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Project Report on

"Design and Development of Novel patch Antenna and it's Array for 5G Applications"

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CERTIFICATE

This is to certify that the project work entitled **" Design and Development of Novel Patch Antenna and it's Array for 5G Applications"** is carried out by **Ashwini Kumar, Shubham Shrivastava , Abhyudai Singh and Avishek Kumar** bearing USN: **1CR16EC023, 1CR14EC182, 1CR16EC003 ,1CR15EC032 respectively,** bonafide students of **CMR INSTITUTE OF TECHNOLOGY** in partial fulfillment for the award of **Bachelor of Engineering** in Electronics and Communication Engineering from **Visvesvaraya Technological University,** Belagavi during the academic year **2019-20**. It is certified that all corrections/suggestions indicated for Internal Assessment have been incorporated in the report deposited in the department library. The Project Report has been approved and satisfies the academic requirements with respect to Project work prescribed for the said degree.

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ABSTRACT

A microstrip patch antenna consists of radiating patch on one side of dielectric substrate and has the ground plane on other side. The study of microstrip patch antennas has made great progress in recent years. Compared with conventional antennas, microstrip patch antennas have more advantages and better prospects. They are lighter in weight, low volume, low cost, low profile, smaller in dimension and ease of fabrication and conformity. Moreover, the microstrip patch antennas can provide dual and circular polarizations, dual-frequency operation, frequency agility, broad band-width, feedline flexibility, beam scanning omnidirectional patterning. This work explores the performance enhancement of microstrip patch antenna. The antennas are analyzed using the different antenna parameters like Radiation pattern, Gain, Return loss, Directivity and Radiation pattern.

In this project we have mainly focused on Antennas and it's various parameters which help us in indicating the efficiency of Antennas, microstrip patch Antenna ,different Array Antennas and various feeding techniques and finally we have designed patch as well as array antennas using Ansys HFSS software .After simulation we have calculated and compared the different parameters so that we can detect the most efficient antenna among them. At last we have concluded with different useful Applications, Advantages and scope for future work.

TABLE OF CONTENTS

List of Figures

Lists of Tables

CHAPTER 1

OVERVIEW OF THE PROJECT

In this chapter introduction, motivation, objectives, software requirements, methodology adopted, organization of project are presented.

1.1 INTRODUCTION

Microstrip patch antennas are very popular among Wireless Local Area Network (WLAN), Wide Area Network (WAN) technologies due to their advantages such as light weight, low volume, low cost, compatibility with integrated circuits and easy to install on rigid surface.

In this project a millimeter wave microstrip patch antenna and its array for 5G applications is proposed. The 5G Microstrip patch is designed on rogers RT Duroid 5880 substrate with standard thickness 0.787 mm having relative dielectric constant (r) = 2.2 and tan δ = 0.0013.The antenna resonates at 24.2 GHz with a return loss 25.94 dB and a bandwidth 2.4 GHz. An array of 1x4, 1x2, 2x2, 4x4 element of the proposed antenna is designed using HFSS software. Appreciable improvement in gain is observed with the array of antennas. The antenna and its array can be used for 5G mobile communication because of its compactness.

1.2 MOTIVATION

Wireless technology has skyrocketed over a past decade or so. Everyone is using mobile phones, tablets, Wi-Fi and PC's for conducting research, for playing online games, for watching videos and business purposes. Every user demands higher date rates so the ultimate problem that service provider will face is bandwidth shortage. Today cellular phones and other wireless devices operates at lower frequency of below 8 GHz, so a cell tower capacity is limited even with using today's 4G LTE technology. The only way out is apparently using millimeter range frequency of above 20 GHz. Then so much bandwidth will be available to users and problem of shortage of spectrum will be solved, thus leading to providing greater data rates to the consumers of the next generation. The tentative frequency band for 5G is 24-28 GHz. So far 4G can provide data rates as high as upto 20Mbps. But 5G will provide data rates up to 1Gbps. So designing a good performance antenna for future 5G applications is the need of current time.

Over the past two decades micro strip patch antennas has attracted researchers because of being low profile and smaller in size. Their fabrication is easy and are generally more compact than other antennas. Because of being light weight and compact, they are used in cellular phones for mobile communications.

1.3 PROJECT OBJECTIVE

The main objective of this project is to design and analysis of microstrip novel patch antenna in which we will use rectangular patch antenna configuration, by using ansys HFSS software. After designing and generating the model, we will complete the optimized design and simulate the derived model and after implementation , we will find the results of the design.

We will also design multiple array antennas 1x2, 2x2, 1x4, 4x4. We will follow the same process in the software and after simulating ,we will find the the various results and then we will compare different parameters and conclude with which one gives the desirable results.

1.3 PROJECT METHODOLOGY

To carry out this project, the following methodology is designed,which is to be carried out in the HFSS Software:

- Generating the model
- Complete the optimized design.
- Simulating the derived model.
- Hardware implementation.
- Results of the design

1.4 SOFTWARE USED

HFSS 15.0 (High Frequency Structural Simulation) software is used in this project to design & simulate the Microstrip Patch Antenna and array designs.

1.5 ORGANISATION OF THE PROJECT

In chapter 2 the literature survey of the project is given. In chapter 3 the detailed explanation of antenna, types of antenna, antenna parameters are explained. A comprehensive explanation of microstrip antenna is presented in chapter 4. About array antenna in 5. . Design of patch and array antennas using HFSS alongwith results & Discussions is explained in 6. Applications & advantages in 7. Conclusion and future scope of array antenna are concluded in chapter 8.

CHAPTER 2

LITERATURE SURVEY

Microstrip is probably the most successful and revolutionary antenna technology ever. Its success comes from very well known advantages such as; light weight, low profile, easy and low cost fabrication, planar but also conformal to non planar geometries, mechanical robustness, easy integration of components (including active devices), easy association in arrays and versatility in terms of electromagnetic characteristics (input impedance, radiation pattern, polarisation). It can be used in a very broad range of frequencies roughly from 1GHz to 100GHz. Ofcourse it also has some disadvantages, the most well known being the internet narrow band width and low frequency. However even these drawbacks have been overcome several techniques have been developed to increase the bandwidth and very wideband microstrip antennas have been presented. The development of new technologies and processes and the use of new materials have provided low loss microwave and millimetre wave substrates.

Microstrip antennas have been used in many and varied military and commercial applications, such as radar, satellite, communication, biomedicine, automotive industry, mobile communications (both base stations and handsets), Wireless Local Area Network (WLAN's), Ultra Wideband (USB), Radio Frequency Identification(RFID).

The microstrip antenna papers published in the IEEE transactions on antenna and propagation is presented initially it serves the purpose of evaluating and research activity carried out science the initial practical implementation until now. The introduction of the microstrip antenna concept and the early years of its practical implementation are analysed in detail. The introduction of microstrip transmission line and more specifically of the associated radiation losses, are analysed as a possible bridge leading to microstrip antenna the fast development of microstrip antenna in the last three decades is also analysed and the more important fields of the applications are highlighted. finally, nowadays situation and trends allow the prediction of possible future microstrip antenna issues and applications.

The first microstrip entry ever in IEEE transactions on antenna and propagation happened in 1974. however the term microstrip was initially associated with transmission line. The microstrip line was introduced in 1952 by grieg and englemenn . a microstrip entry already exist in the first issue of the predecessor of the nowadays transactions and microwave theory and Techniques.

The paper by Deschamps and sichak [9] is usually referred as the first microstrip antenna paper [10][5] not surprisingly this paper is almostly contemporary of the first microstrip line paper [6] and the authors worked for the same institution (federal telecommunication laboratories) another frequently referred initial piece is the 1955 french patent by gutton and boissinot [11].

However, neither Deschamps and Sichak paper nor the French patent proposed configurations that are microstrip antennas as we know them today. In both cases the term “microstrip” refers to a microstrip transmission line. In the former the radiating elements are planar horns or lenses and in the latter radiation is promoted by discontinuities intentionally exaggerated in the microstrip line. The radiation losses in microstrip lines were analysed later but as an unwanted effect.

The enormous growth of wireless data traffic in recent years has made the millimeter-wave (mm-wave) technology as a good fit for high-speed communication systems. Extensive works are continuing from the device to system, to the radio architecture, to the network to support the communication in mm-wave frequency ranges. To support this extensive high data rate, beam forming is found to be the key-enabling technology. Hence, an array antenna design is an extremely important issue. The beam-forming arrays are chosen to achieve the desired link capacity considering the high path loss and atmospheric loss at mm-wave frequencies and also to increase the coverage of the mm-wave communication system. There are diverse design challenges of the array due to the small size, use of large numbers of antennas in close vicinity, integration with radio-frequency (RF) front ends, hardware constraints, and so on. This paper focuses on the evolution and development of mm-wave array antenna and its implementation for wireless communication and numerous other related areas. The scope of the discussion is extended on the reported works in every sphere of mm-wave antenna array design, including the selection of antenna elements, array configurations, feed mechanism, integration with front-end circuitry to understand the effects on system performance, and the underlying reason of it. The new design aspects and research directions are unfolded as a result of this discussion.

The huge development during 1950 – 60s made the antenna array specially phased array an inevitable technology for different applications e.g. radar, communications, remote sensing, navigation, automotive, biomedical imaging and in many other fields. The continuous growth in the area of wireless services and applications has become helpful for the design of today’s array antennas. The array antennas are broadly classified in several categories according to the various design parameters, e.g. geometrical configuration, electrical architecture, feeding mechanism etc.

CHAPTER 3

ANTENNA TERMINOLOGY

3.1 INTRODUCTION

An antenna is defined by Webster's Dictionary as ―usually a metallic device for radiating or receiving radio waves‖. The IEEE Standards Definitions define antenna (or aerial) as ―a means for radiating or receiving radio waves‖. In other words the antenna is the transitional structure between free space and a guiding device.

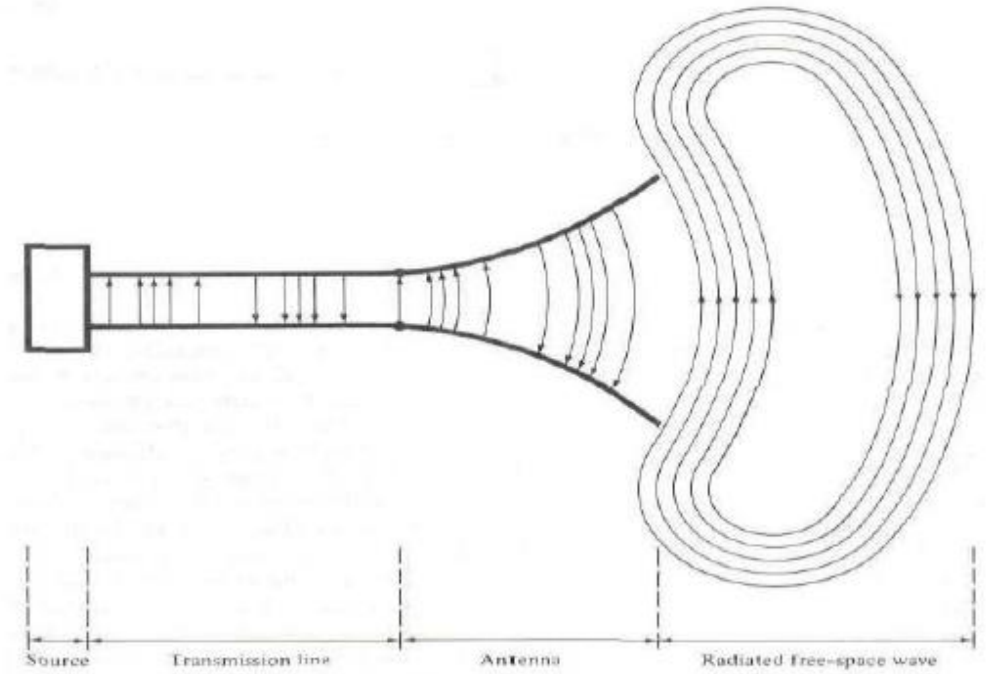


Fig.1 Antenna as a transmission device showing constructive interference in between the transmission line and finally release into the open media.

In addition to receiving or transmitting energy, an antenna (in an advance wireless system) is usually required to optimise or accentuate the radiation energy in some directions and suppress it in others. Thus the antenna must also serve as a directional device in addition to a probing device. It must then take various forms to meet the particular need at hand.

The field of antenna is vigorous and dynamic, and over the last 50 years, antenna technology has been an indispensable partner of the communication revolution. Many major advances that occurred during this period are in common use today. However many more issues are facing us today, especially since the demands for the system performance is even greater. Hence antenna development and testing is of great interest to the engineering community of the day.

3.2 ANTENNA TERMINOLOGY

To describe the performance of an antenna, definitions of various parameters are necessary. Some of the parameters are interrelated and not all of them need be specified for complete description of the antenna performance.

3.2.1 RADIATION PATTERN

An antenna radiation pattern or antenna pattern is defined as ―a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates. In most cases, the radiation pattern is determined in the far-field region and is represented as a function of the directional coordinates. Radiation properties include power flux density, radiation intensity, field strength, directivity, phase, or polarization‖.

The radiation property of most concern is the two- or three-dimensional spatial distribution of radiated energy as a function of the observer's position along a path or surface of constant radius. A convenient set of coordinates is shown in Figure. A trace of the received electric (magnetic) field at a constant radius is called the amplitude field pattern. On the other hand, a graph of the spatial variation of the power density along a constant radius is called an amplitude power pattern. Often the field and power patterns are normalized with respect to their maximum value, yielding normalized field and power patterns. Also, the power pattern is usually plotted on a logarithmic scale or more commonly in decibels (dB).

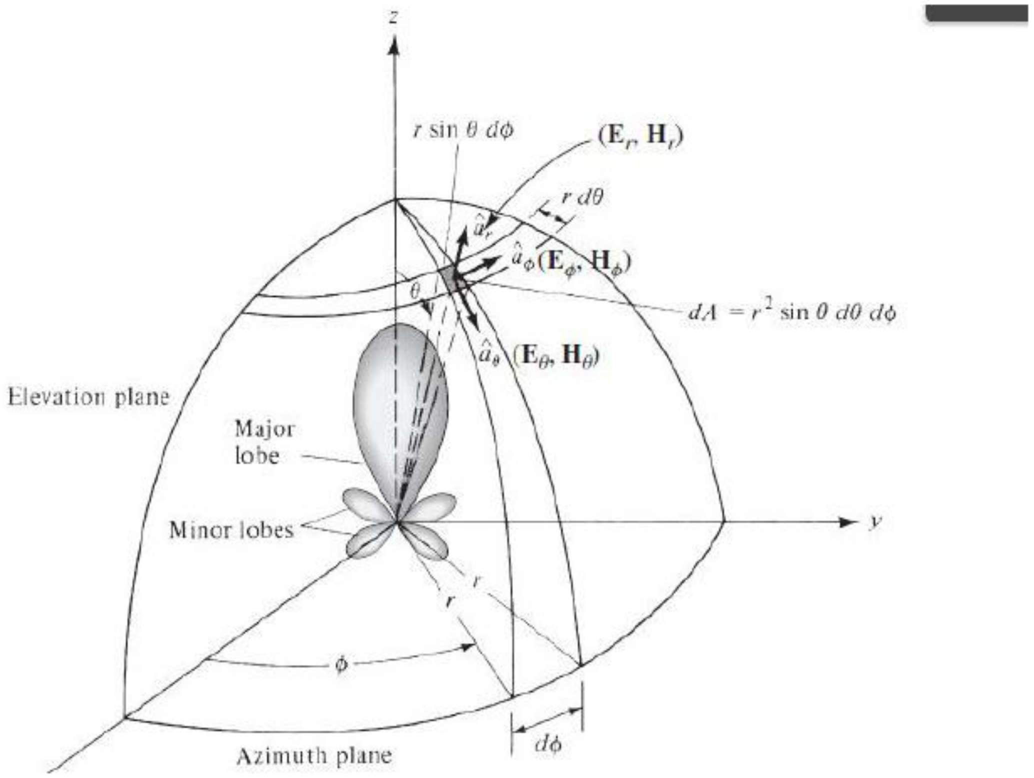


FIG 3.2 Radiation pattern shown in antenna coordinates

Various parts of a radiation pattern are referred to as lobes, which may be sub-classified into major or main, minor, side, and back lobes. A radiation lobe is a ―portion of the radiation pattern bounded by regions of relatively weak radiation intensity‖. Figure 3.3 demonstrates a symmetrical three-dimensional polar pattern with a number of radiation lobes. Some are of greater radiation intensity than others, but all are classified as lobes.

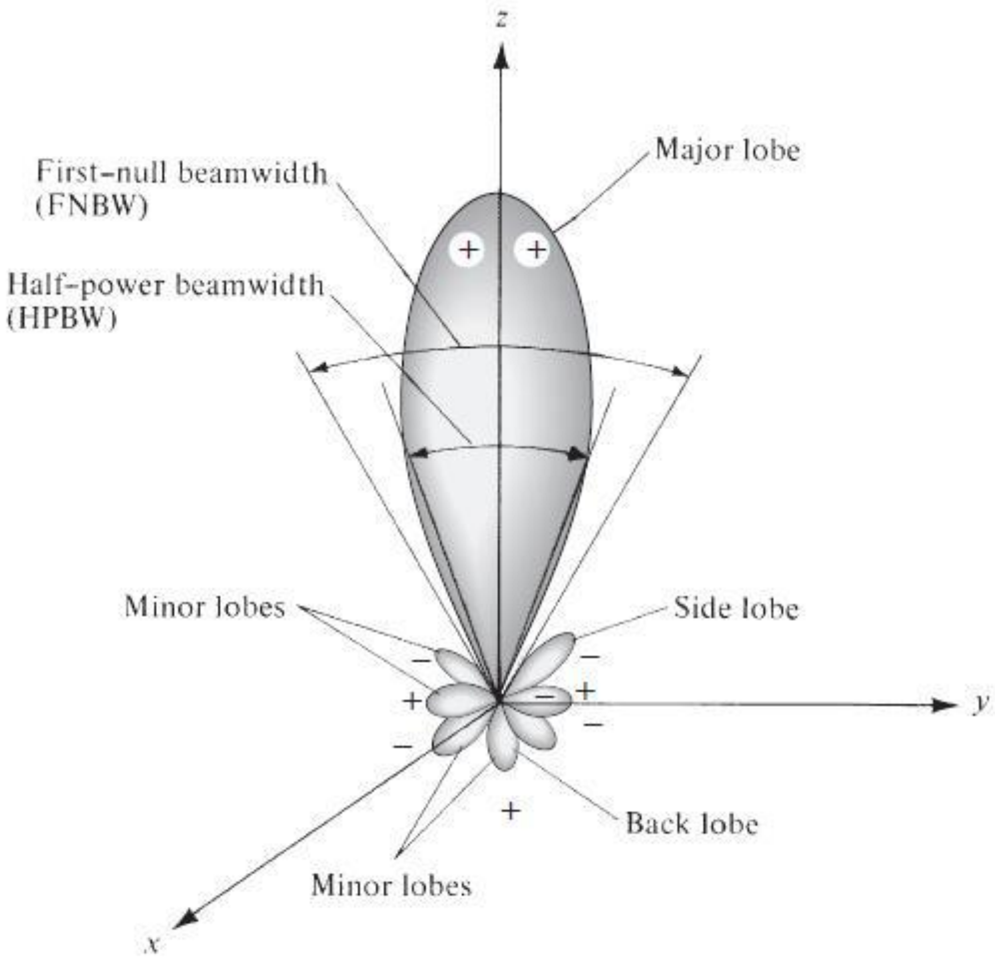


Fig 3.4 Radiation pattern showing all the lobes

A major lobe (also called main beam) is defined as ―the radiation lobe containing the direction of maximum radiation‖. In the figure, the major lobe is pointing in the Θ =0 direction. In some antennas, such as split-beam antennas, there exist more than one major lobe.

A minor lobe is any lobe except a major lobe. A side lobe is ―a radiation lobe in any direction other than the intended lobe‖. (Usually a side lobe is adjacent to the main lobe and occupies the hemisphere in the direction of the main beam.) A back lobe is ―a radiation lobe whose axis makes an angle of approximately 180◦ with respect to the beam of an antenna‖. Usually it refers to a minor lobe that occupies the hemisphere in a direction opposite to that of the major (main) lobe. Minor lobes usually represent radiation in undesired directions, and they should be minimized. Side lobes are normally the largest of the minor lobes. The level of minor lobes is usually expressed as a ratio of the power density in the lobe in question to that of the major lobe. This ratio is often termed the side lobe ratio or side lobe level. Side lobe levels of −20 dB or smaller are usually not desirable in many applications.

3.2.2 ISOTROPIC, DIRECTIONAL, AND OMNI – DIRECTIONAL PATTERN

An isotropic radiator is defined as ―a hypothetical lossless antenna having equal radiation in all directions‖. Although it is ideal and not physically realizable, it is often taken as a reference for expressing the directive properties of actual antennas. A directional antenna is one ―having the property of radiating or receiving electromagnetic waves more effectively in some directions than in others. This term is usually applied to an antenna whose maximum directivity is significantly greater than that of a half-wave dipole‖. Omni-directional antennas radiate at a specific direction, with no side lobes what so ever. An omni-directional pattern is then a special type of a directional pattern.

3.2.3 RADIATION POWER DENSITY

Electromagnetic waves are used to transport information through a wireless medium or a guiding structure, from one point to the other. It is then natural to assume that power and energy are associated with electromagnetic fields. The quantity used to describe the power associated with an electromagnetic wave is the instantaneous Poynting vector defined as

W = **E** ×**H**

W = instantaneous Poynting vector (W/m2)

E = instantaneous electric-field intensity (V/m)

H = instantaneous magnetic-field intensity (A/m)

Note that script letters are used to denote instantaneous fields and quantities, while roman letters are used to represent their complex counterparts. Since the Poynting vector is a power density, the total power crossing a closed surface can be obtained by integrating the normal component of the Poynting vector over the entire surface. In equation form

$$\mathscr{P} = \oiint_S \mathscr{W} \cdot d\mathbf{s} = \oiint_S \mathscr{W} \cdot \hat{\mathbf{n}}\, da$$

where

P = instantaneous total power (W)

n = unit vector normal to the surface

da = infinitesimal area of the closed surface (m2)

$$\boxed{\mathbf{W}_{av}(x, y, z) = [\mathscr{W}(x, y, z; t)]_{av} = \frac{1}{2}\mathrm{Re}(\mathbf{E} \times \mathbf{H}^*)} \quad (\mathrm{W/m^2})$$

The time-average Poynting vector (average power density) can be written

The ½ factor appears in Eq. because the **E** and **H** fields represent peak values, and it should be omitted for RMS values. Based on the definition of Equation, the average power radiated by an antenna (radiated power) can be written

$$P_{\rm rad} = P_{\rm av} = \oiint_S \mathbf{W}_{\rm rad} \cdot d\mathbf{s} = \oiint_S \mathbf{W}_{\rm av} \cdot \hat{\mathbf{n}}\, da = \frac{1}{2} \oiint_S {\rm Re}(\mathbf{E} \times \mathbf{H}^*) \cdot d\mathbf{s}$$

3.2.4 ANTENNA BEAM WIDTH

Associated with the pattern of an antenna is a parameter designated as beam width. The beam width of a pattern is defined as the angular separation between two identical points on opposite sides of the pattern maximum. In an antenna pattern, there are a number of beamwidths. One of the most widely used beamwidths is the half-power beam width (HPBW), which is defined by IEEE as: ―In a plane containing the direction of the maximum of a beam, the angle between the two directions in which the radiation intensity is one-half value of the beam‖. Another important beam width is the angular separation between the first nulls of the pattern, and it is referred to as the first-null beam width (FNBW). Both of the HPBW and FNBW. Other beamwidths are those where the pattern is −10 dB from the maximum, or any other value. However, in practice, the term beam width, with no other identification, usually refers to the HPBW.

The beam width of an antenna is a very important figure-of-merit and often is used as a trade-off between it and the side lobe level; that is, as the beam width decreases, the side lobe increases and vice versa. In addition, the beam width of the antenna is also used to describe the resolution capabilities of the antenna to distinguish between two adjacent radiating sources or radar targets. The most common resolution criterion states that the resolution capability of an antenna to distinguish between two sources is equal to half the First-null beam width (FNBW/2), which is usually used to approximate the half-power beam width (HPBW).

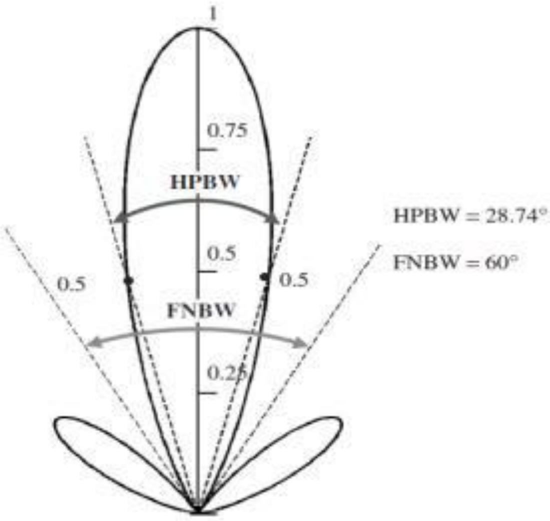


Fig. 3.5

3.2.5 DIRECTIVITY

In the 1983 version of the IEEE Standard Definitions of Terms for Antennas, there was a substantive change in the definition of directivity, compared to the definition of the 1973 version. Basically the term directivity in the 1983 version has been used to replace the term directive gain of the 1973 version. In the 1983 version the term directive gain has been deprecated. According to the authors of the 1983 standards, ―this change brings this standard in line with common usage among antenna engineers and with other international standards, notably those of the International Electrotechnical Commission (IEC)‖. Therefore directivity of an antenna is defined as ―the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions. The average radiation intensity is equal to the total power radiated by the antenna divided by 4π. If the direction is not specified, the direction of maximum radiation intensity is implied‖. Stated more simply, the directivity of a non isotropic source is equal to the ratio of its radiation intensity in a given direction over that of an isotropic source. In mathematical form, it can be written –

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

If the direction is not specified, it implies the direction of maximum radiation intensity (maximum directivity) expressed as –

$$D_{max} = D_0 = \frac{U|_{max}}{U_0} = \frac{U_{max}}{U_0} = \frac{4\pi U_{max}}{P_{rad}}$$

Where,

D = directivity (dimensionless).

D0 = maximum directivity (dimensionless).

U = radiation intensity (W/unit solid angle).

Umax = maximum radiation intensity (W/unit solid angle).

U0 = radiation intensity of isotropic source (W/unit solid angle).

Prad = total radiated power (W).

The directivity of an isotropic source is unity since its power is radiated equally well in all directions. For all other sources, the maximum directivity will always be greater than unity, and it is a relative ―figure-of-merit‖ that gives an indication of the directional properties of the antenna as compared with those of an isotropic source. The directivity can be smaller than unity; in fact it can be equal to zero. The values of directivity will be equal to or greater than zero and equal to or less than the maximum directivity (0≤D≤D0).

3.2.6 ANTENNA EFFICIENCY

Associated with an antenna are a number of efficiencies that can be defined. The total antenna efficiency e0 is used to take into account losses at the input terminals and within the structure of the antenna. Such losses may be due, referring to figure,

I. Reflections because of the mismatch between the transmission line and the antenna and

II. I 2R losses (conduction and dielectric).

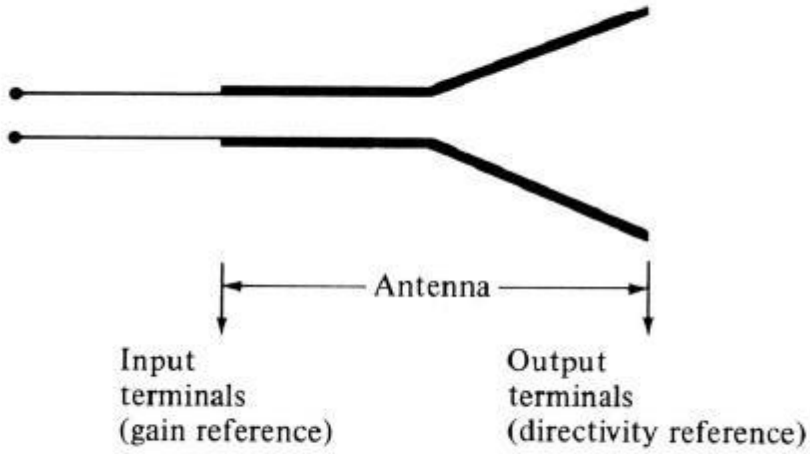


Fig. 3.6 Antenna with input and output terminals

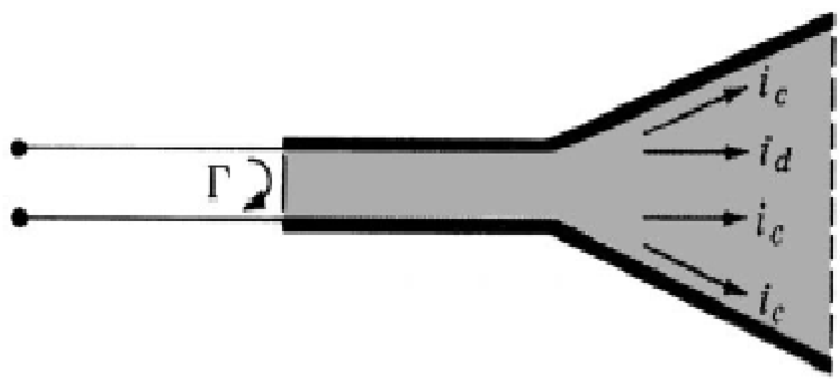


Fig 3.7 Reflection, conduction and dielectric losses

In general, the overall efficiency can be written

$$e_0 = e_r e_c e_d$$

Where,

e0 = total efficiency (dimensionless)

err = reflection (mismatch) efficiency=(1−|_|2) (dimensionless)

ec = conduction efficiency (dimensionless)

ed = dielectric efficiency (dimensionless)

[$\Gamma = (Z_{in} - Z_0)/(Z_{in} + Z_0)$ where Z_{in} = antenna input impedance and Z_0 = characteristic impedance of the transmission line]

Γ = voltage reflection coefficient at the input terminals of the antenna

VSWR = voltage standing wave ratio $= (1 + |\Gamma|)/(1 - |\Gamma|)$

Usually **ec** and **ed** are very difficult to compute, but they can be determined experimentally. Even by measurements they cannot be separated, and it is usually more convenient to write as

$$e_0 = e_r e_{cd} = e_{cd}(1 - |\Gamma|^2)$$

where ecd =eced =antenna radiation efficiency, which is used to relate the gain and directivity.

3.2.7 ANTENNA GAIN

Another useful measure describing the performance of an antenna is the gain. Although the gain of the antenna is closely related to the directivity, it is a measure that takes into account the efficiency of the antenna as well as its directional capabilities.Gain of an antenna (in a given direction) is defined as —the ratio of the intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically. The radiation intensity corresponding to the isotropically radiated power is equal to the power accepted (input) by the antenna divided by 4π‖. In most cases we deal with relative gain, which is defined as ―the ratio of the power gain in a given direction to the power gain of a reference antenna in its referenced direction‖. The power input must be the same for both antennas. The reference antenna is usually a dipole, horn, or any other antenna whose gain can be calculated or it is known. In most cases, however, the reference antenna is a lossless isotropic source.

Thus

$$G = \frac{4\pi U(\theta, \phi)}{P_{\text{in}}(\text{lossless isotropic source})} \quad \text{(dimensionless)}$$

When the direction is not stated, the power gain is usually taken in the direction of maximum radiation.We can write that the total radiated power (Prad) is related to the total input power (Pin) by –

$$P_{\text{rad}} = e_{cd} P_{\text{in}}$$

where ecd is the antenna radiation efficiency (dimensionless). Here we define two gains:

1. gain (G), and the other,

2. absolute gain (Gabs), that also takes into account the reflection/mismatch losses.

Thus we can introduce an absolute gain Gabs that takes into account the reflection/mismatch losses (due to the connection of the antenna element to the transmission line), and it can be written as –

$$G_{abs}(\theta,\phi) = e_r G(\theta,\phi) = (1-|\Gamma|^2)G(\theta,\phi) = e_r e_{cd} D(\theta,\phi) = e_o D(\theta,\phi)$$

The maximum absolute gain G(0)abs is related to the maximum directivity D(0) by –

$$G_{0abs} = G_{abs}(\theta,\phi)|_{max} = e_r G(\theta,\phi)|_{max} = (1-|\Gamma|^2)G(\theta,\phi)|_{max} = e_r e_{cd} D(\theta,\phi)|_{max} = e_o D(\theta,\phi)|_{max} = e_o D_0$$

If the antenna is matched to the transmission line, that is, the antenna input impedance Z in is equal to the characteristic impedance Z 0 of the line, then the two gains are equal, i.e. Gabs =G. Usually the gain is given in terms of decibels instead of the dimensionless quantity. The conversion formula is given by –

$$G_0(\text{dB}) = 10\log_{10}[e_{cd} D_0 \text{ (dimensionless)}]$$

3.2.8 BANDWIDTH

The bandwidth of an antenna is defined as ―the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard‖. The bandwidth can be considered to be the range of frequencies, on either side of a centre frequency (usually the resonance frequency for a dipole), where the antenna characteristics (such as input impedance, pattern, beam width, polarization, side lobe level, gain, beam direction, radiation efficiency) are within an acceptable value of those at the centre frequency. For broadband antennas, the bandwidth is usually expressed as the ratio of the upper-to-lower frequencies of acceptable operation. For example, a 10:1 bandwidth indicates that the upper frequency is 10 times greater than the lower. For narrowband antennas, the bandwidth is expressed as a percentage of the frequency difference (upper minus lower) over the centre frequency of the bandwidth. For example, a 5% bandwidth indicates that the frequency difference of acceptable operation is 5% of the centre frequency of the bandwidth.

Because the characteristics (input impedance, pattern, gain, polarization, etc.) of an antenna do not necessarily vary in the same manner or are not even critically affected by the frequency, there is no unique characterization of the bandwidth. The specifications are set in each case to meet the needs of the particular application. Usually there is a distinction made between pattern and input impedance variations. Accordingly pattern bandwidth and

impedance bandwidth are used to emphasize this distinction. Associated with pattern bandwidth are gain, side lobe level, beam width, polarization, and beam direction while input impedance and radiation efficiency are related to impedance bandwidth. For example, the pattern of a linear dipole with overall length less than a half-wavelength is insensitive to frequency. The limiting factor for this antenna is its impedance, and its bandwidth can be formulated in terms of the Q. The Q of antennas or arrays with dimensions large compared to the wavelength, excluding super directive designs, is near unity. Therefore the bandwidth is usually formulated in terms of beam width, side lobe level, and pattern characteristics. For intermediate length antennas, the bandwidth may be limited by either pattern or impedance variations, depending on the particular application.

3.2.9 POLARISATION

Polarization of an antenna in a given direction is defined as ―the polarization of the wave transmitted (radiated) by the antenna. When the direction is not stated, the polarization is taken to be the polarization in the direction of maximum gain‖. In practice, polarization of the radiated energy varies with the direction from the centre of the antenna, so that different parts of the pattern may have different polarizations.

Polarization of a radiated wave is defined as ―that property of an electromagnetic wave describing the time-varying direction and relative magnitude of the electric-field vector; specifically, the figure traced as a function of time by the extremity of the vector at a fixed location in space, and the sense in which it is traced, as observed along the direction of propagation‖. Polarization then is the curve traced by the end point of the arrow (vector) representing the instantaneous electric field.

Linear, Circular, and Elliptical Polarizations

Polarization may be classified as linear, circular, or elliptical briefly they can be described as,

Linear Polarization - A time-harmonic wave is linearly polarized at a given point in space if the electric-field (or magnetic-field) vector at that point is always oriented along the same straight line at every instant of time. This is accomplished if the field vector (electric or magnetic) possesses the following:

I. Only one component, or

II. Two orthogonal linear components that are in time phase or 180◦ (or multiples of180◦) out-of-phase.

Circular Polarization - A time-harmonic wave is circularly polarized at a given point in space if the electric (or magnetic) field vector at that point traces a circle as a function of time. The necessary and sufficient conditions to accomplish this are if the field vector (electric or magnetic) possesses all of the following:

I. The field must have two orthogonal linear components, and

II. The two components must have the same magnitude, and

III. The two components must have a time-phase difference of odd multiples of 90 degrees.

The sense of rotation is always determined by rotating the phase-leading component toward the phase-lagging component and observing the field rotation as the wave is viewed as it travels away from the observer. If the rotation is clockwise, the wave is right-hand (or clockwise) circularly polarized; if the rotation is counter clockwise, the wave is left-hand (or counter clockwise) circularly polarized. The rotation of the phase-leading component toward the phase-lagging component should be done along the angular separation between the two components that is less than 1800. Phases equal to or greater than 00 and less than 1800 should be considered leading whereas those equal to or greater than 180degree and less than 3600 should be considered lagging.

Elliptical Polarization - A time-harmonic wave is elliptically polarized if the tip of the field vector (electric or magnetic) traces an elliptical locus in space. At various instants of time the field vector changes continuously with time in such a manner as to describe an elliptical locus. It is right-hand (clockwise) elliptically polarized if the field vector rotates clockwise, and it is left-hand (counter clockwise) elliptically polarized if the field vector of the ellipse rotates counter clockwise. The sense of rotation is determined using the same rules as for the circular polarization. In addition to the sense of rotation, elliptically polarized waves are also specified by their axial ratio whose magnitude is the ratio of the major to the minor axis.

A wave is elliptically polarized if it is not linearly or circularly polarized. Although linear and circular polarizations are special cases of elliptical, usually in practice elliptical polarization refers to other than linear or circular. The necessary and sufficient conditions to accomplish this are if the field vector (electric or magnetic) possesses all of the following:

I. The field must have two orthogonal linear components, and

II. The two components can be of the same or different magnitude.

III. (a) If the two components are not of the same magnitude, the time-phase difference between the two components must not be 00 or multiples of 1800 (because it will then be linear). (b) If the two components are of the same magnitude, the time-phase difference between the two components must not be odd multiples of 900 (because it will then be circular).

3.2.10 ANTENNA RADIATION EFFICIENCY

The antenna efficiency that takes into account the reflection, conduction, and dielectric losses. The conduction and dielectric losses of an antenna are very difficult to compute and in most cases they are measured. Even with measurements, they are difficult to separate and they are usually lumped together to form the ecd efficiency. The resistance RL is used to represent the conduction–dielectric losses. The conduction–dielectric efficiency ecd is defined as the ratio of the power delivered to the radiation resistance Rr to the power delivered to Rr and RL. The radiation efficiency can be written

$$e_{cd} = \frac{R_r}{R_L + R_r} \quad \text{(dimensionless)}$$

For a metal rod of length l and uniform cross-sectional area A, the dc resistance is given by-

$$R_{\text{dc}} = \frac{1}{\sigma}\frac{l}{A} \quad \text{(ohms)}$$

3.2.11 RELATION BETWEEN DIRECTIVITY & RELATIVE AREA

In general then, the maximum effective area (Aem) of any antenna is related to its maximum directivity (D0) by –

$$\boxed{A_{em} = \frac{\lambda^2}{4\pi} D_0}$$

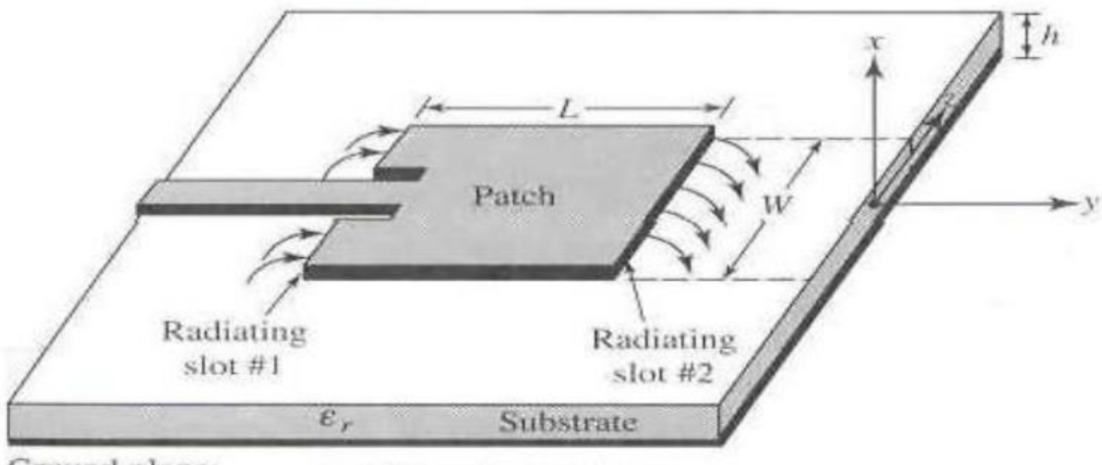
Thus this equation is multiplied by the power density of the incident wave it leads to the maximum power that can be delivered to the load. This assumes that there are no conduction- dielectric losses (radiation efficiency ecd is unity), the antenna is matched to the load (reflection efficiency er is unity), and the polarization of the impinging wave matches that of the antenna (polarization loss factor PLF and polarization efficiency pe are unity). If there are losses associated with an antenna, its maximum effective aperture above equation must be modified to account for conduction-dielectric losses (radiation efficiency). Thus

$$A_{em} = e_{cd} \left(\frac{\lambda^2}{4\pi} \right) D_0$$

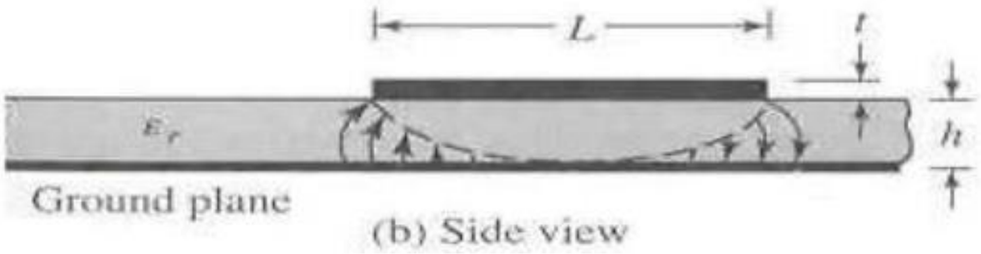
CHAPTER 4

MICROSTRIP PATCH ANTENNA

Microstrip antenna, consist of a very thin (t << 0, where 0 is the free space wavelength) metallic strip (patch) placed a small fraction of a wavelength (h << 0 , usually 0.0030 ≤ h ≤ 0.05 0) above a ground plane. The microstrip patch is designed so its pattern maximum is normal to the patch (broadside radiator). This is accomplished by properly choosing the mode of excitation beneath the patch. For the rectangular patch the length L of the element is usually 0 /3< L < 0 /2. The strip and the ground are separated by a dielectric sheet. There are numerous substrate that can be used to design microstrip antennas, and their dielectric constant are usually in the range 2.2. The ones that are most often used are thick substrates whose dielectric constant is in the lower end the range because they provide better efficiency, larger bandwidth, loosely bound field for radiation; but do all this at the expense of larger element size. Thin substrate with higher dielectric constant are desirable for microwave circuitry because ther require tightly bound fields to minimise undesirable radiation and coupling, and lead to smaller element size.



(a) Microstrip antenna



Feed Methods

There are many configurations that can be used to feed the microstrip match antenna. The four most popular are –

Microstrip Line feed – is easy to fabricate, usually is much smaller as compared to the patch. However as the substrate thickness increases, surface waves and spurious feed radiation increases, which for practical design limits the bandwidth.

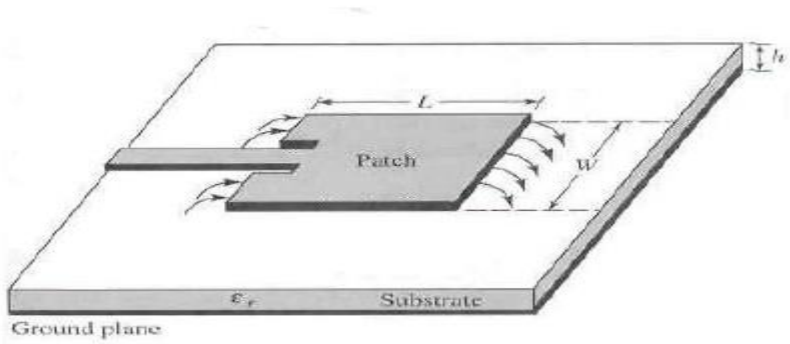


Figure 4.1 Microstrip line feed

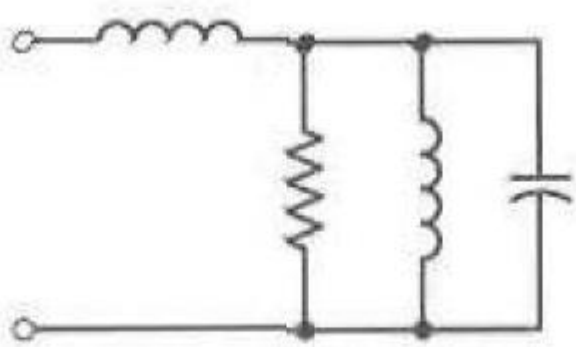


Fig 4.2 Equivalent circuit

Variation in Microstrip feed can be provided by having more than one feeds

This may lead to orthogonal polarisation, if the 2 feeds are in phase, otherwise if they are 900 apart, circular polarisation may take place.

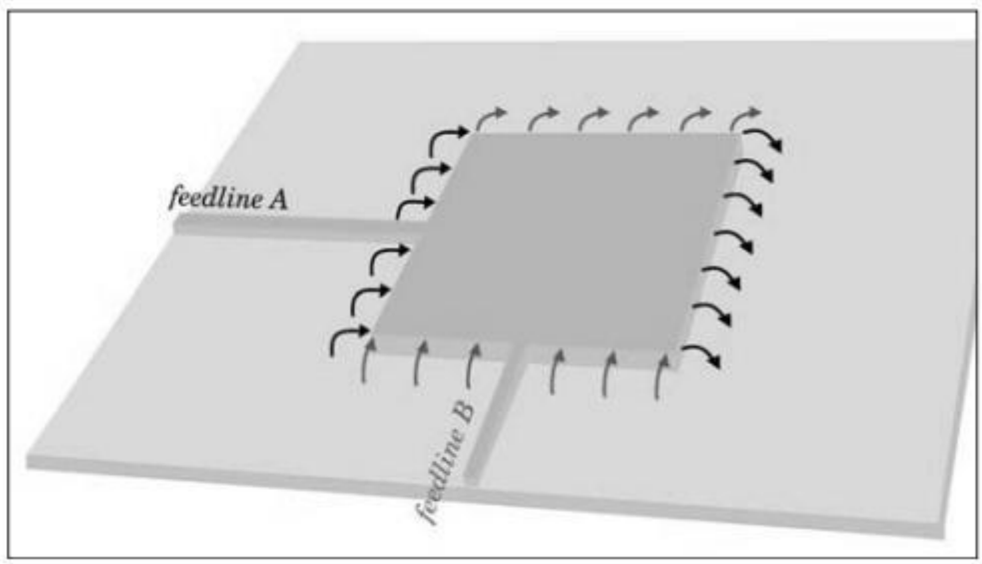


Fig. 4.3 Microstrip feed

Coaxial Probe feed – the inner conductor of the coax is attached to the Radiating patch while the outer conductor is connected to the ground plane. It is also easy to fabricate and match, and has low spurious radiation. However, it has narrow bandwidth and is more difficult to model if the substrate is thick.

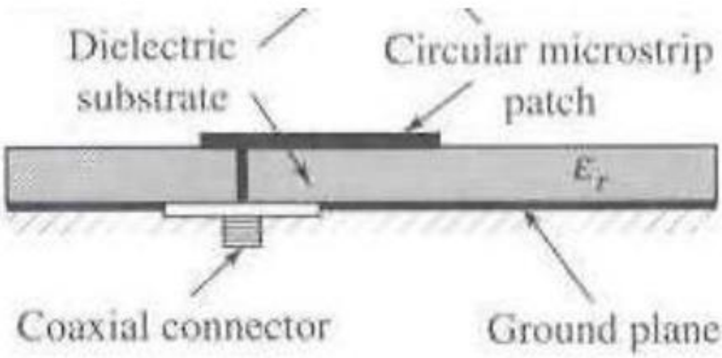


fig.4.4 coax probe feed

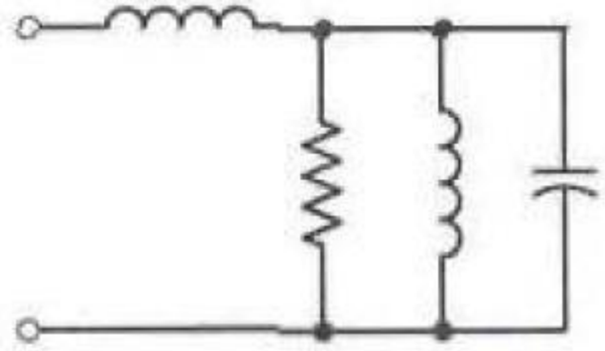


fig. 4.5 Equivalent circuit

Advantages and Drawbacks

Advantages:

1. The extremely low profile of the microstrip antenna makes it lightweight and it occupies very little volume of the structure or vehicle on which it is mounted.

2. The patch element or an array of patch elements, when produced in large quantities, can be fabricated with a simple etching process, which can lead to greatly reduced fabrication cost.

3. Multiple-frequency operation is possible by using either stacked patches or a patch with loaded pin or a stub.

4. There are other miscellaneous advantages, such as the low antenna radar cross section (RCS), and the microstrip antenna technology can be combined with the reflectarray technology to achieve very large aperture without any complex and RF lossy beamformer.

Besides no of advantages MSPA has following drawbacks also.

1. A single-patch microstrip antenna with a thin substrate (thickness < 0.02 of freq) generally has a narrow bandwidth of less than 5%.

2. The microstrip antenna can handle relatively lower RF power due to the small separation between the radiating patch and its ground plane. Depending on the substrate thickness, metal edge sharpness, and the

frequency of operation, a few kilowatts of peak power for microstrip lines at X-band have been reported.

3. The microstrip array generally has a larger ohmic insertion loss than other types of antennas of equivalent aperture size. This ohmic loss mostly occurs in the dielectric substrate and the metal conductor of the microstrip line power dividing circuit.

4. Patch antennas have quite a few benefits, including the aforementioned inexpensive price, versatility, and ease of manufacture. The low profile nature of patch antennas is also obvious as well as the small size needed to generate a sizeable directive gain.

5. Patch antennas however do have some disadvantages. Primarily; narrow bandwidth and poor efficiency are top issues that plague microstrip antenna designers. It is common to require multiple patch antennas to cover different frequency bands due to their narrow bandwidth.

6. This disadvantage is being somewhat mitigated by the fact that many communications protocols are moving towards CDMA and TDMA techniques which uses a single band. The poor efficiency of patch antennas is also a particular disadvantage in favored applications like cell phones and space hardware due to the limited power resources in these cases.

7. Small applications which benefit greatly from the compact size of patch antennas also seek efficient systems which allow for longer battery life in mobile applications. The efficiency of patch antennas can be increased by utilizing materials with lower dielectric constants for the substrate, as well as moving the antenna farther away from the ground plane (ex. utilizing a thicker substrate). These methods change the frequency characteristics and gain patterns of the antennas while also creating challenges in design.

8. Another disadvantage of patch antennas is the complex nature of performing analyses to determine gain patterns. While simple patch antennas (squares and circles) are relatively easy to analyze, complex structures often become necessary to improve gain, pattern, bandwidth or efficiency.

9. These complex patterns are non-trivial to analyze and thus are often modeled utilizing the FDTD method which can handle more complex structures with much more facility.

ANTENNA DESIGN

Equations for the calculation of dimensions of a microstrip antenna design.

Parameter	Symbol	Equation
Resonance frequency	f_r	$f_r = \frac{c}{2W\sqrt{(\varepsilon_r+1)/2}}$
Effective dielectric length	ε_e	$\varepsilon_e = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h1}{W}\right]^{-\frac{1}{2}}$
Effective length	L_{eff}	$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_r}}$
Length of patch	L (mm)	$L = L_{eff} - 2h\Delta L$ $\Delta L = 0.412\left[\frac{(\varepsilon_e+0.3)\left(\frac{W}{h_1}+0.26h_1\right)}{(\varepsilon-0.258)\left(\frac{W}{h_1}+0.8\right)}\right]$
Length of ground	L_g (mm)	$L_g = 6h+L$
Width of ground	W_g	$W_g = 6h+W$
Inset feed location	x_f , y_f	$x_f = \frac{L}{2\sqrt{\varepsilon_e}}, y_f = \frac{W}{2}$

Table 4.1

CHAPTER 5

ARRAY ANTENNAS

An antenna, when individually can radiate an amount of energy, in a particular direction, resulting in better transmission, how it would be if few more elements are added it, to produce more efficient output. It is exactly this idea, which led to the invention of **Antenna arrays.** It can be better understood by seeing the given images.

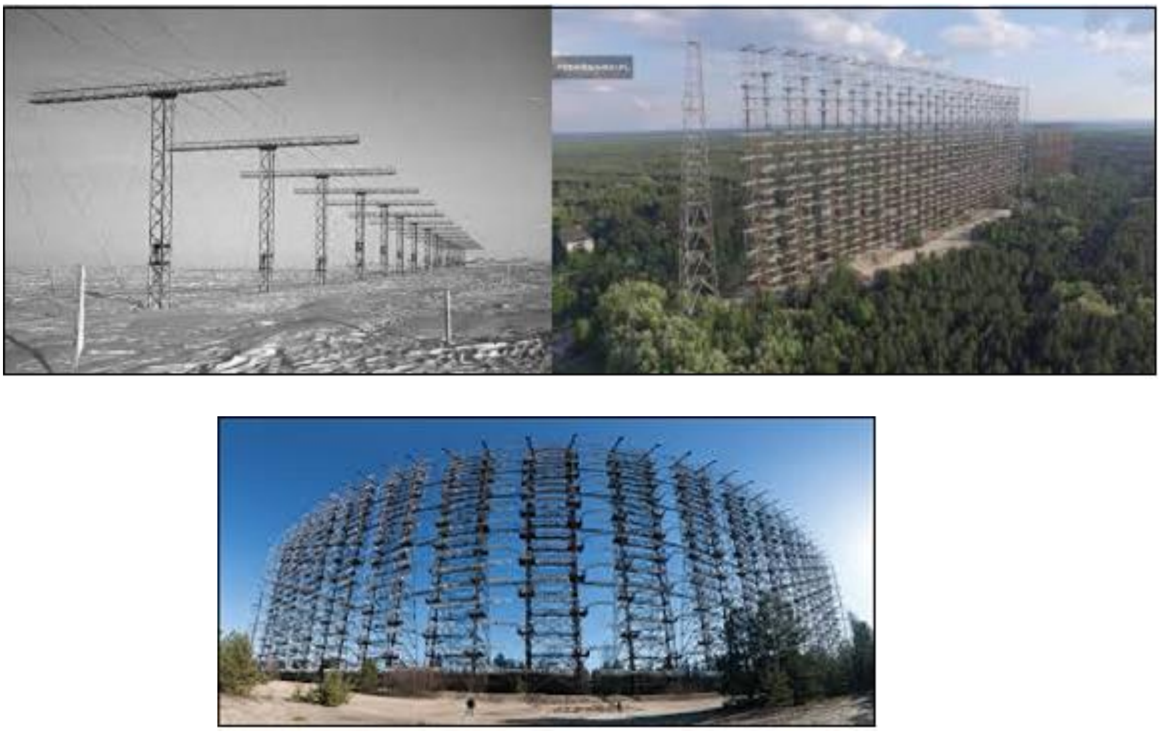


Fig 5.1 Array antennas

An **antenna array** is a radiating system, which consists of individual radiators and elements. Each of this radiator, while functioning has its own induction field. The elements are placed so closely that each one lies in the neighbouring one’s induction field. Therefore, the radiation pattern produced by them, would be the vector sum of the individual ones. The following image shows another example of an antenna array.

The spacing between the elements and the length of the elements according to the wavelength are also to be kept in mind while designing these antennas.

The antennas radiate individually and while in array, the radiation of all the elements sum up, to form the radiation beam, which has high gain, high directivity and better performance, with minimum losses.

Advantages

The following are the advantages of using antenna arrays −

- The signal strength increases
- High directivity is obtained
- Minor lobes are reduced much
- High Signal-to-noise ratio is achieved
- High gain is obtained
- Power wastage is reduced
- Better performance is obtained

Disadvantages

The following are the disadvantages of array antennas −

- Resistive losses are increased
- Mounting and maintenance is difficult
- Huge external space is required

Applications

The following are the applications of array antennas −

- Used in satellite communications
- Used in wireless communications
- Used in military radar communications
- Used in the astronomical study

CHAPTER 6

DESIGN APPROACH USING HFSS

Antenna designs which will be described below were performed with an agenda to have an increased gain of the individual antenna, which would be capable to form an array with limited number of elements with better gain and steerability with low fluctuations in gain throughout the scanning range. The aim was to have a slightly greater gain so that the array of such elements can achieve a gain above 10 dB or more with not more than four elements, owing to the size limitations of the platform. Array was designed such that its overall size should not exceed 10cm in length, typically for a 4-element design.

Patch antenna was chosen as the starting design because of its simple design structure, moderately better gain, low profile, optimum size and fixed analyzable broadside radiation characteristics in the dominant mode.

Construction on HFSS –

1. Patch – Patch needs to be calculated based on the given equation. It can be constructed using various drawing tools on HFSS. Boundary condition of finite conductivity is provided.

2. Dielectric Substrate – Constructed in form of Cube just below the Patch. It is then given the properties of a suitable material (in our case duroid). Its length must be taken into account.

3. Ground Plane – A sheet is provided beneath the dielectric substrate, it is provided with the boundary condition of finite conductivity, based on property of a conductor (we used Copper).

4. Feed – A strip of copper (dimensionally very small to the patch) is provided for EM wave from wave port to patch. It must be of 50 ohm conductivity.

5. Wave port – Wave port is used to provide excitation to the whole model. Its length must be at least /4.

6. Air Box – It is provided to restrict the area where the antenna must radiate. It must be big enough but not very big to provide reflected interference. It is provided with Radiation Boundary condition

7. Meshing – A Meshing length is provided to the air box which must be /10.

8. Far Field Set up – An infinite sphere far field condition is set up to calculate far field parameter.

6.1 DESIGN OF NOVEL PATCH ANTENNA

6.1.1 Specifications of proposed antenna

- A millimeter wave microstrip patch antenna and its array for 5G applications is proposed. The 5G Microstrip patch is designed on rogers RT Duroid 5880 substrate with standard thickness 0.787 mm having relative dielectric constant (r) = 2.2 and tangent loss of 0.0013.
- The patch antenna resonates at 24.2 GHz with a return loss 25.94 dB and a bandwidth 2.4 GHz.
- An array of 1x4 , 1x2, 2x2, 4x4 element of the proposed patch antenna is designed.
- Appreciable improvement in gain is observed with the array of antennas.
- Desired return loss of less than -10dB for operating frequency.
- Different parameters

Parameter	discription	value(mm)
L_s	length of substrate	10
W_s	width of substrate	10
L_p	length of patch	3.4
W_p	width of patch	4
t	height of ground	0.0175
W_f	width of feedline	2.2
W_q	width of quarter wavelength	0.4
L_q	length of quarter wavelength	2.8626
l	length of feedline	0.9374

Table 6.1

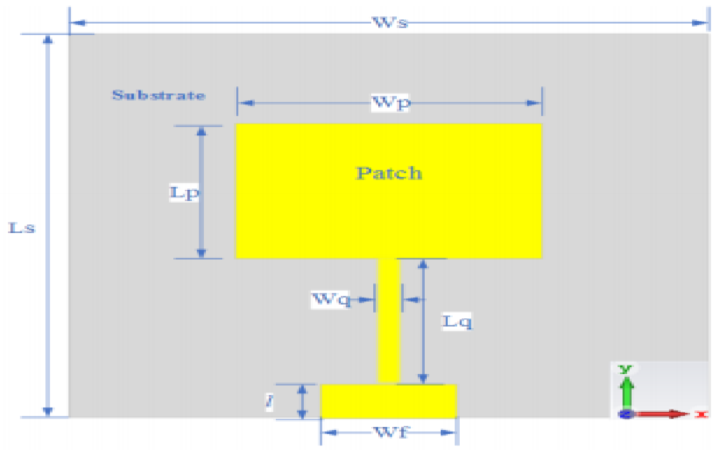


Fig 6.1 antenna structure

After simulating we have got the following results in Ansys HFSS

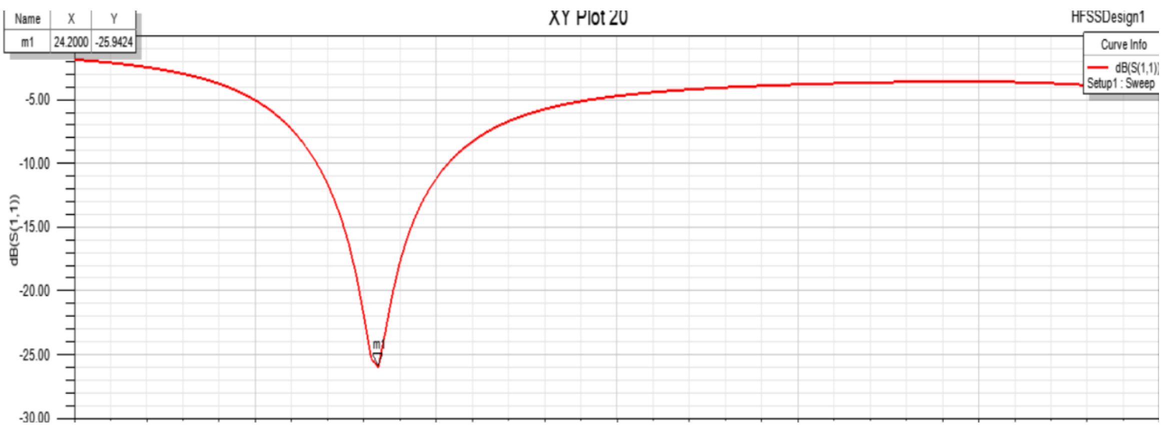


Fig 6.2 Return loss

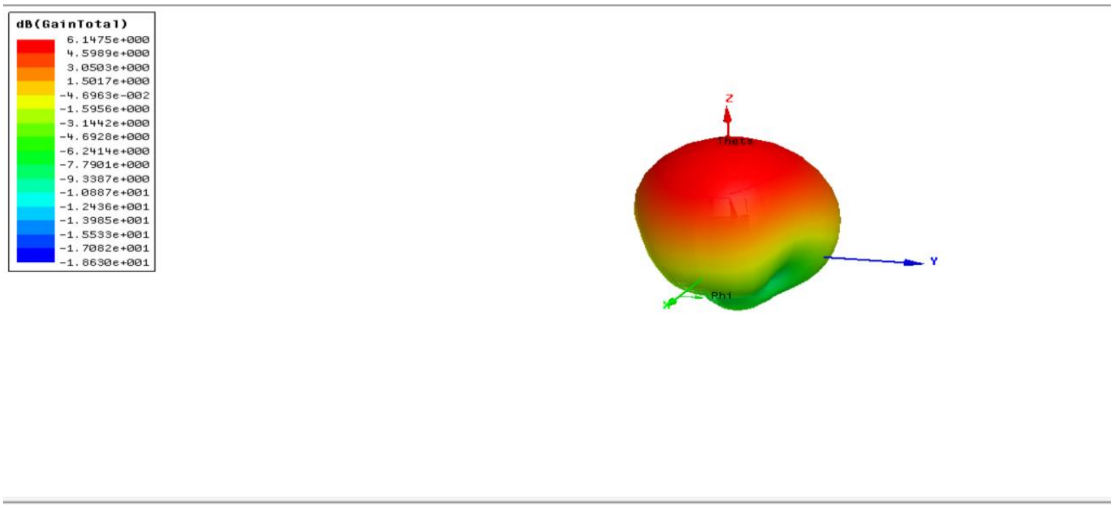


Fig. 6.3 Gain

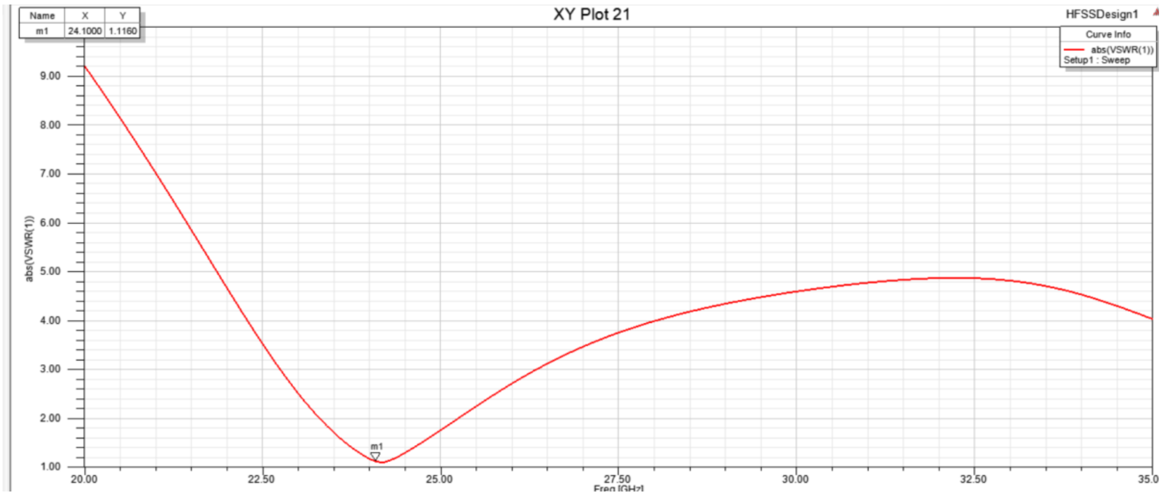


Fig. 6.4 VSWR

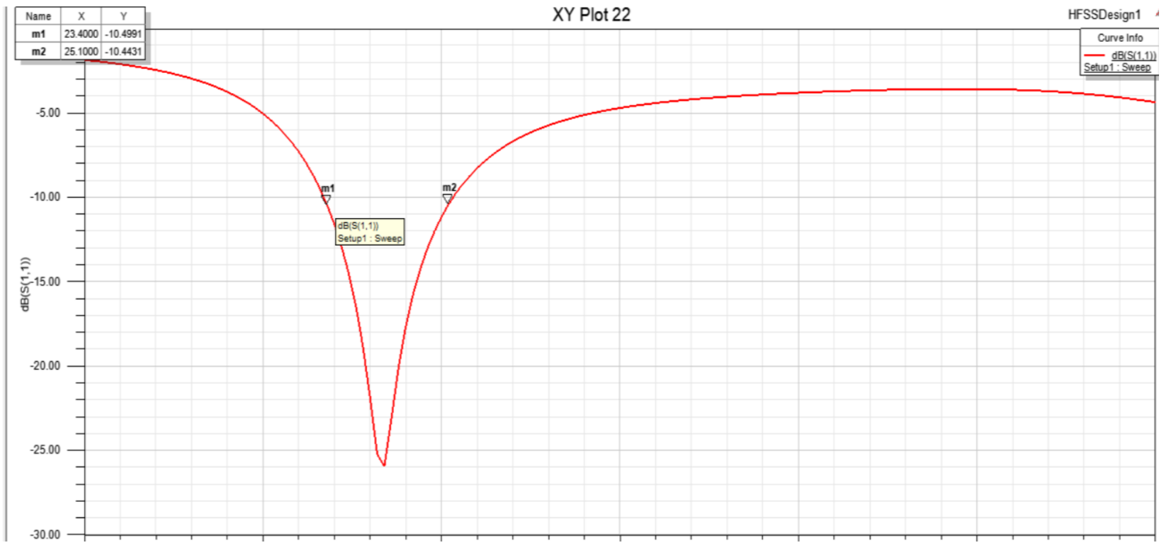


Fig. 6.5 Bandwidth

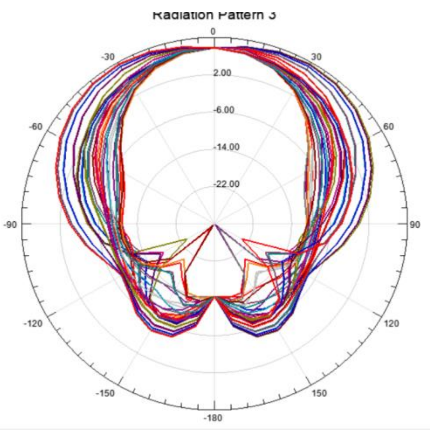


Fig. 6.6 Radiation pattern

6.1.2 RESULTS

Parameter	Value:
Return Loss: VSWR: Gain: Bandwidth:	-25.9424 db 1.1160 6.1475db 2.4 GHZ

6.2 DESIGN OF 1x2 ARRAY ANTENNA

6.2.1 Specifications

- An antenna array (or array antenna) is a set of multiple connected antennas .
- Equal element of regular geometry is used.
- 1X2 antenna array has two antenna unit cells placed together along the same line positioned on the structure.
- In this model , for each element we are using microstrip feedline.
- spacing between 2 patch is λ/4 mm.

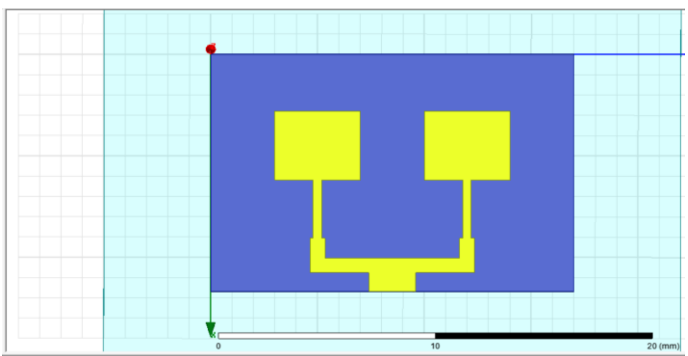


Fig.6.7 Antena structure

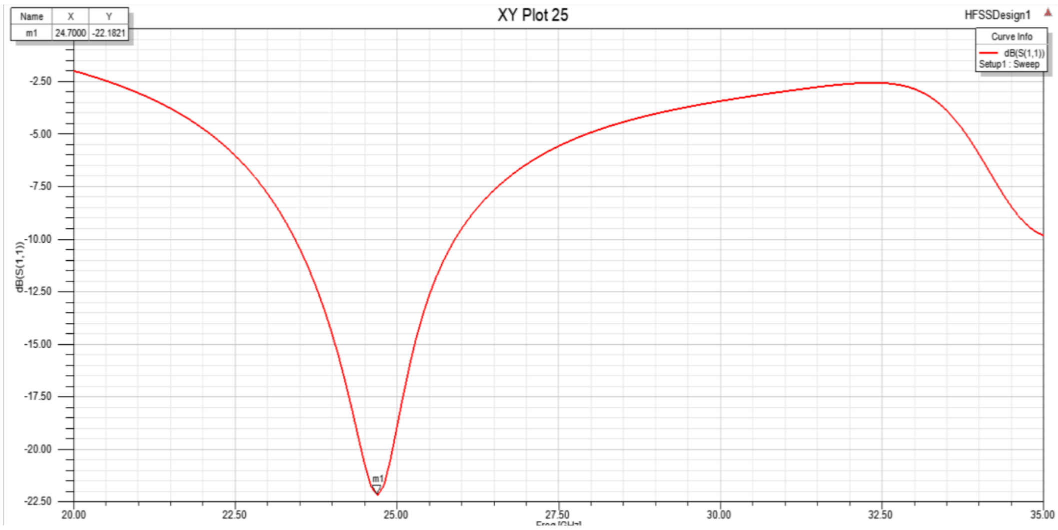


Fig 6.8 Return loss

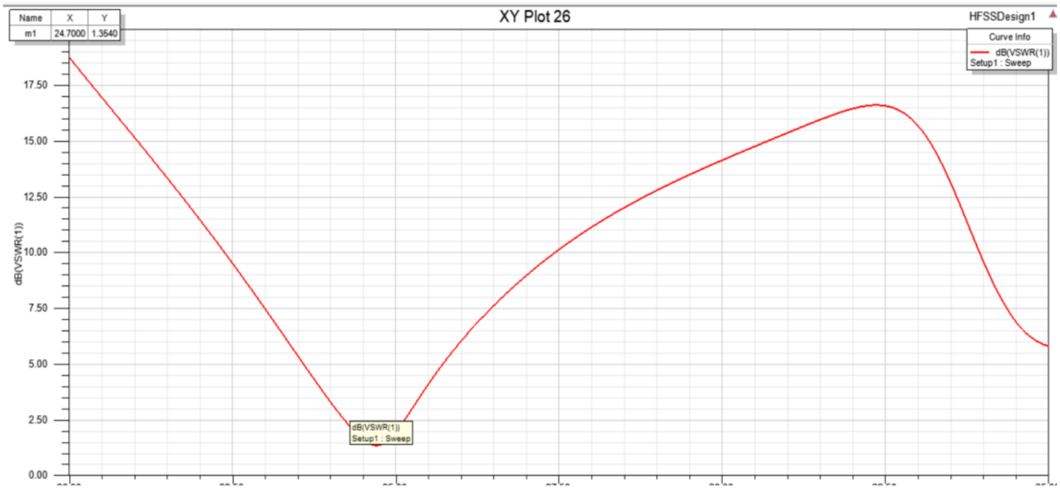


Fig. 6.9 VSWR

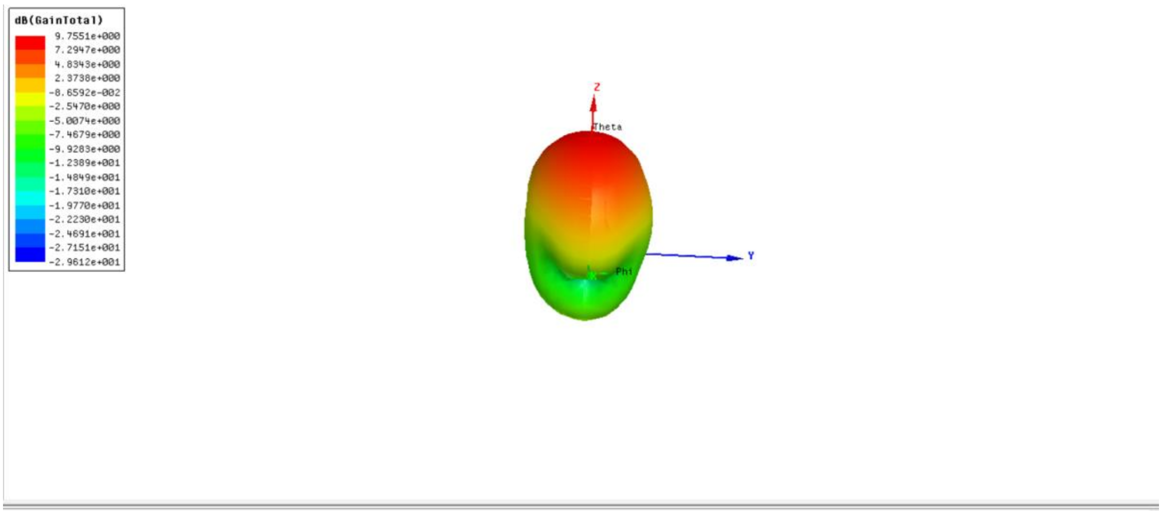


Fig. 6.10 Gain

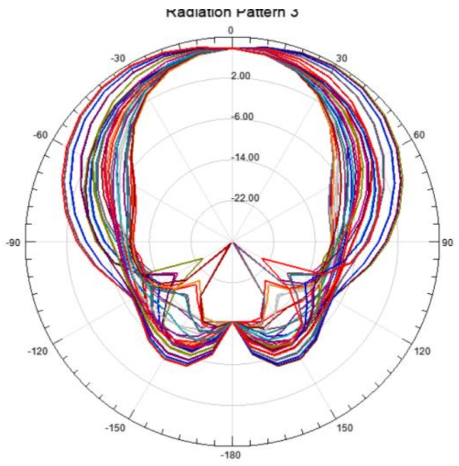


Fig. 6.11 Radiation pattern

6.2.2 Results

Parameter	Value
Return Loss: Resonant frequency: VSWR: Gain: Bandwidth:	-22.181 db 24.7 Ghz 1.354 9.7551 db 2.5 GHZ

6.3 DESIGN OF 1x4 ARRAY ANTENNA

6.3.1 Specifications

- The design of 1X4 array antenna contains four unit cells are placed along the same line positioned on the structure .
- 1X4 array antenna unit cell were designed to improve gain.
- 1x4 array antenna is simulated at 25 GHz. Both of the simulated and measured result show excellent performance comparing to the conventional microstrip patch antenna.
- The antenna array resonants at four different frequencies i.e. 22.4 GHz, 28 GHz, 32.9 GHz and 43.6 GHz.

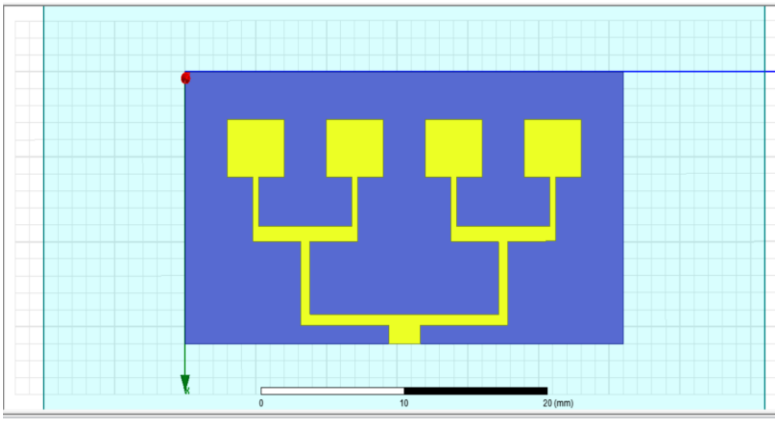


Fig. 6.12 1x4 antenna structure

6.3.2 RESULTS

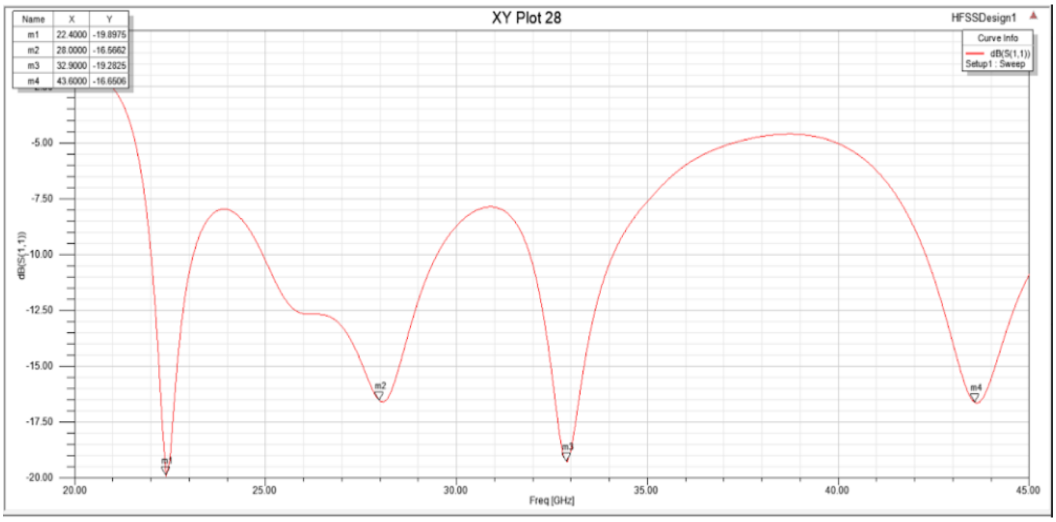


Fig.6.13 Return loss

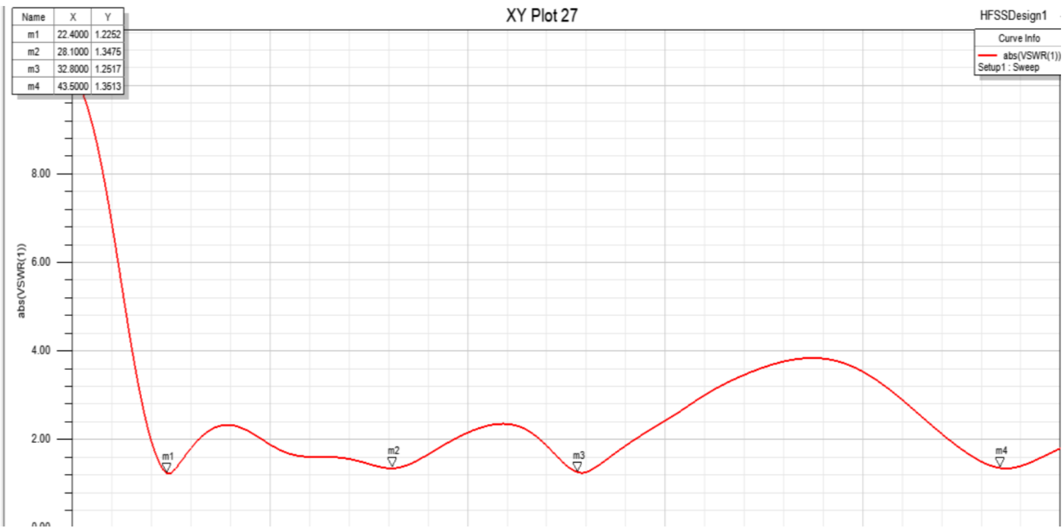


Fig.6.14 VSWR

Fig.6.15 Gain

Results :

Parameter	Results
Return Loss:	-19.8 db,-16.6 db,-19.285 db,-16.2806db
VSWR:	1.2
Gain:	13.751 db
Bandwidth:	1.1Ghz,4.6 Ghz, 2.2 Ghz

6.4 DESIGN OF 2X2 ARRAY ANTENNA

6.4.1 Specifications

- This 2x2 structure achieves low-loss property and wide bandwidth simultaneously.
- This array antenna can used in GSM application because of array formation it gives better radiation and return loss.

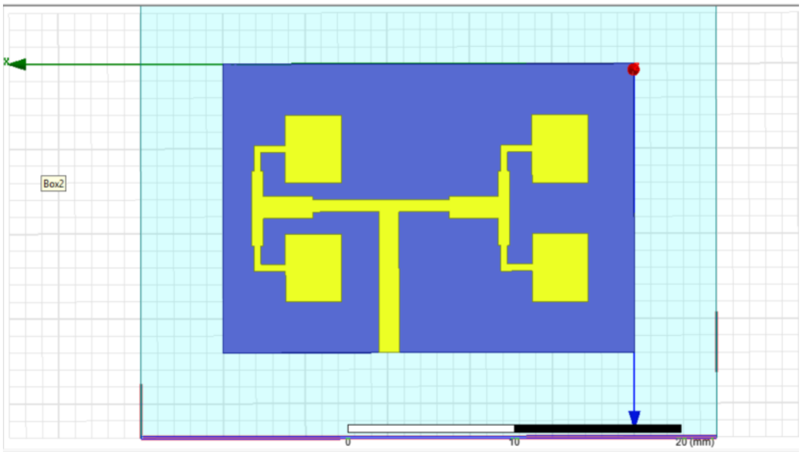


Fig. 6.16 antenna structure

6.4.2 Results

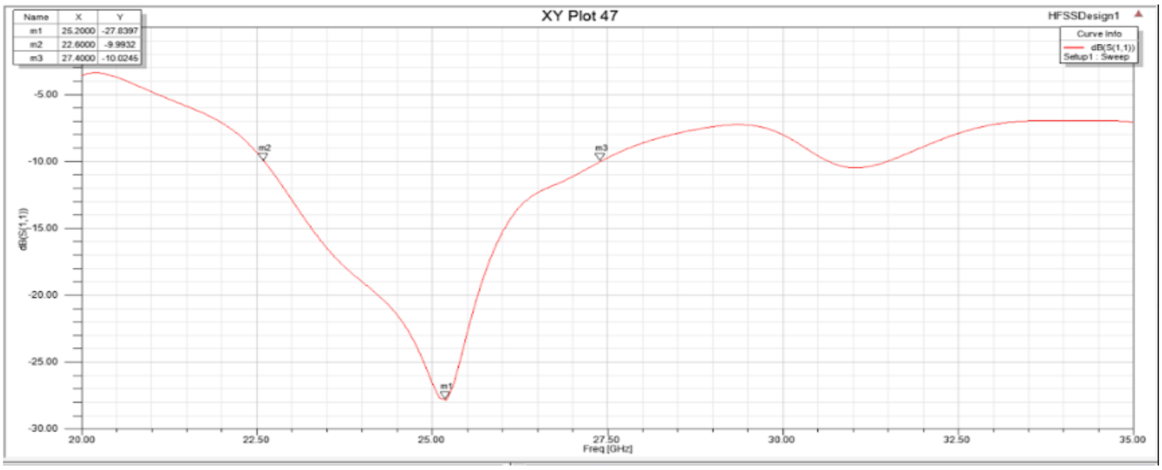


Fig. 6.17 Return loss

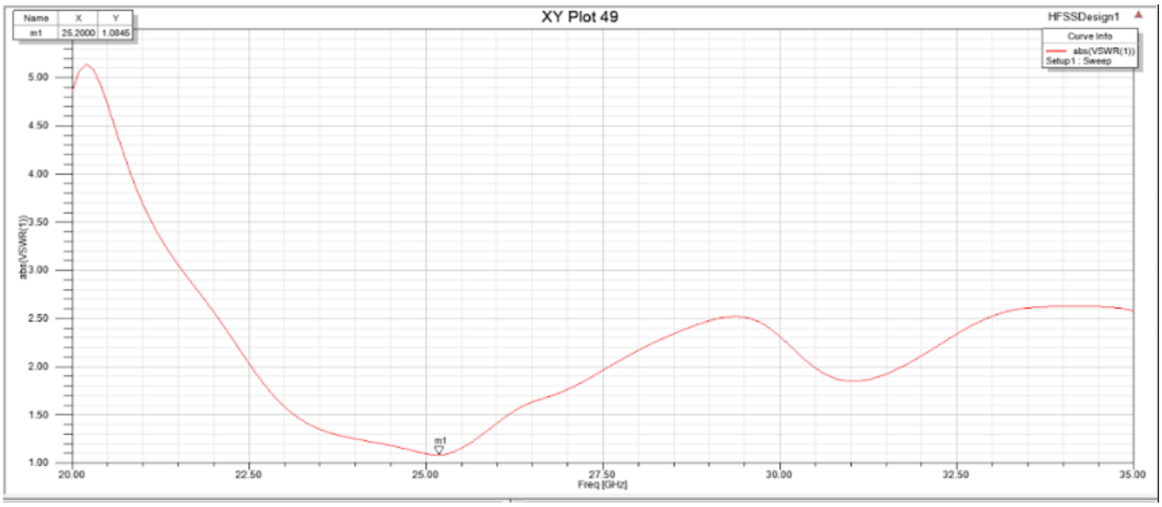


Fig. 6.18 VSWR

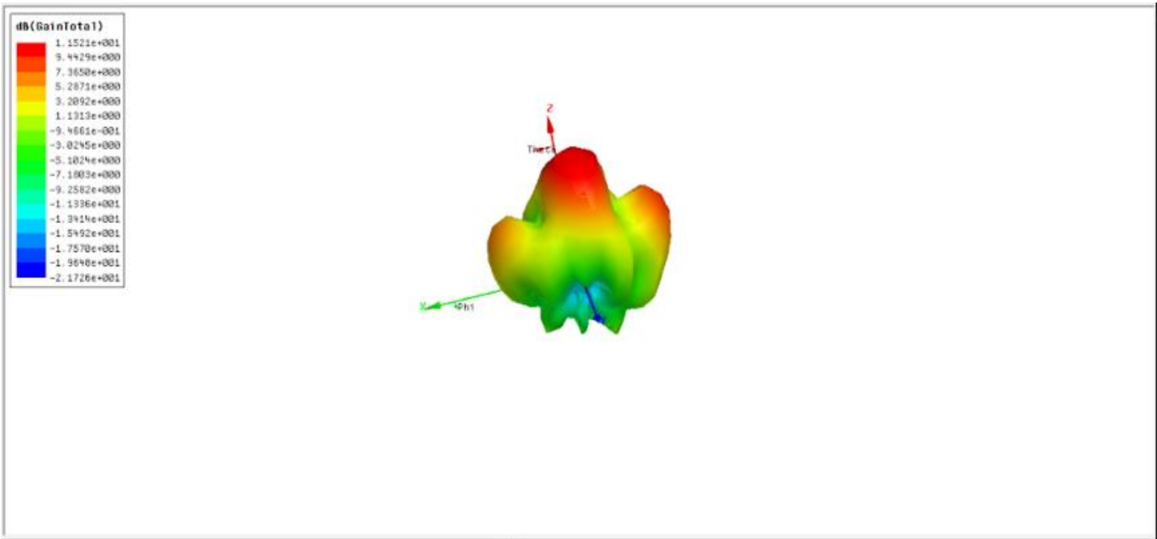


Fig. 6.19 Gain

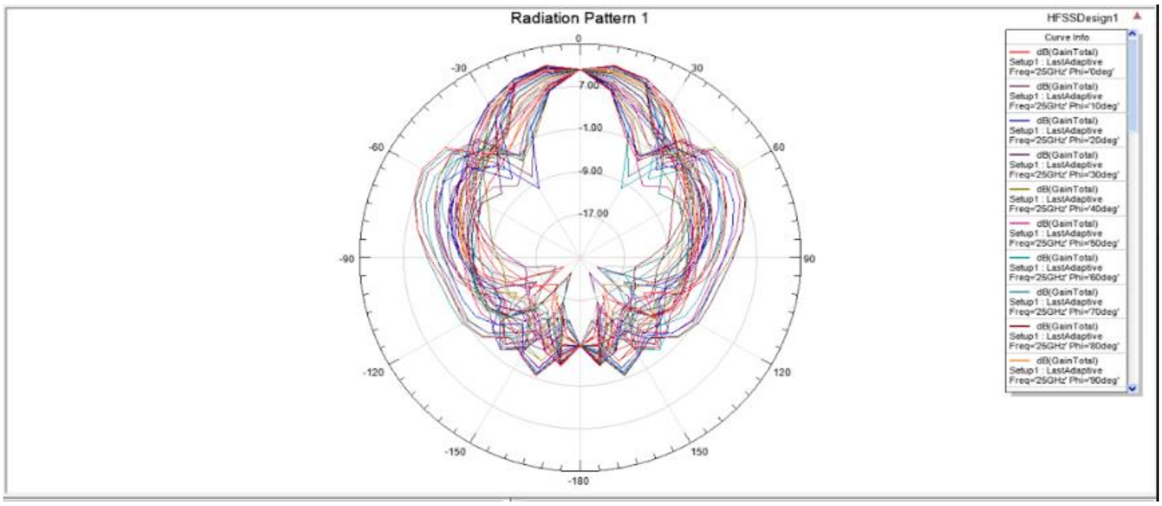


Fig. 6.20 Radiation pattern

Results:

Parameter:	Values:
Return Loss:	-27.8 db
VSWR:	1.0845
Gain:	11.521db
Bandwidth:	4.8 GHZ

6.5 DESIGN OF 4x4 ARRAY ANTENNA

6.5.1 Specifications

- This 4x4 array antenna provides good polarization isolation to support simultaneous transmit and receive communications as desired in 5G communications.
- This array can be used as a base station panel for the Massive Multiple Input Multiple Output (MIMO) array.
- This 4x4 array antenna can avoid long-line effect which is a limit to the bandwidth of the antenna.

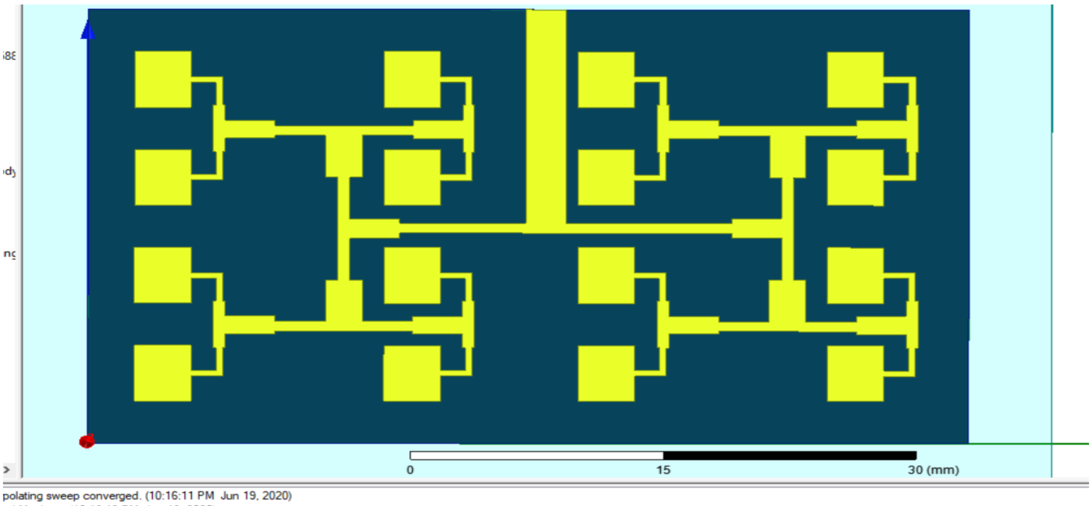


Fig. 6.21 4x4 antenna structure

6.5.2 Results

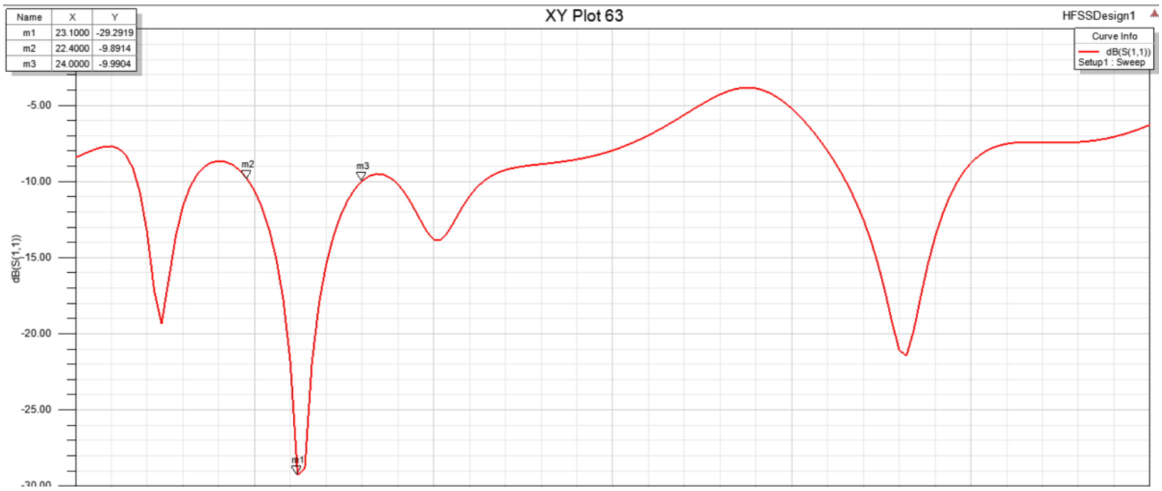


Fig. 6.22 Return loss

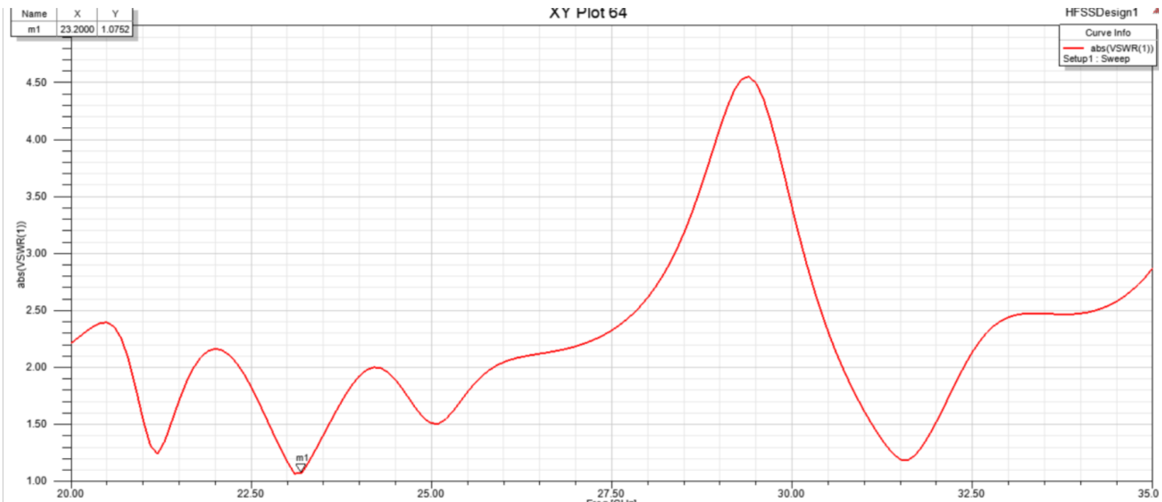


Fig. 6.23 VSWR

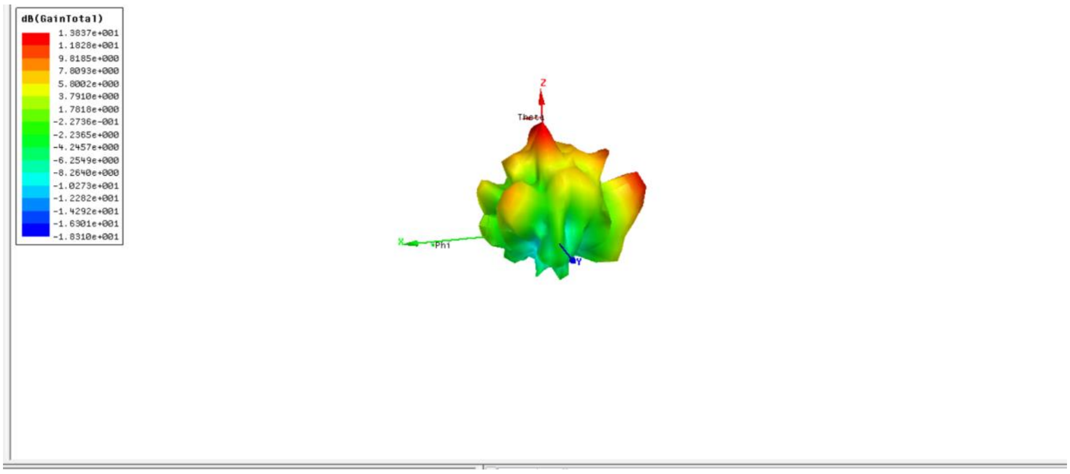


Fig. 6.24 Gain

Results:

Parameter:	Value:
Return Loss: VSWR: Gain: Resonant Frequency: Directivity: Bandwidth:	-29.29 db 1.07 dB 13.837 db 23.2 GHZ 1.3921 1.6 GHZ

6.6 RESULTS & DISCUSSIONS

As we can see an **antenna array** is used to increase overall gain, provide diversity reception, cancel out interference, maneuver the **array** in a particular direction, gage the direction of arrival of incoming signals.It also maximizes signal to interference plus noise ratio.it also gives path diversity(also called MIMO) which increases communication reliability. Other advantages are:

- Signal strength increases
- High directivity is obtained
- Power wastage and minor lobes ae reduced much

Hence overall , it is a much more efficient as compared to patch antenna.

We can see tha gain of 4x4 array antenna is 13.837dB which is more than gain of 2x2 array antenna which is 11.521dB and also more than 1x2 array antenna (9.7551dB) and ofcourse much more than that of a patch antenna which is 6.1475dB.

CHAPTER 7

APPLICATIONS & ADVANTAGES

Antennas are widely used from mobile telecommunications to military services. There are a lot of applications.some are mentioned below:

- Used in satellite communications.
- Used in military radar communications.
- Used in the astronomical study.
- Can be used for path finder or providing guidance to destination for Land, Air or Sea.
- Used as a smart antenna, in turn to align with direction of radiation.
- Any unauthorized persons radiation can be catch hold. This can take care of security aspects (Enemy or other unauthorized person can be captured). This is called application of direction finder.

The antennas can also be used under water, through soil, and rock to certain frequencies of short distance. The basic use of an antenna is to transmit and receive radio waves. When an antenna is tilted to a horizontal position gets much better and down coverage. The multi directional antennas are useful in areas where there are no proper signals. When an antenna is place at a high position is more useful because there will be a proper reception of signals. Antennas are used in radar systems to detect foreign signals. These are mainly used in defense areas. The small directional antennas are used where there is a small place. They are easy to fix and carry.

Hence it is widely used and thus need a lot of research work.

CHAPTER 8

CONCLUSIONS AND SCOPE FOR FUTURE WORK

CONCLUSION

The Microstrip Multiband Patch Antenna design described here is simulated and analysed using HFSS(High Frequency Structural Simulator) software. In this documentation, we have seen the definition of antenna, types of antenna, antenna parameters and about the design of microstrip multiband patch antenna. A detailed explanation of Microstrip patch antenna is disclosed. The desired radiation patterns, bandwidth of the antenna are achieved. Few noteworthy points regarding the design of a multiband microstrip antenna are mentioned in this document. By seeing simulated results, we can say that the single antenna is designed such that it radiates at the desired multiband resonance frequencies and also different array antennas which gives more gain shows it’s more efficient and usable as compared to patch antennas.

FUTURE WORK

This work will be key contribution in the upcoming 5G wireless mobile communication networks infrastructure development and advanced mobile communication services. Future work in this research will be focusing on fabricating and testing antenna in real time applications and tuning this antenna for other major 5G frequency bands for the improvement of its performance and applications.

One key area of foundational research is continued advancements to multiple antenna MIMO technology.

One of the key goals in 5G was to expand cellular to new vertical markets and use cases, and 5G IoT is one area that is generating a lot of interest from both the mobile and industrial ecosystems. 5G will replace today’s wired industrial ethernet to make factories more flexible and reconfigurable. 5G automotive vision is Cellular-Vehicle-to-Everything (C-V2X), which allows cars to communicate, even in non-line-of-slight (NLOS) situations, to other cars (V2V), road infrastructure (V2I), pedestrians (V2P), and networks (V2N).

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APPENDIX A