DESIGN AND ANALYSIS OF ANTENNA ARRAY ON CURVATURE SURFACE FOR 5G APPLICATIONS

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE AWARD OF THE DEGREE

OF

MASTER OF TECHNOLOGY

IN

MICROWAVE AND OPTICAL COMMUNICATION

Submitted By

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CANDIDATE'S DECLARATION

I, **Prerna Singh (2K20/MOC/06)** student of **M.Tech (Microwave and Optical Communication Engineering),** hereby declare that the project Dissertation titled "Design and Analysis of Antenna Array on Curvature Surface for 5G Applications**"** which is submitted by me to the Department of Electronics and Communication Engineering, **Delhi Technological University**, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

Place: Delhi **PRERNA SINGH**

Date: 25/05/2022

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

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CERTIFICATE

I hereby certify that the Project Dissertation titled "**Design and Analysis of Antenna Array on Curvature Surface for 5G Applications"** which is submitted by **Prerna Singh, (2K20/MOC/06)** in Department of Electronics and Communication Engineering, **Delhi Technological University**, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi **Mr. M.GANESH**

Date: 25/05/2022 (SUPERVISOR)

ACKNOWLEDGEMENT

The success and final outcome of this project require a lot of guidance and assistance from many people and I am extremely fortunate to get this all along the completion of my project work. Whatever I have done is only due to such guidance and assistance and I would not forget to thank them.

I owe my profound gratitude to my project guide **Mr. M.Ganesh** for giving an opportunity to do this work. **Mr. M.Ganesh** who took keen interest on my project work and guided me throughout, till the completion of my project work by providing all the necessary information, constant encouragement, sincere criticism and sympathetic attitude.

PRERNA SINGH

ABSTRACT

In conjunction with the advancement of wireless communication technology, 5G can be considered as an upcoming new generation in the field of wireless mobile systems. Within this project, an antenna array with coaxial feed has been designed and simulated at Ka band (35GHz). The purpose of designing an antenna array is that it has better gain & bandwidth as compared to the microstrip patch antenna. Further, the designed antenna array which comprises of 8 antenna elements with a consistent spacing conformed on a cylindrical, conical and spherical curvature surface. A study on parametric analysis by varying the radius of curvature, thickness of substrate and relative permittivity has been done in terms of return loss and gain. By modelling and simulating the design, observations were made that return loss of the conformal array is less than -10dB , narrow bandwidth and better gain has been achieved which meet the requirement of enhancing the antenna performance. The proposed antenna design and its parametric analysis is simulated through HFSS 3D simulation tool.

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LIST OF ABBREVATIONS

dB	Decibel
HPBW	Half Power Bandwidth
IC	Integrated Circuits
ISM	Industrial, Scientific and Medical
HFSS	High Frequency Structure Simulator
VSWR	Voltage Standing Wave Ratio

CHAPTER 1

INTRODUCTION

In conjunction with the advancement of wireless communication technology area, 5G can be considered as an upcoming new generation in the sphere of wireless mobile communication systems. Conformal Microstrip antenna [1] [2], can be of compact size and it can be considered a new area of research for military, aircraft and navigation applications. Conformal antennas are implantable [3] and can be used for ISM band applications. Multiple Input Multiple Output conformal antenna with an antenna array conformed on cylindrical [4] and spherical surface [5] provides broad bandwidth and better value of return loss. Due to excellent performance parameters, these antennas can be expected as the modern technology in the area of 5G communication systems. Antenna have better radiation efficiency when wrapped around a cylindrical surface [6]. They play a supreme role in the advancement of mobile and automobile applications. When we vary the radius of curvature, then it is observed that HPBW remains constant and there is a very little distinction in the value of return loss [7] [8]. Understanding the mathematical concept is crucial for the proper modelling of an antenna.

In [9] [10] a proper theoretical and mathematical concept has been given which is useful to design any type of antenna with proper dimensions and a suitable material that has to assigned and also for the best choice of antenna for different frequency bands and their applications. With the recent advancement, slotted conformal antenna can be made wearable to different parts of the body by considering the distance between antenna and human body part on which antenna has to be wrapped [11]. The accuracy of global positioning system is very important. Slotted conformal antenna is designed for global positioning system [12]. It is observed that radiation pattern is omnidirectional and value of gain is high which makes it suitable for global positional system applications. Analysis of wearable conformal antenna [14] with ultrawide band is done by the varying the radius of curvature. To conform on any shape and size of body part, antenna should be flexible.

When slots are etched from ground planes where material assigned to latter is metal then the calculated radiation efficiency is more that 60% and bandwidth achieved is about 4-6% at the centre frequency [15]. These unidirectional antennas are considered to best choice for designing conformal antenna. Microstrip patch antenna [17] and an array of microstrip patch conformed on cylindrical curvature [18] are designed and analysed. The peak gain is observed as 24.5 $\boldsymbol{dB}$ from gain vs frequency curve for cylindrical conformal antenna. Method of moment [20] has been used for the numerical analysis of a flexible conformal antenna array. The simulated and numerical results are verified successfully for mobile wireless applications.

Our present work focuses on the software simulation of antenna array on different curvature surfaces. It also includes the parametric and comparative study among the conformed antenna array.

1.1 ANTENNA

An antenna is a system of conductors which mainly consists of transmitter and receiver.

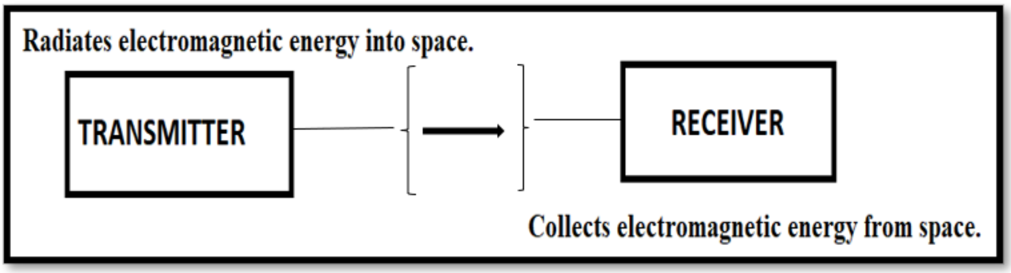


Figure 1.1: Basic Communication System

1.1.1 Antenna Gain

It is termed as a potential of the antenna to radiate in any direction which can be more or less in comparison to a theoretical antenna.

1.1.2 Antenna Efficiency

An antenna efficiency will be high when the power which is present at input radiates away at most while it will be low when it will get absorbed or reflected away. It can be due to impedance mismatch.

1.1.3 Effective Area

$$P = pA_e \tag{1.1}$$

$where\ P = power\ present\ at\ the\ terminals\ of\ antenna\ in\ Watt$

p = power density of antenna

Ae = effective aperture

1.1.4 Return Loss

It indicates the amount of power that is lost to the load and does not come back as a reflection.

When a graph shows a dip at the operating frequency of the antenna with a minimum dB value at this frequency then it can be considered as better performance of an antenna.

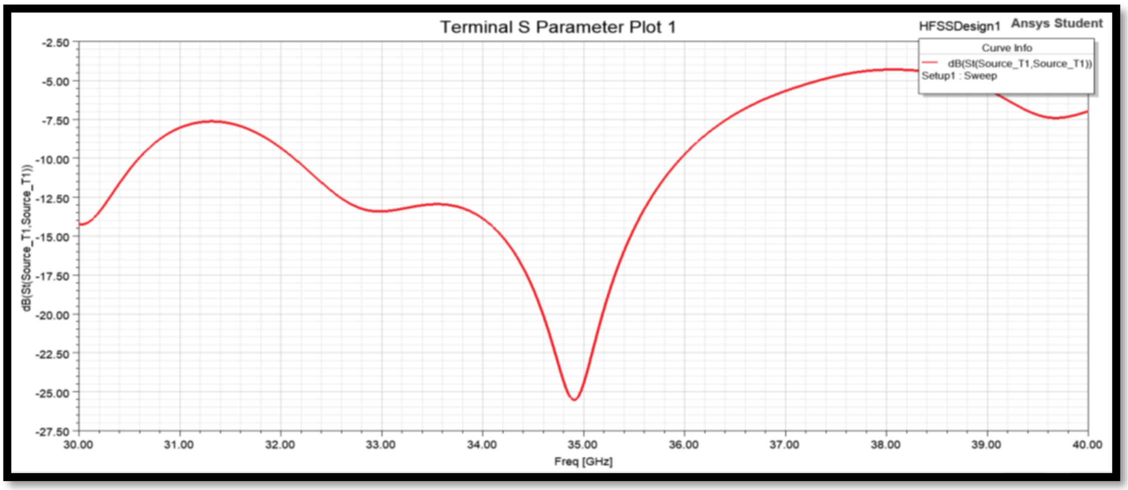


Figure 1.2: Return loss curve of an antenna

1.1.6 Radiation Pattern

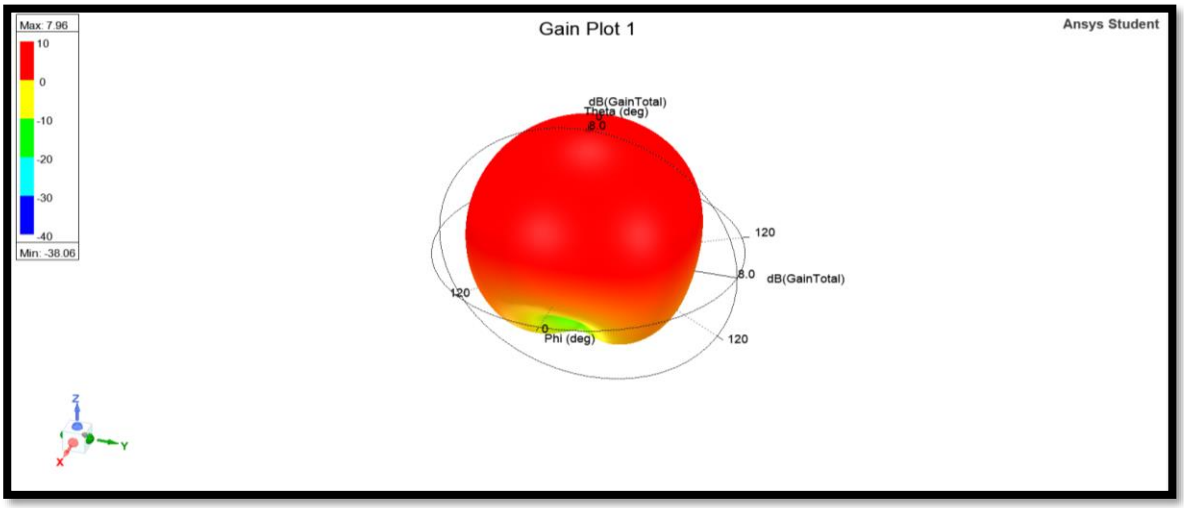


Figure 1.3: 3D Polar Plot for a rectangular microstrip patch antenna

1.1.7 Beamwidth

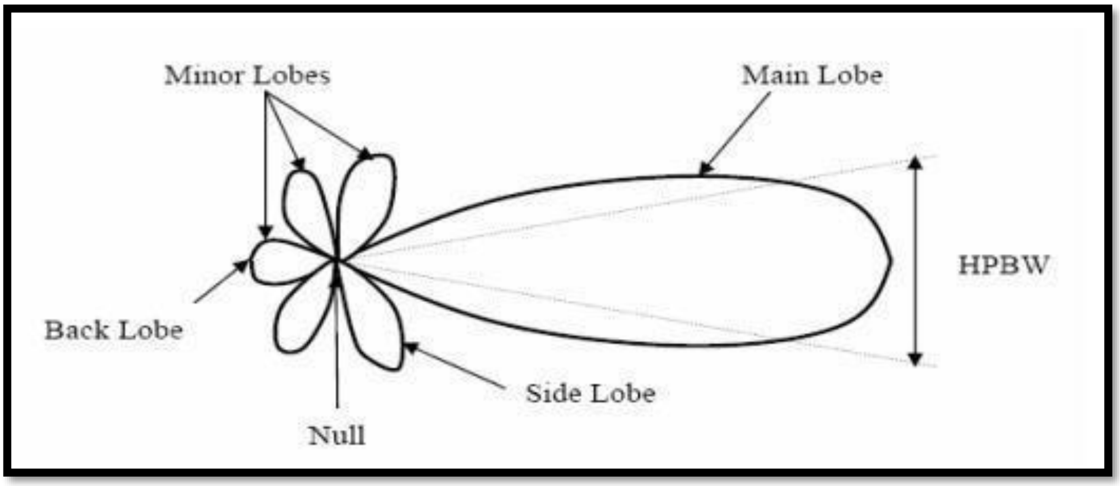


Figure 1.4: Determination of HPBW from 2D radiation pattern

1.2 CLASSIFICATION OF ANTENNAS

They can be categorised on the basis of various factors that are entangled in the working of an antenna. It can be the frequency band in which antenna is operating or the physical structure and design. They can be nondirectional such as dipoles or monopoles which are simple or directional antennas which are more complex such as microstrip antenna, array etc. With the advancement of wireless communication technology, 5G can be considered as an upcoming new generation in the area of wireless mobile communication systems. And it has developed a new type of antenna which are referred as conformal antenna in which an antenna or antenna array are wrapped around the surface of curvature. These type of antennas shows better results and can be used in aircraft and missiles applications.

CHAPTER 2

OVERVIEW OF MICROSTRIP PATCH ANTENNA

2.1 INTRODUCTION

Microstrip antennas as patch antennas are used in an extended variety of applications from navigation to satellites and non-satellites systems such as medical applications.

2.2 MICROSTRIP PATCH ANTENNA

Microstrip antennas which has a simple design and structure as shown in Figure 2.1. It comprises of a rectangular patch which acts as a radiator, a dielectric substrate, and a ground plane.

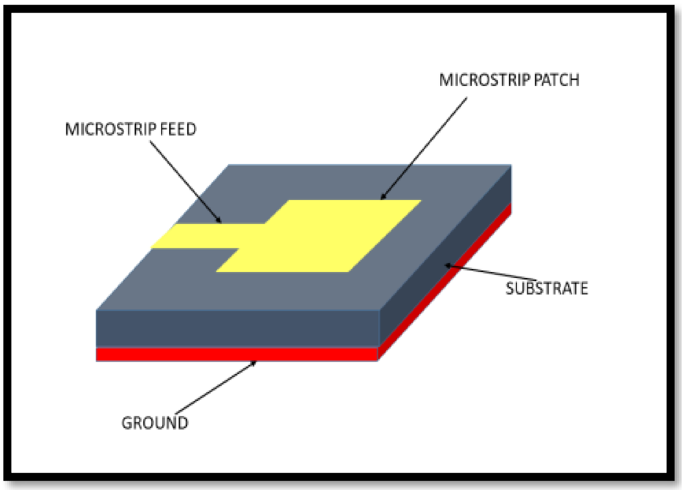


Figure 2.1: Microstrip Patch Antenna

Many substrates are used for the designing of microstrip antennas. The relative permittivity (ε_r) generally ranges $2.2 \leq \varepsilon_r \leq 12$. The patch and ground are generally can be constructed of perfectly electric conductor.

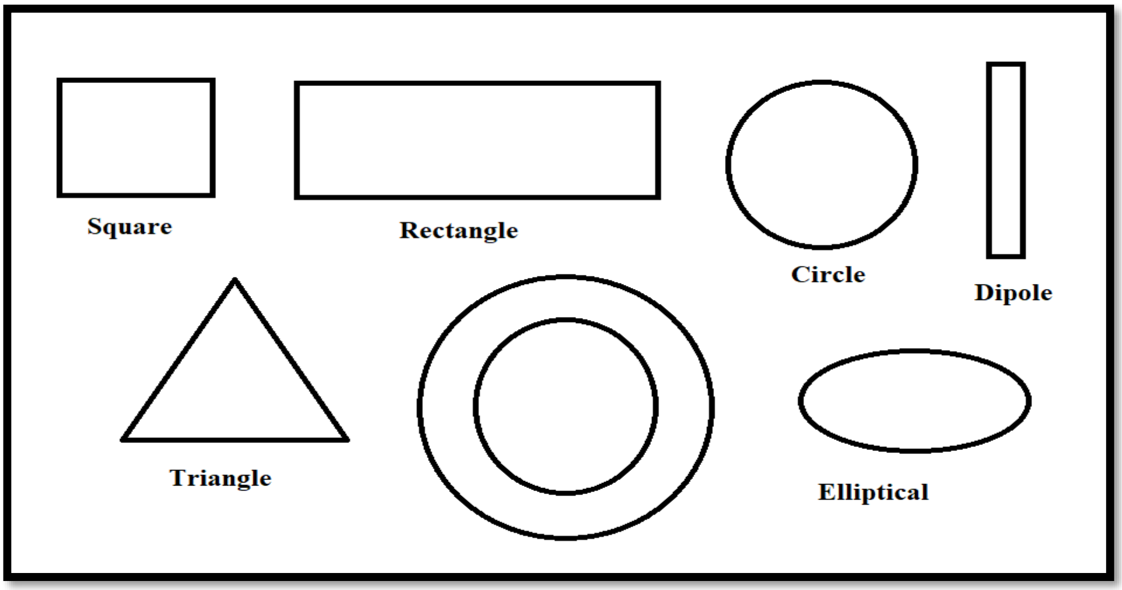


Figure 2.2: Different shapes of patch

2.2.1 Radiation Pattern

A microstrip patch antenna radiates energy via its patch (which act as a radiator) in certain directions and we termed this parameter as the antenna's directivity.

2.2.2 Bandwidth

The bandwidth depends on various parameters like quality factor Q, type of feed, substrate height etc. The patch antenna shows narrow bandwidth in comparison to antenna array.

2.3 FEED TECHNIQUES

There are many feeding techniques which are used to feed a microstrip patch antenna.

2.3.1 Microstrip Line Feed

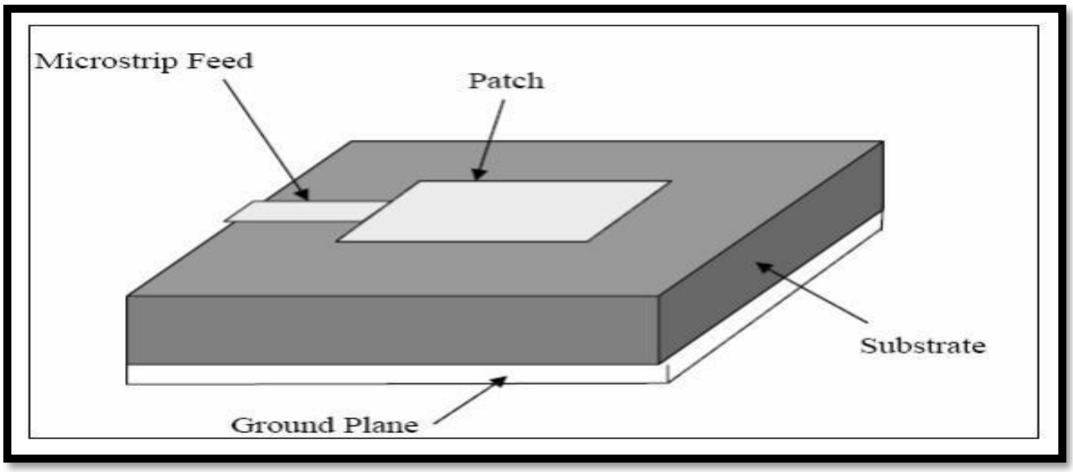


Figure 2.3: Microstrip Line Feed

2.3.2 Coaxial Feed

It can be attached to any desirable spot which should be within the patch where it can achieve impedance matching.

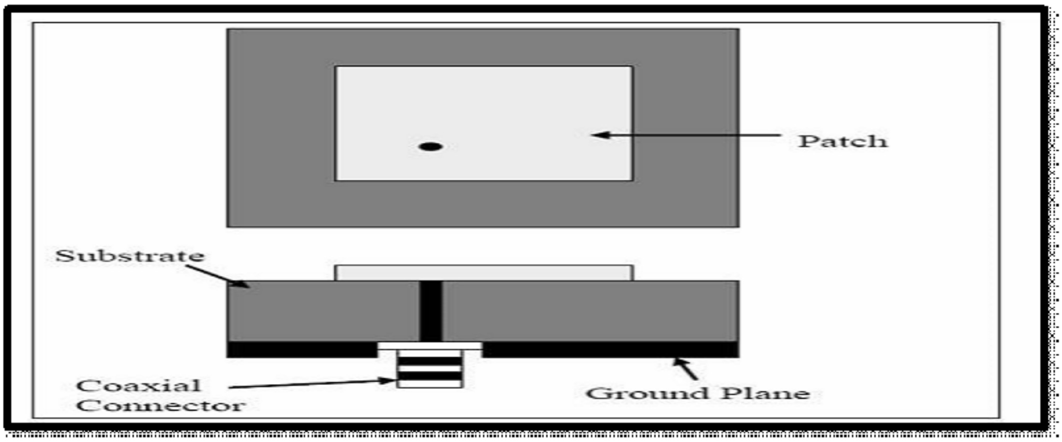


Figure 2.4: Coaxial Feed

2.3.3 Aperture Coupled Feed

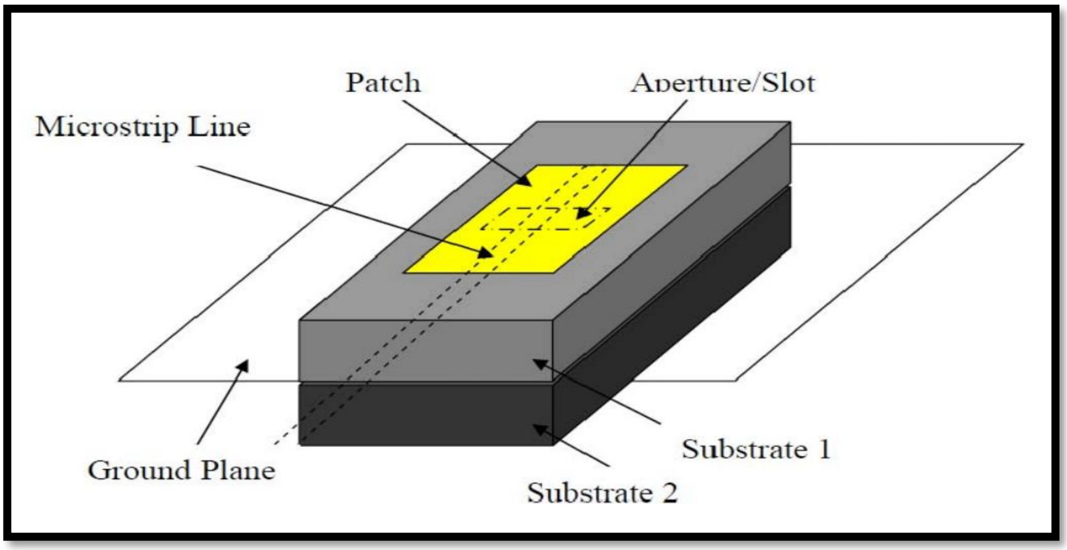


Figure 2.5: Aperture Coupled Feed

2.3.4 Proximity Coupled Feed

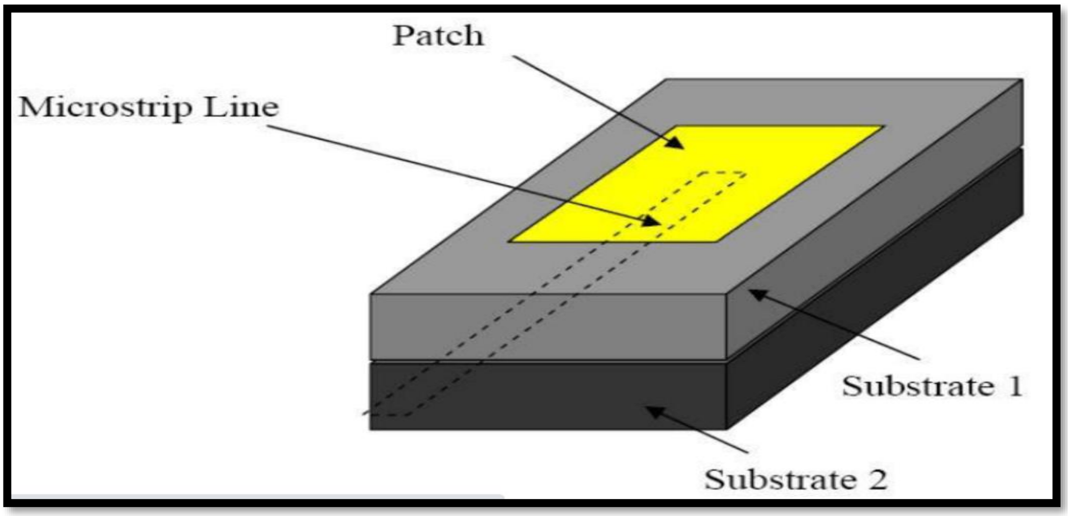


Figure2.6: Proximity Coupled Feed

Table 2.1: Comparing Feed Methods

Characteristics	Microstrip Line Feed	Coaxial Feed	Aperture Coupled feed	Proximity Coupled Feed
Spurious emission	More	More	Less	Minimum
Reliability	Better	Poor dur to soldering	Good	Good
Impedance Matching	Simple	Simple	Simple	Simple
Bandwidth	3-7%	4-8%	4-8%	13-15%

2.4 ADVANTAGES OF MICROSTRIP PATCH ANTENNA

• Light weight, low volume, low fabrication cost and conformable.

• Can be easily Integrated on microwave IC’s.

2.5 DISADVANTAGES OF MICROSTRIP PATCH ANTENNA

- Narrow bandwidth
- Low efficiency
- Low Gain

CHAPTER 3

OVERVIEW OF CONFORMAL ANTENNA

3.1 INTRODUCTION

With the technology development, there is an improvement in the area of communication systems and navigation systems as well. New technologies are developed and new approaches are coming in picture. By simulation and optimisation, there can be an improvement in the overall system performance such as lower interference signals, high bandwidth, increased gain, better accuracy, better aerodynamics, light weight, 360 beam coverage etc. Conformal antennas can be easily installed on any curvature which finds its applications in the area of aircraft, radar and navigation systems. It is required to follow the performance characteristic of the antennas. It will also help to find the best applications for their use.

This present work is of conformal antennas. The purpose is to design antenna array and do the analysis by making it conformal by wrapping it around different curvature surface.

The objectives of this project include designing of

- Conformal antenna array on different curvatures.
- Comparison between conformal and planar antennas.

3.2 OVERVIEW OF CONFORMAL ANTENNAS

So far if we consider the design process of conformal antennas then it follows the process of conforming patch antenna or an array on a fixed shape which makes them effective for airplanes and navigation systems. Radiation characteristics are signifying features of these antennas. Conformal antennas have broader beams than planar antennas. Conformal antennas can be wearable on different parts of body. As they are integrated in the system, they are less visible. It has usefulness for military environments.

Arrays are conformed on single and double curved surfaces. Till now investigation of conformal antennas shows that cylindrical, cone and spherical surface are the most analysed conformed surface.

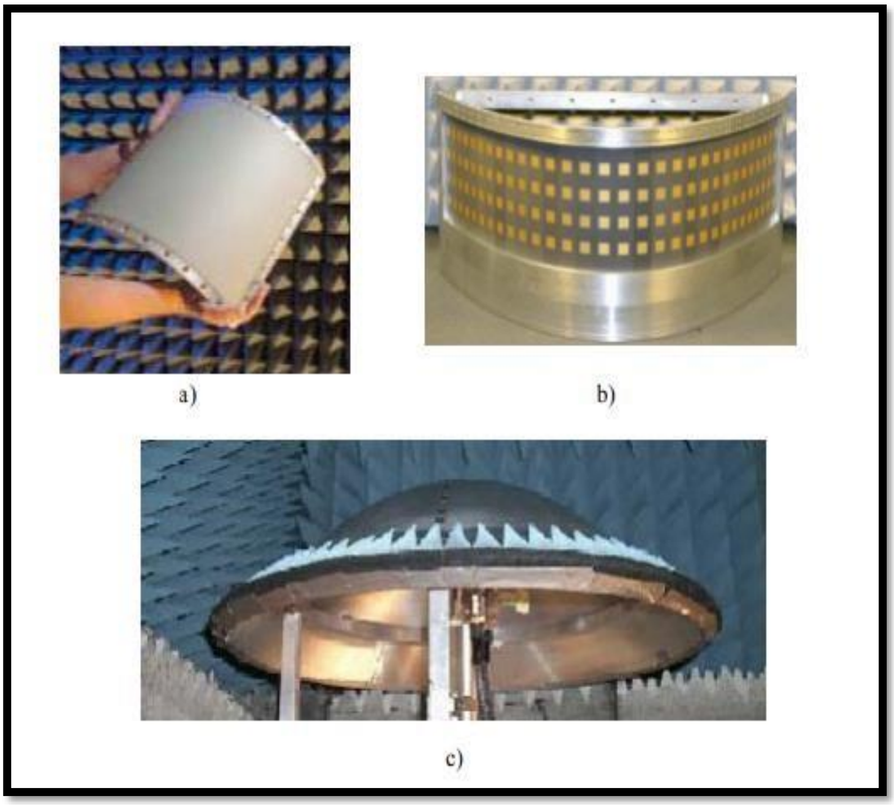


Figure 3.1: Examples of conformal antennas

3.3 LITERATURE REVIEW

Some works from the literature which has done research in this area are shown in this section.

Conformal Microstrip antenna [1] [2], can be of compact size and it can be considered a new area of research for military, aircraft and navigation applications. "5G MIMO Conformal Microstrip Antenna Design" concentrates on wrapping an antenna array on cylindrical curvature for 5G applications. Conformal antennas are implantable [3] and can be used for ISM band applications "Analysis of conformal antennas for avionics application" [4] done analysis on conforming patch on single curved surface such as cylindrical and double curved surface such as toroidal for avionics application.

It can be observed that cylinder is mostly used as carrier for conformal antennas. References found are on similar type of geometry. We will find very few literatures when design and analysis is done on conical, elliptical or other geometries.

However, we gave designed and analysed an antenna array which is conformed on cylindrical, conical and spherical surface of curvature. Afterwards a comparative study is done to observe the performance characteristics of various simulated antennas by return losses, bandwidth and 3D polar plot.

CHAPTER 4

ANTENNA DESIGN

4.1 A RECTANGULAR MICROSTRIP PATCH ANTENNA

To design a rectangular microstrip patch antenna, firstly we chose the material for substrate. To minimize the loss, substrates with low loss tangent dielectric reduces the dielectric loss. And to minimize the radiation loss, small substrate height is preferred.

Considering these factors, following dimensions have been taken into account.

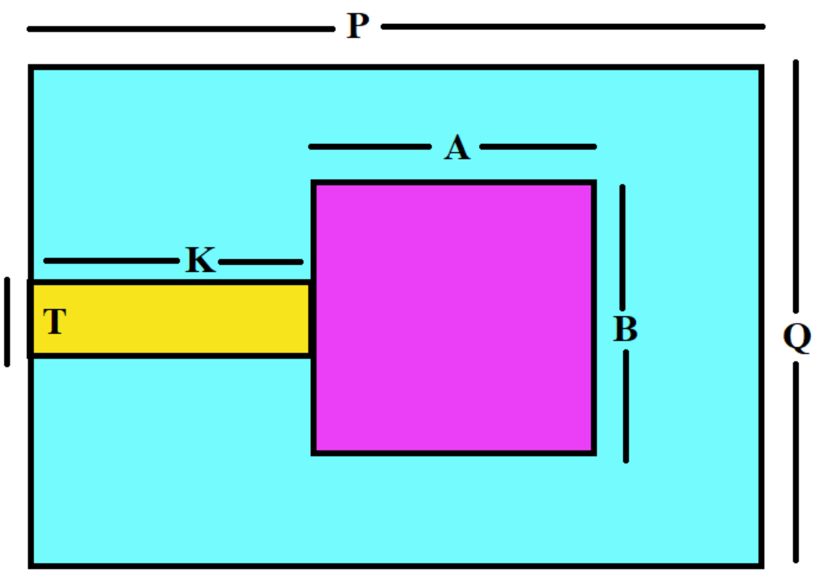


Figure 4.1: The model of rectangular microstrip patch antenna

Table 4.1: Dimensions of Rectangular Microstrip Antenna

S.No.	Parameters	Dimensions
1.	P (Length of substrate)	6mm
2.	Q (Width of substrate)	6mm
3.	A (Length of patch)	2.45mm
4.	B (Width of patch)	3.32mm
5.	K (Length of microstrip feed)	1.57mm
6.	T (Width of microstrip feed)	0.46mm
7.	H (Height of substrate)	0.5mm
8.	Relative permittivity of dielectric material	2.2

Microstrip line feeding, coaxial feeding and electromagnetic coupling are used to feed the microstrip antenna.

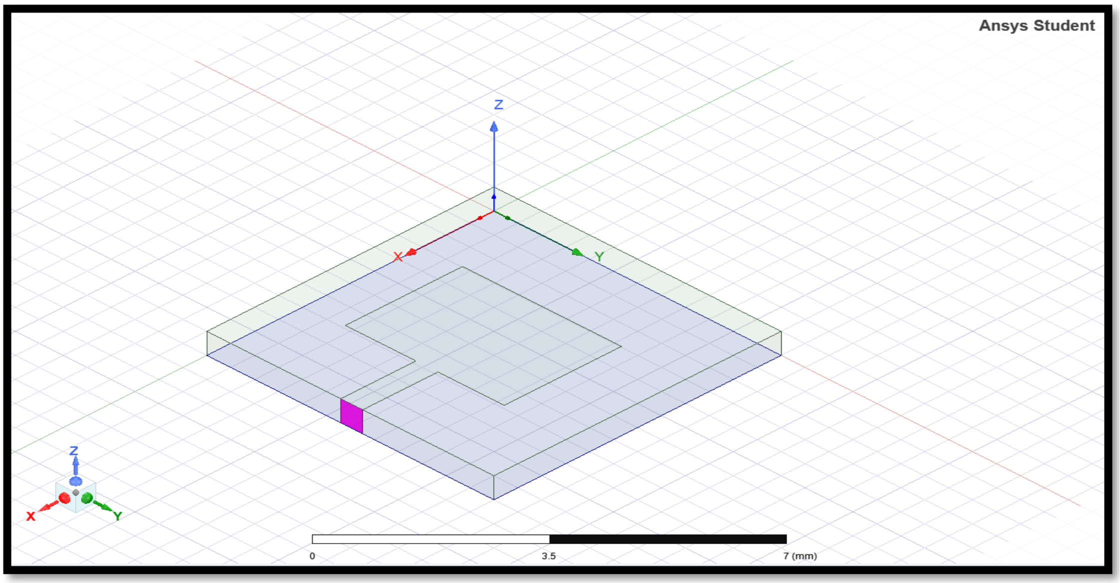


Figure 4.2: Simulated Microstrip Patch Antenna

The line width is taken as 0.46mm and the characteristic impedance is 50 Ω.

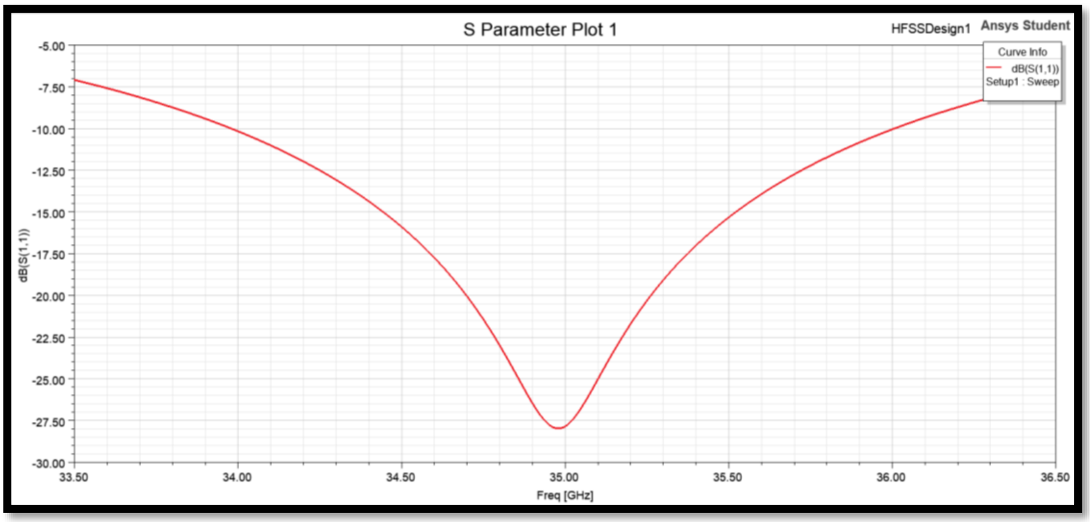


Figure 4.3: S-parameter vs Freq curve of rectangular microstrip patch antenna.

The simulation is performed on HFSS simulation software. Figure 4.3 is a representation of S-parameter vs Frequency (GHz) curve of rectangular microstrip patch antenna. It clearly shows that return loss has been found to be -28 dB at 35 GHz. So consequently, the relative bandwidth for $|s_{11}| < -10dB$ is evaluated from the Figure 4.3 as 5.74%.

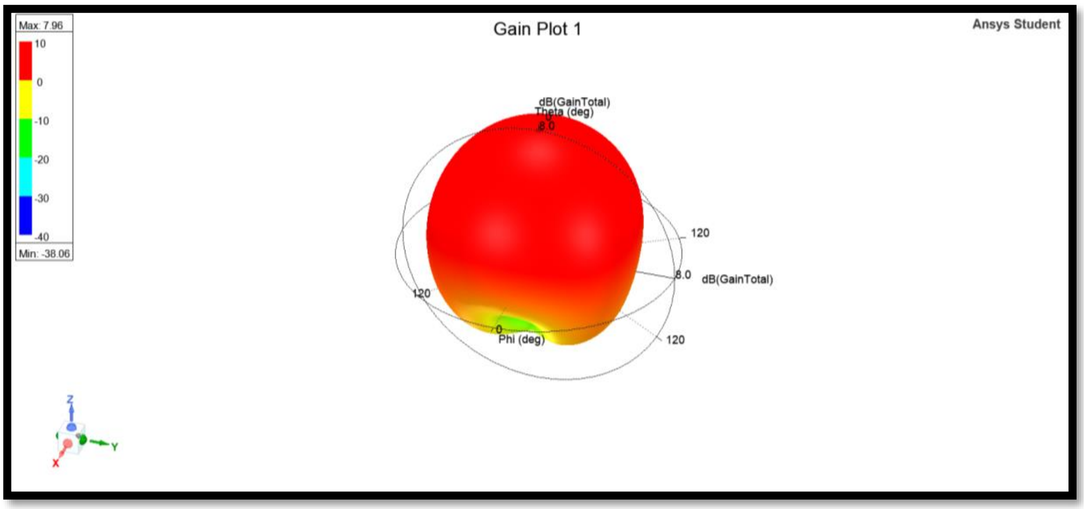


Figure 4.4: 3D Polar plot of rectangular microstrip patch antenna

From Figure 4.4, patch element’s maximum gain is 7.96 dB.

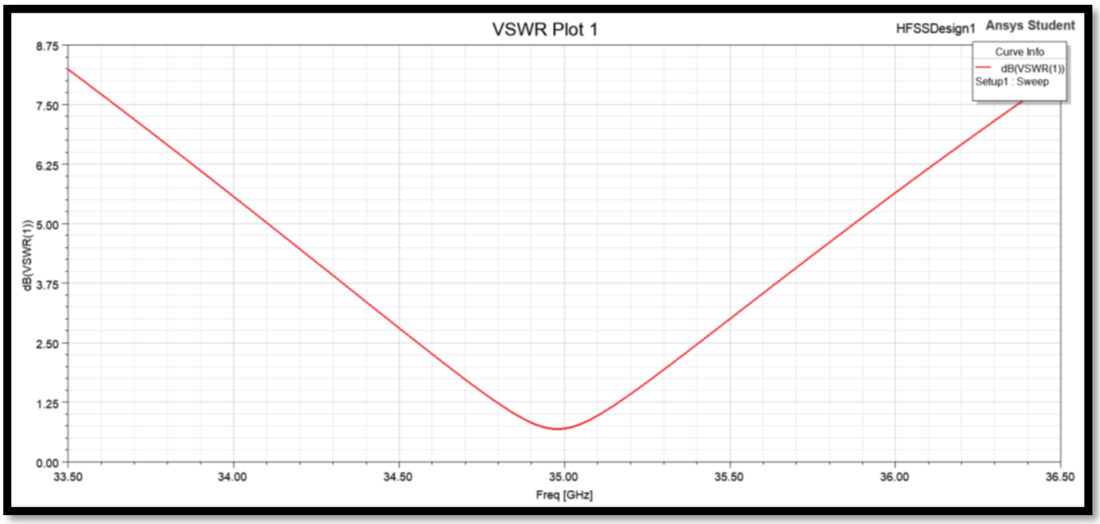


Figure 4.5: VSWR of rectangular microstrip patch antenna

VSWR should be less than 2 for the better antenna performance. Figure 4.5 shows that VSWR is approx. 0.95 for the above simulated antenna.

It seems that calculated bandwidth is not enough for the best output of the system. Therefore, we will now analyse the array antenna with different position of feed to meet the best outcome of frequency bandwidth.

4.2 AN ANTENNA ARRAY WITH ONE-END FEEDING

A rectangular microstrip series fed array is designed to reduce the return loss as less than -10 dB and to achieve high gain & bandwidth. It is an eight-element antenna array which is connecting a microstrip line. The first patch element is fed with a coaxial line.

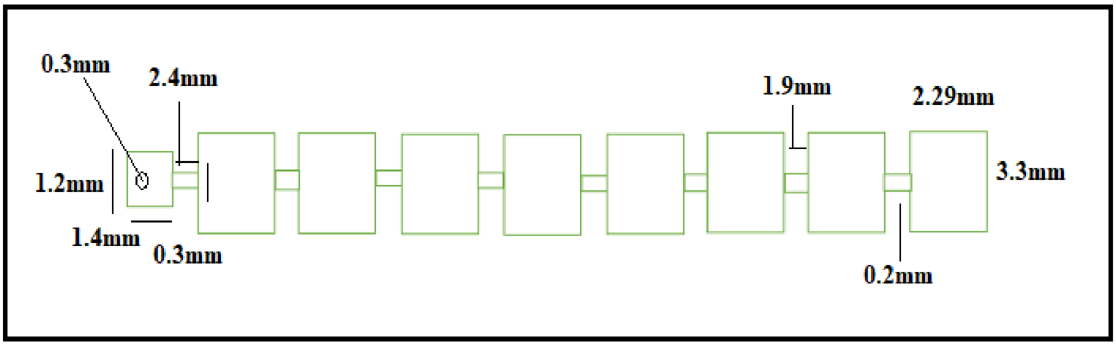


Figure 4.6: Model of Antenna Array with One-End Coaxial Feed

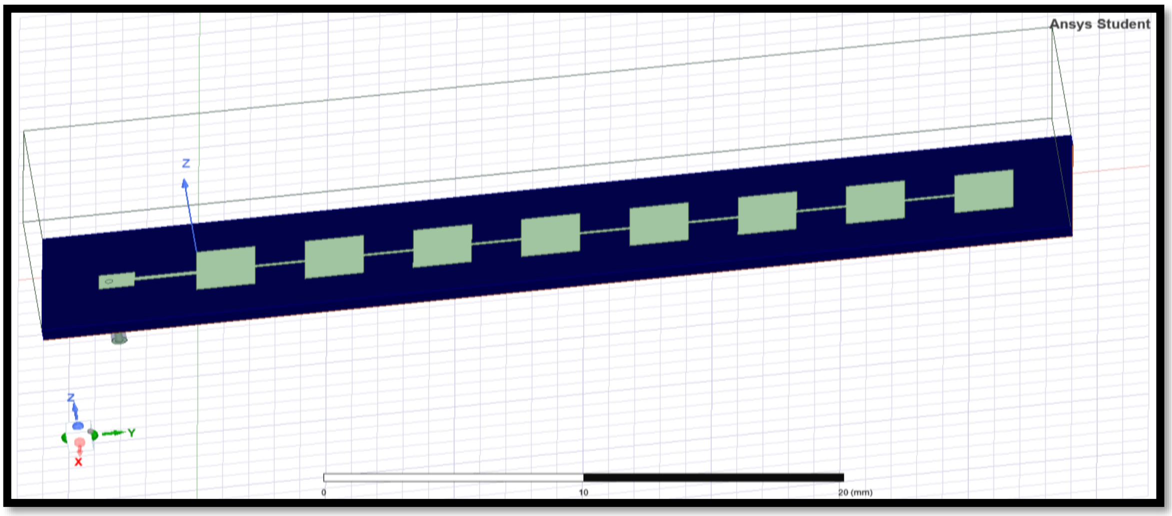


Figure 4.7: Simulated an eight-element array with one-end coaxial feed

The rectangular microstrip patches are of same shape and the spacing between them is same. The array is attached to the 50ohm coaxial line feed.

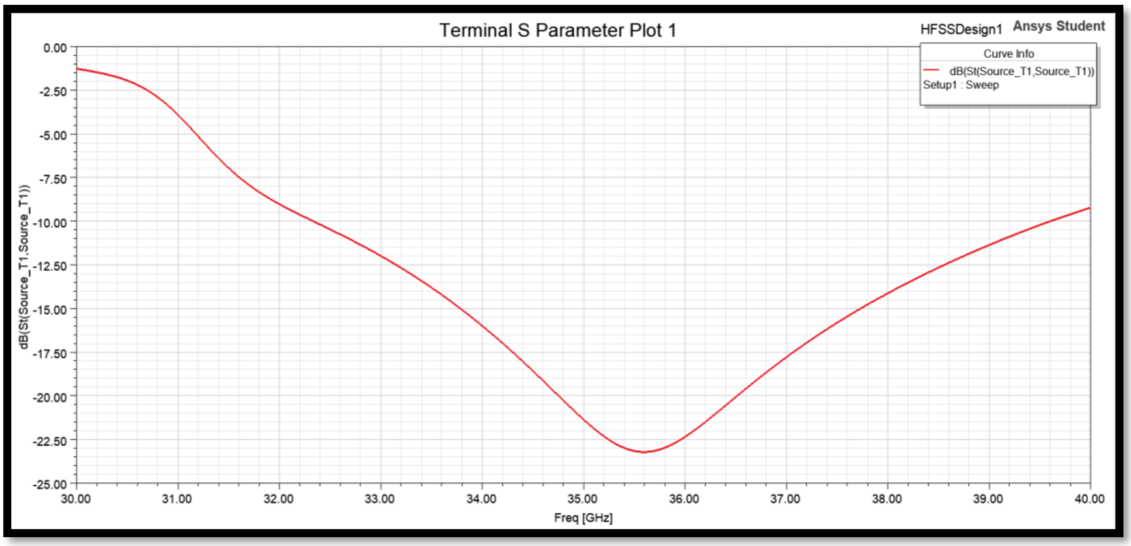


Figure 4.8: S Parameter Plot of a rectangular array

The S-parameter vs Frequency (GHz) curve of above designed array having coaxial feed at one end of the array as depicted in Figure 4.8. It is clearly seen in the Figure 4.8 that the value of resonant frequency is 35.5 GHz where the return loss is -23.50 dB. So consequently, the relative bandwidth for $|s_{11}| < -10dB$ is evaluated from the Figure 4.3 as 20.29%.

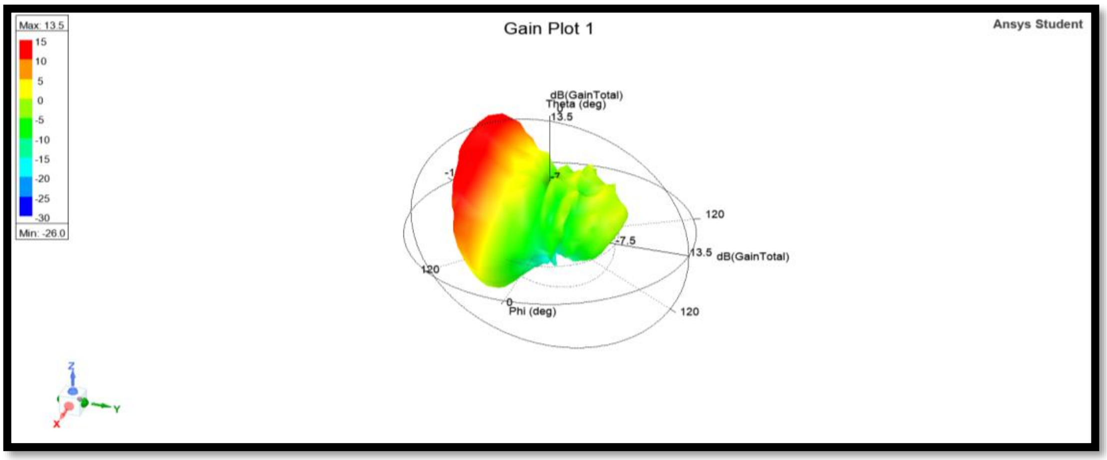


Figure 4.9: 3D Polar plot of a rectangular array

From Figure 4.9, patch element's maximum gain is 13.5 dB.

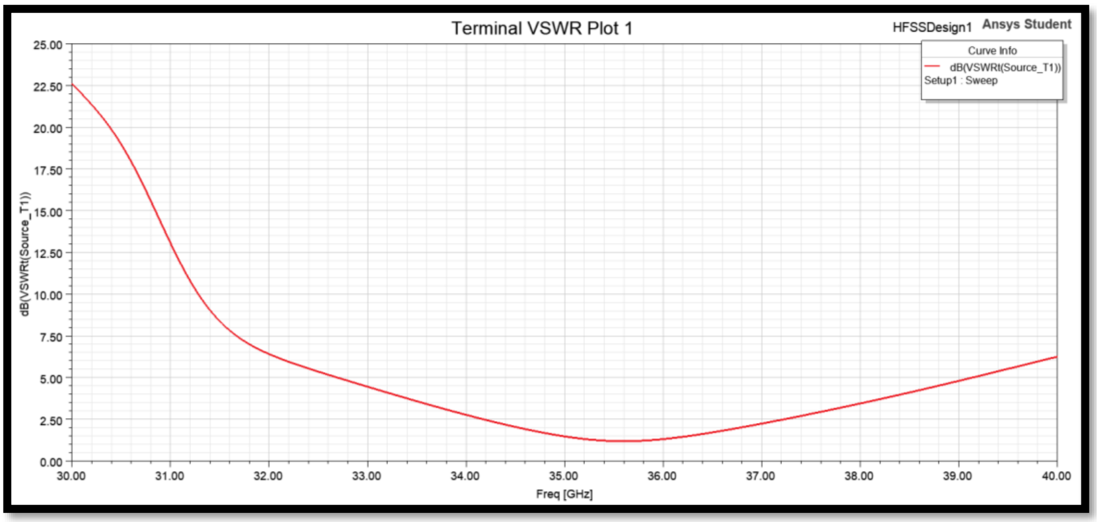


Figure 4.10: VSWR of a rectangular array

From the fig 4.10, it can be seen that the VSWR value is equal to 1 at the centre frequency 35GHz. It is good value of VSWR as it shows that transmitted waves are not reflected to the source.

4.3 AN ANTENNA ARRAY WITH INTERMEDIATE FEEDING

It is also an eight elements antenna array which is attached via a microstrip line. Here we have assigned position of the feed at the centre of the array to a 50ohm coaxial line. The spacing between antennas element is the same.

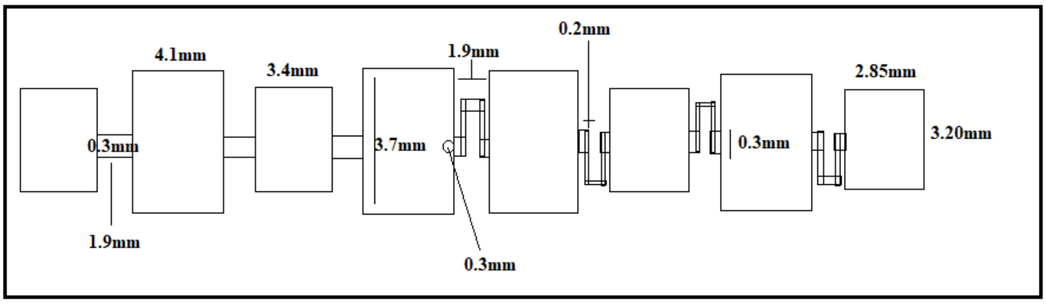


Figure 4.11: Model of Antenna Array with intermediate coaxial feed

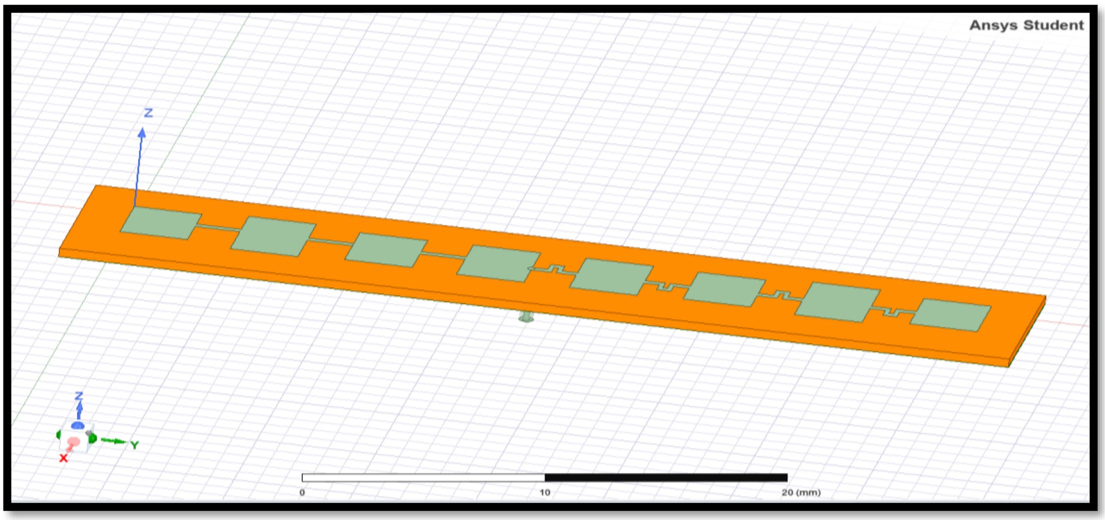


Figure 4.12: Simulated an eight-element array having intermediate coaxial feed

Rectangular microstrip patches has similar dimensions can be used to design eight element arrays. It is a symmetric structure.

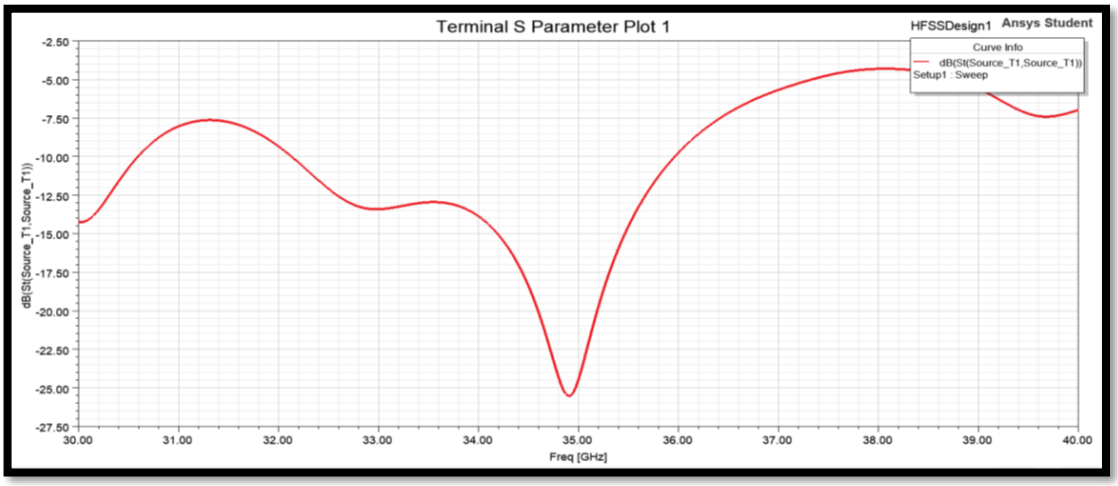


Figure 4.13: S-parameter plot of a rectangular array

The S-parameter vs Frequency (GHz) curve of above designed array having coaxial feed in the middle of the array as depicted in Figure 4.13. It is clearly seen in the Figure 4.13 that the value of resonant frequency is 35 GHz where the return loss is $-26.50\ dB$. So consequently, the relative bandwidth for $|s_{11}| < -10dB$ is evaluated from the Figure 4.3 as 11.30%.

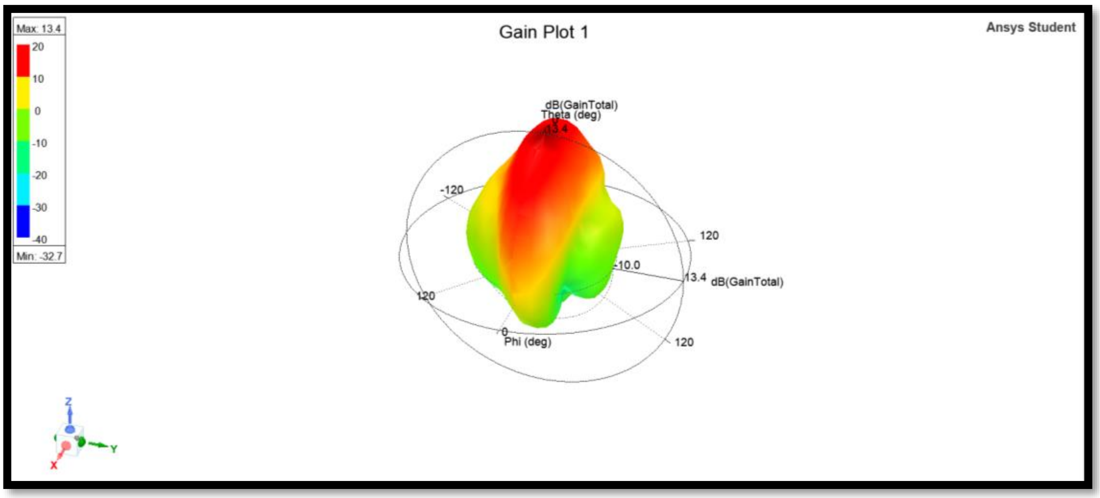


Figure 4.14: 3D polar plot of a rectangular array

From Figure 4.14, the patch element's maximum gain is 13.4 dB .

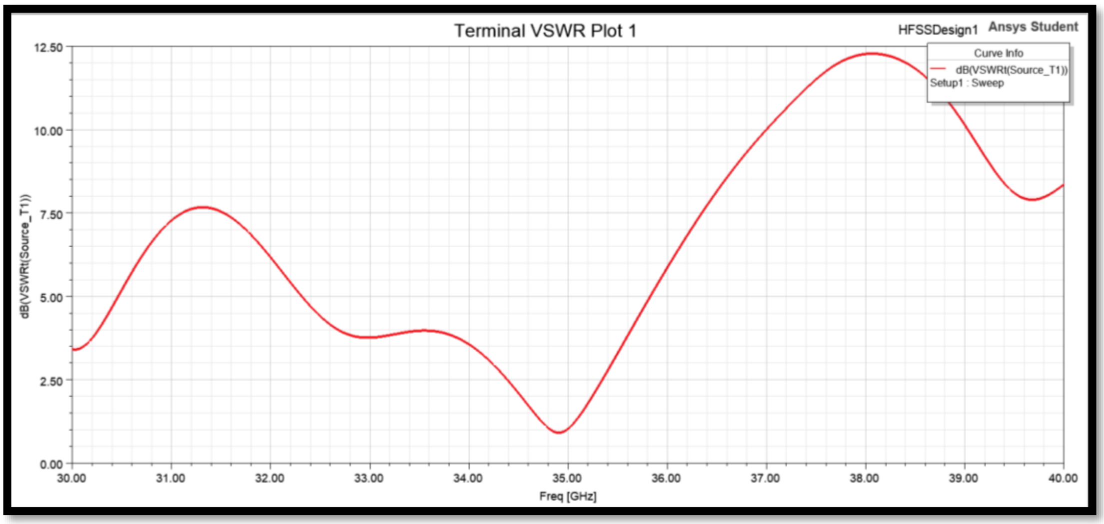


Figure 4.15: VSWR of rectangular array with intermediate feeding

From the figure 4.15, it can be seen that the VSWR value is equal to 1 at the centre frequency 35GHz. It is good value of VSWR as it shows that transmitted waves are not reflected to the source.

4.4 PROPOSED ANTENNA DESIGN

The conformal array is designed and the conformal carrier is taken as cylinder, cone and sphere surface of curvature.

In this section, the focus is to determine the effect of parameters of a single antenna array which is conformed on a cylindrical, conical and spherical structure such as radius of carrier, thickness of substrate and the substrate permittivity. We have taken return loss, gain and bandwidth into consideration for the comparative study of different curvatures.

4.4.1 THE MICROSTRIP ANTENNA CONFORMAL ARRAY ON CYLINDER CURVATURE SURFACE

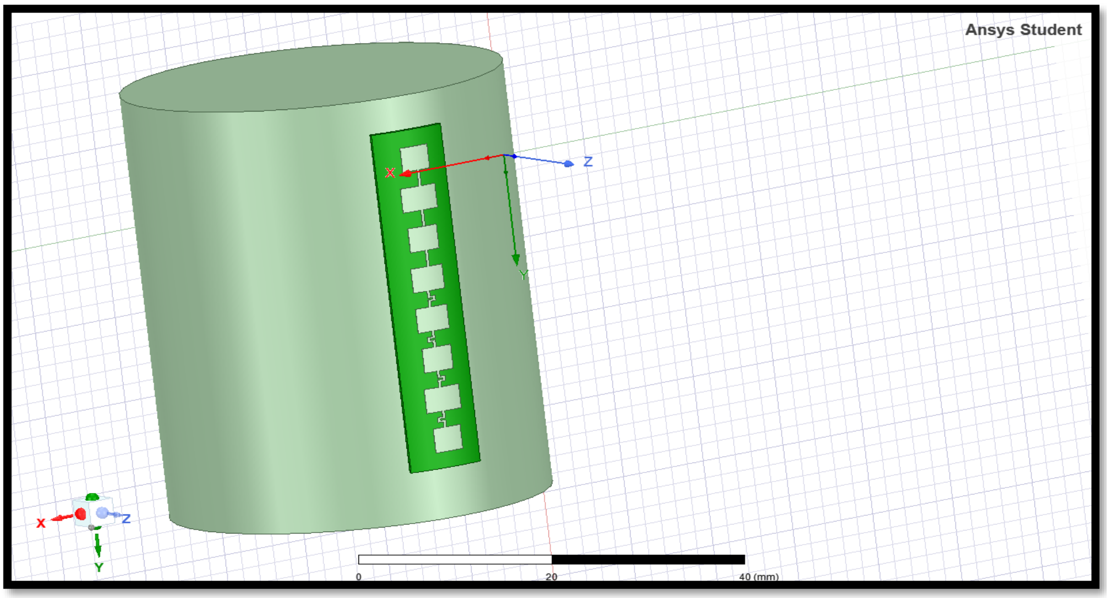


Figure 4.16: Conformal antenna array on cylinder surface

- **By Varying the radius of curvature**

We have varied the radius of curvature from 30mm to 50mm and observed the following results.

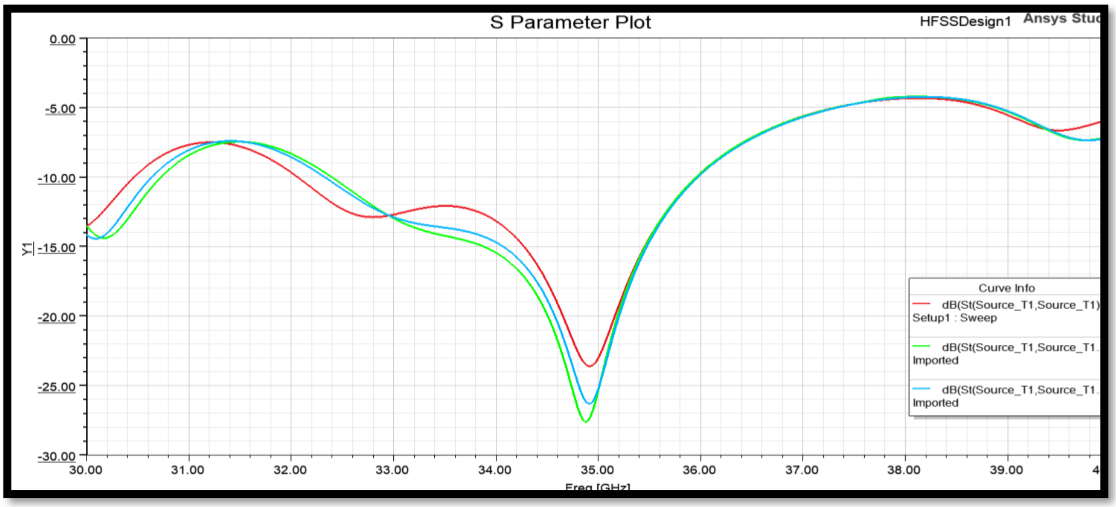
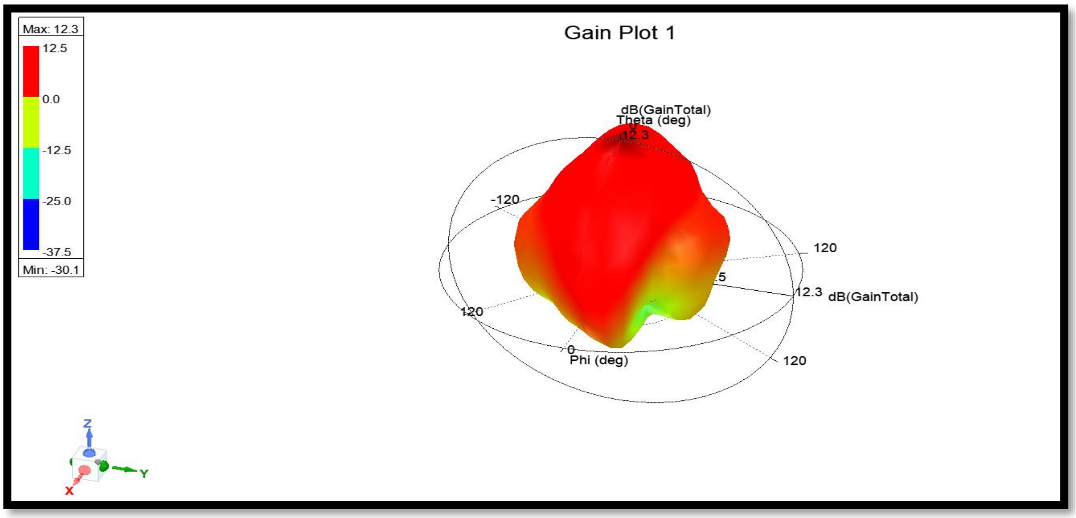
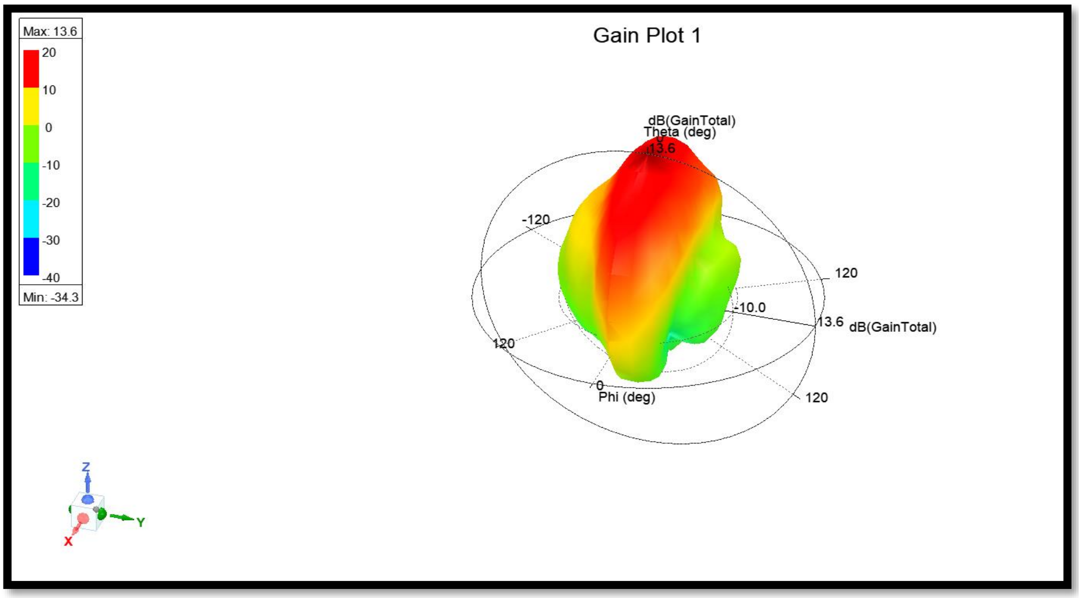


Figure 4.17: *S* Parameter vs Frequency Plot of Cylindrical Curvature

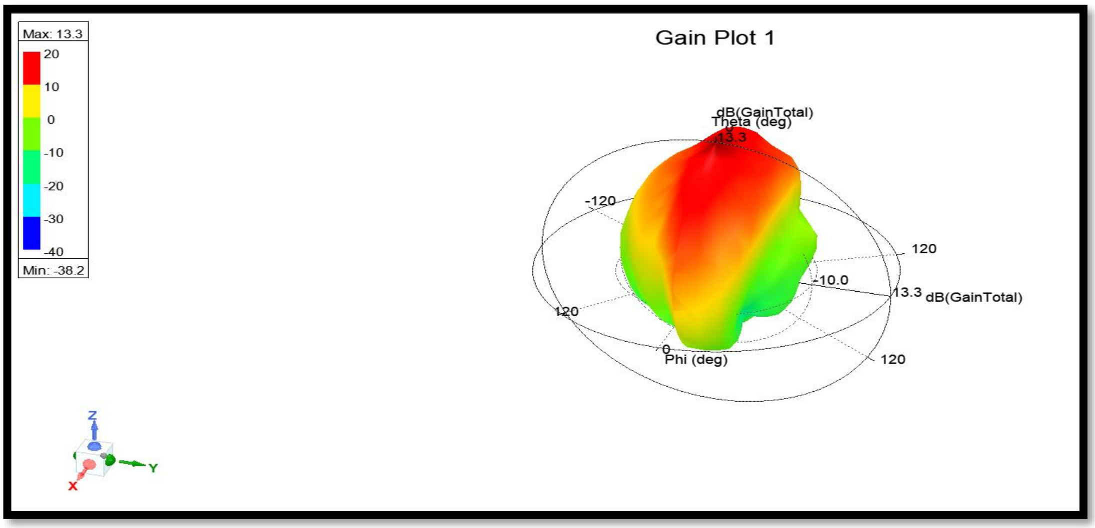
In Figure 4.17, it can be clearly seen that there is a very little variation in the value of return loss when we have varied radius of cylinder from 30 mm to 50 mm.



(a)



(b)



(c)

Figure 4.18: 3D Polar Plot for radii (a) 30 mm (b) 40mm (c) 50mm

It can be observed that maximum gain is achieved at radius of 50mm of about 13.6 dB.

Table 4.2: Comparative Results at different radius of curvature

Radius	Return Loss	Bandwidth	Relative Bandwidth	Gain
30 mm	-26.2953	2.575	10.45%	12.3
40 mm	-27.5336	3.65	10.68%	13.3
50 mm	-23.6023	3.90	11.46%	13.6

- **By Varying the relative permittivity of dielectric material**

We have assigned different dielectric material to substrate and observed the following results.

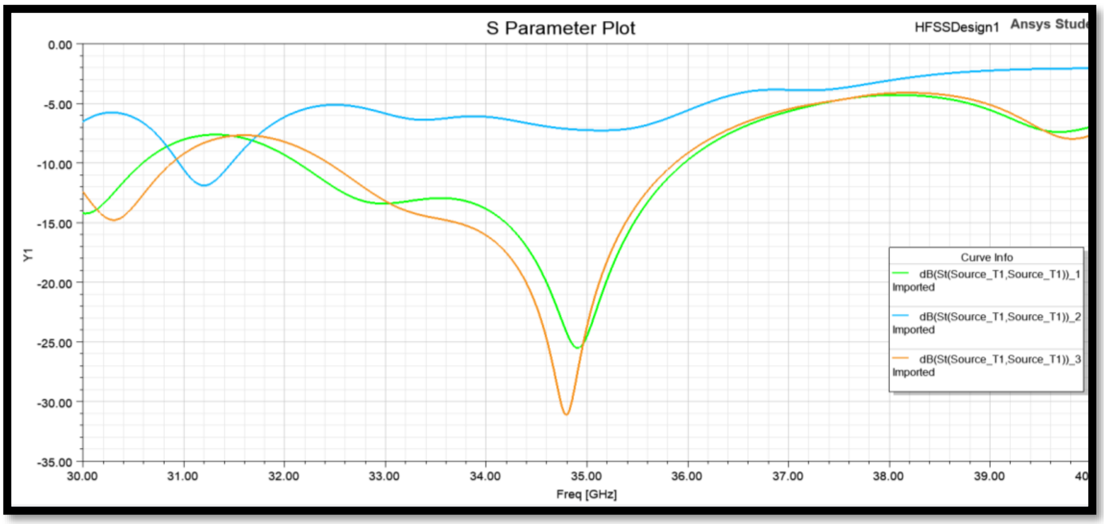


Figure 4.19: S-parameter vs Frequency plot for different dielectric material

From Figure 4.19, it can be easily observed that when relative permittivity is increased, bandwidth has been become narrow and value of return loss has also shown significant variation. Resonance frequency has also decreased as we increase the value of relative permittivity. Hence, while manufacturing the conformal antenna all the factors should be considered equally important.

Table 4.3: Comparative Results for different dielectric material

Relative Permittivity	Return Loss	Resonant Frequency	Bandwidth	Gain
1	-31.58	34.9	3.875	13.9
2.2	-26.29	34.7	2.575	12.3
4.4	-12.89	31.2	.5251	3.6

- **By Varying the thickness of substrate**

We have varied the thickness of substrate and observed following results.

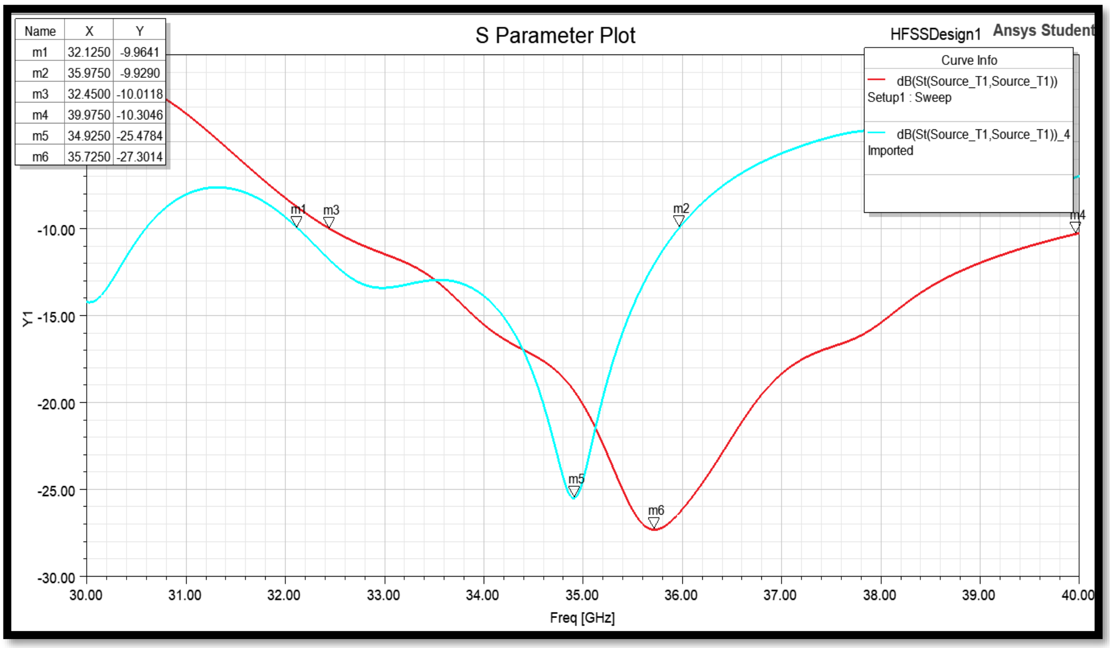
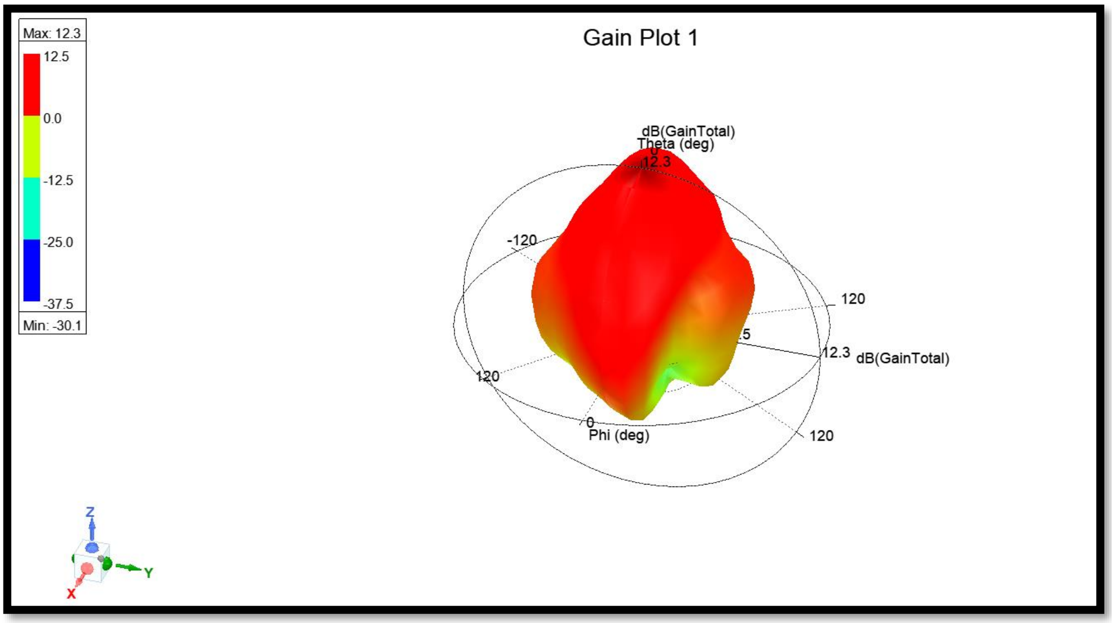
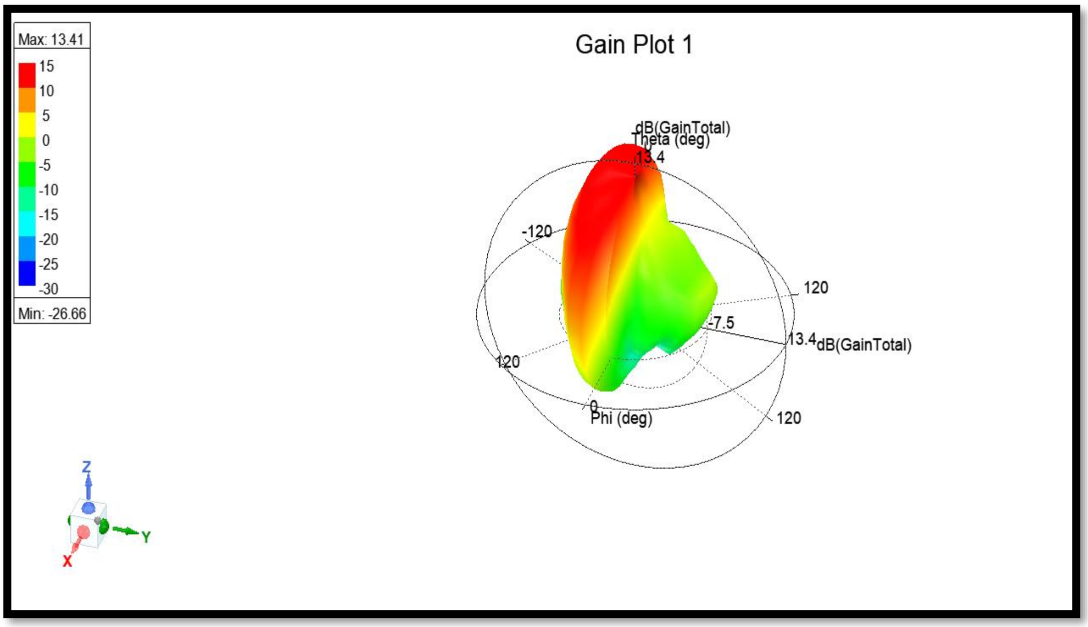


Figure 4.20: S Parameter vs Frequency plot for different thickness of substrate

In Figure 4.20, it is seen clearly that when there is increment in the value of substrate thickness, there is a shift in resonant frequency and also bandwidth increases.



(a)



(b)

Figure 4.21: Gain Plot for substrate thickness (a)0.5 mm (b)1.6 mm

It is also observed that when we increase the thickness the substrate, then there is an increment in the value of gain of antenna.

Table 4.4: Comparative Results at different substrate thickness

Substrate Thickness	Resonant Frequency	Bandwidth	Gain
0.5	34.9	2.575	12.3
1.6	35.7	7.5250	13.41

4.4.2 THE MICROSTRIP ANTENNA CONFORMAL ARRAY ON CONICAL CURVATURE SURFACE

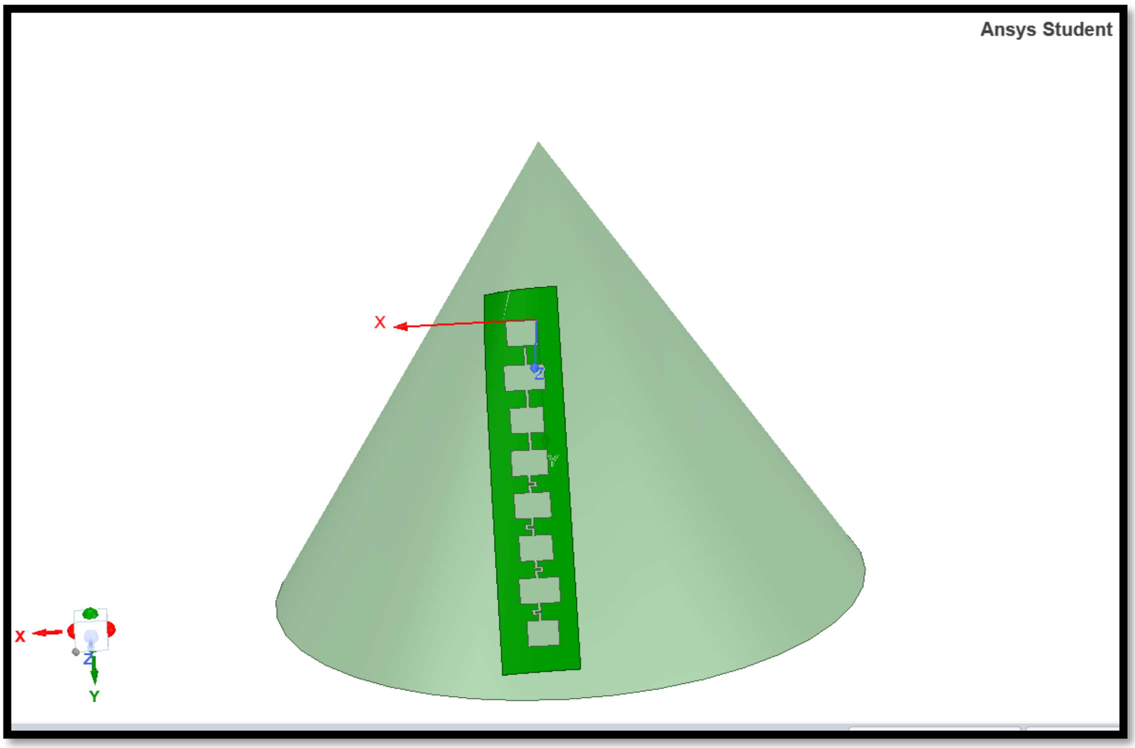


Figure 4.22: Conformal antenna array on conical surface

- **By Varying the radius of curvature**

We have varied the radius of curvature from 30mm to 50mm and observed the following results.

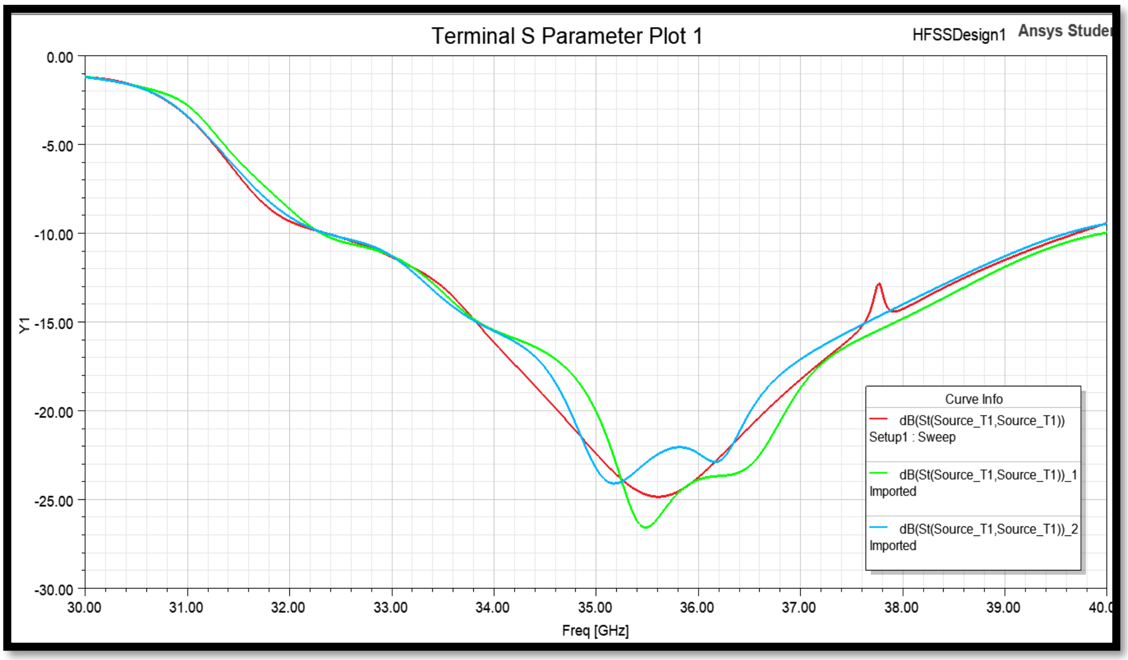
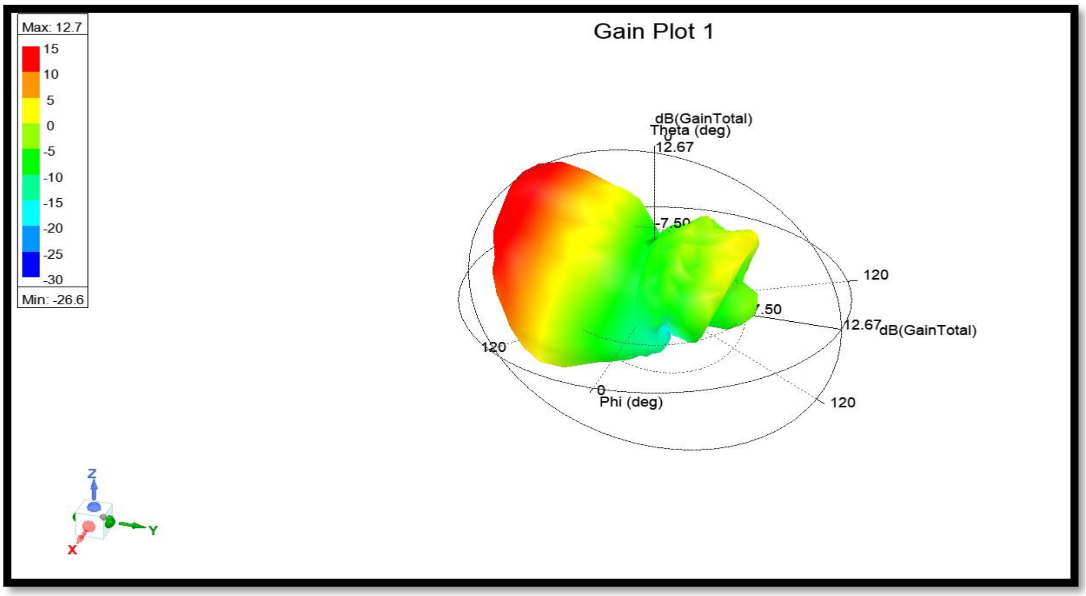
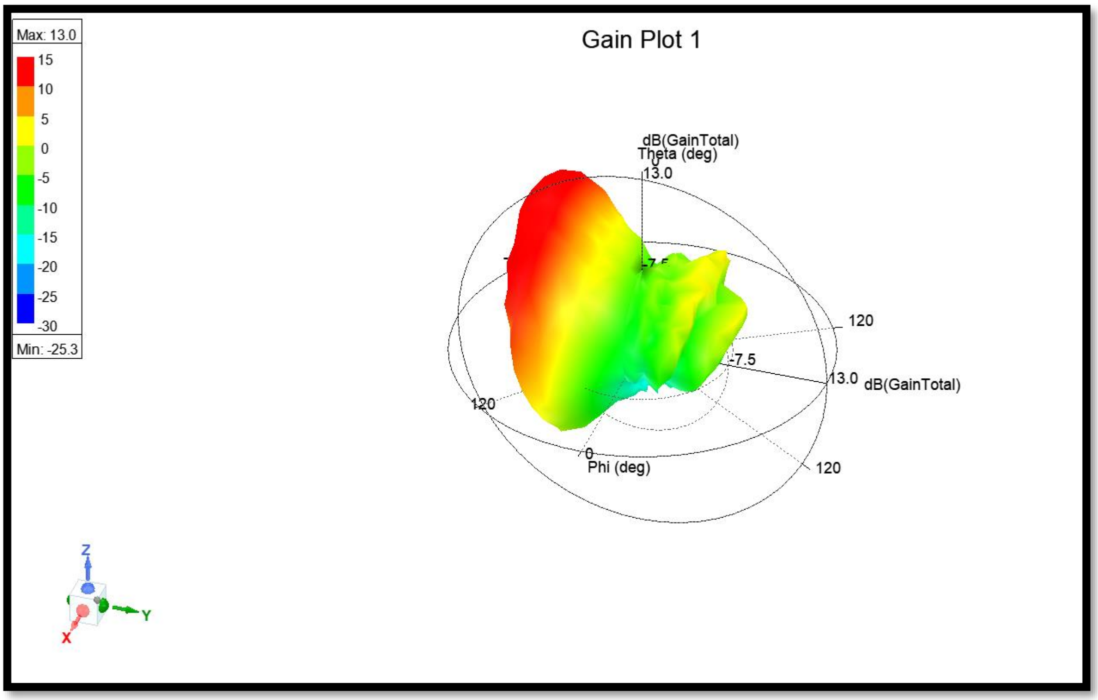


Figure 4.23: S Parameter vs Frequency plot for conical curvature

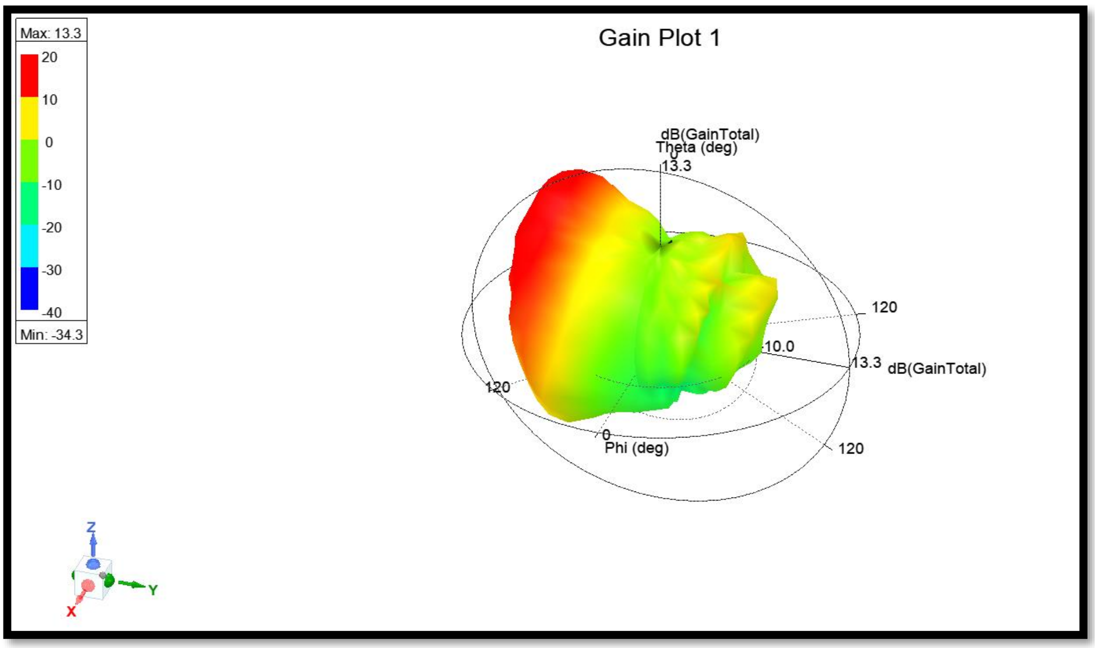
In Figure 4.23, it can be clearly seen that there is a very little variation of about 0.5 to 1 dB in the value of return loss when we have varied radius of cone from 30 mm to 50 mm.



(a)



(b)



(c)

Figure 4.24: 3D Polar Plot for radii (a) 30 mm (b) 40mm (c) 50mm

Just like a cylindrical curvature, while using a conical curvature maximum gain has also shown when radius=50mm which is about 13 dB.

Table 4.5: Comparative Results at different radius of curvature.

Radius	Return Loss	Bandwidth	Relative Bandwidth	Gain
30 mm	-24.0674	7.2250	20.09%	12.7
40 mm	-24.8283	7.4000	20.58%	13.0
50 mm	-26.5604	7.6000	21.02%	13.3

- **By Varying the relative permittivity of dielectric material**

We have assigned different dielectric material to substrate and observed the following results.

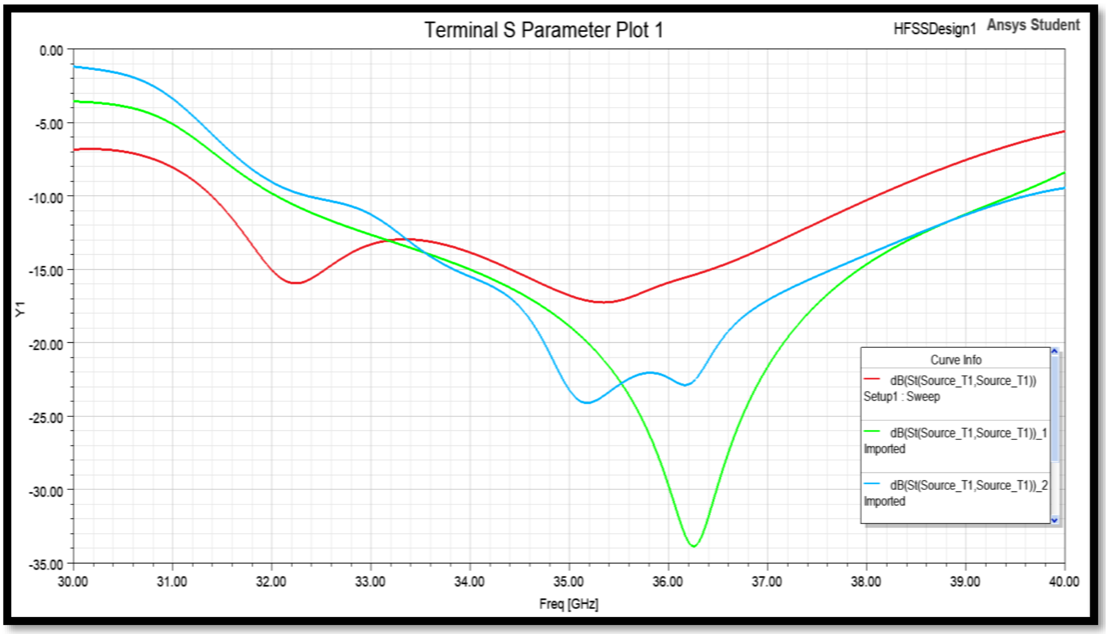


Figure 4.25: S Parameter vs Frequency plot for different dielectric material of substrate

From Figure 4.25, it can be easily observed that when relative permittivity is increased, bandwidth has been become narrow and value of return loss has also shown significant variation. Resonance frequency has also decreased as we increase the value of relative permittivity. Hence, while manufacturing the conformal antenna all the factors should be considered equally important.

It is also seen that there is a significant variation in the value of return loss of about 9 dB when we have varied the radius of conical curvature.

Table 4.6: Comparative Results for different dielectric material

Relative Permittivity	Return Loss	Resonant Frequency	Bandwidth	Gain
1	-33.8395	36.25	7.987	13.5
2.2	-24.0674	35.20	7.2250	12.7
4.4	-15.9352	32.20	6.567	9.7

- **By Varying the thickness of substrate**

We have varied the thickness of substrate and observed the following results.

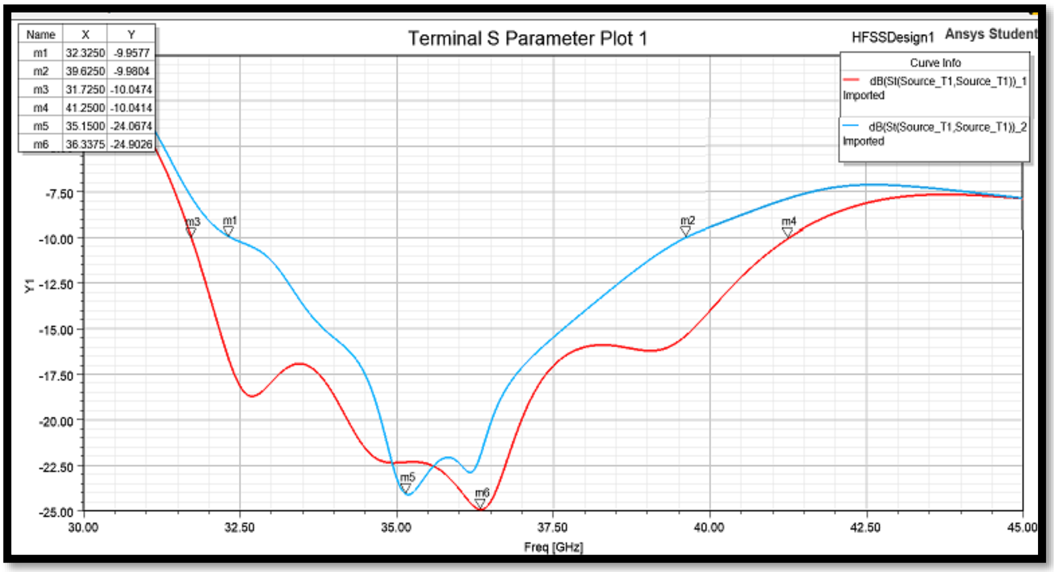
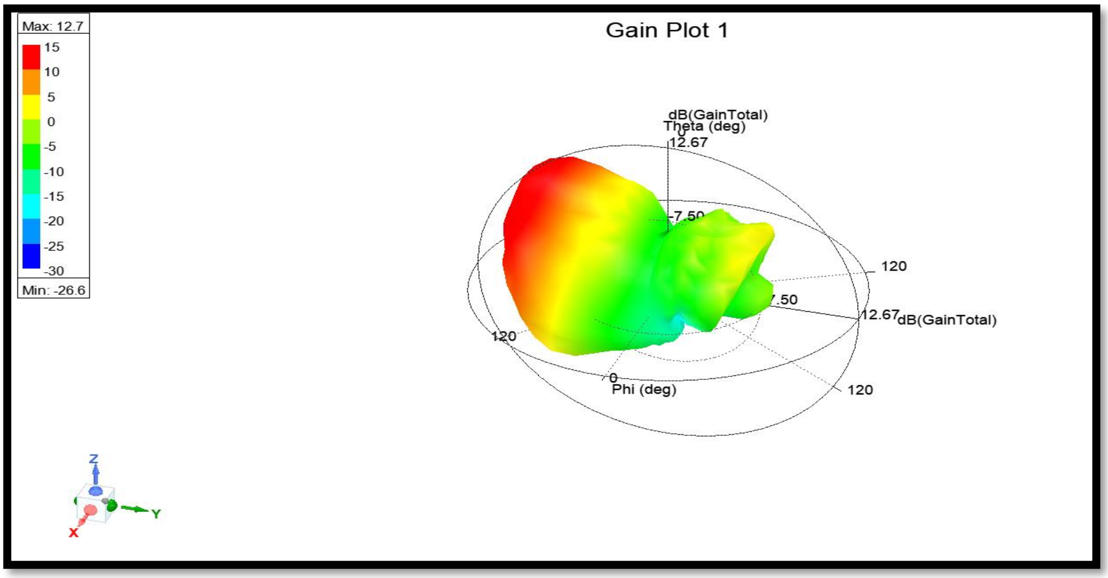
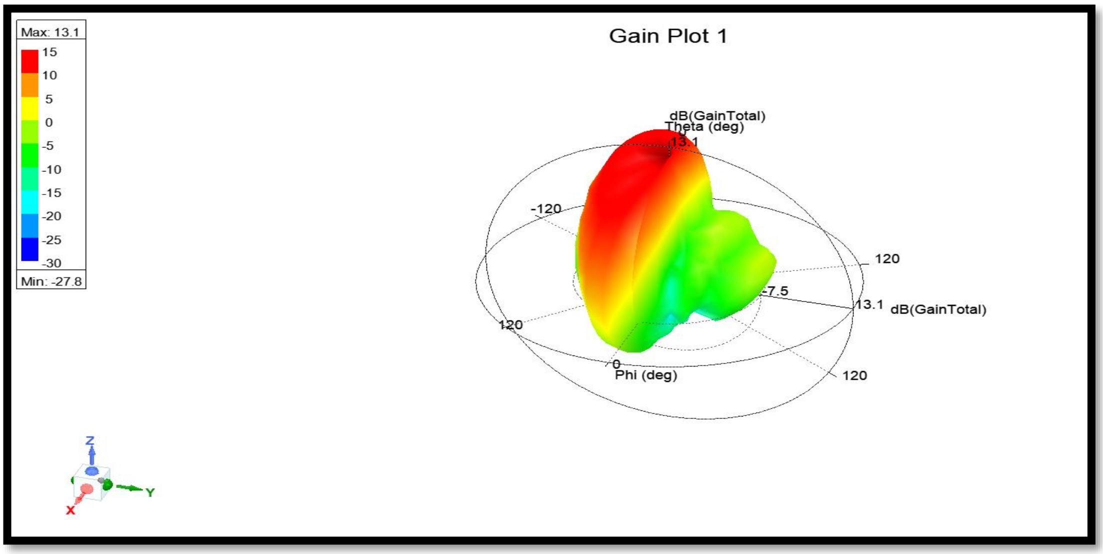


Figure 4.26: Return loss for different substrate thickness

From Figure 4.26, it can be clearly seen that when there is an increment in the value of substrate thickness, there is a shift in in resonant frequency and also bandwidth increases.



(a)



(b)

Figure 4.27: 3D polar plot for substrate thickness (a)0.5 mm (b)1.6 mm

It is also observed that when we increase the thickness the substrate, then there is an increment in the value of gain of antenna.

Table 4.7: Comparative Results for different substrate thickness.

Substrate Thickness	Return Loss	Resonant Frequency	Bandwidth	Gain
0.5	-24.0674	35.20	7.2250	12.7
1.6	-24.9026	36.3375	9.5250	13.1

4.4.3 THE MICROSTRIP ANTENNA CONFORMAL ARRAY ON SPHERICAL SURFACE

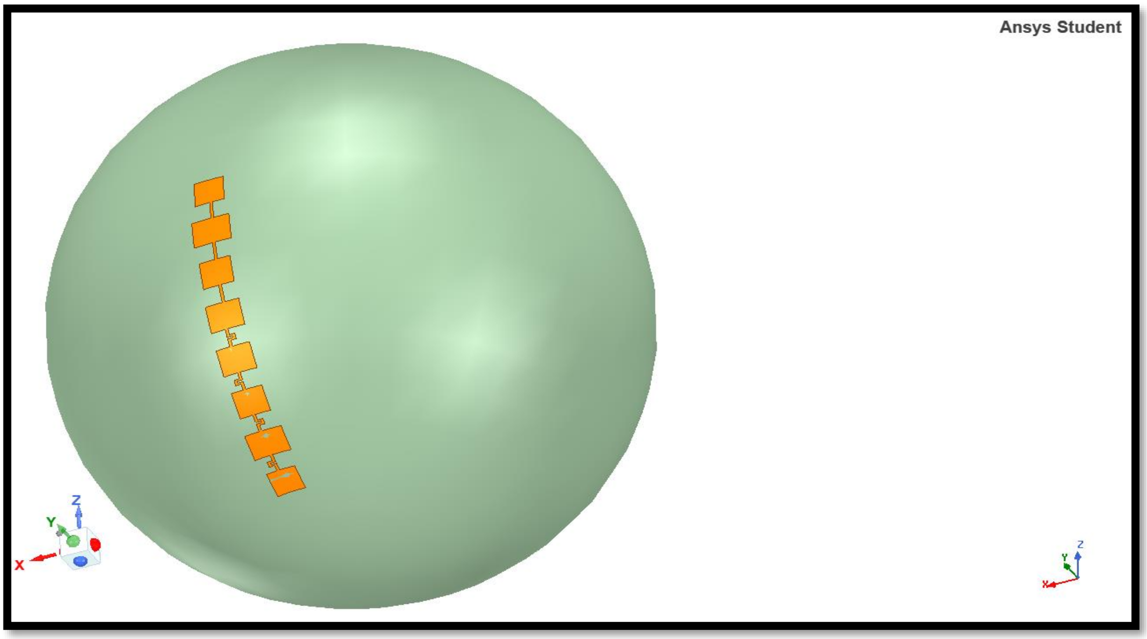


Figure 4.28: Conformal antenna array on spherical surface

- **By Varying the radius of curvature**

We have varied the radius of curvature from 30mm to 50mm and observed the following results.

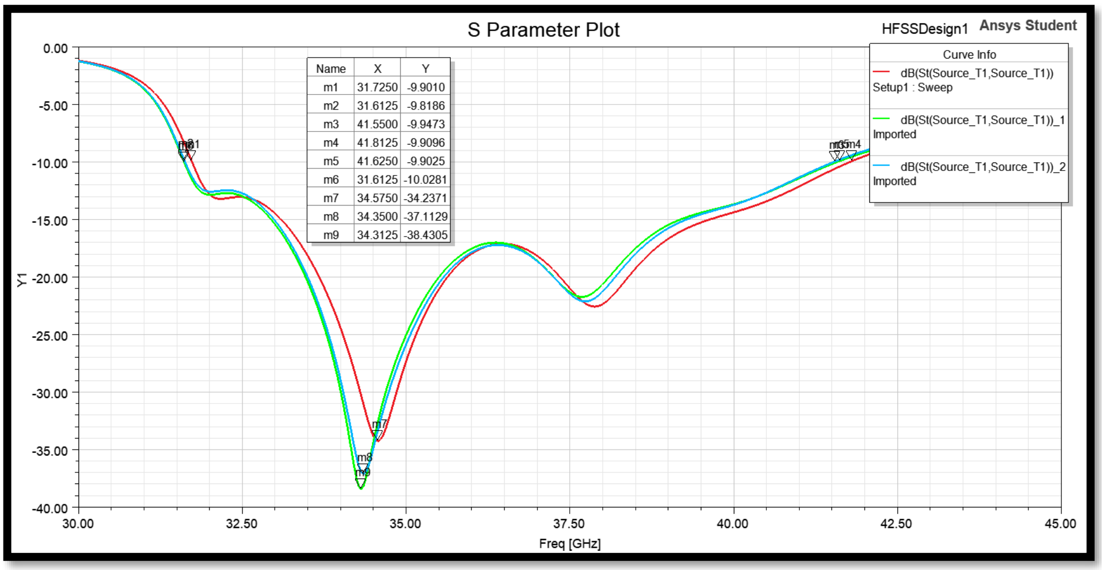
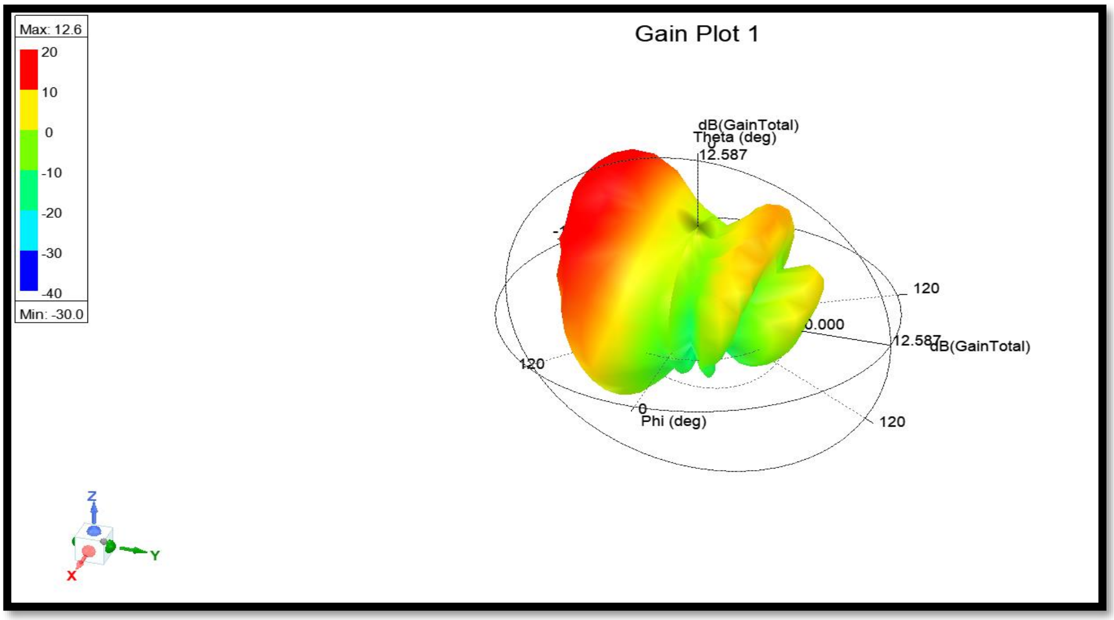
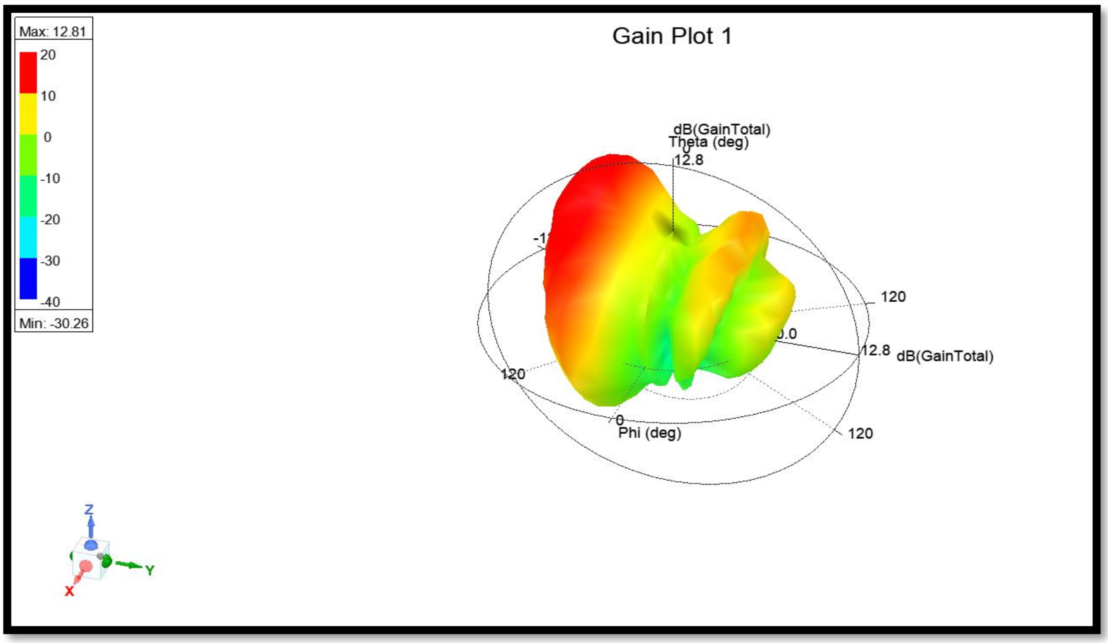


Figure 4.29: S Parameter vs Frequency plot for spherical curvature

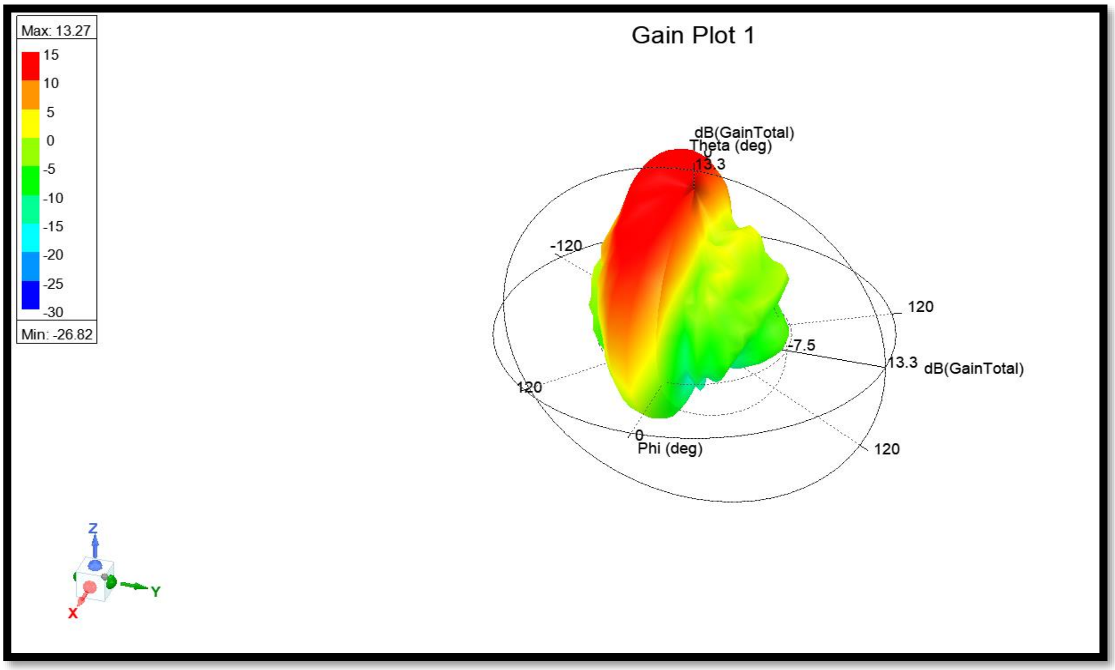
In Figure 4.29, it can be seen that there is a very little variation in the value of return loss in comparison to the cylindrical and cone curvature results when we have varied radius of sphere from 30 mm to 50 mm.



(a)



(b)



(c)

Figure 4.30: 3D Polar Plot for radii (a) 30 mm (b) 40mm (c) 50mm

It has been calculated that the fractional bandwidth has increased to a great extent in comparison to the relative bandwidth which has been achieved on cylindrical and conical curvature.

Table 4.8: Comparative Results at different radius of curvature.

Radius	Return Loss	Bandwidth	Relative Bandwidth	Gain
30 mm	-34.2371	9.9000	36.675	12.60
40 mm	-37.3500	9.9375	36.589	12.81
50 mm	-38.4305	10.0125	36.581	13.27

- **By Varying the relative permittivity of dielectric material**

We have assigned different dielectric material to substrate and observed the following results.

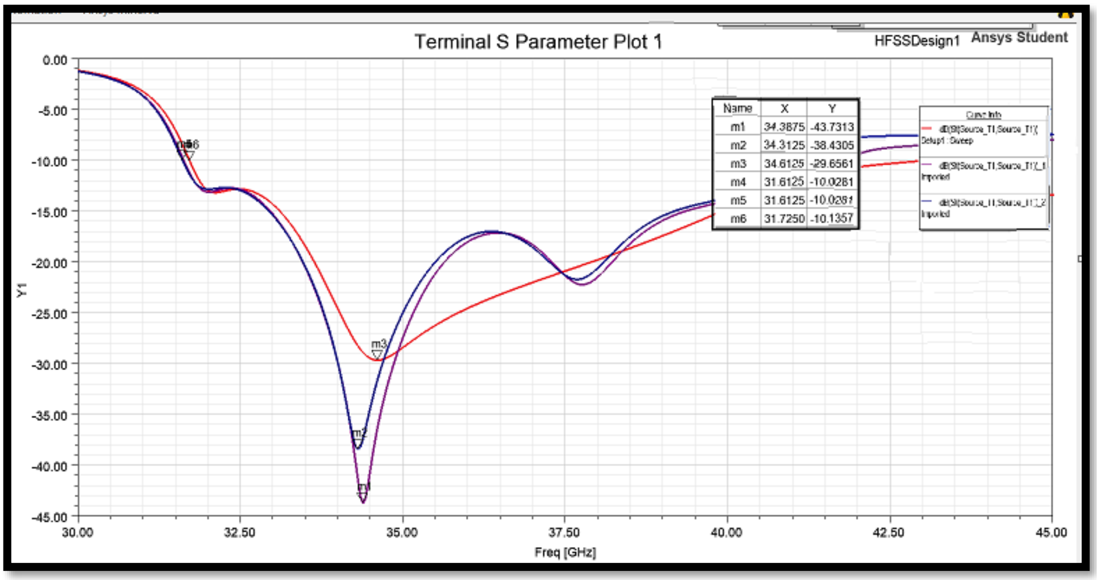


Figure 4.31: Return loss for different dielectric material of substrate

From figure 4.31, it can be easily observed that when relative permittivity is increased, bandwidth has been become less narrow and value of return loss has also shown significant variation. Resonance frequency has also decreased as we increase the value of relative permittivity. Hence, while manufacturing the conformal antenna all the factors should be considered equally important.

It is also seen that there is a significant variation in the value of return loss of about 5-7 dB when we have varied the radius of conical curvature. And also gain has decreased to a greater extent at a radius of 50mm.

Table 4.9: Comparative Results for different relative permittivity.

Relative Permittivity	Return Loss	Resonant Frequency	Bandwidth	Gain
1	-43.7313	34.3875	11.7750	13.94
2.2	-38.4305	34.3125	9.9000	12.60
4.4	-29.6561	34.6125	8.8875	7.6

- **By Varying the thickness of substrate**

We have varied the thickness of substrate and observed the following results.

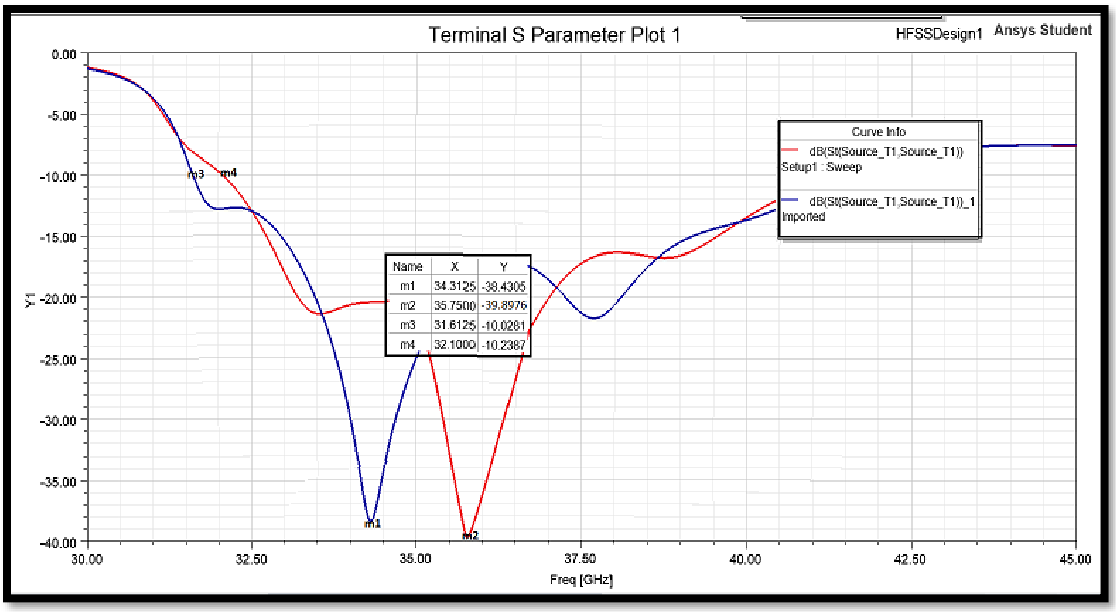
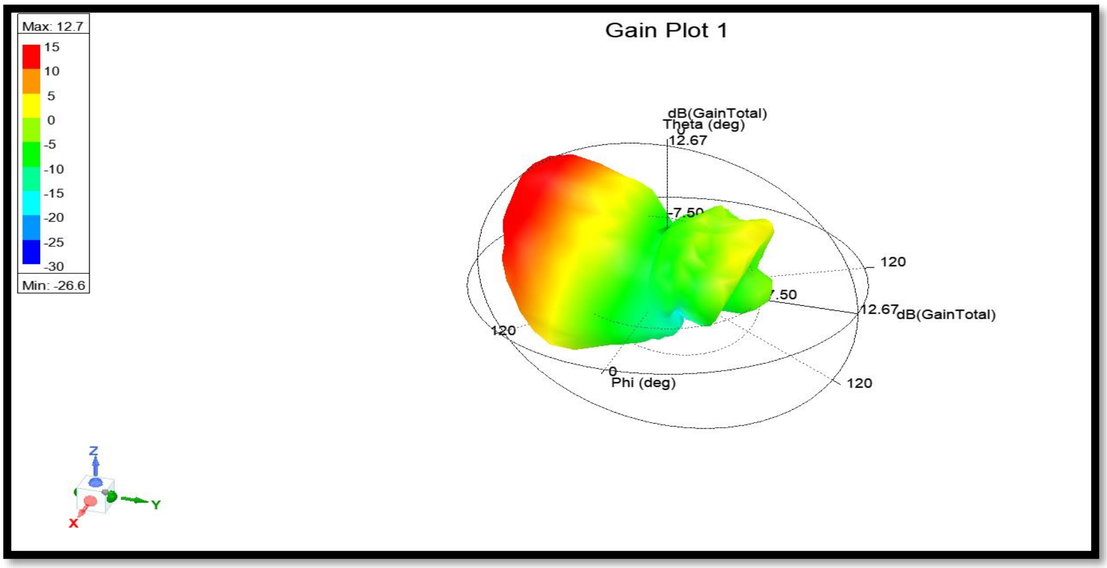


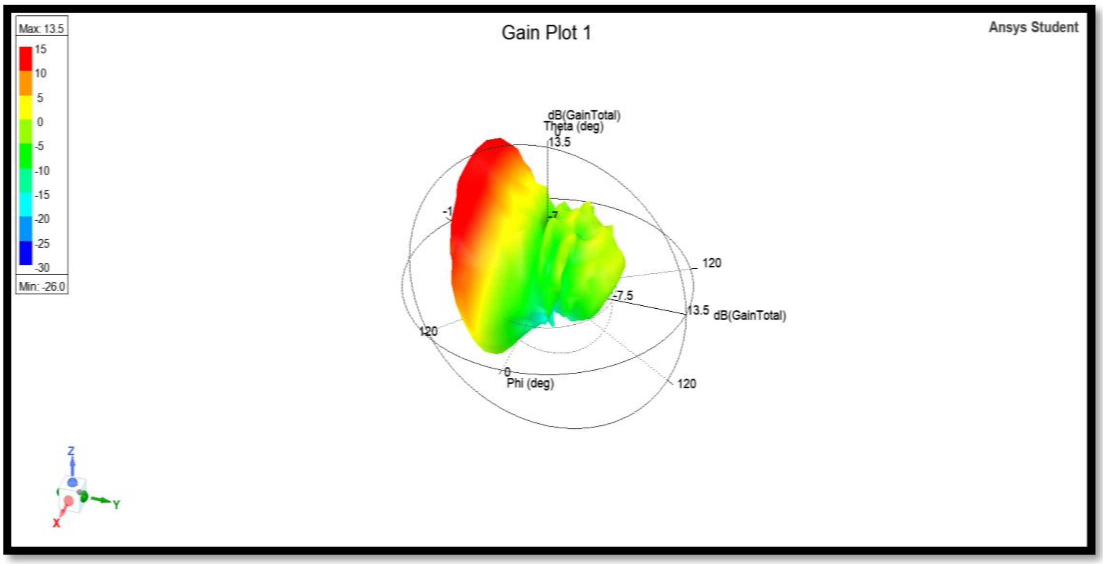
Figure 4.32: Return loss for different substrate thickness

From figure 4.32, it is clearly seen that when there is an increment in the value of substrate thickness then there is a shift in in resonant frequency and bandwidth increases.

As far as we concerned about manufacturing of conformal antenna then if the thickness of the substrate is more, then it will hard to bend over the curvature and if it is too thin then it will very easily break while bending over the curvature.



(a)



(b)

Figure 4.33: Gain Plot for substrate thickness (a)0.5 mm (b)1.6 mm

There is an increment in bandwidth and gain while varying the substrate thickness.

Table 4.10: Comparative Results for different substrate thickness.

Substrate Thickness	Return Loss	Resonant Frequency	Bandwidth	Gain
0.5	-38.4305	34.3125	9.9000	12.60
1.6	-39.8976	35.7500	11.4987	13.5

4.5 CONCLUSION

In this project, initially a microstrip patch antenna is designed & analysed it's all parameters. Afterwards for having better bandwidth and gain, we have implemented an antenna array with coaxial feeding as well as intermediate feeding in the array itself. The intermediate feeding gives better results as compared to one end feeding.

The antenna array is analysed for different conformal surfaces which includes cylindrical, conical and spherical curvature surfaces. And among three of the curvature that we have simulated, spherical curvature has given best results.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 COMPARATIVE STUDY

Type Of Antenna		Return Loss	Resonant Frequency	Bandwidth	Gain
Microstrip Patch Antenna		-28	35	2.00	7.96
Antenna Array with one end feeding		-23.50	35.50	7.20	13.5
Antenna Array with intermediate feeding		-26.50	35	9.8	13.4
Conformal antenna array on cylindrical curvature	R=30mm	-26.29	34.7	2.57	12.3
	R=40mm	-27.53	34.8	3.65	13.3
	R=50mm	-23.60	34.9	3.90	13.6
	ε_r=1	-31.58	34.9	3.87	13.9
	ε_r=2.2	-26.29	34.7	2.57	12.3
	ε_r=4.4	-12.89	31.2	0.52	3.6

	H=0.5mm	-31.29	34.9	2.57	12.3
	H=1.6mm	-35.72	35.7	7.52	13.41
Proposed Design					
Conformal antenna array on conical curvature	R=30mm	-24.06	35.20	7.22	12.7
	R=40mm	-24.82	35.40	7.40	13.0
	R=50mm	-26.56	35.50	7.60	13.3
	ε_r=1	-33.83	36.25	7.98	13.5
	ε_r=2.2	-24.06	35.20	7.22	12.7
	ε_r=4.4	-15.93	32.20	6.56	9.7
	H=0.5mm	-24.06	35.20	7.22	12.7
	H=1.6mm	-24.90	36.33	9.52	13.1
Conformal antenna array on spherical curvature	R=30mm	-34.23	35.31	9.90	12.60
	R=40mm	-37.35	35.35	9.375	12.81
	R=50mm	-38.43	35.75	10.01	13.97
	ε_r=1	-43.73	34.38	11.77	13.94
	ε_r=2.2	-38.43	34.31	9.900	12.60
	ε_r=4.4	-29.65	34.61	8.88	7.6
	H=0.5mm	-38.43	34.31	9.900	12.60
	H=1.6mm	-39.89	35.75	11.49	13.50

It shows how return loss, bandwidth and gain varied with different curvature, radius of curvature, relative permittivity and thickness of substrate.

CHAPTER 6

CONCLUSION

6.1 CONCLUSION

With the help of this present work, we are able to analyse the effect of different curvature surface for conformal antenna. The results of conformal antenna are far better than the results of microstrip patch antenna and antenna array. When an antenna array is conformed on cylindrical, cone and spherical curvature then performance of array has become better and it shows better results. Between cylindrical and conical conformed antenna, we can observe that conical has better return loss value and broad bandwidth and gain in comparison to cylindrical. And among three curvature surfaces, we can easily determine that spherical has shown the best results. And it can be the area of new research for wireless communication systems. The parametric analysis done on physical parameters is an important tool to analyse the performance of an antenna characteristics. We have successfully designed, simulated and analysed the different antenna designs in this project work.

6.2 FUTURE SCOPE

This project provides an opportunity to design conformal antenna on some other curvature surfaces such as elliptical and toroidal. We can also vary the feeding techniques and compare with the existing research. Fabrication will give more realistic output hence we can try to fabricate conformal antennas.

The investigation on conformal antenna arrays should be continued which will give more additional advantages over planar antennas.

REFERENCES

[1] Mishra, P. and Gupta, P., Compact U-Slotted Dual Band Conformal Microstrip Antenna.

[2] Redondo Gonzalez, M.D.C., 2007. *Analysis of Conformal Antennas for Avionics Applications* (Doctoral dissertation, Chalmers University of Technology).

[3] Naik, K.K., Sri, P.A.V. and Srilakshmi, J., 2017, November. Design of implantable monopole inset-feed c-shaped slot patch antenna for bio-medical applications. In *2017 Progress in Electromagnetics Research Symposium-Fall (PIERS-FALL)* (pp. 2645-2649). IEEE.

[4] Wang, Q., Mu, N., Wang, L., Safavi-Naeini, S. and Liu, J., 2017. 5G MIMO conformal microstrip antenna design. *Wireless Communications and Mobile Computing*, *2017*.

[5] Sun, D., Shen, R. and Yan, X., 2014. A broadband conformal phased array antenna on spherical surface. *International Journal of Antennas and Propagation*, *2014*.

[6] Gottwald, G. and Wiesbeck, W., 1995, June. Radiation efficiency of conformal microstrip antennas on cylindrical surfaces. In *IEEE Antennas and Propagation Society International Symposium. 1995 Digest* (Vol. 4, pp. 1780-1783). IEEE.

[7] K.-L. Wong and S.-Y. Ke, "Cylindrical-Rectangular Microstrip Patch Antenna for Circular Polarization", IEEE Tran. On Antennas and Prop., Vol. 41, No. 2, February 1993.

[8] Q. Jinghui, Z. Lingling, Du Hailong and Li Wei, "Analysis and Simulation of Cylindrical Conformal Omnidirectional Antenna", Microwave conference Proceedings, 2005. Asia-Pacific Conference Proceedings. Vol. 4, Dec. 2005.

[9] Lars Josefsson and Patrik Persson, "Conformal Array Antenna Theory and Design", Wiley-IEEE Press, March 2006. pp. 1-5, 230-238, 265-302.

[10] C. A. Balanis, "ANTENNA THEORY. Analysis and Design", John Wiley & Sons Inc., Second Edition, 1007. pp. 722-772.

[11] Li, E., Li, X.J. and Seet, B.C., 2021. A Triband Slot Patch Antenna for Conformal and Wearable Applications. *Electronics*, *10*(24), p.3155.

[12] Sahoo, R., Vakula, D. and Sarma, N.V.S.N., 2017, November. A wideband conformal slot antenna for GPS application. In *2017 Progress in Electromagnetics Research Symposium-Fall (PIERS-FALL)* (pp. 589-592). IEEE.

[13] Aziz, M.A., Roy, S., Berge, L.A., Nariyal, S. and Braaten, B.D., 2012, March. A conformal CPW folded slot antenna array printed on a Kapton substrate. In *2012 6th European Conference on Antennas and Propagation (EUCAP)* (pp. 159-162). IEEE.

[14] Gupta, N.P., Kumar, M. and Maheshwari, R., 2019, August. Development and performance analysis of conformal UWB wearable antenna under various bending radii. In *IOP Conference Series: Materials Science and Engineering* (Vol. 594, No. 1, p. 012025). IOP Publishing.

[15] Löcker, C., Vaupel, T. and Eibert, T.F., 2005. Radiation efficient unidirectional low-profile slot antenna elements for X-band application. *Advances in Radio Science*, *3*(B. 1), pp.143-146.

[16] Bai, T., Jiang, D., Luo, S. and Zhu, K., 2021. Design of Cylindrical Conformal Array Antenna based on Microstrip Patch Unit. *The Applied Computational Electromagnetics Society Journal (ACES)*, pp.1008-1014.

[17] Patidar, P.K., 2021. A Review Paper on Microstrip Patch Antenna (MPA) for 5G Wireless Technology. *Turkish Journal of Computer and Mathematics Education (TURCOMAT)*, *12*(13), pp.1741-1747.

[18] P. Nagarajan, C. Sujatha, 2016, Design and Analysis of Rectangular Microstrip Patch Antenna and S Slot Dual Band Frequency Microstrip Patch Antenna, INTERNATIONAL JOURNAL OF ENGINEERING RESEARCH & TECHNOLOGY (IJERT) ICETET – 2016 (Volume 4 – Issue 16).

[19] Koushick, V. and Divya, C., 2017. Design and analysis of array of slot antenna for s-band application. *International Journal of Advanced Trends in Engineering and Technology*, *2*(1), pp.115-121.

[20] Zadeh, M. and Manzoni, A.C., 2017. Numerical analysis of flexible ultra-thin conformal antenna array. *arXiv preprint arXiv:1705.08517*.