X band Phased Microstrip Patch Antenna Array with Integrated Heatsink

A PROJECT REPORT

Submitted in the fulfilment of the requirements for

the award of the degree of

Bachelor of Technology
in
Electronics and Communication Engineering

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(ACCREDITED BY **NAAC** WITH **"A+"** GRADE)

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING
(ACCREDITED BY **NBA**)

VIGNAN'S FOUNDATION FOR SCIENCE, TECHNOLOGY AND RESEARCH
(Deemed to be University)

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May 2024.

CERTIFICATE

This is to certify that project report entitled **"X Band Phased Microstrip Patch Antenna Array with Integrated Heatsink"** that is being submitted by Chukka Yeswanth Venkata Ganesh [201FA05046], Shaik Mahammad Maruf [201FA05087] and Vemulapalli Jeevana [211LA05044] in fulfilment for the award of B. Tech degree in Electronics and Communication Engineering, Vignan's Foundation for Science Technology and Research University, is a record of bonafide work carried out by them under the guidance of Dr. Arka Bhattacharyya of ECE Department.

	24/5/24.
Signature of the guide	Signature of Head of the Department
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DECLARATION

We hereby declare that the project report entitled **"X Band Phased Microstrip Patch Antenna Array with Integrated Heatsink"** is being submitted to Vignan's Foundation for Science, Technology and Research (Deemed to be University) in fulfilment for the award of B. Tech degree in Electronics and Communication Engineering. The work was originally designed and executed by us under the guidance of Dr. Arka Bhattacharyya at the Department of Electronics and Communication Engineering, Vignan's Foundation for Science Technology and Research (Deemed to be University) and was not a duplication of work done by someone else. We hold the responsibility of the originality of the work incorporated into this project report.

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ABSTRACT

This project report presents the design, implementation, and performance analysis of an X- band Phased Microstrip Patch antenna array integrated with an innovative heatsink structure. The array is specifically engineered to operate efficiently within the X-band frequency range (8-12 GHz), making it suitable for radar and satellite communication applications. The incorporation of the heatsink is aimed at addressing thermal management issues that commonly arise in high-power antenna systems, thus enhancing the reliability and longevity of the antenna array.

The design employs a 1x4 microstrip patch configuration, optimized through simulation to achieve ideal results in terms of gain, bandwidth, and radiation pattern. The heatsink is seamlessly integrated into the antenna structure, utilizing advanced materials and thermal interface technologies to ensure minimal impact on the antenna's electromagnetic performance.

Comprehensive simulations and experimental results demonstrate that the integrated heatsink significantly reduces the operating temperature of the antenna array without compromising its electrical performance. The phased array capability allows for electronic beam steering, providing a high degree of directional control and flexibility. The measured results indicate a peak gain of 8.99 dBi, a bandwidth of 232 MHz, and a beam steering range of 4 degrees with sidelobe levels maintained below -20 dB and return loss of -25.61dB.

The innovative combination of a phased microstrip patch antenna array with an integrated heatsink presents a robust solution for high-performance X-band applications, ensuring both high efficiency and effective thermal management.

Major Design (Final Year Project Work) Experience Information

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Project Title	X band Phased Microstrip Patch Antenna Array with integrated Heat Sink		
Program Concentration Area	X band Antenna Array where Heat sink acts as antenna		
Program Concentration Area	Electromagnetic Performance Analysis of Microstrip Antenna Array with Integrated Heat Sink		
Constraints – Examples			
Economic	Limited Budget		
Environmental	High Power Radiation		
Sustainability	None		
Manufacturability	Limited Fabrication Facility		
Ethical	None		
Health and Safety	None		
Social	None		
Political	None		
Other	Helps to develop low heat generation in RADAR systems		
Standards			
1. IEEE 145-1973,2023	IEEE standard definitions of terms of antennas		
2. IEEE 521-2019	IEEE standard letter designations for RADARA bands (X band 8-12 GHz)		
3. IEEE 51-1995	Guiding Principles for Dielectric Tests		
Previous Course required for the Major Design Experience	1.Electromagnetics Waves and Transmission Lines(EMTL) 2.Antenna and Wave Propagation(AWP)		

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24/5/24

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LIST OF ACRONYMS AND ABBREVIATIONS

CAD……………………………..Computer Aided Design
CST………………………………Computer Simulation Technology
FNBW……………………………First Null Beam Width
GNSS…………………………….Global Navigation Satellite Systems
GPS………………………………Global Positioning System
HPW……………………………...Half Power Beam Width
IR………………………………….Infrared
MIC……………………………….Microwave Integrated Circuits
MIMO…………………………….Multiple Input Multiple Output
MMIC……………………………..Monolithic Microwave Integrated Circuit
PCB………………………………..Printed Circuit Board
RADAR……………………………Radiation Detection And Ranging
RFIC……………………………….Radio Frequency Integrated Circuits
RFID……………………………….Radio Frequency Identification
TIM………………………………..Thermal Interface Material
VSWR……………………………..Voltage Standing Wave Ratio

CHAPTER 1

INTRODUCTION

1.1 Introduction to X band Phased Microstrip Patch Antenna Array with Integrated Heatsink:

Phased array antennas have revolutionized modern radar, communication, and electronic warfare systems due to their ability to electronically steer beams without moving parts. Among various types of phased arrays, the microstrip phased array stands out for its low profile, lightweight, and ease of fabrication using printed circuit technology. When designed for the X-band frequency range (8 to 12 GHz), these arrays are particularly useful for applications requiring high resolution and rapid beam steering, such as in military radar and satellite communication systems.

Microstrip antennas are constructed with a radiating patch of metal on a grounded dielectric substrate, offering a low-profile and lightweight solution that is easy to produce using standard PCB processes. Their design makes them suitable for mass production and ideal for applications where space and weight are critical considerations. The X-band range provides high gain and directivity, crucial for long-range detection and high data rate communication, making it a preferred choice for applications requiring detailed imaging and precise communication.

One of the major challenges faced by X-band phased microstrip phased arrays is thermal management. High-power operation in these arrays generates significant heat, which can degrade performance and reliability. Excessive heat can alter the antenna’s impedance characteristics, reduce efficiency, and potentially damage electronic components. Effective thermal management is therefore critical to maintain performance and reliability. Integrating heatsinks directly into the array structure offers a solution to this challenge, providing efficient heat dissipation while maintaining the antenna's electromagnetic performance.

The integration of heatsinks into microstrip phased arrays requires careful design to ensure minimal interference with the antenna's electromagnetic properties. This involves the use of high thermal conductivity materials such as copper and aluminum, which efficiently transfer heat away from the active components of the array. Advanced thermal management techniques, including heat spreaders and embedded heat pipes, can further enhance heat dissipation capabilities. The integration process can be achieved using standard PCB manufacturing techniques, maintaining the compact and lightweight advantages of microstrip antennas.

By incorporating heatsinks within the array structure, the overall design remains compact and lightweight, crucial for applications with stringent size and weight constraints, such as airborne and spaceborne systems. This integration not only ensures efficient thermal management but also enhances the reliability of the phased array system by reducing the risk of thermal-induced failures. Maintaining optimal operating temperatures allows the phased array to deliver consistent performance without degradation due to thermal stress.

Thermal interface materials (TIMs) improve thermal contact between the heatsink and heat-generating components, filling microscopic air gaps to enhance heat transfer. The heatsink design, including fin structures and airflow considerations, must be carefully planned to ensure minimal impact on the antenna's electromagnetic properties.

Integrating heatsinks into X-band phased microstrip phased arrays effectively addresses the challenge of thermal management, allowing these systems to operate at high power levels while maintaining their compact and lightweight form factor. This innovation supports the development of advanced radar and communication systems with enhanced performance, reliability, and operational lifespan. As technology evolves, the combination of efficient thermal management and advanced phased array capabilities will continue to drive progress in aerospace, defense, and telecommunications sectors.

1.2 Motivation

The motivation to design an X-band phased microstrip phased array with an integrated heatsink stems from the critical need to enhance the performance, reliability, and operational efficiency of modern radar and communication systems. In various high-stakes applications, such as military radar, satellite communications, and advanced sensing systems, the ability to achieve rapid and precise beam steering is essential. Phased array antennas, particularly those operating in the X-band frequency range (8 to 12 GHz), are ideally suited for these purposes due to their high resolution and excellent directivity.

However, one of the significant challenges in deploying high-power phased array systems is effective thermal management. High-power operation in these systems generates substantial heat, which can severely affect the performance and longevity of the antennas. Excessive heat can lead to changes in the antenna's impedance characteristics, reduced efficiency, and potential damage to critical electronic components. These thermal issues can result in degraded signal quality, reduced reliability, and increased maintenance costs, which are unacceptable in critical applications such as defense and aerospace.

The integration of heatsinks directly into the microstrip phased array design addresses these thermal management challenges by providing a robust solution for efficient heat dissipation. This integration ensures that the system can maintain optimal operating temperatures, thereby enhancing the performance and reliability of the antenna array. The use of high thermal conductivity materials, such as copper and aluminum, in the heatsink design, coupled with advanced thermal management techniques like heat spreaders and embedded heat pipes, allows for effective heat transfer away from active components.

In summary, the motivation to design an X-band phased microstrip phased array with an integrated heatsink is driven by the need to enhance performance, reliability, and operational efficiency in critical radar and communication systems. This design addresses the pressing issue of thermal management, preserves the benefits of microstrip technology, and supports the development of robust, reliable, and cost-effective phased array systems for a wide range of high-stakes applications.

1.3 Literature Survey

[1] High gain microstrip array antennas were designed and analyzed specifically for X-band RADAR applications. These antennas are excited using the inset feeding technique and are tuned to a center operating frequency of 10 GHz. All antennas utilize the Rogers RT/duroid 5880™ substrate, which has a relative permittivity of 2.2. The operating band achieved ranges from 9.77 GHz to 10.15 GHz, providing a bandwidth of 380 MHz

The proposed 2×4 element array features a peak gain of 15.5 dB, directivity of 15.82 dBi, and a return loss of 30.27 dB. For beam steering, a 1×4 elements array employs a switched line phase shifter, achieving a beam direction of (θ, φ) = (16º, 0). This configuration provides a half power beam width (HPBW) of 16.88º, a return loss of -33.28 Simulations for these designs were conducted using the ANSYS high-frequency structural simulator (HFSS).

In related work, dB, a voltage standing wave ratio (VSWR) of 1.04, and a high bandwidth of 880 MHz. a 32×8 high-gain microstrip array designed using CST for the X-band at 9.37 GHz demonstrated a gain of 28 dB, a side lobe level of -25 dB, and an HPBW of 5º in the E-plane and 10º in the H-plane.

This paper contributes a 2×4 elements microstrip array antenna and a 1×4 elements beam steering array antenna for X-band RADAR applications, highlighting the potential for high gain and efficient beam steering.

RADAR systems are used for remote object detection and tracking. Microstrip patch array antennas are preferred due to their high gain, low profile, lightweight, and precise radiation pattern control. Beam steering is achieved electronically using switched line phase shifters. Previous studies have explored patch array antennas for marine RADAR, Wi-Fi, and X-band applications. This paper focuses on designing and characterizing a high- gain microstrip patch array antenna for X-band RADAR applications.

[2] The development of a multi-layer cavity-backed 16x16 planar array specifically tailored for X-band RADAR applications. The main goal is to create an antenna configuration suitable for phased array radar operation within the X-band frequency range of 9-10 GHz. Employing E-shaped patch antenna elements, the array is meticulously crafted to function within a bandwidth of 1 GHz (8.8 GHz to 9.8 GHz), with the potential for customization up to a 2 GHz bandwidth.

Simulation results highlight promising performance metrics. These include a return loss exceeding 10 dB over the frequency range of 8.9-10.1 GHz and a consistent gain of 28±0.3 dBi across the entire operational frequency band. Furthermore, the antenna exhibits a beamwidth of 6.4° in the E-plane and 5.9° in the H-plane, along with impressive front-to-back ratio and cross-polarization levels surpassing 13 dB and 20 dB, respectively.

In terms of implementation, the antenna is deployed for ±60° azimuth and ±45° elevation scanning in an active phased array airborne radar. This underscores the importance of achieving both high efficiency and wide bandwidth for X-band phased array radar applications. The study thus contributes valuable insights into advancing radar capabilities within the X-band spectrum.

[3] The paper focuses on the design and analysis of a 2x3 phased array microstrip patch antenna tailored for GNSS (Global Navigation Satellite System) augmentation. The introduction highlights the significance of antennas in the context of rapid technological advancements in wireless communication. Microstrip patch antennas, favored for their compact size and gain, have become prevalent, especially in satellite communication where higher gain often necessitates array configurations. Phased array antennas, known for their higher gain and beam scanning capabilities, are extensively employed in various applications, including satellite communication, radar, and GNSS augmentation systems

CST Microwave Studio is employed for design, examination, and observation of crucial antenna parameters. Key terms such as Phased Array Antenna, VSWR (Voltage Standing Wave Ratio), S-Parameter, Scan Angle, and Array Factor are emphasized for understanding the antenna's capabilities and performance metrics. In conclusion, the 2x3 phased array antenna designed for GNSS augmentation offers beam scanning capabilities and improved performance within the Galileo E6 signal band, catering to the evolving demands of satellite navigation systems.

[4] This paper introduces a novel design concept that integrates a heatsink with an antenna, aiming to achieve controllable and optimum electromagnetic (EM) and thermal dissipation performance. The primary objective is to design and implement an antenna with an integrated heatsink, addressing challenges such as miniaturization of wireless communication and radar systems, managing parasitic couplings, localized heat dissipation, and reliability concerns.

The methodology involves connecting the heatsink to the antenna using Microelectromechanical Systems (MEMS) cantilever switches. This integrated heatsink, co-designed with the antenna, demonstrates notable improvements, including temperature reduction of 14°C (when switches are OFF) and 27°C (when switches are ON), along with controllable reflection coefficient (-23 dB when OFF and -15 dB when ON) and increased gain of 8.1 dB from 5.9 dB, enhancing EM performance.

The integration approach emphasizes addressing EM compatibility and volume issues by integrating the heatsink with the antenna. MEMS cantilever switches play a crucial role in controlling the connection state between the heatsink and antenna, strategically positioned away from the resonating edges to prevent performance interference.

Design optimization efforts focus on achieving better EM performance through heatsink antenna design optimization, highlighting the potential for improved performance in wireless communication systems. Overall, this innovative approach combines EM and thermal management, offering promising prospects for enhancing performance and reliability in wireless communication systems.

[5] This research investigates the heat sink properties of a 4x2 wideband dual linear polarized phased array antenna designed for operation in the X-band frequency range. The antenna comprises 3D metal printed all-metallic radiators, which serve both as radiating elements and heat sinks. Key design features include two single radiators with a height nearly equal to $\lambda/2$, shaped intuitively and placed orthogonal to each other. A metal ring of square cross-section surrounds the radiators, forming the dual linear polarized radiating element, while orthogonal strip line feeds through a trapezium-shaped metal plate feed the radiators. Via fences placed beneath each antenna element serve as thermal paths between the beamforming network (BFN) and the antenna aperture.

Performance characteristics of the antenna include a wide impedance bandwidth of 8.5-11.5 GHz, good radiation patterns with low cross-polarization throughout the bandwidth, and a peak broadside gain ranging between 14-11 dBi. Beam scans are viable up to ±50° in the $\phi = 0°$ plane and ±30° in the $\phi = 90°$ plane. Integration involves building the array antenna aperture using 3D metal printing technology, with a BFN comprising commercial silicon Radio Frequency Integrated Circuit (RFIC) chips integrated into the antenna aperture. A beamforming algorithm is applied through a serial peripheral interface (SPI) controller during the measurement process to achieve beam steering.

The heat sink structure successfully achieves a temperature reduction of 60°C, with temperature distribution comparison between the BFN with and without the heat sink validating its effectiveness. The heat sink antenna maintains a temperature of only 41°C, confirmed using an infrared (IR) camera. Index terms associated with the research include heat sink, 3D metal printed, dual linear polarized, phased array, RFIC, and beamforming. Overall, this research contributes to the advancement of high-speed wireless communication systems for naval ships, emphasizing stable radiation patterns, high gain, and beam steering properties.

CHAPTER 2

ANTENNAS

2.1 INTRODUCTION

In the 1890s, there were only a few antennas in the world. These rudimentary devices were primarily a part of experiments that demonstrated the transmission of electromagnetic waves. By World War II, antennas had become so ubiquitous that their use had transformed the lives of the average person via radio and television reception. The number of antennas in the United States was on the order of one per household, representing growth rivalling the auto industry during the same period. By the early 21st century, large part to mobile phones, the average person now carries one or more antennas on them wherever they go (cell phones can have multiple antennas, if GPS is used, for instance). This significant rate of growth is not likely to slow, as wireless communication systems become a larger part of everyday life. In addition, the strong growth in RFID devices suggests that the number of antennas in use may increase to one antenna per object in the world (product, container, pet, banana, toy, cd, etc.). This number would dwarf the number of antennas in use today. An antenna is defined as "a metallic device (as a rod or wire) for radiating or receiving the radio waves". The IEEE Standard Definitions of Terms for Antennas [IEEE 145-1973,2023] defines the antenna or aerial as "a means for radiating or receiving radio waves". The following Figure 2.1 shows the basic antennas.

Fig 2.1. Basic Antenna

In other words, the antenna is the transitional structure between free-space and a guiding device, as shown in Figure 2.2. The guiding device or transmission line may take the form of a coaxial line or a hollow pipe (waveguide), used to transport electromagnetic energy from the transmitting source to the antenna, or from the antenna to the receiver. The reflected waves from the interface create, along with the travelling waves from the source toward the antenna, constructive and destructive interference patterns, referred to as standing waves, inside the transmission line which represent pockets of energy concentrations and storage, typical of resonant devices.

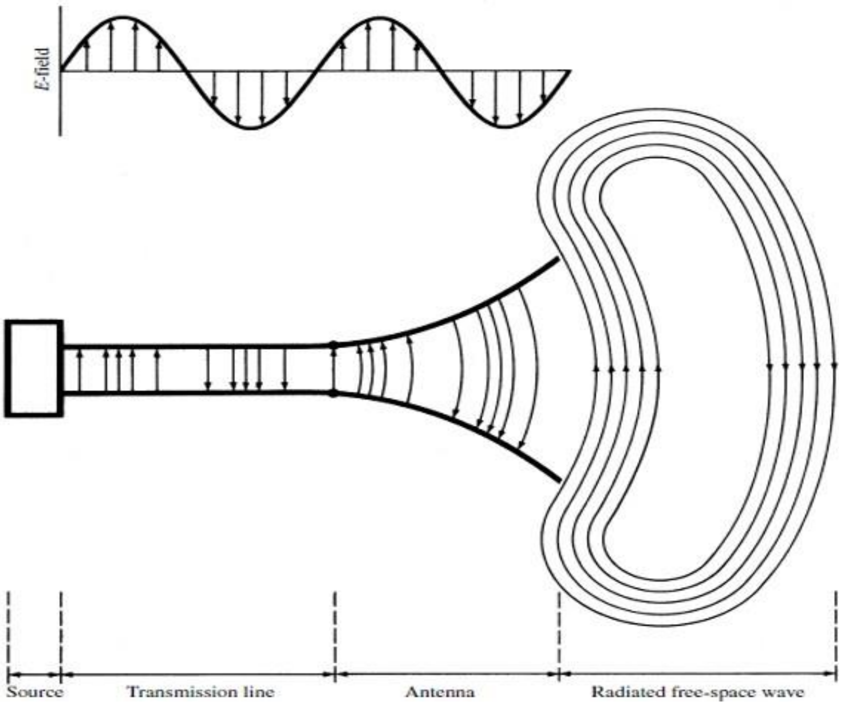


Fig 2.2. Antenna as a Transitional device

A transmission-line Thevenin equivalent of the antenna system of Figure 2.2 in the transmitting mode is shown in Figure 2.3as follows, where the source is represented by an ideal generator, the transmission line is represented by a line with characteristic impedance ZC, and the antenna is represented by a load.

ZA [ZA= (RL + Rr) +jXA]

Where, RL=Load resistance,

Rr =Radiation resistance,

XA=Impedance reactance.

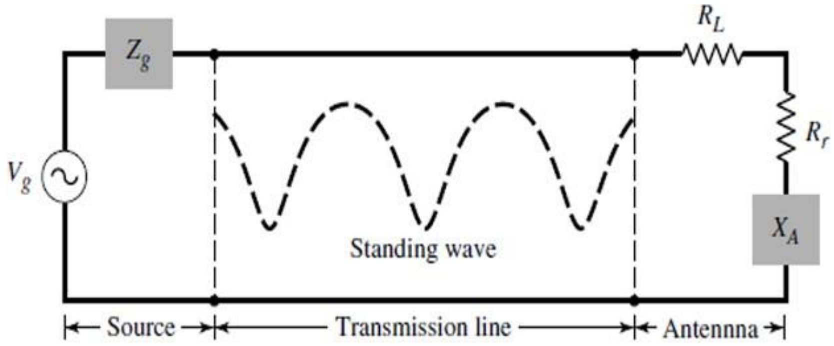


Figure.2.3 Transmission-line Thevenin equivalent of antenna in transmitting mode

The reflected waves from the interface create, along with the travelling waves from the source toward the antenna, constructive and destructive interference patterns, referred to as standing waves, inside the transmission line which represent pockets of energy concentrations and storage, typical of resonant devices. A typical standing wave pattern is shown dashed in Figure 2.2. If the antenna system is not properly designed, the transmission line could act to a large degree as an energy storage element instead of as a wave guiding and energy transporting device.

If the maximum field intensities of the standing wave are sufficiently large, they can cause arching inside the transmission lines. The losses due to the line, antenna, and the standing waves are undesirable. The losses due to the line can be minimized by selecting low-loss lines while those of the antenna can be decreased by reducing the loss resistance represented by RL in Figure 2.3. The standing waves can be reduced, and the energy storage capacity of the line minimized, by matching the impedance of the antenna (load) to the characteristic impedance of the line.

In addition to receiving or transmitting energy, an antenna in an advanced wireless system is usually required to optimize 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, and it may be a piece of conducting wire, an aperture, a patch, an assembly of elements (array), a reflector, a lens, and so forth. For wireless communication systems, the antenna is one of the most critical components.

A good design of the antenna can relax system requirements and improve overall system performance. A typical example is TV for which the overall broadcast-reception can be improved by utilizing a high-performance antenna. The antenna serves to a communication system the same purpose that eyes and eyeglasses serve to a human.

2.2. TYPES OF ANTENNAS

There are various types of antennas and they include wire antennas, aperture antennas, reflector antennas, lens antennas, micro-strip antennas and array antennas. However, after giving a brief idea on wire antennas, aperture antennas, reflectors and lens antennas emphasis will be given to micro-strip patch antennas. The different types of antennas are discussed below. 2.2.1 Wire Antennas Wire antennas are familiar to the layman because they are seen virtually everywhere on automobiles, buildings, ships, aircraft, spacecraft, and so on. There are various shapes of wire antennas such as a straight wire (dipole), loop, and helix which are shown in Figure 2.4 as,

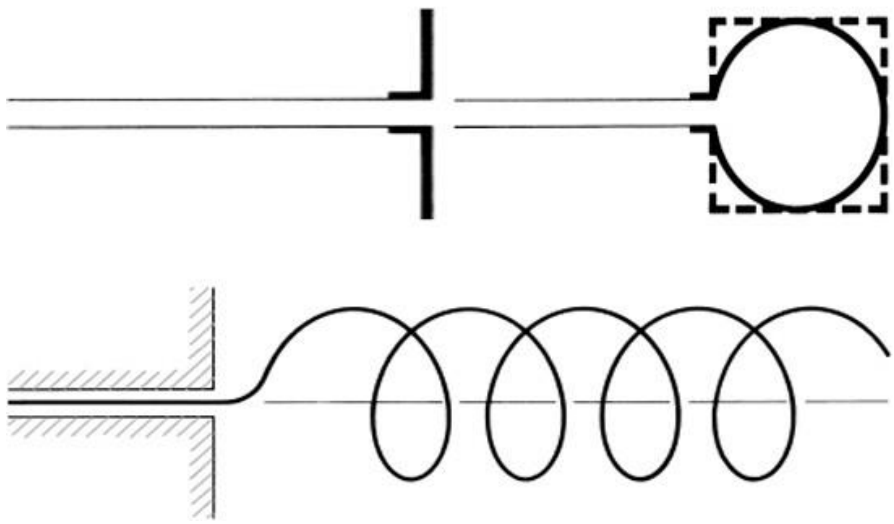
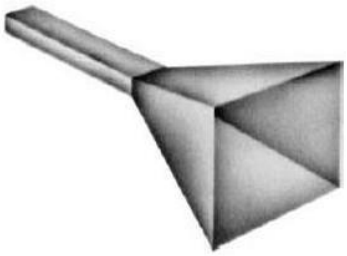


Figure.2.4 Dipole, Loop and Helix antenna shapes

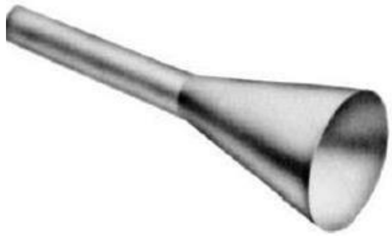
Loop antennas need not only be circular. They may take the form of a rectangle, square, ellipse, or any other configuration. The circular loop is the most common because of its simplicity in construction. Wire antennas need to be made a bit long and cut to resonance. They are affected by height above the ground and surrounding objects. In order to get an idea of the right place to start, certain formulas are generally accepted.

2.2.1 Aperture Antennas

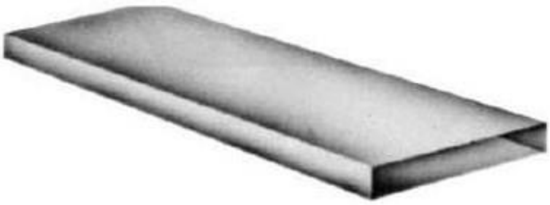
Aperture antennas may be more familiar to the layman today than in the past because of the increasing demand for more sophisticated forms of antennas and the utilization of higher frequencies. Some forms of aperture antennas are shown in Figure 2.5 as,



(a) Pyramidal horn



(b)Conical horn



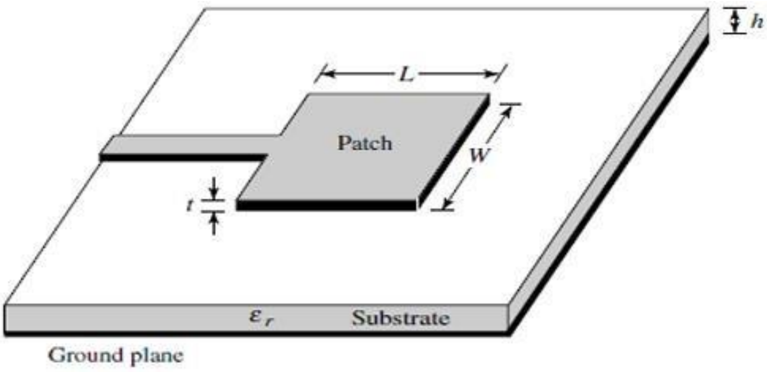
(c) Rectangular Wave guide

Figure.2.5 Aperture antenna configurations

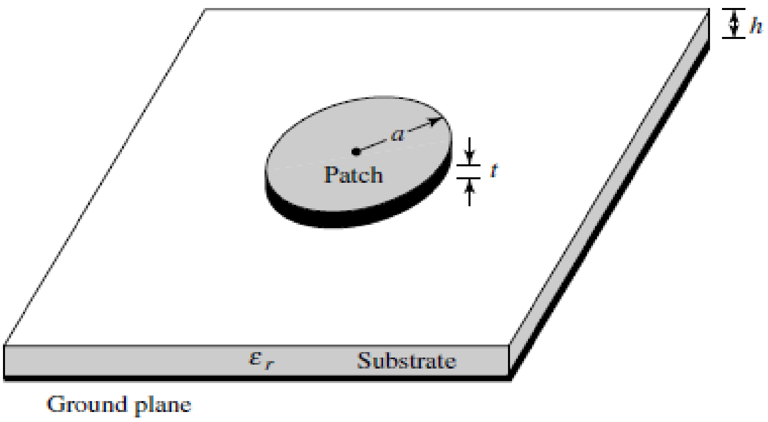
Antennas of this type are very useful for aircraft and spacecraft applications, because they can be very conveniently flush-mounted on the skin of the aircraft or spacecraft. In addition, they can be covered with a dielectric material to protect them from hazardous conditions of the environment.

2.2.2 Micro-strip Antennas

Micro-strip antennas consist of a metallic patch on a grounded substrate. The metallic patch can take many different configurations. However, the rectangular and circular patches, shown in Figure 2.6, are the most popular because of ease of analysis and fabrication, and their attractive radiation characteristics, especially low cross-polarization radiation. The micro-strip antennas are low profile, comfortable to planar and non-planar surfaces, simple and inexpensive to fabricate using modern printed-circuit technology, mechanically robust when mounted on rigid surfaces, compatible with MMIC designs, and very versatile in terms of resonant frequency, polarization, pattern, and impedance.



(a) Rectangular



(b) Circular

Figure.2.6 Rectangular and circular micro-strip (patch) antennas.

2.2.3 Reflector Antennas

The success in the exploration of outer space has resulted in the advancement of antenna theory. Because of the need to communicate over great distances, sophisticated forms of antennas had to be used in order to transmit and receive signals that had to travelmillions of miles. A very common antenna form for such an application is a parabolic reflector .Antennas of this type have been built with diameters as large as 305m.Such largedimensions are needed to achieve the high gain required to transmit or receive signals after millions of miles of travel. Another form of a reflector, although not as common as the parabolic, is the corner reflector.

2.2.4 Lens Antennas

Lenses are primarily used to collimate incident divergent energy to prevent it from spreading in undesired directions. By properly shaping the geometrical configuration and choosing the appropriate material of the lenses, they can transform various forms of divergent energy into plane waves. They can be used in most of the same applications as are the parabolic reflectors, especially at higher frequencies. Their dimensions and weight become exceedingly large at lower frequencies. Lens antennas are classified according to the material from which they are constructed, or according to their geometrical shape.

2.3. BASIC ANTENNA PARAMETERS

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. Antenna is chosen for operation in a particular application according to its physical and electrical characteristics. Furthermore, the antenna must perform in a required mode for the particular measurement system. Typically, antenna characteristics are measured in two principal planes and they are knownas azimuth and elevation planes, which can also be considered as the horizontal and verticalplanes.

2.3.1 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 regionand is represented as a function of the directional coordinates. Radiation properties includepower flux density, radiation intensity, field strength, directivity, phase or polarization.”Aconvenient set of coordinates is shown in Figure 2.7. 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 arenormalized 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). This scale is usually desirable because a logarithmic scale can accentuate in more details those parts of the pattern that have very low values, which laterwe will refer to as minor lobes.

For an antenna, the field and power pattern given as,

(a). field pattern (in linear scale) typically represents a plot of the magnitude of the electricor magnetic field as a function of the angular space.

(b). power pattern (in linear scale) typically represents a plot of the square of the magnitudeof the electric or magnetic field as a function of the angular space.

(c). power pattern (in dB) represents the magnitude of the electric or magnetic field, in decibels, as a function of the angular space.

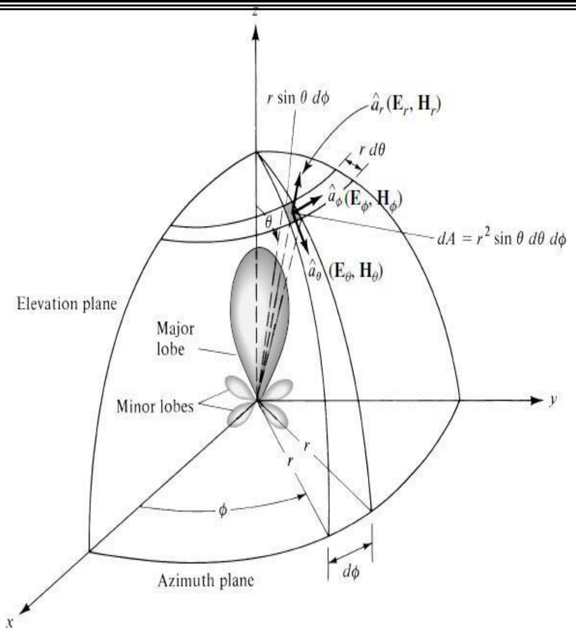
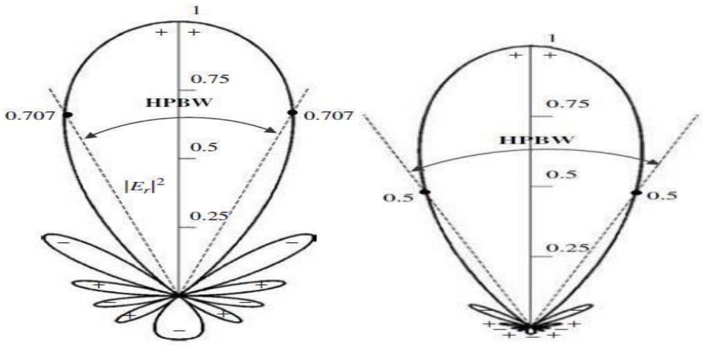
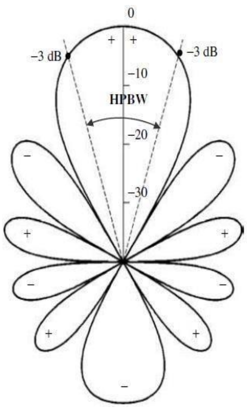


Figure.2.7 Coordinate system for antenna analysis.

To demonstrate this, the two-dimensional normalized field pattern (plotted in linear scale),power pattern (plotted in linear scale), and power pattern (plotted on a logarithmic B scale) of a 10-element linear antenna array of isotropic sources, with a spacing of d= 0.25λbetween the elements, are shown in Figure 2.8.



(a)Field pattern (in linear scale) (b) Power pattern (in linear scale)



(c) Power pattern (in dB)

Figure. 2.8 Two-dimensional normalized field pattern (linear scale), power pattern (linearscale), and power pattern (in dB) of a 10-element linear array with a spacing of d = 0.25λ.

In this and subsequent patterns, the plus (+) and minus (−) signs in the lobes indicate the relative polarization of the amplitude between the various lobes, which changes (alternates) as the nulls are crossed. To find the points where the pattern achieves its half-power (−3 dB points), relative to the maximum value of the pattern, you set the value of the following:(a). field pattern at 0.707 value of its maximum, as shown in Figure 2.8(a)

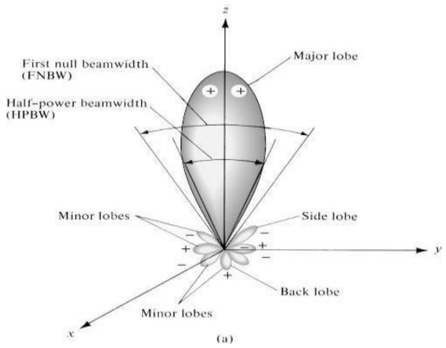
(b). power pattern (in a linear scale) at its 0.5 value of its maximum, as shown inFigure 2.8(b)

(c). power pattern (in dB) at −3 dB value of its maximum, as shown in Figure 2.8(c).

(d).

2.3.1.1 Radiation Pattern Lobes

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 ofthe radiation pattern bounded by regions of relatively weak radiation intensity." Figure 2.9(a) 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 aslob



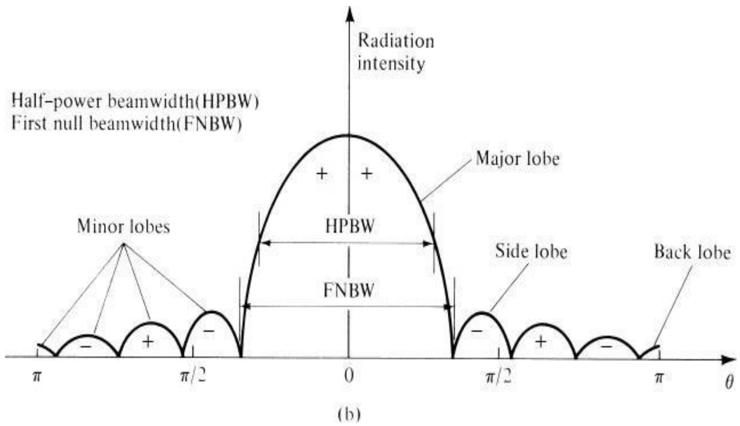


Figure.2.9 (a) Radiation lobes and beam widths of an antenna pattern. (b)Linear plot of power pattern and its associated lobes and beam widths.

A major lobe (also called main beam) is defined as “the radiation lobe containing the direction of maximum radiation.” In Figure 2.9 the major lobe is pointing in the $\theta = 0$ direction. In some antennas, such as split-beam antennas, there may exist more than one major lobe. A minor lobe is any lobe except a major lobe. In Figures 2.9(a)and (b) all the lobes with the exception of the major can be classified as minor lobes. 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$180^{\circ}$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.

2.3.2 Field Regions

The space surrounding an antenna is usually subdivided into three regions: (a) reactive near-field, (b) radiating near-field (Fresnel) and (c) far-field (Fraun hofer) regions as shown in Figure 2.10. These regions are so designated to identify the field structure in each.

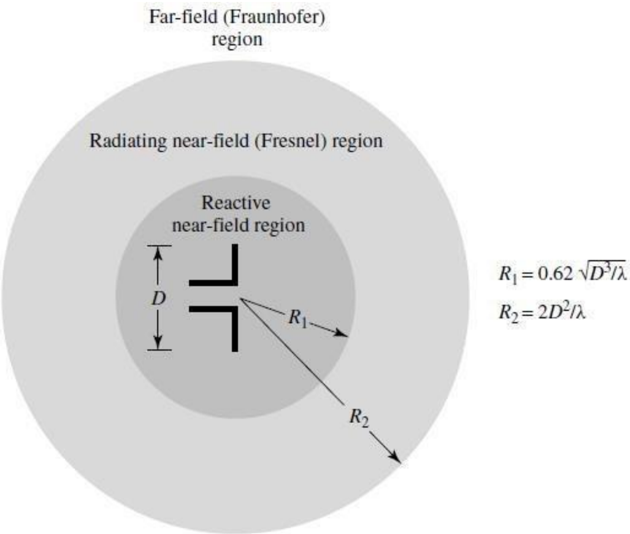


Figure.2.10 Field regions of an antenna.

Reactive near-field region is defined as “that portion of the near-field region immediately surrounding the antenna wherein the reactive field predominates.”

Radiating near-field (Fresnel) region is defined as “that region of the field of an antenna between the reactive near-field region and the far-field region where in radiation fields predominate and wherein the angular field distribution is dependent upon the distance from the antenna.”

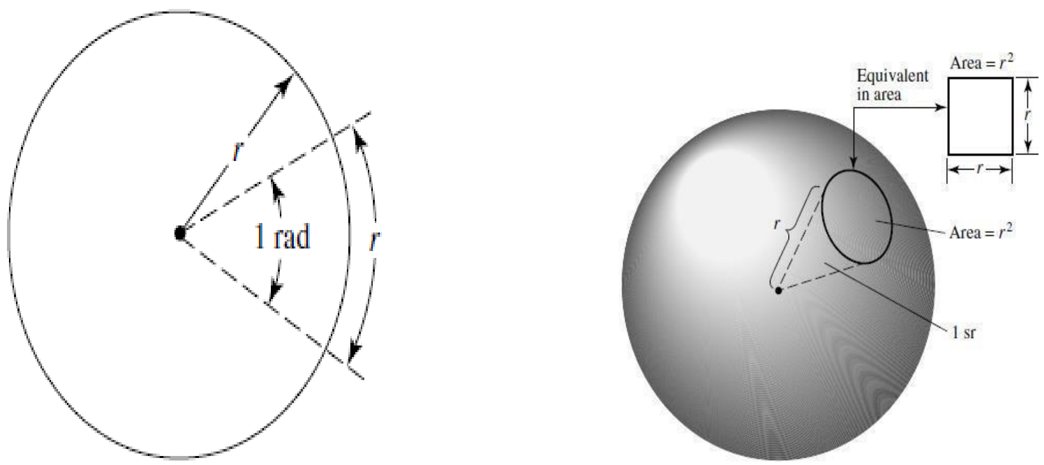
Far-field (Fraun hofer) region is defined as "that region of the field of an antenna wherethe angular field distribution is essentially independent of the distance from the antenna."

2.3.3 Radian and Steradian

The measure of a plane angle is a radian. One **radian** is defined as the plane anglewith its vertex at the centre of a circle of radius **r** that is subtended by an arc whose lengthis **r**. A graphical illustration is shown in Figure 2.11(a). Since the circumference of a circleof radius **r** is, **C = 2πr**, there are **2π rad (2πr/r)** in a full circle.

The measure of a solid angle is a Steradian.

One **Steradian** is defined as the solid angle with its vertex at the centre of a sphere of radius**r** that is subtended by a spherical surface area equal to that of a square with each side of length **r**. A graphical illustration is shown in Figure 2.11(b). Since the area of a sphere of radius **r** is, $\mathbf{A = 4\pi r^2}$, there are **4πsr** ($\mathbf{4\pi r^2/r^2}$) in a closed sphere.



(a)Radian (b) Steradian

Figure.2.11 Radian and steradian

2.3.4 Radiation Power Density

Electromagnetic waves are used to transport information through a wireless medium or a guiding structure, from one point to the other. The quantity used to describe the power associated with an electromagnetic wave is the instantaneous Pointing vector defined as,

$$P = E \text{ X } H$$

Where, P = instantaneous Pointing vector (W/m^2)

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

instantaneous magnetic-field intensity (A/m)

2.3.5 Radiation Intensity

Radiation intensity in a given direction is defined as "the power radiated from an antenna per unit solid angle." The radiation intensity is a far-field parameter, and it can be obtained by simply multiplying the radiation density by the square of the distance. In mathematical form it is expressed as,

$$U = r^2 W_{rad}$$

Where, U= radiation intensity (W/unit solid angle)

W_{rad}=radiation density (W/m^2)

For an isotropic source the radiation intensity is given as, $U = \frac{P_{rad}}{4\pi}$

2.3.6 Beam width

The beam width of a pattern is defined as the angular separation between two identical points on opposite side of the pattern maximum. In an antenna pattern, there are a number of beam-widths. One of the most widely used beam widths is the Half-Power Beamwidth (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).The beam-width of the antenna is also used to describe the resolution capabilitiesof 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).

2.3.7 Directivity

Directivity of an antenna 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 ratioof its radiation intensity in a given direction over that of an isotropic source [5]. In mathematical form it can be written as,

$$D=\frac{U}{U_o} = \frac{4\pi U}{P}$$

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

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

Where, D=directivity(dimensionless)

D_0= maximum directivity (dimensionless)

U= radiation intensity (W/unit solid angle)

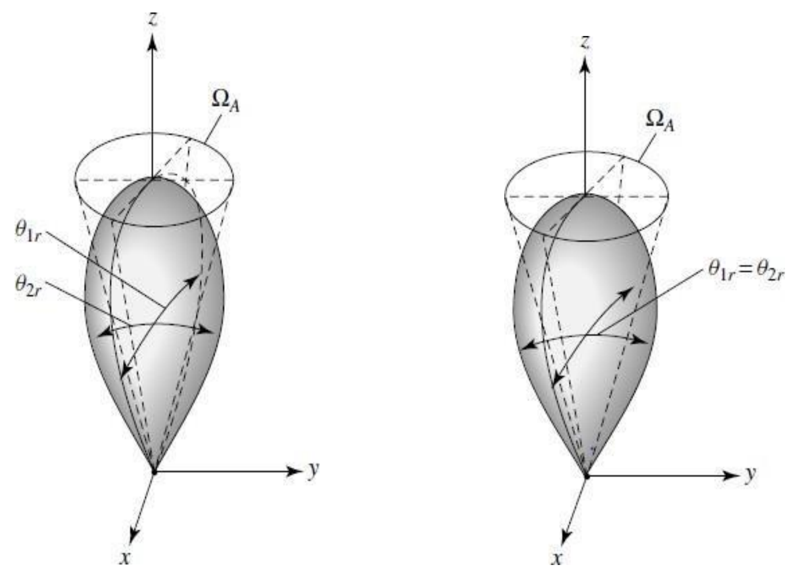
U_{max}= maximum radiation intensity (W/unit solid angle)

U_0= radiation intensity of isotropic source (W/unit solid angle)

P_{rad}= total radiated power (W)

2.3.7.1 Directional Patterns

Instead of using the exact expression to compute the directivity, it is often convenient to derive simpler expressions, even if they are approximate, to compute the directivity. These can also be used for design purposes. For antennas with one narrow majorlobe and very negligible minor lobes, the beam solid angle is approximately equal to the product of the half-power beam widths in two perpendicular planes shown in Figure 2.12.For a rotationally symmetric pattern, the half-power beam widths in any two perpendicularplanes are the same.



(a) Non-symmetrical pattern (b)Symmetrical pattern

Fig 2.12 Beam solid angles for non-symmetrical and symmetrical radiation patterns

With this approximation, D can be approximated by,

$$\boldsymbol{D = \frac{4\pi}{\Omega A} \cong \frac{4\pi}{\Theta 1r \Theta 2r}}$$

The beam solid angle Ω_A has been approximated by,

$$\Omega A \cong \Theta 1r \Theta 2r$$

Where, Θ1r= half-power beam width in one plane (rad)

Θ2r= half-power beam width in a plane at a right angle to the other (rad)

If the beam widths are known in degrees, (2-26) can be written as,

$$D_0 = \frac{4\pi}{\Omega_A} \cong \frac{4\pi(180/\pi)^2}{\Theta_{1d}\Theta_{2d}} = \frac{41253}{\Theta_{1d}\Theta_{2d}}$$

Where, Θ1d= half-power beam width in one plane (degrees)

Θ2d= half-power beam width in a plane at a right angle to the other (degrees)

For planar arrays, a better approximation to (2-27) is,

$$D_0 = \frac{32400}{\Omega_A(\text{degree})^2} = \frac{32400}{\Theta_{1d}\Theta_{2d}}$$

2.3.8 Antenna Efficiency

The total antenna efficiency $e_0$is used to take into account losses at the input terminals andwithin the structure of the antenna. Such losses may be due to,

1. reflections because of the mismatch between the transmission line and the antenna

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

In general, the overall efficiency can be written as, $e_0 = e_r e_c e_d$

Where, e_0= total efficiency (dimensionless)

e_r= reflection(mismatch) efficiency = $(1 - |\Gamma|^2)$ (dimensionless)

e_c= conduction efficiency (dimensionless)

e_d = dielectric efficiency (dimensionless)

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

[$\Gamma = (Z_{in} - Z_0)/(Z_{in} + Z_0)$

where Z_{in}= antenna input impedance,

Z_0= characteristic impedance of the transmission line]

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

2.3.9 Gain

An antenna's power gain or simply gain is a key performance number which combines the antenna's directivity and electrical efficiency. As a transmitting antenna, the gain describes how well the antenna converts input power into radio waves headed in a specified direction. As a receiving antenna, the gain describes how well the antenna converts radio waves arriving from a specified direction into electrical power. When no direction is specified, "gain" is understood to refer to the peak value of the gain. A plot ofthe gain as a function of direction is called the radiation pattern.

Gain is related to directivity with antenna efficiency factor as

$$G = kD$$

Where, K=antenna efficiency factor ($0 \leq k \leq 1$).

2.3.10 Return Loss

Return Loss (dB) is defined as a ratio of the incoming signal to the same reflected signal as it enters a component. The Return Loss (RL) may also be explained as the difference between the power of a transmitted signal and the power of the signal reflectionscaused by variations in link and channel impedance. A return loss plot indicates how well the link and channel's impedance matches its rated impedance over a range of frequencies. High return loss values mean a close impedance match, which results in greater differentiation between the powers of transmitted and reflected signals.

$$\text{Return loss(dB)} = 10 * \log \left(\frac{Reflected\ Power}{Incident\ power}\right)$$

2.3.11 VSWR

VSWR (Voltage Standing Wave Ratio), is a measure of how efficiently radio-frequency power is transmitted from a power source, through a transmission line, into a load. In an ideal system, 100% of the energy is transmitted. This requires an exact match between the source impedance, the characteristic impedance of the transmission line and all its connectors, and the load's impedance.

The signal's AC voltage will be the same from end to end since it runs through without interference. n real systems, mismatched impedances cause some of the power to be reflected back toward the source (like an echo). Reflections cause destructive interference,leading to peaks and valleys in the voltage at various times and distances along the line. VSWR measures these voltage variances. It is the ratio of the highest voltage anywhere along the transmission line to the lowest. The VSWR is always a real and positive number for antennas. The smaller the VSWR is, the better the antenna is matched to the transmission line and the more power is delivered to the antenna. The minimum VSWR is1.0. In this case, no power is reflected from the antenna, which is ideal.

$$\text{VSWR}= \left(\frac{1+|\tau|}{1-|\tau|}\right)$$

Where, τ = reflection coefficient.

2.3.12 Beam Efficiency

Another parameter that is frequently used to judge the quality of transmitting and receiving antennas is the beam efficiency. For an antenna with its major lobe directed alongthe z-axis ($\theta = 0$), the beam efficiency (BE) is defined by,

If θ_1 is chosen as the angle where the first null or minimum occurs, then the beam efficiency will indicate the amount of power in the major lobe compared to the total power. A very high beam efficiency (between the nulls or minimums), usually in the high 90s, is necessary for antennas used in radiometry, astronomy, radar, and other applications where received signals through the minor lobes must be minimized.

2.3.13 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 center 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 center frequency.

2.3.14 Polarization

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, thepolarization is taken to be the polarization in the direction of maximum gain."Polarizationof a radiated wave is defined as "that property of an electro-magnetic wave describing thetime-varying direction and relative magnitude of the electric-field vector; specifically, thefigure 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 may be classified as linear, circular, or elliptical. If the vector that describesthe electric field at a point in space as a function of time is always directed along a line, thefield is said to be linearly polarized. In general, however, the figure that the electric fieldtraces is an ellipse, and the field is said to be elliptically polarized. Linear and circular polarizations are special cases of elliptical, and they can be obtained when the ellipse becomes a straight line or a circle, respectively.

2.3.15 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 difficultto separate and they are usually lumped together to form the e_{cd} efficiency. The resistance R_L is used to represent the conduction-dielectric losses. The conduction-dielectric efficiency e_{cd} is defined as the ratio of the power delivered to theradiation resistance R_r to the power delivered to R_r and R_L.

2.4 ANTENNA VECTOR EFFECTIVE LENGTH AND EQUIVALENTAREA

An antenna in the receiving mode, whether it is in the form of a wire, horn, aperture, array, dielectric rod, etc., is used to capture (collect) electromagnetic waves and to extractpower from them. For each antenna, an equivalent length and a number of equivalent areas can then be defined. These equivalent quantities are used to describe the receiving characteristics of an antenna, whether it be a linear or an aperture type, when a wave is incident upon the antenna .The effective length of an antenna, whether it be a linear or an aperture antenna, is a quantity that is used to determine the voltage induced on the open-circuit terminals of the antenna when a wave impinges upon it. With each antenna, we can associate a number of equivalent areas. These are used to describe the power capturing characteristics of the antenna when a wave impinges on it.

2.5 MINIMUM RADIATION QUALITY FACTOR OF A SMALLANTENNA

The minimum radiation quality factor and the maximum bandwidth of an ideal single resonant small antenna are ultimately limited by the antenna size. The fields outside a virtual sphere (radius a), which completely encloses an antenna structure or an arbitrary current distribution, can be expressed with a complete set of orthogonal, spherical wave functions (spherical TM_{mn} and TE_{mn} wave modes).

The space outside the virtual sphere can be thought of as a spherical wave-guide where the waves propagate in the radial direction. The cut-off radius of the spherical wave-guide is $r_{cn}\lambda_o/2\pi$, where n is the mode number. The cut-off radius is independent of the mode number n. All the modes excited by the antenna contribute to the reactive power while only the propagating modes contribute to the radiated power. When the sphere around the antenna decreases, the number of propagating modes decreases and Q_r increases. When the sphere becomes small enough, even the lowest mode (n=1) becomes evanescent (non-propagating), and Q_r increases rapidly, as evanescent modes contribute very little to the radiated power.

With the use of the spherical wave modes, it is shown that of all linearly polarized small antennas, the lowest possible Q_r is obtained with an antenna that excites only either one of the lowest modes (TM_{01} or TE_{01}) outside the enclosing virtual sphere and stores no energy inside it.

In practice, however, all the antennas store energy also within the enclosing sphere, which increases their Q_r. The radiation quality factor of an ideal small antenna is approximately inversely proportional to the volume of the antenna in wavelengths (V/λ_o^3). Based on the spherical wave mode theory, practical small antennas such as shorted patches, must behave qualitatively the same way as the ideal antenna. The radiation quality factors of practical antennas are just higher, as explained above.

Generally, to minimize or, the antenna structure should use the space inside the enclosingsphere as efficiently as possible. For example, the Q_r of the PIFA is known to decrease as its height increases. The height of a basic PIFA can be increased without in-creasing the radius of the enclosing sphere, because the condition for its fundamental resonance is related to its length (l) and height (h) as $l + h = \lambda/4$.

2.6 DIFFERENT TYPES OF ANTENNAS

Antennas have to be classified to understand their physical structure and functionality more clearly. There are many types of antennas depending upon the applications.

Type of antenna	**Examples**	**Applications**
Wire Antennas	Dipole antenna, Monopole antenna, Helix antenna, Loop antenna	Personal applications, buildings, ships, automobiles, space crafts
Aperture Antennas	Waveguide opening, Hornantenna	Flush-mounted applications,air-craft, space craft
Reflector Antennas	Parabolic reflectors, Corner reflectors	Microwave communication, satellite tracking, radio astronomy
Lens Antennas	Convex-plane, Concave-plane, Convex-convex, Concave Lenses	Used for very high frequency applications
Microstrip Antennas	Circular-shaped, Rectangular shaped metallic patch above the ground plane	Air-craft, space-craft, satellites, missiles, cars, mobile phones etc.
Array Antennas	Yagi-Uda antenna, Micro strip patch array, Aperture array, Slotted wave guide array	Used for very high gain applications, mostly when needs to control the radiation pattern

Table 2.1. Types of antennas

CHAPTER 3

MICROSTRIP PATCH ANTENNA

In high-performance aircraft, spacecraft, satellite, and missile applications, where size, weight, cost, performance, ease of installation, and aerodynamic profile are constraints, low-profile antennas may be required. These antennas are low profile, conformable to planar and non-planar surfaces, simple and inexpensive to manufacture using modern printed-circuit technology, mechanically robust when mounted on rigid surfaces, compatible with MMIC designs, and when the particular patch shape and mode are selected, they are very versatile in terms of resonant frequency, polarization, pattern,and impedance.

Major operational disadvantages of micro-strip antennas are their low efficiency, low power, high Q (sometimes in excess of 100), poor polarization purity, poor scan performance, spurious feed radiation and very narrow frequency bandwidth, which is typically only a fraction of a percent or at most a few percent. In some applications, such as in government security systems, narrow bandwidths are desirable.

3.1 INTRODUCTION

Micro-strip antennas also called as patch antennas consist of a metallic patch on a grounded substrate. It is the most useful antenna at microwave frequencies (f >1 GHz). The following figure 3.1 shows the structure of a micro-strip antenna as follows, Micro-strip antennas generally consist of a very thin ($t \ll \lambda_0$, where λ_0 is the free-space wavelength) metallic strip (patch) placed a small fraction of a wave length ($h \ll \lambda_0$, usually $0.003\lambda_0 \le h \le 0.05\lambda_0$) above a ground plane.

The micro-strip patch is designed so its pattern maximum is normal to the patch (broadsideradiator). This is accomplished by properly choosing the mode (field configuration) of excitation beneath the patch. End-fire radiation can also be accomplished by judicious mode selection. For a rectangular patch, the length L of the element is usually $\lambda_0/3 < L < \lambda_0/2$.The strip (patch) and the ground plane are separated by a dielectric sheet (referredto as the substrate), as shown in Figure 3.1.

In telecommunication, a microstrip antenna usually means an antenna fabricated using microstrip techniques on a printed circuit board. It is a kind of internal antenna. Theyare mostly used at microwave frequencies. An individual microstrip antenna consists of a patch of metal foil of various shapes on the surface of a PCB with a metal foil ground plane on the other side of the board. Most microstrip antennas consist of multiple patches in a two-dimensional array. The antenna is usually connected to the transmitter or receiver through foil microstrip transmission lines. The radio frequency current is applied between the antenna and ground plane. Microstrip antennas have become very popular in recent decades due to their thin planar profile which can be incorporated into the surfaces of consumer products, aircraft and missiles.

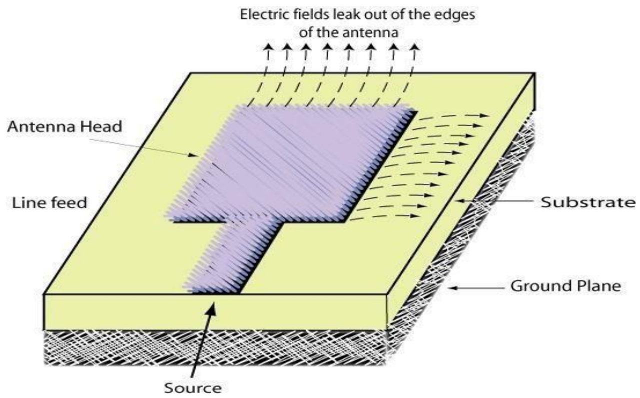


Figure.3.1 Structure of Micro-strip patch antenna

There are numerous substrates that can be used for the design of micro-strip antennas, andtheir dielectric constants are usually in the range of $2.2 \leq \epsilon_r \leq 12$. The ones that are most desirable for good antenna performance are thick substrates whose dielectric constant is in the lower end of the range because they provide better efficiency, larger bandwidth, looselybound fields for radiation into space, but at the expense of larger element size. Often micro-strip antennas are also referred to as patch antennas.

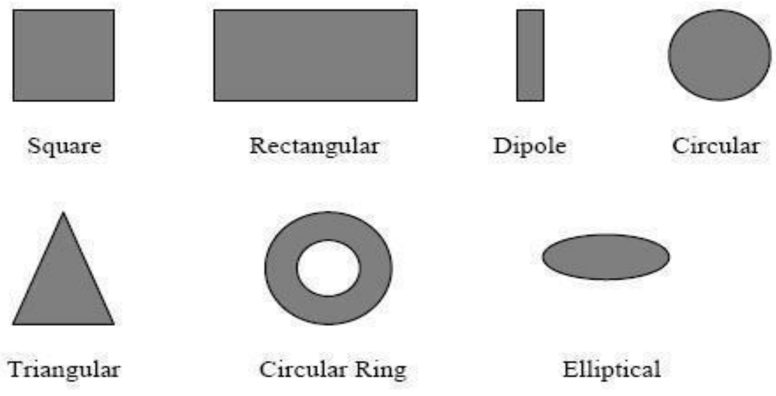


Figure.3.2 Common shapes of Micro-strip patch antennas

The radiating elements and the feed lines are usually photo etched on the dielectric substrate.The radiating patch may be square, rectangular, thin strip (dipole), circular, elliptical, triangular, or any other configuration. There are various shapes of patch antennas. The following figure 3.2 shows some of the common shapes of micro-strip patches.

3.2 ADVANTAGES AND DISADVANTAGES

Micro strip patch antennas are increasing in popularity for use in wireless applications due to their low-profile structure. Therefore they are extremely compatible forembedded antennas in handheld wireless devices such as cellular phones, pagers etc...

The telemetry and communication antennas on missiles need to be thin and conformal andare often in the form of Micro strip patch antennas. Another area where they have been used successfully is in Satellite communication. Some of their principal advantages are given below:

- Light weight and low volume.
- Low profile planar configuration which can be easily made conformal to host surface.
- Low fabrication cost, hence can be manufactured in large quantities.
- Supports both, linear as well as circular polarization.
- Can be easily integrated with microwave integrated circuits (MICs).
- Capable of dual and triple frequency operations.

Micro strip patch antennas suffer from more drawbacks as compared to conventional antennas. Some of their major disadvantages are given below:

- Narrow bandwidth.
- Low efficiency.
- Low Gain.
- Extraneous radiation from feeds and junctions.
- Poor end fire radiator except tapered slot antennas.
- Low power handling capacity.

3.3 FEEDING TECHNIQUES

A feed line is used to excite or radiate by direct or indirect contact. Feeding is mainly classified as contacting and non-contacting schemes. In contacting scheme, RF power is fed directly to the radiating patch and in non-contacting scheme; electromagneticfield coupling is done to transfer power between micro-strip line and radiating patch [10]. There are many different methods of feeding and four most popular methods are,

a) Micro-strip line feed

b) Coaxial probe

c) Aperture coupling

d)Proximity coupling

3.3.1 Microstrip Feed Line

In this type of feed technique, a conducting strip is connected directly to the edge of the Micro strip patch. The conducting strip is smaller in width as compared to the patchand this kind of feed arrangement has the advantage that the feed can be etched on the samesubstrate to provide a planar structure. The purpose of the inset cut in the patch is to matchthe impedance of the feed line to the patch without the need for any additional matching element. The figure 3.3 shows the microstrip line feed technique. Advantages of micro- strip line feed are easy to fabricate, simple to match by controlling the inset position, simpleto model, surface thickness increases surface waves, spurious radiations and limits bandwidth for practical designs (typically 2-5%)

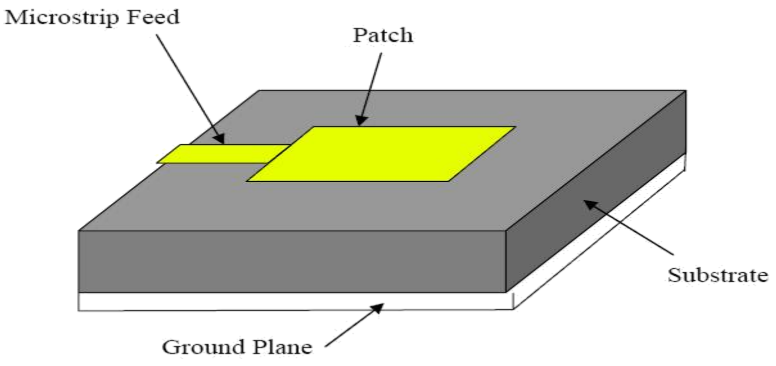


Figure.3.3 Micro strip Line Feed

3.3.2 Coaxial Feed

The Coaxial feed or probe feed is a very common technique used for feeding Micro-strip patch antennas

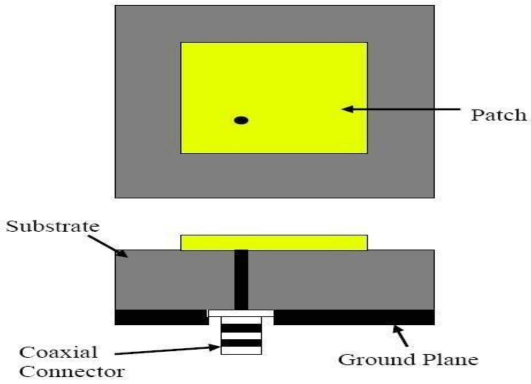


Figure.3.4. Coaxial (Probe) feed Rectangular Micro strip Patch Antenna

Here, the inner conductor of the coaxial connector is attached to the radiating patch, whilethe outer conductor is connected to the ground plane. The following figure 3.4 shows the coaxial (probe feed) as above. Advantages of coaxial (probe feed) is easy to fabricate and match, low spurious radiations. Some of the disadvantages of Coaxial feed are narrow bandwidth and more difficult to model for thick substrates. Both micro-strip feed and probefeed possess inherent asymmetries such as, generate higher order modes and produce cross- polarized radiation. To overcome these problems, non-contacting aperture coupling feed isintroduced.

3.3.4 Aperture Coupled Feed

It consists of two substrates separated by a ground plane. On the bottom side of the lower substrate there is a micro-strip feed line and its energy is coupled to the patch through a sloton the ground plane separating two substrates. The following figure 3.5 shown as,

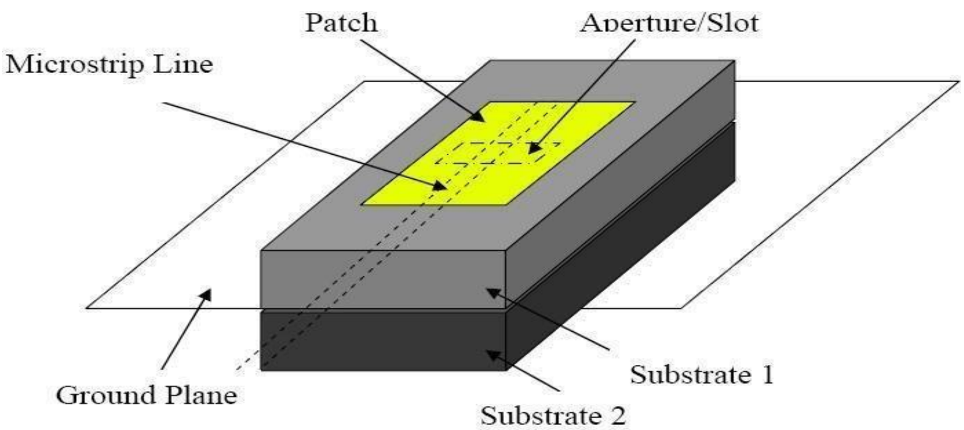


Figure.3.5 Aperture coupled feed

A high dielectric material is used for bottom substrate and for top substrate a thick low dielectric material is used. Ground plane between two substrates, isolates feed from radiating element and minimizes interference of spurious radiation for pattern formation and polarization purity.

3.3.4 Proximity Coupled Feed

This type of feed technique is also called as the electromagnetic coupling scheme. Here two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate. The figure 3.6 shows the proximity coupled feeding technique. The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth (as high as 13%), due to overall increase in the thickness of the micro strip patch antenna.

3.4 METHOD ANALYSIS

The preferred models for the analysis of Micro-strip patch antennas are the transmission line model, cavity model, and full wave model (which include primarily integral equations/Moment Method). The transmission line model is the simplest of all and it gives good physical insight but it is less accurate. The cavity model is more accurate and gives good physical insight but is complex in nature. The full wave models are extremely accurate, versatile and can treat single elements, finite and infinite arrays, stacked elements,arbitrary shaped elements and coupling.

3.4.1 Transmission Line Model

The transmission-line model is the easiest of all but it yields the least accurate results and it lacks the versatility. However, it does shed some physical insight. This model represents the micro-strip antenna by two slots of width W and height h, separated by a transmission line of length L. The following figure 3.7 shows the micro-strip line and its electric field lines. The micro-strip line is essentially a non-homogeneous line of two dielectrics,typically the substrate and air.

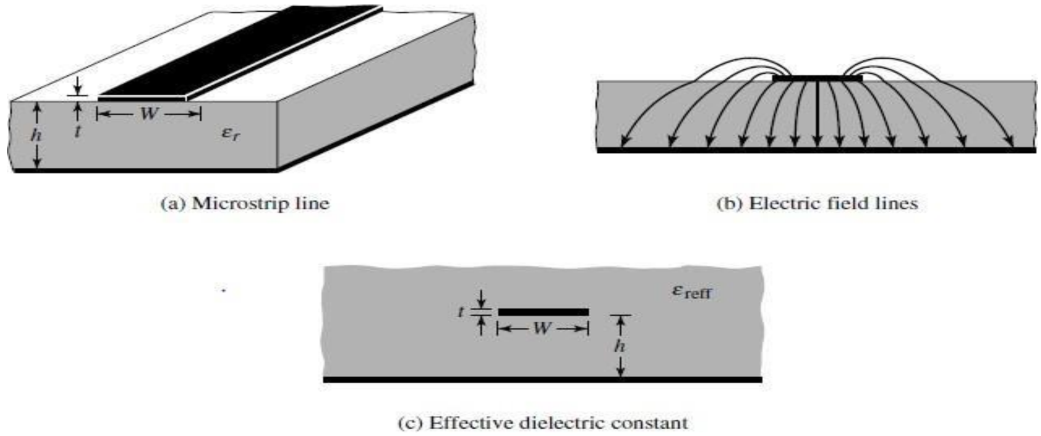


Figure.3.6 Micro-strip line and its electric field lines, and effective dielectric constant

The effective dielectric constant is defined as the dielectric constant of the uniform dielectric material so that the line of Figure 3.7(c) has identical electrical characteristics, particularly propagation constant, as the actual line of Figure 3.7(a).For a line with air above the substrate, the effective dielectric constant has values in the range of 1 $<\epsilon_{reff}<\epsilon_r$. For most applications where the dielectric constant of the substrate is much greater than unity ($\epsilon_r >>1$), the value of ϵ_{reff}will be closer to the value of the actual dielectric constant $\epsilon_r$of the substrate. The effective dielectric constant is also a function of frequency. As the frequency of operation increases, most of the electric field lines concentrate in the substrate. Therefore the micro-strip line behaves more like a homogeneous line of one dielectric (onlythe substrate), and the effective dielectric constant approaches the value of the dielectric constant of the substrate.

$$\frac{W}{h} > 1$$

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2}$$

Where, ∈reff = Effective dielectric constant

∈r = Dielectric constant of substrate

h= Height of dielectric substrate

W= Width of the patch

For the principal E-plane (xy-plane), the dimensions of the patch along its length have been extended on each end by a distance ΔL, which is a function of the effective dielectric constant ∈reff and the width-to-height ratio (W/h). A very popular and practical approximate relation for the normalized extension of the length is given as,

$$\frac{\Delta L}{h} = 0.412\frac{(\epsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)}$$

Since the length of the patch has been extended by ΔLoneach side, the effective length of the patch is now,

$$L_{eff}=L+2\Delta L$$

For the dominant TM010 mode, the resonant frequency of the micro-strip antenna is a function of its length. Usually it is given by,

$$(f_r)_{010} = \frac{1}{2L\sqrt{\epsilon_r}\sqrt{\mu_0\epsilon_0}} = \frac{v_0}{2L\sqrt{\epsilon_r}}$$

For a given resonance frequencyf0, the effective length is given as,

$$L_{eff} = \frac{c}{2f_0\sqrt{\epsilon_{reff}}}$$

3.4.2 Cavity Model

Although the transmission line model discussed in the previous section is easy to use, it hassome inherent disadvantages. Specifically, it is useful for patches of rectangular design andit ignores field variations along the radiating edges. These disadvantages can be overcomeby using the cavity model. In this model, the interior region of the dielectric substrate is modelled as a cavity bounded by electric walls on the top and bottom. The basis for this assumption is the following observations for thin substrates. Since the substrate is thin, the fields in the interior region do not vary much in the z direction, i.e. normal to the patch. The electric field is **z**-directed only, and the magnetic field has only the transversecomponents H_X and H_Y in the region bounded by the patch metallization and the ground plane.

When the micro strip patch is provided power, a charge distribution is seen on the upper and lower surfaces of the patch and at the bottom of the ground plane. The attractive mechanism is between the opposite charges on the bottom side of the patch and the groundplane, which helps in keeping the charge concentration intact at the bottom of the patch. The repulsive mechanism is between the like charges on the bottom surface of the patch, which causes pushing of some charges from the bottom, to the top of the patch. As a resultof this charge movement, currents flow at the top and bottom surface of the patch.

CHAPTER 4

INTRODUCTION TO CST

4.1 Introduction to CST

CST (Computer Simulation Technology) software, specifically CST Studio Suite, is a suite of tools used for simulating electromagnetic fields in all frequency bands. It is widely used in various fields such as telecommunications, automotive, aerospace, defense, medical devices, electronics, and academic research. CST Studio Suite allows engineers and researchers to design, analyze, and optimize electromagnetic components and systems.

Key Features of CST Studio Suite

1. Comprehensive Electromagnetic Simulation:
   - Covers a wide frequency range from static to optical frequencies.
   - Includes solvers for electromagnetic fields, circuit co-simulation, and multi-physics problems.
2. Solver Technology:
   - Time Domain Solver: Suitable for wideband and broadband applications, fast computation of transients.
   - Frequency Domain Solver: Ideal for narrowband and resonant problems.
   - Integral Equation Solver: Effective for electrically large structures.
   - Asymptotic Solver: For very large problems where other methods would be impractical.
   - Eigenmode Solver: Useful for resonator design and cavity filter design.
3. Multiphysics and Coupled Simulations:
   - Thermal and mechanical analysis integrated with electromagnetic simulations.
   - Coupling between different physics domains to study effects like thermal expansion and stress.
4. Advanced Modeling Tools:
   - Parametric modeling and optimization tools.
   - Advanced meshing techniques for accurate and efficient simulations.
   - CAD import and export capabilities for seamless integration with other design tools.
5. Post-Processing and Visualization:
   - Comprehensive post-processing tools to analyze and visualize simulation results.
   - Creation of 2D and 3D plots, field distributions, S-parameters, radiation patterns, etc.

6. Applications:

- Antenna Design: Analysis and optimization of antennas and antenna arrays.
- Microwave Components: Design of filters, couplers, and other microwave components.
- EMC/EMI: Analysis of electromagnetic compatibility and interference.
- Bio-Electromagnetics: Study of electromagnetic effects on biological tissues.
- Optical Devices: Simulation of photonic and optical components.

Benefits of Using CST Studio Suite

- Accuracy and Reliability: High fidelity simulations that are trusted in critical applications.
- Efficiency: Optimized solvers and parallel computing capabilities for fast simulations.
- Integration: Compatible with various CAD tools and simulation environments.
- Flexibility: Suitable for a wide range of applications and industries.
- Support and Documentation: Extensive documentation, tutorials, and support from CST and user communities.

4.2 Typical Work flow in CST Studio Suite

Model Creation:

Use built-in CAD tools or import geometry from other CAD software.

Define material properties and assign them to different parts of the model.

Setup Simulation:

Choose the appropriate solver based on the problem requirements.

Define simulation parameters, boundary conditions, and sources.

Meshing:

Generate the mesh for the computational domain.

Use adaptive meshing techniques to refine the mesh for better accuracy.

Run Simulation:

Execute the simulation using the chosen solver.

Monitor progress and ensure the convergence of the solution.

Post-Processing:

Analyze results using the post-processing tools.

Visualize field distributions, S-parameters, radiation patterns, etc.

Optimization:

Use parametric studies and optimization algorithms to improve design performance.

Iterate on the design based on simulation results.

CHAPTER 5

INTRODUCTION TO X band Phased Microstrip Patch Antenna Array with Integrated Heat Sink

5.1 Microstrip Patch Antenna

Micro-strip antennas also called as patch antennas consist of a metallic patch on a grounded substrate. It is the most useful antenna at microwave frequencies (f >1 GHz). Thefollowing figure 3.1 shows the structure of a micro-strip antenna as follows, Micro-strip antennas generally consist of a very thin ($t \ll \lambda_0$, where λ_0 is the free-space wavelength) metallic strip (patch) placed a small fraction of a wave length ($h \ll \lambda_0$, usually $0.003\lambda_0 \le h \le 0.05\ \lambda_0$) above a ground plane.

A dielectric substrate is a material used in electronics, especially in devices like antennas and circuit boards, that does not conduct electricity but can support an electric field. Think of it like a special kind of plastic or ceramic that helps control and guide electrical signals without letting them just flow everywhere. This helps in making sure the electronic devices work correctly and efficiently.[IEEE 51-1995]

In telecommunication, a microstrip antenna usually means an antenna fabricated using microstrip techniques on a printed circuit board. It is a kind of internal antenna. They are mostly used at microwave frequencies. An individual microstrip antenna consists of a patch of metal foil of various shapes on the surface of a PCB with a metal foil ground plane on the other side of the board. Most microstrip antennas consist of multiple patches in a two-dimensional array. The antenna is usually connected to the transmitter or receiver through foil microstrip transmission lines.

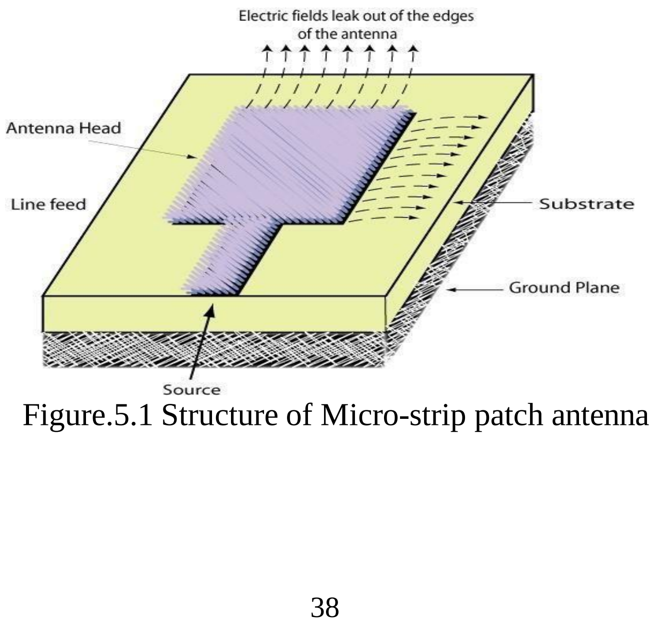


Figure.5.1 Structure of Micro-strip patch antenna

The ones that are most desirable for good antenna performance are thick substrates whose dielectric constant is inthe lower end of the range because they provide better efficiency, larger bandwidth, looselybound fields for radiation into space, but at the expense of larger element size. Often micro-strip antennas are also referred to as patch antennas.

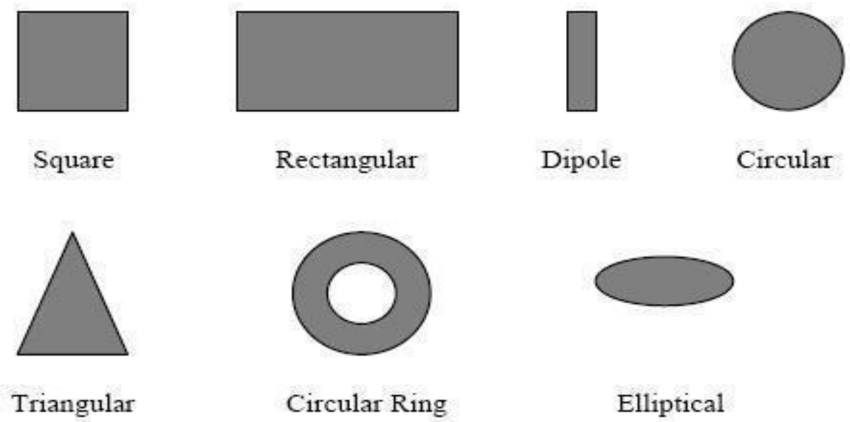


Figure.5.2 Common shapes of Micro-strip patch antennas

The radiating elements and the feed lines are usually photo etched on the dielectric substrate.The radiating patch may be square, rectangular, thin strip (dipole), circular, elliptical, triangular, or any other configuration. There are various shapes of patch antennas. The following figure 5.2 shows some of the common shapes of micro-strip patches.

5.2 Antenna Array

An antenna array is a system of multiple antennas working together as a single antenna to transmit or receive electromagnetic waves. The main purpose of an antenna array is to achieve desired radiation patterns that single antennas cannot provide, including improved gain, directivity, beamforming, and steering capabilities. Antenna arrays are widely used in various applications such as telecommunications, radar, satellite communications, and wireless networks.

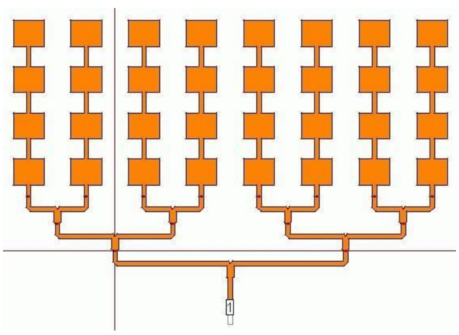


Fig 5.3 Antenna Array

Key Concepts of Antenna Arrays

1. Elements of an Antenna Array

- Individual Antennas: The basic units that make up the array. These can be dipoles, patches, slots, or any other type of antenna.
- Feed Network: The structure that distributes the input signal to the individual antennas or combines the received signals from the antennas. It can be designed to control the phase and amplitude of the signal fed to each element.

2. Array Configuration

- Linear Arrays: Antennas are arranged in a straight line. This is the simplest form of an array and is often used for horizontal or vertical scanning.
- Planar Arrays: Antennas are arranged in a two-dimensional grid. Planar arrays are used for more complex beamforming and two-dimensional scanning.
- Circular Arrays: Antennas are arranged in a circular pattern, providing omnidirectional scanning and beamforming capabilities.
- Conformal Arrays: Antennas are arranged to conform to a particular shape, often the surface of a vehicle or structure, allowing for flexible and adaptive radiation patterns.

3. Radiation Pattern

- Main Lobe: The direction in which the antenna array radiates the strongest signal.
- Side Lobes: Smaller lobes that represent radiation in undesired directions. Minimizing side lobes is crucial for reducing interference.
- Beamwidth: The angular width of the main lobe, which determines the directivity and resolution of the array.
- Nulls: Directions where the array produces little or no radiation. These are used to suppress interference or jamming signals.

5.2.1 Design Parameters

1. Element Spacing

- The distance between individual antennas in the array. Optimal spacing is typically around half a wavelength ($\lambda/2$) to prevent grating lobes and ensure constructive interference in the desired direction.

2. Amplitude and Phase Control

- Amplitude Tapering: Adjusting the amplitude of the signal fed to each element to control the side lobe levels.
- Phase Shifting: Adjusting the phase of the signal fed to each element to steer the beam in the desired direction.

3. Beamforming

- The process of shaping the radiation pattern by adjusting the amplitude and phase of the signals at each antenna element. Beamforming can be static (fixed beam) or dynamic (adaptive beam steering).

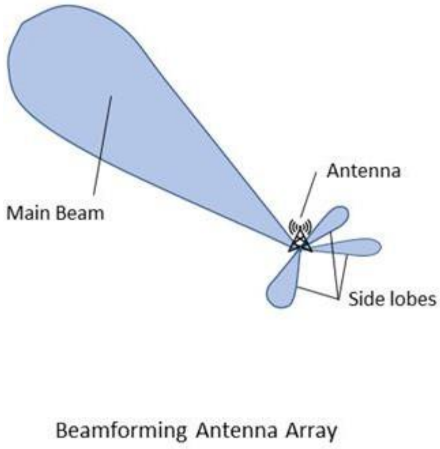


Fig 5.4 Beamforming

Types of Beamforming

1. Analog Beamforming

- Utilizes phase shifters and attenuators in the feed network to control the phase and amplitude of the signal. It is simpler and cheaper but less flexible than digital beamforming.

2. Digital Beamforming

- Uses digital signal processing techniques to control the phase and amplitude of the signals. It offers greater flexibility and precision, allowing for advanced beamforming algorithms and adaptive beam steering.

3. Hybrid Beamforming

- Combines both analog and digital beamforming techniques to balance cost and performance. It is often used in modern communication systems like 5G networks.

5.2.2 Applications of Antenna Arrays

1. Telecommunications

- Used in cellular base stations and wireless communication systems to enhance coverage, capacity, and signal quality. Massive MIMO (Multiple Input Multiple Output) arrays in 5G technology are a key example.

2. Radar Systems

- Employed in military and civilian radar systems for target detection, tracking, and imaging. Phased array radar can rapidly steer beams without moving parts, providing fast and accurate scanning.

3. Satellite Communications

- Utilized in satellite antennas to provide high-gain, directional beams for uplink and downlink communications, enabling efficient use of bandwidth and power.

4. Wireless Networks

- Implemented in Wi-Fi access points and routers to enhance signal strength, reduce interference, and increase data rates through techniques like MU-MIMO (Multi-User MIMO).

5. Medical Imaging

- Applied in medical devices such as ultrasound machines and MRI scanners to improve imaging resolution and accuracy.

5.2.3 Challenges and Considerations

1. Mutual Coupling

- Interaction between elements in close proximity can affect the radiation pattern and impedance. Careful design and isolation techniques are required to mitigate mutual coupling effects.

2. Complexity and Cost

- Designing and implementing large arrays with precise control over amplitude and phase can be complex and expensive. Advances in technology are making it more feasible, but it remains a significant consideration.

3. Calibration and Maintenance

- Regular calibration is necessary to maintain the performance of the array. Environmental factors like temperature and mechanical deformation can affect array performance.

5.3 PHASED ANTENNA ARRAY

A phased antenna array is a type of antenna array where the relative phases of the signals feeding the individual antennas are varied to steer the direction of the radiation pattern or the beam. This electronic beam steering capability makes phased arrays particularly useful in applications that require rapid changes in beam direction without physically moving the antennas. Phased arrays are widely used in radar, telecommunications, satellite communications, and other fields that demand high precision and flexibility in signal direction.

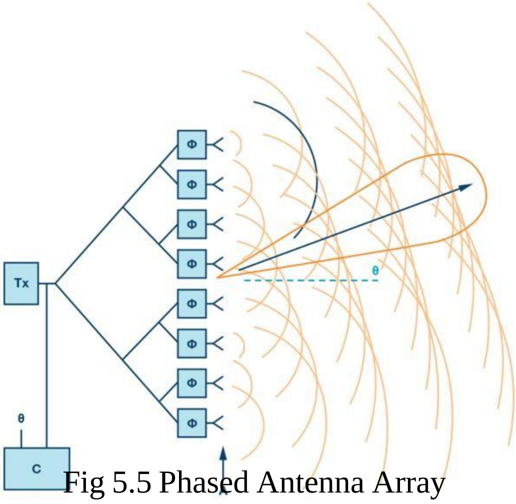


Fig 5.5 Phased Antenna Array

Key Concepts of Phased Antenna Arrays

1. Basic Principle

The core principle of a phased array is that by adjusting the phase of the input signals to the array elements, constructive and destructive interference can be controlled to form and steer the main radiation beam in a desired direction.

2. Components

- Antenna Elements: The individual antennas that make up the array. These can be of various types, including dipoles, patches, or horns.
- Phase Shifters: Devices that adjust the phase of the signal fed to each antenna element.
- Feed Network: Distributes the signal to the antenna elements with the correct phase and amplitude adjustments.
- Control System: Manages the phase shifters and adjusts the beam direction based on input commands.

5.3.1 Types of Phased Arrays

1. Active Phased Array

   - Each element or group of elements is connected to an active component, such as an amplifier, which can provide gain and additional control.
   - Common in modern radar and communication systems, such as Active Electronically Scanned Arrays (AESA).

2. Passive Phased Array

   - Relies on passive components to adjust the phase of the signals. Typically, it uses a central transmitter or receiver.
   - Simpler and cheaper than active arrays but offers less flexibility and performance.

5.3.2 Advantages of Phased Arrays

1. Beam Steering
   - The ability to steer the beam electronically without moving the antennas.
   - Fast and precise beam steering.
2. Multiple Beam Capability
   - Digital beamforming allows the creation of multiple beams from a single array.
   - Supports multi-target tracking and communications.
3. Flexibility and Adaptability
   - Can adapt to different frequencies and operational modes.
   - Suitable for dynamic environments and diverse applications.
4. Reduced Physical Size and Weight
   - No need for mechanical steering mechanisms.
   - Compact and lightweight designs, especially in AESA systems.

5.4 Heat Sink

Heat sinks are critical components used to manage and dissipate heat generated by electronic devices and components. Effective thermal management is essential to maintain the performance, reliability, and longevity of electronic systems, as excessive heat can lead to failures, reduced efficiency, and shortened lifespan of components.

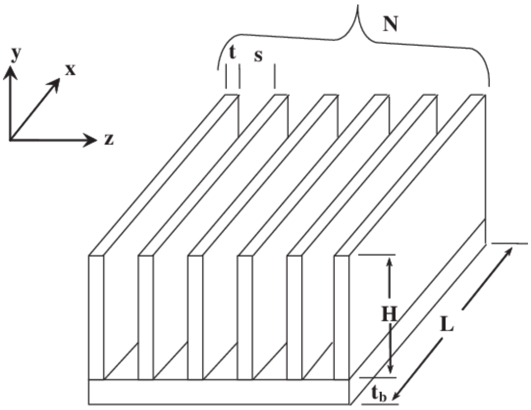


Fig 5.6 Heat Sink

Key Concepts of Heat Sink

1. Basic Principle

A heat sink works by increasing the surface area available for heat dissipation, allowing heat to be transferred away from the electronic component to the surrounding environment more efficiently. This process involves conduction, convection, and sometimes radiation.

2. Components and Structure

- Base: The part of the heat sink that makes direct contact with the heat source (e.g., CPU, GPU, power transistor).

- Fins: Thin, extended surfaces that increase the overall surface area for heat dissipation.

- Heat Pipes: Sometimes integrated to enhance thermal conductivity and spread heat more uniformly across the fins.

- Fan: Active cooling element that increases air flow over the heat sink, improving convective heat transfer.

5.4.1 Types of Heat Sinks

1. Passive Heat Sinks

-Natural Convection: Relies on natural airflow to dissipate heat. It does not have any moving parts.

- Materials: Typically made from high thermal conductivity materials like aluminium or copper.

- Applications: Used in environments where noise is a concern or where active cooling is not feasible.

2. Active Heat Sinks

-Forced Convection: Uses fans or blowers to increase air flow over the heat sink.

- Efficiency: More effective than passive heat sinks in dissipating heat, particularly in high-power applications.

- Applications: Commonly used in computers, power electronics, and other high-heat-generating devices.

3. Hybrid Heat Sinks

-Combination: Integrates both passive and active cooling techniques.

-Performance: Offers a balance between efficiency and reliability.

-Applications: Used in high-performance computing and other demanding applications.

5.4.2 Design Considerations

1. Thermal Conductivity

-Materials: Copper and aluminium are the most commonly used materials due to their high thermal conductivity. Copper has higher thermal conductivity but is heavier and more expensive than aluminium.

-Surface Treatment: Anodizing, plating, or other treatments can improve thermal performance and corrosion resistance.

2. Surface Area

-Fins: The design, number, and arrangement of fins significantly affect the heat sink's ability to dissipate heat. More fins or higher surface area increases heat dissipation.

- Geometry: Optimized fin shapes and spacing to maximize airflow and heat transfer.

3. Air Flow

- Natural vs. Forced: Natural convection is less effective than forced convection. Ensuring good airflow around the heat sink is crucial for performance.

- Orientation: The orientation of the heat sink in relation to gravity can impact natural convection efficiency.

4. Heat Sink Size and Weight

-Form Factor: Must fit within the physical constraints of the device while providing adequate cooling.

-Weight: Especially in portable or mobile applications, weight is a significant consideration.

5. Mounting and Interface

-Thermal Interface Material (TIM): Materials like thermal paste or pads are used to improve the thermal connection between the heat source and the heat sink by filling in microscopic air gaps.

- Mounting Mechanism: Secure and stable mounting methods to ensure consistent thermal performance.

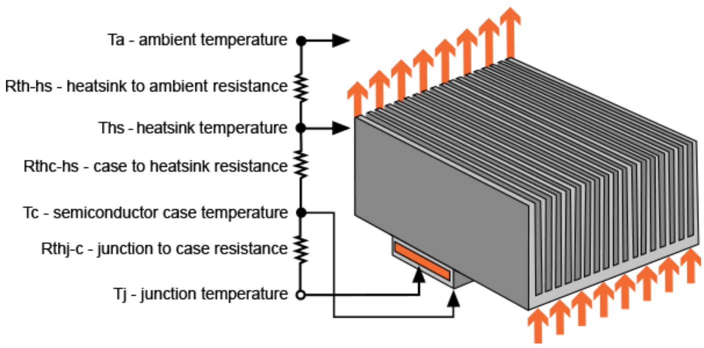


Fig 5.7 Calculations of Heat Sink

5.5 INTEGRATION OF HEAT SINK WITH ANTENNA ARRAY

Integrating heat sinks with antenna arrays is essential for managing the thermal challenges posed by high-power and high-performance antennas, particularly in applications such as phased arrays, massive MIMO systems, and radar systems. Effective thermal management ensures the reliability, efficiency, and longevity of these systems by preventing overheating and maintaining optimal operating conditions.

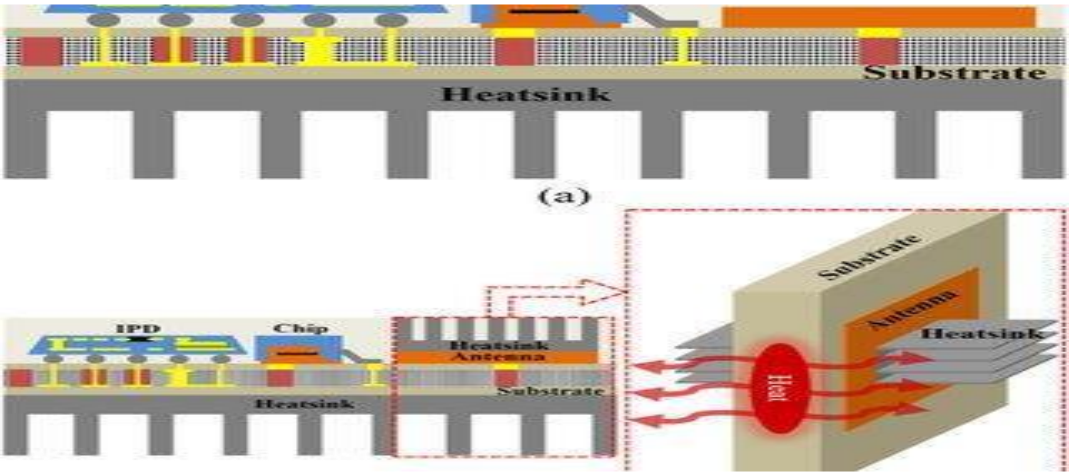


Fig 5.8 Basic Structure of Heat sink Integrated with Antenna

Key Considerations for Integration

1. Heat Generation in Antenna Arrays

- Power Amplifiers: These components generate significant heat, especially in active phased array systems where each antenna element may have its own amplifier.

- High-Density Electronics: The compact arrangement of electronics in antenna arrays can lead to high heat density.

- Environmental Factors: Outdoor and space applications may experience varying temperatures and require robust thermal management solutions.

2. Thermal Management Requirements

- Efficient Heat Dissipation: Ensuring that the generated heat is effectively transferred away from the active components.

- Minimal Impact on Performance: The heat sink design must not interfere with the antenna's performance, including its radiation pattern and electromagnetic compatibility.

- Compact and Lightweight: Especially important for mobile and space applications where size and weight are constrained

5.5.1 Design and Integration Strategies

1. Thermal Interface Materials (TIMs)

- High-Performance TIMs: Materials like thermal grease, pads, or phase change materials used to improve thermal contact between the antenna components and the heat sink.

- Minimizing Thermal Resistance: Ensuring that the TIMs are applied uniformly and appropriately to minimize thermal resistance and improve heat transfer.

2. Structural Integration

-Direct Mounting: Heat sinks can be directly mounted onto the PCB or the housing of the antenna array, ensuring a good thermal path.

- Modular Designs: Heat sinks designed as modular components that can be easily attached or detached for maintenance and upgrades.

3. Optimized Heat Sink Design

-Custom Geometry: Heat sinks are often custom-designed to fit the specific layout and thermal profile of the antenna array.

- Material Selection: Choosing materials with high thermal conductivity (e.g., copper for base plates, aluminium for fins) to optimize heat dissipation.

4. Maintaining Electromagnetic Performance

-Non-Interference: The heat sink design must ensure that it does not interfere with the electromagnetic performance of the antenna array.

- RF Shielding: Incorporating RF shielding if necessary to prevent electromagnetic interference between the heat sink and the antenna elements.

CHAPTER 6

DESIGN OF X BAND PHASED MICROSTRIP PATCH ANTENNA ARRAY WITH INTEGRATED HEATSINK

6.1 Antenna Design

Calculation of the patch Length and Width (a): The dimensions of the Microstrip patch is given by:

Length(L):

$$L=\frac{c}{2f_r}\times\frac{1}{\sqrt{\varepsilon_{reff}}}-2\Delta L$$

$$\Delta L=h\times 0.412\frac{(\varepsilon_{reff}+0.3)(\frac{w}{h}+0.264)}{(\varepsilon_{reff}-258)(\frac{w}{h}+0.8)}$$

Effective di-electric constant (ε_{reff}):

$$\varepsilon_{reff}=\left(\frac{\varepsilon_r+1}{2}\right)+\left(\frac{\varepsilon_r-1}{2}\right)[1+12\frac{h}{w}]^{\frac{-1}{2}}$$

Width (W):

$$W=\frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}}$$

Characteristic Impedance (Z_0):

$$Z_0=\sqrt{Z_{in}\times Z_l}$$

Where f_r is Frequency of operation, ε_r and h are Dielectric constant and height of substrate.

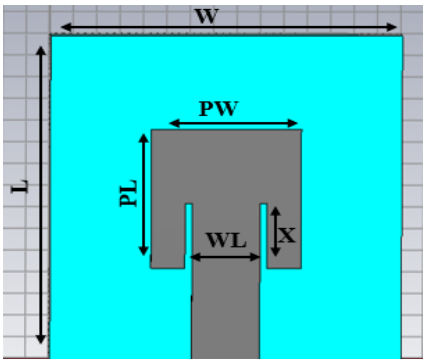


Fig 6.1 Single element Antenna

Parameters	Values(mm)
W	15
L	15
PL	6.8
PW	6.4
X	2.45
WL	2.95
QL	7.14
QW	1.6

Table 6.1: Antenna Parameters

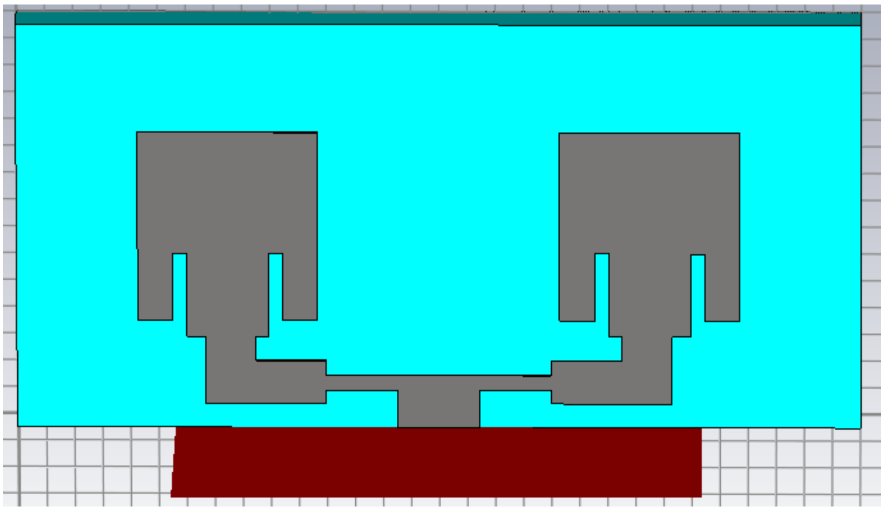


Fig 6.2 Two element Array

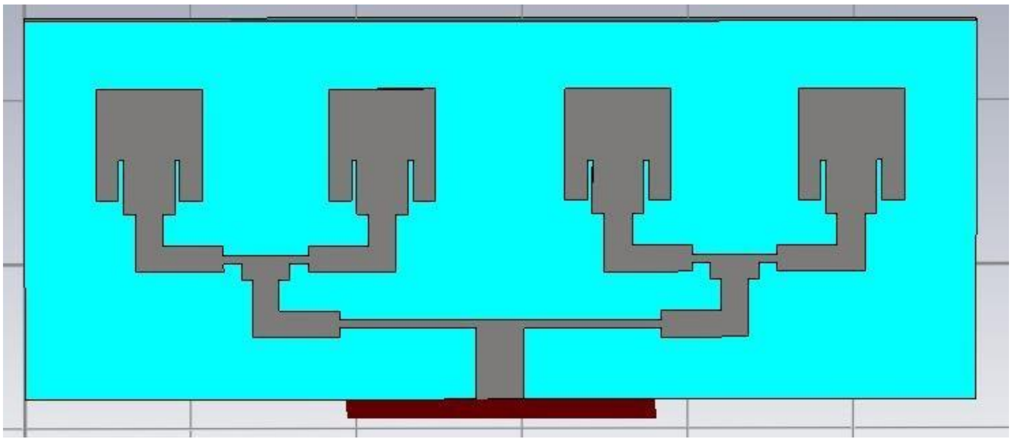


Fig 6.3 Four element Array

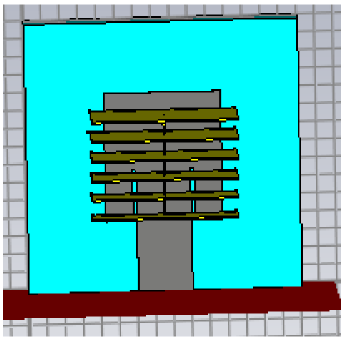


Fig 6.4 Single element Antenna with Heatsink

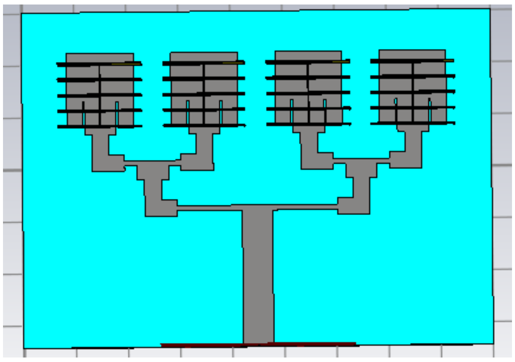


Fig 6.5 Four element Array with Heatsink

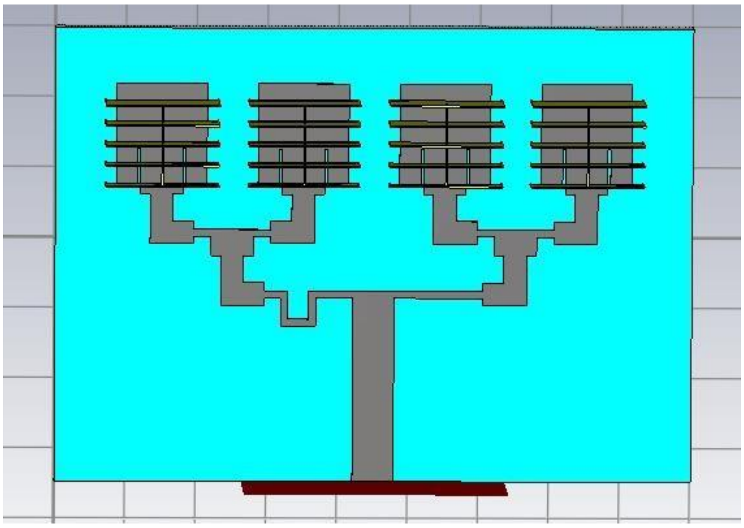


Fig 6.6 Final design of X band Phased Microstrip Patch Antenna Array with integrated Heatsink

6.2 RETURN LOSS

Return loss is the loss of signal power resulting from the reflection caused at a discontinuity in a transmission line. This discontinuity can be mismatch with the terminating load (or) with a device inserted in the line. It is usually expressed as a ratio in decibels (dB);

$$RL\ (dB) = 10 \log_{10} (pi / pr)$$

A match is good if the return loss is high and for a lower insertion loss higher return loss is desirable. Taking the ratio of reflected to incident power, we obtain a return loss is negative.

$$RL\ (dB) = 10 \log_{10}(pr/pi)$$

The return loss with negative sign is called as reflection coefficient. Caution is required when discussing increasing (or) decreasing return loss. Since these terms strictly have the opposite meaning when return loss is defined as a negative quantity.

The Return loss equation in terms of reflection coefficient is:

Return loss = -20 x log [mag ()]

6.2.1 X band Frequency

The X band is a segment of the microwave radio region of the electromagnetic spectrum. It ranges from about 8 to 12 (GHz)[IEEE 521-2019] . This frequency band is commonly used in radar, satellite communications, and some types of wireless networks. Because of its ability to penetrate weather conditions and provide high-resolution images, it's particularly useful for weather monitoring, air traffic control, and military applications.

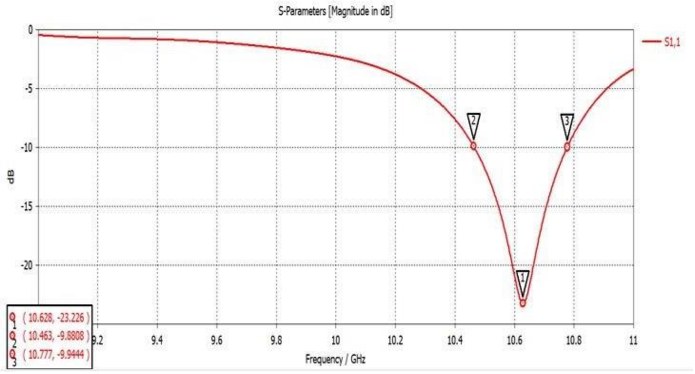


Fig 6.7 S11 Parameter of Single Patch Antenna

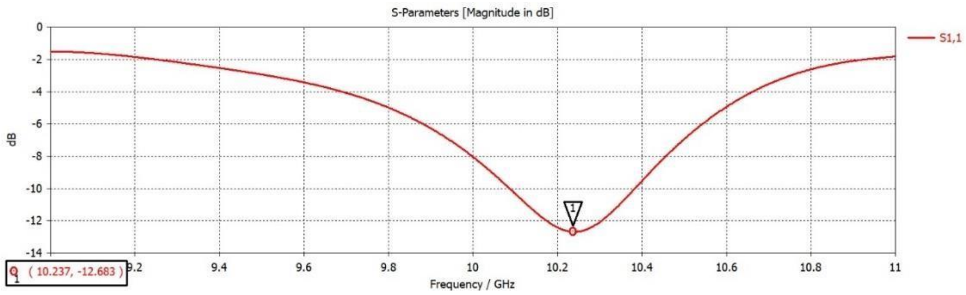


Fig 6.8 S11 parameter of 1x2 Array

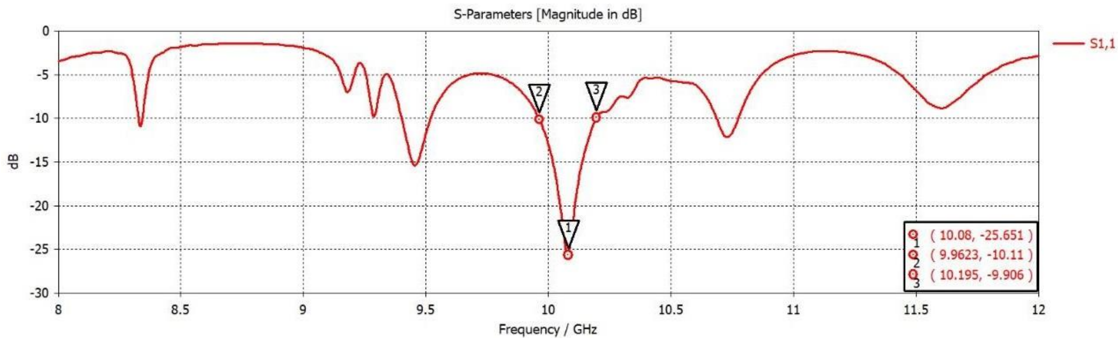


Fig 6.9 S11 parameter of 1x4 array with heatsink

6.3 VSWR

The Voltage Standing Wave Ratio (VSWR) is a measure of how well an antenna is matched to its transmission line, and it is an important parameter in antenna engineering and RF system design. VSWR is a ratio of the maximum voltage to minimum voltage along the transmission line, which corresponds to the maximum and minimum amplitudes of the standing wave that is generated by the reflection of the transmitted signal at the antenna.

Fig 6.10 VSWR of Single element

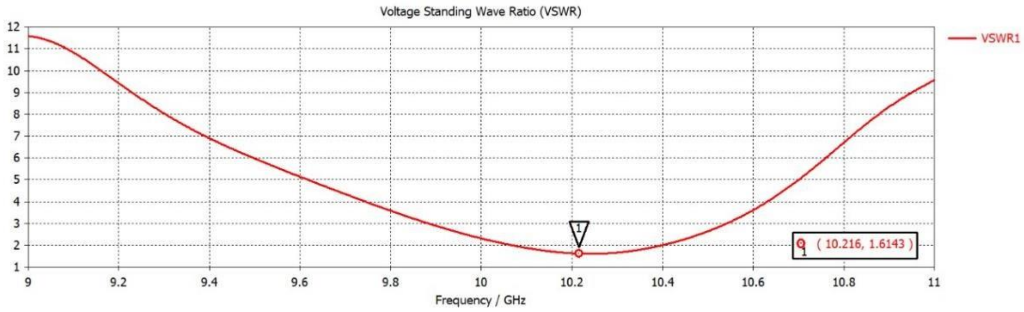


Fig 6.11 VSWR of 1x2 array

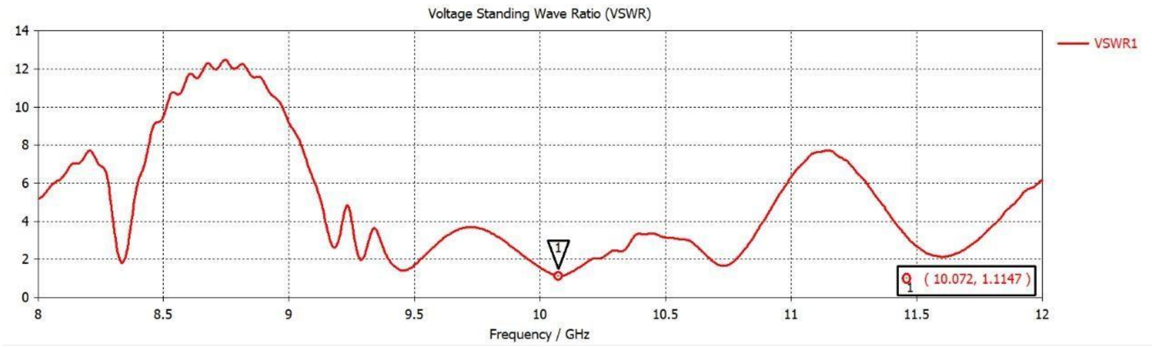


Fig 6.12 VSWR of 1x4 array with heatsink

6.4 Antenna Gain

The term Antenna Gain describes how much power is transmitted in the direction of peak radiation to that of anisotropic source. Gain of an antenna is a key performance figure which combines the antenna's directivity and electrical efficiency.

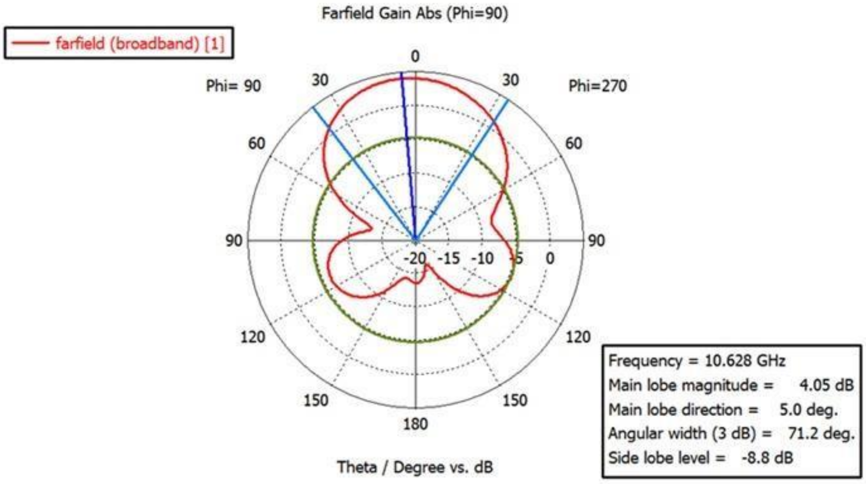


Fig 6.13 Gain of Single element

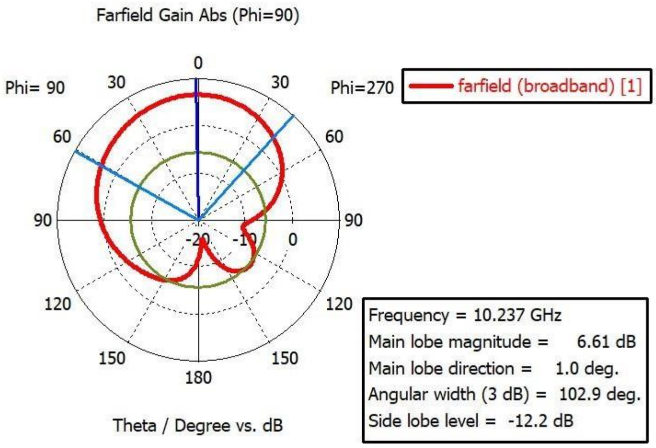


Fig 6.14 Gain of 1x2 array

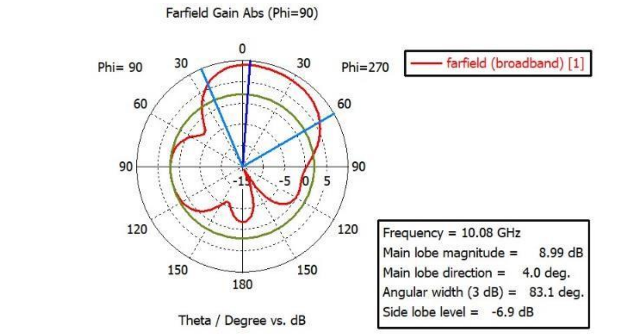


Fig 6.15 Gain of 1x4 array with heatsink

6.5 RADIATION PATTERN

E Plane:

For a linearly-polarized antenna, this is the plane containing the electric field vector and the direction of maximum radiation. The electric field or "E" plane determines the polarization or orientation of the radio wave. For a vertically polarized antenna, the E-plane usually coincides with the vertical/elevation plane. For a horizontally polarized antenna, the E-Plane usually coincides with the horizontal/azimuth plane. E- plane and H-plane should be 90 degrees apart.

H plane:

For a linearly-polarized antenna, this is the plane containing the magnetic field vector and the direction of maximum radiation. The magnetizing field or "H" plane lies at a right angle to the "E" plane. For a vertically polarized antenna, the H-plane usually coincides with the horizontal/azimuth plane. For a horizontally polarized antenna, the H-plane usually coincides with the vertical/elevation plane.

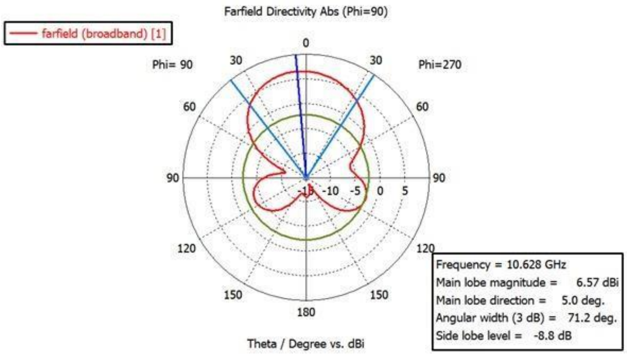


Fig 6.16 radiation Pattern of Single element

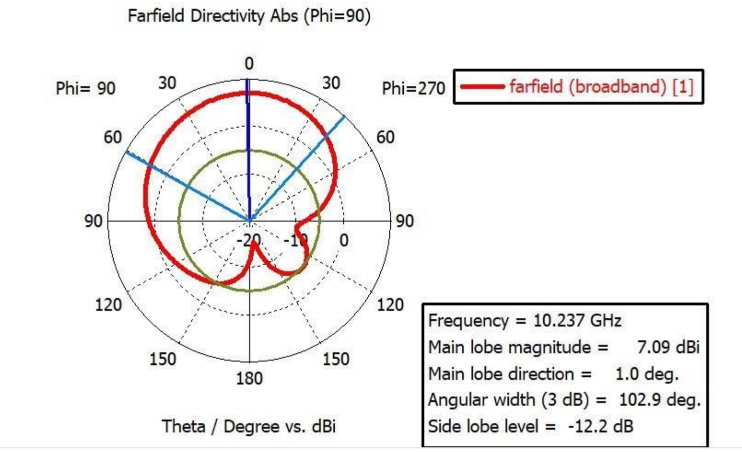


Fig 6.17 Radiation Pattern of 1x2 array

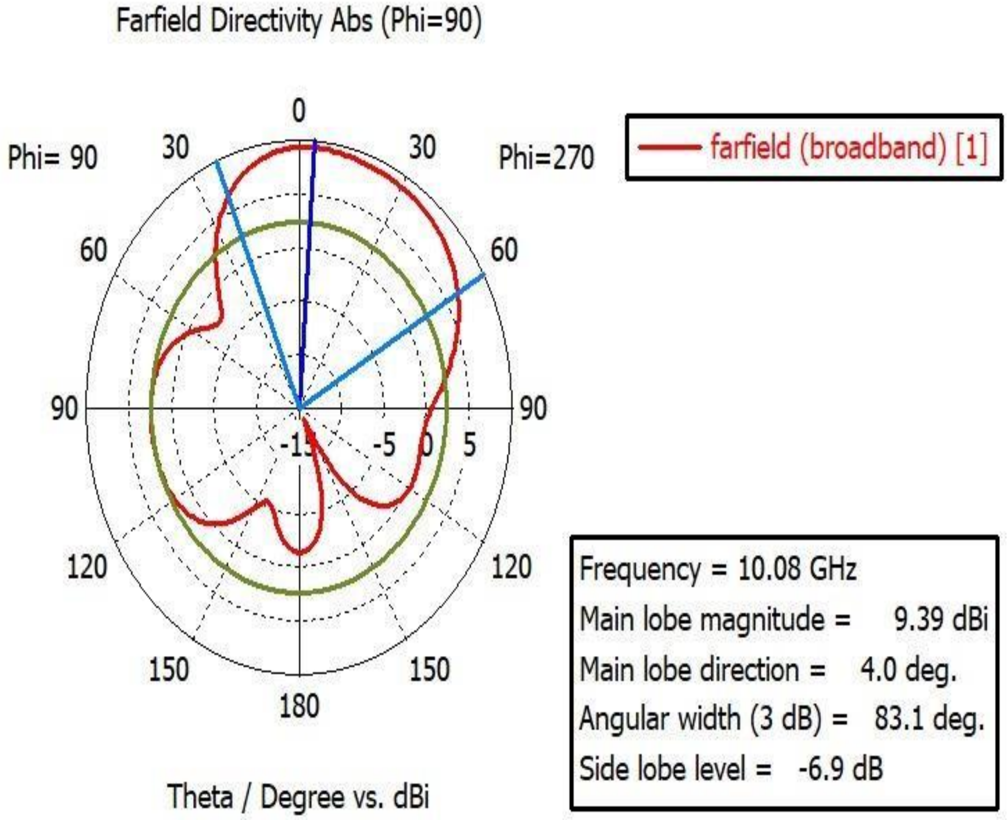


Fig 6.18 Radiation Pattern of 1x4 array with heatsink

CONCLUSIONS

In this study, we have successfully designed and demonstrated an X-band phased microstrip patch antenna array with an integrated heatsink. The innovative design addresses critical thermal management challenges inherent in high-power antenna systems, ensuring improved reliability and operational longevity without compromising on performance.

Our experimental results validate the effectiveness of the integrated heatsink, showing significant reductions in operating temperature. The antenna array exhibits excellent electromagnetic performance, with a peak gain of 8.99 dBi, a 232 MHz bandwidth, and a beam steering capability of 4 degrees. Additionally, the sidelobe levels were effectively maintained below -20 dB and return loss of -25.61 dB showcasing the design's high precision and efficiency.

The integration of the heatsink into the antenna array represents a significant advancement in antenna technology, particularly for X-band applications such as radar and satellite communications. The combined benefits of efficient thermal management and high-performance phased array capabilities position this design as a robust and reliable solution for demanding applications.

Future work will focus on further optimizing the heatsink design and exploring its scalability for larger arrays and higher frequency bands. This study paves the way for the development of more advanced antenna systems capable of operating at higher power levels and in more challenging thermal environments.

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