Techniques used for improvement of results
1	E Shape microstrip patch [8]	< -26.5 dB	≈ 7 dBi	Shape notching
2	W Shape microstrip patch [2]	< -27 dB	> 6 dBi	Multiple ports, DGS
3	Slotted Rook Shaped Patch [3]	< -29 dB	> 5.8 dBi	DGS
4	Inverted L-Slot Patch [4]	< -25.6 dB	> 6.8 dBi	Slots in shape, DGS
5	Novel fractal geometry patch [5]	< -21 dB	> 7.2 dBi	Fractal geometry
6	Microstrip patch with four circular slots [6]	< -32 dB	> 6.1 dBi	Slots in Shape
7	Triangular microstrip patch [7]	< -42.5 dB	> 6.1 dBi	Shape/Structural based
8	Metasurface superstrate antenna [9]	< -21 dB	> 5.8 dBi	LHM, FSS and EBG
9	H shape microstrip [10]	< -27 dB	> 5.9 dBi	Changing location of ports

2.3 Gain enhancement Techniques used in proposed antennas

Very first demand of proposed antennas for satellite communication is high gain and very low return loss. Due to its larger distance, satellite communication requires more power and very low return losses [1]. To fulfill this demand, different design engineers used different techniques for the improvement of gain. In this section, different gain improvement techniques available in literature will be presented.

2.3.1 Geometry of antenna (Shape and Size)

The shape and size of microstrip patch antenna plays an important role in overall results. Antennas with different shape and size provide different results for same frequency bands.

Initially, rectangular patch antennas were introduced in market for the purpose to use microstrip patch antennas for different applications. This type of antennas became very famous due to their small size, light weight and top of all easy and quick to fabricate. With the passage of time design engineers felt that with the change in their shape and size, their results can be improved and in this way changes in shape and size of patch antennas were started. Initially, little bit changes were made in rectangular patch to improve the results but this race gave birth to the complete change in shape and introduced totally new shapes in microstrip patch antennas.

Microstrip patch antennas with lot of shapes and design are present in market today. Few of them are presented in this unit of literature survey with their parameters and results. Antennas with different alphabets shape are present in market i.e. E shape antenna, inverted F shape antenna, H shape antenna, inverted L shape antenna, S shape antenna, U shape antenna, W shape antenna, X shape antenna, Y shape antenna and Z shape antenna. All these antennas have their own characteristics and results [2], [4], [8], [9]. Similarly microstrip patch antennas with many shapes other than alphabets are present in market i.e. circular shape antenna, triangular shape antenna, elliptical shape antenna, dipole antenna, slotted rook antenna, fractal shape antenna, pentagon shape antenna, hexagon shape antenna etc. All these antennas have their own characteristics and results [3], [5], [6], [7].

In a nutshell, the shape and size of patch antennas matters a lot in their characteristics and results. Due to this fact most of the antennas proposed for satellite communication comprises different shapes and size.

2.3.2 Use of slots in patches and ground plane

As, it is discussed in previous section that shape and size of antenna matters a lot in their radiating properties, so use of slots in shape may affect its many properties like return loss, gain and radiation pattern of antenna.

Different researchers concluded in their research that use of slots may affective in either gain improvement or reduction in return losses. In the research paper of "microstrip patch antenna with four circular slots", the researcher elaborates that how these slots are useful for the improvement of gain [6]. Similarly "inverted L-slot patch antenna" uses inverted L shape slot in its patch to increase the gain, reduce the return losses and to improve the radiation pattern [4]. Moreover, slots in patch are helpful for circular polarization as well as other parameters improvement but slots in ground plane are purely helpful for the improvement of gain of antennas [11].

2.3.3 Defected Ground Structure (DGS)

The conducting metal of ground plane is etched off in specific shape according to design of patch or requirements that provides wide rejection of band and covers some frequency range. This type of structure is known Defected ground structure (DGS). [11]

Researches shows that defected ground can be used for the improvement of gain. According to the researchers the defects in a ground plane of antenna can store a fraction of energy and due to this property of DGS technique; it is very helpful in improvement of gain and some other parameters. [12]

DGS is introduced on antennas to improve their gain. Different research papers show the improvement of gain in the range of (0.7 – 1.6) dBi using DGS technique. [11], [12]. DGS technique is very affective in antennas that are proposed for satellite communication because it needs more gain as compared to the other applications.

2.4.4 Electromagnetic Band Gap (EBG) structures

"Some square patches that are spread over substrates of certain size at a certain distance is called electromagnetic band gap (EBG)". EBG can improve gain, radiation efficiency and can wide the bandwidth. In this research paper, the EBG technique is applied at circular patch antenna proposed for inter satellite link (ISL) on low orbit satellite [17].

One of the researchers properly compared his results with and without implementation of EBG techniques. According to his results EBG technique is efficient for the improvement of gain in patch antenna and ultra wide band (UWB) in different antenna [13]. Different researchers introduce EBG technique for the improvement of different parameters but one of them has shown the results of gain improvement in microstrip patch antenna [16].

It is analyzed from research papers that EBG technique plays an important role in the improvement of different parameters of all the microstrip patch antenna and especially microstrip patch antennas used for wireless communication [15]. Similarly, this technique is found to be very useful for other antennas like horn antenna for the improvement of gain [14]

2.4.5 Notching Technique

This technique is based on the concept to implement notches of different sizes at different locations in a design of an antenna. The basic purpose of implementation of this notching technique is to improve different parameters like return losses, gain, and radiation pattern. Most of the UWB antenna uses this technique to provide ultra wide bandwidth [18]. Notches can be made at different locations of patch of antenna according to the design and specifications but notches ate edges are useful to improve gain [20].

One of the researcher implemented notching technique for UWB MIMO antenna to achieve most of the UWB and improved gain [21]. Most of the UWB antenna designer used notching technique to achieve ultra wide band and good isolation. This technique is more helpful in UWB antenna and for UWB MIMO antennas [22].

Notching technique not only provides results improvement but this technique provides extra bands for communication as in [23]. Analysis of all the types of notching and improvements in results is presented in [19].

2.4.6 Frequency Selective Surface (FSS)

A two-dimensional periodic array structure, which is constructed by metal patch units is known Frequency selective surface (FSS). These patches are arranged periodically. Like a band stop or spatial filter, FSS is used to control the transmission characteristics of the incident electromagnetic wave. In this way the total reflection or transmission is obtained on the resonance frequency of the surface [25].

FSS acts as reflection plane and due to property of reflection it can easily manage the directivity of an antenna. It is highly gain and directivity improvement technique for microstrip patch antennas [24].

Analysis of FSS technique shows that it is highly efficient in gain improvement. It is shown from research papers that it can improve gain up to 10 dBi in different patch antennas [26].

2.4.7 Antenna Arrays

Different techniques for the improvement of gain and return losses can be implemented as discussed above but modern communication system demands more and more gain due to all the practical facts of today's communication. Antenna array is nothing but it is set of antennas that can work together as a single antenna is called antenna array.

Antenna arrays were being implemented on patch antennas, used for different applications but now a day's the demand of antenna arrays is increased due to their use in 5G applications antennas and many other such applications [28].

Depending upon the antenna array technique, phased array patch antennas are being proposed over large reflector antennas for satellite communication. So phased array technique is very important for satellite communication with reduction in size and enhancement in gain [30]. Adjustment of large mechanical antennas at satellite is very difficult, so simple patch antennas with array are being proposed for downlink satellite communication as well as uplink communication [29].

Practically, arrays can be made by different ways and specifications depending upon our requirements. Different types of array with their specifications are discussed in [27].

2.4 Comparison

Each technique has its own merits and demerits. All the discussed techniques have their own unique features for the improvement of different parameters but they may have some demerits as well.

Uses of slots can improve many parameters of antenna but in different cases they cause reduction in gain. DGS brings lot of improvement in parameters but changes the phase and magnitude of ground plane which may affect the applications depending upon phase and magnitude. Similarly use of slots improves many parameters but may cause narrow bandwidth in many cases. EBG and FSS are efficient techniques for the improvement of gain and radiations but these techniques are costly as compared to the other techniques. High gain is achieved using antenna array technique but it may results in increase in return loss.

So each technique has its own merits and demerits but design engineer should choose which technique; it depends upon its requirements and area of applications. Comparison of different techniques is presented in [31].

Chapter 3

DUAL BAND NOVEL DESIGN B-SHAPE MICROSTRIP PATCH ANTENNA

In this chapter, design and analysis of dual band B shape microstrip patch antenna is presented. Similarly, another two antennas at these two frequencies that are used in dual band are presented separately as Antenna-1 and Antenna-2. Antenna-1 operates at 4 GHz proposed for downlink satellite communication and Antenna-2 operates at 7.92 GHz proposed for uplink satellite communication. The design process of these antennas is divided in three major stages. First stage is the design of single element B shape microstrip patch antenna. Second stage is implementation of edges notching technique for the enhancement of gain. Third stage is the design of arrays and main aim of this stage is to fulfill the criteria of phased array technique proposed for satellite communication.

3.1 B -Shape Microstrip Patch Antenna

3.1.1 Parameters Selection

The design process started by the selection of dielectric substrate and in this case, FR4 with dielectric constant 4.7 is chosen as dielectric substrate. Height of substrate used in design process is 1.59 mm due to its availability in Pakistan. FR4 is very low-cost substrate and easily available in market. The goal of these antennas design is to achieve overall better results for uplink and downlink satellite communication according to the ITU standard keeping the size of antenna in normal range.

Following B –shape novel design microstrip patch antennas are proposed in this thesis: Antenna-1 for downlink at 4 GHz, Antenna-2 for uplink at 7.92 GHz and dual band antenna for both downlink and uplink at 4 GHz and 7.92 GHz frequencies.

3.1.2 Basic Structure

The idea of novel design B –shape antenna is the aim of thesis and it not very difficult to achieve this B shape structure. Take two adjacent circular patches and join them and then cut their lower semi circles. Adjust rectangular patch equal to the width of these two semi circles below the upper semi circles. Assign a feed line to the B- shape patch. It is simple B –shape microstrip patch antenna as shown in figure in 3.1

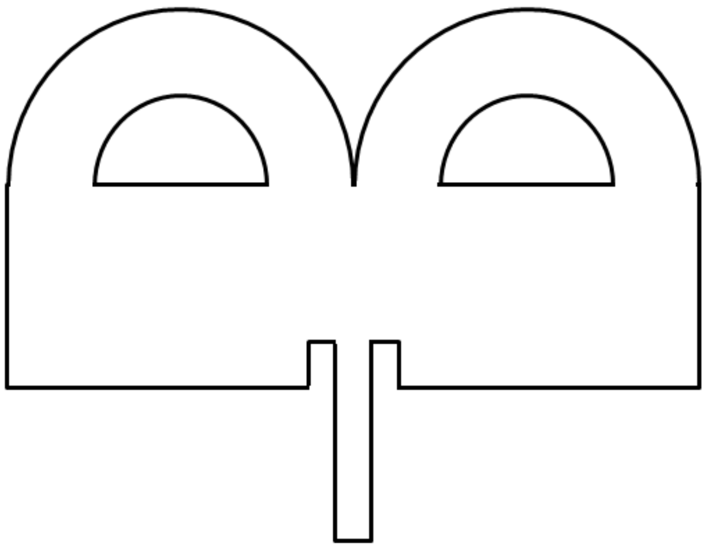


Figure 3.1 Basic Structure of B -Shape Antenna in Stage 1 of design Process

B shape microstrip patch antenna consists of four elements, radiating patch, substrate, ground plane and transmission feed. The design of B shape microstrip patch antenna starts with the selection of the shape of radiating patch and the transmission line feed structure.

Rectangular patch is selected as radiating element of B shape microstrip patch and its size is 12.5-14.2 mm x 31.4 – 47.8 mm for different antennas operating at 4 GHz, 7.92 GHz and dual band frequencies. The antennas are fed by.5.8-5.9 mm long transmission line (TL). The width of transmission line for single patch is 9.13 mm so that the impedance of TL is matched to 50-ohm. The basic structure of antenna at this stage is shown in Fig 3.1. Stage 1 of simulated B –shape microstrip patch antenna with single element using CST is shown in figure 3.2

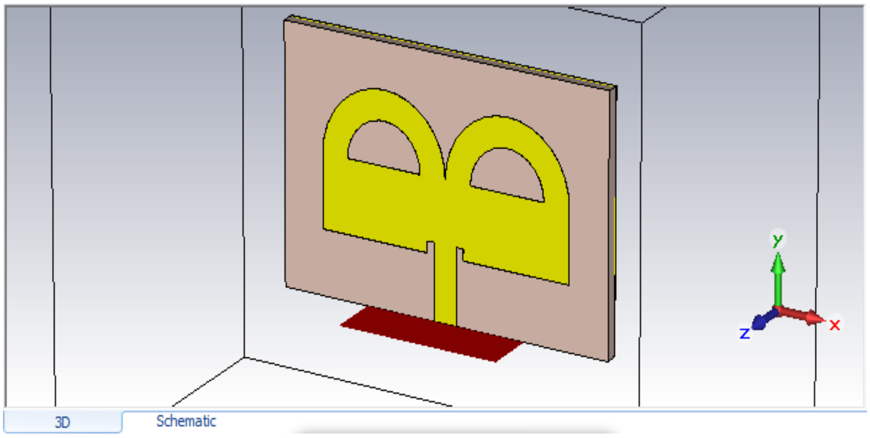


Figure 3.2 B -Shape Antenna model without Notched edges (Simulated)

3.1.3 Notched Edges B –Shape patch antenna

As, it is discussed earlier in literature review (chapter 2) that different techniques can be adopted gain improvement. One of them is notching edges technique. It is very important to keep in mind that the most important parameter for proposed antenna is its gain, that's why this notching edges technique is applied in initial design stage. We can improve the gain of antenna by using different techniques after design of patch but it will be icing on cake to implement notching edge technique in design. Quarterly circles cutting is performed from the bottom of edges as shown in figure 3.3

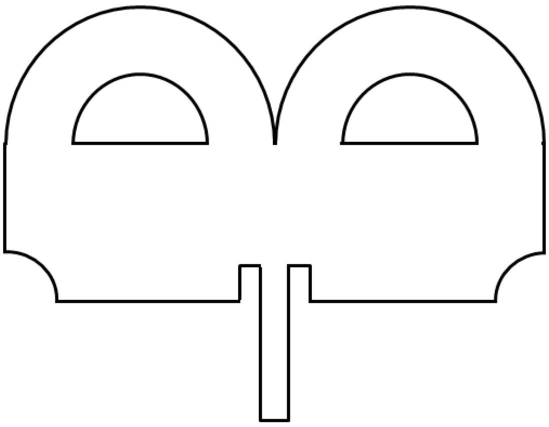


Figure 3.3 B -Shape Antenna model with Notched edges in Stage 2 of design Process.

The size of notching will be discussed in next section of parametric values discussion as its size varies for different antennas. Simulated Notched edges B –shape antenna using CST software is shown in figure 3.4

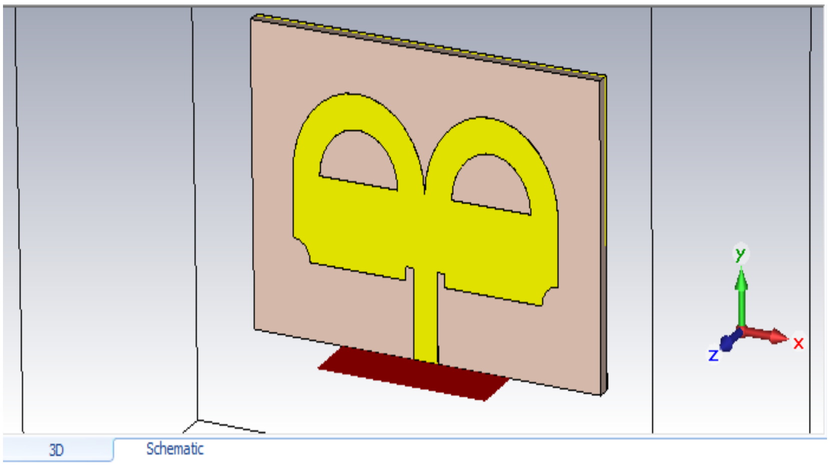
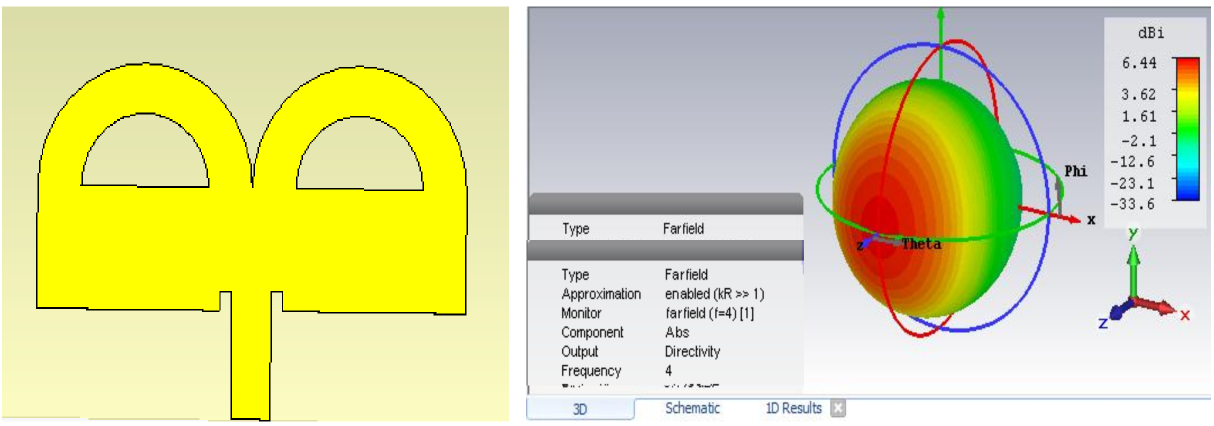


Figure 3.4 B -Shape Antenna with Notched edges (Simulated)

3.1.3.1 Gain Improvement with Notched Edges Technique

This notching edges technique is very helpful in improvement of the gain. I would like to elaborate this concept with the help of single element B shape antenna operating at 4 GHz. Antenna without notched edges provides the gain of 6.44 dBi as shown in figure 3.5(a) and 3.5(b).



(a) **(b)**

Figure 3.5(a) B-shape antenna without notched edges **(b)** Gain of B-shape antenna without notched edges

Same B shape antenna operating at 4 GHz with all the same parameters provides the gain of 6.69 dBi after implementation of notching edge technique. This B –shape notched edge antenna and its gain is shown in figure 3.5(a) and 3.5(b).

(a) **(b)**

Figure 3.6(a) B-shape antenna with notched edges **(b)** Gain of notched edges B-shape antenna

Therefore, this technique is very helpful in improvement of gain. This technique fulfills the requirement of high gain proposed antenna for both uplink and downlink satellite communication.

3.1.3.1 Reduction in Return Losses with Notched Edges Technique

With the improvement of gain, the notching edges technique is also proved to be beneficial for the reduction in return losses.

Return loss with and without notched edge technique of different antennas will be presented in this thesis. I would like to use a single B –shape antenna with and without notched edges operating at 4 GHz for the comparison of return losses. Single B shape antenna without notches provides the gain of -17.77 dB at 4 GHz as in Figure 3.7(a).

But the same antenna with same parameters provides the gain of -35.9 dB when notching edge technique is applied as shown in figure 3.7(b).

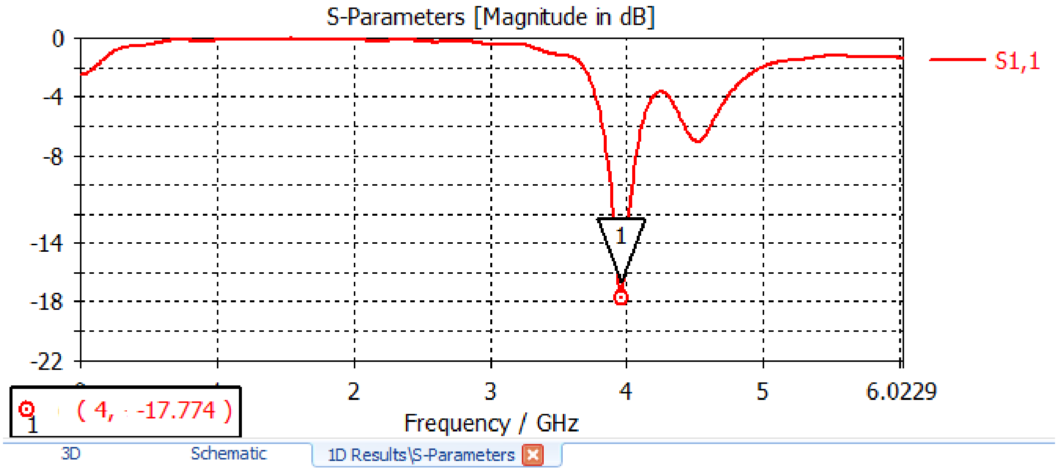


Figure 3.7(a) S11 of B-shape antenna without notched edges

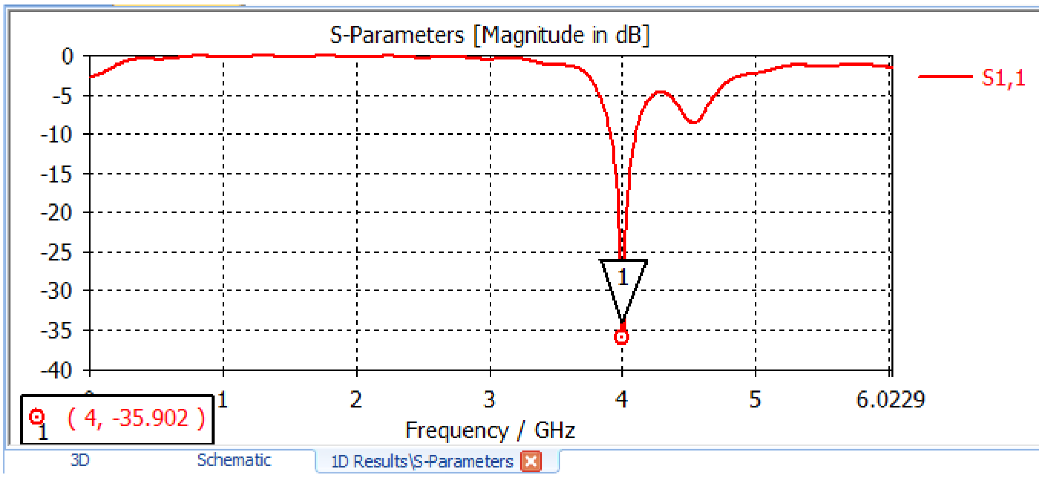


Figure 3.7 (b) S11 of B-shape antenna with notched edges

So notching edge technique is very beneficial in reduction of return losses as it has reduced the losses from -17.7dB to -35.9 dB.

3.1.4 Description of Parameters used in B –Shape antenna

Patch of B Shape microstrip patch antenna comprises two adjacent semi circles empty from inner side, one rectangular patch and single inset feeding line. These values or parameters are represented by the combination of different alphabets. It is very important to elaborate these parameters which are represented by alphabets.

These parameters are shown in a proper cutting edge B shape antenna in figure 3.8 and explanation of these parameters in represented in Table 3.1

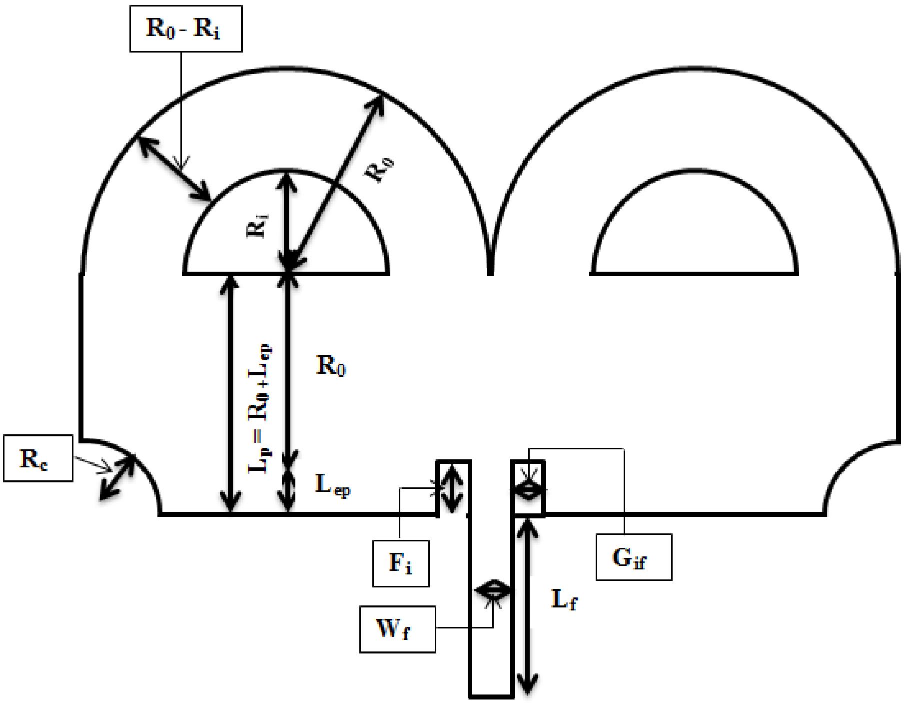


Figure 3.8 Notched edge B –Shape antenna with parameters

Table 3.1 Description of parameters used in B Shape antenna

Sr. No.	Parameter	Description
01	Ro	Outer Radius of circular patch
02	Ri	Inner Radius of circular patch
03	Lep	Length of Extra patch
04	Rc	Radius of Cutting edge circle
05	Fi	Feed Inset
06	Wf	Width of Feed line
07	Lf	Length of Feed line
08	Gif	Gape between Inset Feed

Upper part of patch is the combination of two adjacent semi circles but lower part of patch is combination of two rectangular patches. First part of rectangular patch is a patch with length equal to Ro, but there is an extra rectangular patch below this rectangular patch whose length is represented with variable Lep. Use of variable is very helpful in results optimization. Instead of opening geometry of each antenna and changing its values manually, we can easily change the value of any parameter. That's why all above mentioned parameters are used with variables and discussed in detail in Table 3.1

3.2 B –Shape antennas for Satellite Communication

Different B –shape antennas are the part of this thesis for satellite communication. According to the ITU standard and PTA specifications C band frequencies ranging from 3.7 GHz to 4.2 GHz can be used for Downlink (Space to Earth) satellite communication and 7.9 GHz to 8.025 GHz frequency range can be used for Uplink (Earth to Space) [32]. Therefore three different B shape antennas are designed according to the ITU and PTA standard for uplink as well as downlink satellite communication. Antenna-1 is designed at 4 GHz to cover downlink satellite communication; Antenna-2 is designed at 7.92 GHz to cover Uplink satellite communication and finally a dual band antenna at 4GHz and 7.92 GHz is designed to provide coverage for both Uplink as well as Downlink satellite communication.

3.2.1 B –Shape antenna for Downlink Satellite Communication

B –shape antenna operating at 4.2 GHz proposed for Downlink (Space to Earth) satellite communication is shown in figure 3.9. Values of the entire parameters of B shape antenna operating at 4 GHz are given in Table 3.2.

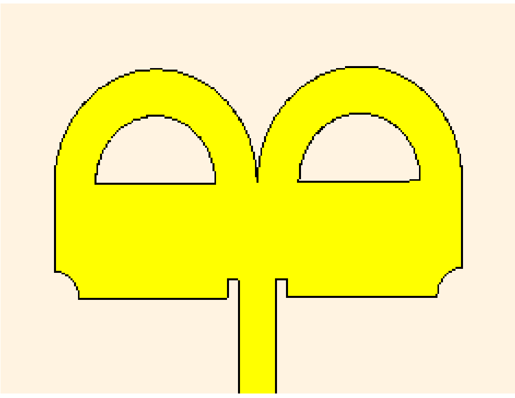


Figure 3.9 Proposed B shape antenna for Downlink (Simulated)

Table 3.2 Values of parameters used in Downlink B Shape antenna

Sr. No.	Parameter	Description	Value (in mm)
01	Ro	Outer Radius of circular patch	8
02	Ri	Inner Radius of circular patch	4.75
03	Lep	Length of Extra patch	0
04	Rc	Radius of Cutting edge circle	2
05	Fi	Feed Inset	1.25
06	Wf	Width of Feed line	2.913
07	Lf	Length of Feed line	5.8
08	Gif	Gape between Inset Feed	0.9

Height of substrate is set be 1.59 mm as it is easily available in market and height of patch is 0.035 mm. This single element B shape antenna provides better results of S11 and gain which will be represented in next chapter.

3.2.2 B –Shape antenna for Uplink Satellite Communication

B –shape antenna operating at 7.92 GHz proposed for Uplink (Earth to Space) satellite communication is shown in figure 3.10. Values of the entire parameters of B shape antenna operating at 7.92 GHz are given in Table 3.3.

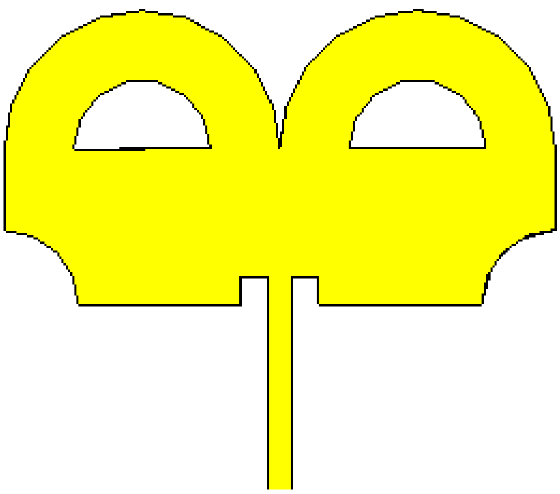


Figure 3.10 Proposed B shape antenna for Uplink (Simulated)

Table 3.3 Values of parameters used in Uplink B Shape antenna

Sr. No.	Parameter	Description	Value (in mm)
01	Ro	Outer Radius of circular patch	4.02
02	Ri	Inner Radius of circular patch	2
03	Lep	Length of Extra patch	0.5
04	Rc	Radius of Cutting edge circle	2.25
05	Fi	Feed Inset	0.8
06	Wf	Width of Feed line	2.913
07	Lf	Length of Feed line	5.6
08	Gif	Gape between Inset Feed	0.8

Height of substrate is set be 1.59 mm as it is easily available in market and height of patch is 0.035 mm. Both antenna are designed at allotted frequencies of the ITU Frequency allocation table for uplink and downlink satellite communication.

3.2.3 Dual band B –Shape antenna for Uplink and Downlink Satellite Communication

A dual band B –shape antenna is designed at these both frequencies of downlink and uplink. It operates at 4 GHz and 7.92 GHz for Downlink and Uplink satellite communication respectively. Antenna is shown in figure 3.11 and values of the entire parameters of dual band B shape antenna are given in Table 3.4.

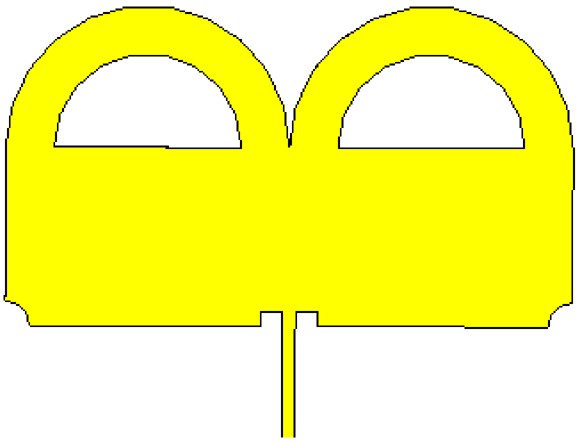


Figure 3.11 Proposed Dual band B shape antenna (Simulated)

Table 3.4 Values of parameters used in Dual band B Shape antenna

Sr. No.	Parameter	Description	Value (in mm)
01	Ro	Outer Radius of circular patch	6.97
02	Ri	Inner Radius of circular patch	4.6
03	Lep	Length of Extra patch	1.81
04	Rc	Radius of Cutting edge circle	1.2
05	Fi	Feed Inset	0.7
06	Wf	Width of Feed line	2.913
07	Lf	Length of Feed line	5.72
08	Gif	Gape between Inset Feed	1.1

Height of substrate is set be 1.59 mm as it is easily available in market and height of patch is 0.035 mm. Dual band B shape antenna follows the allotted frequencies of the ITU Frequency allocation table for uplink and downlink satellite communication [32]

3.3 B –Shape Microstrip Patch antenna Arrays

As, it is discussed earlier in Chapter 1 that phased array patch antennas are being promoted for satellite communication. So arrays are very important in all proposed antenna for satellite communication. Antenna arrays are implemented on all antennas to enhance gain and improve some other parameters.

3.3.1 Discussion of parameters used in B –Shape antenna Arrays

3.3.1.1 Feeding Technique

There are different feeding techniques that can be used for arrays. Corporate array, lambda by 4 transformer and power divider techniques are mostly used for antenna arrays. Thesis provides two elements array implemented by using power divider feeding technique. The spacing is based on $\frac{1}{2}\lambda$(or half wavelength) using appropriate feeding technique. Value of spacing may be increased by the product of 3, 5 and so on depending upon the types and specification of antennas.

3.3.1.2 Impedance Matching

Impedance of feed line near the patch or directly connected to the patch is kept 100 Ω and impedance of initial feed line or feed line within the port is kept 50 Ω for proper impedance matching. While impedance of the combined feed line, connecting feed lines of two elements is measured by using the given formula.

$$Z_o = \sqrt{Z_1 \times Z_2}$$

So the impedance of combine feed line, connecting the feed lines of two elements is 70.71 Ω. In this way impedance matching is done by choosing these impedances of specified feed lines. Impedance is calculated from analytical line impedance calculator in CST. Impedance calculation depends upon the following three parameters:

i. Material of Substrate
ii. Height of Substrate
iii. width of Feed line

Material of substrate cannot be changed once it is chosen. Similarly it is not possible to change height of substrate for different antenna designs. FR4 material with height of 1.59 is easily available in market that's why it is preferred over any other material. So one and only parameter that can be changed is the width of feed line. That's why width of feed line is changed to adjust different values of impedance. What should be the values width of feed lines to obtain required impedances, are shown in table 3.5?

Table 3.5 Values of parameters for impedance calculation

Width of Feed line (mm)	Height of Substrate (mm)	Permittivity of Substrate	Calculated Impedance (Ω)
2.913	1.59	4.7 / 4.4	50
1.512	1.59	4.7 / 4.4	70.71
0.645	1.59	4.7 / 4.4	100

3.3.2 B –Shape antenna array for Downlink Satellite Communication

Design of two elements array of B shape antenna for Downlink communication is shown in figure 3.12. Antenna operates at 4 GHz. Antenna arrays is designed using CST software. All the parameters of this antenna are same as discussed in atble 3.2. Newly added parameters for arrays like spacing and impedence matching are also discussed in section 3.1.2, so there is no need to show the values of these parameters at this stage.

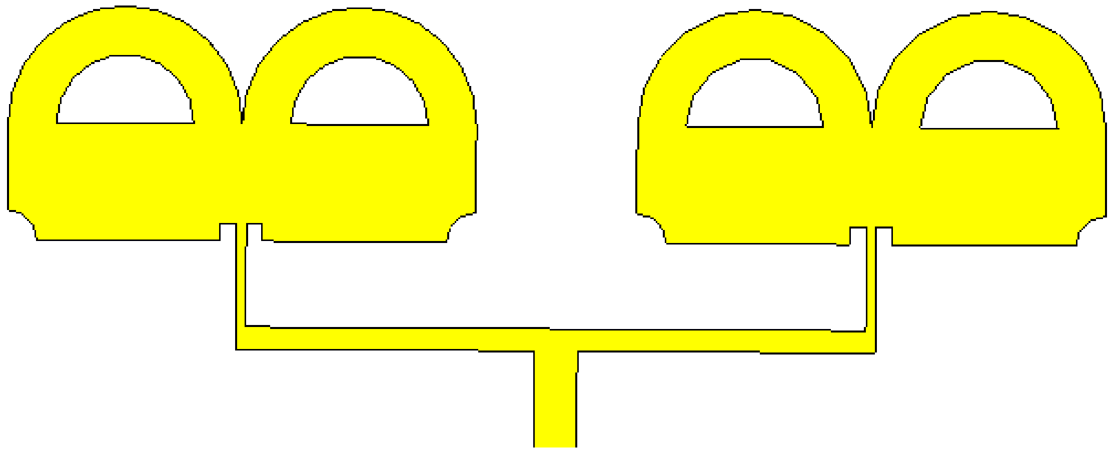


Figure 3.12 Two element array of B –Shape antenna for Downlink Communication (Simulated)

3.3.3 B –Shape antenna array for Uplink Satellite Communication

Design of two elements array of B shape antenna for Uplink communication is shown in figure 3.13. Antenna operates at 7.92 GHz. Antenna arrays is designed using CST software. All the parameters are same as discussed in table 3.3. Newly added parameters for antenna array like spacing and impedence matching are also discussed in section 3.1.2, so there is no need to show the values of these parameters at this stage.

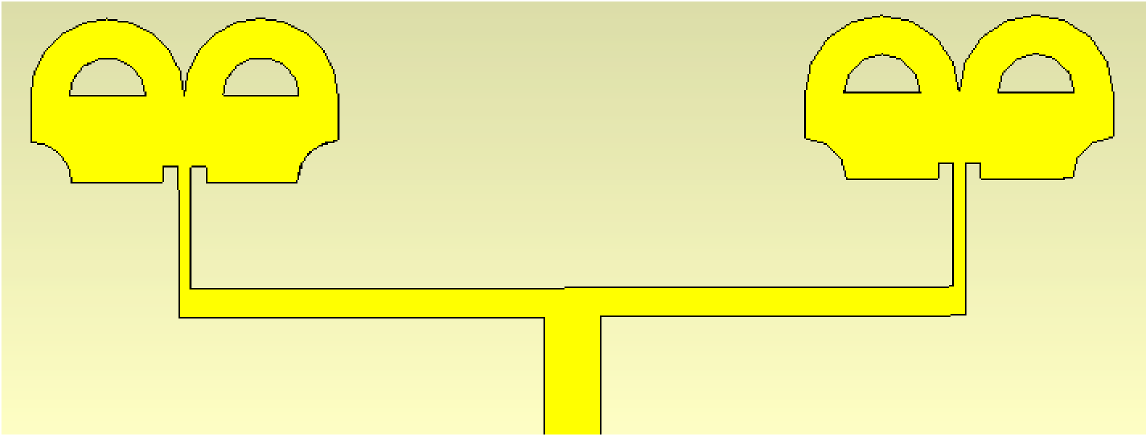


Figure 3.13 Two element array of B –Shape antenna for Uplink Communication (Simulated)

3.3.4 Dual Band B –Shape antenna array for Downlink and Uplink Satellite Communication (Simulated)

Two elements array of Dual band B shape antenna is shown in figure 3.14. Antenna operates at 4 GHz for Downlink and at 7.92 GHz for Uplink communication. Antenna array is designed using CST software. All the parameters are same as discussed in table 3.4. Newly added parameters for antenna array like spacing and impedence matching are also discussed in section 3.1.2 which are same for all the antenna arrays, so there is no need to show the values of these parameters at this stage.

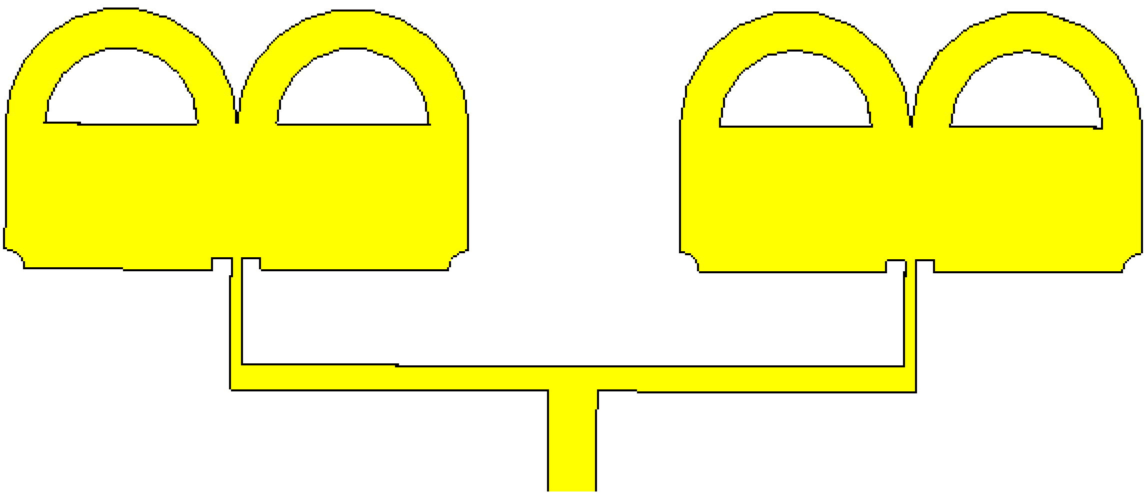


Figure 3.14 Dual band B –Shape antenna array for Downlink and Uplink Communication (Simulated)

3.4 Fabricated B –Shape antennas

Simulated designs of different antennas were fabricated from National Institute of Pakistan (NIE), Islamabad, Pakistan. Fabricated antennas are shown in figure 3.15-17.

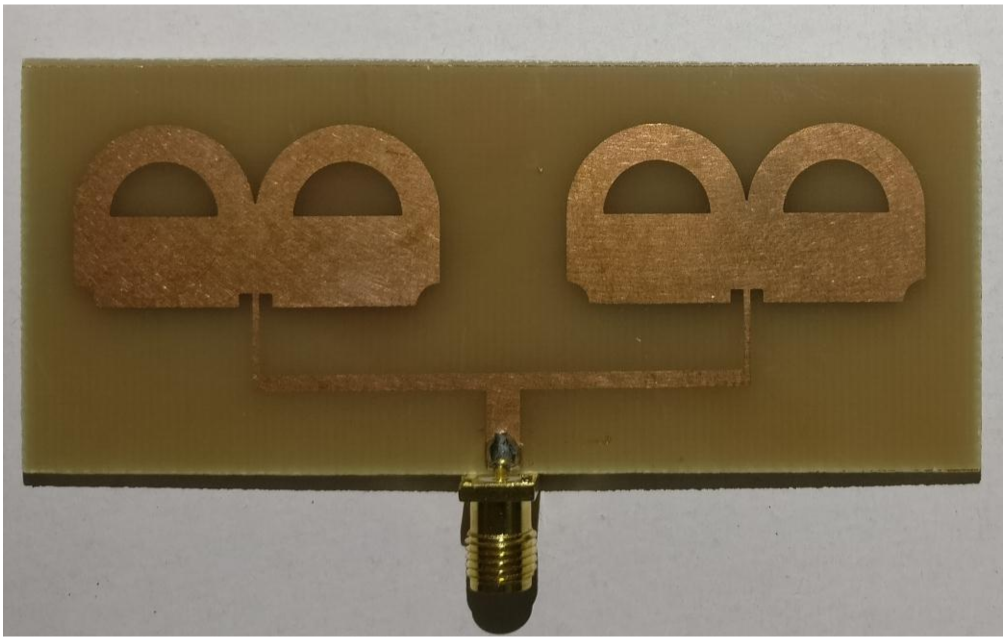


Figure 3.15 Two element array of B –Shape antenna for Downlink Communication (Fabricated)

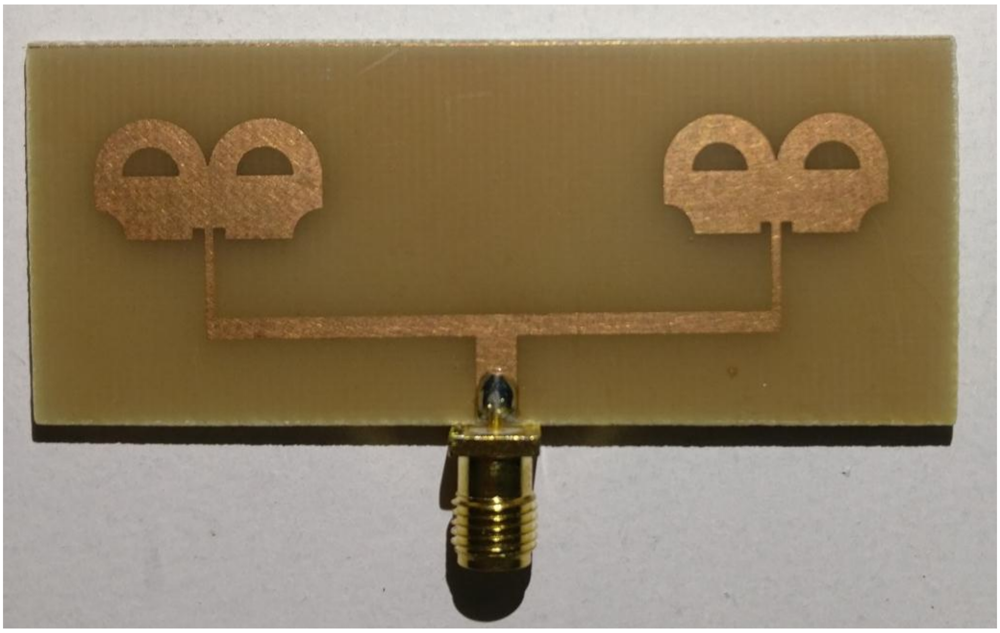


Figure 3.16 Two element array of B –Shape antenna for Uplink Communication (Fabricated)

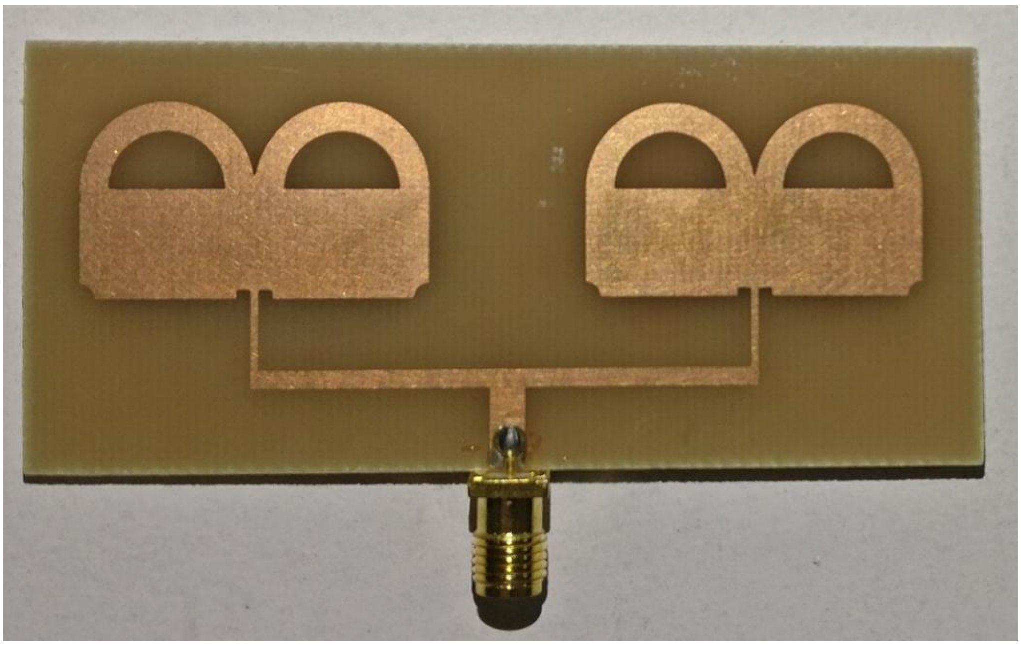


Figure 3.17 Dual band B –Shape antenna array for Downlink and Uplink Communication (Simulated)

Chapter 4

RESULTS AND DISCUSSION

4.1 Simulated Results

The proposed B shape Microstrip patch antennas are designed for both uplink and downlink satellite communication operating at the 4 GHz and 7.92 GHz. Results of three antennas are represented in this chapter; Antenna-1 at 4 GHz for downlink satellite communication, Antenna-2 at 7.92 GHz for uplink satellite communication and a dual band antenna for operating at 4 GHz and 7.92 GHz. To meet the requirements of high gain and low losses for satellite communication, results of two elements array are represented. The results of S11, gain and other parameters of all the antennas are represented one by one.

4.1.1 B –Shape antenna for Downlink satellite Communication

4.1.1.1 Return Loss (S11)

Frequency of 4 GHz is to be chosen for downlink satellite communication according to the standard of ITU. B shape antenna operating at 4 GHz provides S11 of -40.7 dB as shown in figure 4.1.

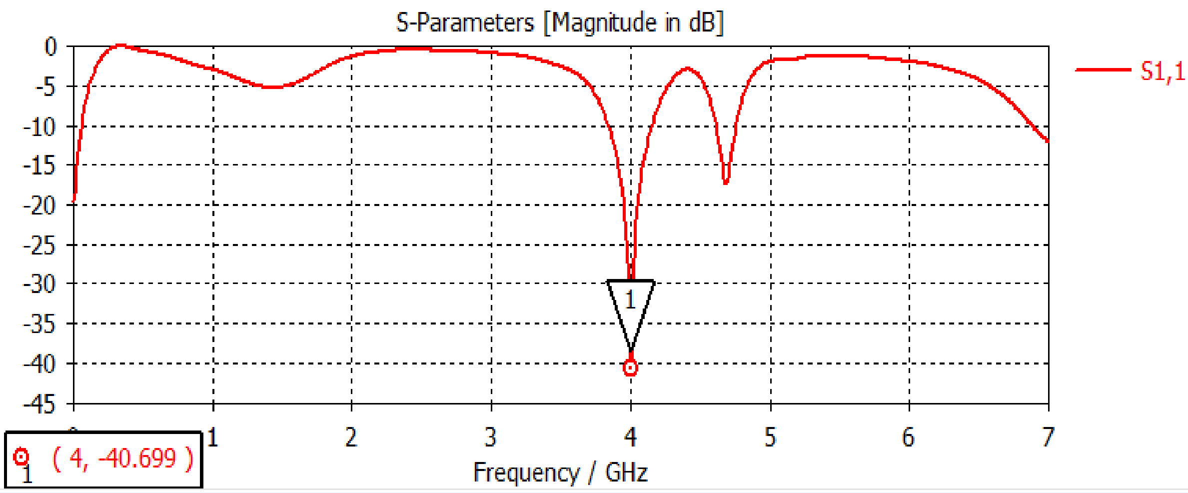


Figure 4.1 S11 of B shape antenna at Downlink frequency (Simulated Results)

4.1.1.2 Gain

B shape antenna for downlink communication provides the gain of 9.29 dBi as shown in figure 4.2

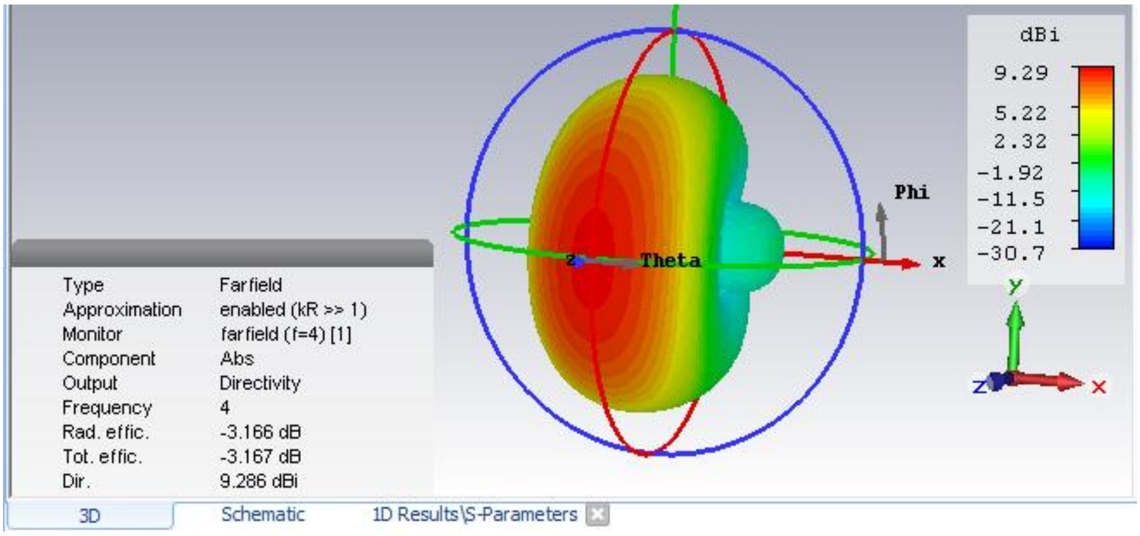
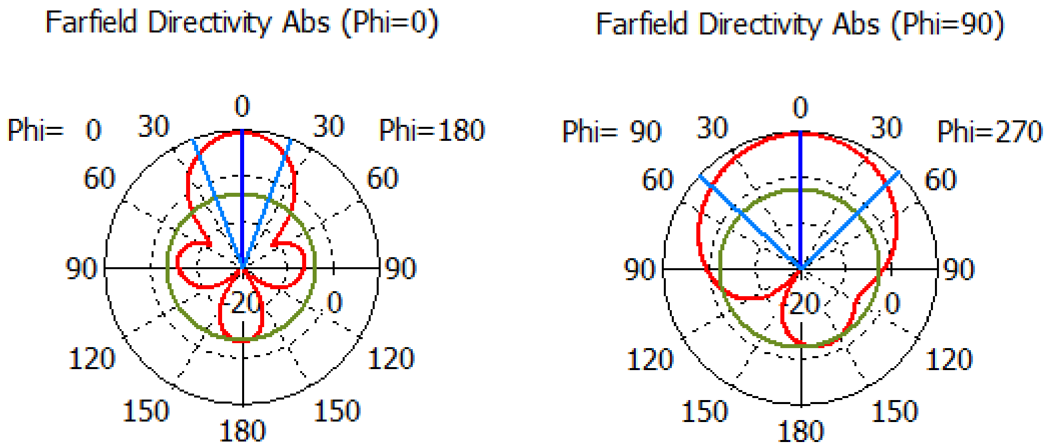


Figure 4.2 Gain of B shape antenna at Downlink frequency (Simulated Results)

4.1.1.3 Radiation Pattern

Radiation pattern of B shape antenna at downlink frequency is shown in figure 4.3 for both E and H fields.



(a) E- Field **(b)** H-Field

Figure 4.3 E and H Field Radiation Pattern of B shape antenna at Downlink Frequency (Simulated Results)

4.1.2 B –Shape antenna for Uplink Satellite Communication

4.1.2.1 Return Loss (S11)

Frequency of 7.92 GHz is to be chosen for uplink satellite communication according to the standard of ITU. It provides S11 of -35.2 dB as shown in figure 4.4.

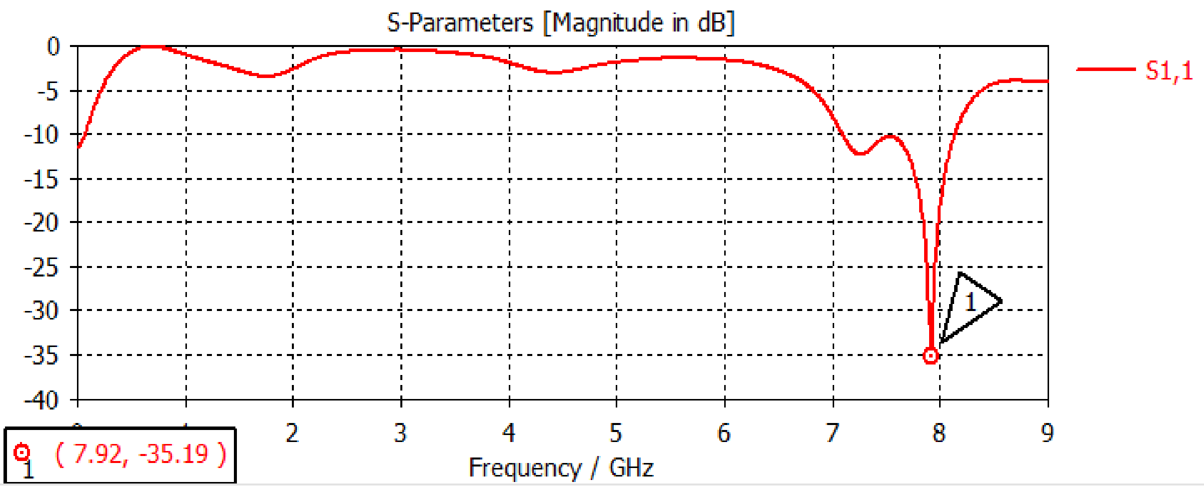


Figure 4.4 S11 of B shape antenna at Uplink frequency (Simulated Results)

4.1.2.2 Gain

B shape antenna for downlink communication provides the gain of 9.29 dBi as shown in figure 4.5

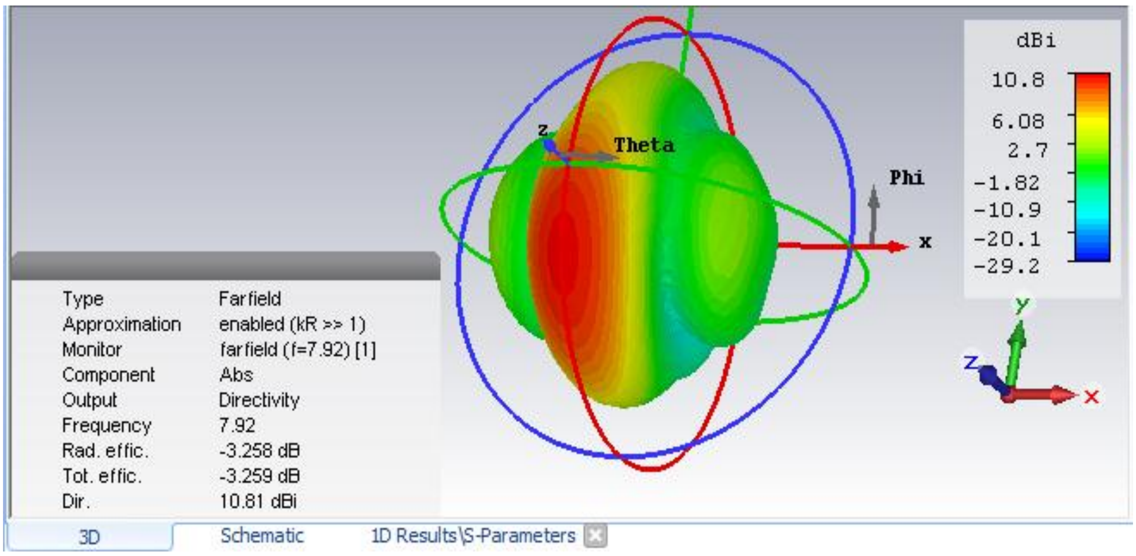
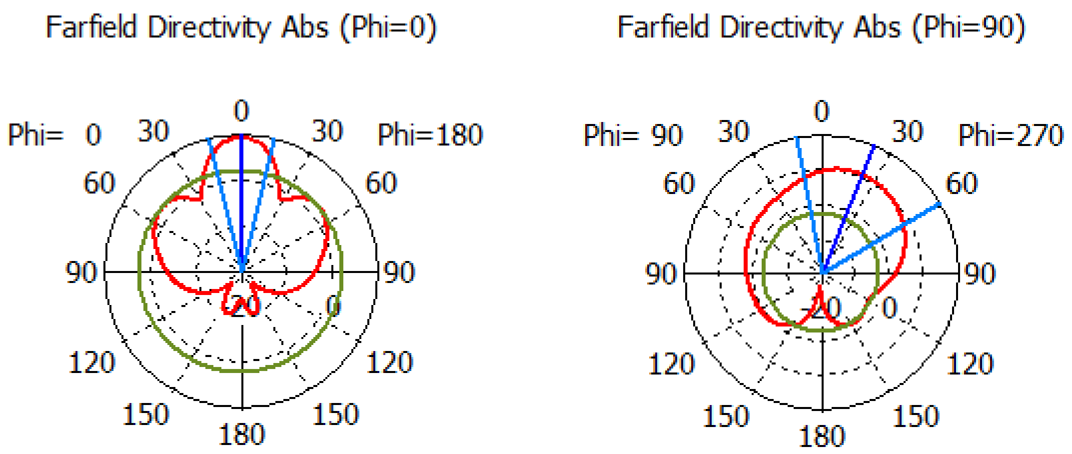


Figure 4.5 Gain of B shape antenna at Uplink frequency (Simulated Results)

4.1.2.3 Radiation Pattern

Radiation pattern of B shape antenna at uplink frequency is shown in figure 4.6 for both E and H fields.



(a) E- Field **(b)** H-Field

Figure 4.6 E and H Field Radiation Pattern of B shape antenna at Uplink Frequency (Simulated Results)

4.1.3 Dual band B –Shape antenna for Uplink and Downlink Satellite Communication

4.1.3.1 Return Loss (S11)

Same frequencies of 4 GHz and 7.92 GHz are chosen for downlink and uplink satellite communication respectively. It provides S11 of -25.2 dB for downlink frequency and -30.8 dB for uplink frequency as shown in figure 4.7.

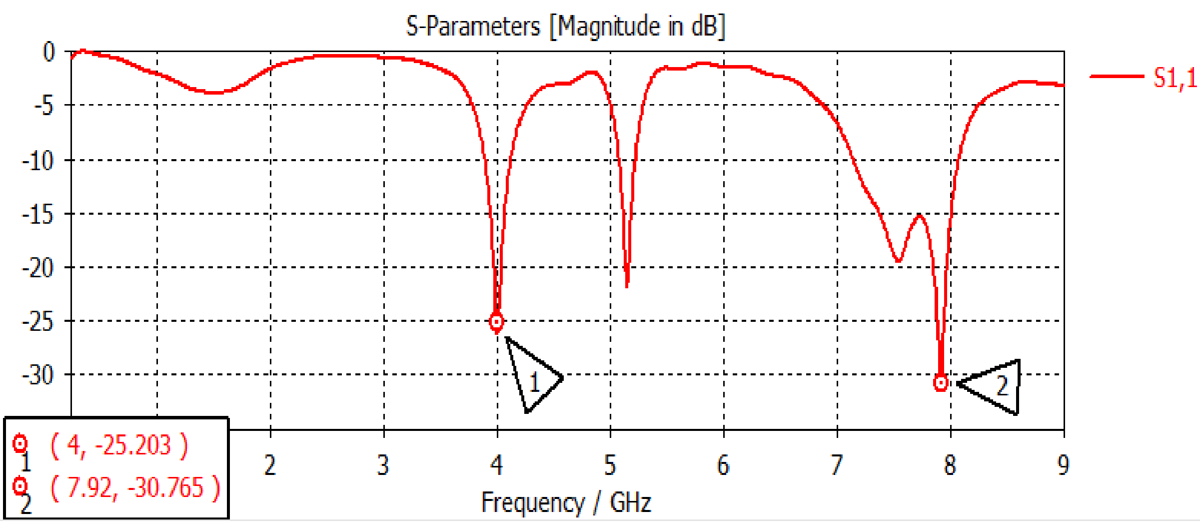


Figure 4.7 S11 of dual band B shape antenna at Downlink and Uplink Frequency (Simulated Results)

4.1.3.2 Gain

Dual band B shape antenna provides the gain of 9.1 dBi at downlink frequency as shown in figure 4.8

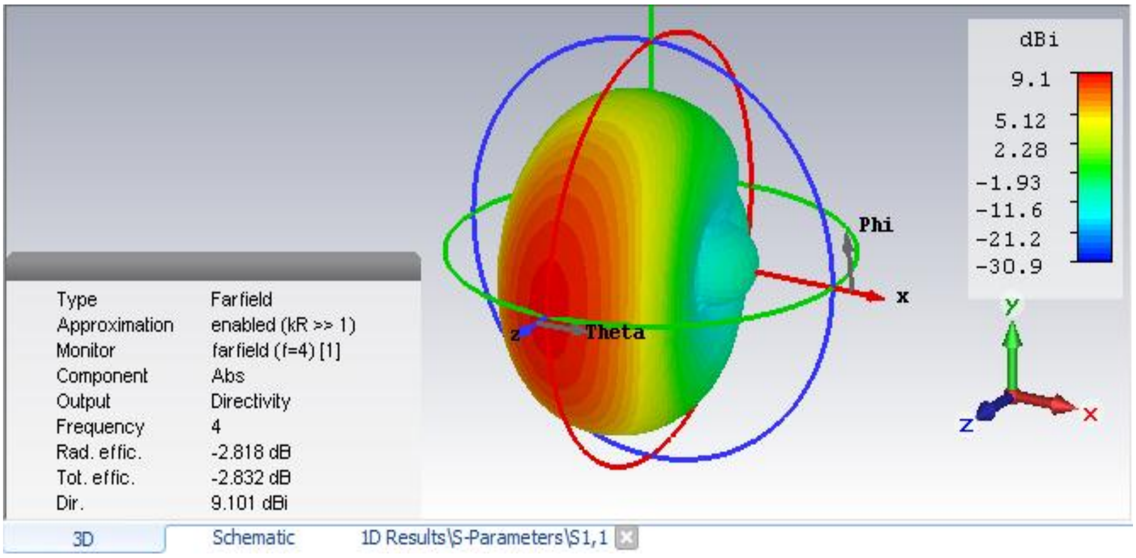


Figure 4.8 Gain of Dual band B shape antenna at Downlink frequency (Simulated Results)

Similarly, it provides the gain of 9.9 dBi at uplink frequency as shown in figure 4.9

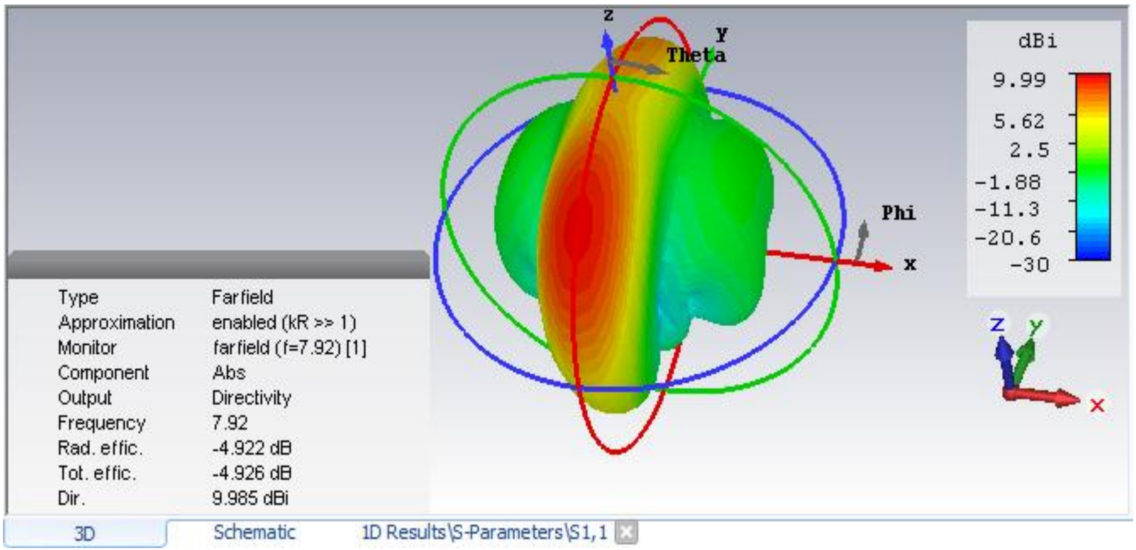
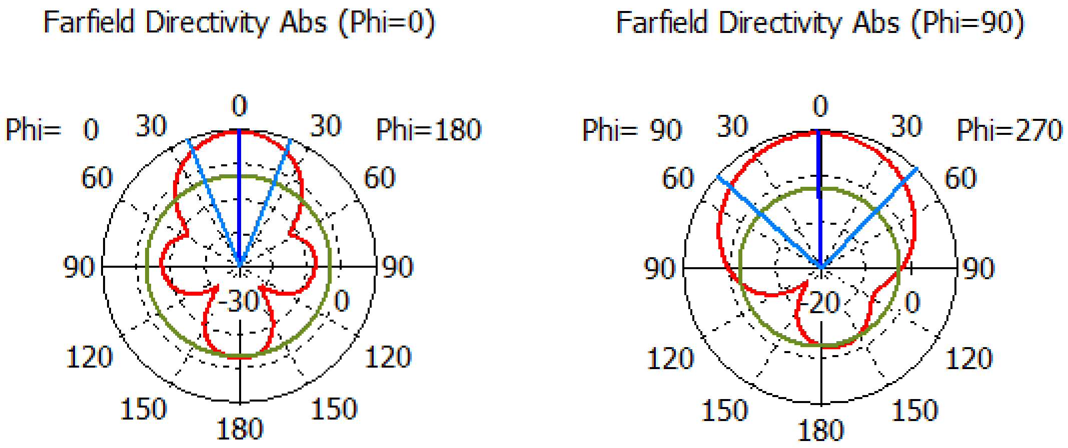


Figure 4.9 Gain of Dual band B shape antenna at Uplink frequency (Simulated Results)

4.1.3.3 Radiation Pattern

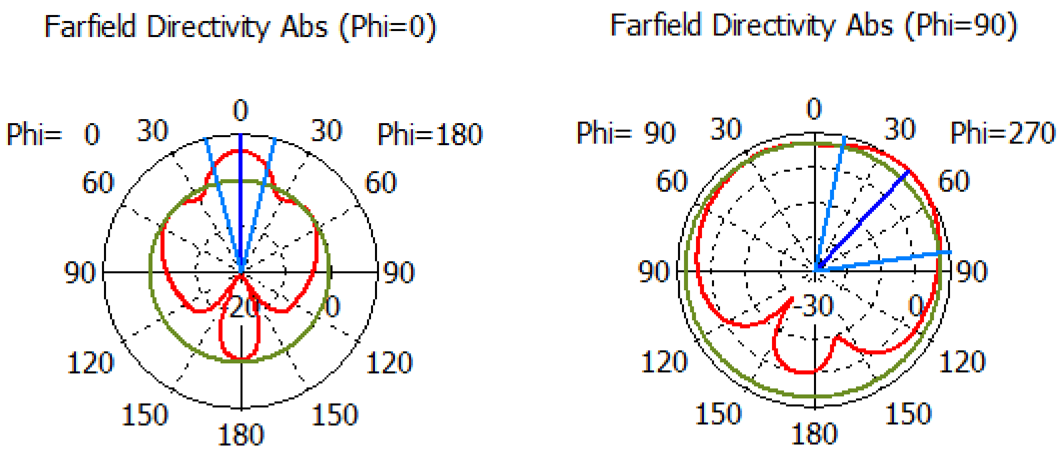
Radiation pattern of dual band B shape antenna at downlink frequency is shown in figure 4.10 for both E and H fields.



(a) E- Field **(b)** H-Field

Figure 4.10 E and H Field Radiation Pattern of dual band B shape antenna at Downlink Frequency (Simulated Results)

Similarly, radiation pattern of dual band B shape antenna at uplink frequency is shown in figure 4.11 for both E and H fields.



(a) E- Field **(b)** H-Field

Figure 4.11 E and H Field Radiation Pattern of dual band B shape antenna at uplink Frequency (Simulated Results)

4.2 Measured Results

Measured results of all the antennas are represented separately. Measured results of s11 parameter were measured using VNA from National Institute of Electronics (NIE), Islamabad, Pakistan.

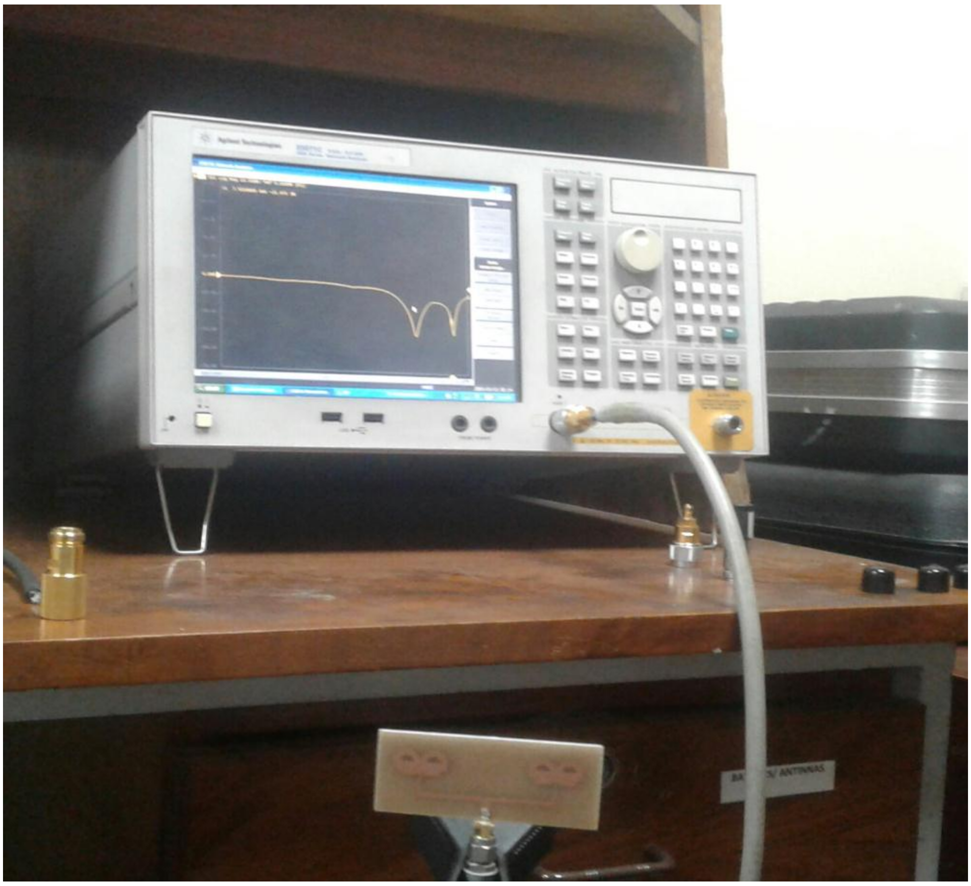


Figure 4.12 Measurement of results using Vector Network Analyzer (VNA)

4.2.1 B –Shape antenna for Downlink satellite Communication

4.2.1.1 Return Loss (S11)

Two elements B-shape antenna operating at 4 GHz provides S11 of –19.01 dB as shown in figure 4.13. This measured result is very good as compared to the other antennas designed for Downlink satellite communication. In general, antenna arrays results in improvement of gain but increases return losses but in this design it provides very low losses even in its arrays.

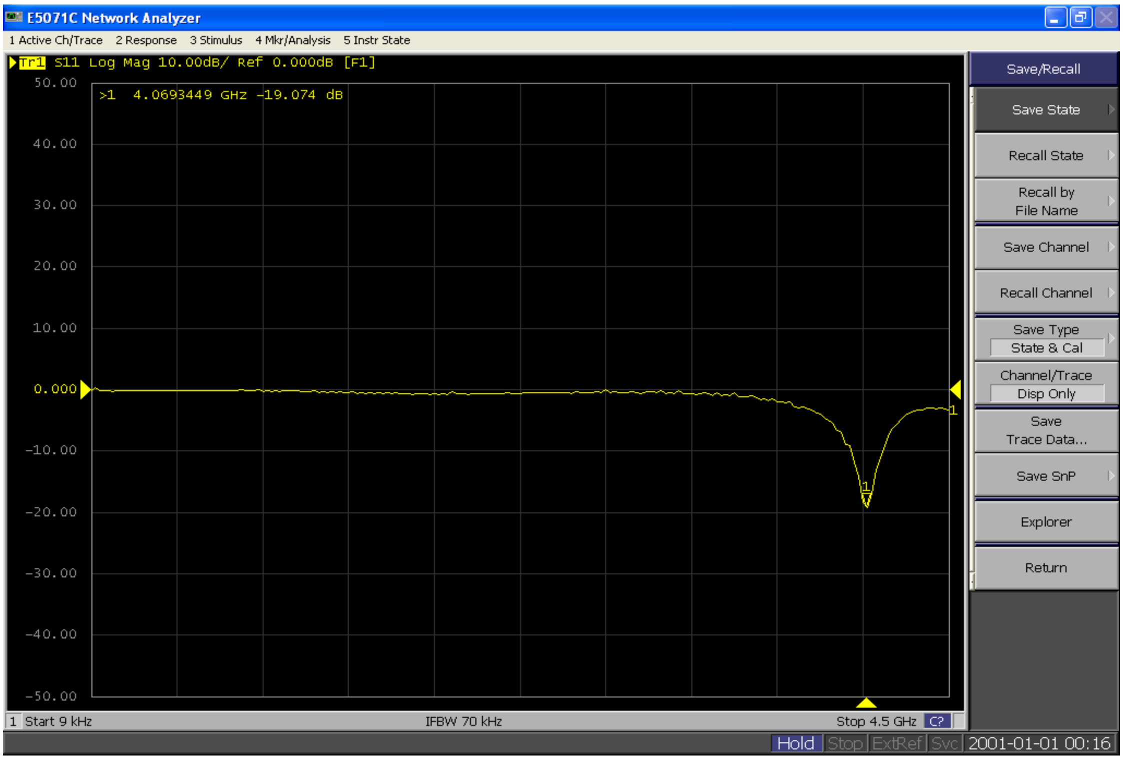


Figure 4.13 S11 of B shape antenna at Downlink frequency (Measured Results)

4.2.2 B –Shape antenna for Uplink Satellite Communication

4.2.2.1 Return Loss (S11)

Two elements B-shape antenna operating at 7.92 GHz provides S11 of –21.47 dB as shown in figure 4.14. This measured result is very good as compared to the other antennas designed for Uplink satellite communication.

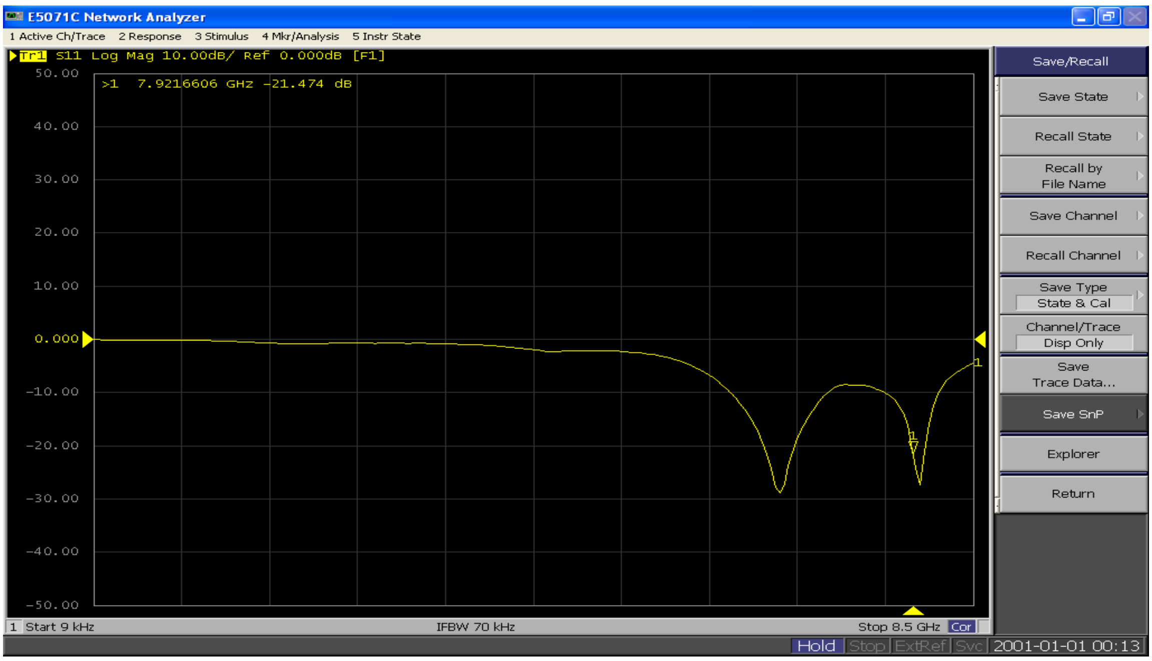


Figure 4.14 S11 of B shape antenna at Downlink frequency (Measured Results)

4.2.3 Dual band B –Shape antenna for Uplink and Downlink Satellite Communication

4.2.3.1 Return Loss (S11)

Two elements B-shape antenna provides S11 of –17.5 dB for downlink frequency and –14.5 dB for uplink frequency as shown in figure 4.15. This measured result is very good as compared to the other dual band antennas for Uplink and Downlink satellite communication. In general, antenna arrays results in improvement of gain but increases return losses but in this design it provides very low losses even in its arrays.

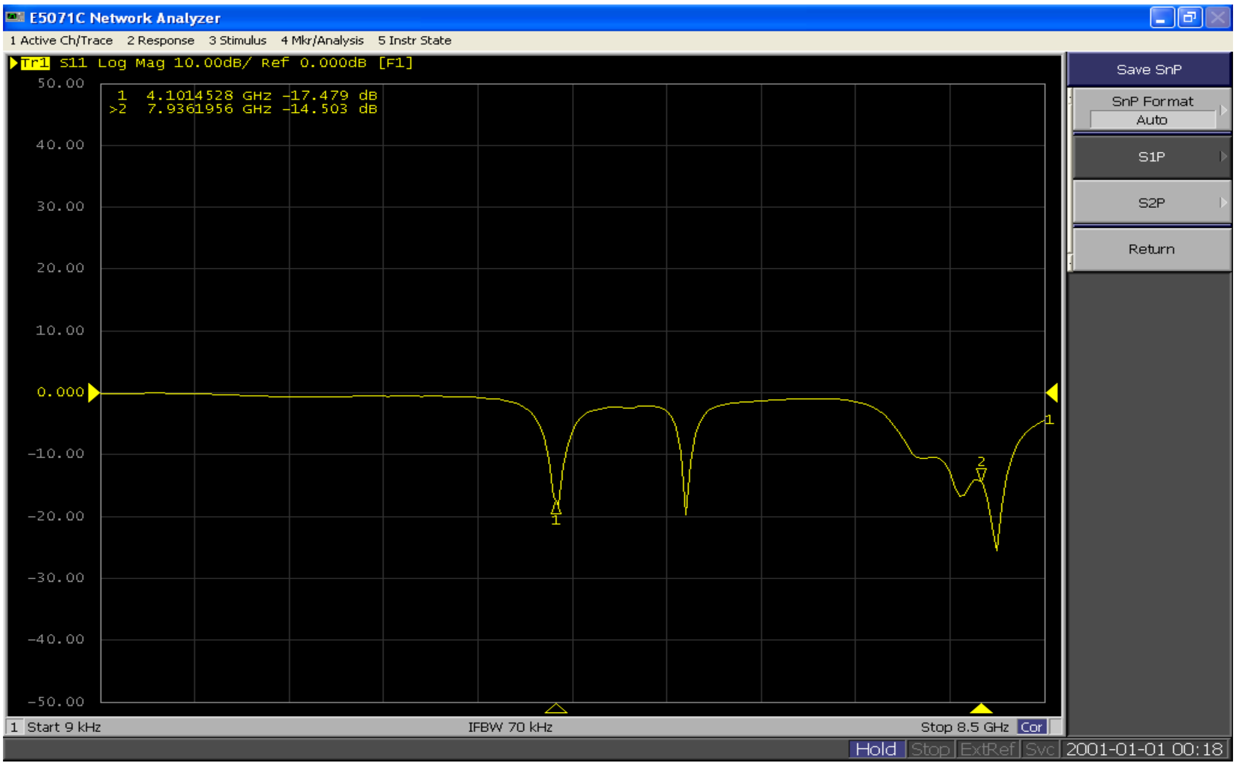


Figure 4.15 S11 of dual band B shape antenna at Downlink and Uplink Frequency (Measured Results)

4.3 Comparison of simulated and measured Results

This segment shows the comparison of measured and calculated results of antennas. Simulated and measured results can be compared better by representing them on a same graph, that's why both results are shown here on a same graph.

4.3.1 Comparison of Return losses for Downlink antenna

Comparison of measured and calculated results of S11 for B-shape antenna operating at 4 GHz is shown in figure 4.16. Its simulated value of S11 is -40.7 dB while measured results shows losses of -19.01 dB.

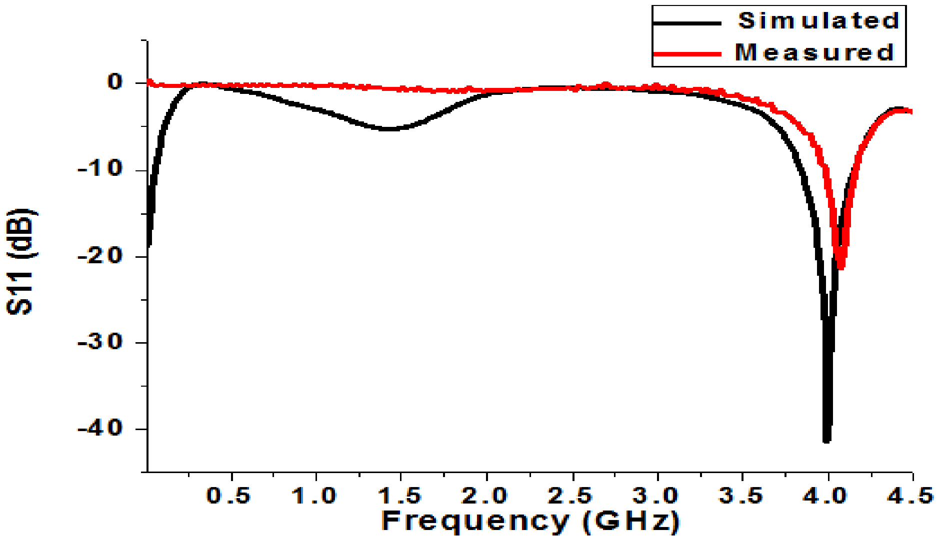


Figure 4.16 Comparison of Simulated and Measured result of S11 for downlink B shape antenna

4.3.2 Comparison of Return losses for Uplink antenna

Comparison of measured and calculated results of S11 for B-shape antenna operating at 7.92 GHz is shown in figure 4.17. Its simulated value of S11 is -35.2 dB while measured results shows losses of -21.5 dB.

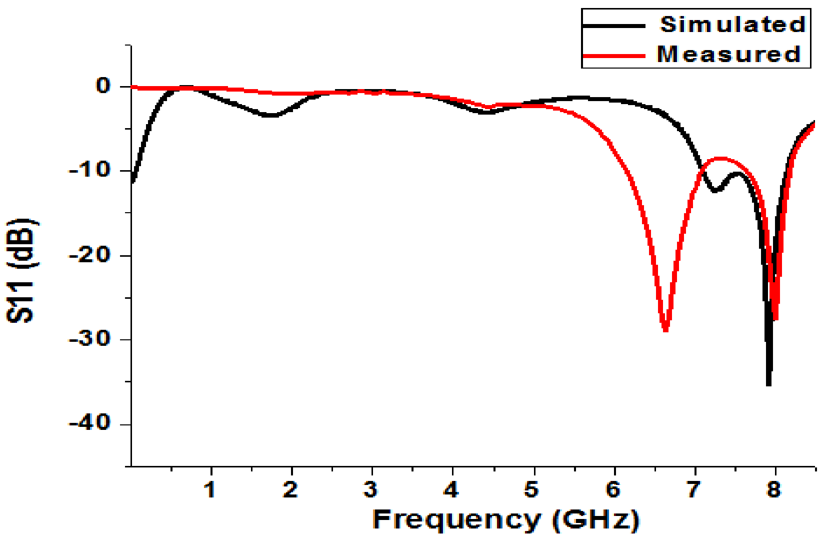


Figure 4.17 Comparison of Simulated and Measured result of S11 for Uplink B shape antenna

4.3.3 Comparison of Return losses for Dual band antenna

Comparison of measured and calculated results of S11 for B-shape dual band antenna operating at 4 GHz and 7.92 GHz is shown in figure 4.18. Its simulated value of S11 at 4 GHz is -25.2 dB and -30.8 at 7.92 GHz, while measured results shows losses of -17.5 dB at 4 GHz and -14.5 at 7.92 GHz.

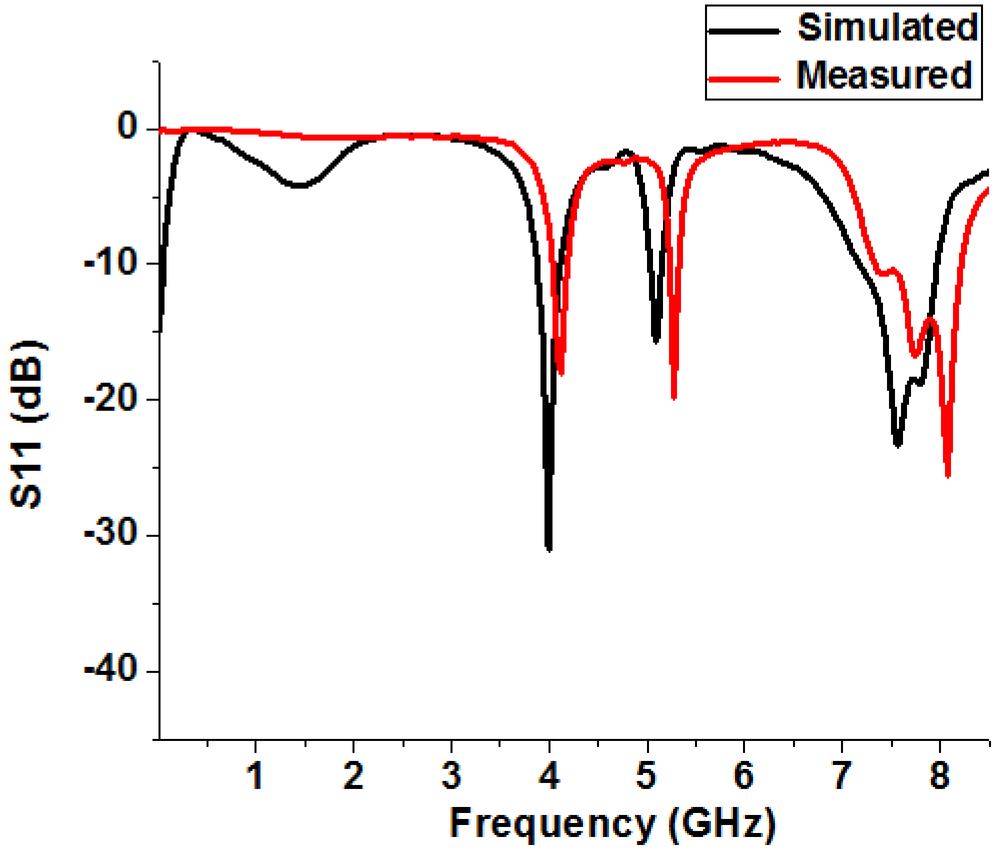


Figure 4.18 Comparison of Simulated and Measured result of S11 for Dual band B shape antenna

4.3 Research Contribution

The main objective of thesis is to design an efficient gain and low losses dual band novel design antenna. After throughout literature review, antenna designing, results and discussion for proof of concept, it is observed that the proposed antenna is efficient in gain and has low losses as compare to existing antennas in literature with greater performance, as shown in Table 4.1.

Table 4.1 Comparison of Proposed Antenna

References	Name of Antenna	Return Loss (S_{11}) (dB)	Gain (dBi)	Techniques used for improvement of results
[4]	Inverted L-Slot Patch	< -25.6	> 6.8	Notched edges, DGS
[5]	Novel fractal geometry patch	< -21	> 7.2	Fractal geometry
[6]	Microstrip patch with four circular slots	< -32	> 6.1	Slots in Shape
[7]	Triangular microstrip patch	< -42.5	> 6.1	Shape/Structural based
Thesis	B-Shape microstrip patch	< -40.7	> 9.2	Notched edges

Moreover novel design is another aspect of the research.

Chapter 5

CONCLUSION AND FUTURE WORKS

5.1 Conclusion

Phased array technology for satellite communication is very demanding in modern satellite communication systems, weather radar applications, maritime communication, aviation security, VSAT and different military applications. As compare to the other large reflector antennas for these applications, microstrip patch antennas should be preferred due to their light weigh, low profile, easy and simple to fabricate. It is the demand of modern satellite communication to use such a planer antenna to reduce the structure and weight of system. Phased array antennas are ideally suited to incorporate all the demands because of their planar structure, easy installation and simple fabrication. Designing an antenna that can meet the demand of satellite communication is a great challenge for antenna designer. This thesis contributes in the field of satellite communication by designing a novel design B Shape antenna having a very good gain and low losses.

Thesis provides separate novel design B shape antennas for downlink and uplink satellite communication with gain of 10.2 dBi and losses of -40.7 dB. Similarly, a novel design dual band B shape antenna for both uplink and downlink satellite communication is also presented. The proposed antenna has gain of 9.99 dBi and very low losses of -35.6 dB

5.2 Future Works

Phased array microstrip patch antennas have great deal of study and research. Challenges of high gain and low losses have been analyzed and efficient results have been achieved.

Following further can be done in the same area:

1. To achieve high gain, FSS technique can be implemented. .
2. To achieve high gain, DGS technique can also be implemented.
3. As thesis represents array technique for the enhancement of high gain, but MIMO technique can also be implemented to fulfill the requirements of the satellite communication.

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