DEVELOPMENT AND STUDY OF 28GHz ANTENNA FOR DIFFERENT SHAPES AND WORK ON ANTENNA TRANSPARENCY FOR CELLULAR DEVICES

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A thesis submitted to the Department of Electrical and Electronic Engineering in partial fulfilment of the requirements for the degree of
B.Sc. in Electrical and Electronic Engineering

Department of Electrical and Electronic Engineering
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Spring 2020

DECLARATION

It is hereby declared that,

1. The thesis submitted is my/our own original work while completing degree at BRAC University.
2. The thesis does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The thesis does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. We have acknowledged all main sources of help.

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ABSTRACT

In this paper antenna concept is especially presented for future wireless communication devices (smartphones) to achieve spherical beam steering coverage. It also describes a feasibility study performed on antennas made from various transparent conductors. An opaque antenna array in which the radiating elements are simply demonstrated visible and coupled with the cell phone glass is proposed as a solution for saving huge PCB (printed circuit board) spaces. According to the requirement of 5G network communication technology antenna should be functional at 28Ghz frequency with optimal output which is one of the major challenges in terms of design. Thus, in this paper using some specific transparent substrates it is represented to scrutinize the configuration of rectangular, circular antenna arrays fed by a 28 GHz microstrip feeding line for future 5 G applications. Our simulation (using ANSYS HFSS) gives a maximum result for antenna gain of 1X4 circular patch antenna array which is 8.2460dB, moderate return loss of -6.25dB and also have an efficiency of 99.69% using glass substrate whose transparency is 88%.The simulated results of the return-loss, the gain, directivity, electric field, efficiency and radiation pattern of the antenna array is being discussed.

Keywords: millimeter wave, microstrip patch antenna, gain, return loss, optical transparency

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DEDICATION

We would like to dedicate our study to our parents who have always motivated us to strive for achievement and their never-ending guidance at all phases have brought us so far. We would also love to dedicate this to our supervisor for all his support and encouragement in the development of the final work output.

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ACKNOWLEDGEMENT

We would like to express our sincere thanks to our thesis supervisor, Dr. A.K.M Abdul Malek Azad, Professor, for his guidance, support and feedback in order to complete the thesis successfully. Special thanks to BRAC University's Department of Electrical and Electronics Engineering for providing all the necessary facilities we needed to carry our work forward. Last but not least we would also like to thank our parents and every member of this team whose support has kept us moving forward and also for the commitment to work till the end.

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LIST OF ACRONYMS

UE	User Equipment
5G	5^{th} generation
PIFA	Planar inverted F antennas
PCB	Printed circuit board
GPRS	General Packet Radio Service
LTE	Long Term Evolution
UMTS	Unified Mobile Telecommunications Infrastructure
IP	Internet Protocol
OFDM	Orthogonal Frequency Division Multiplexing
MIMO	Multiple Input Multiple Output
Gbps	Giga Bytes per second
WiMAX	Worldwide Interoperability for Microwave Access
VSWR	Voltage Standard Wave Ratio
EDGE	Enhanced GSM Evolution Data Rates

Chapter 1

Introduction

1.1 BACKGROUND:

The word "G" literally means "GENERATION." The generation is defined as a set of standards for telephone networks, describing a particular cell phone system's technical implementation. Our Internet speed depends on the intensity of signal displayed in alphabets such as 2G, 3G, 4G etc. on your home screen when you are connected to the internet. This technological process started from 1 G in 1979, and continues to be 5G. Growing of the Generations has requirements that have to be followed to use the term G officially. There are organizations which are responsible for standardizing every mobile technology generation. Through generation has criteria defining issues such as speed, latency, etc. that must be met to be considered part of that generation. This was a big technical change when the wireless networks switched from analogue to digital.

1 G:

1 G was the very first generation of smartphone production. This very first generation of commercial cellular networks was introduced during the 1970's. 1 G is an analogue technology and, generally speaking, phones had low battery life and good voice quality, with little coverage, and sometimes weak network. Those are the analogue telecommunications standards introduced in the 1980's, and persisted until 2 G digital telecommunications replaced them. Average velocity 1 G 2.4 Kbps.

2 G:

Mobile phones received their first big upgrade when upgrading from 1 G to 2G. The key distinction between the two mobile telephone systems (1 G and 2 G) is that the 1 G network radio signals are similar, while the 2 G networks have digital signals. In this generation the key motivation was to have a safe and effective means of communication. The words CDMA and GSM are used here. Limited data service available like SMS and MMS. Radiolinja (now part of Elisa Oyj) commercially launched second generation 2 G cellular telecommunications networks on the Finnish GSM platform in 1991. The 2 G features are achieved by multiplexing enabling multiple users on one channel. Mobile were also used for data during 2 G along with voice. The technical transition from 1 G to 2 G introduced many of the essential features we still use today, such as SMS, internal roaming, phone calls, call hold and service-based billing, e.g. long-distance call charges and actual-time billing. General Packet Radio Service (GPRS) max 2 G bandwidth is

50 Kbps or 1 Mbps for Enhanced GSM Evolution Data Rates (EDGE). The lesser-known 2.5 G and 2.75 G was an intermediate norm that bridged the gap before going from 2 G to 3 G for the major cellular networks.

3 G:

This generation, like all of the wireless devices we've seen and enjoyed, has set the standards. Web browsing, email, video streaming, picture sharing, and other third generation mobile technologies were introduced. The goals set for third-generation mobile communication, launched commercially in 2001, were to promote greater voice and data performance, allow for a broader variety of applications and improve data transmission at lower cost. The 3 G standard uses UMTS, a modern technology called Unified Mobile Telecommunications Infrastructure, the core network architecture. 3 G has more general support for and streaming multimedia services. Unlimited connectivity and portability in 3 G is made possible through different types of devices (telephones, PDA's, etc.) 3 G increased efficiency of the frequency spectrum by improving the way audio is compressed during a call, so that several more calls can occur simultaneously at the same frequency range. Like 2 G, 3 G grew to 3.5 G and 3.75 G as more modifications were made to get 4 G. A 3 G telephone cannot communicate via a 4 G network, but almost always new telephone models are built to be backwards compatible, so a 4 G telephone can communicate via a 3 G or even 2 G network.

4 G:

4 G is a slightly different product compared to 3 G, made possible virtually only through technical advances over the last 10 years. The aim is to provide customers with high speed, high quality and high efficiency while increasing safety and reducing the cost of voice and data services, multimedia and internet over IP. Smartphone Opportunity and emerging technologies include improved mobile Internet connectivity, IP telephony, gaming facilities, high-definition mobile television, video conferencing, 3D TV, and cloud computing. MIMO (Multiple Input Multiple Output), and OFDM (Orthogonal Frequency Division Multiplexing) were key innovations that made this possible WiMAX (which has now been fizzled out) and LTE (which has seen widespread implementation) are the two main 4 G standards. 4 G is not the same as 4 G LTE and is very close to meeting the requirements needed. You can do it without having to buffer up to play a new game or watch an HD TV display. New versions of phones are typically built to be backward-compatible, so that a 4 G phone can communicate over a 3 G or even 2 G network. All companies are likely to agree that OFDM is one of the main factors that legally identify a service

as 4G. There are a lot of changes in technology that service providers need to make to deliver. And again, we have the fractional parts: 4.5 G and 4.9 G representing the transformation of LTE (in the stage called LTE-Advanced Pro) which takes us more MIMO, more D2D on the way to IMT-2020 and 5G.

5 G:

5 G provides for a new wave of innovation. The connectivity needs are changing around the world and this 5 G has the ability to change the world. Especially in dense urban areas, the existing 4 G networks would simply not be able to keep up. Therefore, 5 G is the next technical breakthrough that allows for portable systems.

5 G is a developing technology which aims to build on 4G. 5 G offers much faster download rates, improved security, less latency and other enhancements. Some of the 5 G plans provide device-to - device connectivity, improved battery capacity and enhanced total wireless coverage. The 5 G max speed is targeted at being as fast as 35.46 Gbps, which is more than 35 times faster than 4G. Looking for new technologies: Huge MIMO, Wireless Networking Millimeter Wave, etc. Huge Li-Fi could be used to give unseen low latency 10Gb's to a user and make connections for at least 100 billion devices.

Antennas are one of the main radio elements, and a range of phased array mm Wave antennas will be built into upcoming 5G cellular devices. In [1] the hybrid antenna module concept presented may serve as a catalyst for the realization of a spherical beam steering coverage for future 5G deployment. Implementing a 5G millimetre Wave antenna within a user equipment becomes an inevitable challenge due to the recent implementation of metallic rims and fully display screens. Hence, a transparent antenna array in which the radiating elements are made prominently transparent and is accommodated within the bezel-less region is investigated as a solution for giving an additional degree of freedom. Despite everything this miniaturized antenna implementation are expected to mitigate propagation loss, diffraction loss and polarization mismatch loss due to mobility of smartphones terminals [2]. Several methods have been applied to improve efficiency of optical transparency using different transparent conductive substrate and films [3]-[6].

The reason we have choose antenna for future 5G cellular devices are:

- ❑ Converts an electric signal to the radio wave (transmitter) and vice versa (receiver)
- ❑ Consists of a radiating element that splits the rods and make current flow
- ❑ Gives maximum beam steering coverage
- ❑ Compact
- ❑ Easy to fabricate in now-a-days cellular devices (bezel less region)

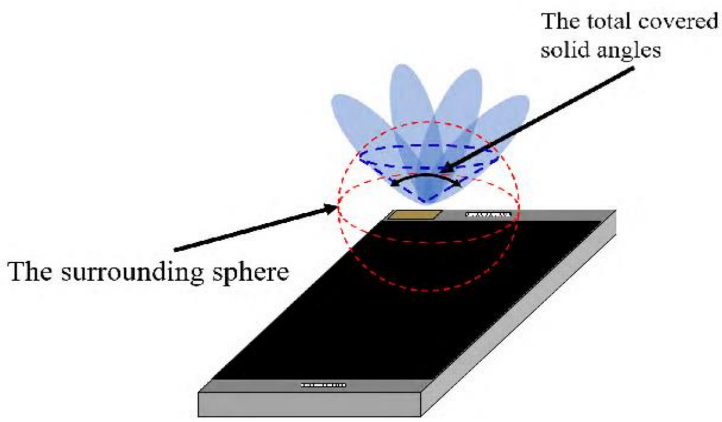


Fig.1 Mobile antenna gives spherical beam steering coverage

In this paper, a simple rectangular and circular shaped microstrip patch antenna operating at the millimetre wave is designed using ANSYS HFSS using different transparent substrates. To conclude, we can say that patch antenna arrays with many benefits and improved performance (for e.g. better efficiency, high transparency, better directivity, directional radiation patterns with good side lobe level and stable gain) were our main objective.

1.2 Literature Review

In [1] an antenna which is based on hybrid concept combining an antenna in package and antenna on display has been presented at 28 GHz aiming at coverage of spherical beam steering which is completely suitable for the present days mobile devices. Considering all the factors, miniaturized antenna design is supposed to reduce loss of propagation, loss of diffraction and loss of polarization misfits due to smartphone terminal mobility [2]. As a result, an optically transparent antenna can be designed implementing a glass substrate for display application where the transparency is approximately 88% at 28 GHz [3]. Furthermore, an array of microstrip patch antenna is designed using a meshed grid gold layer which gives the maximum transparency of

74.6% [4]. In [5] a transparent coplanar patch antenna is designed using micron line width-sized copper mesh which achieved a very high transparency of 92%. In addition, [6] presents a method for the realization of optically clear patch antennas consisting of double-sided aluminium metallisation of mesh structures on fused silica giving the transparency of 82%. As a result, using these substrate transparent antenna designs can be done for display application of mobile devices. On the other hand, [10] logically classify the transparent electrodes for the transparent antenna, and define the transparent antennas according to the characteristics of each electrode. Moreover, [11] offers an overview of some significant antenna designs and cell phone developments over the past 15 years, and discusses the recent introduction of modern LTE antenna technologies and lightweight multi-input multi-output (MIMO) terminals. The ultimate aim of [12] is to highlight the different frequencies of mobile terminal antennas for different applications, to focus mobile terminal antennas built for 5 G applications, to research and discuss the effects of the user's hand on 5 G smartphone terminal antennas, to address problems, challenges in the field of user effects for 5 G applications on mobile terminal antennas. In [13] a design of three subarrays of patch antennas has been compactly positioned along the edge of the cell phone printed circuit board (PCB) to form the antenna kit in order to achieve a broad three-dimensional scanning area coverage with high-gain beams for 5G.Finally, [15] stated that microstrip patch antenna is used in 5G due to its basic physical structure, is fairly inexpensive to produce and build. Microstrip patch antenna has multi-band specifications and a compact structure which has therefore emerged as a promising candidate for handheld devices using HFSS software to incorporate the proposed concept. There is currently considerable interest in developing a new technology for future wireless cellular communication networks to meet the increasing demand for higher data rates [18].

1.3 Inspiration and Goals

5G is the next big thing in Internet connectivity which plays a major role in the transformation to pervasive communication, stimulates research priorities and standardization initiatives. Recently it has been hyped that 5G is the mobile and networking sector that is supposed to have a significant impact on society and business that goes far beyond the information and communication technology area. Compared to the previous generation network, 5G faster upload speed, a lower latency (10 times less than 4G), more devices can be linked and the possibility of implementing virtual networks will be introduced. When the wireless networks switched from analogue to digital, this was a big technical change. Hence, considered as the interesting field to be worked on.

In 5G networks radio antenna is potentially a new type of antenna with some very remarkable specifications. As there are several components in grids placed next to each other will allow some extremely smart beam steering coverage for individual users. The antenna footprint in the millimetre band will be much smaller and configuration of the antenna design will ensure the maximum antenna efficiency for the specified area.

Our aim in this paper is to implement a patch antenna array with much benefits and improved performance using a variety of transparent substrates. Improvements include better efficiency, high transparency, better directivity, directional radiation patterns with good side lobe level and stable gain.

1.4 Overview of the Thesis Organization

This thesis was divided into 6 chapters consisting of the basic knowledge descriptions of the antenna module and future 5 G mobile applications, the mathematical models and equations needed, the basic structure and simulation method of the antenna to be built, the results obtained from simulations and a detailed overview of all the research work carried out with future objectives and scopes.

Chapter 1

Here, this writing provides the definition and importance of miniaturized antenna module concept for 28GHz 5G beam steering mobile terminals. Our inspiration and goals, motivations of choosing this research field, a brief literature review, problem statement and the methods required for solving these problems have also been talked about in this Chapter.

Chapter 2

In this chapter a research has been made about different transparent substrates that can be considered for microstrip patch antennas on display application of recent mobile phones. These specific substrates have been chosen based on their transparency and efficiency features.

Chapter 3

In this we get a good picture of what antenna is, its uses and its benefits. There are four common mobile antenna models whose definitions including merits and demerits of each type are also being listed and discussed in detail. In addition, the reason for approaching microstrip patch antennas as the only module to be implemented for future 5G mobile applications is also explained vividly.

Chapter 4

The parameters defined for each antenna model are explained here for a clearer understanding of what each antenna parameter means. In this chapter the description of the simulated effects of gain, directivity, return loss, electric field and radiation pattern is discussed.

Chapter 5

The simulation results are shown for 4 different transparent substrates, as selected, taking into account all the antenna parameters. This chapter conveys the dimensions for each element and array with proper geometrical calculations. Discussions and findings are listed with the correct table as far as possible.

Chapter 6

What we finally concluded after simulating 1x1,1x2,1x4 rectangular and circular patch antenna is explained here by the parameters which are considered for each antenna model. There was discussion of the overall benefit and efficiency inferred from the comparison. Furthermore, in the future scope, the works that we still plan to do and the editions that need to be completed are listed.

Chapter 2

Substrate Characteristics for Transparency

In this section a study has been discussed about different substrates that can be considered for transparent microstrip patch antennas for display application of mobile. Following substrates have been selected due to its transparency characteristics. Using these substrates, rectangular and circular shaped patch antennas have been implemented in HFSS software. Their simulation results and design are discussed later on chapter 5.

2.1 Glass

An optical transparency of 88% at 28GHz is obtained using a thick alloy electrode of Ag on a substrate which is made of glass [3]

A process of photolithography is used to implement a diamond shaped metal grid with corrugated edges to compensate for the Moiré phenomenon caused by interference between the active display pixels and the periodic unit cells. 2000A thick Ag alloy is chosen as an electrode because of its low heat, resistance to corrosion and high conductivity.

The test samples of the coplanar waveguide are made using the Ag-alloy electrode. This test sets the diamond grid width, height and line width to 100µm, 50µm and 3µm respectively, with transparency of 88%. Increasing the line width, W_{mesh} of the grid improves the insertion loss whereas decreases the optical transparency. This transparency is experimentally measured using Murakami Color Research Laboratory HM-150 haze meter. Alternatively, 2000A-thickness and 3 µm grid width alloy matrix patterns are applied to the substratum using thin film processes consistent with sputtering, resulting in 88% transparency and a sheet resistance of 3.2(ohm/square) with conductivity of 1.55X10^6 S/m.[7]

Due to the visible outlines of the transparent diamond grid, the antenna region has introduced a dummy grid to eliminate any difference in optical transparency. Minimizing the space at fixed interval, W_{gap}, of dummy grids is benefitted in achieving optical invisibility. For maintaining the antenna efficiency and high transparency, W_{gap} is determined to be 3µm.

The S-parameters are measured between 100MHz to 18GHz using the KEYSIGHT N5230A PNA-L. The patterns of far-field radiation are measured using an anechoic chamber with mmWave.

2.2 Copper

A transparent patch antenna can be designed by using copper mesh that operates from 2.36 to 2.76 GHz and from 4.92 to 6 GHz [4]. The radiation pattern of this antenna is omnidirectional. This antenna has the efficiency up to 45% using the copper mesh film. This type of transparent antennas can be used in different transparent structures for instance spectacles, displays, doors and windows. The main focus of this type of construction is to maintain the good conductivity along with the transparency. In this case, the film of copper mesh has the micron-sized line width and achieved the transparency approximately 90%. This copper mesh antenna results in higher conductivity compared to other TCFs (transparent conductive film). In addition, this mesh copper antenna is really easier to fabricate that results a positive impact on display applications. The simulation of the antenna has been done using CST microwave studio and the measurements have also been done using CST. A vector analyser has been used to measure the reflection coefficient of the antenna that achieved less than -10 dB for 2.36 to 2.76 GHz. The radiation pattern has been measured by the SATIMO StarLab system that resulted in omnidirectional. The transparency of the mesh is achieved approximately 92% which is desirable for our display application. As a result, we have used copper for our antenna design at 28 GHz frequency that results in a good gain and good return loss using HFSS.

2.3 Aluminium

A design of transparent microstrip patch antenna can be done using aluminium. This antenna performs at 77 GHz [5] having the transparency of 81%. The number four element transparent microstrip patch antenna has been designed with a doubled sided meshed metallization using aluminium. This particular type of antenna can be used in various applications specially to embed in the glass of a display and to hide the antenna behind a screen. This is the reason we considered aluminium as one of our substrates for transparent antennas for mobile display application. The theoretical transparency can be measured using the formula, $T = (p - \frac{w}{p})^2$ where, p represents the pitch of the mesh and w represents the strip width of the mesh. Different results can be achieved by varying these parameters. This type of antenna is better than other transparent antennas in terms of gain and directivity. The simulation using aluminium substrate has been done using HFSS in this thesis.

2.4 Gold

A construction of a transparent microstrip patch antenna can be done using gold. This antenna performs at 60 GHz and gives the maximum theoretical transparency of 74.6% [6]. This type of antenna can be used for indoor security systems, wireless telecommunication etc. Gold grid layer has been used to achieve the printed efficient system at the frequency of 60 GHz. A four-patch antenna array with the connector V has been designed to get more efficient results. Au/Ti bilayer has been used with a gold mesh grid. The meshed pattern has a ground plane of 200 um with the width of 20 um whereas the pitch of the mesh is 100 um and the gold strip width is 30 um. Transparency of the antenna is achieved 36.5% if the light passes through the ground and feeding line. Transparency becomes 60% if light passes through the patches and the ground plane. If the light passes through only ground, the transparency is measured 74.6%. As a whole, the transparency is 67.8% varying from the value of 36.5% to 74.6%. The reflection coefficient has been measured under -35 dB using HFSS. The measured gain is approximately 10 dBi at almost 60 GHz. As a result, we have considered gold as a substrate to get good transparency and gain.

Chapter 3

Overview of the Antenna

3.1 Introduction

The first antenna was designed in 1888 by a German Physicist Heinrich Hertz and was one of the experimental works to prove what James Clerk Maxwell predicted. In the last 60 years, antenna technology has played a major role in advancement in communication and is the most important part of wireless communication. The basics of the antenna principle need the antenna to be "impedance match" with the transmission line otherwise the antenna does not radiate. The VSWR definition is implemented as a measure of how good a related antenna is. When the antenna does not suit free space, power is reflected back to the transmitter, which results in a loss of power emitted. An antenna is a metal structure that radiates from the transmitter, or receives electromagnetic waves. This is often conceived as a transitional system between guide and free space which may take the shape of a wave guide. This wave guide helps to transmit the energy of the wave from the transmitting device to the antenna or vice versa. The antenna used for a given antenna network shall be chosen based on operating frequency, radiation field polarity, radiation direction, bandwidth, power handling capacity, input impedance. Oscillating current was created by electrons movement that was caused by the oscillating current and magnetic field of radio waves exerting force. There are three types of antenna – Omnidirectional, Semi directional and Highly Directional. Some of the common mobile antenna models are mentioned below:

- Short dipole Antenna –Wire Antenna
- Planar Inverted F antenna-PIFA
- Microstrip Patch Antenna
- Helical Antenna

Phased Array Antenna is the most suitable structure to be built for enhanced Gain. An array antenna is a series of several antennas that are connected together and act as one antenna. Specific antennas called elements are connected by feedline to the transmitter or receiver. This feedline feeds power to every single item in an array. Array layout must be such that emission from each dimension adds up in a given direction to give peak radiation. It increases benefit dramatically, and cancels interference in a given set of directions.

Uses of Antenna: Radio broadcasting, broadcast television, radars, mobile phones and satellite communication.

3.2 Antenna Models

3.2.1 Short Dipole Antenna-Wire Antenna

Wire antennas are one of the easiest to install and assemble antennas. A long wire antenna is simply connected to the transmitter or receiver via an antenna tuner. The end wire antenna is made up of wire length that is as high as possible and relatively long. This wire is then connected to the communication station which transmits and receives radio. There are variants of wire antennas such as Multi-wavelength long wire, end fed half wave antenna. They are the simplest antennas which have many flexible applications. Wire antennas can be compressed in the form of straight wire, dipole loop and helix loop antennas. Moreover they can be of any shape like circular, rectangular, square, ellipse and many more.

3.2.2 Planar Inverted F Antenna (PIFA)

An inverted F antenna is used in wireless portable lightweight devices which were first conceived in the 1950s as bent wire antennas. This type of antenna is mostly used in mobile wireless devices for its space saving feature.

Planar inverted F antennas (PIFA)may be printed using the microstrip format, a widely used technique that enables printed RF components to be assembled as part of the same PCB (printed circuit board) used to connect other modules. PIFAs include cell phones and tablet computers which use wireless communication. They are the most commonly used antenna in the layout of mobile phones.

3.2.3 Helical Antenna

Helical Antenna is a type of wire antenna in which the conducting wire is helically wrapped and led to the ground surface by a feeder line. The feed line of the helical antenna is attached to the ground plane and to the helix at the bottom. This is the simplest antenna that generates polarised circular waves. Two types of normal mode and axial mode will activate this antenna. This can be used in mobile radars and broadcast antennas while axial mode is used in satellite communication while it is in regular mode. Helical antenna radiation, turn size, and angle of pitch depend on helix diameter.

3.2.4 Microstrip Patch Antenna

Microstrip antennas gained the most popularity and are being widely used printed antennas.

Structure of the microstrip antenna is: on the top of the dielectric substrate a radiating patch is being connected whereas a ground plane is attached beneath it. For improved performance thicker substrate, whose dielectric constant is lower, used to give a better efficiency. The highly conductive metal builds the patch antenna, microstrip and ground plane transmission line. Microstrip patch antennas may be rectangular, circular, planar, rectangle, triangular and other types of variety.

Table I

Merits and Demerits of various types of antenna

SL No	Antenna Models	Advantage	Disadvantage
3.2.1	Short dipole antenna	• Low cost • Simple to install • Ease of multiband operation	• Interference • Good earth connection needed • High level of radiation can give odd effects
3.2.2	PIFA	• Shorter • Lightweight • Easy fabrication • Low profile	• narrow bandwidth characteristics
3.2.3	Helical antenna	• highest directivity • wider bandwidth • simple design	• larger in size • requires much space • efficiency decreases
3.2.4	Microstrip Patch antenna	• thin profile • easy to fabricate • inexpensive • no cavity backing required • used to create simple arrays	• low efficiency • narrow bandwidth • low power handling capacity • tolerance problems

3.3 Choice of Antenna

Microstrip antennas have gained significant use in the microwave frequency region because they are quick and easy to print on circuit board (PCB). Patch antenna when attached to the rigid surface they become mechanically solid and durable. According to the patch shapes and modes resonant frequency of the patch antenna can be adjusted.

Some of the typical patch antennas are made from a metal patch on top of a grounded substrate with highly conductive metal being implemented. The patch and the ground plane is separated by a layer named Di electric constant. The effect and thickness of different substrate materials and

their effects on antenna performance as a whole are explained in [9].

The microstrip patch antenna is fed by a feeding point of a microstrip transmission line. The most common two shapes are rectangular and circular as shown in the figures below. The patch is the length L, width W, radius a, height of the substrate h. The thickness of the substrate should be considered less than 0.025 of wavelength so that the antenna efficiency doesn't degrade. Because of the patch's finite length and width the geometric distortion effect is noticed at the borders of the patch by the electric field. The geometric distortion effect, electrically sound, makes the patch of the microstrip antenna appear larger than its actual measurements. The amount of blotches is determined by the patch measures and the substrate height. Ratio of the L/h should be greater than 1 for microstrip patch antenna to reduce the fringing effect.

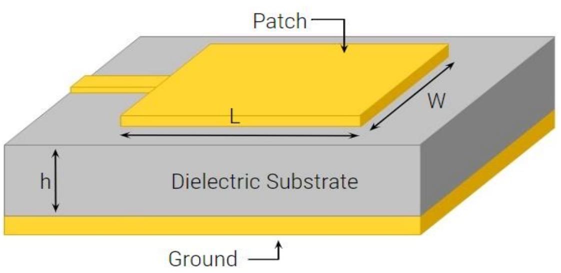


Fig2a: Simple rectangular patch antenna

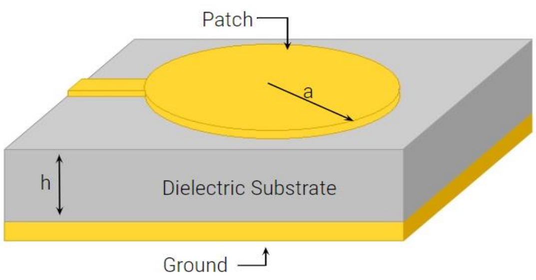


Fig2b: Simple circular patch antenna

From overall study and the comparisons in Table II shows that microstrip patch antenna plays the most convenient role as an antenna in mobile phones. Due to the simple and easy to print circuit board this antenna has gained a lot of use in the microwave frequency region. Thus the choice of microstrip patch antenna is a wise decision as they are well matched with printed circuit technology and are easy to produce as single and array antenna.

Chapter 4

Antenna Parameters

4.1 Radiation Pattern

The power radiated by an antenna as a function from the direction in a distance from the antenna is known as a radiation pattern. Flux density, radiation intensity, field strength directivity and polarization or phase makes up the radiation properties. It is situated in a distant field region and is represented by means of a function of directional coordinates**.** There is two or three dimensional basic determinant of the radiated energy which is a function of the orientation of the observer along with a trajectory or surface of constant radius.

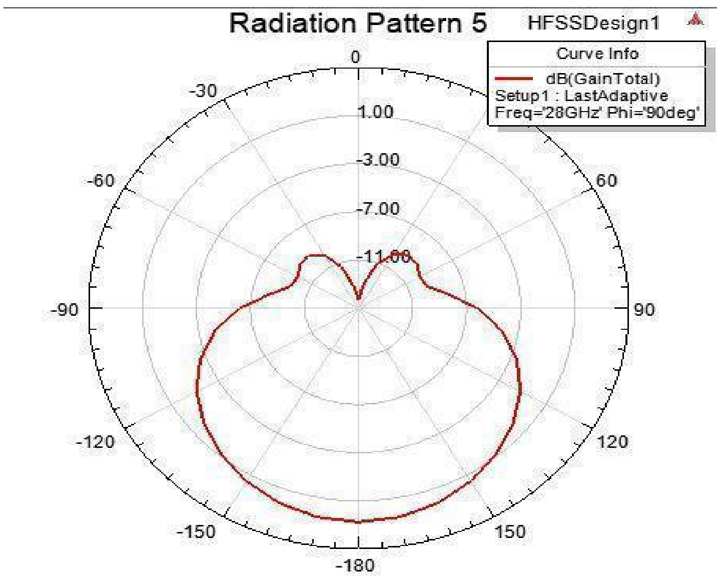


Fig3: Radiation pattern

Basically, we prefer to draw our attention to 2 factors, field and power pattern when it comes to antenna radiation patterns. A field pattern represents a plot of the amplitude of the electrical or magnetic flux which is a function of the angular space while an influence pattern refers to a plot of the square of the amplitude of the electrical or magnetic flux which is defined as a function of the angular space. Normally power is represented in patterns in decibels (dB) because it can consist of even the parts of the pattern. When it involves antenna radiation patterns we regularly categorize the individual parts as lobes. At the same time within those lobes there are subclasses like side lobes, back lobes, major lobes and minor lobes.

Major lobes can be defined as the radiation lobe which consists of the direction of highest radiation and it's the lobe pointing within the $\theta=0$ direction or z axis. In the other hand. Every lobe except the main lobe is a minor lobe, while a side lobe can be a radiation lobe that is not in the direction of the desired lobe, and inevitably a back lobe that is 180 out of phase with the direction of the antenna beam.

Small lobes in unfavourable directions are known as indicators of radiation and side lobes are the largest of them, and should be reduced. Side Lobes are smaller than -20dB are not normally required for various applications.

Finally, we've null beam width and the half-power beam width (HPBW). HPBW is defined as the angular separation during which the magnitude of the pattern decreases by 50% (or -3 dB) from the height of the beam. Null Beam width is stated intrinsically the angular separation from which the magnitude of the pattern decreases to zero (negative infinity dB) aloof from the most beam.

Field-Pattern

The distribution of radiated field strength around an antenna may be a function of both the antenna size itself and the angular co-ordinates. In plain terms it is the area of the electromagnetic field surrounding a transmitting antenna. Since it is important for us to be told about the design of an antenna, we would like to get familiar with the characteristics of the sphere regions surrounding the antenna first. This area has been divided into three regions: near-field sensitive, near-field radiative and lastly far-field. It's important to say the structure of the sphere within each of those regions. Nevertheless, it has been found that there are no distinctive changes in the transition from

one field to the next, rather it is instead undetectable and there are no characteristic changes between them.

Near-Field Region

Reactive

The closest region to the antenna is known as the near-field region which is reactive. Since it is in the immediate vicinity of the antenna, there is both a reactive and a radiative portion. But during this region the reactive field prevails as the intensity of the reactive component deteriorates very rapidly as we move further away from the antenna. This simply means that there is a phase difference of 90 degrees between the magnetic fields and electric fields. The boundary of this region is understood to be,

$$r < 0.62\sqrt{\frac{d^3}{\lambda}}$$

Where, r is the distance from the layer of the antenna; λ is known as the wavelength and d represents the largest dimension of the antenna. However, for radiators like short dipoles this boundary is expected to vary at $\lambda/2\pi$ distance from the surface of the antenna.

Radiative

The reactive component gave the impression to predominate within the previous region. But when we go past the boundaries of the reactive near-field region and enter the near-field radiative region it is the portion of radiation that begins to dominate and not much of the reactive portion. This area can be referred to as Fresnel. In this area, the angular field distribution differs by the distance from the surface of the antenna. In this area the pattern dramatically changes with distance. There is understanding of this area respectively,

$$0.62\sqrt{\frac{d^3}{\lambda}} < r < \frac{2d^2}{\lambda}$$

This measurement is predicated on a maximum phase error of $\pi/8$. A big thing to notice here is that if d, which is that the maximum dimension isn't substantial enough compared to the wavelength this region may perhaps not exist.

Far Field Region

Radiative

The most important of the three subdivisions is the far-field region, sometimes referred to as Fraunhofer region. This is because most antennas are used to communicate long distance, so far field region will be the best place to research, since this is where the most antennas work. This is the region farthest from the antenna, and the angular field distribution is essentially independent of the distance from the antenna only in this region. And the components in the field are basically transversal. While we switch away from the antenna the radiation pattern shape is not affected at all. The regions inner limit is given by,

$$r > \frac{2d^2}{\lambda}$$

This region's outer boundary stretches out to infinity. However, they are not insensitive to phase variance across their apertures for a few specific antennas, for example multi beam reflector antennas. The following internal boundary is not appropriate to them. The pattern nearest to the antenna is more uniform and extended, with little change. But as we advance into the region of Fresnel the pattern is seen to smooth and lobes form. And then finally the pattern becomes distinct in the Fraunhofer area, consisting of a broad lobe and few minor lobes.

4.2 Antenna Gain

Antenna gain is the most significant parameter. Antenna gain is assumed to be a measure of the amount of power transmitted by reference to an isotropic source within the range of the height radiation. For example, if we had a 4 dB gain transmitting antenna, the capacity obtained from the antenna is 4 dB higher compared to what we would see from the lossless isotropic antenna having the same amount of input power. Similarly, a receiving antenna with a 4 dB in an excessively broad direction means that, if compared to a lossless isotropic antenna, it will receive 4 dB more power. Antenna gain will be related to directivity (D) and antenna efficiency by the following,

$$G=\eta rad\ .D$$

Here,

G = Antenna Gain,

ηrad = Radiation efficiency

D = Antenna Directivity

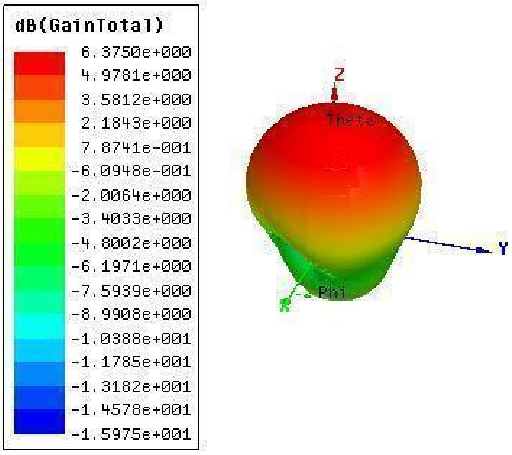


Fig4: Gain of single rectangular patch antenna

The gain on an antenna is commensurate with its electrical scale. An outsized platter antenna may have high gains (as high as 50 dB or more) as an example, but this would rarely be the case. Likewise, it may also be extremely small as in the case of short dipole antennas, but in principle it is not just 0dB, but it is likely that its peak will have a lower value due to low performance. Antenna gain also can be measured as a function of an angle which is technically a plot of the graph where the units are measured in antenna gain.

4.3 Antenna Directivity

Directivity is one of the antenna's opposite critical parameters, and is basically a calculation of the direction of its radiation signal. Directivity of an antenna is defined because the radiation intensity ratio in a very specific direction from the antenna to the radiation intensity was averaged in all directions where the normal radiation intensity is to the total radiated power from the antenna and it's separated by 4π respectively. It is assumed that where no direction is defined, direction of maximum radiation intensity is inferred. An antenna that radiates uniformly in all directions would essentially have virtually zero direction, and this type of antenna would have a directionality of 1 or 0 dB[16].

The expression for this description can be seen below,

$$D_r = \frac{U_r}{U_h} = \frac{4\pi U_r}{P_{rad}}$$

If path is not defined, we can take maximum radiation intensity as,

$$D_m = D_h = \frac{U_m}{U_h} = \frac{U_m}{U_h} = \frac{4\pi U_m}{P_r}$$

Here,

D_r = Directivity

D_h = Highest directivity

U_r = Radiation intensity

U_m = Highest intensity of radiation

U_h = Intensity of radiation from isotropic source

P_r = Complete radiated power

When it includes antennas with orthogonal polarization, it is possible to refer to the partial directivity of an antenna for a certain polarization in a certain direction as the portion of the radiation intensity directivity corresponding to a given polarization divided by the average total radiation intensity in all directions. Furthermore, for any two orthogonal polarizations, complete directivity can be defined as the sum of the partial directivities. If we conduct with spherical coordinates, the complete cumulative D0 can be denoted as, $D_r = \frac{4\pi U_r}{(P_r)_r + (P_r)_\varphi}$

$$D_\varphi = \frac{4\pi U_\varphi}{(P_r)_\theta + (P_r)_\varphi}$$

Here,

U_θ = Strength of radiation in the given direction included in the θ field

U_φ = Strength of radiation in the given direction included in the φ field

$(P_r)_\theta$ = power radiated in all directions contained in θ field

$(P_r)_\varphi$ = power radiated in all directions contained in φ field

The general equation for directivity and maximum directivity can be expressed as,

$$D(r,\varphi) = 4\pi \frac{f(r,\varphi)}{\int_0^{2\pi} \int_0^{\pi} f(r,\varphi)\, sin\, sin\, r dr d\varphi}$$

$$D_m = 4\pi \frac{f(r,\varphi)|_{maximum}}{\int_0^{2\pi} \int_0^{\pi} f(r,\varphi)\, sin\, sin\, r dr d\varphi}$$

4.4 S Parameters

S parameter is considered one of the main parameters which helps us to assess the antenna's overall efficiency. This parameter essentially specifies the input-output port relation in a device. For example, the power transmitted from channel 2 to 1 will be categorized by S12 in a two-port network, unsurprisingly called channel 1 and 2. S21 also reflects the power transmitted from port 1 to port 2. In comparison, S11 and S22 will be the reflected power that port 1 and port 2 attempt to transmit, respectively.

Similar to S12 or S21, S11 is the most common parameter when it comes to the subject of antennas. This simply means the sum of power which is basically expressed from the antenna. This can also be expressed using the Coefficient of Reflection, denoted by Return loss. This power loss that's returned may occur because of some reasonable discontinuity usually because of mismatch in conductor between two impedances. Return loss is normally expressed in dB(decibels) as shown below,

$$Rl_{dB} = 10\frac{P_l}{P_r}$$

Here P_i represents the incident power and P_r denotes the power which is reflected. In the same way the relation between return reduction and coefficient of reflection is given by the following,

$$\Gamma = \frac{Z_l - Z_s}{Z_l + Z_s}$$

$$Rl_{dB} = -10\, log\, log\, |\Gamma|^2 = -20\, log\, log\, |\Gamma|$$

Normally return loss is a negative value in decibels. A more detrimental loss in exchange means more loss. This means a good match for impedance, and less power is reflected back to source. With a return loss of 0 dB it is proposed that all the power was reflected back and that none was radiated by the antenna.

Whereas a return loss of -10 dB suggests that for the 3 dB incident power -7 dB which was reflected while the rest was either radiated or absorbed by the antenna. Yet, generally speaking, the capacity is radiated.

S-parameters for a given frequency and device impedance are usually specified, and differ as a function of frequency. And the bandwidth of an antenna can be estimated from its S-parameter.

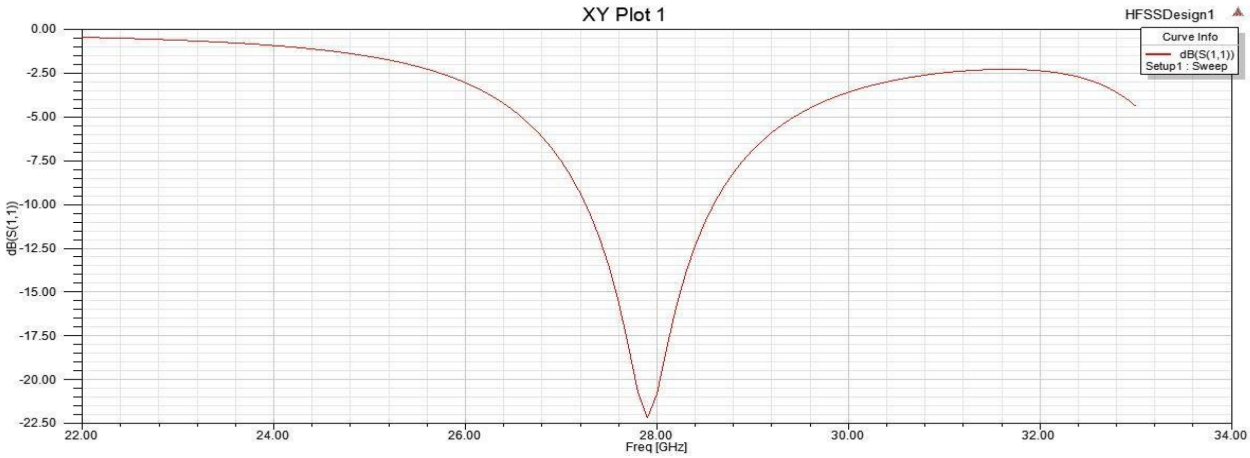


Fig5: S parameter of single rectangular patch antenna

4.5 Antenna Efficiency

Antenna efficiency can be expressed as the intensity of radiation which is another highly important parameter for antenna. It's defined as the power ratio the antenna provides to the power the antenna actually radiates to. A very high efficiency suggests that most of the incident power at the input of the antenna was effectively radiated. Whereas, a defective antenna indicates a major power loss. Such losses can be due to I2R (conductive and di-electrical) losses. The equation given below gives an antenna's radiation efficiency. This may also be transmitted in ratio, percentage, or even decibels, and is dependent on frequency. $\varepsilon_r = \frac{P_l}{P_i}$

$$\varepsilon_r = E_c E_d$$

Practically it is impossible for the antenna output to be 100%, but platter antennas, half-wavelength dipoles have almost no loss materials around them, so they come close to it. Nevertheless, the peak radiation efficiency in radiation is substantially different from the efficiency in radiation.

$$E_0 = E_r E_c E_d$$

Chapter 5

Antenna Design and Simulation Results

5.1 A Simple Rectangular Patch Antenna Design

Microstrip patch antennas are designed in HFSS software operating at 28GHz which uses substrates of gold, aluminium, copper and glass. Measurement for a simple 1X1 rectangular patch antenna is performed using the following formulas as in [8]. Similarly the array measurement was carried out for further simulation.

The dimensions used for rectangular patch antennas are:

1. The Patch Width,

$$W = \frac{C}{2f_o\sqrt{\frac{\varepsilon_o + 1}{2}}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..(1)$$

C= velocity of electromagnetic wave

f_o = operating frequency,

ε_o =dielectric constant of the substrate

2. Effective Length

$$L_{eff} = \frac{C}{2f_o\sqrt{\varepsilon_{eff}}} \dots\dots\dots\dots\dots\dots\dots\dots...(2)$$

3. Length of the Patch

$$L = L_{eff} - 2\Delta L \Delta L = 0.412h\left[\frac{(\varepsilon_{eff} + 0.8)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{h} + 0.8\right)}\right]$$

$$L = \frac{C}{2f_o\sqrt{\varepsilon_{eff}}} - 0.824h\left[\frac{(\varepsilon_{eff} + 0.8)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{h} + 0.8\right)}\right] \dots\dots\dots..(3)$$

4. Ground Plane dimensions

$$L_g = L + 6p$$

$$W_g = W + 6p$$

Here,

$$L_g = length\ of\ substrate$$

$$W_g = width\ of\ the\ substrate$$

Here p is given by,

$$p = \frac{0.0606\lambda}{\sqrt{\varepsilon_o}}$$

5. Effective Di-electric Constant

$$\varepsilon_{eff} = \frac{\varepsilon_o + 1}{2} + \frac{\varepsilon_o - 1}{2}\left[\frac{1}{\sqrt{1 + 12\left(\frac{h}{W}\right)}}\right] \dots\dots (4)$$

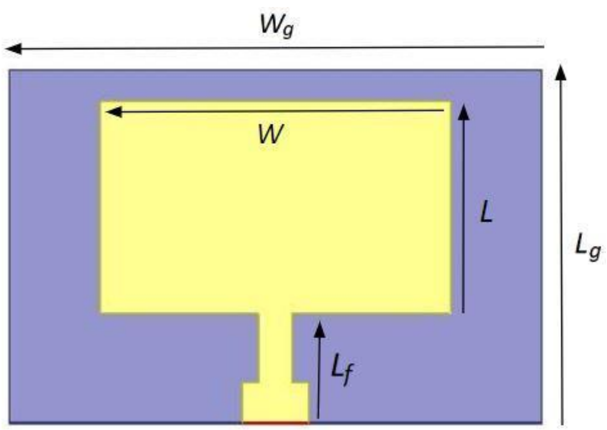


Fig6a: Design of 1X1 rectangular patch antenna

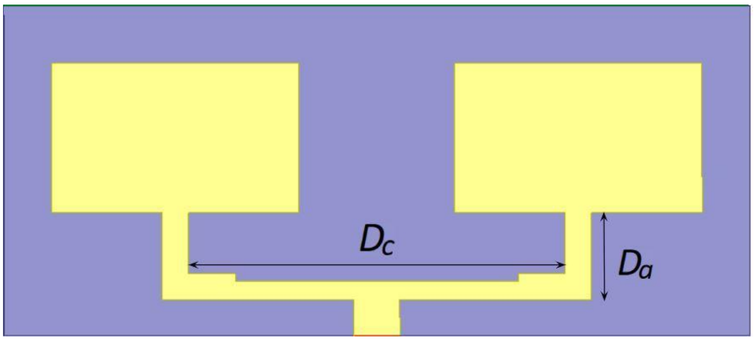


Fig6b: Design of 1x2 rectangular antenna array

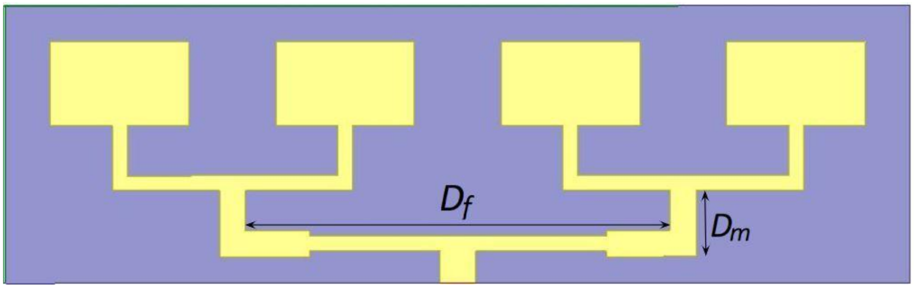


Fig6c: Design of 1x4 rectangular antenna array

Table II

Measurements of single rectangular patch

Parameters	Value in mm
Patch length, L	1.87
Patch width, W	3.10
Substrate length, L_s	3.11
Substrate width, W_s	4.70
Feed length, L_f	0.10
D_c	4.73
D_a	1.09
D_f	9.53
D_m	1.48

5.1.1 1x1 Rectangular Patch Antenna Simulation Results

In the HFSS simulation of a single rectangular patch antenna, Fig6a, using different transparent substrates, is shown. Glass substrate gives a higher gain of 6.2681 dB and 101% efficiency using equation 6 for a single element antenna.

5.1.1a Glass Substrate

The simulation results for rectangular patch antenna using Glass substrate are shown below:

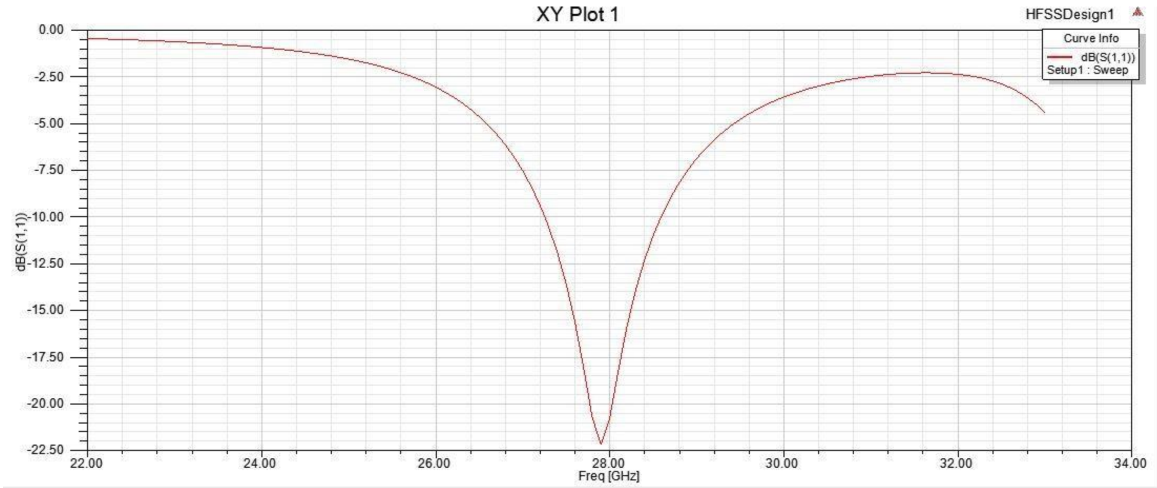


Fig 7a: S Parameter for 1x1 patch antenna

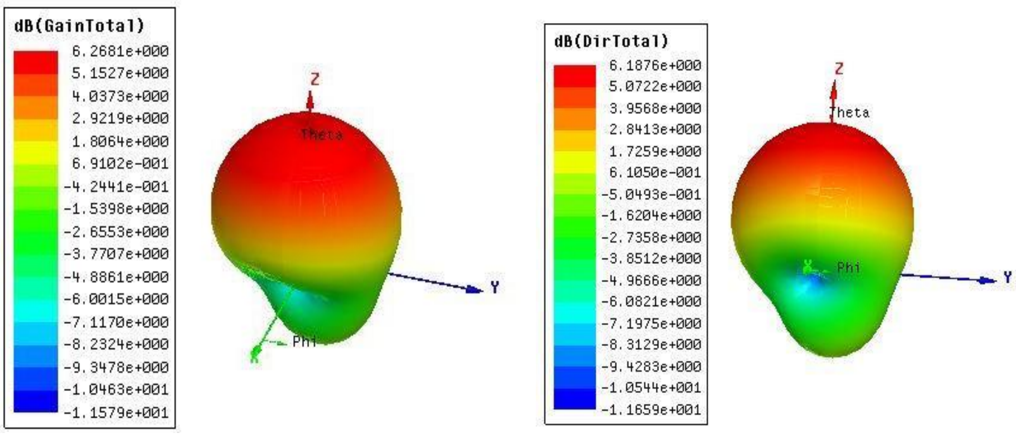
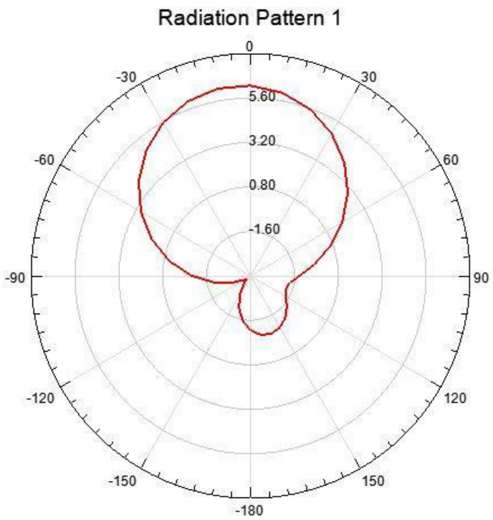


Fig 7b: Gain and Directivity for 1x1 rectangular patch antenna



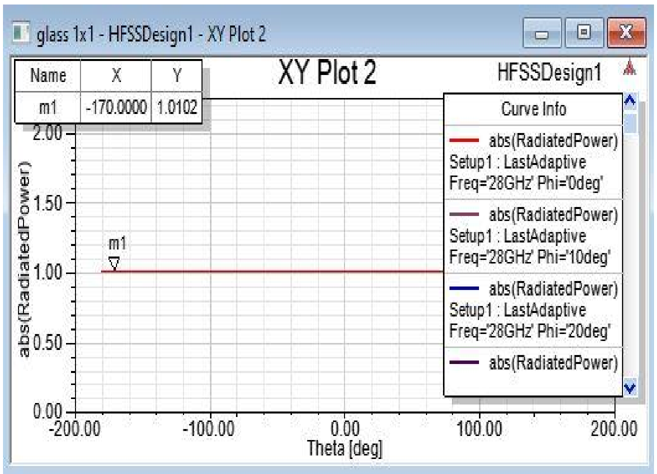


Fig7c. Radiation Pattern and Efficiency for 1x1 rectangular patch

5.1.1b Gold Substrate

The simulation results for 1x1 rectangular shaped element using gold substrate:

Fig 8a: S Parameter for 1x1 patch antenna

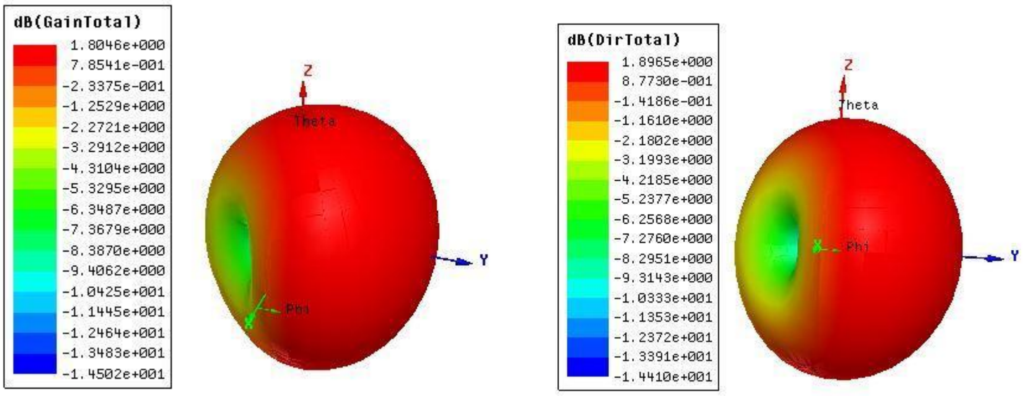


Fig 8b: Gain and Directivity for 1x1 rectangular patch antenna

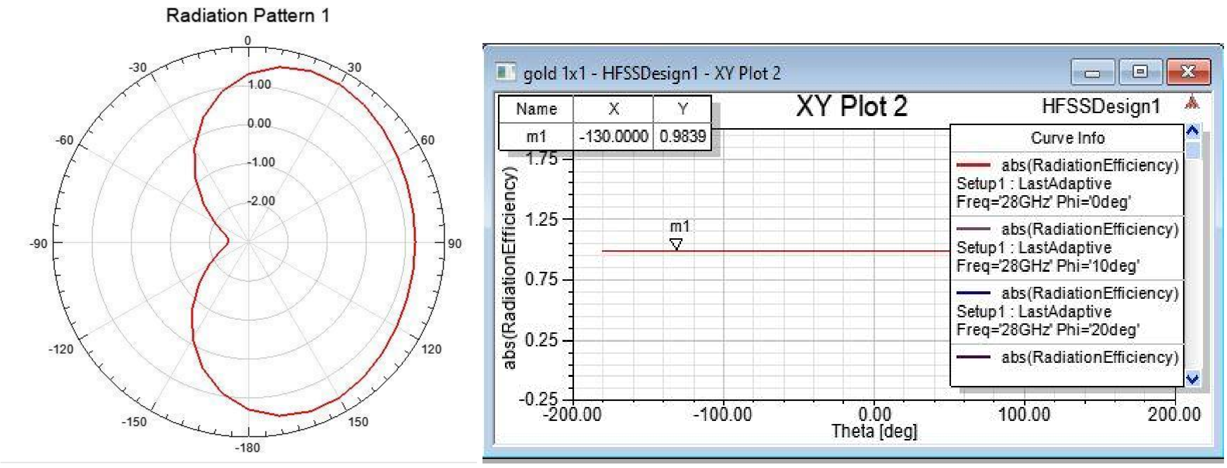


Fig8c: Radiation pattern and Efficiency for 1x1 rectangular patch antenna

5.1.1c Copper Substrate

The simulation results for 1x1 rectangular shaped element using copper substrate:

Fig 9a: S Parameter for 1x1 rectangular patch antenna

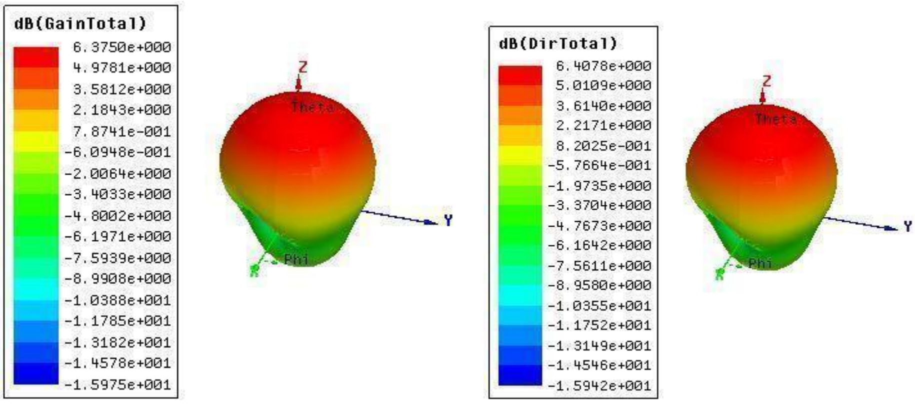


Fig 9b: Directivity and Gain for 1x1 rectangular patch antenna

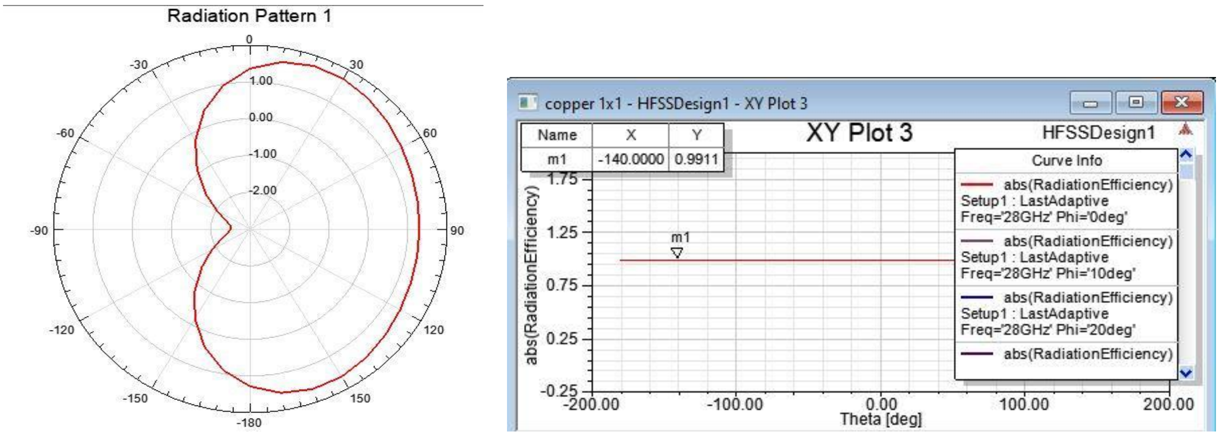


Fig 9c: Radiation Pattern and Efficiency for 1x1 rectangular patch antenna

5.1.1d Aluminium Substrate

The simulation results for 1x1 rectangular shaped element using aluminium substrate:

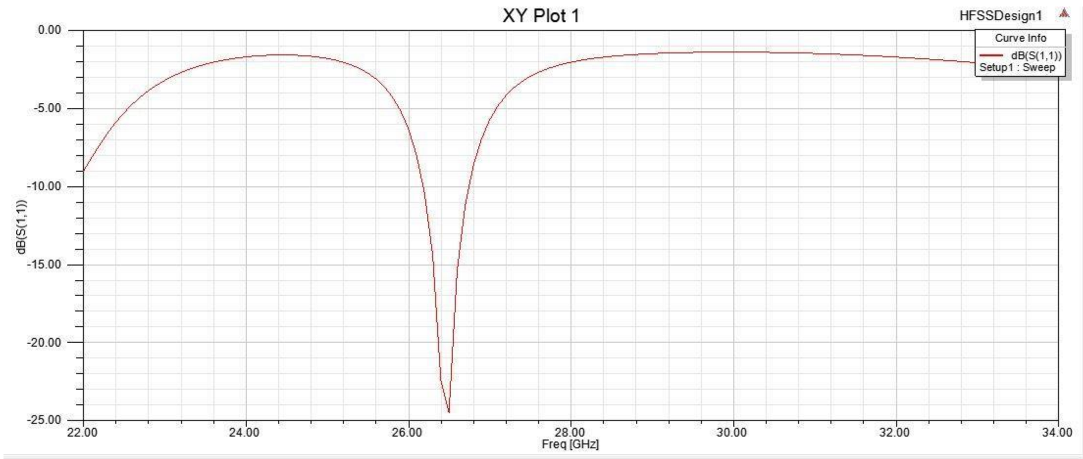


Fig 10a: S Parameter for 1x1 rectangular patch antenna

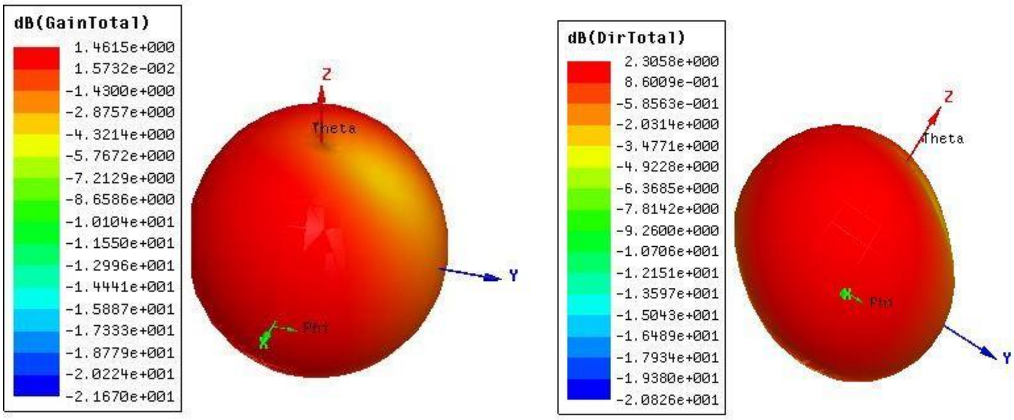


Fig 10b: Gain and Directivity for 1x1 rectangular patch antenna

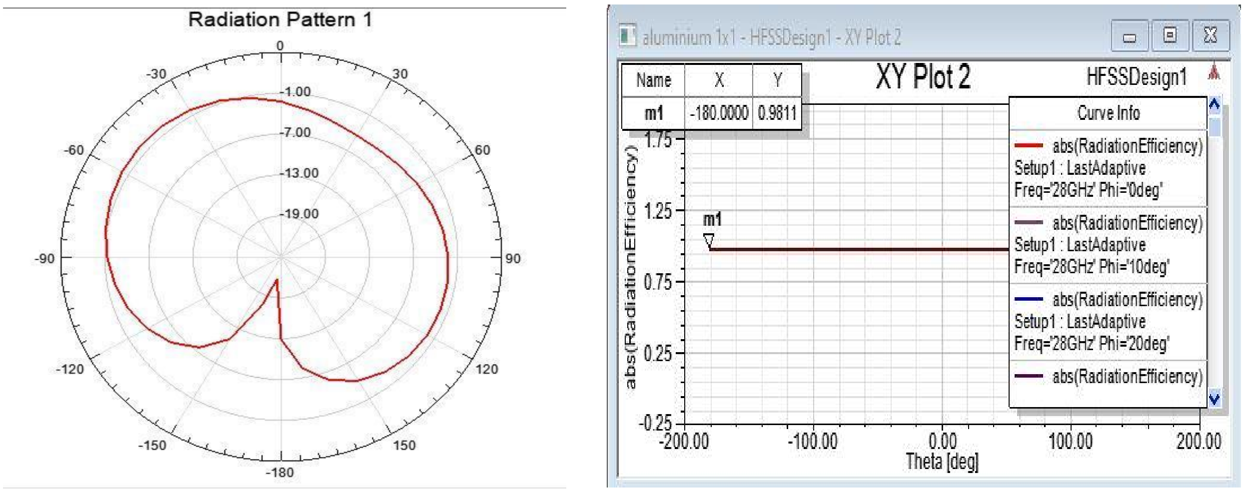


Fig 10c: Radiation Pattern and Efficiency for 1x1 rectangular patch antenna

5.1.2 1x2 Rectangular Patch Antenna Array Simulation Results

Phased Array emphasises on improved performance than a single element. We simulate a 1X2 circular antenna array as shown in Fig 6b, which arises in a slightly smaller gain compared to our single element antenna. Here we can see that copper gives a higher gain of 4.6328dB and an efficiency of 100.8% whereas for 1x1 glass substrate is observed to have high gain.

5.1.2a Glass Substrate

The simulation results for 1x2 rectangular shaped array antenna using glass substrate:

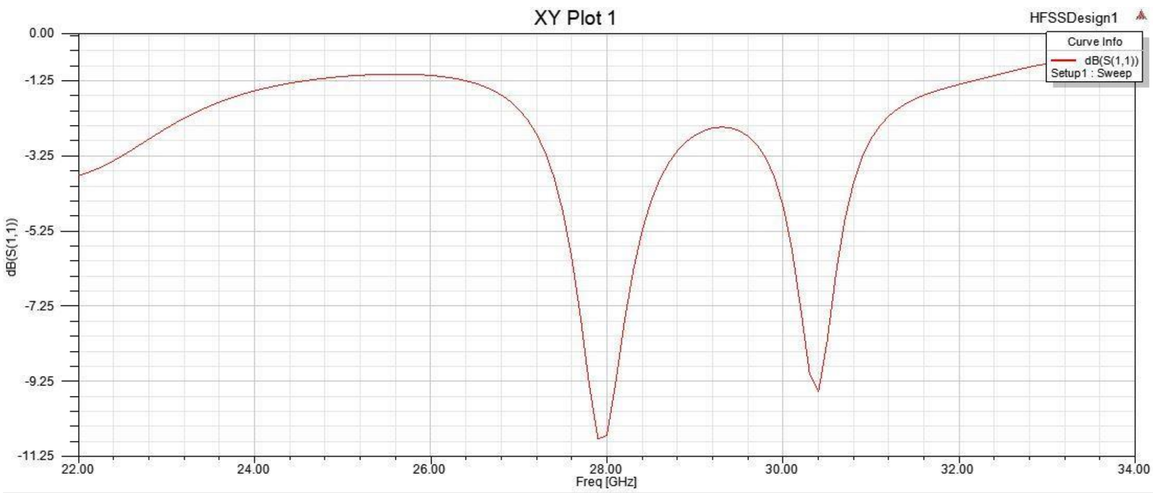


Fig 11a: S Parameter for 1x2 rectangular patch antenna

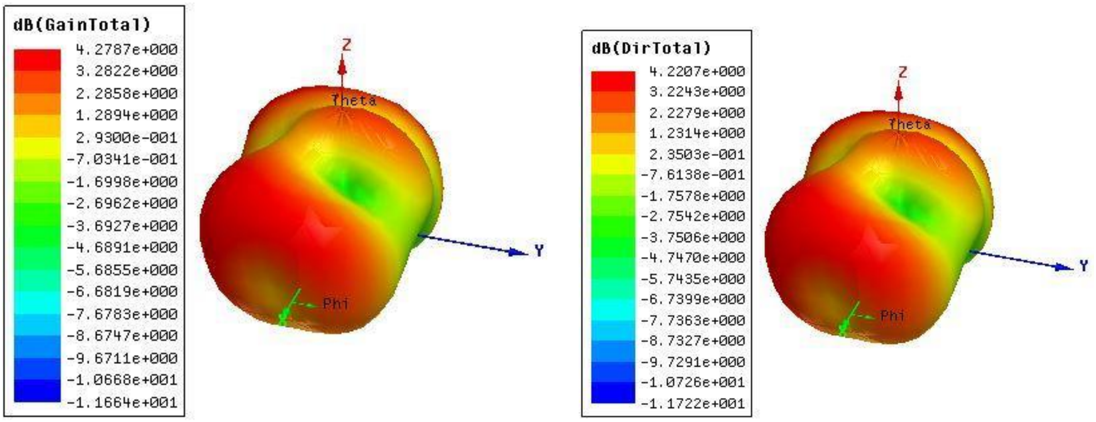


Fig 11b: Gain and Directivity for 1x2 rectangular patch antenna

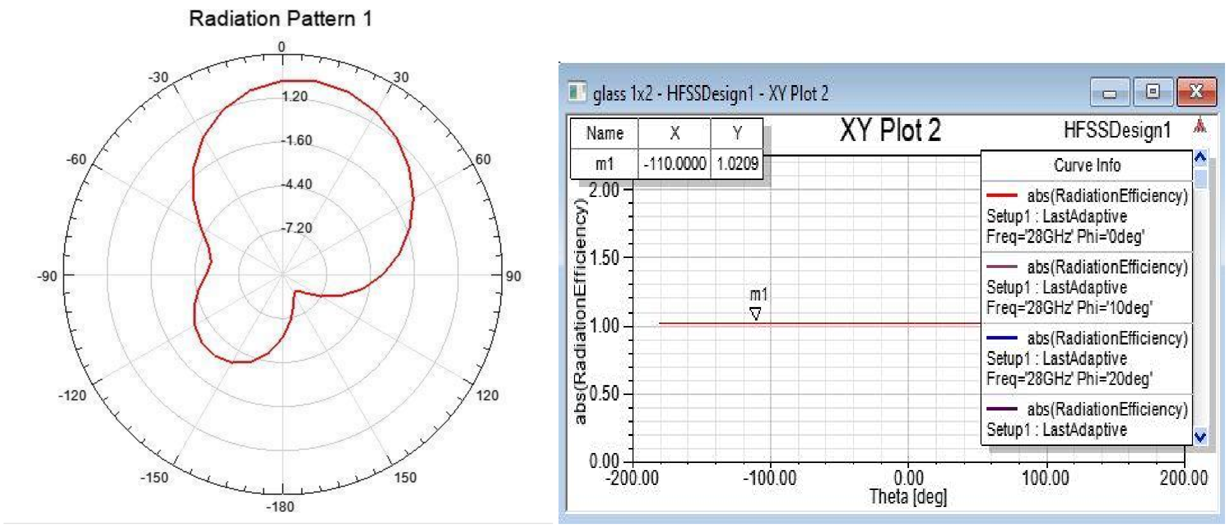


Fig 11c: Radiation Pattern and Efficiency for 1x2 rectangular patch antenna

5.1.2b Gold Substrate

The simulation results for 1x2 rectangular shaped array antenna using gold substrate:

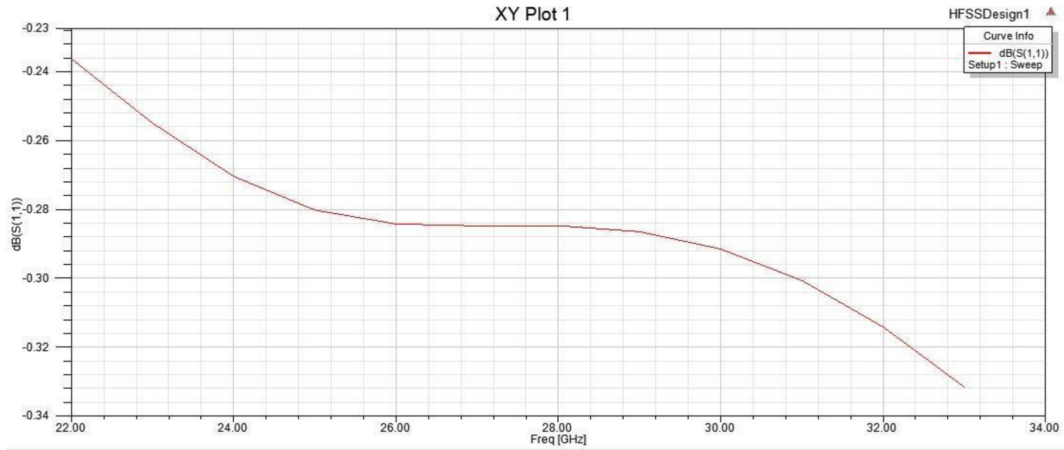


Fig 12a: S Parameter for 1x2 rectangular patch antenna

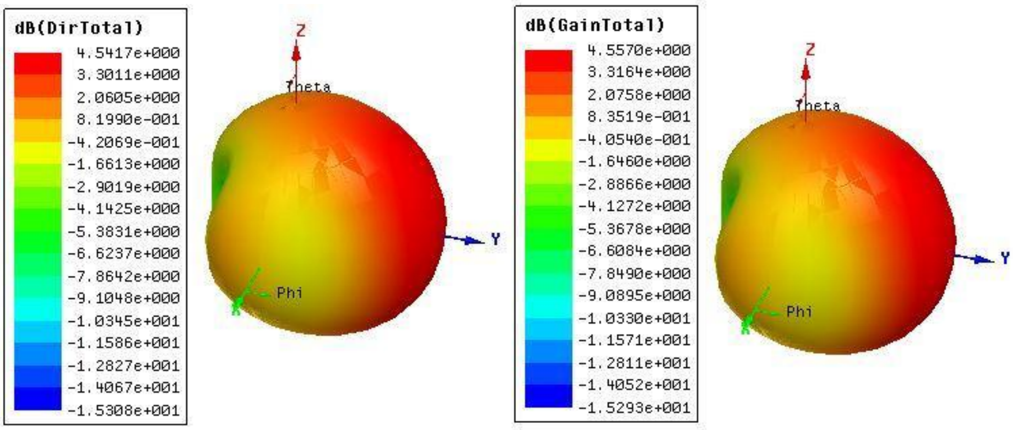


Fig 12b: Directivity and Gain for 1x2 rectangular patch antenna

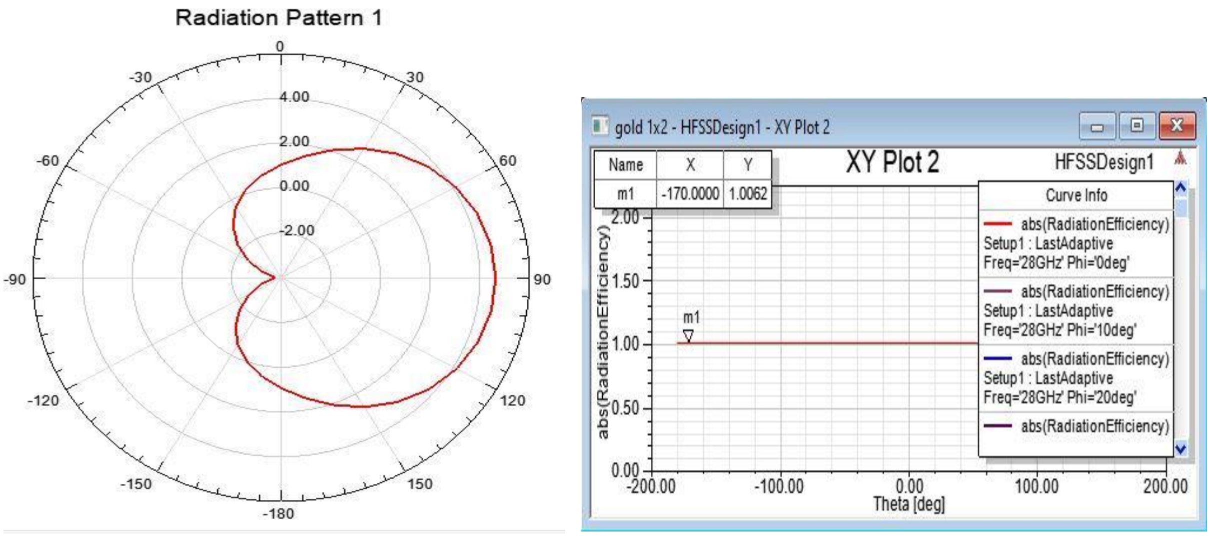


Fig 12c: Radiation Pattern and Efficiency for 1x2 rectangular patch antenna

5.1.2c Copper Substrate

The simulation results for 1x2 rectangular shaped array antenna using copper substrate:

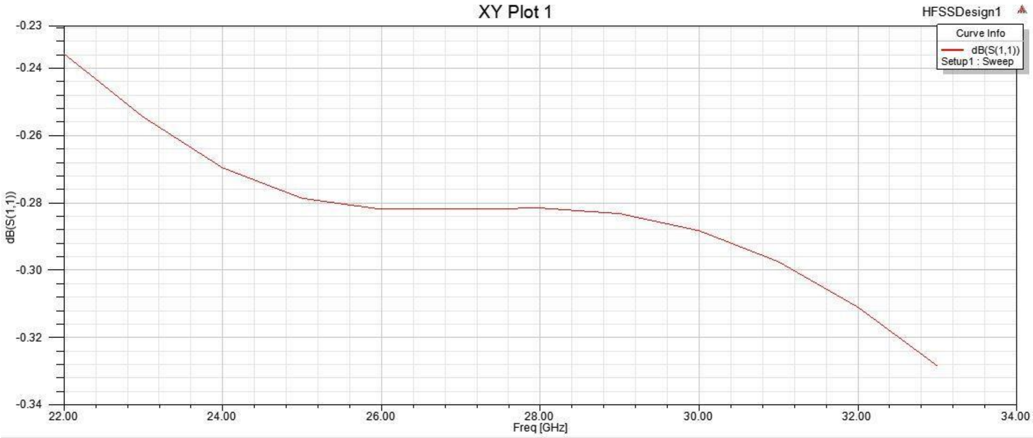


Fig 13a: S Parameter for 1x2 rectangular patch antenna

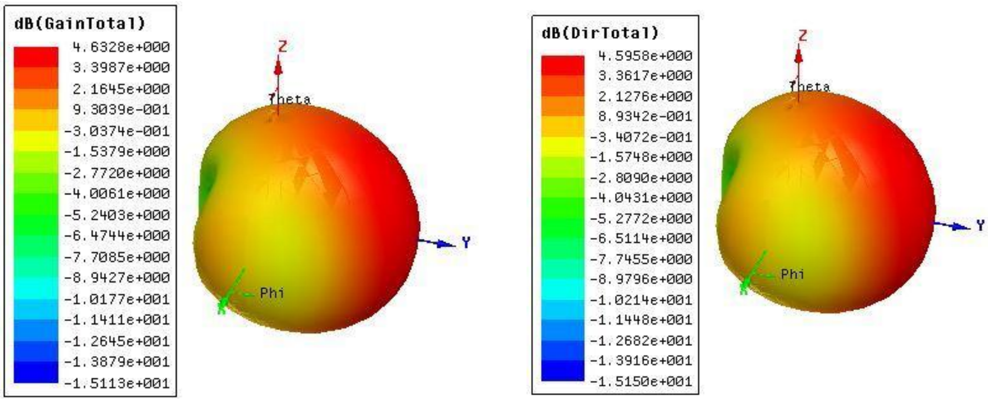


Fig 13b: Gain and Directivity for 1x2 rectangular patch antenna

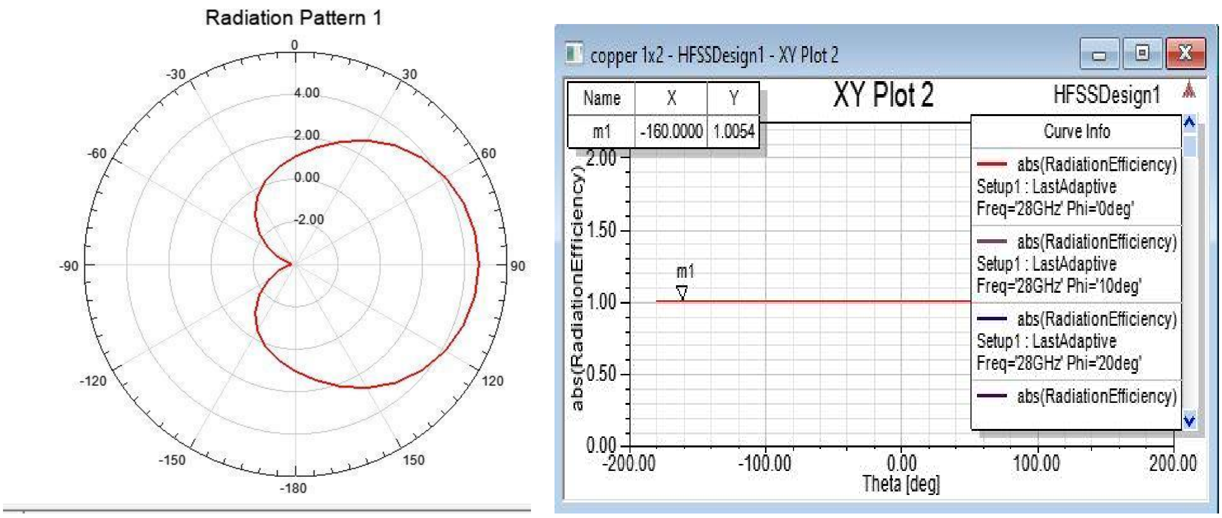


Fig 13c: Radiation Pattern and Efficiency for 1x2 rectangular patch antenna

5.1.2d Aluminium Substrate

The simulation results for 1x2 rectangular shaped array antenna using aluminium substrate:

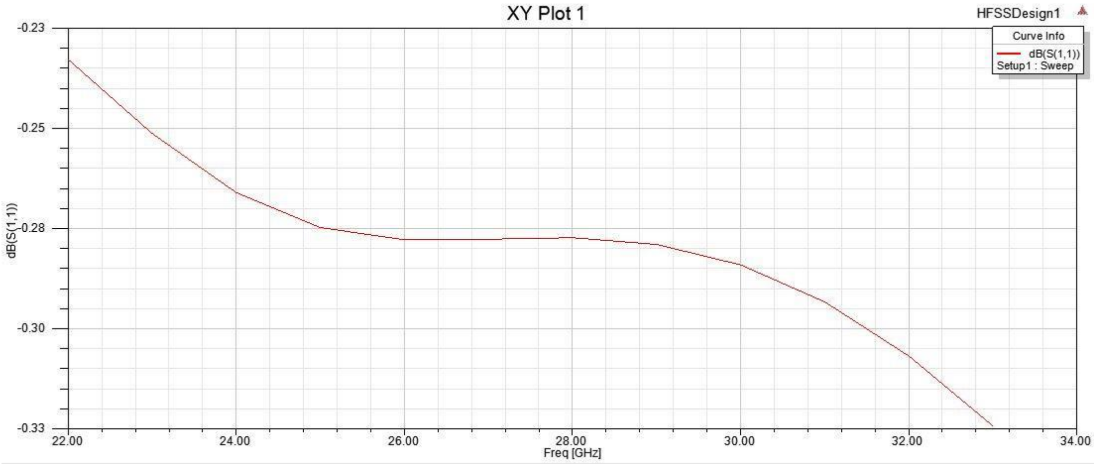


Fig 14a: S Parameter for 1x2 rectangular patch antenna

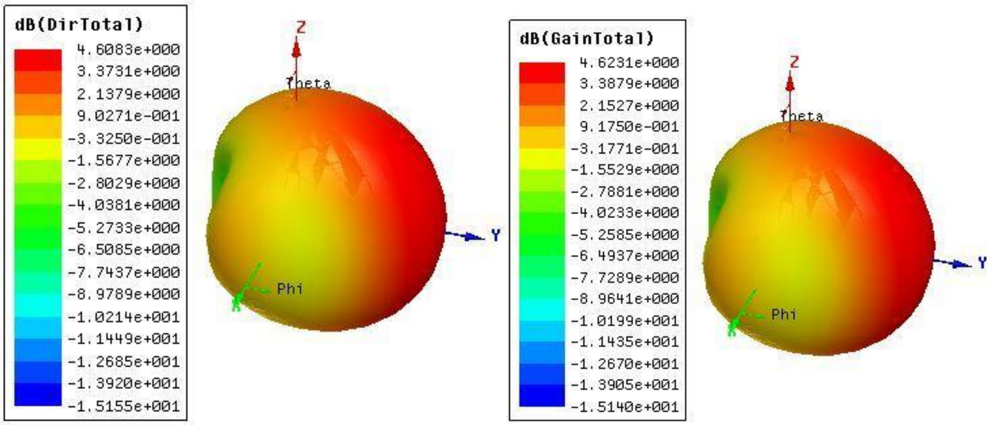


Fig 14b: Directivity and Gain for 1x2 rectangular patch antenna

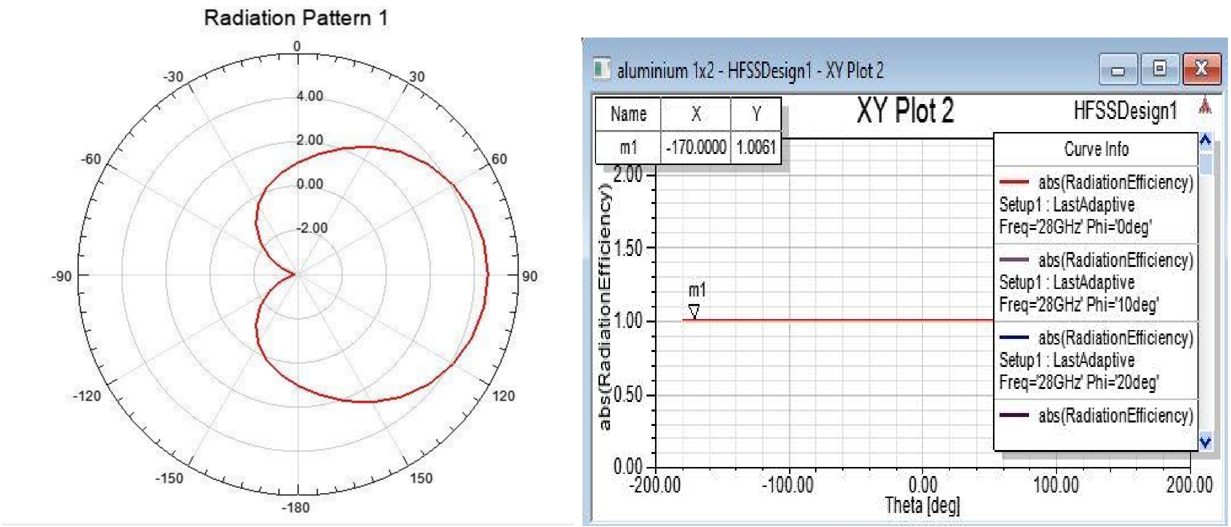


Fig 14c: Radiation Pattern and Efficiency for 1x2 rectangular patch antenna

5.1.3 1x4 Rectangular Patch Antenna Array simulation results

Fig 6c shows the design of 1X4 rectangular patch antenna array. Among all the designs we have done, we are getting the highest gain from 1 X 4 rectangular antenna using glass substrate (see Fig 15a), which is 7.2024dB and 101% efficiency (using equation 6).

5.1.3a Glass Substrate

The simulation results for 1x4 rectangular shaped array antenna using glass substrate:

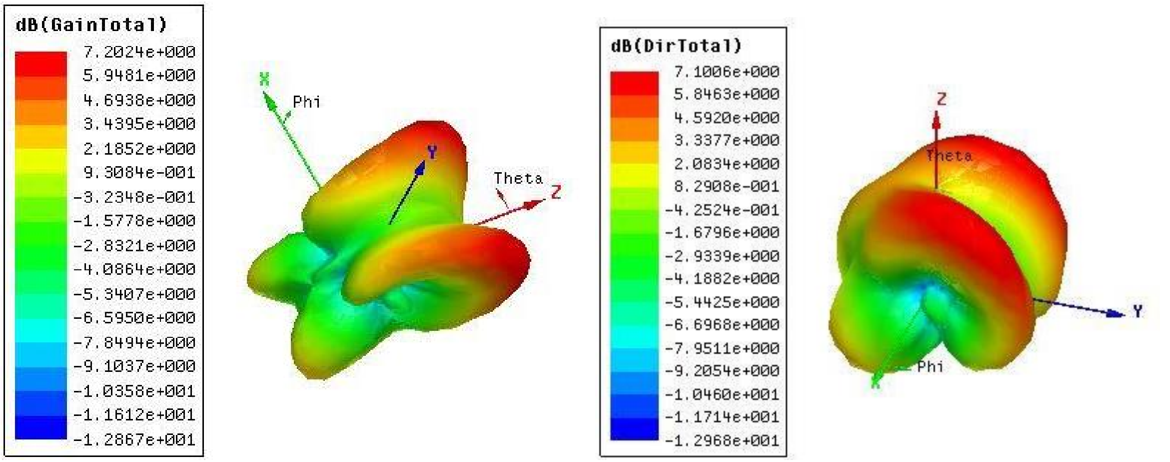


Fig 15a: Directivity and Gain for 1x4 rectangular patch antenna

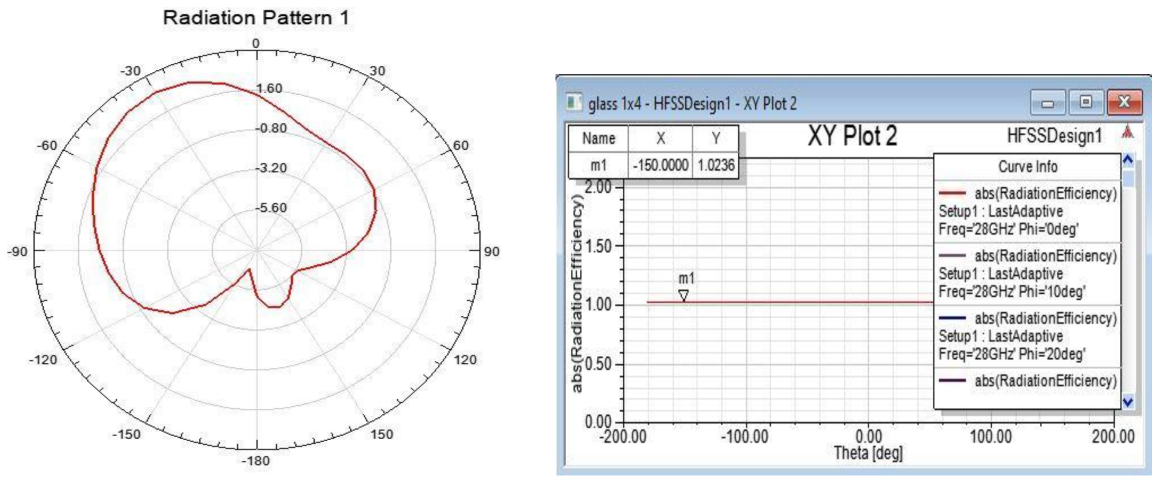


Fig 15b: Radiation Pattern and Efficiency for 1x4 rectangular patch antenna

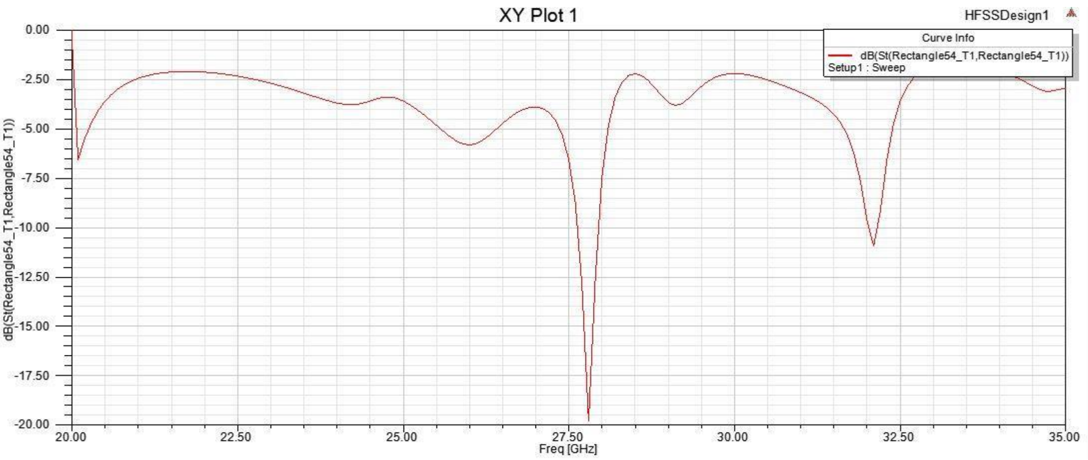


Fig 15d: S Parameter for 1x4 rectangular patch antenna

5.1.3b Gold Substrate

The simulation results for 1x4 rectangular shaped array antenna using gold substrate:

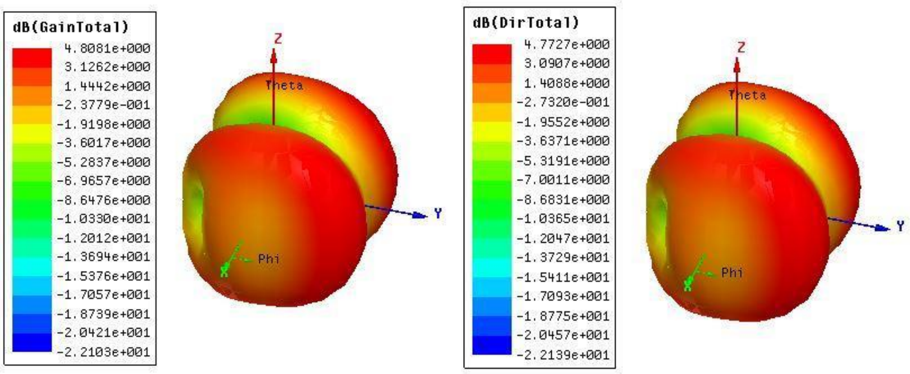


Fig 16a: Directivity and Gain for 1x4 rectangular patch antenna

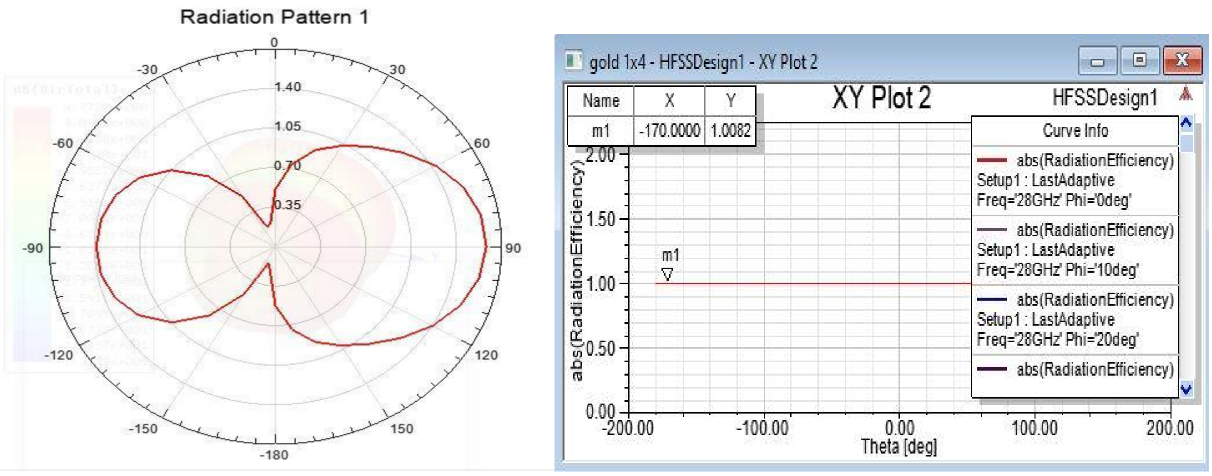


Fig 16c: Radiation Pattern and Efficiency for 1x4 rectangular patch antenna

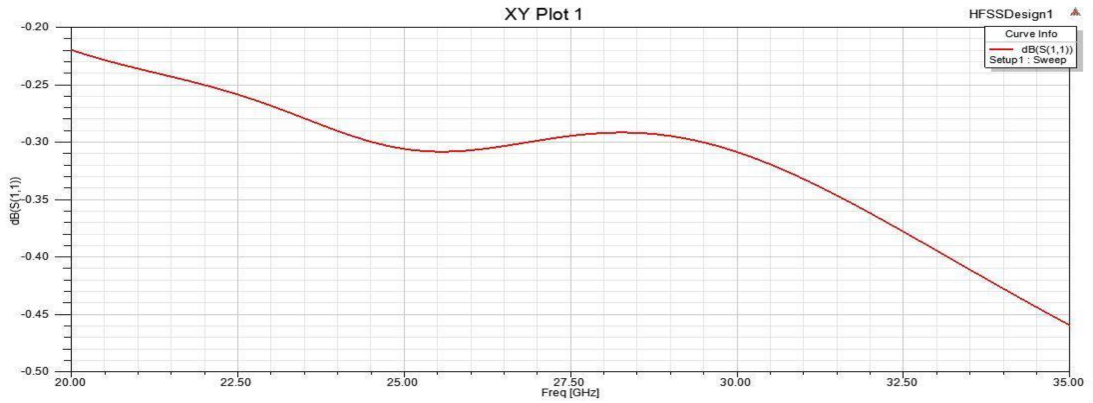


Fig 16d: S Parameter for 1x4 rectangular patch antenna

5.1.3c Copper Substrate

The simulation results for 1x4 rectangular shaped array antenna using copper substrate:

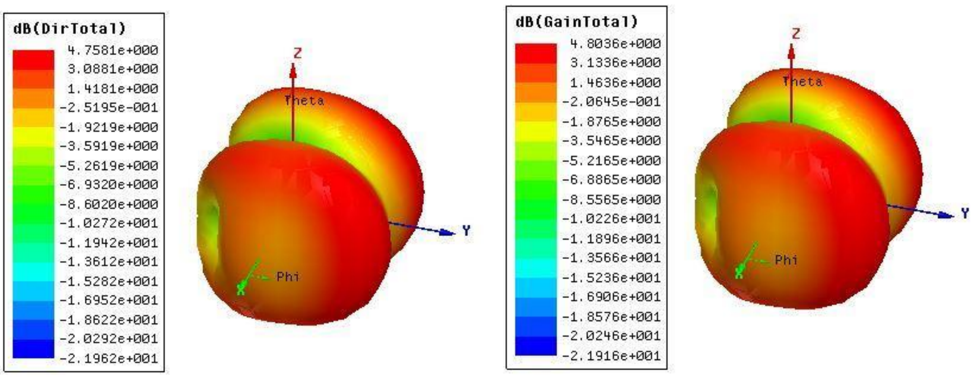


Fig 17a: Directivity and Gain for 1x4 rectangular patch antenna

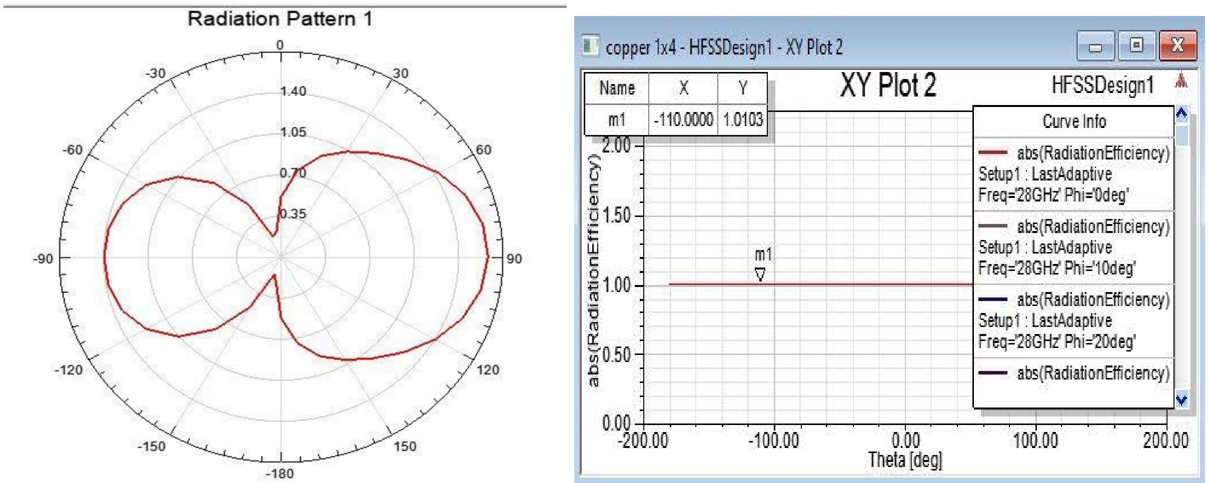


Fig 17b: Radiation Pattern and Efficiency for 1x4 rectangular patch antenna

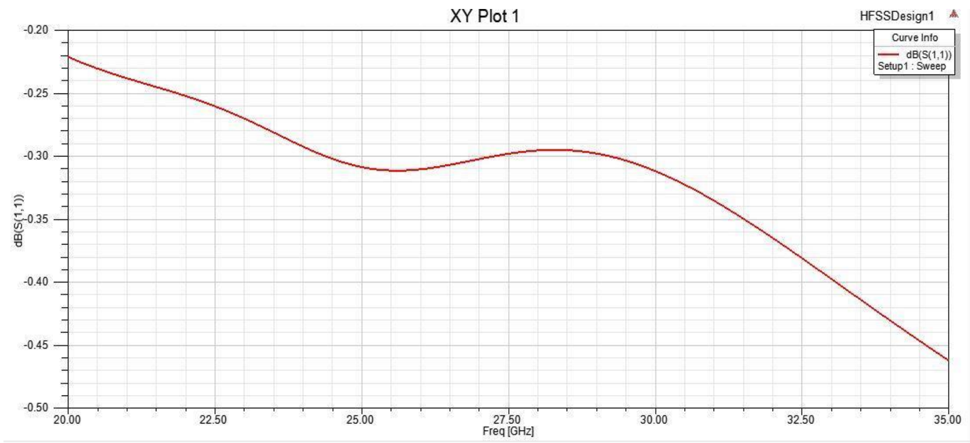


Fig 17c: S Parameter for 1x4 rectangular patch antenna

5.1.3d Aluminium Substrate

The simulation results for 1x4 rectangular shaped array antenna using aluminium substrate:

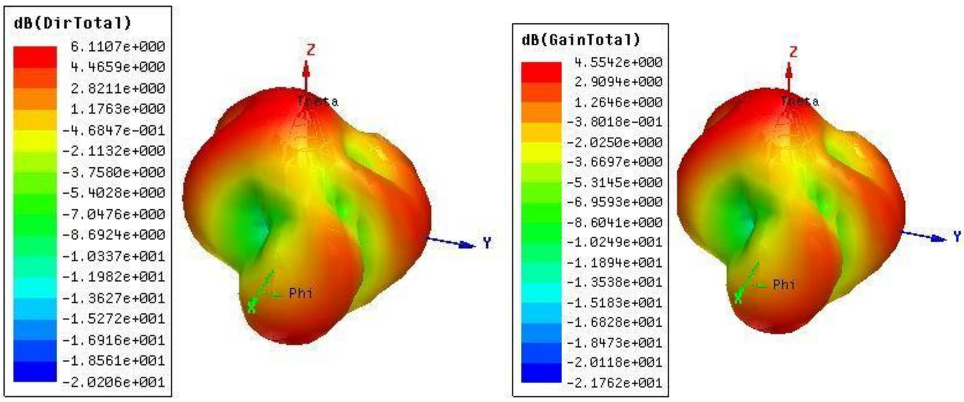


Fig 18a: Directivity and Gain for 1x4 rectangular patch antenna

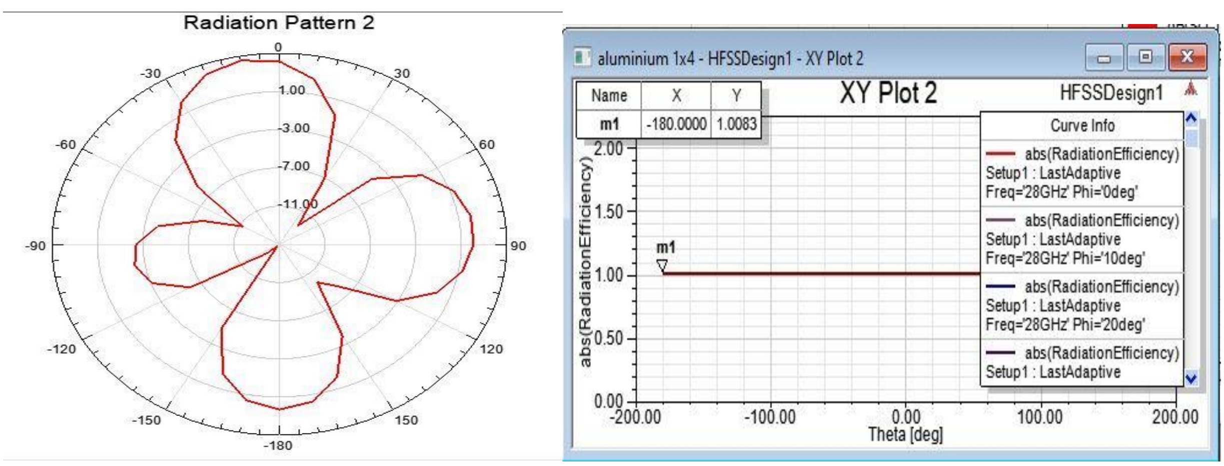


Fig 18b: Radiation Pattern and Efficiency for 1x4 rectangular patch antenna

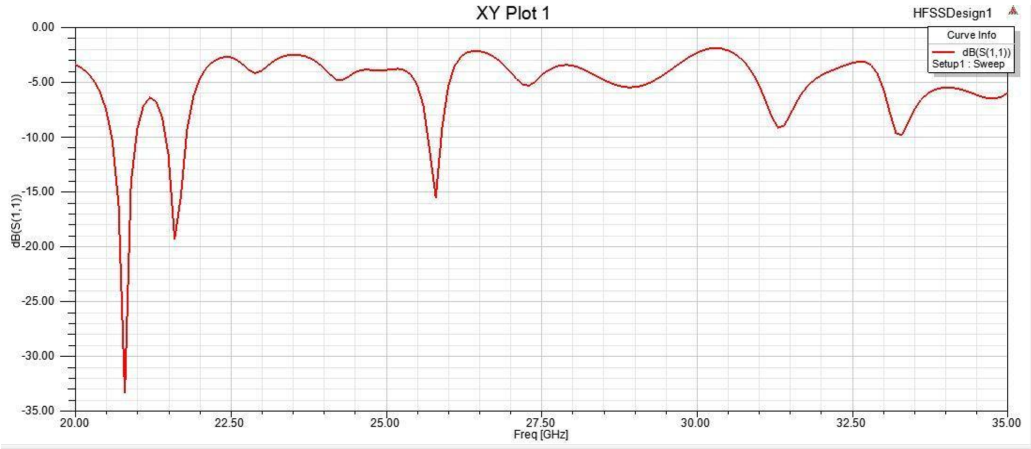


Fig 18c: S Parameter for 1x4 rectangular patch antenna

5.2 A Simple Circular Patch Antenna

We know that circular shape patch antennas are one of the most common shape antennas for mobile applications. Thus the dimensions used for single circular patch antennas are given below. Similarly the array antennas are performed.

$$a_e = \frac{K_{mn} * c}{2\pi f_r \sqrt{\varepsilon_o}} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots . (7)$$

$$a = a_e \left\{ 1 + \left(\frac{2h}{\pi a \varepsilon_o} \right) \left[ln\, ln \left(\frac{\pi a_e}{2h} \right) + 1.7726 \right] \right\}^{-\frac{1}{2}} \dots \dots \dots (8)$$

Where,

a_e = effective radius of the circular patch

a=radius of the circular patch antenna

$K_{mn} = 1.84118$

Using equation number (7) and (8) we got the radius of a single circular patch antenna which is a=1.34 mm. The design of this circular patch antenna is shown below:

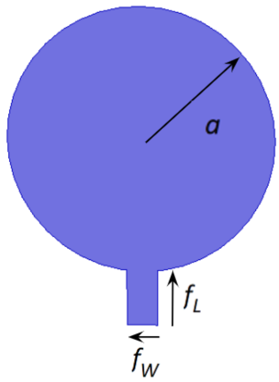


Fig 19a:Design of 1X1 circular patch antenna

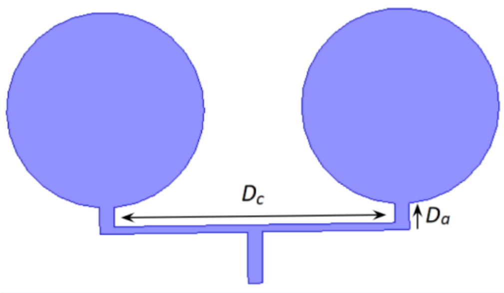


Fig. 19b: Design for 1x2 circular patch antenna

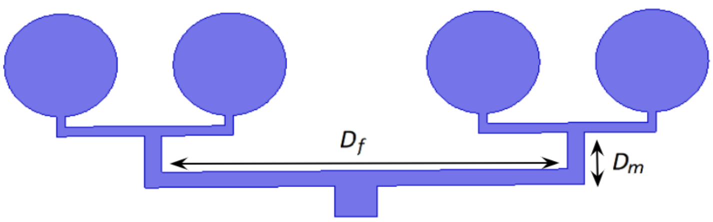


Fig.19c: Design for 1X4 circular patch antenna.

Table III

Measurements for single circular patch antenna

Parameters	Value in mm
Radius, a	1.34
Feed length, f_r	0.55
Feed width, f_w	0.30
D_c	3.80
D_a	0.37
D_f	9.60
D_m	1.35

5.2.1 1x1 Circular Patch Antenna simulation results

Simulating a single circular patch antenna shown in Fig19a using different transparent substrates . Glass substrate gives a higher gain of 4.6331dB and 99.63% efficiency using equation 6. The gain is moderate but the efficiency calculated is higher.

5.2.1a Glass Substrate

The simulation results for 1x1 circular shaped element using glass substrate:

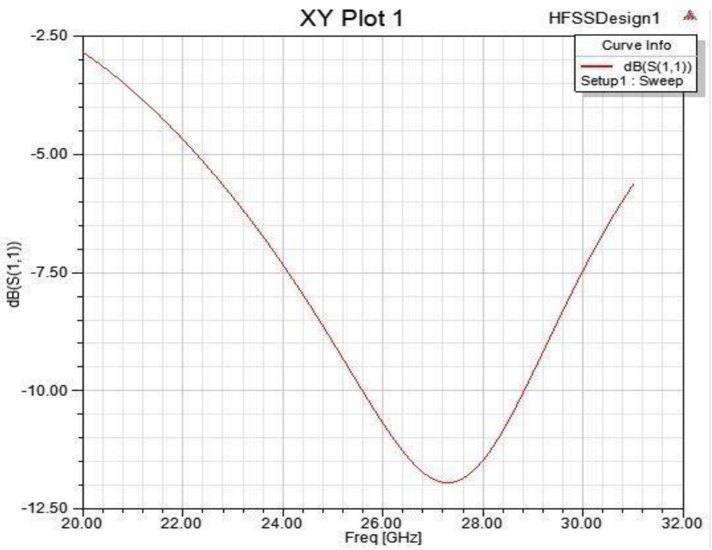


Fig 20a: S Parameter for 1x1 circular patch antenna

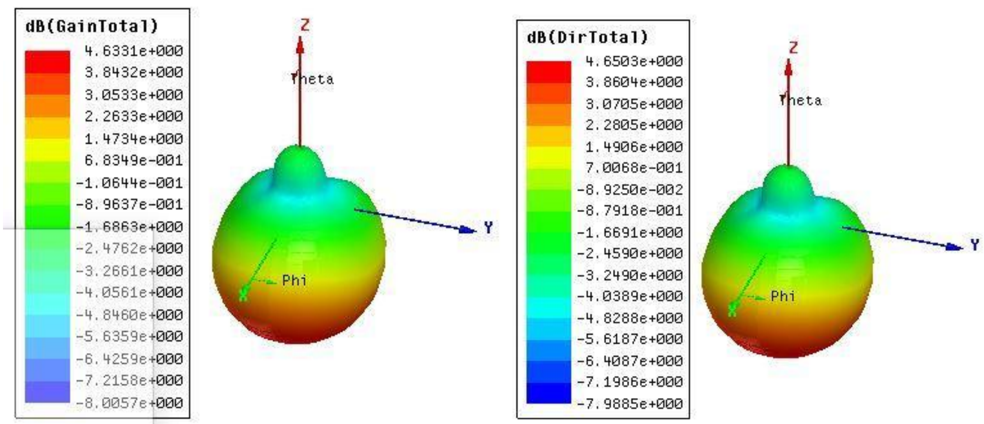


Fig 20b: Gain and Directivity for 1x1 circular patch antenna

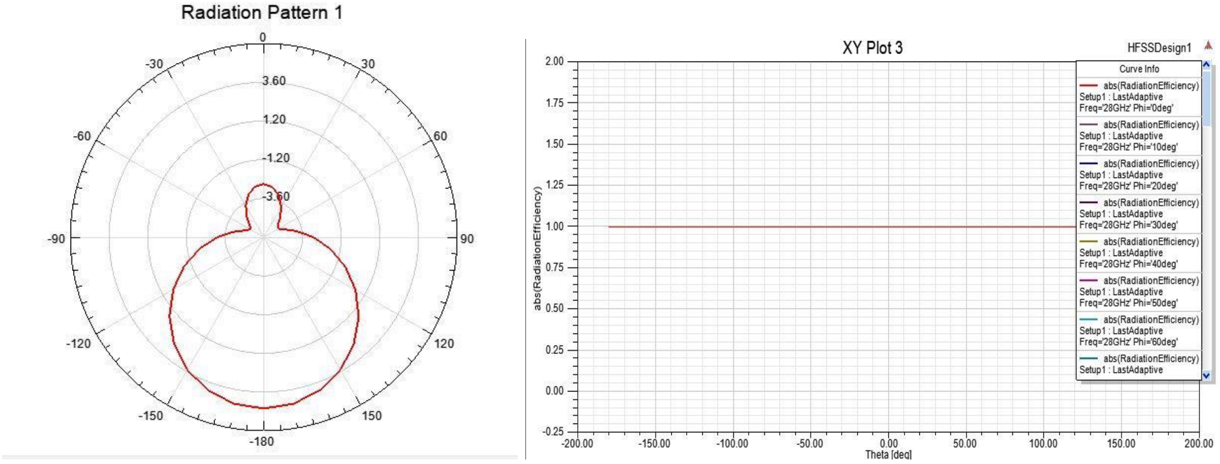


Fig 20c: Radiation Pattern and Efficiency for 1x1 circular patch antenna

5.2.1b Gold Substrate

The simulation results for 1x1 circular shaped element using gold substrate:

Fig 21a: S Parameter for 1x1 circular patch antenna

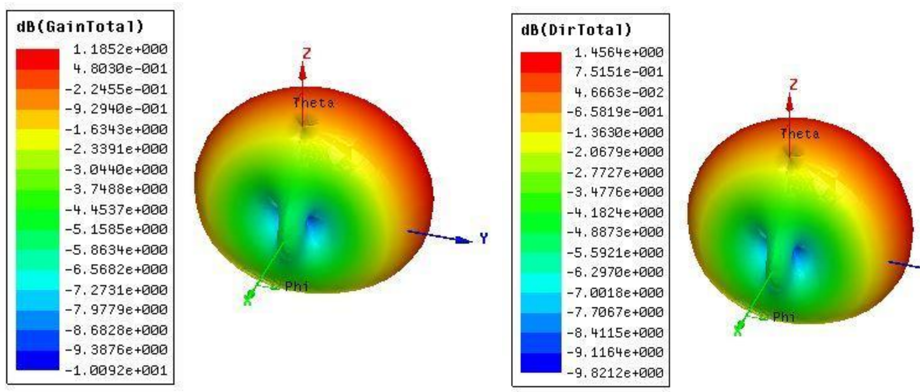


Fig 21b: Gain and directivity for 1x1 circular patch antenna

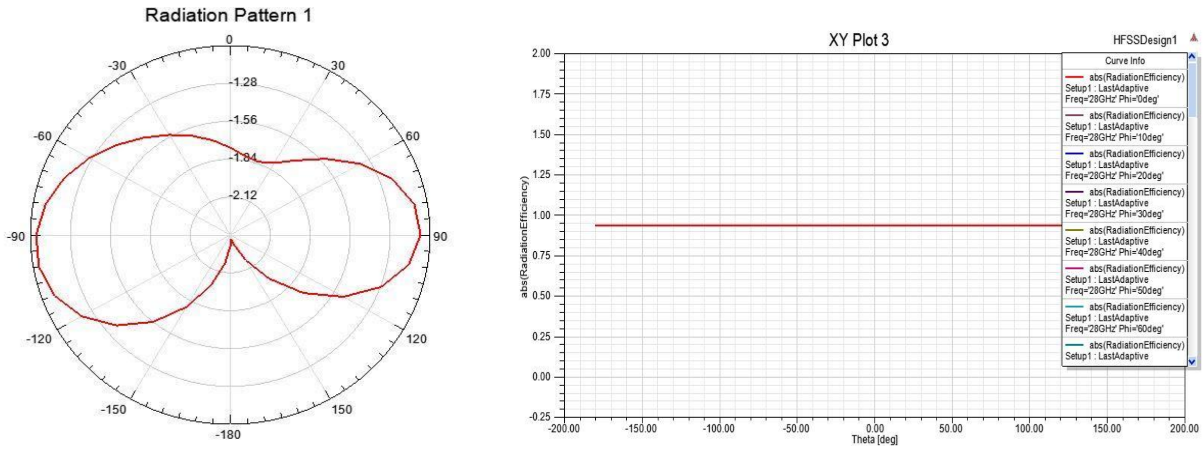


Fig 21c:Radiation Pattern and Efficiency for 1x1 circular patch antenna

5.2.1c Copper Substrate

The simulation results for 1x1 circular shaped element using copper substrate:

Fig 22a: **S Parameter for 1x1 circular patch antenna**

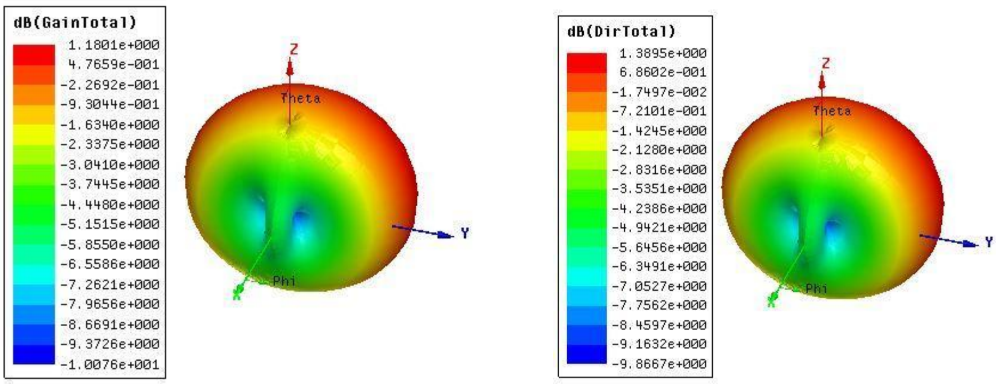


Fig 22b: Gain and Directivity for 1x1 circular patch antenna

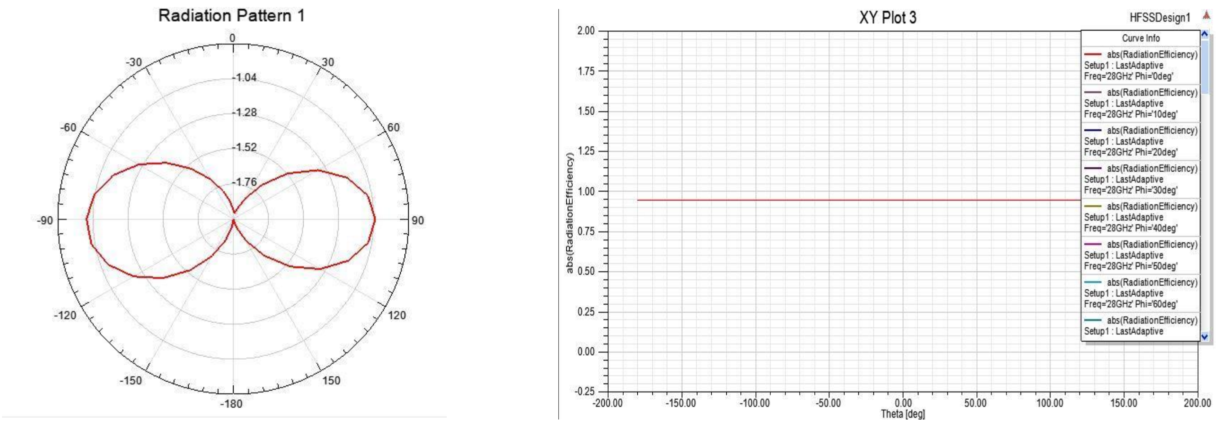


Fig 22c: Radiation Pattern and Efficiency for 1x1 circular patch antenna

5.2.1d Aluminium Substrate

The simulation results for 1x1 circular shaped element using aluminium substrate:

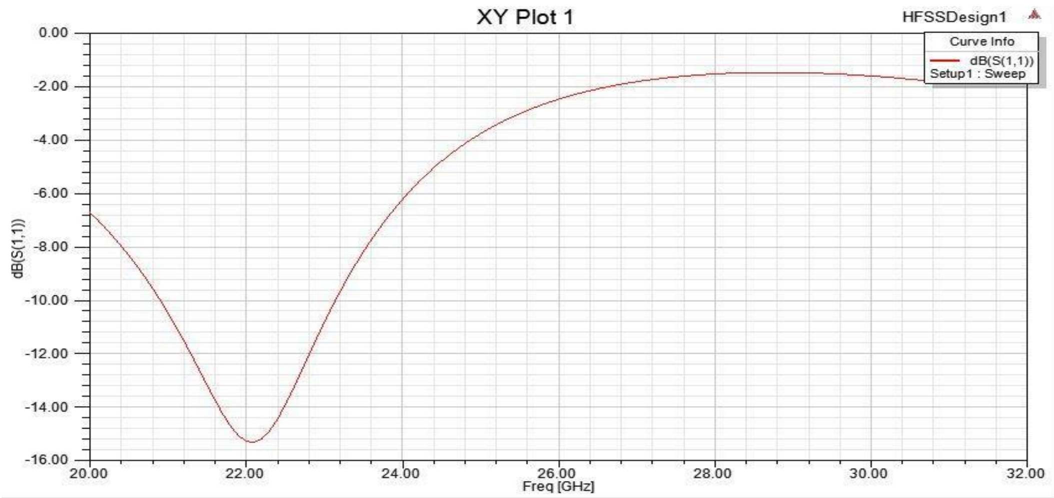


Fig 23a: S Parameter for 1x1 circular patch antenna

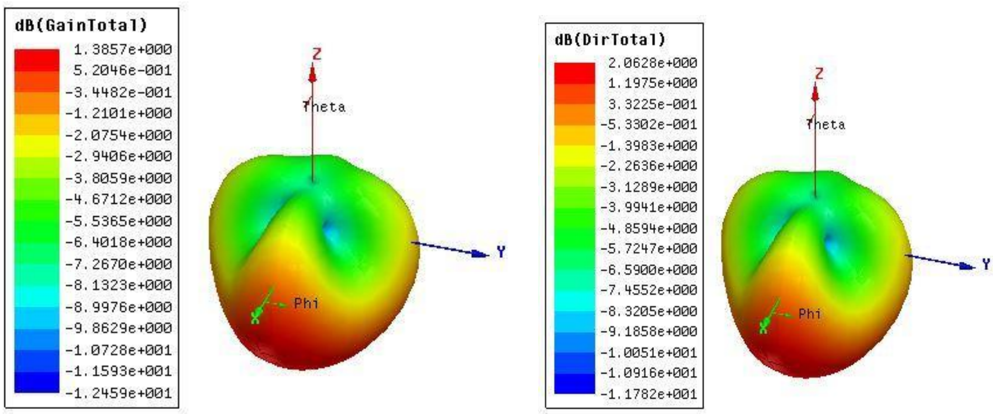


Fig 23b: Gain and Directivity for 1x1 circular patch antenna

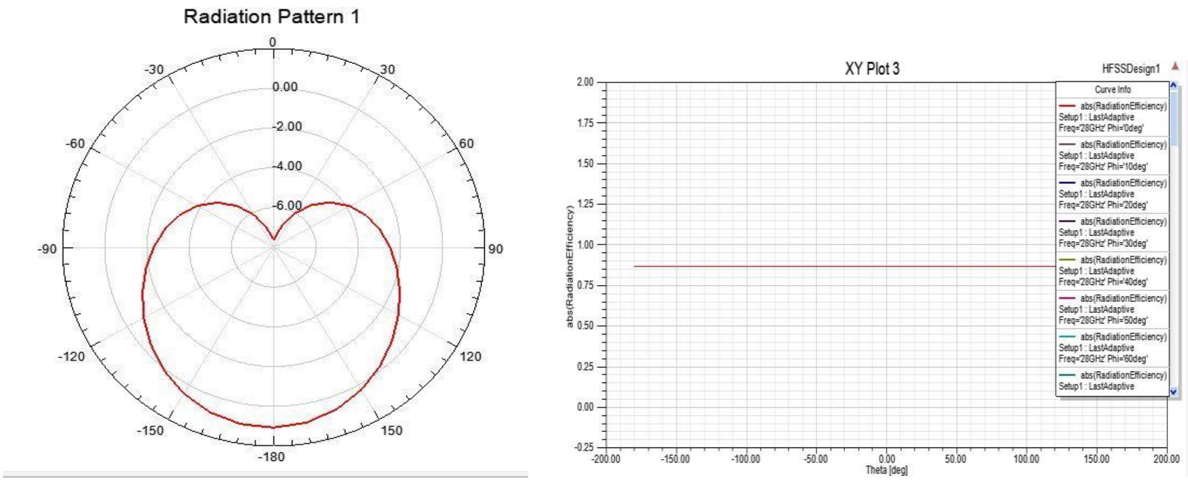


Fig23c: Radiation Pattern and Efficiency for 1x1 circular patch antenna

5.2.2 1x2 Circular Patch Antenna Array simulation results

As our emphasis is on higher gain and the antenna array often gives higher gain than a single element, we simulate a 1X2 circular antenna as shown in Fig 19b, which arises in a slightly higher gain and a lower efficiency performance compared to our single element antenna. Here we can see that glass gives a higher gain of 3.4515dB and an efficiency of 99.17%.(using equation 6)

5.2.2a Glass Substrate

The simulation results for 1x2 circular shaped array antenna using glass substrate is:

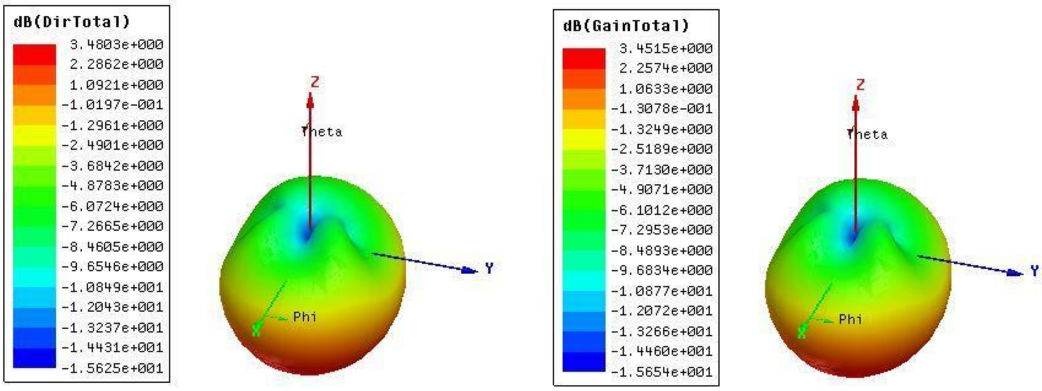


Fig 24a: Directivity and Gain for 1x2 circular antenna

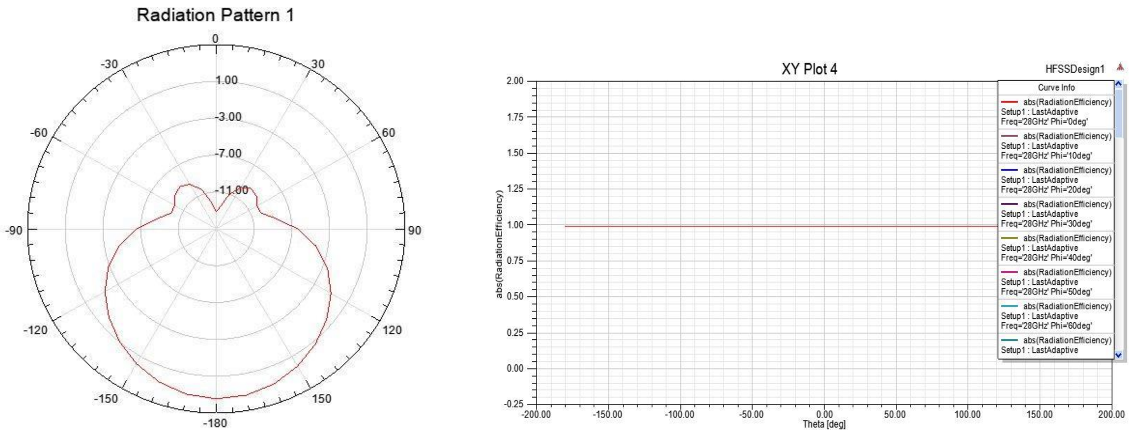


Fig 24b: Radiation pattern and Efficiency for 1x2 circular patch antenna

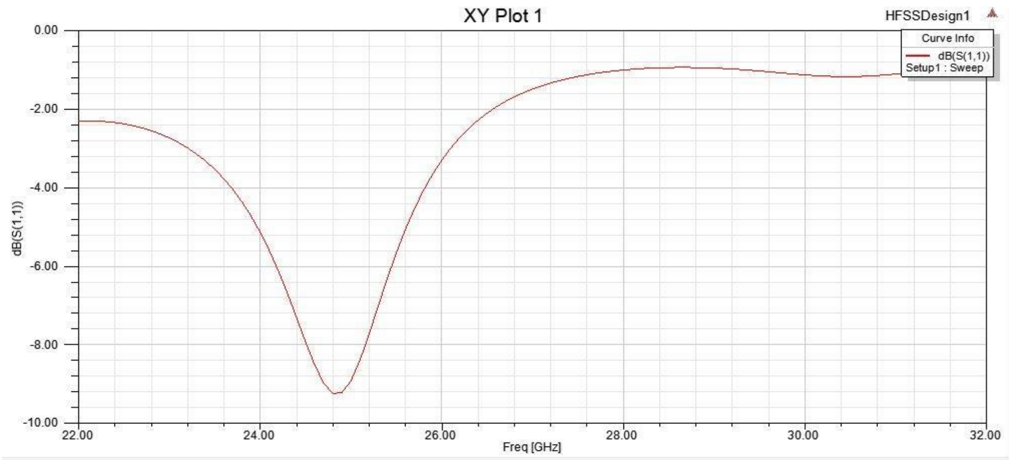


Fig: 24c S-Parameter for 1x2 circular patch antenna

5.2.2b Gold Substrate

The simulation results for 1x2 circular shaped array antenna using gold substrate:

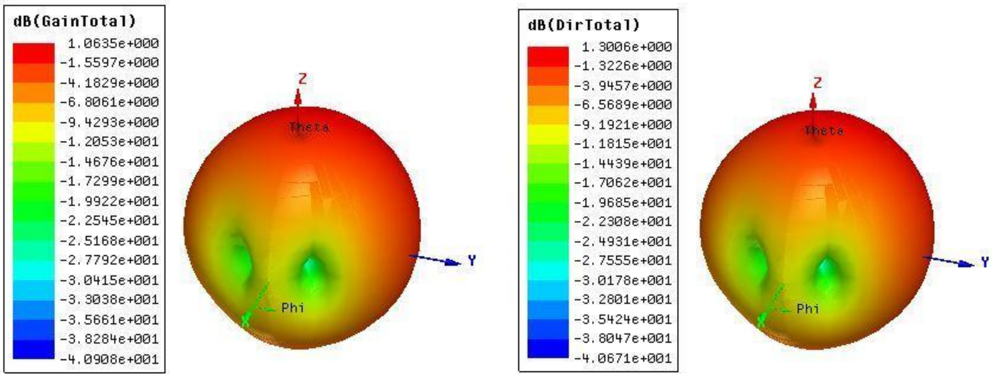


Fig 25a: Gain and directivity for 1x2 circular antenna

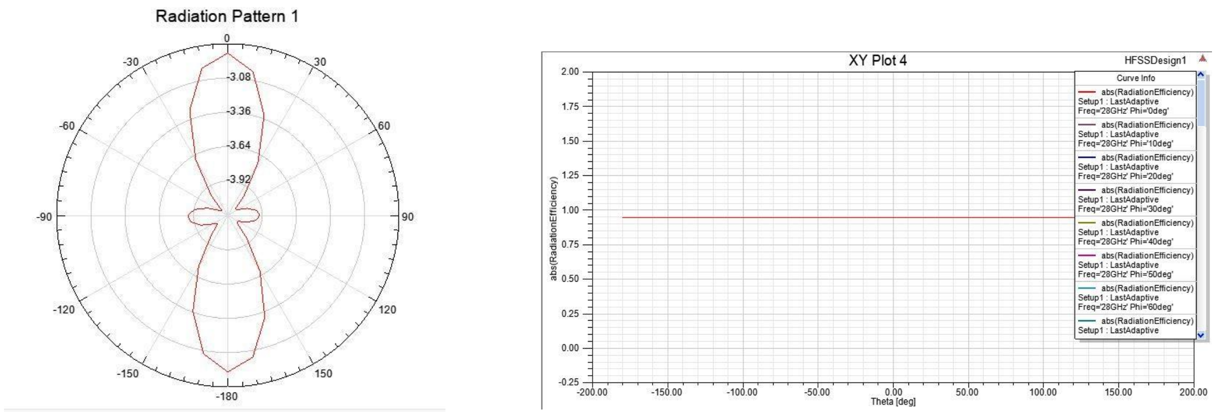


Fig 25b: Radiation pattern and Efficiency for 1x2 circular Patch antenna at 90deg

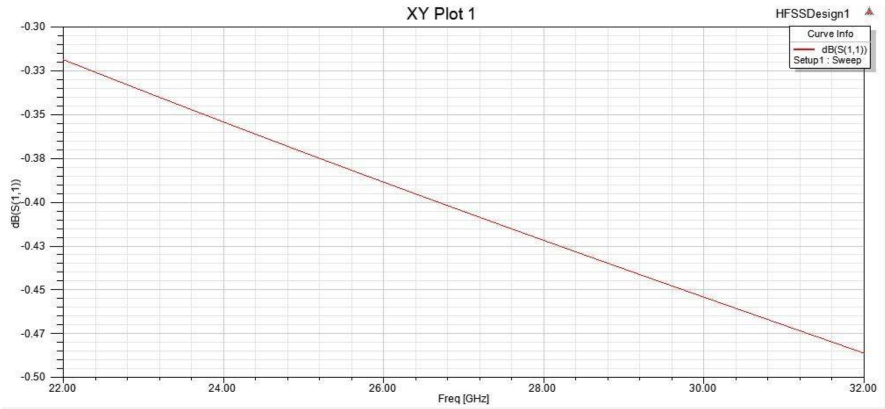


Fig: 25c S-Parameter for 1x2 circular patch antenna

5.2.2c Copper Substrate

The simulation results for 1x2 circular shaped array antenna using copper substrate:

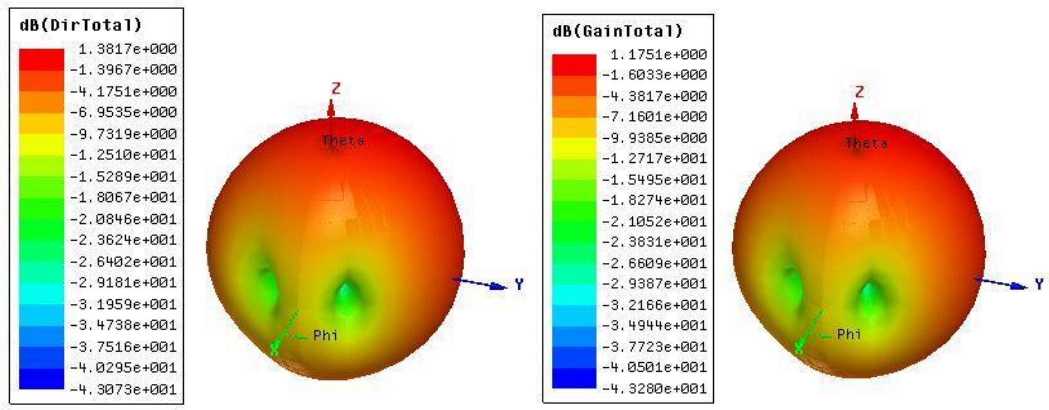


Fig 26a: Directivity and Gain for 1x2 circular shaped array antenna

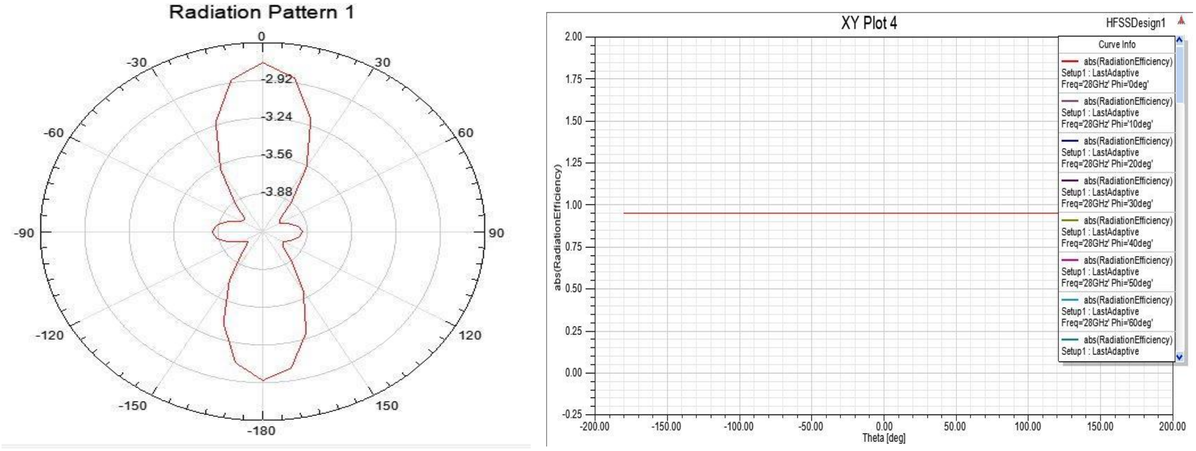


Fig 26b: Radiation Pattern and Efficiency for 1x2 circular shaped array antenna at 90deg

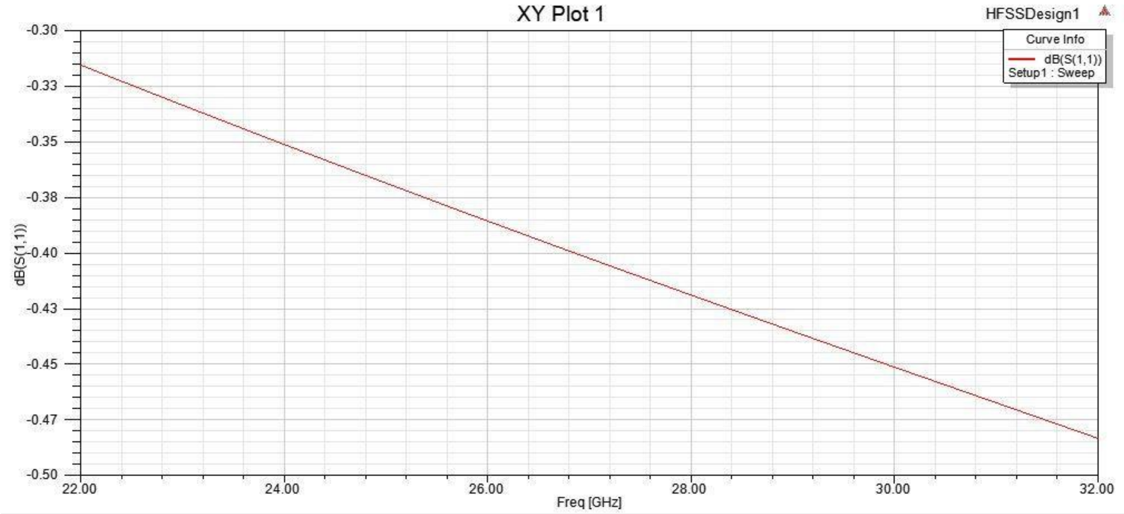


Fig 26c: S Parameter for 1x2 circular shaped array antenna

5.2.2d Aluminium Substrate

The simulation results for 1x2 circular shaped array antenna using aluminium substrate:

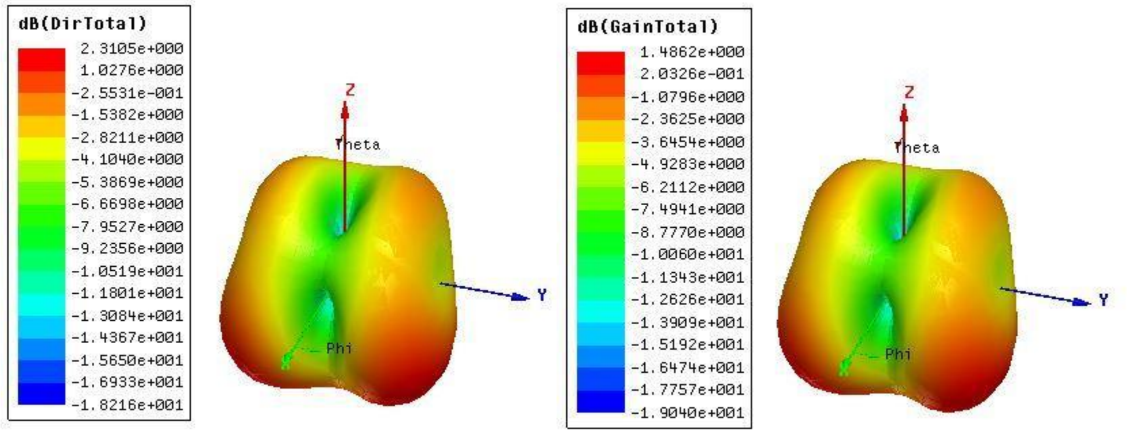


Fig 27a: Directivity and Gain for 1x2 circular shaped array antenna

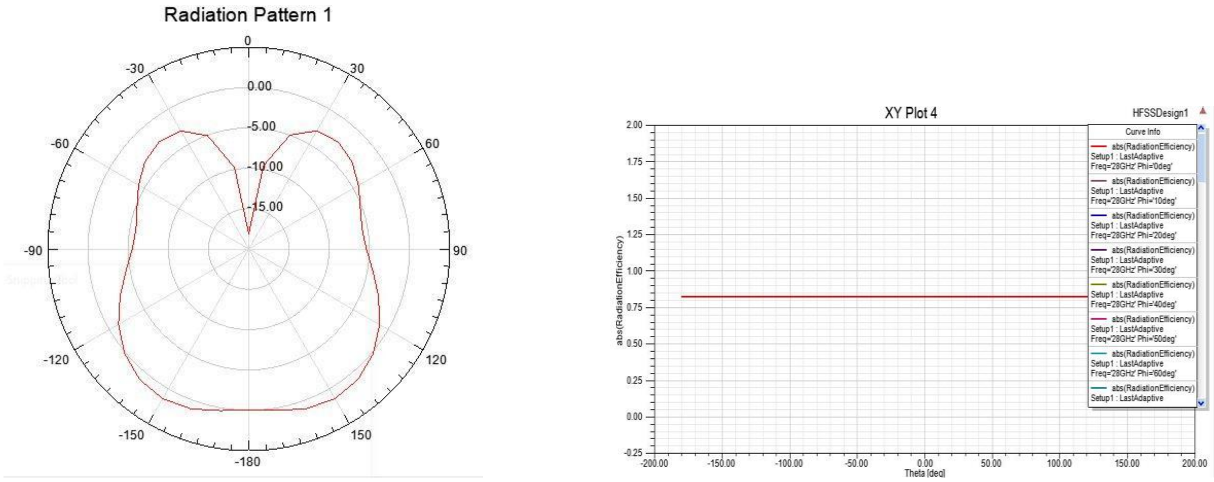


Fig 27b: Radiation Pattern and Efficiency for 1x2 circular shaped array antenna at 90deg

Fig: 27c S-Parameter for 1x2 circular patch antenna

5.2.3 1x4 Circular Patch Antenna Array simulation results

Fig 19c shows the implementation of 1X4 circular patch antenna. Among all the designs we have done, we are getting the highest gain from 1 X 4 circular antenna using glass substrate (see Fig 30a), which is 8.2460dB and 99.69% efficiency (using equation 6).

5.2.3a Glass Substrate

The simulation results for 1x4 circular shaped array antenna using glass substrate:

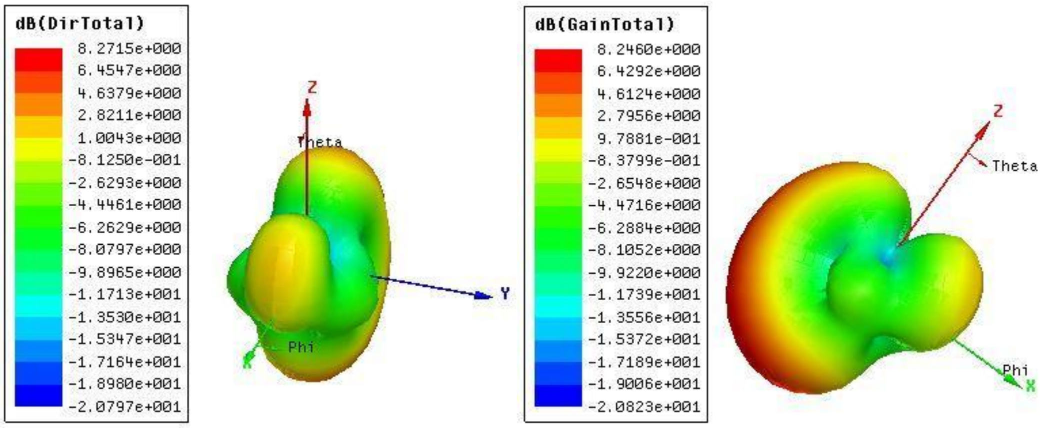


Fig 28a: Directivity and Gain for 1x4 circular shaped array antenna

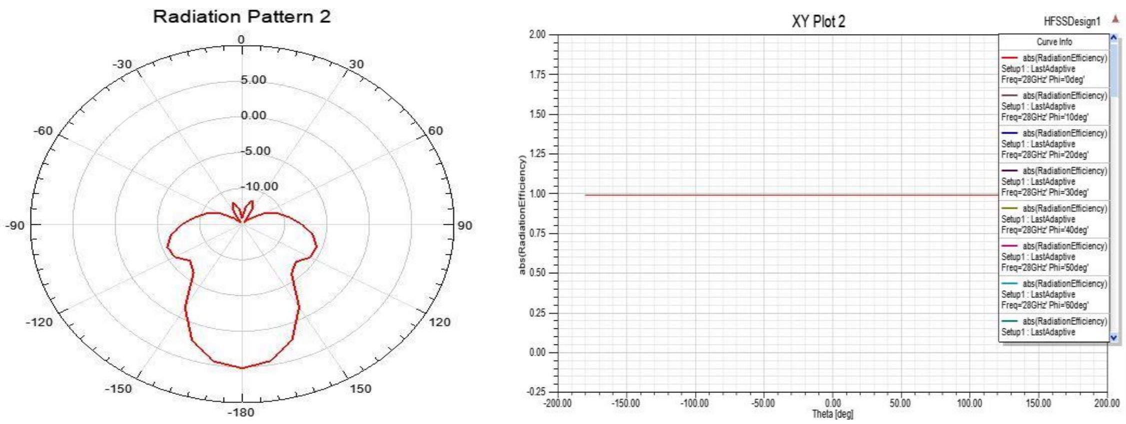


Fig 28b: Radiation pattern and Efficiency for 1x4 circular shaped array antenna

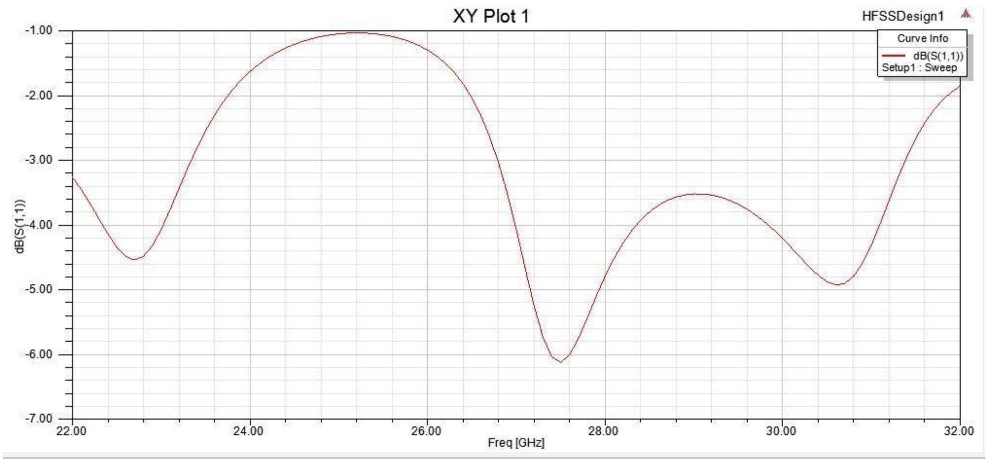


Fig 28c: S Parameter for 1x4 circular shaped array antenna

5.2.3b Gold Substrate

The simulation results for 1x4 circular shaped array antenna using gold substrate is:

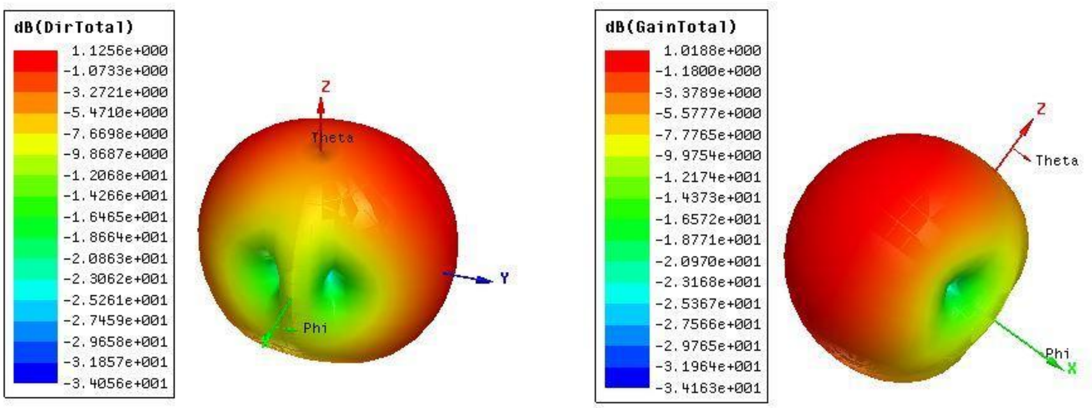


Fig 29a: Directivity and Gain for 1x4 circular shaped array antenna

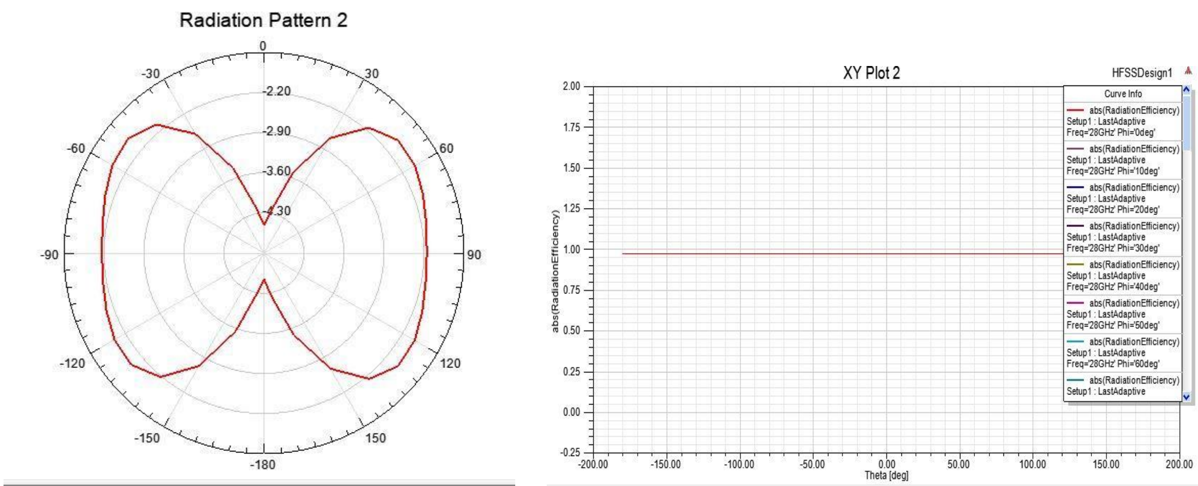


Fig 29b: Radiation pattern and Efficiency for 1x4 circular shaped array antenna

Fig 29c: S Parameter for 1x4 circular shaped array antenna

5.2.3c Copper Substrate

The simulation results for 1x4 circular shaped array antenna using copper substrate:

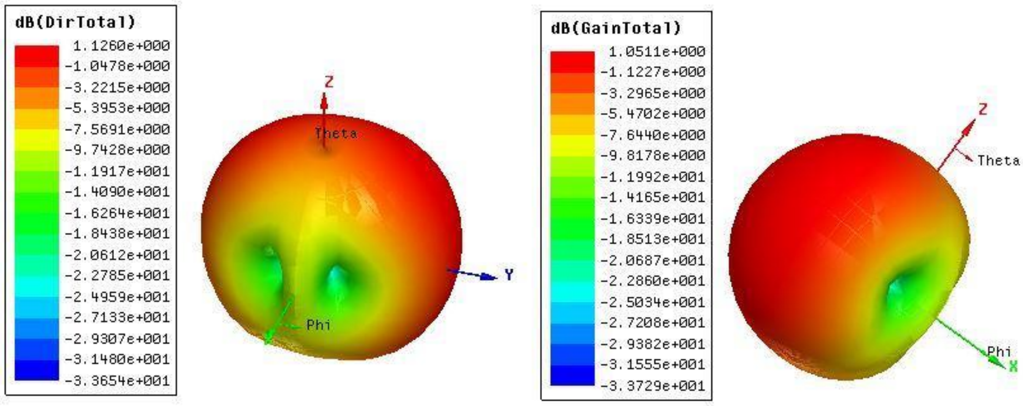


Fig 30a: Directivity and Gain for 1x4 circular shaped array antenna

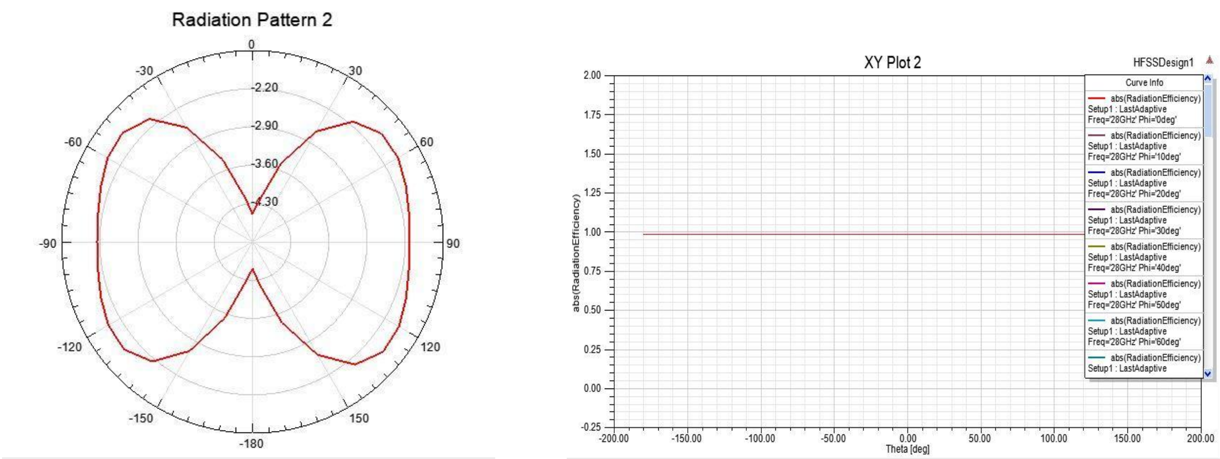


Fig 30b: Radiation pattern and Efficiency for 1x4 circular shaped array antenna

Fig 30c: S Parameter for 1x4 circular shaped array antenna

5.2.3d Aluminium Substrate

The simulation results for 1x4 circular shaped array antenna using aluminium substrate:

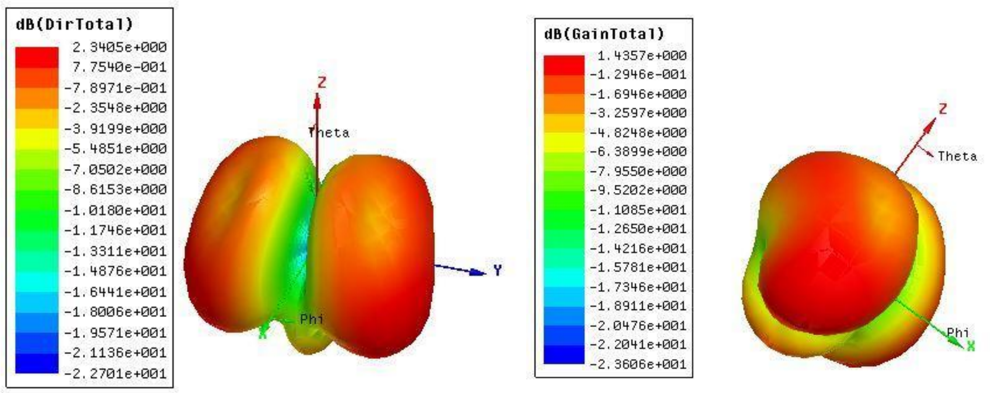


Fig 31a: Directivity and Gain for 1x4 circular shaped array antenna

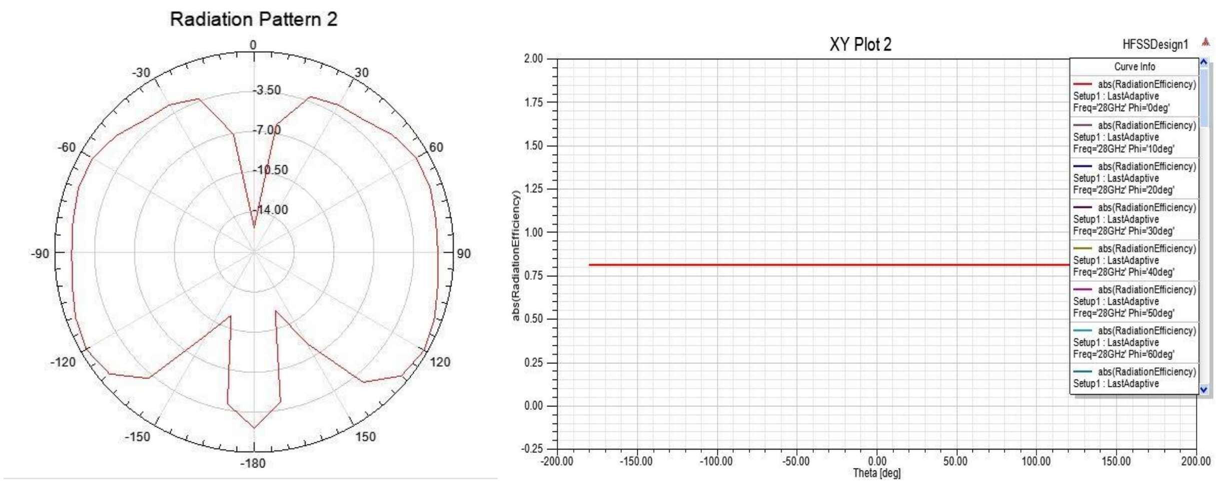


Fig 31b: Radiation pattern and Efficiency for 1x4 circular shaped array antenna

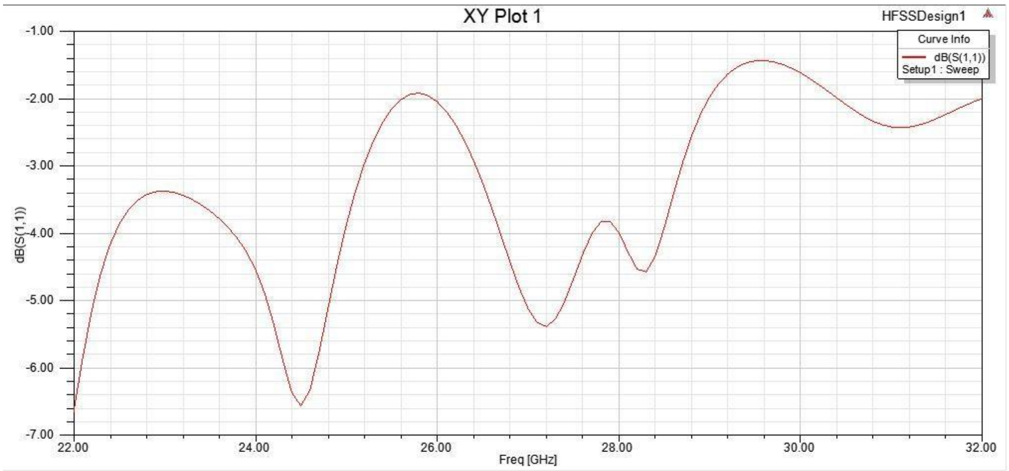


Fig 31c: S Parameter for 1x4 circular shaped array antenna

5.3 Results and Discussions

In HFSS, our simulation results for 1x1 rectangular patch antenna are achieved with S-parameter of -20.787dB using glass substrate and the gain and directivity is 6.2681 dB and 6.1876 dB respectively. In addition, the gain we got from the simulation using gold, copper, and aluminium is 1.8046, 1.8396, 1.4615 dB respectively. As a result, we can specify that using copper substrate we get the maximum value of gain for 1x1 rectangular patch antenna. Furthermore, the directivity of this particular antenna using gold, copper and aluminium gives the result to be 1.8965, 1.8988, 2.3058dB respectively which indicates that using copper we get the highest directivity. Finally, the simulation result of S-parameter using gold, aluminium, copper respectively is -0.2357,-0.2369,-24dB which means copper gives the best result of S-parameter. Efficiency of the antenna is calculated using the formula described in chapter4.

The comparison of the results are shown in the table below:

Table IV

1x1 Rectangular Patch antenna simulated results using transparent substrates

Substrates	Gain(dB)	Directivity(dB)	Return Loss(dB)	Efficiency (%)
Glass	6.2681	6.1876	-20.787	101.02
Gold	1.8046	1.8965	-0.2369	98.39
Copper	1.8396	1.8988	-0.2357	99.11
Aluminium	1.4615	2.3058	-24.000	98.11

We obtain a S-Parameter of-10.6724dB for 1x2 rectangular patch antenna using glass substrate and the gain and directivity is 4.2787dB and 4.2207dB respectively. In addition, the gain we got from the simulation using gold, copper, and aluminium is 4.5570, 4.6328, 4.6231 dB respectively. As a result, we can specify that using gold substrate we get the maximum value of gain of 1x2 rectangular patch antenna. Furthermore, the directivity of this particular antenna using gold, copper and aluminium gives the result to be 4.5417, 4.5958, 4.6083 dB respectively which indicates that using gold we get the highest directivity. Finally, the simulation result of S-parameter using gold, aluminium, copper respectively is -0.2820, -0.2790, -0.2770dB which means gold gives the best result of S-parameter. As a whole, it is seen that gold gives the best result in terms of gain, directivity and the s-parameter for 1x2 rectangular arrays.

The comparison of the results are shown in the table below:

Table V

1x2 Rectangular Patch antenna simulated results using transparent substrates

Substrates	Gain(dB)	Directivity(dB)	Return Loss(dB)	Efficiency (%)
Glass	4.2787	4.2207	-10.6724	102.09
Gold	4.5570	4.5417	-0.2820	100.62
Copper	4.6328	4.5958	-0.2790	100.54
Aluminium	4.6231	4.6083	-0.2770	100.61

Simultaneously for 1x4 rectangular patch antenna, we get S-parameter of -20.0000dB using glass substrate and the gain and directivity is 7.2024 dB and 7.1006dB respectively. In addition, the gain we got from the simulation using gold, copper, and aluminium is 4.8081, 4.8036, 4.5542 dB respectively. As a result, we can identify that using glass substrate we get the maximum value of gain of 1x4 rectangular patch array. Furthermore, the directivity of this particular array using gold, copper and aluminium gives the result to be 4.7727, 4.7581, 6.1107 dB respectively which indicates that using glass substrate we get the highest directivity. Finally, the simulation result of s-parameter using aluminium, copper, gold respectively is -0.2920, -0.2972, -33.500dB which means aluminium gives the best result for s parameter. As a whole, glass gives the best result in terms of gain and directivity and an acceptable result of return loss.

The comparison of the results is shown in the table below:

Table VI

1x4 Rectangular Patch antenna simulated results using transparent substrates

Substrates	Gain(dB)	Directivity(dB)	Return Loss(dB)	Efficiency (%)
Glass	7.2024	7.1006	-20.0000	102.36
Gold	4.8081	4.7727	-0.2920	100.82
Copper	4.8036	4.7581	-0.2972	101.03
Aluminium	4.5542	6.1107	-33.5000	100.83

Similarly, using HFSS software the simulation results for 1x1 circular patch antennas is discussed. We get a S parameter of -11.00 dB using glass substrate and the gain and directivity is 4.6331 dB and 4.6503 dB respectively. On the other hand, the gain we got from the simulation using gold, copper, and aluminium is 1.1852, 1.1801, 1.3857 dB respectively. As a result, we can specify that using a glass substrate we get the maximum value of gain of 1x1 circular patch antenna. Furthermore, the directivity of this particular antenna using gold, copper and aluminium gives the result to be 1.4564, 1.3895, 2.0628 dB respectively which indicates that using glass we achieve the highest directivity. Finally, the simulation result of S-parameter using copper is -0.417 which means glass gives the best result of s parameter. Lastly, it can be mentioned that glass is the best substrate considering the result of gain, directivity, electric field and the return loss.

Table VII

1x1 Circular Patch antenna simulated results using transparent substrates

Substrates	Gain (dB)	Directivity(dB)	Return Loss(dB)	Efficiency (%)
Glass	4.6331	4.6503	-11.00	99.99
Gold	1.1852	1.4564	-0.413	94.50
Copper	1.1801	1.3895	-0.417	95.00
Aluminium	1.3857	2.0628	-15	84.50

Here, for 1x2 circular array, using glass substrate in HFSS simulation, we get the gain and the directivity is 3.4515 dB and 3.4803 dB respectively. In addition, the gain using gold, copper, aluminium is seen to be respectively 1.0635, 1.1751, 1.4862dB. So, it can be identified that using aluminium substrate we get the highest value of gain. On the other hand, the directivity we got from the simulation using gold, copper, aluminium is 1.3006, 1.3817, 2.3105 dB respectively. As a result, we can specify that using gold substrate we get the maximum value of directivity of 1x2 circular patch antenna. Lastly, it is determined that using aluminium as substrate, the gain is highest but the directivity is very low compared to other substrates whereas glass gives the maximum result of directivity with an average gain and has a return loss of -9.6.

Table VIII

1x2 Circular Patch antenna simulation results using transparent substrates

Substrates	Gain(dB)	Directivity(dB)	Return Loss(dB)	Efficiency (%)
Glass	3.4515	3.4803	-9.6	99.50
Gold	1.0635	1.3006	-0.427	94.99
Copper	1.1751	1.3817	-0.427	95.00
Aluminium	1.4862	2.3105	-10.57	94.98

In this case, for 1x4 circular shaped patch antenna array, we get s parameter of -21 dB using glass substrate and the gain and directivity is 8.2460 dB and 8.2715 dB respectively. In addition, the gain we got from the simulation using gold, copper, and aluminium is 1.0180, 1.0511, 1.4357 dB respectively. As a result, we can identify that using copper substrate we get the maximum value of gain of 1x4 circular patch antenna. On the other hand, the directivity of this particular antenna using gold, copper and aluminium gives the result to be 1.1256, 1.1260, 2.3405 dB respectively which indicates that using aluminium we get the highest directivity of 1x4 circular shaped patch antenna array. Furthermore, the simulation result of S-parameter using aluminium is -6.5 which means aluminium gives the best result of s parameter. Lastly, we can put a conclusion saying that glass gives the highest gain, gives the highest directivity and the return loss is also noticeable.

Table IX:
1x4 circular patch antenna simulation results using transparent substrates

Substrates	Gain (dB)	Directivity (dB)	Return Loss (dB)	Efficiency (%)
Glass	8.2460	8.2715	-6.25	98.90
Gold	1.0180	1.1256	-0.427	96.99
Copper	1.0511	1.1260	-0.427	98.12
Aluminium	1.4357	2.3405	-6.5	81.00

Hence, we can compare the tables for antenna arrays and make a conclusion that 1x4 circular patch antenna using transparent glass substrates gives maximum gain of 8.2460dB and a directivity of 8.2715dB with a moderate return loss result of -6.25dB.

Table X: Comparison with other research paper at 28 GHz

Parameters	Our Observation	Reference Paper Observation
No of elements in array	1x4	1x8
Substrate	Glass	Glass
Shape	Circular	Rectangular
Gain (dB)	8.2460	6.66

In our comparison we can observe that we have obtained higher gain for 1x4circular antenna array compared to the other research paper using the same substrate.

Chapter 6
Conclusion

6.1 Summary

In our work we have created a comprehensive mmWave frequency phased array designed exclusively for spherical beam steering coverage.

Microstrip patch antennas were initially used to build the preliminary array. Our goal was to develop the Phased array antenna use at 28GHz for future 5G mobile applications. We infer from the feasibility analysis that gold, aluminium, copper and glass are the transparent conductors found to be ideal for use as substrates with moderate optical clarity. Till now using two common shapes, rectangular and circular, of patch antenna we have observed that 1x4 circular patch antenna gives the maximum gain of 8.2460dB, return loss of -6.25dB and an efficiency of 98.90%.This antenna gain was achieved by implementing the glass substrate whose optical transparency of 88% at 28GHz is obtained using a thick alloy electrode of Ag on the substrate. Our observation result was comparatively higher than another research paper whose result for gain was 6.66dB using 1x8 glass substrate array.

Overall, our design has shown improved performance with higher gain and better efficiency results. Nonetheless, that doesn't mean that more changes can't be made. Further changes in our design can be made which will reveal superior efficiency and better beam steering. Hopefully we will be doing research in the future and will help to improve our results.

6.2 Future Scope

In future we will seek to make an array of more elements and compare their radiation efficiency, total efficiency, S-Parameter, gain and directivity to see if it results in better output. In addition, we can also improve the antenna gain by means of distinctive shapes and size of slots to achieve optimum beam steering results. At the same time, we can render transparent antennas for display application by comparing more different materials and layers with high transparency result for broadside beam.

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