A

DISSERTATION REPORT

ON

GAIN ENHANCEMENT OF C-BAND ANTENNA USING FSS REFLECTORS

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MASTER OF TECHNOLOGY

IN

ELECTRONICS AND COMMUNICATION ENGINEERING

BY

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CERTIFICATE

This is to certify that the dissertation report entitled "**GAIN ENHANCEMENT OF C-BAND ANTENNA USING FSS REFLECTORS"** submitted by **SURESH KUMAR** (2015PEC5337), in partial fulfillment of Degree **Master of Technology** in **Electronics & Communication Engineering** during the academic year **2016-2017**.To best of my knowledge and belief that this work has not been submitted elsewhere for the award of any other degree.

The work carried out by him has been found satisfactory under my guidance and supervision in the department and is approved for submission.

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Suresh Kumar

Abstract

The microstrip antenna is one of the most referable and popular for small & VLSI apparatus, especially when a built-in antennas are required. It has many advantages such as low profile and easy fabrication. However for low frequency applications, the microstrip antenna size becomes too large in order to implement practically. The problems in microstrip antenna technology are the reduction of the antenna sizes and obtain a larger bandwidth. The aim of this dissertation is to design and simulate compact microstrip patch antennas with good gain.

A Defected Ground Substrate C-slot microstrip antenna is designed and investigated for C-band application. Stepwise simulation results have been presented while changing the various parameters of the patch, slot and ground. The design parameters of all the proposed structures are calculated by cavity model and transmission line model design formula. The overall dimension of the antenna proposed is 27 mm x 25 mm x 1.67 mm. The proposed antenna consists of rectangular patch with a C-Slot on ground metallic conductor where FR 4 substrate is filled. The feed point used in antenna design is microstrip type feed having SMA connector. The S11 parameter, VSWR, Gain and radiation pattern of the antenna are obtained using CST Microwave Studio and the simulated results are discussed. Our designed antenna radiates in standard C-band operation for satellite communication applications. Although, IEEE C-band consists of 4-8 GHz but as per our application we need dual resonant bands in this C-band for transmission and reception of signals separately so that interference is avoided.

We have designed and investigated two 16-element FSS reflectors. Unit cells are place as 4x4 way having 25 mm periodicity in both X and Y direction. The dimension of FSS full structure reflector is 100 mm x 100 mm x 15.84 mm. In the end this double layered FSS reflector is placed behind the antenna designed firstly. The dimension of antenna with array is 100 mm x 100 mm x 42.51 mm. The FSS designed have all desired characteristics which a high gain antenna should have for satellite band communication.

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Chapter 1

1 *Microstrip Patch Antenna*

1.1 Antenna Overview

Antennas played a significant role in the field of wireless communication. An antenna is a transducer or radiator or impedance matching device which is used for transmission and reception of electromagnetic signals in wireless communication. Thus, an antenna is a transitional structure between free space and a guided device [1]. An antenna is an inactive reciprocal gadget. Thus, antenna convert electric energy to RF waves in the case of transmitting antenna and vice versa. Antennas are divided into two parts: Non resonant antenna and Resonant antenna.

A. Resonant Antennas:

Resonant antennas have multidirectional radiation patterns. Main lobe and back lobe existing in resonant antenna. These are periodic antennas in which current and voltage are not in phase.

B. Non resonant Antenna:

Non resonant antennas have unidirectional radiation pattern. Standing waves does not exist in non-resonating antenna because there is no reflection in non-resonant antenna.

Micro-strip patch antenna was invented by the Deschamps in 1953, but his work was not listed in literature until early 1970’s. The first practical patch antenna was proposed by Howell [1972] and Munson [1973][2-3]. These are most suitable for satellite and missile application due to their light weight, small size and easy installation. They are essential equipment for wireless applications. For low frequency applications, the micro-strip antenna size becomes too large for practical implementation. The aim is to design and simulate compact micro-strip patch antenna with desired bandwidth. In micro-strip patch antenna’s simplest structure there is a radiating patch on one side of a dielectric material and another side is consist of a conducting material as ground plane as shown in Figure 1.1

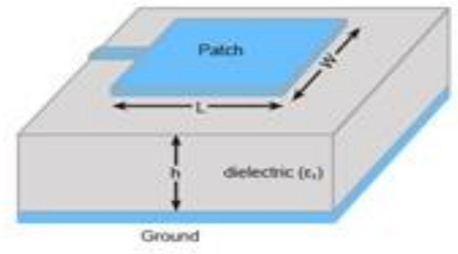


Figure 1.1 Micro-strip Patch Antenna Cofiguration

Micro-strip patch antenna is designed such that we get maximum radiation in the direction which is normal to the patch. This is achieved by properly selecting the mode (field configuration) of excitation beneath the patch. The strip and the ground are separated by a dielectric sheet. Bandwidth and efficiency of an antenna is the function patch size, shape, substrate thickness, dielectric constant of substrate, feed point type and its location, etc. The size of an antenna can be reduced by making slot or slots on the patch.

The length of receiving wire is about half wavelength in the dielectric; it is an extremely basic Parameter, which chooses the thunderous recurrence of the antenna. There are no Hard and quick standards to discover the width of the patch. The dielectric constant of the substrate should be low, to enhance the fringe field because micro-strip antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. Micro-strip patch antenna printed over an infinite grounded dielectric substrate with small thickness. The radiating patch and the feed lines are usually photo etched on the dielectric substrate.

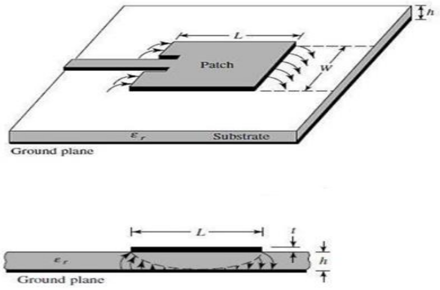


Figure 1.2 Fringing Field Lines Between Patch and Ground

1.2 Radiation Mechanism of Micro-strip Antenna

The main cause of radiation in micro-strip patch antenna is fringing fields between the ground and the edge of the patch conductor [4]. Lewin was the first scientist who explains the radiation due to the discontinuities in the micro-strip patch antenna. The effect of the radiation on quality factor Q of the micro-strip antenna can be calculated by Lewin's method [5]. The Lewin method was based on the field present in slot, formed by the ground plane and open edges of the path conductor. Q factor was described as a function of resonator dimensions like substrate thickness, relative dielectric constant and operating frequency.

The theoretical and experimental results show that at high frequencies the radiation loss is much larger than conductor and dielectric loss. It was also observed that open circuit micro-strip lines radiate more power when substrate thickness is high and dielectric constant is low.

To understand the radiation mechanism of micro-strip patch antenna consider the antenna as a rectangular micro-strip patch placed at a distance, a small fraction of wavelength, above the ground plane as shown in Figure 1.3

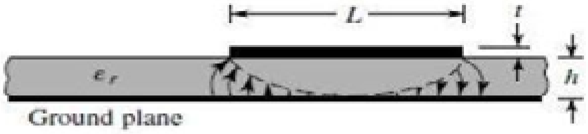


Figure 1.3 Side View of Micro-strip patch antenna

Assuming that there no variation in electric field along the thickness and width of substrate. The electric field lines can be represented as shown in Figure 1.4

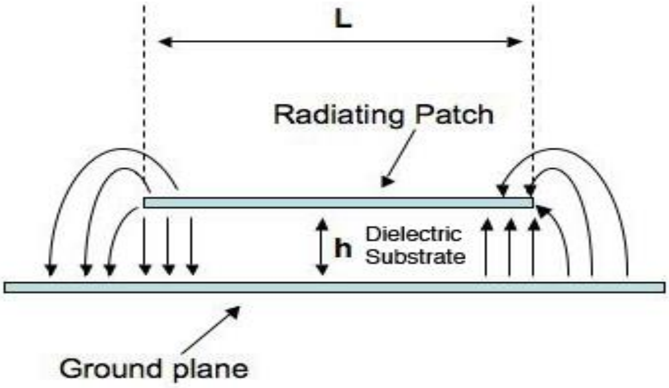


Figure 1.4 Electric Field Lines between Patch Edges and Ground plane

Radiation may be ascribed mostly to the fringing fields at the open circuited edges of the patch. The field at the end can be resolved in the tangential and normal components as compare to ground plane. As the length of the patch is equal to half of the wavelength, the normal components are out of phase. Therefore the far field radiation produced by them canceled in broadside direction. The component parallel to the ground plane are in phase so added up to provide a strong radiation field normal to the surface structure, which is known as broadside of antenna, therefore the patch may be represented as two slots at half wavelength distance from each other, which are excited in phase and radiating in the half upper half space above the ground plane.

1.3 Methods of Analysis

For the analysis of the micro-strip patch antenna, antenna can be considered as a 2-D planar component since antenna has a two dimensional radiating patch on the thin dielectric material. The method of analysis of micro-strip patch can be classified into two categories [6].

A. On the basis of equivalent magnetic current distribution around the edge of micro-strip patch.

There are three popular analytical techniques in this category

1. The transmission line model
2. The cavity model
3. The multiple network model

B. On the basis of equivalent electric current distribution on the patch conductor and the ground plane. Some of analytical methods in this category are

1. The method of moment
2. The finite element method
3. The spectral domain technique
4. The finite difference time domain method

1.3.1 Transmission Line Model

This model was introduced by Munson and Derneryd[7]. This model works on fringing effect. In this model antenna is assumed as a transmission resonator in which electric field varies only along the length of the transmission line. Transmission line model is simplest model but accuracy of this model is less. It gives good physical insight of the micro-strip antenna. The rectangular patch is considered as two slot that are L distance apart from each other. Where L is the length of patch. Which is approximately equal to half of a wavelength. This model was originally developed for rectangular patches but has been extended for generalized patch shapes.

Due to the finite length of patch, the field at the edge of micro-strip antenna undergoes fringing. Amount of fringing is a function of substrate height, patch dimensions. Because of fringing effect, the length of the patch is increases up to some extent. This increased length is known ad electrical length. Dielectric constant of the substrate decreases due to the fringing field effect. These altered quantities can be expressed as following

Approximate relation for extension of length is

$$\boldsymbol{\Delta L = 0.412h\left[\frac{\varepsilon_{reff} + 0.300}{\varepsilon_{reff} - 0.258}\right]\left[\frac{\frac{W}{h} + 0.264}{\frac{W}{h} + 0.813}\right]}$$

Where W is width of patch

h is height of patch

ε_{eff} is effective dielectric constant

$$\boldsymbol{\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[\frac{1}{1 + 12\frac{h}{W}}\right]} \qquad \text{(W>h)}$$

1.3.2 Cavity model

In cavity model [8] antenna is treated as a cavity between the patch and the ground plane. Patch and ground plane are considered as the electric walls and the periphery of the patch in substrate as magnetic walls. Since the substrate is thin (W>>h) the field inside the cavity is uniform along the thickness of the thickness of the substrate. The field underneath the patch can be communicated as a summation of the different resonant modes of the 2-D resonator.

This model is intricate as contrast with transmission line model. It likewise gives great physical knowledge of the micro-strip patch antenna. This model is more exact. The fringing fields around the outskirts are dealt with by developing the patch limits outward so that the powerful measurements are bigger than the physical measurements of the patch. The far field emanated power is figured from equivalent magnetic current around the outskirts. This model is suitable for geometries in which Helmholtz comparison has a systematic arrangement for example plates, circles, rectangles, triangles and so on.

1.4 Advantage and Disadvantages of Micro-strip Patch Antenna

Micro-strip patch antennas have several advantages compare to conventional microwave antenna and therefore many application over the broad frequency range some of the principle advantage of micro-strip patch antenna compare to conventional antenna are

1. Light weight, low volume, low profile planer configuration, which can be made conformal.
2. They don’t disturb the aero-dynamics of host aerospace automobiles. Because of low fabrication cost readily ameliorate to mass production can be made thin.

3. These antennas are congruous with solid state devices or modular designs such as mixers, phase shifter, oscillators, modulars, amplifiers, switches, variable attenuators etc. can be connected directly to the antenna.
4. The antenna has low scattering cross section.
5. Linear and circular polarization can be achieved by simply changing the position of the feed.
6. No cavity backing required.
7. The may be easily clambered on missiles rockets and satellite without major modification.
8. We can easily make Dual frequency antenna.
9. Matching network and feed lines are fabricated simultaneously with antenna structure.

However micro-strip antennas have some disadvantages compared to conventional microwave antennas including-

1. Lower power handling capability
2. Poor isolation between the feed and the radiating patch element.
3. Practical limitations on the maximum gain.
4. Most micro-strip antennas radiates in to a half plane.
5. Narrow bandwidth
6. Lower gain.
7. Possibility of excitation of surface waves which causes spurious radiation at the edge of the micro-strip antenna. These waves propagate in to the substrate outside the micro-strip patch and give rise to end-fire radiation. The upper frequency limit for the antenna operation is defined by the lowest.

1.5 Literature Survey

A paper presented on an accurate and numerically efficient model for the rectangular microstrip antenna [9]. It concerns a transmission-line model which features the following three major improvements with respect to earlier such models: the mutual radiative coupling (both real and imaginary parts) between the equivalent slots is fully taken into account; the influence of the side slots on the radiation conductance is taken into account implicitly; simple analytic expressions are introduced for all relevant model parameters. By way of illustration, the new model is applied to antennas with a single microstrip feed line. Due to its numerical efficiency, this model is extremely suitable for design purpose. The model has very broad range of validity in terms of patch aspect ratio (W/L), substrate dielectric constant and substrate electrical thickness (h/λ).

A new design of single-feed, reduced-size dual-frequency rectangular microstrip antenna with a cross slot of equal length is presented on paper[10]. The frequency ratio of the two operating frequencies is mainly determined by the aspect ratio of the rectangular patch, and the reduction in the two operating frequencies is achieved by cutting a cross slot in the microstrip patch. Thus the length of cross slot affects the frequency ratio of the two operating frequency.

A paper on analyses and design of a Dual-Band Rectangular Patch Antenna With Two Pairs of parallel silts, gives direction to design an antenna using slits which provides dual band resonance characteristics [11]. The length parameters are quite important as it decides the amount of fringing which helps in desired operation of frequency.

A literature on Studies of the planar inverted-F antenna with a U-shaped slot[12] further provide dual band antenna design with parasitic Grided patch. They described a new aperture-coupled microstrip patch antenna with H-shaped slots for dual-band and dual-polarized operations. Two orthogonal modes are excited in a single long rectangular patch to achieve the two resonant frequencies with a separation of more than 2:1. By using five parasitic conducting strips stacked on the driven patch, the impedance bandwidths can be increased and isolation of more than 34 dB between the two ports is obtained. Moreover, the cross-polarization levels for the two polarizations are found to be better than 25 dB. Thus, they proposed methods to improve bandwidth characteristics of an microstrip patch antenna.

A paper on thin, broad-band, E-shaped microstrip patch antennas (ESPAs)[13], operating in the 5-6 GHz frequency range, are presented. They are intended for high-speed (IEEE 802.11a, 54 Mb/s) wireless computer local area networks (WLAN) and other wireless communication systems. They are suitable for WLAN adaptor cards in the PCMCIA (also known as PC) format, allowing users of current notebook computers to upgrade to this high-speed wireless standard at a low cost. Importantly, our antennas are thin enough to be accommodated in a PCMCIA card of standard 5-mm thickness, without making the antenna end thicker than the card itself. Two different closely spaced antenna pairs are also presented for diversity. A new ESPA configuration with a microstrip feed is presented for easy integration with microwave transceivers. In all cases, within the two IEEE 802.11a WLAN bands (5.15-5.35 GHz and 5.725-5.825 GHz), the reflection coefficient at the antenna input is <-10 dB and in both antenna pairs, mutual coupling between the two antennas is <-20 dB.

Adil Hameed Ahmad and Basim Khalaf Jar’alla [14] suggested many techniques are and analyses for rectangular microstrip antenna (RMSA) operating in X-band for 10 GHz center frequency. These approaches are:

a. Lowering quality factor,

b. Shifting feeding point,

c. Using reactive loading and modification of the patch shape.

The plan of a RMSA is made to a few dielectric materials, and the determination depends on which material gives a superior reception apparatus execution with diminished surface wave misfortune. Duroid 5880 and Quartz are the best materials for proposed configuration to accomplish a more extensive Bandwidth (BW) and preferred mechanical qualities over utilizing air. The general radio wire BW for RMSA is expanded by 11.6 % with Duroid 5880 with moved encouraging point and with focal shorting pin (Reactive stacking) while that for Quartz is 17.4 %. Adjustment of fix shape with comparable enhancing methods gives a general expanding VSWR transmission capacity of 26.2 % for Duroid 5880 and a data transfer capacity of 30.9 % for Quartz.

A paper on design of coaxial fed microstrip antenna for LEO[15] satellites presents a step by step procedure for designing microstrip antenna for LEO satellites. The design uses transmission line method as it offers good physical insight. The design is simulated using Ansoft HFSS TM V9.2 which employs finite element method to achieve the desired specification. The paper presents simulated results for total gain and far field radiation patterns.

In 2008 conference, a paper proposed a Microstrip Patch Antenna (MPA) fabricated using a conducting polymer, Polypyrrole (PPy), as a ground plane[16]. The bulk conductivity level of the PPy ground plane is 2000 S/m and its thickness is 330 µm. The antenna is designed to operate in the 11 GHz region. The measured and simulated results at the resonant frequency such as return loss, gain, radiation pattern and bandwidth are presented in comparison with a similar copper ground plane antenna. CST Microwave Studio was used as a design and simulation tool and experimental measurements of the antenna made to validate the simulations. The results show that a microstrip antenna with PPy as the ground plane provides a gain of 4.1 dB at 10.5 GHz as against 5.35 dB for copper ground plane at 11 GHz. The Q factor for PPy as ground plane is 7.6 while for copper as a ground plane have 13.56. Since we know that bandwidth is inversely proportional to the Q-factor and by decreasing it we can enhance bandwidth of the antenna. Thus, this is an alternative approach to foe bandwidth enhancement at the cost of Gain and Q-factor.

In 2010 conference, a paper proposed the use of a patch antenna with two U-shaped slots to achieve dual band operation [17]. A thick substrate expands the individual data transfer capacities i.e. bandwidth. The reception apparatus is outlined in light of broad IE3D recreation contemplates. A model recieving wire is created and tentatively confirmed for the required execution. The essential preferred standpoint of this approach is simplicity of creation as the outline does not require arrangement between various layers of dielectrics and metal. The two U-openings framed give the coveted full band of recurrence and by changing viewpoint proportion and width alongside the counterbalanced of the bolster point from the inside area chooses the data transfer capacity of the patch antenna.

Another paper that described the general method of using U-slots to design dual- and triple-band patch antennas [18]. In this approach, one starts with a broadband patch antenna, which can consist of one or more patches. At the point when a U-space is cut in one of the patches, an indent is brought into the coordinating band, and the patch antenna turns into a double band recieving antenna. On the off chance that another U-space is cut in a similar fix or in another fix, a triple-band patch antenna comes about. This strategy is connected to the L-test bolstered fix, the M-probe fed fix, and in addition the coaxially nourished and opening coupled stacked patches. It is discovered that the examples and additions of the double and triple-band radio wires are like those of the first broadband recieving antenna. Since the band indents presented by the U-spaces happen inside the data transmission of the reception apparatus without openings, this strategy is appropriate when the recurrence proportions of the neighboring groups are little, normally under 1.5.

A paper that proposed a full composite fractal antenna, having a modified Sierpinski fractal antenna [19] with 50-Ω microstrip line, used for dual band wireless applications. The S11 parameter and radiation characteristics of the antenna design indicate that a Sierpinski fractal antenna with circular slot having Dual Band frequency bandwidth from 3.8 GHz to 4.4 GHz and 4.8 GHz to 5.4 GHz to covering 5.2 GHz for C-Band and X-Band wireless applications in 3.8 GHz- 14 GHz frequency range. The proposed antenna is fed by a 50-Ω microstrip line and designed on a low cost FR4 substrate having dimensions 96 (L) ×72 (W) × 1.5 (t) mm^3 with ε_r=4.9 and tan δ= 0.025. The antenna shows acceptable gain with nearly omni-directional radiation patterns in the frequency band.

In 2014 structure proposed on Koch curve fractal antenna for wireless applications [20]. The antenna has been designed by increasing the perimeters of triangular shape patch by using self-similarity property. Number of iterations by the designing Koch snowflake for different resonant frequency, are given. The proposed antenna is designed to operate at Wi-MAX frequency from 3.4 GHz -3.69 GHz and C-Band applications in 2.8 GHz-6.4 GHz frequency range. The proposed antenna is fed by a 50-Ω microstrip line and fabricated on a low-cost FR4 substrate. The antenna shows acceptable gain with nearly omni-directional radiation patterns in the frequency band for wireless applications.

A novel that presented a conservative slotted planar square ring-molded smaller scale strip receiving wire at the same time reasonable for indicate point correspondence at 60 GHz[21] . The reception apparatus is reenacted by the product CST. CST simulation and innovation test software is utilized to investigate the proposed reception apparatus and the E and H plane radiation design and polar plot pattern is exhibited. The reproduction and estimation result met the IEEE 802.11ad standard work in 60 GHz band for indicate point correspondence. The deliberate outcomes demonstrates an arrival loss of - 26.69 dB and the voltage standing wave proportion VSWR < 2 at 60 GHz showing that the radio wire is a decent contender for rapid WLAN applications.

1.6 Simulation Software

There are many software present for simulation of patch antenna. Some of them are Ansoft Designer, HFSS Micro-stripes, IE3D and CST Micro-strip Studio. We used CST Microwave Studio software. The silent features of CST Microwave Studio and Designer simulation software are presented below.

CST Microwave Studio

It is a specialist tool for the 3D EM simulation of high frequency component. It is a technology for electromagnetic simulation to yield high accuracy analysis and design of complicated microwave and RF printed circuit, antenna, high speed digital circuits and other electronic components. Fast and accurate analysis of high frequency component can be achieved by this software. It is a fully automatic, user friendly software which gives you an insight into the EM behavior of the high frequency designs. In CST MWS [22] each parameter can be varied (one at a time) to get proper results, in parameter sweep option. New and powerful optimization technique allow even for multiple parameters in reasonable length of time.

CST MWS has six powerful solver modules

a. Transient solver
b. Frequency domain solver
c. Asymptotic solver
d. Eigen mode solver
e. Integral equation solver
f. Resonant solver

Transient solver is for efficient calculation for loss free and lossy structure. A broadband calculation of s-parameter is performed by this solver from one single calculation run. Frequency domain solver with adaptive sampling supports both, hexahedral and tetrahedral meshes. The frequency domain solver also contains two solvers being specialized on strongly resonant structure. The first calculate S-parameters whereas second calculates fields which require some additional calculation time.

1.7 Problem statement

From the study, we came to know with a specific end goal to plan a satellite C-band antenna we need to make our reception apparatus structure to resonant on two resonant frequency, one for up-link and other for down link, and appropriate bandwidth accomplishment by keeping in perspective of gain as a basic parameter which is very critical parameter. The desired specifications of antenna are as follows:

Table 1.1 Detailed Specification of Antenna Requirement

Antenna Used	Parameter	Value
Single Patch antenna	**Frequency Band**	**C-band:** 5.850 – 6.425(Tx) 3.625 -4.200(Rx)
	Return loss	**Better than 20dB**
	Directivity	**Better than 4dbi**
Antenna With Double Layer FSS Reflector(16-Element in each)	**Frequency Band**	**C-band:** 5.850 – 6.425(Tx) 3.625 -4.200(Rx)
	Return loss	**Better than 15dB**
	Directivity	**Better than 13dBi**

1.8 Structure of Thesis

The report consists of 5 chapters which contains a C-band antenna design along with formation of FSS reflectors and its utilization. Here, chapter 1 consists of basic introduction of the antenna with description of antenna radiation mechanism and literature survey. Chapter 2 deals with design aspects of microstrip patch antenna. While, in chapter 3, we have discussed about the Frequency selective surface and design double layer FSS reflector. In chapter 4, we have described the effect of FSS reflector and use it with the antenna designed in chapter 2 and compare the results for antenna with FSS and without FSS reflector. All Simulated results in CST have been shown with proper comparison. In the end in Chapter5, we have discussed our conclusion and future work.

Chapter 2

2 Microstrip Antenna design

The rectangular patch is by far the most broadly utilized configuration. It is very easy to investigation utilizing both transmission line model and cavity model, which are most precise for thin substrate. We utilize the transmission line model because it is easier to illustrate. Based on the simplified formulation, a design procedure is outlined which leads to practical designs of rectangular micro-strip antenna. The procedure assumed that the specified information includes the dielectric constant of the substrate, resonant frequency, and height of the substrate.

2.1 Design Procedure

The dimensions used in order to design of dual resonant C-band antennas deals with step wise approach from antenna structure 1 to 3. All dimensions are calculated from the theory of antennas as discussed below using transmission line model.

The name given to different antenna is as follows:

Antenna 1 :- Simple Patch antenna resonant at 6 GHz

Antenna 2 :- Dual resonant antenna without proper matching

Antenna 3 :- Dual resonant antenna with proper matching

- First of all we specify the dielectric constant (ε_r) and height of the substrate and the resonant frequency. From our design we are using FR4 substrate which is 1.6mm thick and has dielectric constant (4.4). The resonant frequency is 6 Ghz.

- Determine the width of radiating patch using following equation

$$\mathbf{W} = \frac{\mathbf{1}}{\mathbf{2f_r\sqrt{\mu_o\varepsilon_o}}}\sqrt{\frac{\mathbf{2}}{\boldsymbol{\varepsilon}_\mathbf{r} + \mathbf{1}}}$$

Or

$$\mathbf{W} = \frac{\boldsymbol{\upsilon}_\mathbf{o}}{\mathbf{2f_r}}\sqrt{\frac{\mathbf{2}}{\boldsymbol{\varepsilon}_\mathbf{r} + \mathbf{1}}}$$

Where $\boldsymbol{\upsilon_o}$ is the free space velocity of light.

By substituting all the values in given equation we get W=22.81mm

- Calculate the effective dielectric constant of the substrate using following equation for W>>h

$$\boldsymbol{\varepsilon_{reff}} = \frac{\boldsymbol{\varepsilon_r} + \mathbf{1}}{\mathbf{2}} + \frac{\boldsymbol{\varepsilon_r} - \mathbf{1}}{\mathbf{2}}\left[\frac{\mathbf{1}}{\mathbf{1} + \mathbf{12}\frac{\boldsymbol{h}}{\boldsymbol{W}}}\right]^{\frac{\mathbf{1}}{\mathbf{2}}}$$

On substation of all the values for 4 ghz resonant frequency we get effective dielectric constant ε_{reff}=3.952.

- Once W is calculated, Determine the extension of the length ΔL using

$$\mathbf{\Delta L = 0.412h}\left|\frac{\boldsymbol{\varepsilon}_\mathbf{reff} + \mathbf{0.300}}{\boldsymbol{\varepsilon}_\mathbf{reff} - \mathbf{0.258}}\right|\left[\frac{\frac{\mathbf{W}}{\mathbf{h}} + \mathbf{0.264}}{\frac{\mathbf{W}}{\mathbf{h}} + \mathbf{0.813}}\right]$$

On the substitution of all the required parameters we get the value of extension in length $\Delta L = 0.731\text{mm}$.

- Actual length of the patch can now be calculated by solving

$$\mathbf{L} = \frac{\mathbf{1}}{\mathbf{2f_r\sqrt{\boldsymbol{\varepsilon}_{reff}}\sqrt{\mu_o\varepsilon_o}}} - \mathbf{2\Delta L}$$

And we get L=17.409mm.

- Calculate free space wavelength λ_o

$$\boldsymbol{\lambda_o = \frac{\upsilon_o}{f}}$$

At 4 Ghz λ_o=75mm

Since λ_o>W

We can calculate conductance G_1 at the radiating edge of the patch by using following equation

$$\mathbf{G_1 \approx \frac{1}{90}\left[\frac{W}{\lambda_o}\right]^2}$$

On the substitution of values of W and λ_o, we get conductance G_1=0.0010277 siemens.

- Input impedance of the antenna can be expressed as

$$\mathbf{R_{in} = \frac{1}{2G_1}}$$

So R_{in}=490.196Ω.

Now as we know

$$\boldsymbol{R_{in}(y = y_o) = R_{in}(y = 0)cos^2(\frac{\pi}{L}y_o)}$$

$$\boldsymbol{50 = 490.196\ cos^2(\frac{\pi}{L}y_o)}$$

By solving this equation we get y_o=7.47mm. Where y_o is inset feed point.

- Substrate length l_s and width w_s can be obtained by given formulas

$$\boldsymbol{l_s = 6h + \mathrm{l_p}}$$

$$\mathbf{w_s = 6h + w_p}$$

All the comparative design parameters are illustrated in given below table.

2.2 Design Structures of Proposed Antenna

As per above listed dimensions of all the proposed structures of different antennas are designed in CST software and the design view is listed below:

Table 2.1 Dimensions of all design structure

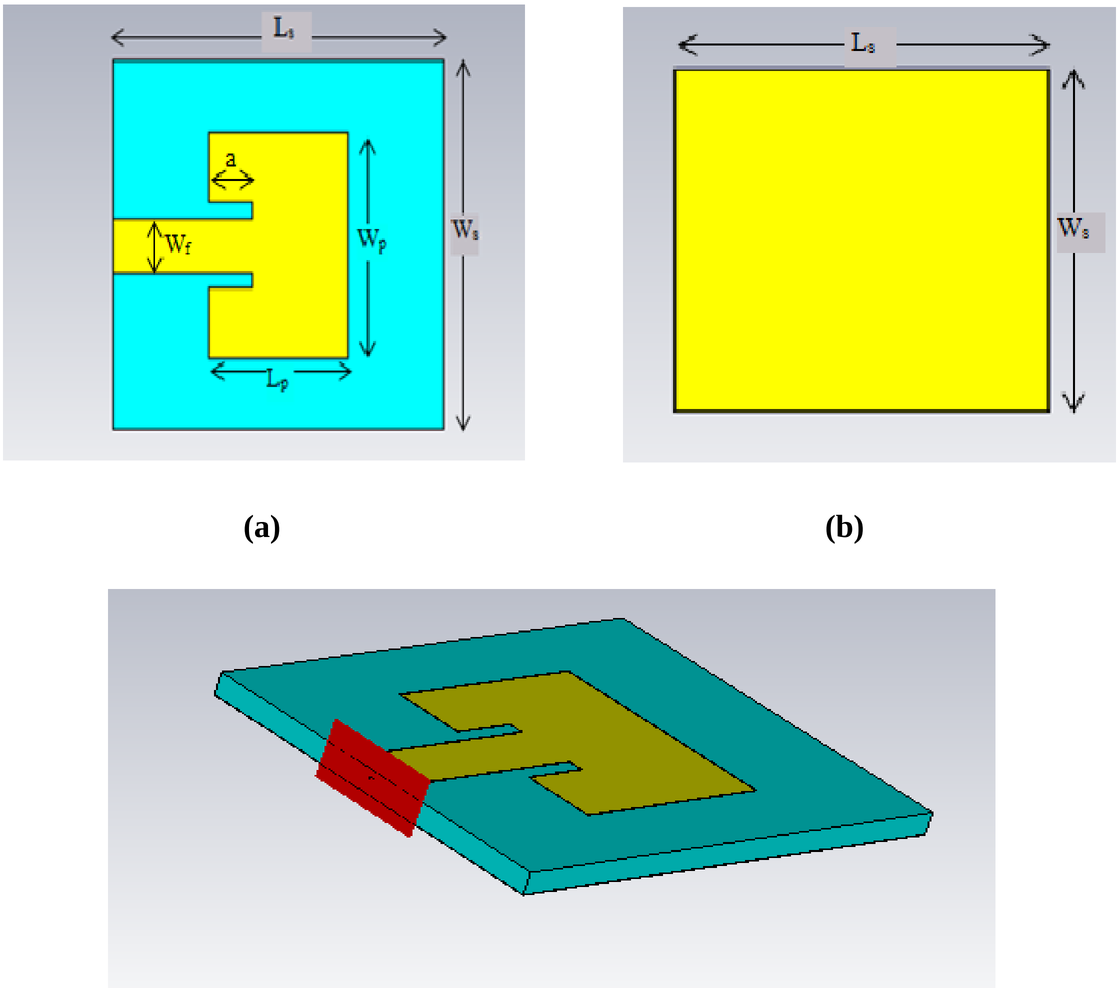
Antenna No.	Substrate Dimensions (mm)			Patch Dimensions(mm)			Feed Point	Frequency Band
	W_S	L_S	h	W_P	L_P	t	(x,y)	(F_L,F_H)
Antenna 1	25	27	1.6	15.21	11.33	.035	(-2.16,0)	(5.925,6.425)
Antenna 2	25	27	1.6	15.21	11.33	.035	(-2.46,0)	(3.8-4.3, 5.925-6.425)
Antenna 3	25	27	1.6	15.21	12.83	.035	(-2.76,-2.40)	(3.8-4.3, 5.925-6.425)

Table 2.2 Dimensions of C-Slot for both design structures

Antenna No.	C- Slot Dimensions(mm)		
	Inner radius R_1	Outer Radius R_2	Centre of Slot
Antenna 1	7	6	(0,0)
Antenna 2	7	6	(0,0)

2.2.1 Design View of Simple Patch Antenna At 6 GHz

The below shown structure is designed to resonant at 6 Ghz frequency



(a)

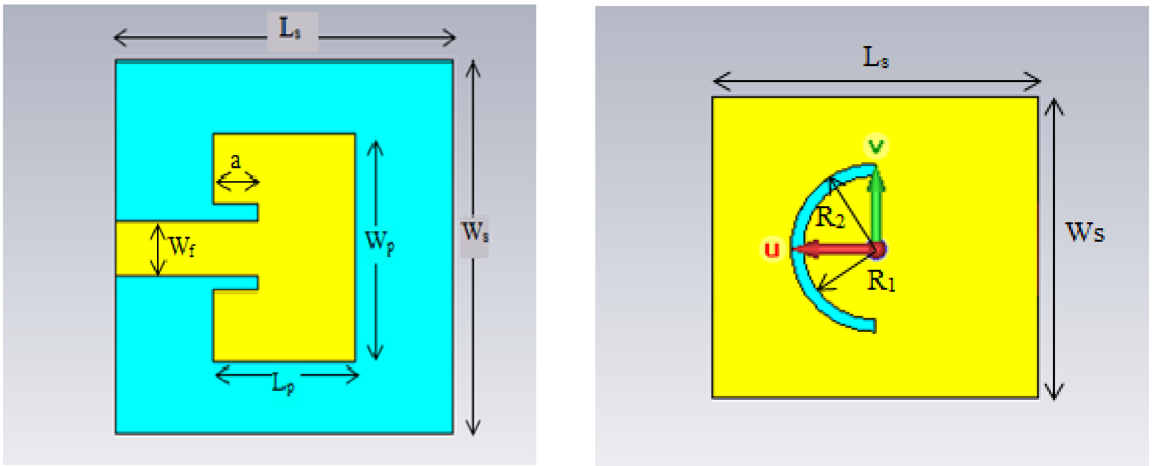
(b)

(c)

Figure 2.1 (a) Front View (b) Back View (C) 3-D View of Microstrip Patch Antenna

The above figure shows the geometric design of simple patch which resonant at 6 GHz along with all the dimensions whose values are mentioned in table 4.1

2.2.2 Design View of C-Slot Patch Antenna for dual Resonance



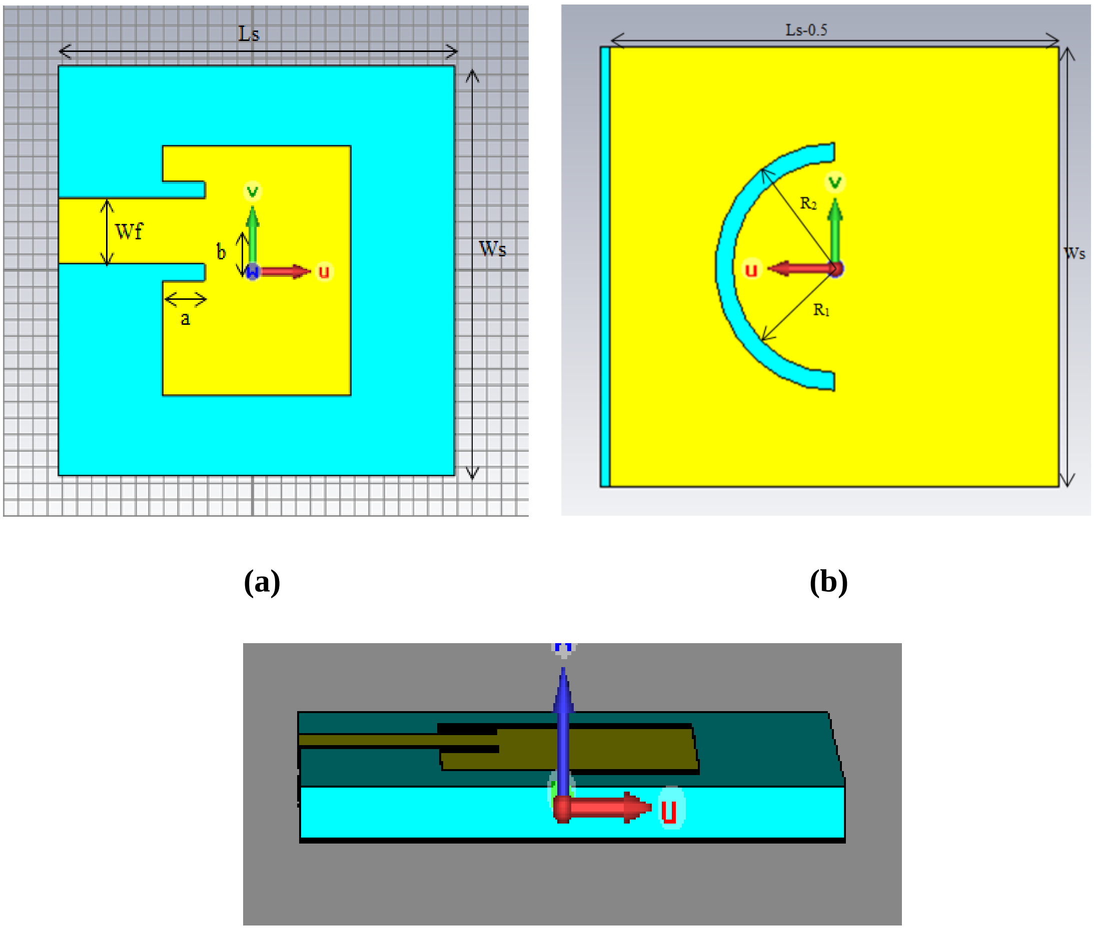
(a) **(b)**

Figure 2.2 (a)Front and (b) Back View of Dual resonant C-band antenna

The above structure shows the 2D view of dual resonant structure of the C-band antenna whose all dimensions are shown in above table while comparing it previous section 2.2.1 structure the only difference is of cutting of C-slot on ground plane for fulfilling our design needs.

2.2.3 Optimized Design for Dual resonant antenna

The design geometry of the proposed modified antenna is shown below is described by two dimensional view in CST softwares. Although the dimensions marked in figures are entitled in table of section 2.1.



(a) **(b)**

(c)

Figure 2.3 Dual resonant C-band antenna (a)Front view (b) Back view (c) Side view

The common thing in all these antenna structures is use of same feeding method although their point of feed got changed in antenna structure to structure for the search of best feed location impedance match. The ground plate is slightly modified to achieve proper bandwidth and the length of the patch is increased to decrease the resonant frequency.

2.3 Antenna Simulation Results

2.3.1 S_{11}– Parameter [Return loss]

The most commonly quoted parameter in regards to antennas is S_{11}. S_{11} represents how much power is reflected from the antenna, and hence is known as the reflection coefficient or return loss.

For example, if S_{11} = 0 dB, then all the power is reflected from the antenna and nothing is radiated. If S_{11} = -10dB, indicates if 2 dB power is delivered to antenna then -8 dB power is reflected.

Mathematically,

Return loss (dB) = $-20 * \log_{10}| S_{11}|$

From the S_{11} curve we can easily check resonance frequency of the antenna along with the bandwidth of the antenna. Generally the bandwidth of consideration is at -10dB return loss as for this band the reflected power is quite low to disturb the antenna's radiation characteristics.

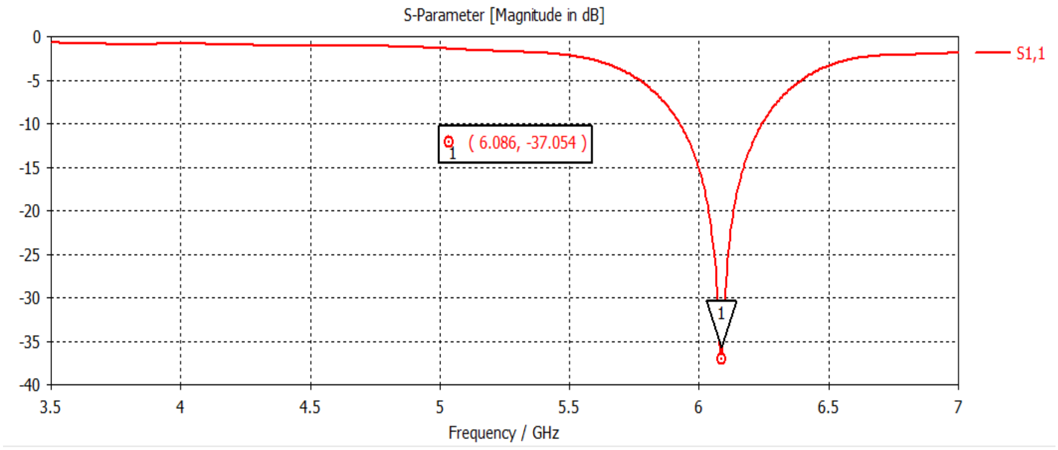


Figure 2.4 Return loss for simple patch antenna [6GHz]

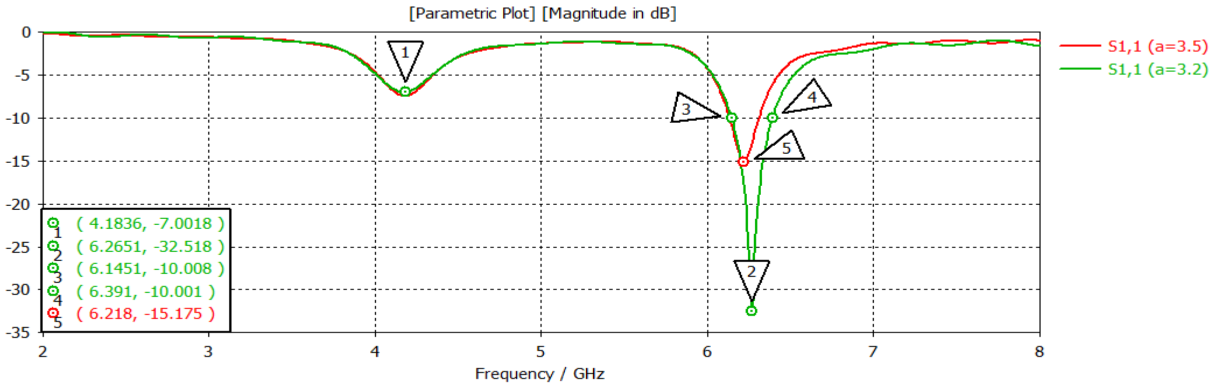


Figure 2.5 S_{11}Plot for dual resonant antenna with C-slot

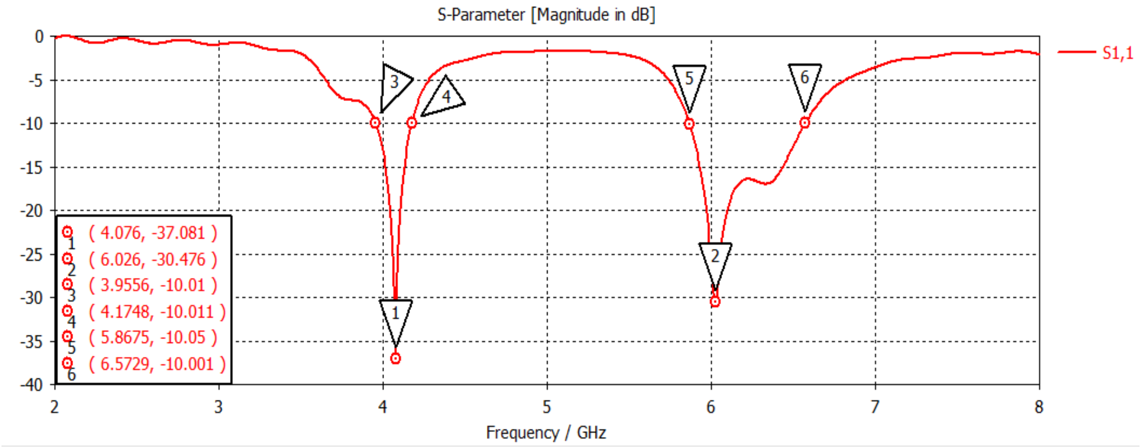


Figure 2.6 S_{11} Plot for modified Antenna With Proper Matching

Table 2.3 Comparision of Bandwidth & Frequency of Operation

Antenna No.	Resonant Frequency(GHz)		Lower side band (at -10dB)		Upper side band (at -10dB)		Bandwidth (MHZ)	
1	6.0		5.9		6.2		300	
2	4.18	6.26	#	#	6.14	6.39	#	250
3	4.07	6.02	3.9	4.1	5.8	6.5	200	700

2.3.2 VSWR Plot

Voltage standing wave ratio parameter is ratio of maxima to minima ratio of voltage amplitudes. Further it is related with S11 or refection coefficient parameter. While the term Smith chart depicts the impedance matching of the antenna and shows how with the variation of the frequency the antenna impedance is changed.

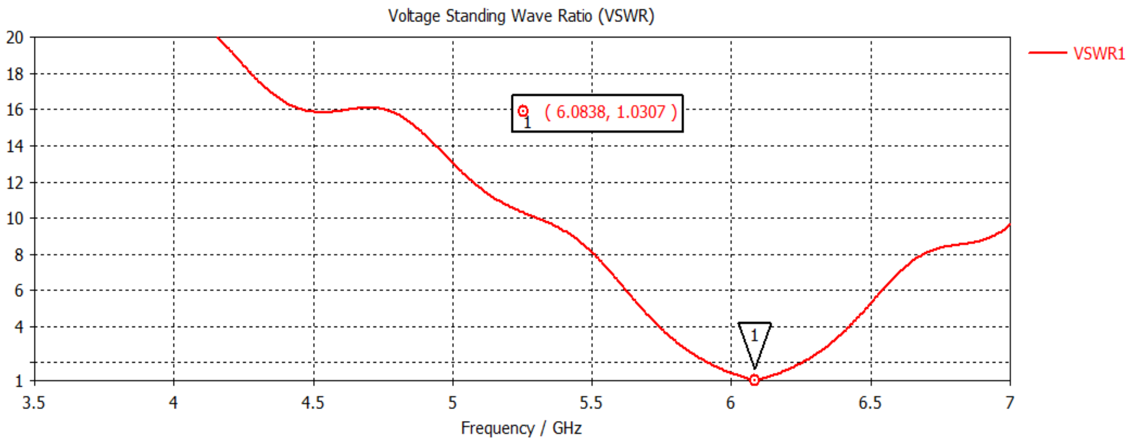


Figure 2.7 VSWR curve of Simple Patch Antenna [6 GHz]

From the above curve we can say that VSWR curve is very good at resonance frequency it is 1.0307 which is ideal value for any device as the range of VSWR lies from 1 to infinity because

$$\mathbf{VSWR} = \frac{1+|\Gamma|}{1-|\Gamma|}$$

Where Γ lies between 0 to 1.

Also the effective VSWR must be within limit of 2 as shown in above figure it is also a criteria to show bandwidth of consideration.

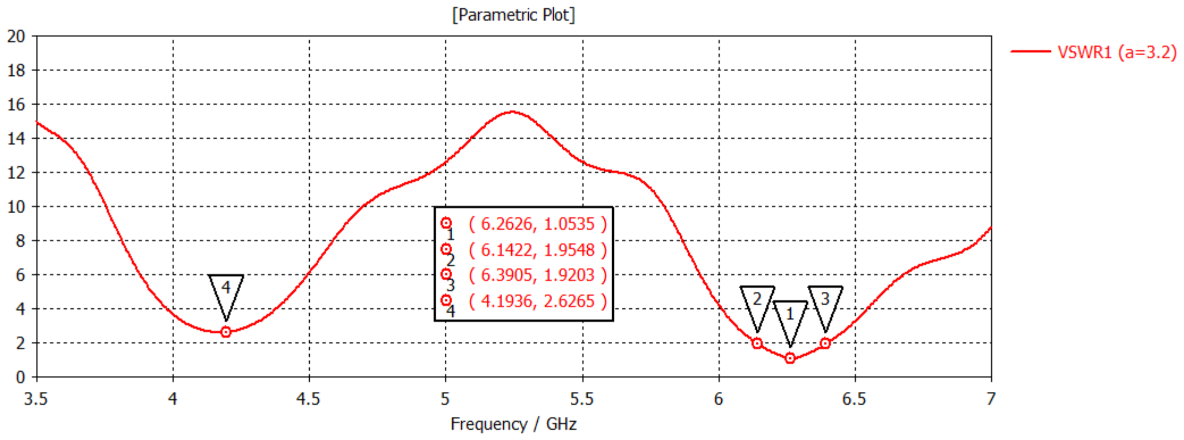


Figure 2.8 VSWR Plot of dual resonant antenna with C-slot

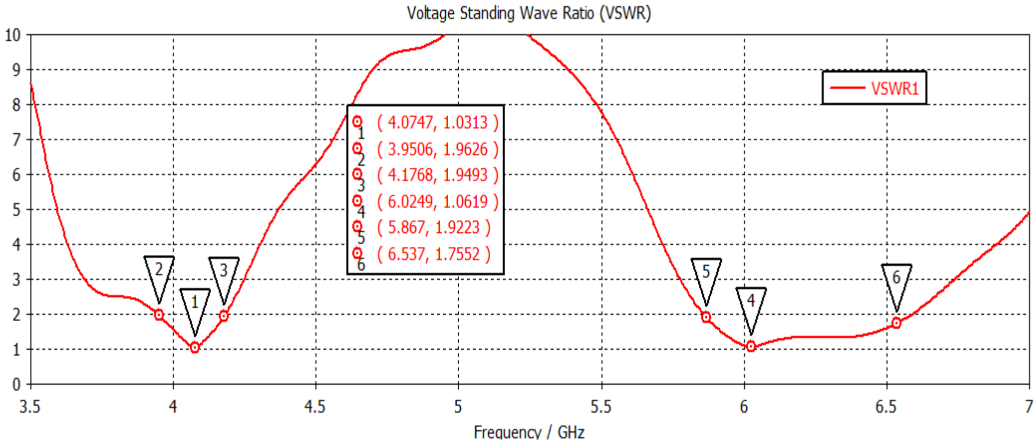


Figure 2.9 VSWR Plot for modified Antenna With Back Metal

From the above results of VSWR, we can see that all antenna structures proposed have good results and their VSWR values are shown in below table

Table 2.4 Comparison of for VSWR Simulation Results

Antenna No.	Resonant Frequency (GHz)		VSWR	
1	6.08		1.030	
2	4.19	6.26	2.62	1.053
3	4.07	6.02	1.03	1.06

2.3.3 Smith Chart Plot

The smith chart which gives impedance characteristics of an antenna is also related with the S11 and VSWR parameters. This shows that all parameters are interrelated and on variation of one other is also affected. Thus we have to make prime focus on feed to the antenna which should be best, so that reflections are minimum. The smith chart diagram for simple patch is shown below:

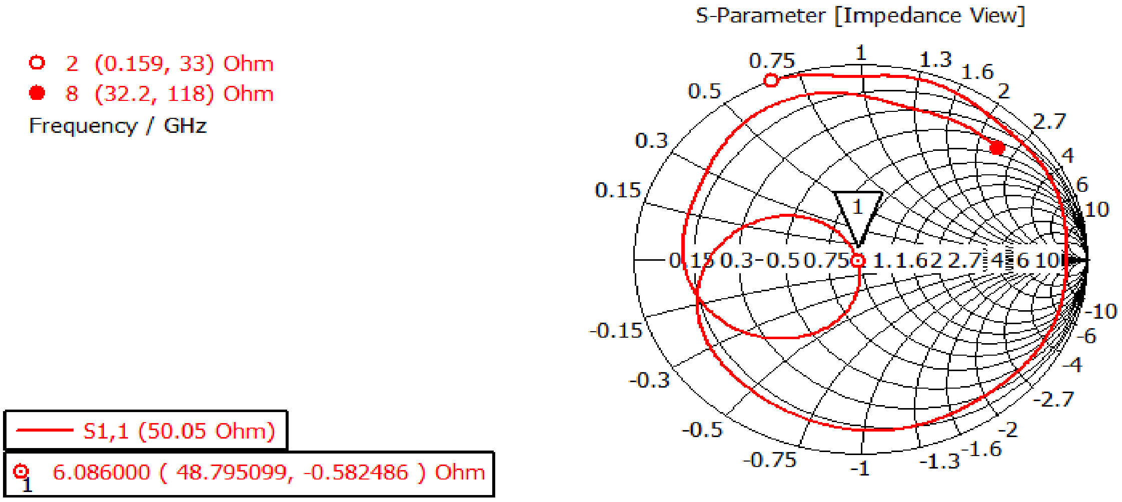


Figure 2.10 Smith Chart of Simple Patch Antenna [6 GHz]

From the above figure, it is clear at frequency of operation the impedance of antenna is real which gives maximum paper to transfer on impedance match with the line and for other frequencies it is varying for reactive terms which depicts in reflections from the antenna with the power feed from the micro strip feed line.

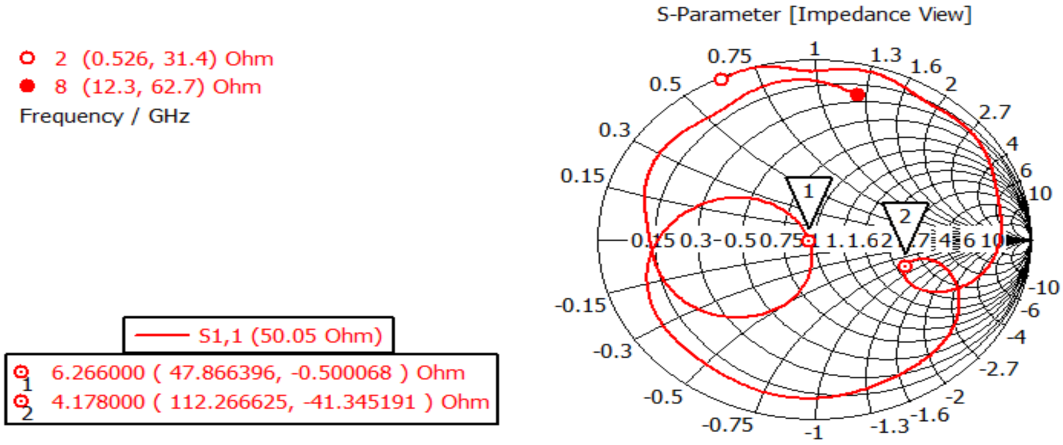


Figure 2.11 Smith Chart Plot dual resonant antenna with C-slot

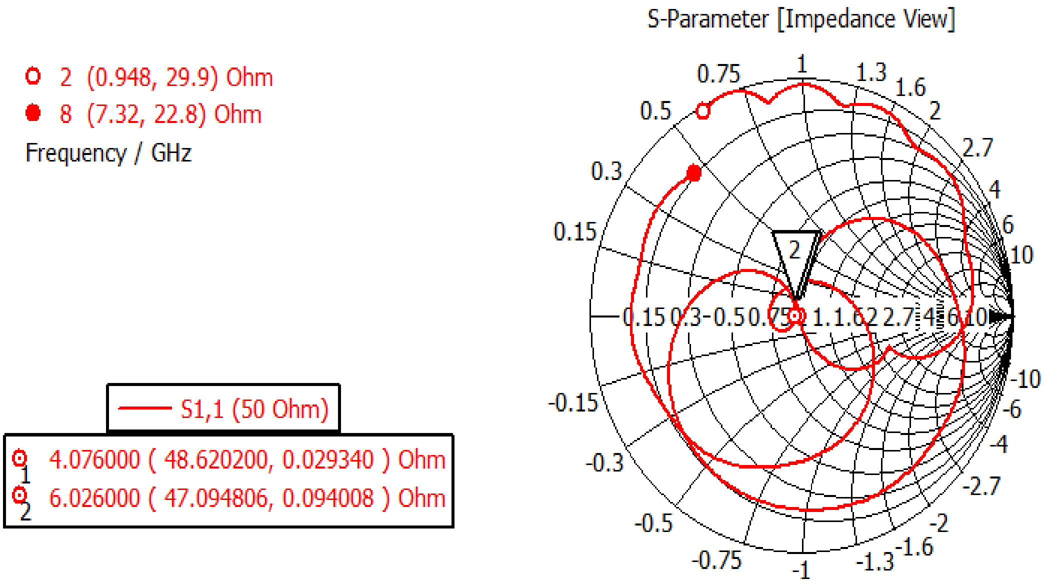
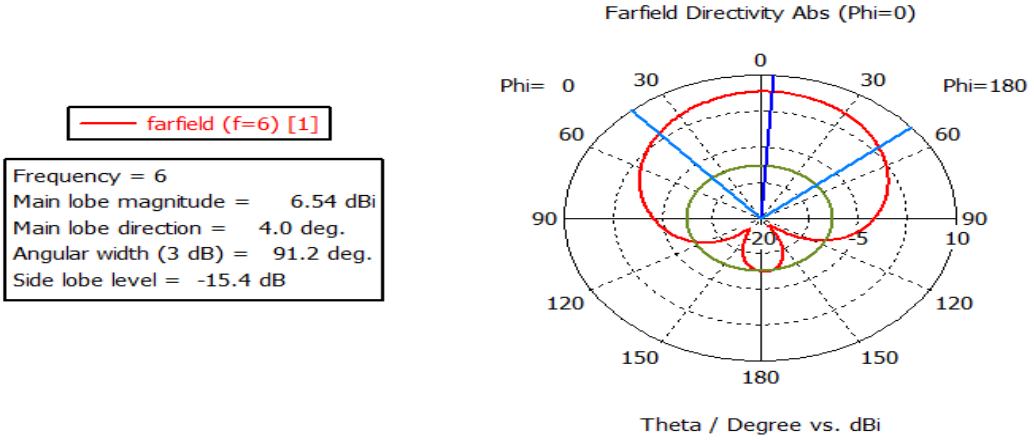


Figure 2.12 Smith Chart Plot for modified Antenna

By comparing the results of above antennas, we can see that there is a slight improvement in VSWR curve because reflections are reduced due to better optimised results.

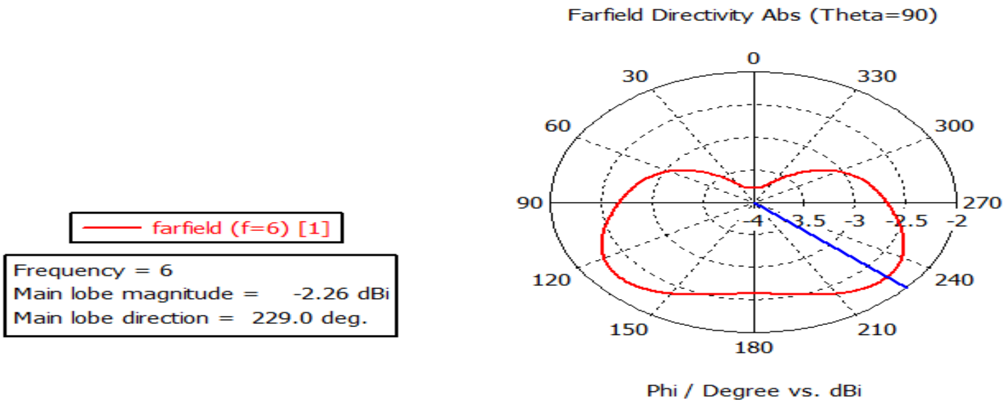
2.3.4 Elevation, Azimuth Pattern of Proposed Antennas

The Far Field characteristics of an antenna are viewed from the elevation and the azimuth pattern of an antenna. The elevation Pattern gives the far field pattern for $\Phi = 0$ and θ varying while Azimuth pattern gives far field pattern for $\theta = 90^o$ degree and Φ varying. Elevation pattern shows the E-field variation in x-z plane. Azimuth pattern shows variation in H-field in x-y plane. Radiation in x-y plane must to be minimum because it degrades the radiation efficiency of antenna. It is known as cross polarization. In the given below figures the above discussed characteristics are shown as polar plot of 3-D radiation pattern.



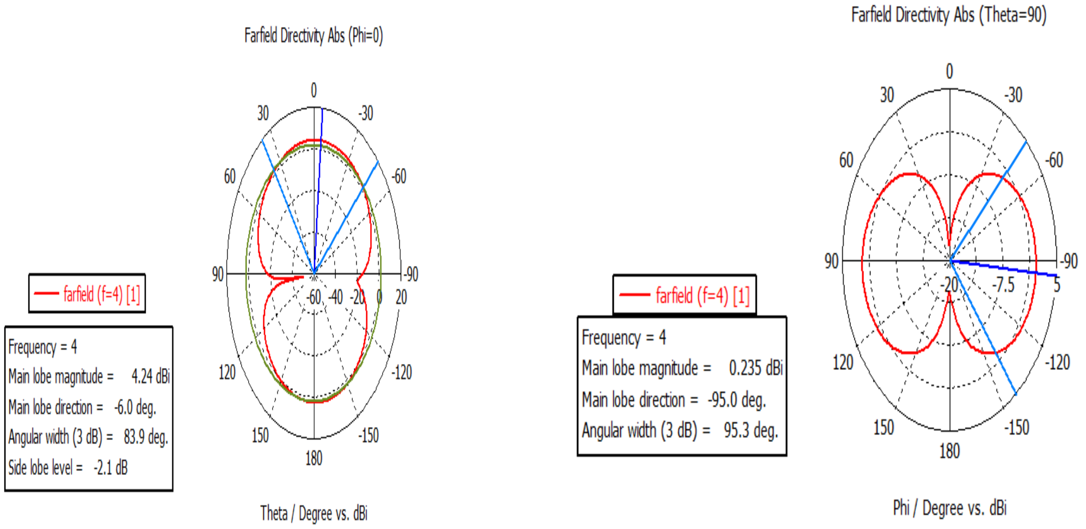
Frequency = 6
Main lobe magnitude = 6.54 dBi
Main lobe direction = 4.0 deg.
Angular width (3 dB) = 91.2 deg.
Side lobe level = -15.4 dB

(a)



Frequency = 6
Main lobe magnitude = -2.26 dBi
Main lobe direction = 229.0 deg.

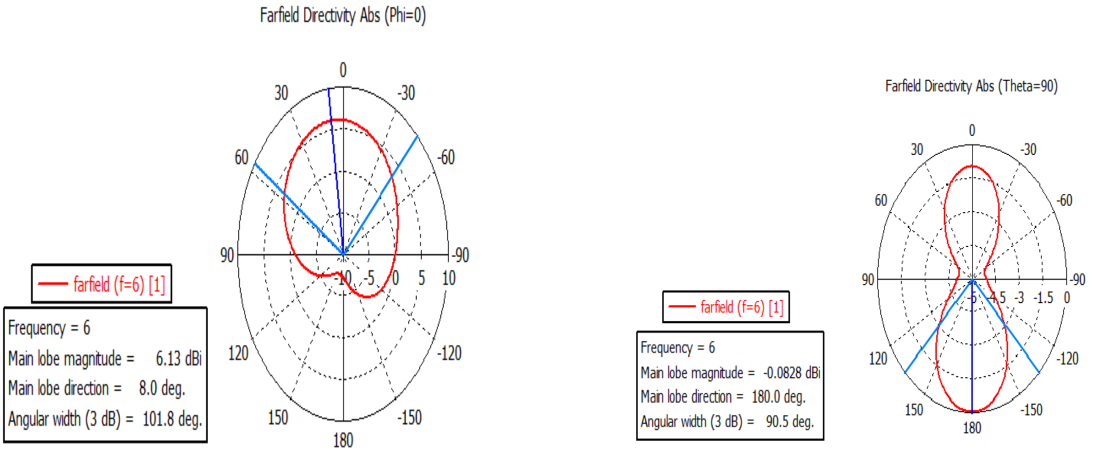
Figure 2.13 (a) Elevation Pattern (b) Azimuth Pattern for Simple Patch Antenna



Frequency = 4
Main lobe magnitude = 4.24 dBi
Main lobe direction = -6.0 deg.
Angular width (3 dB) = 83.9 deg.
Side lobe level = -2.1 dB

Frequency = 4
Main lobe magnitude = 0.235 dBi
Main lobe direction = -95.0 deg.
Angular width (3 dB) = 95.3 deg.

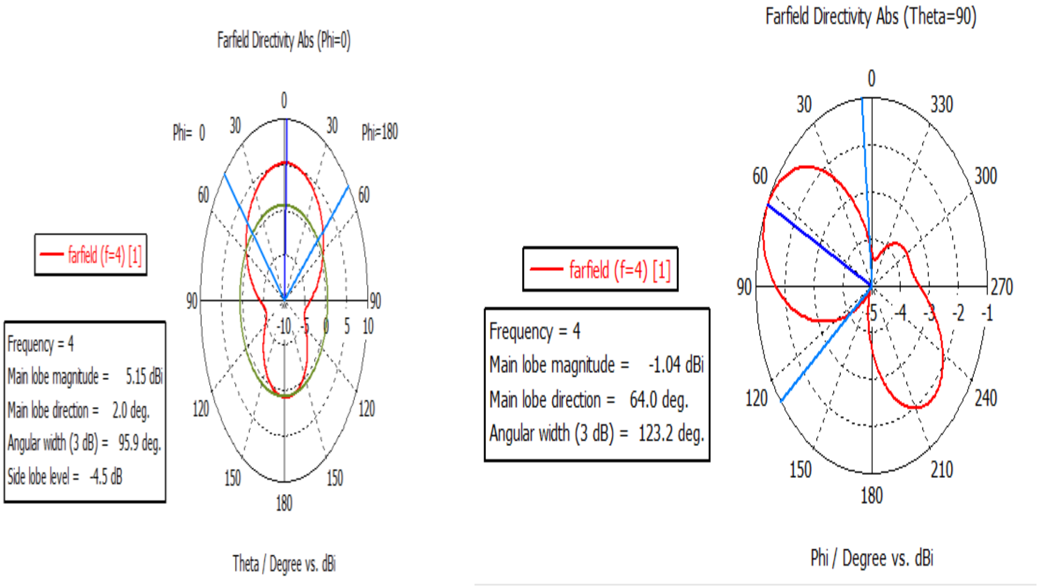
(a)



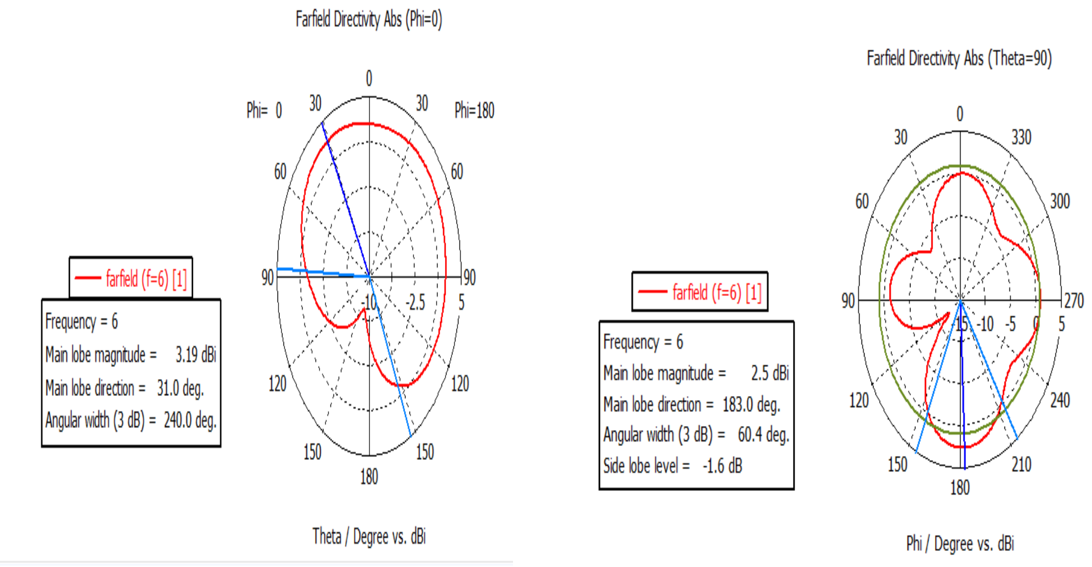
(b)

Figure 2.14 Elevation and Azimuth Pattern for C-slot antenna (a)At 4Ghz (b) At 6 Ghz

Since, Elevation (Φ = 0 constant), Azimuth (θ = 90 constant) and directivity gives the pattern for radiation view of RF waves which gives us idea for direction of radiation and maximum gain of the antenna.



(a)



(b)

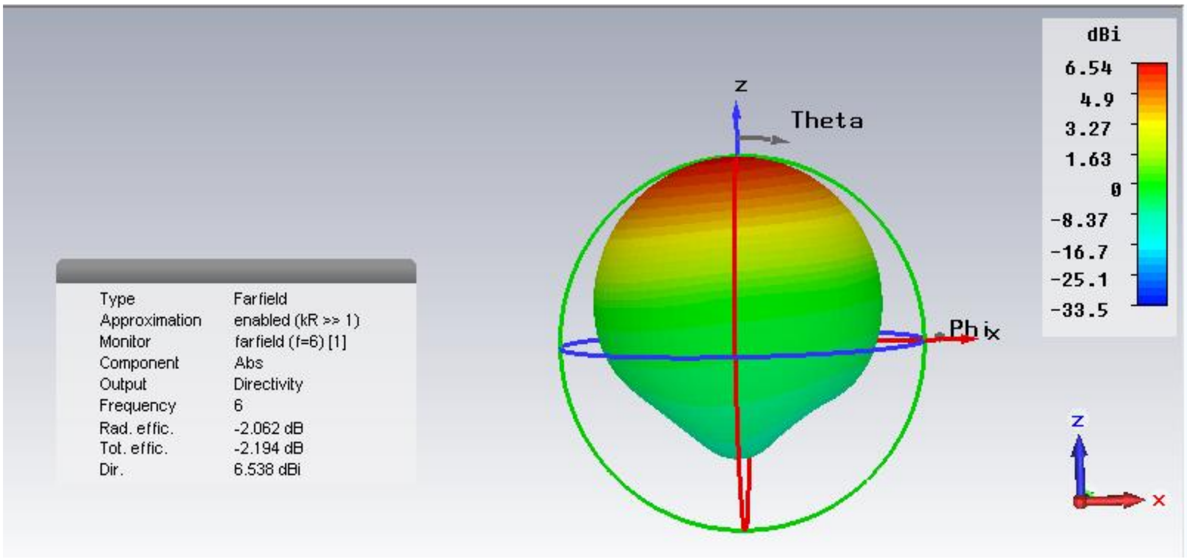
Figure 2.15 Elevation and Azimuth Pattern for Modified C-slot antenna
(a)At 4Ghz (b) At 6 Ghz

The above figure shows the polar plot for far field radiations of the above antenna with different constant plane of Φ for elevation plane and constant θ plane for azimuth plane. Also the 3D directivity view of the above dual resonant antenna is illustrated in next section.

Table 2.5 Comparison of Side lobe levels & Main lobe Magnitude

Antenna No.	Side lobe level(dB)	Resonant Frequency(GHz)		Main Lobe Magnitude(dBi)	
1	-15.4	6		6.54	
2	-2.1	4	6	4.24	6.13
3	-6.1	4	6	5.15	3.19

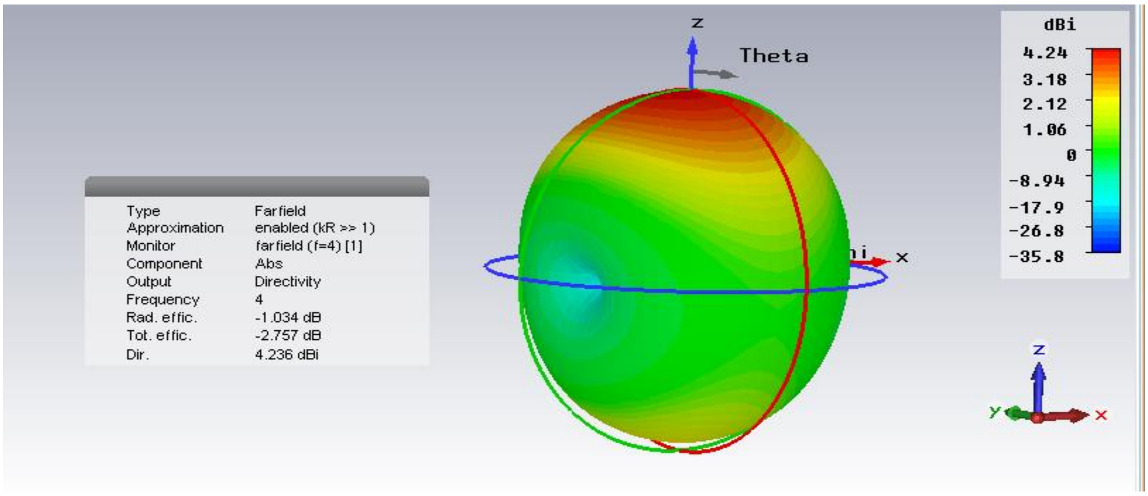
2.3.5 3D-Directivity View



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=6) [1]
Component	Abs
Output	Directivity
Frequency	6
Rad. effic.	-2.062 dB
Tot. effic.	-2.194 dB
Dir.	6.538 dBi

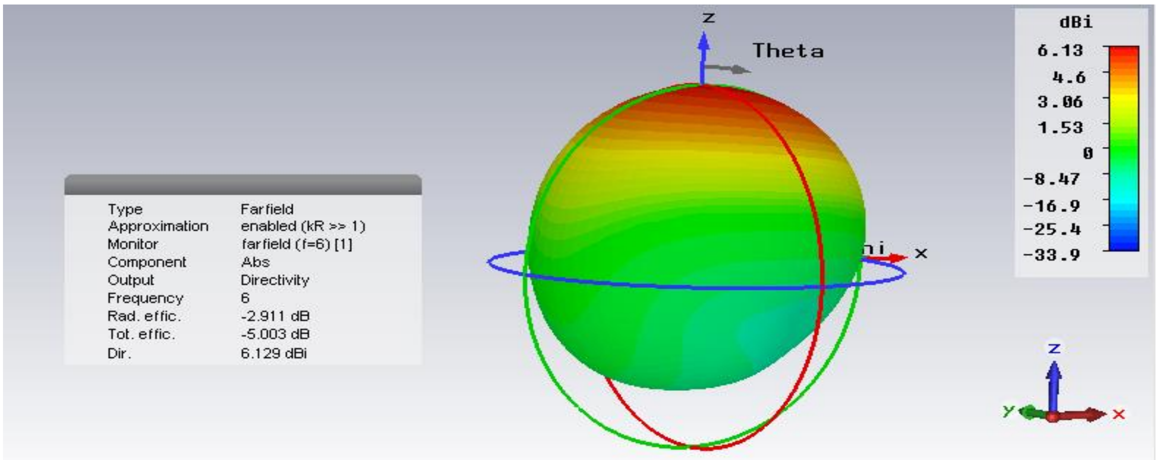
Figure 2.16 3D Directivity pattern of the antenna for simple patch[6 GHz]

From the directivity pattern, it is clear that majority of the power of given antenna radiates its power towards main lobe with directivity i.e. maximum gain of 6.538 dBi. Also the side lobe of the antenna is quite low -15.4 dB.



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=4) [1]
Component	Abs
Output	Directivity
Frequency	4
Rad. effic.	-1.034 dB
Tot. effic.	-2.757 dB
Dir.	4.236 dBi

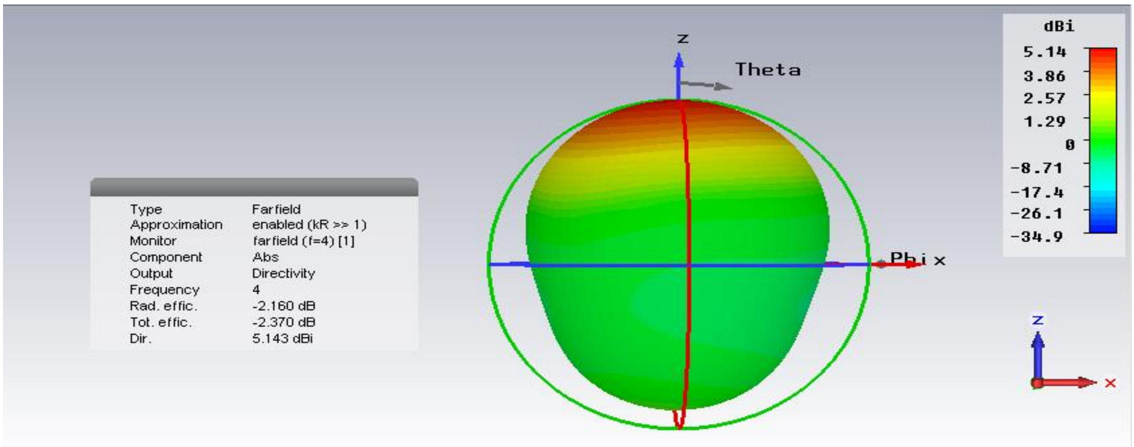
(a)



Type Farfield
Approximation enabled (kR >> 1)
Monitor farfield (f=6) [1]
Component Abs
Output Directivity
Frequency 6
Rad. effic. -2.911 dB
Tot. effic. -5.003 dB
Dir. 6.129 dBi

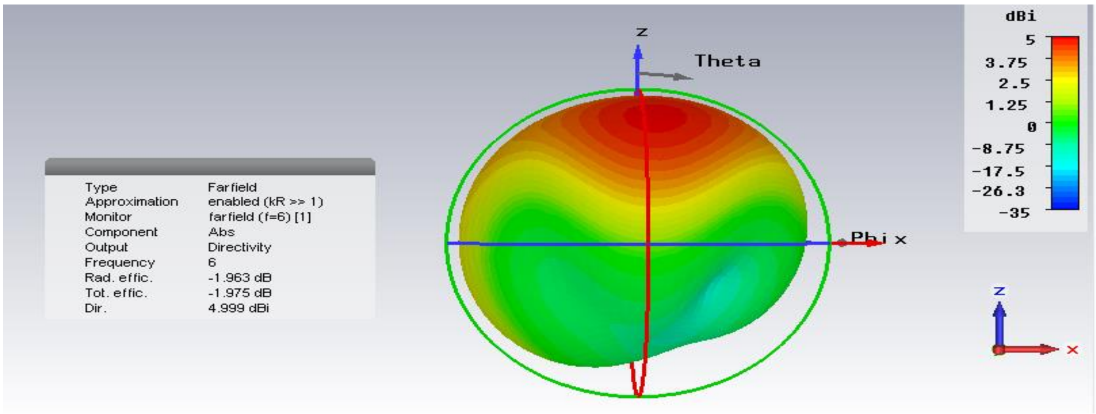
(b)

Figure 2.17 3D Directivity Plot for Dual resonant antenna with C –slot



Type Farfield
Approximation enabled (kR >> 1)
Monitor farfield (f=4) [1]
Component Abs
Output Directivity
Frequency 4
Rad. effic. -2.160 dB
Tot. effic. -2.370 dB
Dir. 5.143 dBi

(a)



Type Farfield
Approximation enabled (kR >> 1)
Monitor farfield (f=6) [1]
Component Abs
Output Directivity
Frequency 6
Rad. effic. -1.963 dB
Tot. effic. -1.975 dB
Dir. 4.999 dBi

(b)

Figure 2.18 3D Directivity Plot for Dual resonant antenna with C –slot

Table 2.6 Comparision of Directivity Of All Proposed Antennas

ANTENNA NO.	DIRECTIVITY(dBi)	
	4 GHz	**6GHz**
Antenna 1	**#**	**6.538**
Antenna 2	**4.236**	**6.129**
Antenna 3	**5.143**	**4.999**

After getting all simulation results, we can compare them in order to see the changes in the antenna pattern and accept the best desired design so that our results would be superior. Although the simulation results are compared together and analysis report is presented in tabular form, thereby the modified antenna structure 3 is more superior than other antenna structure designed due to more Gain and better return loss curve.

From the above study we can say that our antenna radiates in desired band of frequency with required bandwidth along with the much needed parameter i.e. Antenna Gain. Hence our design is so good so far and now we move towards concept of frequency selective surfaces in order to enhance our gain and the design aspects for that are discussed in next chapter.

Chapter 3

3 Frequency Selective Surfaces

3.1 Introduction

Frequency selective surface [23-26] is an assembly of identical elements arranged in a one or two directional array. This array can be either radiating or non-radiating. These element arrays are used as electromagnetic filters which are used in wide variety of applications like Radomes, Dichroic surfaces, mean-derline polarizers and circuit analog absorbers. Radomes are the protective surfaces which are used to minimize the radar cross section. Properly designed circuit analog absorber (array of resistive elements) can achieve greater than 25dB of attenuation over a decade of bandwidth. Mean derline polarizer are used to transform linear polarization to circular polarization and vice-versa over a bandwidth of upto an octave. Dichroic surface is designed to reflect one frequency and transmit other frequency. It works as an electromagnetic filter.

3.1.1 FSS Element Comparison

There are a variety of possible elements to realize FSS array. Following four type are commonly used

1. Center connected
2. Loop type
3. Plate type
4. Combination of all

The center connected element works both as radiating and non-radiating array. For non-radiating array loop elements are admirable alternative. These elements are smaller in size in X and Y direction for given wavelength and can arrange more elements per unit area. Plate type elements in general do not have very desirable characteristics. The dimensions round the X and Y is around half of a wavelength, which limits the packing density of elements. In addition the plates are highly inductive element with small capacitance which has difficulties in achieving resonance condition. At resonance, the FSS becomes short circuit and acts as a perfect electric conductor ground plane, which reflects the EM wave. So if the FSS not resonant, then it is impossible to achieve perfect reflections. Finally combination of elements is used to get any generalized form in in any meaningful way. In this category we can combine any type of elements according to the imagination of the designer.

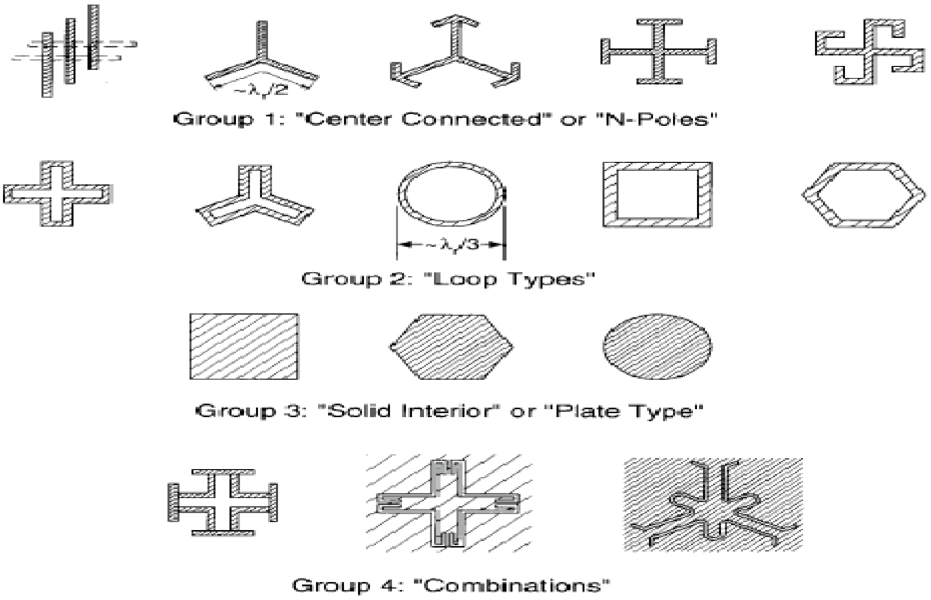


Figure 3.1 Type of FSS Elements

3.1.2 Infinite FSS Array

Infinite FSS array is the only true FSS due to requirement of periodicity. So it is advised to discuss the infinite FSS array first and then apply this knowledge to the closets realizable approximation, namely finite arrays.

Bandwidth is very important concern. As we know that closer element spacing leads to larger bandwidth. When impedance of FSS is low it works as good conductor and lowest impedance can be achieved at the resonance, where all the capacitive components of FSS cancel all of the inductive components. Another method is to simply reduce the total possible impedance.

3.1.3 Finite FSS Array

Only finite FSS array are physical realizable. Infinite arrays are useful for understanding many properties of FSS arrays, which can be applied finite FSS arrays. Infinite FSS arrays can’t be realized physically because in infinite FSS array we assume infinite number of elements.

3.1.4 Grating Lobes

Grating lobes [27-28] are important concern in FSS array design. Phase difference between two collinear point sources can be expressed by

$$\psi = r sin\theta cos\phi$$

if this phase difference or phase delay is equal to 2π, then two source will add in phase and create a grating lobe. The smallest spacing this will occur when

$$sin\theta cos\phi = 1$$

Or when $$r_{rad} = \frac{2\pi r_m}{f} = 2\pi$$

$$r_m = f$$

When the element does not radiate energy in the direction of a grating lobe, then the lobe can-not radiate energy. This is easily shown by considering that an array pattern can be generated using pattern multiplication, which states that

$$E(\theta,\phi) = E_s(\theta,\phi) * E_x(\theta,\phi) * E_y(\theta,\phi) * E_z(\theta,\phi)$$

Where E_s is the pattern of the single element and

E_x, E_y, E_z are the patterns of a linear array of point sources in the **x, y, z** direction respectively.

Thus if the source doesn't radiate energy in a given direction, then neither will the array radiate in given direction. The performance of an antenna degrades significantly due to the presence of the grating lobes. For example if an antenna is being used as a receive antenna, it will receive signals from the both the desired direction and also the direction in which the grating lobe is present. It is impossible to avoid grating lobes completely, because grating lobes are only a function of frequency and element spacing. So it is mostly important to be aware of their presence.

3.1.5 Radiating Surface waves

Radiating surface waves [29-30] show about 20-30 % below resonance when the inter-element spacing is less than 0.5 λ_o.There are two surface waves, in frequency range where radiating surface wave exist, for the finite array. These waves propagate in opposite direction to each other along the array. The current associated with these waves is many times stronger than the Floquent currents. Floquent currents [31] are the currents induced by an incident wave used to excite the array and have the same amplitude and phase as the incident wave. These currents are induced in both finite and infinite FSS arrays. Surface waves cause high currents near the edges of the array. The pus point is that strong surface wave do not radiate as efficiently as floquent currents.

There are two techniques to reduce the surface waves. The first is to curve the FSS and second is to add resistive loading to the elements to reduce the current levels. The addition of a resistive component results to a significant degradation of the reflectivity of the FSS. Since the surface wave currents are highest at the edges, it is sufficient to add relatively high resistive components only on the edge elements of the FSS array.

3.2 FSS Unit Cell Design approach

The structure explored here comprises of two patches per cell and is utilized as a beginning stage to display dual band frequency selective surfaces upheld by a single dielectric layer. For this situation, we consider the minimal cost FR-4 fiberglass substrate with relative permittivity ε_r= 4.4, thickness d = 1.6 mm and dielectric loss tangent tan(δ)= 0.02. The array shaped by square circle and crossed dipole components (Crossed Loops) is imprinted on the fiberglass substrate keeping in mind the end goal to be researched as far as some electromagnetic parameters, for example, the transmission coefficient, resonant frequency and bandwidth. Reproduced consequences of the transmission coefficients are acquired utilizing CST software.

3.2.1 Dimensions for FSS unit cell design

For FSS unit cell structure design need uses certain dimensions in its geometry which is indicated in listed below table:

Where,

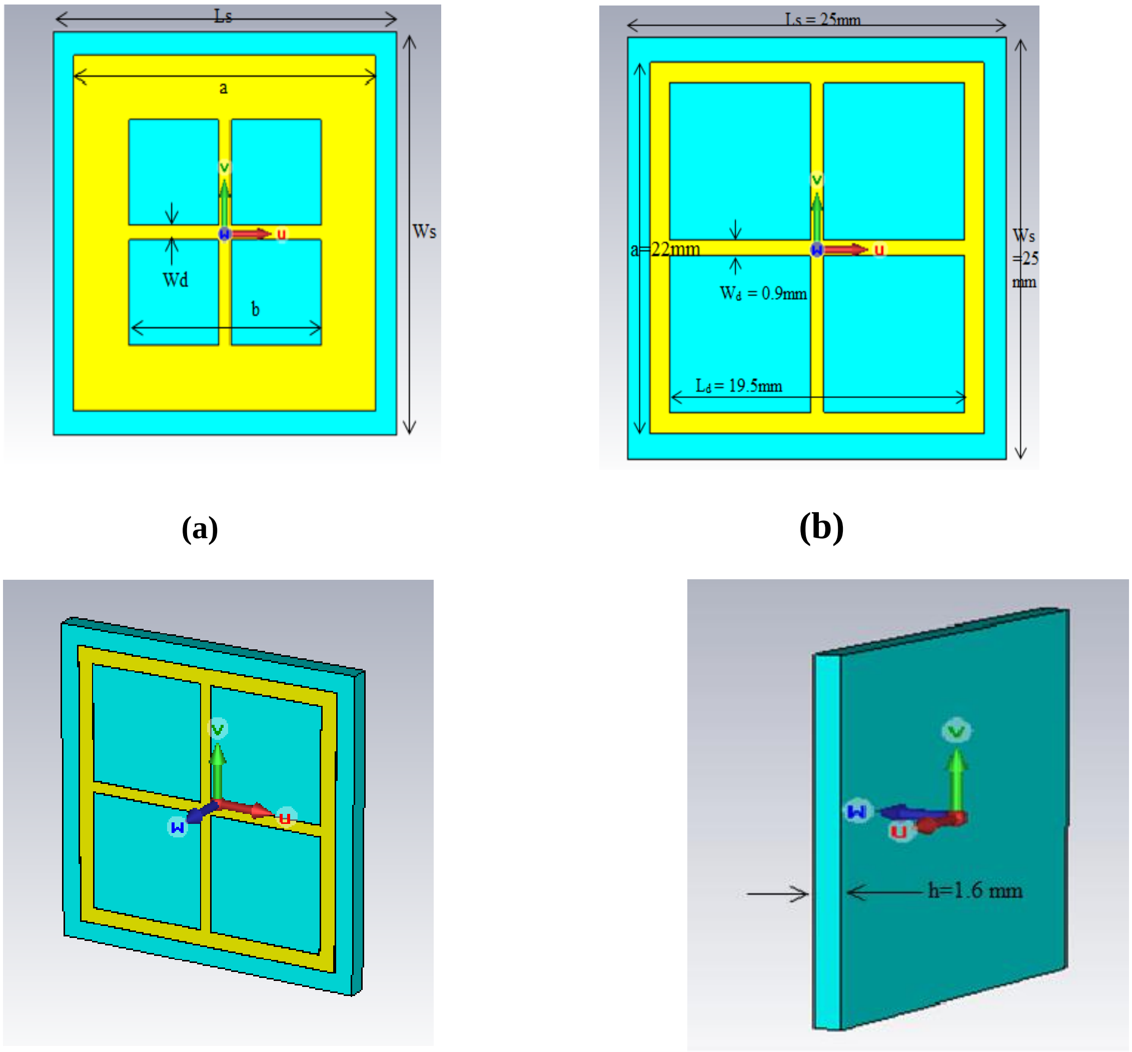
Unit cell 1 = Designed to resonant at 6 Ghz

Unit cell 2 = Designed to resonant at 4 Ghz

Table 3.1 Dimensions for FSS unit cell design

Unit Cell No.	**Substrate Dimensions(mm)**			**Patch Dimensions(mm)**		
	Width W_S	**Length L_S**	**Height H**	**Side of Patch a**	**Side of Slot $b=L_d$**	**Width of Dipole W_d**
Unit Cell 1	**25**	**25**	**1.6**	**22**	**14**	**0.9**
Unit Cell 2	**25**	**25**	**1.6**	**22**	**19.5**	**0.9**

3.2.2 Design Structure of FSS Unit Cells



(a) **(b)**

(c) **(d)**

Figure 3.2 (a) unit cell 1 (b) unit cell 2 (c) front view of unit cell (d) back view of unit cell

As shown in Figure 5.1 the side of square slot on the patch is dominant parameter to control the resonant frequency of the FSS unit cell. The results of slot side variation are shown in given figure as S- parameters of unit cells.

3.2.3 Reflection and Transmission Characteristics of Unit Cells

S-parameters of any structure shows the reflection and transmission characteristic of considered structure. S_{11} and S_{22} are known as reflection coefficients, which shows how much reflected back. S_{12} and S_{21} are transmission coefficients.

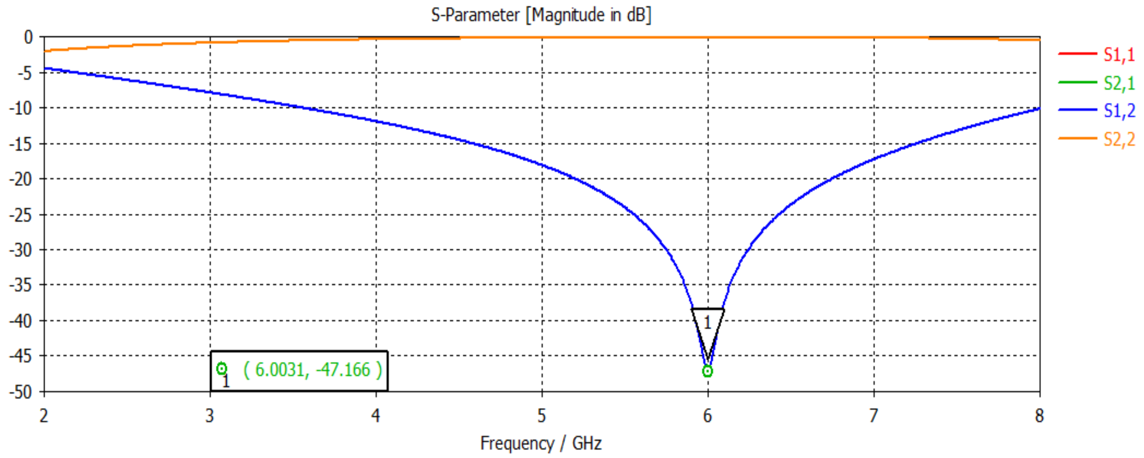


Figure 3.3 Reflection and Transmission parameters of Unit cell 1

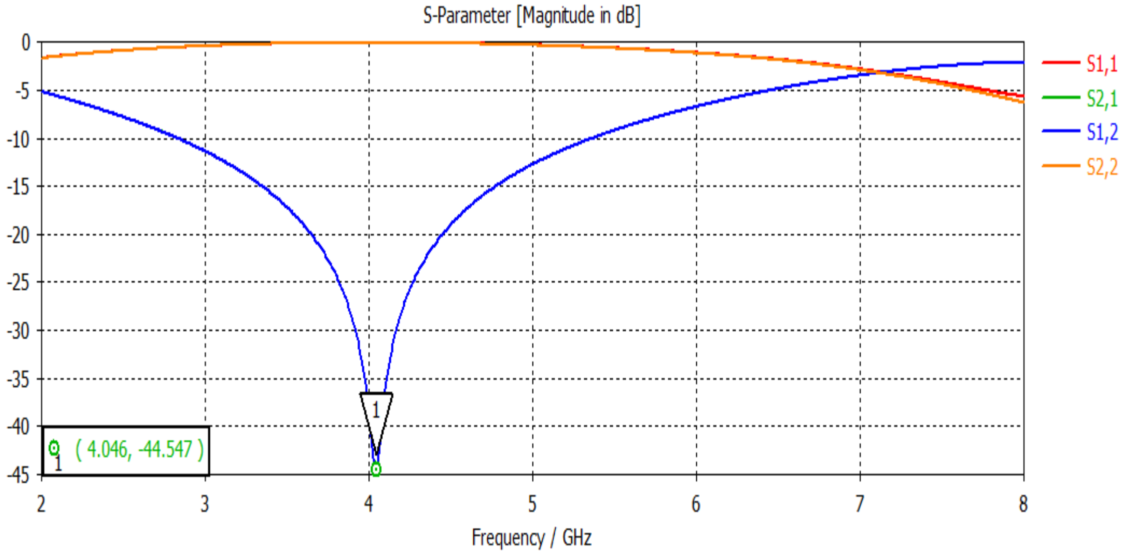


Figure 3.4 Transmission and Reflection parameter of Unit cell 2

As the results shows the reflection coefficient at resonant frequency is 0dB that mean the structure is reflecting all the power applied to it at same resonant frequency the transmission coefficient S_{12} or S_{21} is approximately -45 dB that shows no transmission of power from one port to other port. So we can say that our designed structures are working as perfect reflectors. For reflections at two different frequencies we need to apply two reflectors as shown below:

3.3 Double Layered FSS Unit Cell

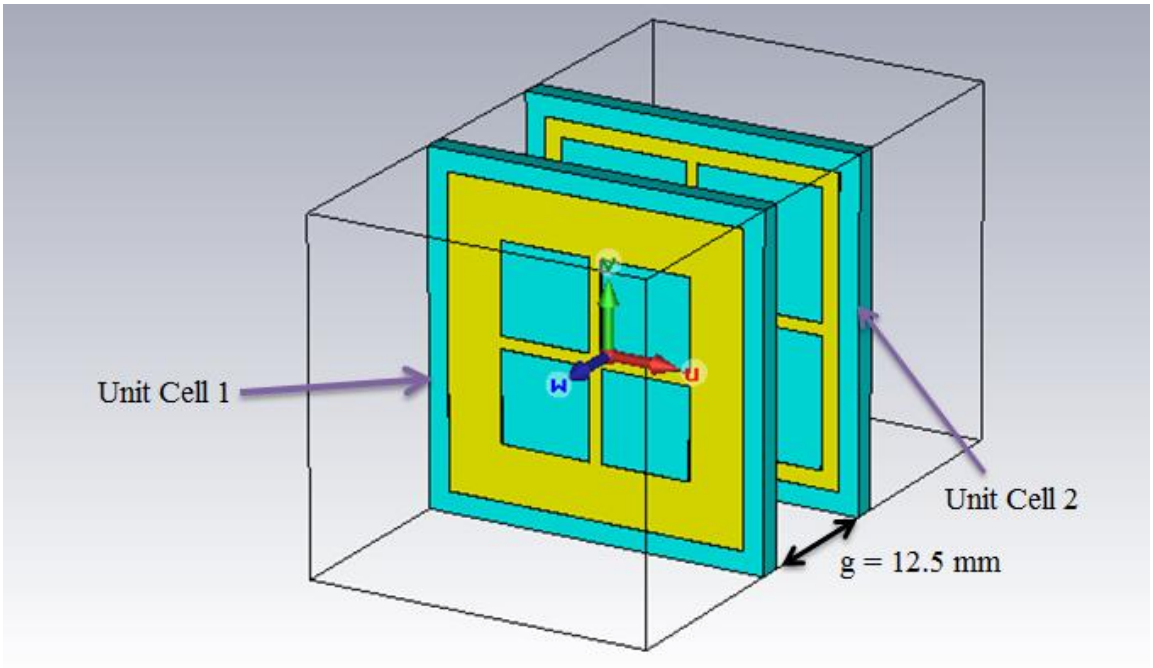


Figure 3.5 Double Layered FSS Unit Cell for Dual Band Reflections

3.3.1 Reflection and Transmission Characteristics of Double layer Unit Cell

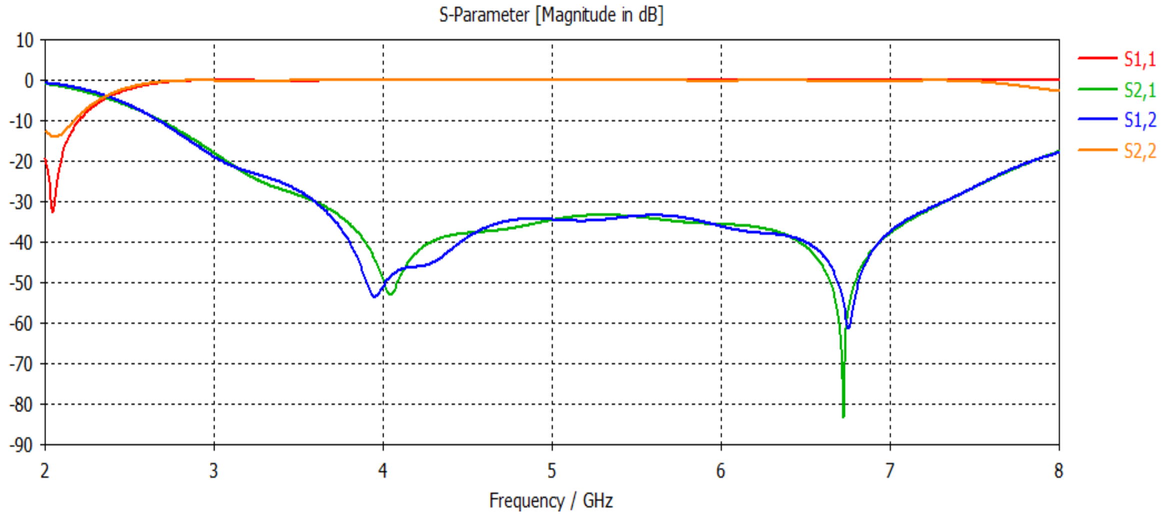


Figure 3.6 S parameter Plot of double Layer Unit Cell

3.3.2 Phase Plot of Dual Layer FSS Unit Cell

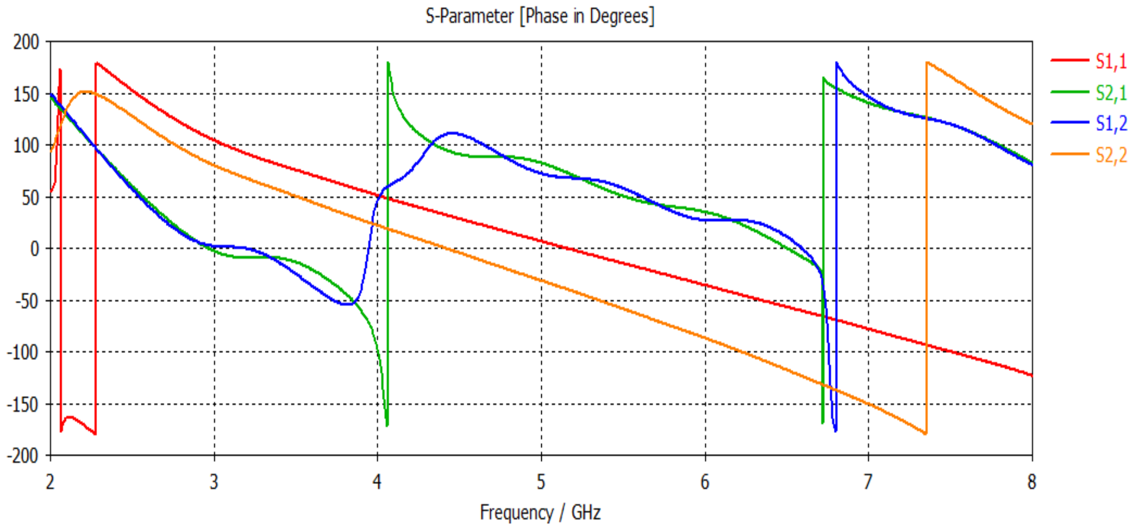


Figure 3.7 Phase Diagram of FSS Double Layer Unit Cell

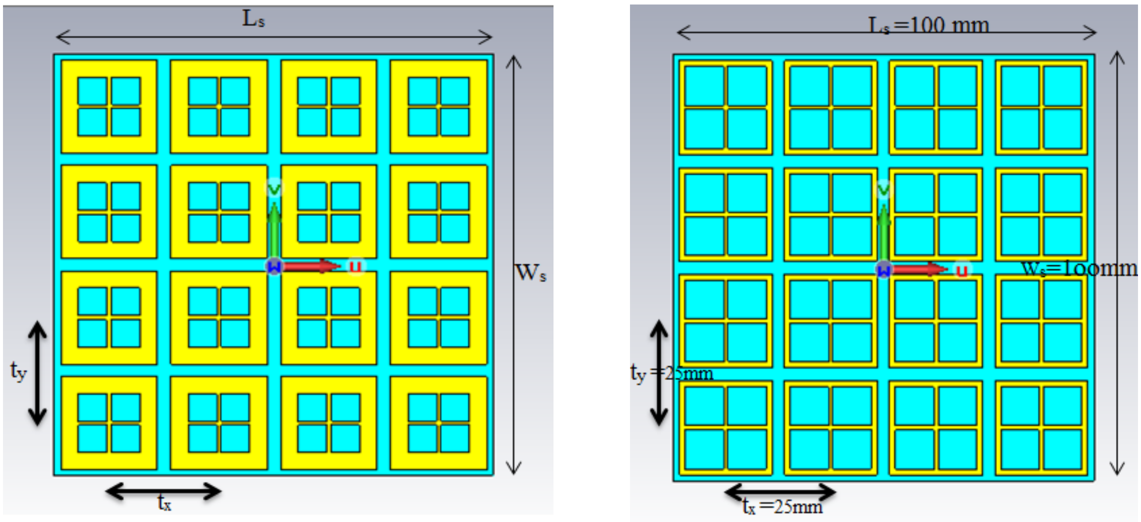
3.4 FSS Full Structure Design

Table 3.2 Dimensions for design of FSS Full Structure

FSS Full Layer No.	Substrate Dimensions(mm)			Unit Cell Periodicity (mm)	
	Width	Length	height	In X Direction	In Y Direction
Layer 1	100	100	1.6	25	25
Layer 2	100	100	1.6	25	25

3.5 Design View of FSS Full Structure

As shown in figure below, to design an FSS full structure we have to create an array of FSS unit cells.



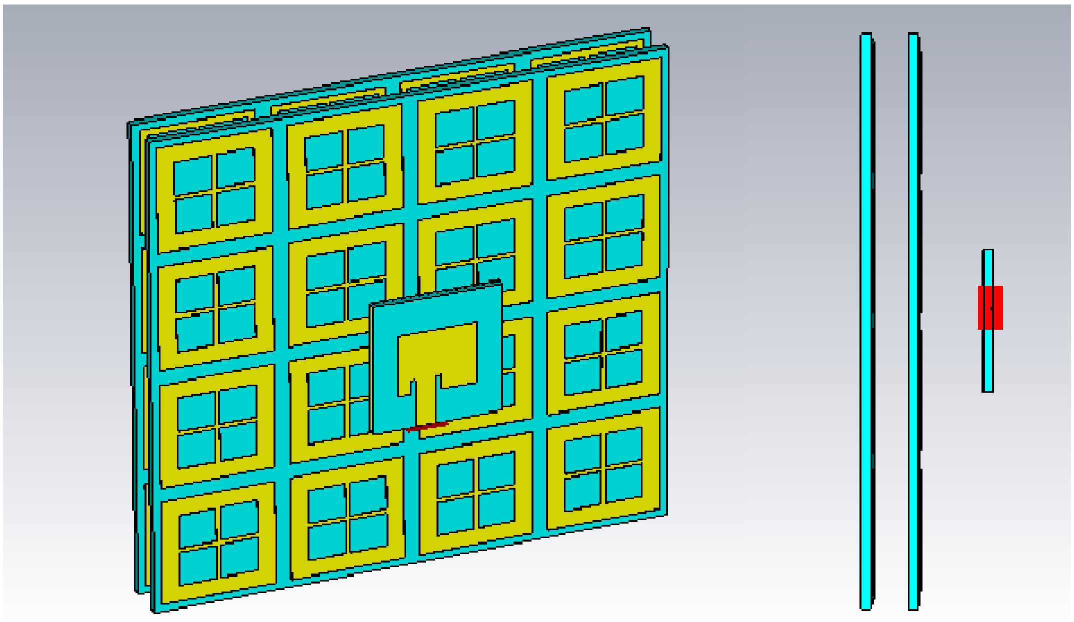
(a) **(b)**

Figure 3.8 FSS Full Structure (a)Resonating at 6Ghz (b) resonating at 4 Ghz

Chapter 4

4 Antenna with Double Layer FSS Reflector

Once the geometry of the unit cell has been fixed, an C-band antenna excited by mictrostrip line feed has been mounted on its top. The FSS structure represented in section 3.4 are used as a reflector for the C-band antenna presented in section 2.2.3. When the is mounted at a distance equal to λ/2 above the FSS, the wave radiated toward the FSS is reflected back and add up in the opposite direction to the out going wave radiated from the antenna. The gain of the antenna will increase when two wave components add up in-phase, giving rise to constructive interference.



(a) (b)

Figure 4.1 C-band Antenna with FSS Reflector

4.1 Simulation Results of C-band Antenna with FSS Reflector

4.1.1 S-Parameter

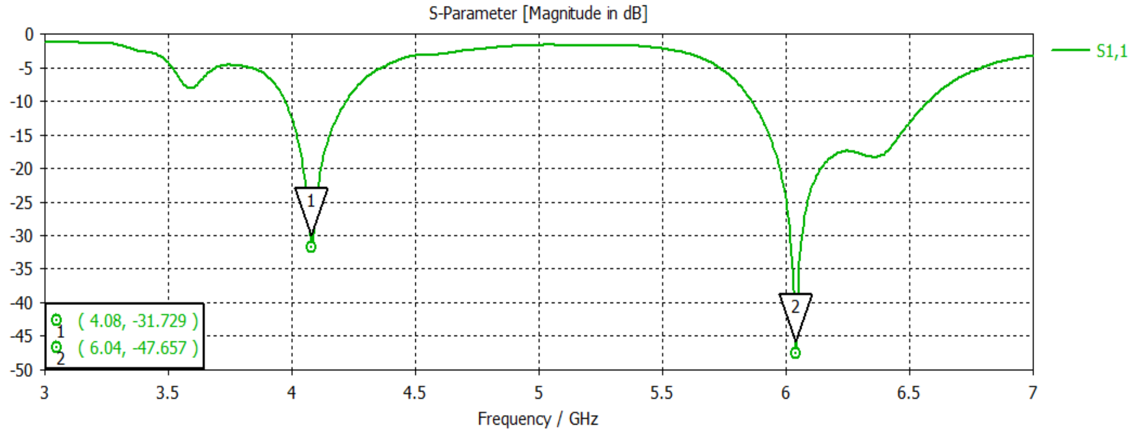


Figure 4.2 S-Parameter for Antenna with FSS Reflector

4.1.2 Smith Chart

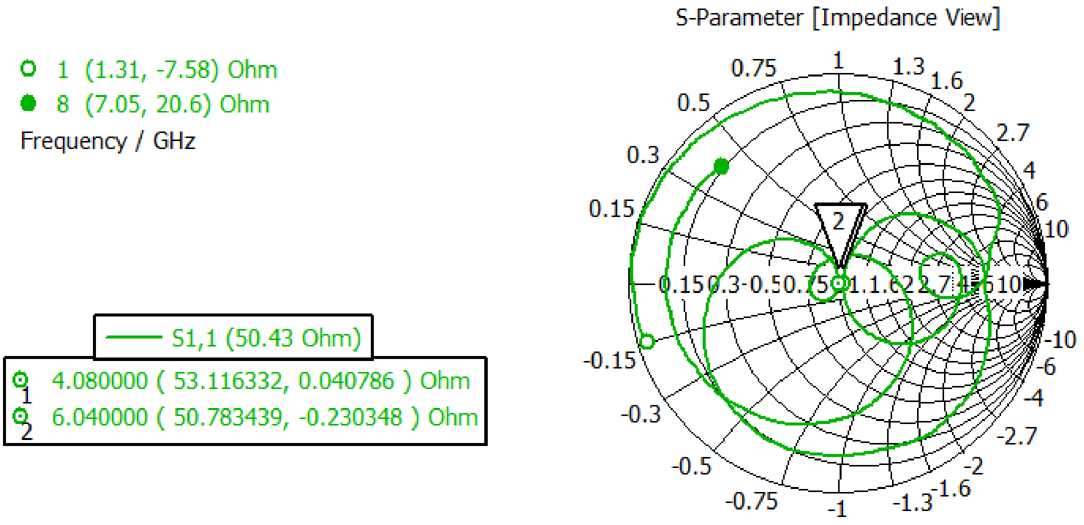
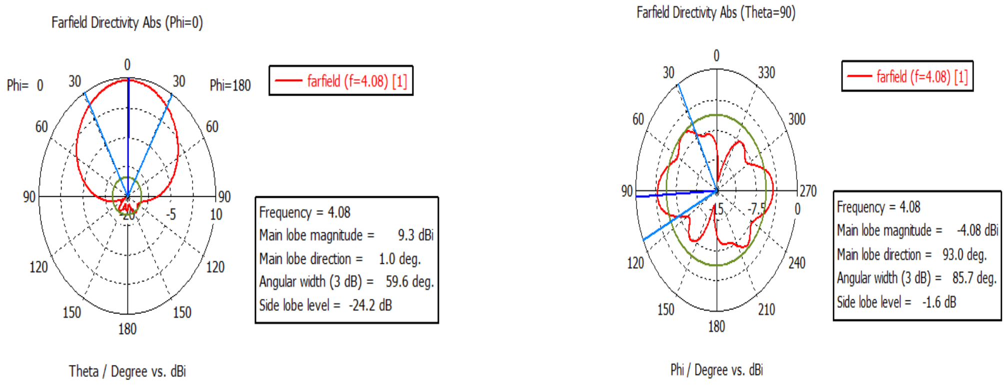


Figure 4.3 Smith Chart for Antenna with FSS Reflectors

4.1.3 Directivity

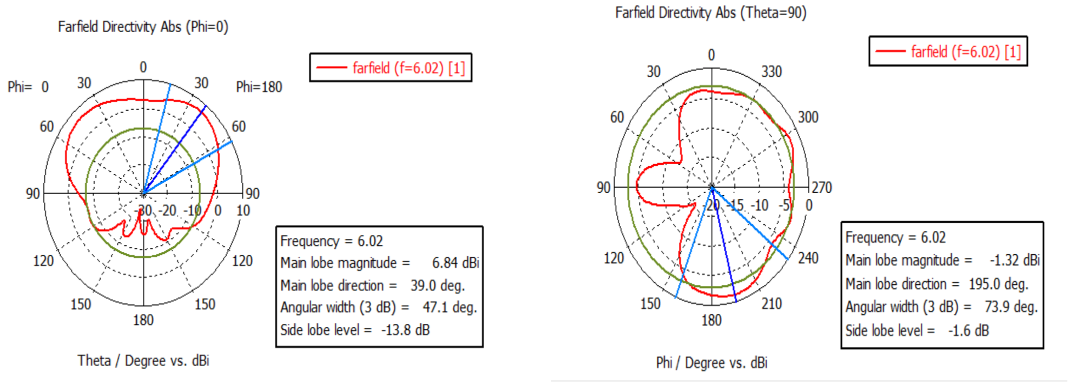


Frequency = 4.08
Main lobe magnitude = 9.3 dBi
Main lobe direction = 1.0 deg.
Angular width (3 dB) = 59.6 deg.
Side lobe level = -24.2 dB

Frequency = 4.08
Main lobe magnitude = -4.08 dBi
Main lobe direction = 93.0 deg.
Angular width (3 dB) = 85.7 deg.
Side lobe level = -1.6 dB

(a) **(b)**

Figure 4.4 Directivity of Antenna with FSS (a) Elevation plane (b) Azimuth plane

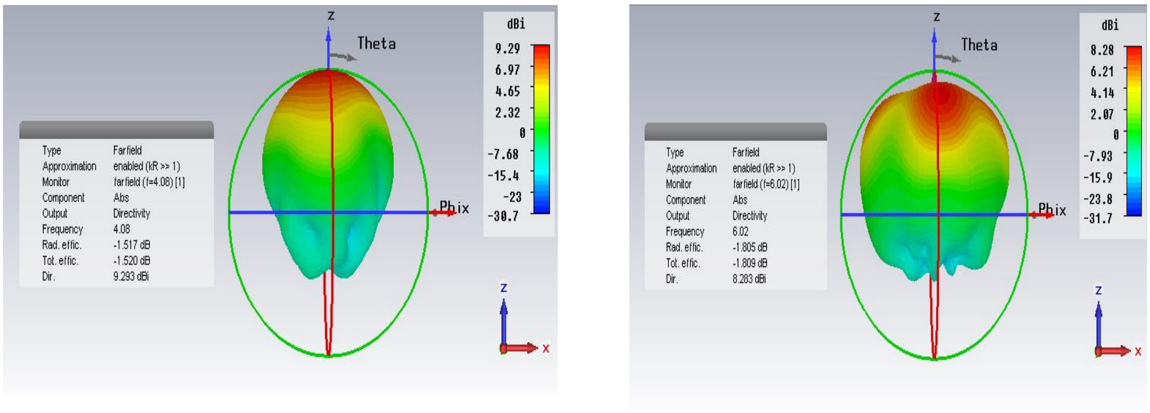


Frequency = 6.02
Main lobe magnitude = 6.84 dBi
Main lobe direction = 39.0 deg.
Angular width (3 dB) = 47.1 deg.
Side lobe level = -13.8 dB

Frequency = 6.02
Main lobe magnitude = -1.32 dBi
Main lobe direction = 195.0 deg.
Angular width (3 dB) = 73.9 deg.
Side lobe level = -1.6 dB

(a) **(b)**

Figure 4.5 Directivity of Antenna with FSS(a) Elevation plane (b) azimuth plane



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=4.08) [1]
Component	Abs
Output	Directivity
Frequency	4.08
Rad. effic.	-1.517 dB
Tot. effic.	-1.520 dB
Dir.	9.293 dBi

Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=6.02) [1]
Component	Abs
Output	Directivity
Frequency	6.02
Rad. effic.	-1.805 dB
Tot. effic.	-1.809 dB
Dir.	8.283 dBi

(a) **(b)**

Figure 4.6 3-D Plot of Directivity (a)At 4 Ghz (b) At 6 Ghz

Table 4.1 Comparison of Results of Antenna without FSS and with FSS

	S_{11} dB		VSWR		Directivity dBi		Gain dB	
	4 Ghz	**6 Ghz**	**4 Ghz**	**6 Ghz**	**4 Ghz**	**6 Ghz**	**4 Ghz**	**6 Ghz**
Antenna Without FSS	**-37.08**	**-30.74**	**1.02**	**1.06**	**5.14**	**4.99**	**2.98**	**3.03**
Antenna With FSS	**-31.72**	**-47.65**	**1.06**	**1.03**	**9.29**	**8.28**	**7.77**	**6.47**

4.2 Results Discussion

From the results obtained after simulations of the antenna design, we come to conclusion about the nature of FSS structure and its proper applications. Finally, By obtaining the FSS array Results we see that it is best suitable to our desired results as it provides optimum bandwidth along with the desired Gain as in case of satellite band reception signal got too much attenuated and thus it requires highly sensitive antennas for proper receptions.

Chapter 5

5 Conclusion

5.1 Report Highlights

An Antenna having C-slot on ground plane operating in C-Band which covers uplink band 5.850-6.425 GHz and Downlink Band 3.625-4.200(Standard C-band) has been designed in chapter 4. In this chapter, we have discussed step wise design approach from rectangular patch to the cutting of C-Slot and later all modifications in the design like use feed point variation to get proper matching and bandwidth each stepwise approach have been shown. We also made parametric approach in order to get best optimised results to our design. Thus, a satellite C-band antenna has been designed in this chapter and its results has been analysed.

After designing of the FSS unit cell in chapter 4, we have proposed an array of 16-element of these unit cells to construct FSS full structure reflector. Full structure of FSS simply provide the in phase reflections to the radiated power in opposite direction. While designing FSS unit cell it is important to keep the reflection coefficient 0 dB. In this project we designed two FSS layer resonating at two different frequencies of C band.

5.2 Future Work

Since we know that after putting all best efforts there is always a scope to improve the characteristics of the design. Thus, in our design that future scope is also available to make it ideal antenna array for C-band by increasing bandwidth and ideally to 500 MHz. This could be possible by changing material used for the design.

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