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ISTANBUL AYDIN UNIVERSITY

INSTITUTE OF GRADUATE STUDIES

RADIATION CHARACTERISTICS AND EFFICIENCY ANALYSIS OF MICROSTRIP PATCH ANTENNAS FOR IOT APPLICATION

MASTER’S THESIS

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Department of Electrical and Electronic Engineering

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MARCH, 2024

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ONAY SAYFASI

DECLARATION

I hereby declare with respect that the study “Radiation Characteristics And Efficiency Analysis Of Microstrip Patch Antenna For Iot Application”, which I submitted as a Master / PhD thesis, is written without any assistance in violation of scientific ethics and traditions in all the processes from the Project phase to the conclusion of the thesis and that the works I have benefited are from those shown in the References. (27/03/2024)

Abdifatah Abdulkadir AHMED

FOREWORD

“First and foremost, I extend my heartfelt gratitude to God for guiding me through this journey and providing me with the strength and perseverance to complete this thesis. I would like to thanks my family members especially my two parents for their support, encouragement, and their constant prayers and emotional support. My Allah continue to reward you.

I express my deepest thanks and gratitude to my honorable supervisor Dr. Necip Gökhan KASAPOĞLU, who always advice, support, guide and contributed to the success of my project work by providing appreciate my necessary information for developing a good system.

I express my heartfelt appreciation to Istanbul Aydin University for granting me the chance to pursue my master's degree and fostering an environment where I could interact with and draw inspiration from some of the most skilled and driven individuals in my field.

Finally, I extend my gratitude to everyone who has supported me - teachers, classmates, and well-wishers. Your belief in my potential and encouragement have made a significant impact on my academic success. Thank you for being part of this meaningful journey.”

March, 2024 Abdifatah Abdulkadir AHMED

RADIATION CHARACTERISTICS AND EFFICIENCY ANALYSIS OF MICROSTRIP PATCH ANTENNAS FOR INTERNET OF THINGS (IoT) APPLICATIONS

ABSTRACT

Recently, microstrip patch antennas have gained significant popularity in the field of Internet of Things (IoT) applications owing to their advantageous characteristics such as their compact form factor, cost-effectiveness, and ease of manufacturing. This study presents an analysis of the radiation characteristics and efficiency of MPAs (Microstrip Patch Antennas) in the context of IoT (Internet of Things) applications. The objective of this study is to enhance and gain insights into the impact of various design factors through the utilization of two widely employed feed methodologies, namely microstrip line feed and coaxial probe feed. The antenna was designed and simulated to operate at a resonant frequency of 2.4 GHz. This was achieved by utilizing a TLY series dielectric substrate with a dielectric constant of around 2.17 and a thickness of 1.6 mm. The evaluation of the antenna performance was conducted using the Computer Simulation Technology (CST) microwave studio software. The antennas under consideration have demonstrated a reflected coefficient of -28.5 dB and -10.30 dB when utilizing microstrip line feed and coaxial probe feed, respectively. The simulation yielded favorable outcomes for VSWR, directivity, gain, bandwidth, and efficiency. In comparison to previous designs reported in the literature, the antenna being presented exhibits a significant enhancement in directivity, beam gain, return loss, and high radiation efficiency.

Keywords: Microstrip patch antenna, IOT, directivity, gain, and CSTMW

NESNELERİN İNTERNETİ (IoT) UYGULAMALARI İÇİN MİKROŞERİT YAMA ANTENLERİNİN RADYASYON ÖZELLİKLERİ VE VERİMLİLİK ANALİZİ

ÖZET

Son zamanlarda mikroşerit yama antenler, kompakt form faktörü, maliyet etkinliği ve üretim kolaylığı gibi avantajlı özellikleri nedeniyle Nesnelerin İnterneti (IoT) uygulamaları alanında önemli bir popülerlik kazanmıştır. Bu çalışma, IoT (Nesnelerin İnterneti) uygulamaları bağlamında MPA'ların (Mikroşerit Yama Antenleri) radyasyon özelliklerinin ve verimliliğinin bir analizini sunmaktadır. Bu çalışmanın amacı, yaygın olarak kullanılan iki besleme metodolojisinin (mikroşerit hat beslemesi ve koaksiyel prob beslemesi) kullanımı yoluyla çeşitli tasarım faktörlerinin etkisini geliştirmek ve bunlara dair içgörü kazanmaktır. Anten 2,4 GHz rezonans frekansında çalışacak şekilde tasarlanmış ve simüle edilmiştir. Bu, dielektrik sabiti yaklaşık 2,17 ve kalınlığı 1,6 mm olan TLY serisi dielektrik alt tabaka kullanılarak elde edildi. Anten performansının değerlendirilmesi Bilgisayar Simülasyon Teknolojisi (CST) mikrodalga stüdyo yazılımı kullanılarak gerçekleştirilmiştir. Söz konusu antenler, mikroşerit hat beslemesi ve koaksiyel prob beslemesi kullanıldığında sırasıyla -28,5 dB ve -10,30 dB'lik bir yansıma katsayısı sergilemiştir. Simülasyon, VSWR, yönlülük, kazanç, bant genişliği ve verimlilik açısından olumlu sonuçlar verdi. Literatürde bildirilen önceki tasarımlarla karşılaştırıldığında, sunulan anten yönlülük, ışın kazancı, geri dönüş kaybı ve yüksek radyasyon verimliliğinde önemli bir gelişme sergiliyor.

Anahtar Kelimeler: Mikroşerit yama anteni, IOT, yönlülük, kazanç ve CSTMW

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LIST OF ABBREVIATIONS

AM : Amplitude Modulation

CST : Computer Simulation Technology

dB : Decibel

EMI : Electromagnetic Interference

FDTD : Finite Difference Time Domain

FBW : Fractional Bandwidth

FEM : Finite Element Method

FM : Frequency Modulation

FNBW : First Null Beamwidth

GBAS : Ground-Based Augmentation System

GHz : Gigahertz

GNSS : Global Navigation Satellite System

GPS : Global Positioning System

GSM : Global System for Mobile Communications

HPBW : Half-Power Beamwidth

IEEE : Institute of Electrical and Electronics Engineers

IoT : Internet of Things

ISM : Industrial, Scientific and Medical

MBAN : Medical Body-Area Network

MLAN : Medical Local Area Networks

MMIC : Monolithic Microwave Integrated Circuit

MoM : Method of Moments

PCS : Personal Communications Services

RHCP : Right-Hand Circular Polarization

SDARS : Satellite Digital Audio Radio Services

UMTS : Universal Mobile Telecommunications System

VSWR : Voltage Standing Wave Ratio

WLAN : Wireless Local Area Network

I. INTRODUCTION

A. Introduction

The Internet of Things (IoT), is clearly becoming more and more prevalent as a prominent technological advancement in recent years, exhibiting a multitude of applications that facilitate intercommunication among physical entities over the internet. The antenna is a crucial component of IoT systems as it facilitates wireless connectivity between devices. The term "Internet of Things" (IoT) refers to a network of interconnected physical objects or devices entities equipped with software, sensors, and connectivity capabilities, enabling them to establish communication among themselves and with the internet (Qian et al., 2007).

Microstrip patch antennas are frequently employed in Internet of Things (IoT) applications due to their compact dimensions, minimal height, and convenient manufacturability. The selection of the feed mechanism for microstrip patch antennas holds significant importance with reference to the Internet of Things' (IoT) applications. There exist four distinct feed approaches in the context of MPAs. However, within the context of IoT applications, the two feed techniques most frequently employed for microstrip patch antennas are microstrip line feed and coaxial probe feed. (Anchidin et al., 2023). A microstrip transmission line is connected to the patch antenna, which is a specific type of planar transmission line consisting of a dielectric substrate with a conductive strip on top and a ground plane connected to the bottom surface. The outer conductor of the coaxial cable is connected to the ground plane during the coaxial probe feeding process, while the inner conductor is connected to the antenna's microstrip patch (Sharma, 2012).

The design of microstrip patch antenna for IoT application required careful consideration of various factors, including frequency range, bandwidth, polarization, and radiation pattern. The antenna must operate at intended frequency range, which will depend on the particular application. The bandwidth of antenna must be sufficiently broad to accommodate fluctuations in frequency resulting from environmental conditions. Selection of the polarization of the antenna should be based on the specific application, whether it requires linear or circular polarization. The antenna's radiation pattern should be optimized to ensure that it provides maximum coverage and signal strength in the desired direction.

The objective of this study is to examine several characteristics associated with the performance of antennas, examples include efficiency, radiation pattern, and return loss. Microstrip line feed and coaxial probe feed are the two different feed technologies that will be used in this study. The antenna in examining has been designed and simulated using a dielectric constant of 2.17 and a thickness of 1.6, with a resonant frequency of 2.4 GHz.

B. Internet of Things (IOT) Applications

One of the main two components of Internet of Things communication the Internet of Things antenna is utilized in communication media are interconnected. The wireless module is the first and the IoT antenna is the second. These two parts together direct effect the communication network’s quality including the distance from the communication how quickly and steadily it moves, and far it can travel.

Device connect to the internet of Things (IoT) must have an antenna. The frequency spectrum expands and IoT antenna designs become more complex as the amount of space available for IoT devices becomes smaller. This includes antennas for NB-IoT, 4G, and 5G in addition to antennas for GSM, Lora, GPRS, UMTS, ISM, GNSS, Wi-Fi, and GPS, and other types of Internets of Things (IoT) antenna are all included (Amit Kumar et al., 2022).

All of these components are combined into one technology called the Internet of Things (IoT), which includes radio modules, actuators, sensors, batteries, MEMS devices, harvesting methods, and, most importantly, completed antenna-using devices. Several application-specific criteria, including as transmit power and frequency range, will determine the antenna's design. IoT networks connect using omnidirectional antennas like wired antennas, rubber ducks, patches, whips, PCBs, and others. Typically, they send small amounts of data over satellites, meshes, or other subnetworks. Analogous antenna arrangements are used for GPS, Bluetooth, and Wi-Fi connectivity in several Internet of Things expansion kits, such as Arduino GSM and Qualcomm IoE. Conversely, wireless networks like IEEE 802.11ax, 5G, and WiGig require large amounts of continuous spectrum space (Zhiqin Qian et al., 2022).

For some applications, such wearable electronics and medical local area networks (MBAN), the surfaces of the device and antenna must also be small. This reaffirmed the necessity of creating antennas to satisfy specific application requirements and for use with terminal equipment.

There are various classifications for IoT antennas based on their use or operational range. A few antennas and the typical frequency ranges in which they function are listed in table 1 below. Antenna technology has an impact on the aerospace industry's availability of permanent communication medium (Amit Kumar et al., 2022). Antenna devices made with non-traditional methods are already produced by many companies.

Table 1. Frequency band and IoT application

Application	Technology	Frequency band
General (Smart home, smart building, etc.)	Wi-Fi	2.4GHz
	Bluetooth	2.4GHz
	GPS	1575.42MHz 1227.6MHz,1176MHz
	ZigBee	915MHZ 2.4GHz
	Z-wave	2.4GHz
medical	MBAN/WBAN IEEE 802.15.6	400MHz,800MHz,900MHz ,2.36GHz,2.4GHZ
LPWAN (Smart agriculture , smart cities)	LoRa	433MHz,868MHz,915MHz
	Sigfox	868MHz,902MHz
IIOT	Wireless HART	2.4GHZ
	ISA 100.11a	2.4GHz
Avionics	WAIC	4200MHz to 4400MHz

There might be a wide variety of antenna types to pick from depending on the various radio frequency bands, and each frequency band needs a distinct kind of antenna. Printed antennas have been chosen as the primary option in contemporary wireless communication systems. These printed antennas are made using a different architecture from what can be observed in laptops, cellphones, and other devices.

1. Challenges of IoT applications

The usage of antennas in Internet of Things applications is not without its difficulties. These difficulties include, among others:

a. Radiation pattern: The antenna's radiation pattern controls the signal's direction and strength. IoT devices may need to connect with other devices that are dispersed across a wide range of latitudes and longitudes. Antennas with omnidirectional or directional radiation patterns are necessary for this, although they can be difficult to build.

b. IoT applications use both licensed and unlicensed bands across a broad spectrum of frequencies. It can be difficult to develop antennas that can function throughout a wide frequency range, which is necessary for this.

c. IoT devices may function in settings with high amounts of electromagnetic interference (EMI). This could have an impact on how well the antenna works and decrease its effectiveness.

C. Literature Review

A brand-new microstrip antenna for Wi-Fi system is designed by Sharma et al. (Md. Sohel et al., 2023). With objective of growing a cost-effective Patch antenna suitable for using indoors or outdoors. The study is evaluated several key parameters, including radiation, gain using HFSS, CSTW, return loss, VSWR, and directivity for simulation. The proposed antenna performs better when simulation software is used to validate the findings of antenna testing.

A small microstrip antenna foe WBAN 2.4GHz application are introduced by Ali et al. (Md. Sohel et al., 2023). The plan consists of a ground plane and a radiating patch. The radiating patch antenna's dimensions is 62x43x1.6mm. The estimated-on body and off-body antennas, at 53% and 46%respectively. Recent measurement was in agreement. Due to the positive outcome. WBANs operating in the ISM band are compatible with the suggested design.

In a research paper by K.R.K Varahala et al (Varahala et al., 2021). A method to enhance the efficiency of microstrip patch antenna used IoT application. The approach involves adding a parasitic patch to the antenna. The study demonstrates that this technique can enhance radiation efficiency by as much as 10%.

In “Radiation characteristics of microstrip patch antenna with different feeding Techniques for IoT application” by S.K.Sharma et al (Sharma et al, 2021). The authors compare the radiation characteristics of microstrip antenna that uses various feeding techniques. The study examines their techniques: coaxial feeding, microstrip feeding, and aperture coupled feeding offers the best radiation characteristics.

A study by A.Kumar et al (A. Kumar et al., 2013). Introduces the design and assessment of microstrip patch antenna that features parasitic patches which is suitable for IoT application. The result of the study indicates that incorporating the parasitic patch into the antenna can improve its radiation efficiency by up to 12%.

A.singhal et.al (A. Singhal et all., 2020). Designed and evaluated in details circular microstrip patch antenna for IoT application that works at 2.4GHz. The study demonstrate that the antenna possesses favorable radiation characteristics and high efficiency.

D. Research Objective And Motivation

The goal of this study is to investigate various parameters for the performance of antennas, including return loss, radiation pattern, and efficiency using both simulation and measurement techniques.

The main aims of this thesis is:

- Analysis of radiation and characteristics and efficiency of microstrip patch antenna for IoT application
- To understand and optimize in terms the performance of microstrip patch antenna of radiation characteristics and efficiency
- Determining radiation characteristics of microstrip patch antenna including, the gain, radiation pattern, return loss, and directivity.

This study aimed to understand the characteristics and efficiency of microstrip patch antenna can help to improve the design of these antenna, and make them more suitable for specific application such as increasing the gain for long distance communication, or optimizing pattern for specific coverage area. This study could advance the design and use of microstrip patch antennas in IoT applications and has major implications for the development of IoT technology.

E. Reporter structure

The thesis is organized into five chapters, which are as follows:

- **Chapter 1** provides an overview of the project, including the background, problem statement, research objectives, significance of the study, and scope of the research.
- **Chapter 2** explain the theory and concepts related to microstrip patch antennas, covering both their introduction and design parameters.
- **Chapter 3** outlines the methodology employed in the project's design process. This section describes the procedures for obtaining crucial data related to the design, including calculations and a parametric study conducted using CSTW software.
- **Chapter 4** provides an analysis of the project's results. This section compares simulation and measurement results to highlight the antenna characteristics.
- **Chapter 5** is devoted to presenting the project's conclusion. This chapter summarizes the overall project successes and offers potential future work after theoretical and measured results have been achieved.

II. THEORETICAL BACKGROUND OF MICROSTRIP PATCH ANTENNA

A. Overview of Microstrip patch antenna

Microstrip patch antenna was initially developed in the 1950sand 1960s to create antennas that were both compact and low profile for military purpose. The first microstrip antenna were made using a thin metal patch on a dielectric substrate, which was then backed by a ground plate. In the 1990s, researchers delved deeper in to characteristics of microstrip patch antenna and discovered that by altering the patch and substrate dimension, they could achieve different results. For IoT applications, microstrip antenna are designed to function in the ISM band at frequency 2.4GHz and 5GHz the antennas consist of a surface at ground level and a rectangular or circular patch fed by a microstrip transmission line that is connected at a precise spot. The design is printed on a thin dielectric substrate. (T.Narang & Sh.Jain, 2013).

In the 1970s, microstrip antennas saw a surge in popularity, primarily for space borne uses. Today, they are employed in both commercial and government applications. These antennas are made of a grounded substrate and a metallic patch. The metallic patch comes in a wide variety of shapes, however, rectangular and circular shapes are the most common, owing to their simple analysis and manufacturing techniques, as well as their attractive radiation properties, particularly low cross-polarization radiation. It is notable for its compact form and ability to adapt to flat and curved surfaces, Current printed-circuit techniques allow simplified and cost-effective manufacturing, as well as durability when put on solid surfaces and the suitability for MMIC designs, and wide range frequency of resonance, polarization, pattern, as well as impedance make the microstrip antennas very versatile. The surfaces of high-performance airplanes, spacecraft, satellites, missiles, vehicles, and other objects can be fitted with these antennas (John Wiley & Sons, 2016).

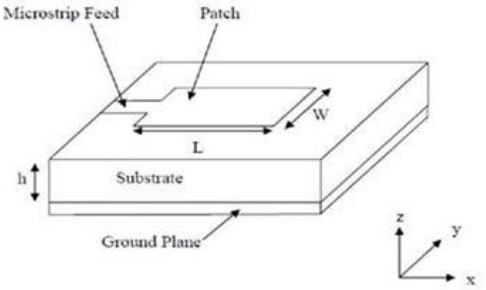


Figure 1. Structure microstrip patch antenna

B. Types Of Microstrip Patch Antenna

There are several shapes of microstrip patch antennas, each designed to meet specific requirements. Figure 2 shows a few common types. Patches in circular, rectangular, and square shapes are the most common.

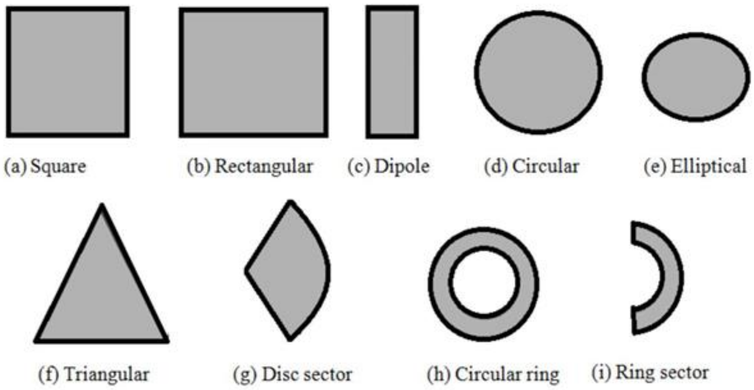


Figure 2. Common shapes microstrip patch antenna

C. Microstrip Antenna Analysis Methods

The resonant length of a rectangular microstrip antenna has been determined to be approximately half of the wavelength when the actual dielectric constant of the substrate was taken into consideration. The resonant resistance of a simple rectangular microstrip radiator required to be determined after the development of the microstrip antenna. A technique for analysis was required (Singh & Tripathi, 2011). Most useful model for this purpose was the transmission line model, which Munson proposed. It approximated resistance values close to the leading edge of the microstrip antennas. Model of lines for transmission, however, was insufficient for addressing different resonant modes. In the late 1970s, a loss resonant cavity in the form of a rectangular microstrip antenna was created by Lo et al. Although having a design that appears easy to understand microstrip antennas presented difficulties in accurate assessment (MarufAhmed et al., 2012). First, the technique of moments (MoM) came into being in the 1980s, a time when modern computers had limited memory and CPU power (Nadeem & Cho, 2018). This was the first computationally effective method for coordinating microstrip antenna research. The ability to apply memory-intensive numerical methods such as the finite element method (FEM) and the finite difference time domain (FDTD) approach was developed throughout time. Due to the increasing processing power and memory capacity of personal computers, these methods required more resources than MoM solutions did in the 1990s (Randy Bancroft, 2009).

D. The Advantages And Disadvantages Of Microstrip Antennas

The following are microstrip antenna's main advantages:

- Affordable production
- Antenna thickness (profile) are small
- Can readily adapt to a curved surface on a product or a vehicle.

Microstrip antennas can be integrated with other microwave devices that are microstrip realizable without requiring additional steps in the fabrication process (such a corporate feed network for an array of microstrip antennas or a branch line hybrid to obtain circular polarization).

Circular or linear polarization can be easily produced by many designs. A vast selection various pattern and gain options (2.5 to 10.0 dBi).

The following are microstrip antenna's main drawbacks:

- Usually, there is a narrow bandwidth (2:1 voltage standing wave ratio, or VSWR) of between 5% and 10%.
- Thin patches can experience significant conductor and dielectric losses, which reduces antenna efficiency.
- Environmental sensitivity, including sensitivity to humidity and temperature.

E. Microstrip Antenna Applications

The rectangular patch microstrip antenna is the most widely used form, which operates at 1.575 GHz and modified to generate the right-hand circular polarization (RHCP). For a given application, several vendors provide ceramic patches with high dielectric constants (r = 6, 20, 36), that make the microstrip antenna, rectangular in shape have the smallest possible footprint. The patches are provided ready for low noise component integration. In order to satisfy a variety of commercial needs, printed and microstrip antennas are utilized. These include the Global Positioning System (GPS), Bluetooth, WiMax, Zigbee, WiFi, and other applications.

In the recent few years, commercial AM and FM communicates in vehicles have been gradually replaced by Satellite Digital Audio Radio Services (SDARS). The complex radiation pattern requirements of the system were satisfied by combining a printed monopole with an annular microstrip antenna of the TM21 mode, which has been modified to produce left-hand circular polarization at 2.338 GHz by adding notches networks of wireless local areas allow mobile devices, like laptop computers, to connect to wireless access points at a short distance and at a high speed. Wi-Fi data link ranges are typically 100–300 feet for indoor connections and 2000 feet for outdoor ones. To communicate wirelessly, IEEE Standards 802.11a, b, and g are utilized. Most WLANs operate in the 2.4 GHz unlicensed spectrum (John Wiley & Sons, 2005).

The system operates in the unlicensed 5 GHz frequency and makes use of both 802.11g and 802.11b in addition to the 802.11a protocol. Two microstrip dipoles are included into the multiband printed antennas inside the ceiling tiles in order to combine signals from GSM cell phones at 860 MHz, PCS cell phones at 1.92 GHz, and 802.11a WLAN service at 2.4 GHz. This is done through the use of a microstrip diplexer. Buildings equipped with wireless access points need to periodically be linked in order to utilize wireless local area network systems.

An omnidirectional printed antenna is required for various applications like inventory control in warehouses. WiMax applications (of interest currently for WiMax applications are frequencies of 2.3, 2.5, 3.5, and 5.8 GHz) and access points both benefit from the usage of omnidirectional microstrip antennas. Microstrip fed printed slot antennas, which also work well with laptop computers for WLAN, have been used to successfully offer vertical polarization (John Wiley & Sons, 2005).

F. Fundamental Parameters Of Antenna (Characteristics)

There are a number of parameters that need to be defined and measured in order to evaluate an antenna's performance. Those parameters are radiation patters, bandwidth, directivity and gain, return loss, input impedance, polarization, effective aperture, antenna efficiency, and effective length. In this section will explain in details those parameters:

1. Radiation Patters

A radiation pattern represents the distribution of power at different separations from an antenna. This distribution's essential components are the nulls, side lobes, and main lobe. Gain measures an antenna's capacity to concentrate power in a particular direction. It is expressed as the ratio of radiation intensity in a given direction to that of a reference antenna (such as an isotropic radiator). The gain of an antenna is essentially a measurement of how well it directs power.

The radiation pattern of the antenna is its most important and vital component. Because of its importance, it might be called the radiation's graphical representation characteristics of the antenna. Using a sphere with electromagnetic fields encircling it at a distance equal to its radius, the antenna is visually displayed. Given that it is a visual representation of the antenna's radiation characteristics are displayed in three directions via the radiation pattern. Angular orientation determines their three-dimensional model of the antenna. The plane on which the field vector is positioned is the E-plane of the patch antenna. Alternatively, the plane containing the H-vector is called the H-plane. Ninety degrees is the proper dipole angle when considering the H-plane.

A useful set of coordinates is shown in Figure 3. The most significant radiation attribute is the two- or three-dimensional spatial distribution of the radiated energy for each observer position along a road or surface with a constant radius. Alternatively, the power density's spatial variation along a constant radius can be shown as an amplified power density graph. (John Wiley & Sons, 2016).

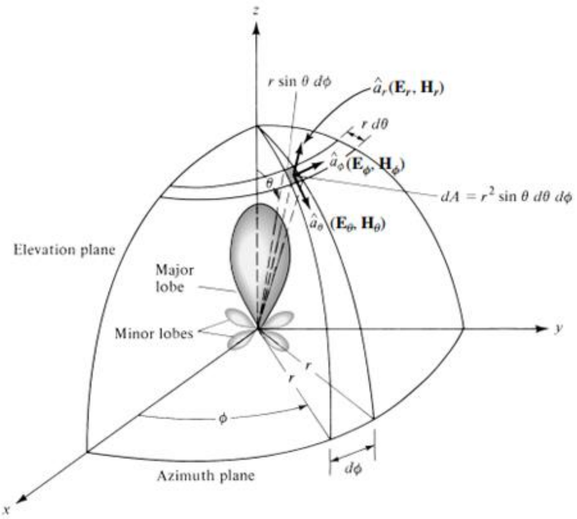


Figure 3. Analysis coordinates system of antenna

2. Beamwidth

An antenna's pattern and beamwidth are interrelated. The beamwidth of a pattern can be expressed as the angle separating two identical spots on the opposite side of the maximum pattern. There are multiple beamwidths in the antenna pattern. The Half-Power Beamwidth (HPBW) is a commonly used beamwidth that can be defined as follows: "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." The IEEE explains this further. The figure in Figure 2.2 provides an illustration of this. An additional significant beamwidth is the angular distance, also known as the First-Null Beamwidth that separates the pattern's initial nulls. The FNBW.

For Example 2, both the HPBW and FNBW are shown for the pattern in Figure 4.4. Beamwidths of less than 10 decibels from the maximum or any other number are considered alternative beamwidths. But in practice, beamwidth—which doesn't need a definition—is usually used to refer to HPBW (A John Wiley & Sons, 2005).

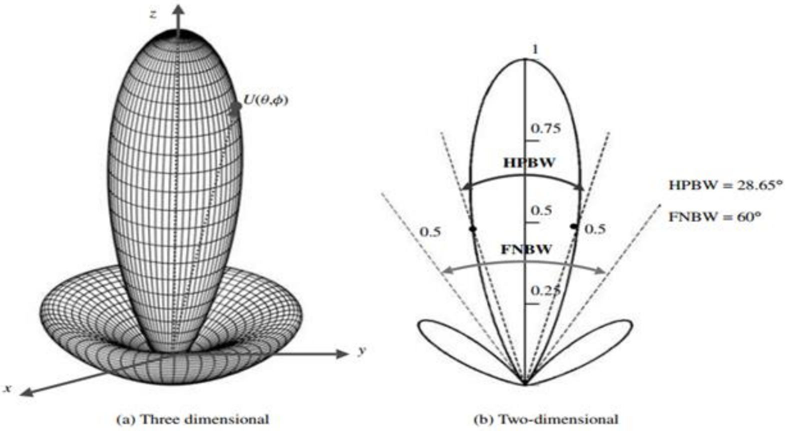


Figure 4. Pattern of amplitude fields in three dimensions and two dimensions, standardized for normalization

An essential performance metric for antennas is their beamwidth, which is frequently used in trade-off with the side lobe level. This means that as the beamwidth reduces, the side lobe level rises, and vice versa. Another word for the antenna's resolution abilities—which allow it to distinguish between two nearby radiating sources or radar targets—is beamwidth. The most widely used resolution criterion specifies that, in order to approximate the half power beamwidth, half of the first-null beamwidth (FNBW/2) must is equivalent to an antenna's ability to discern between two sources. (HPBW). Alternatively, two sources that are at least as far apart angularly as the uniform dispersion antenna's FNBW/2 HPBW may be determined. The antenna will usually smooth out the angular separation if it is lower.

3. Antenna Directivity

The definition of an antenna's directivity is "the ratio of the radiation intensity from the antenna in a given direction to the radiation intensity in all directions." The usual radiation dosage can be obtained by dividing the antenna's total output by 4 π. An antenna's concentration emitted in a certain direction is measured to determine its directivity. An isotropic radiator is always required as the known antenna in order to test the antenna's directivity. Plotting a plot in 2D or 3D is possible, however technically, an antenna's directivity depends on a particular angle. The directivity of an antenna reflects the concentration of power in a specific direction, similar to that of an isotropic radiator. The directed or received power is not arbitrary; rather, it is influenced by the antenna's directivity in different orientations. Patch antennas, for instance, prioritize power concentration in one specific direction, leading to a compromise in directivity in other directions. This results in more focused outputs in one direction but additional responses in alternative directions. In the context of microstrip-configured patch antennas, they are typically positioned horizontally, and their directivity is estimated to fall within the 2 to 7 dB range. Linear polarization occurs in the fields as the radiation pattern is normalized (Sergey N. Makarov, 2002).

$$D = \frac{U}{U0} = \frac{4\Pi U}{Prad} \tag{2.1}$$

When the direction is not given, the maximum directivity (maximum radiation intensity) direction is assumed.

$$Dmax = D0 = \frac{Ulmax}{U0} = \frac{4\Pi Umax}{Prad} \tag{2.2}$$

Where:

D_0 indicates the maximum directivity.

U_{max} is used to denote the peak radiation intensity.

U stands for the overall radiation intensity.

U_0 represents the radiation intensity of an isotropic source.

P_{rad} signifies the total power radiated in watts.

G. Antenna Efficiency

Efficiency is the ability of an antenna to transform input power into radiated power. It is determined by dividing the total input power of the antenna by its output power.

The effectiveness of an antenna is a measurement of its capacity to send and receive electromagnetic waves. An efficient antenna will convert most of the input power into radiated power, while an inefficient antenna will squander more of the input power.

The total energy wasted at the antenna's input ports as well as inside the antenna construction is determined by the antenna's overall efficiency (Sergey N. Makarov et al., 2021). It includes the dielectric/conduction losses as well as any mismatch losses, which are denoted based on the radiation efficiency e as defined by the IEEE:

$$e_0 = e_r e_c e_d \tag{2.3}$$

Where:

The product of an antenna's reflection (mismatch) efficiency gives its e_0. The formula for e_0 = $|\Gamma(1-|\Gamma^2|)|$, where Γ is the voltage reflection coefficient at the input terminals of the antenna. Furthermore, the effectiveness of conduction.

e_0= and dielectric efficiency.

e_d= contribute to the total efficiency.

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \tag{2.4}$$

$$e_0 = e_r e_{cd} = e_{cd}(1-|\Gamma^2|) \tag{2.5}$$

$$where\ e_{cd} = e_c e_d$$
$$= antenna\ radiation\ efficiency, which\ is\ used\ to\ relate\ the\ gain\ and\ directivity$$

H. Antenna Gain

Antenna gain (G) f is the connection between radiation intensity U in a specific direction and the radiation intensity resulting from isotropic radiation if the antenna's power were evenly radiated. Beam-Gain is a useful measurement that focuses consideration the antenna's efficiency, signal-focusing ability, directivity, and other aspects. It is used to evaluate the effectiveness of an antenna. Additionally, directivity is essentially decided by the antenna design because the antenna's directional properties are what determine its influence.

According to its definition, gain is "the ratio of the intensity in a given direction to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically" (in a given direction). The power accepted (input) by 4π can be divided by to find the radiation intensity equal to the isotropically radiated power. (Sergey N. Makarov, 2002). This can be represented as follows in equation form:

$$Gain = 4\pi\ \frac{radiation\ intensity}{total\ input\ \ (accepted) power} = 4\pi \frac{U(\theta,\phi)}{P_{in}} \tag{2.6}$$

$$G = \frac{4\pi U(\theta,\phi)}{P_{in}(lossless\ isotropic\ antenna)} \tag{2.7}$$

İ. Input impedance

The definition of input impedance is "the impedance encountered by an antenna at its terminals, involving the ratio of voltage to current at a specific pair of terminals or the ratio of relevant components in the electric and magnetic fields at a particular point." This section focuses primarily with the antenna's input impedance at the two endpoints designated as the input terminals of the antenna.

The voltage to current ratio at these terminals, in the absence of a connected load, is the antenna's impedance.

$$Z_A = R_A + JX_A \tag{2.8}$$

In this case, X_A id represents the antenna reactance and R_A the antenna resistance. Typically, there are two definitions for antenna resistance:

$$R_A = R_r + R_L \tag{2.9}$$

Where R_L stands for loss resistance and R_r for radiation resistance.

The radiation power P = P_{rad}, the dissipated (loss) power P_i, and the reactive energy stored are all related to the antenna impedance as follows:

$$Z_A = \frac{\Pi_{rad}+\Pi_L+2j\omega(w_m-w_e}{0.5I_{0I_0^*}} \tag{2.10}$$

Here, "wm" stands for the average magnetic energy, and "Io" for the current passing through the antenna terminals. The average electric energy found in the nearfield region is denoted by "we" in the meanwhile. When the reactive component of "Za" disappears and the stored electric and magnetic energy approach balance, the resonance state is established. This phenomena occurs in narrow dipole antennas when the length of the antenna approaches a multiple of half a wavelength (Sergey N. Makarov et al., 2021).

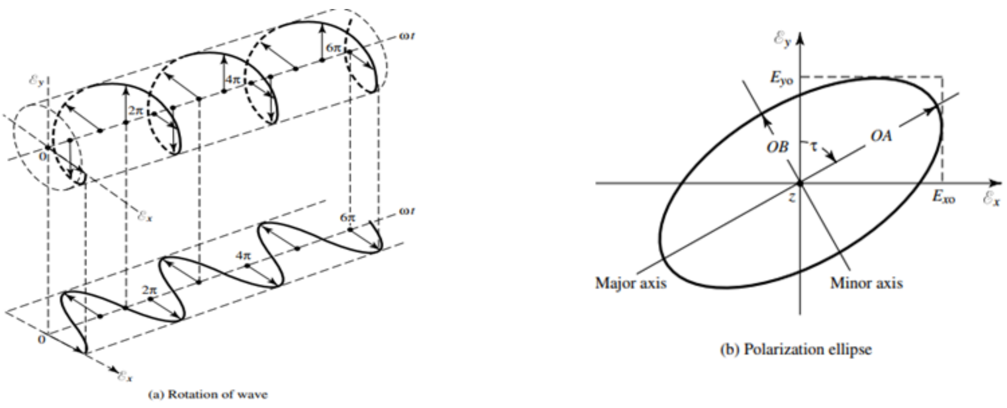
1. Radiation Resistance

Radiation resistance indicates a relationship between the power being radiated and the voltage (or current) at the antenna terminals. As an example, the Thevenin equivalent of the antenna has the following properties:

$$R_r = \frac{2\Pi}{|I^2|}, \Omega \qquad (2.11)$$

J. Polarization of an antenna

The orientation of the transmitted (radiated) wave is referred to as the polarization of an antenna in a particular direction. In the absence of a direction, it is considered that the direction of the highest gain is where the polarization points. Different polarizations for different sections of the pattern may result in practice due to variations in the polarization of radiated energy with respect to the antenna's center direction. The concept of "polarization" refers to the characteristic of an electromagnetic field that "describes the time-varying direction and relative magnitude of the electric-field vector; specifically, the figure traced as a function of time by the extremity of the vector at a fixed location in space, and the sense in which it is traced, as observed along the direction of propagation." The curve that the arrow's (vector) terminal point, which depicts the local electric field, traces is known as polarization. It is important to follow the propagation direction when observing the field. An example trace as an expression of time is shown in figures 5(a) and (b) (Anil Pandey, 2019).



(a) Rotation of wave

(b) Polarization ellipse

Figure 5. Describing the rotation of a plane electromagnetic wave and the corresponding changes in its polarization ellipse at z = 0 over time.

An antenna's direction of radiation (transmission) or reception of a wave can be used to characterize its polarization. The polarization of a wave at a location in the far field that is radiated by an antenna in a specific direction is defined as "the polarization of the (locally) plane wave which is used to represent the radiated wave at that point." A plane wave with a propagation direction away from the antenna and an electric field strength equal to the wave can be used to represent the radiated wave at any location in the far field of an antenna. Because the radius of curvature of the radiated wave's phase front approaches infinity at the same rate that the radial distance does, the radiated wave appears locally as a plane wave in any given direction (A John Wiley & Sons, 2005).

K. Frequency Bandwidth (FBW)

The bandwidth of an antenna is the spectrum of frequencies above which it operates consistently in relation to a certain standard. It includes all frequencies that are close to a center frequency, which is often the dipole's resonance frequency. The antenna's characteristics, including its polarization, gain, side lobe level, beam direction, and radiation efficiency, input impedance, pattern, beamwidth, and radiation pattern, stay quite close to those measured at the central frequency within this speed. Antenna for broadband bandwidth is typically expressed as the ratio between the top and bottom bounds of the allowed operating frequencies. A 10:1 bandwidth, for instance, indicates a 10:1 ratio between the higher and lower frequencies. The procedure for calculating bandwidth in narrowband antennas is to take the percentage of the frequency difference (upper minus lower) with respect to the bandwidth center frequency (John Wiley & Sons, 2008).

Specific criteria must be met by a number of antenna attributes, consisting of gain, side-lobe level, input impedance, radiation pattern, beamwidth, polarization, beam direction, and radiation efficiency. Furthermore, several forms of bandwidth, such pattern and impedance bandwidth, could be added. Once an acceptable level of performance is attained, the fractional bandwidth (FBW), which is the ratio between the upper and lower frequencies, is used to assess the performance of broadband antennas (Anil Pandey, 2019).

$$FBW = f_{max}/f_{min} \tag{2.12}$$

It has been designed to have a broadband antenna with a 40:1 FBW. The term "frequency independent antennas" refers to these antennas. The frequency bandwidth width (FBW) for narrowband antennas is expressed as a percentage of the highest and lowest frequency difference over the center frequency.

$$FBW = \frac{f_{max}-f_{min}}{f_0}.100\% \tag{2.13}$$

$$Usually, f_0 = (f_{max} + f_{\min})\ /2\ or\ f_0 = \sqrt{f_{max}f_{min}} \tag{2.14}$$

L. Voltage Standing Wave Ratio (VSWR)

VSWR, is the measure of voltage. It represents the antennas highest to lowest voltage ratio.

The reflection coefficient ρ, which can be calculated as the voltage reflection coefficient Γ at the antenna's input terminals, is the first value to take into consideration.

$$\rho = |\Gamma| = VSWR - 1/VSWR + 1 \tag{2.15}$$

So, we can write

$$VSWR = V_{max}/V_{min} = |1 + \Gamma|\ /\ |1 - \Gamma| \tag{2.16}$$

M. Return loss

The amount of signal power reflection along a transmission line refers to return loss. The return loss, S11, expressed in decibels (dB), is defined by

S_11 = -20log|Γ| (2.17)

Where Γ is the input terminal voltage reflection coefficient of the antenna.

The power loss in a signal that reflects as a result of impedance mismatch or transmission line disruptions—also referred to as the S11 phenomenon—is measured by the reflection coefficient, which is a ratio of new wave amplitude (V_i) to reflected wave amplitude (V_r).

Decibels (dB) are commonly used to quantify the S11 value. Put a different way, the S11 value approaches infinity when all power is applied to the load (such as an antenna) because reflected power is almost nonexistent (John Wiley & Sons, 2016).

$$S_{11} = 1 - log\left(\frac{P_f}{P_r}\right) \qquad (2.18)$$

Where:

P_f: is the forward power transmitted to antenna

P_r : is the refelected power to the source

N. Feeding Techniques For Microstrip Patch Antenna (Mpa)

Feeding techniques for MPAs are the methods used to link the antenna to the feeling network or line of transmission. For feeding microstrip antennas, there are four different ways: techniques such as proximity coupled, aperture coupled, microstrip line, and coaxial probe.

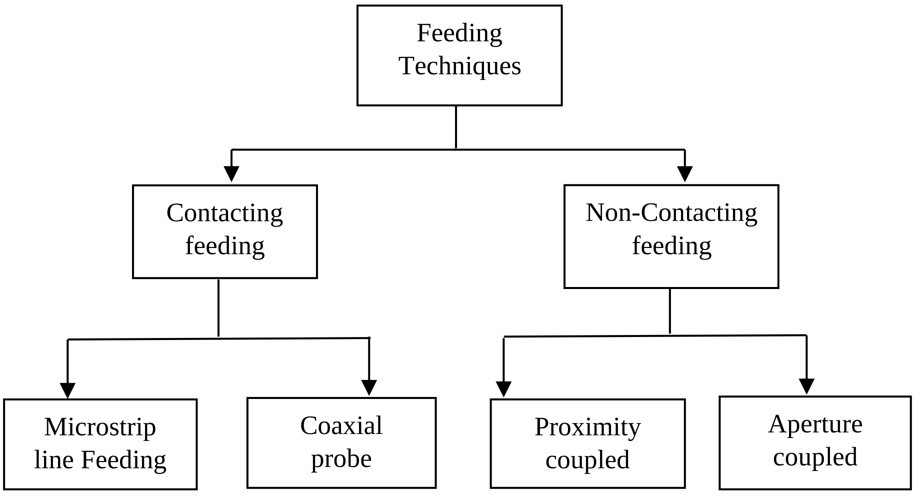


Figure 6. Feeding techniques of microstrip patch antenna.

1. Coaxial probe feed

The antenna's microstrip patch is connected to the inner conductor of the coaxial cable in this method of feeding, while the ground plane is connected to the outer conductor. This method varies from the typical isolation of the feed networks from the microstrip patch. Coaxial feeding has the benefits of being simple to build, generating less spurious radiation, and feeding efficiently. Figure 7 shows the coaxial probe feed.

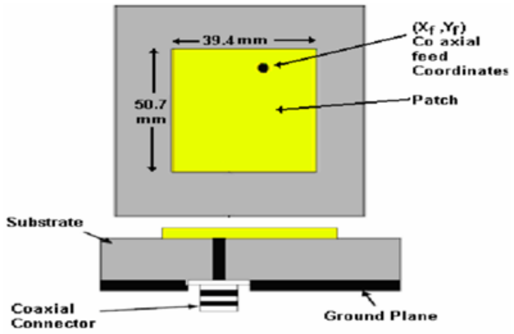


Figure 7. Coaxial probe feed of microstrip patch antenna

This type of feeding method has the benefit of allowing the coax position to be placed anywhere inside the patch to provide the required impedance matching. This feeding method doesn't generate excess radiation, compared to the others, and it is simpler to assemble because it does not require a feeding line.

2. Microstrip line feed

This type of feeding method connects the antenna's microstrip patch straight away to a microstrip feeding line made of conductors. Its dimensions are different from the microstrip patch. The integration method presented here is easy to follow (Singh & Tripathi, 2011). Figure 8 shows this method, which includes directly attaching a thin electrical stripe or line to the radiating patch's edge. This feeding technique provides a flat structure because it allows the necessary feeding pattern to be created on the patch's corresponding substrate, which is thinner than the patch itself due to the conductive stripe's smaller thickness. However, this feeding method's main drawback is the extra radiation that the line introduces, which might change the antenna's overall radiation pattern (Sanchita et al., 2013).

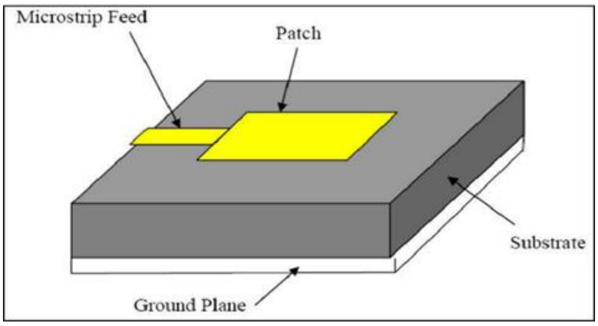


Figure 8. Microstrip line feed of microstrip patch antenna

The patch has more breadth than the strip line when compared to width. Several advantages of this technology include its easy modelling and ease of fabrication.

The inset cut of the patch is created to match the impedance of the feed line to the patch without the need for any extra matching elements. You can accomplish this by carefully adjusting the inset position. This feeding method's ease of fabrication, modelling, and impedance matching make it an essential method. Unfortunately, surface waves and spurious feed radiation also rise with thickness of the employed dielectric substrate, hence decreasing the antenna's bandwidth. Unwanted cross-polarized radiation is also produced by the feed radiation.

3. Aperture Coupled Feed

This feed is divided by a ground plane and contains two different substrates.. Through a ground plane slot, this technique becomes the feed line and microstrip patch. Benefits of the aperture linked feeding approach include interference minimization and pure polarization. In Figure 9, the aperture coupled feed is shown.

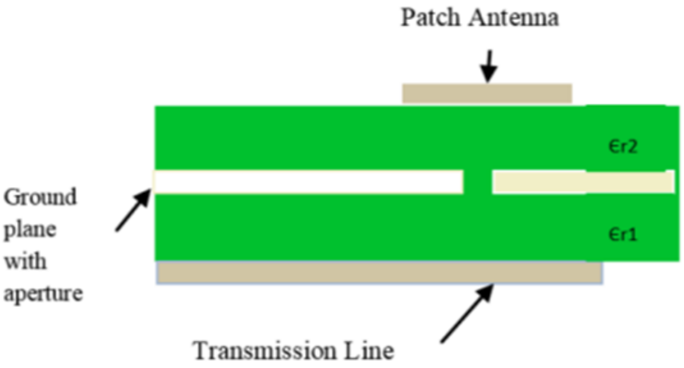


Figure 8. Aperture coupled feed of microstrip patch antenna

The couplet gap is frequently exactly below the fix because to the symmetrical layout of the structure, which reduces cross-polarization. To control the coupling level, adjustments are made to the gap's dimensions and shape. The ground plane, which lies between the feeding line and the patch, reduces the extra radiation from the feed. Although this feeding method has several advantages, using two distinct substrates has increased antenna thickness and created manufacturing issues.

A ground plane divides two dielectric substrates in a configuration called an aperture-coupled antenna, which removes the direct electrical connection between the radiating and feed conductors. The microstrip and the radiating patch transmission line feed can be independently optimized due to this design. Phase shift and excellent isolation of feed circuitry from patch antennas make aperture-coupled antennas the preferred choice for phased arrays. It's crucial to remember, though, that the required structure of layers presents challenges and increases the cost of manufacturing.

- An aperture antenna has the following advantages.
- Compared to a two-wire transmission line, there is more radiation.
- Omi-direction radiation
- Better performance
- Simple construction.

4. Proximity Coupled Feed

The assembly of this feeding technique is a bit more complex. Two dielectric substrates are used. A feed line is positioned between the two substrates, and a microstrip patch is placed on the upper surface of the upper dielectric substrate. This design effectively prevents undesired radiation while ensuring maximum bandwidth provision.

This feeding technique, also known as the electromagnetic connected method, can be seen in Figure 10 which employs two dielectric substrates with the transmitting patch set on top of the lower substrate and the feed line positioned between them.

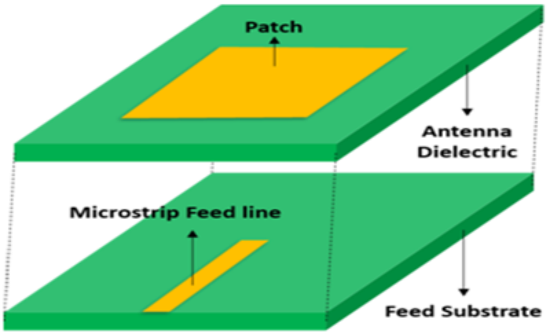


Figure 9. Proximity coupled feed microstrip patch antenna

This technique provides a significant advantage by reducing unnecessary radiation from the metal offer and offering up to 13% of a very high bandwidth. By increasing the MPA's thickness overall, this is achieved. In order to maximize individual performances, the combination of these variables offers an option between two distinct dielectric media: one for the patch and one for the feed line.

In the table below shows the characteristics comparison of different feeding techniques:

Table 2. Characteristics comparison of different feeding techniques

characteristics	**Line feed**	Coaxial probe feed	**Aperture feed**
Return loss	Lower	higher	Lower
Resonant frequency	higher	Lower	Lower
VSWR	<1.5	1.4 to 1.8	≈ 2
Polarization	inferior	inferior	Excellent
Ease of fabrication	straightforward	Requires soldering and drilling	Alignment necessary
Reliability	Superior	lower due to soldering	Good
Impedance matching	simple	simple	simple
Bandwidth	2-5%	2-5%	21%

III. DESIGN AND SIMULATION OF ANTENNAS

A. Introduction

In this section present the methodology of this study, it consists of research antenna characteristics, define antenna characteristics, understand antenna layout CST simulation, and design antenna.

Several methods are utilized to examine the radiation characteristic and efficiency of microstrip patch antennas. These might include modeling tools to model the antenna and its performance parameters, like CST. In order to validate the simulation results, experimental measurements may also be made with the aid of specialist tools like network analyzers or anechoic chambers. The study may entail looking at elements including antenna gain, directivity, radiation pattern, polarization, and impedance matching. These elements may significantly affect the effectiveness and performance of the antenna.

B. Workflow Of The Project

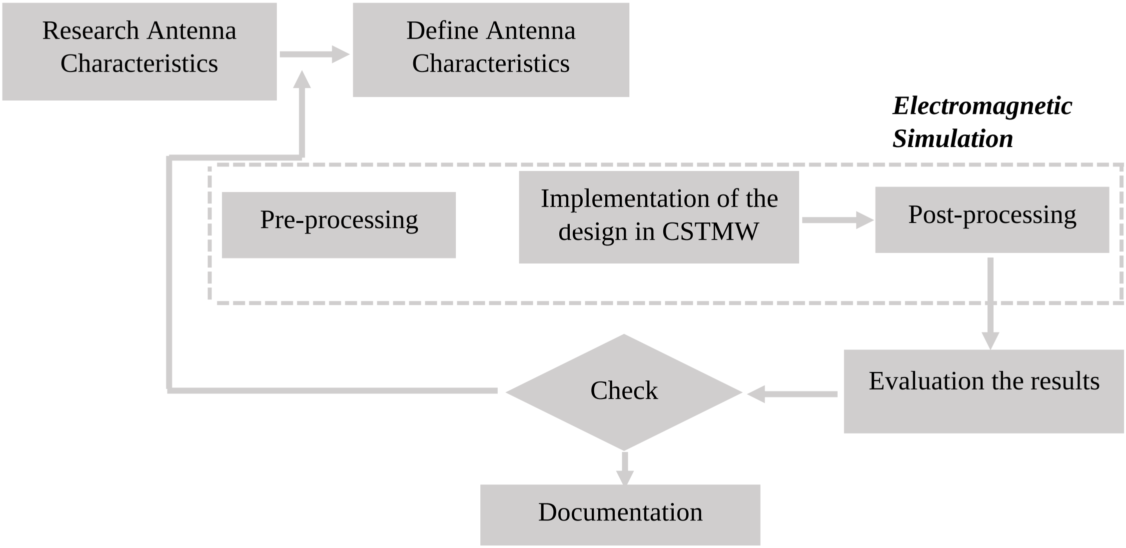


Figure 10. Workflow of the project

1. Research Antenna Characteristics

Although antennas are a major factor in our lives in every aspect and will continuous to exist for incoming generation. There are many reasons why we need or utilize antenna, the important thing that we use antenna is to provide the simple methods to transfer our data. To describe the properties of an antenna, there are many important variables. In microstrip patch antenna, the basic characteristics that you should keep in mind when you design are: radiation pattern, bandwidth, directivity and gain, return loss, input impedance, polarization, effective aperture, antenna efficiency, and effective length.

2. Define Antenna Characteristics

To characterize the performance of an antenna, several parameters must be defined. For a comprehensive examination of the antenna's performance, no all of the characteristics must be stated because some of them are interconnected. We divided the microstrip patch antenna’s characteristics into two main categories:

a. Radiation characteristics

- Bandwidth
- Directivity
- Gain

b. Impedance characteristics

- Return loss
- Voltage Standing Wave Ratio (VSWR)
- Reflected Coefficient

3. Calculating Antenna Parameters Design

The design and development of a microstrip patch antenna requires a basic knowledge of important variables such resonance frequency, dielectric constant, substrate thickness, and conductor height. An overview of the chosen dielectric constants and frequency parameters for the antenna design is given in Table 3.

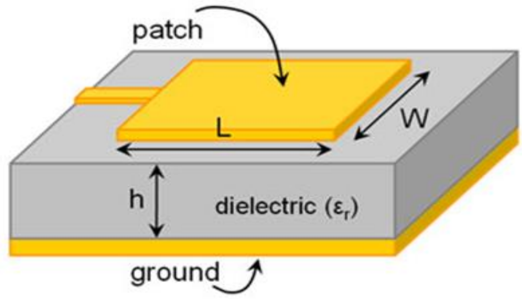


Figure 11. Geometric of microstrip patch antenna

Table 3. Frequency and dielectric constant characteristics.

No	***Parameters***	***Value***
1	Frequency $\mathbf{f_r}$	2.4 GHz
2	Dielectric constant $\boldsymbol{\varepsilon_r}$	2.17
3	Height of dielectric substrate $\mathbf{h_s}$	1.6 mm
4	Height of conductor $\mathbf{h_t}$	0.035 mm

The following equation are used to determine an antenna’s dimensions:

1. Width (W_p)

$$W \equiv \frac{C}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad where\ \ C = 3x10^8 \tag{3.1}$$

2. Effective refractive index

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{w}\right]^{-1/2} \tag{3.2}$$

3. Length
4. The effective length (L_{eff})

$$Leff = \frac{C}{2f_0\sqrt{\varepsilon_{reff}}} \quad where\ \ C = 3x10^8 \tag{3.3}$$

5. The fringing length (ΔL)

$$\Delta L = 0.412\frac{(\varepsilon_{reff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{w}{h}+0.8\right)} \tag{3.4}$$

6. The length (Lg) and width (Wg) of the ground plane

$$L = Leff - 2\Delta L \tag{3.5}$$

$$L_g = L + 6h \tag{3.6}$$

$$W_g = W + 6h \tag{3.7}$$

7. The substrate's length and width are L_g and W_g, respectively, and h is given by

$$h = \frac{0.0606\lambda}{\sqrt{\varepsilon r}} \tag{3.8}$$

8. To find feed length is calculated using below equation

$$feed\ length(Lf) = \frac{\lambda_g}{4} \tag{3.9}$$

9. Where λ_g is the guided wavelength, it determined by :

$$\lambda_g = \frac{\lambda}{\sqrt{\varepsilon reff}} \text{ }, where\ \lambda = \frac{C}{f} \quad (3.10)$$

10. Where λ_g is the guided wavelength, it determined by :

$$\lambda_g = \frac{\lambda}{\sqrt{\varepsilon reff}} \text{ }, where\ \lambda = \frac{C}{f} \quad (3.11)$$

11. Gap between the feed lines

$$\text{GpF} = \frac{\lambda g}{2} \quad (3.12)$$

$$\lambda g = \frac{\lambda}{\sqrt{\varepsilon_{reff}}} \quad (3.13)$$

12. Inset length (Fi)

$$Fi = \frac{w}{2}\left(\frac{1}{\sqrt{\varepsilon_{reff}}} - 1\right) \quad (3.14)$$

NO	**Microstrip line feed**		**Coaxial probe feed**	
	Dimensions	***Values***	***Dimensions***	***Values***
1	Substrate and ground **Wg and Lg**	59.3x51.2	Substrate and ground Wg and Lg	59.3x51.2
2	Thickness of substrate Hs	1.6	Thickness of substrate Hs	1.6
3	Patch antenna Wp and Lp	49.6x41.6	Patch antenna Wp and Lp	49.6x41.6
4	Width of feed antenna wf	4.97	Thickness of patch antenna Ht	0.035
5	Length of feed antenna Lf	14.43	Inner radius Rin	0.5
6	Thickness of patch antenna Ht	0.035	Outer radius Ro	2.31
7	Inset length Fi	14.59		
8	Gap between Feedlines GpF	1		

Table 4. Dimensions and calculated of proposed antennas at fr 2.4GHz.

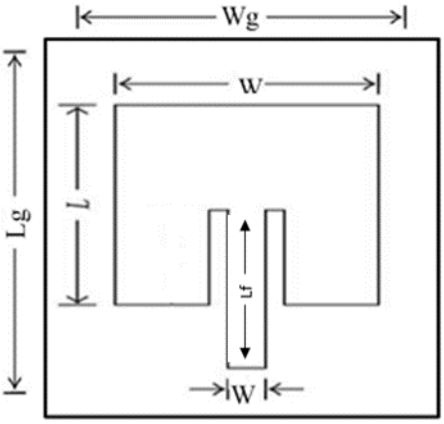


Figure 12. Layout diagram of antenna

Figure 13. Sides of microstrip line feed and coaxial probe feed of MPAs

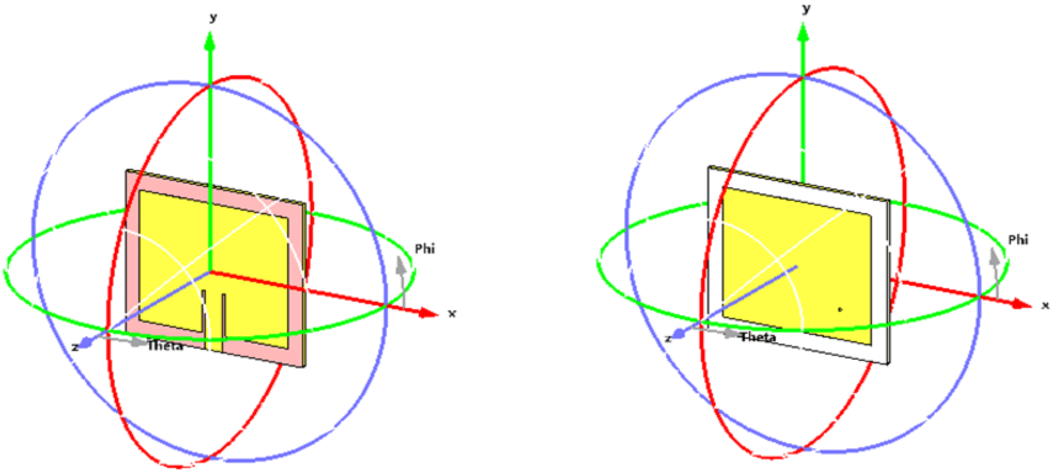


Figure 14. . a). Microstrip line fed and b) coaxial probe feed of MPAs design.

IV. RESULTS AND DISCUSSION

The performance and design of microstrip patch antennas can be influenced by various techniques of feeding. This study indicates the successful design and evaluation of MPAs through the utilization of two different methods of feeding coaxial probe feed and microstrip line feed. The microstrip line feed obtained outstanding performance in terms of return loss, radiation efficiency, beam gain, directivity, and bandwidth. While coaxial probe feed also obtained good impedance matching and acceptable radiation characteristics.

A. Return loss

S11 represents the degree of antenna and transmission line impedance matching. A low return loss value shows better matching and reduced reflection. The return loss for microstrip line feed and coaxial probe feed of MPAs, respectively, have been found to be -28.57db at 2.4GHz for microstrip line feed for MPAs and -10.301dB at 2.4GHz for coaxial probe feed for MPAs, as shown in Figs. 5 and 6. Comparing the two feed techniques, microstrip line feed antenna appears to have excellent impedance matching and is well suited for both transmitting and receiving signals.

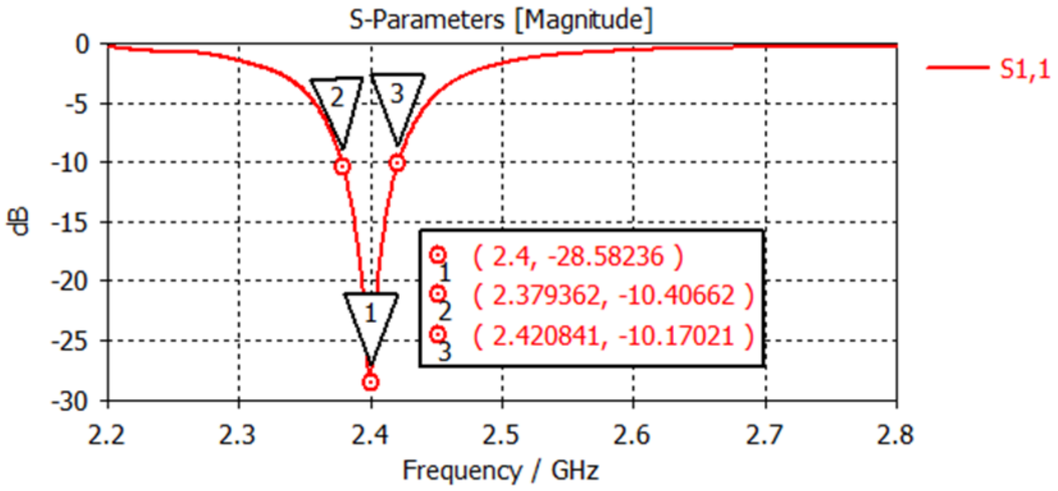


Figure 15. Return loss of Microstrip line feed of MPAs

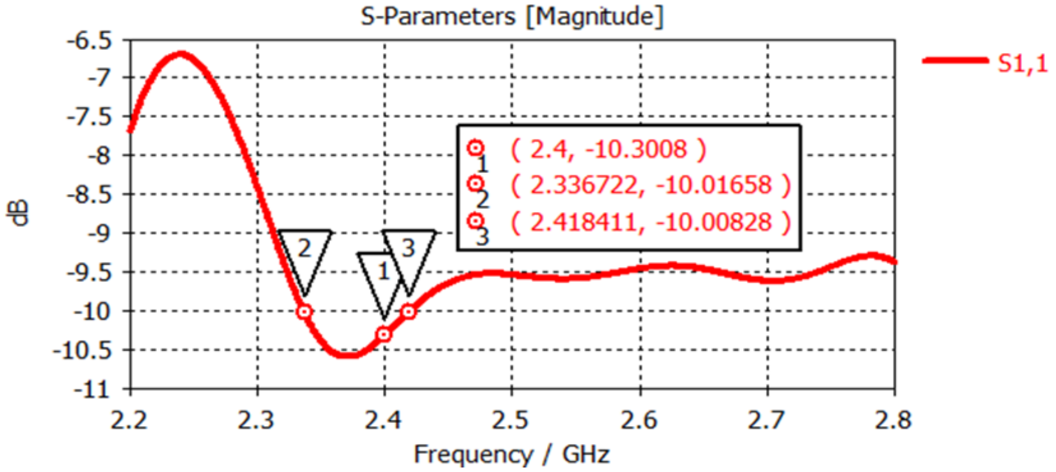


Figure 16. Return loss of coaxial probe feed of MPA

The microstrip line feed found a bandwidth of 41.48MHz at -10.19dB, representing approximately 1.73% bandwidth at fr 2.420GHz, while the coaxial probe feed abstained a bandwidth of 81.68MHz at -10dB with 3.4% at fr 2.4GHz.

B. Voltage Standing Wave Ration (VSWR)

VSWR is an important parameter measure how well an antenna is matched to transmission line. Figures 7 and 8 show, respectively, the VSWR values for the MPAs' microstrip line feed and coaxial probe feed configurations. A VSWR of microstrip line feed is shown 1.07 which indicates good impedance matching and very low reflection. The ideal VSWR Value is close to 1, which denotes a perfect match, in this case the antenna is working incredibly well in this regard. While for coaxial probe feed is found 1.082 at f_r 2.4GHz which is close to the idea value of 1.

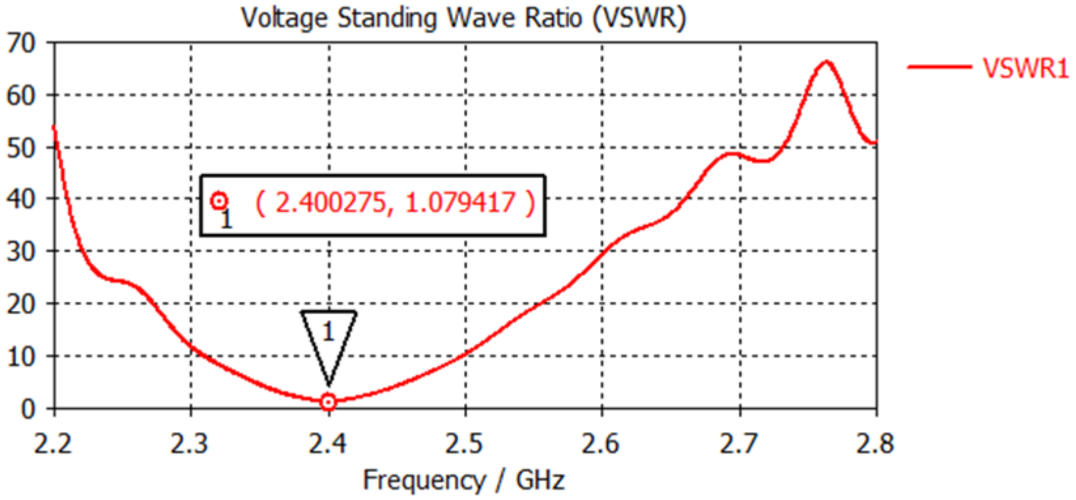


Figure 17. VSWR of microstrip line feed

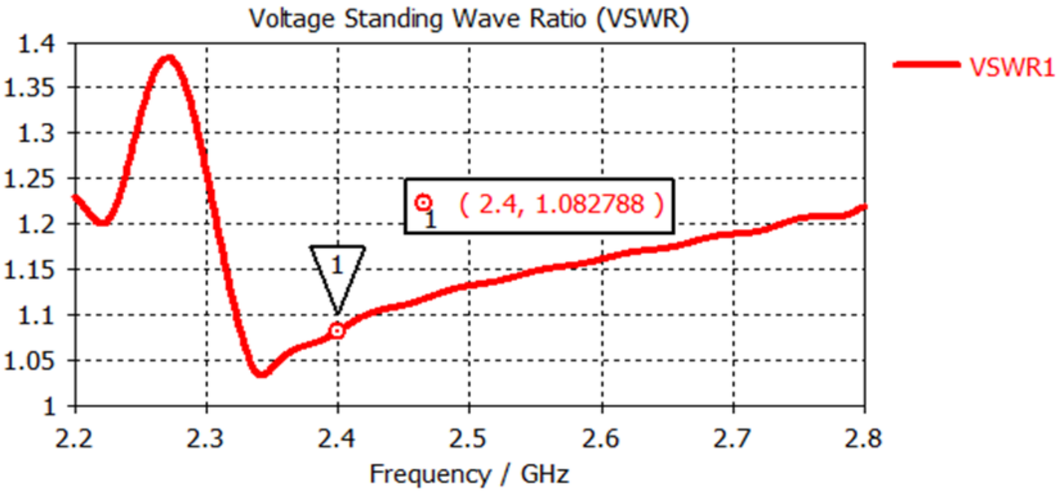
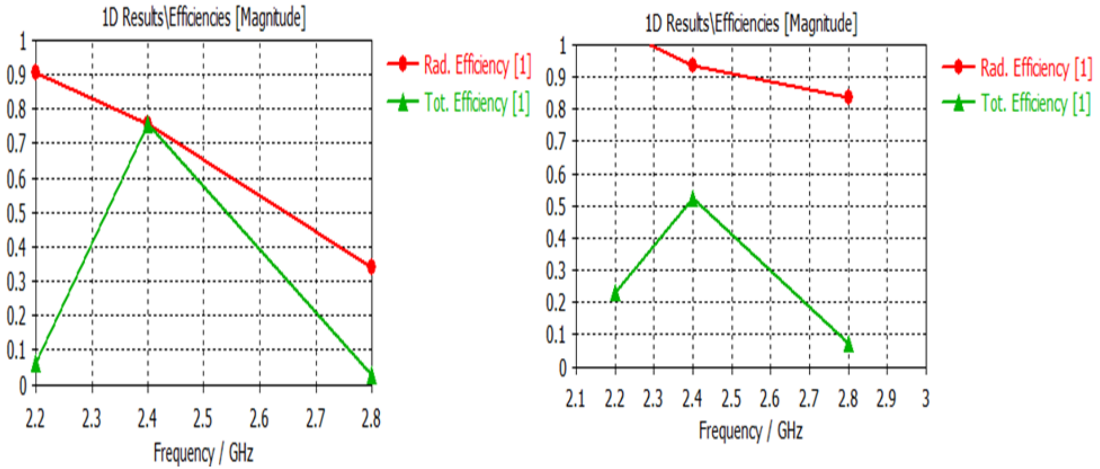


Figure 18. VSWR of Coaxial probe feed of MPA

C. Radiation efficiency

The antenna's radiation efficiency indicates how much power it radiates into its space. As show in Figure 17, microstrip line feed and coaxial probe feed antenna indicates that the radiation efficiency and overall antenna design efficiency approach 93.4%and 75.9% when the substrate height is chosen at 1.6 mm. The graph makes it clear that the radiation efficiency matches the overall efficiency at the resonant frequency, suggesting that the design antenna is a good matched.



a

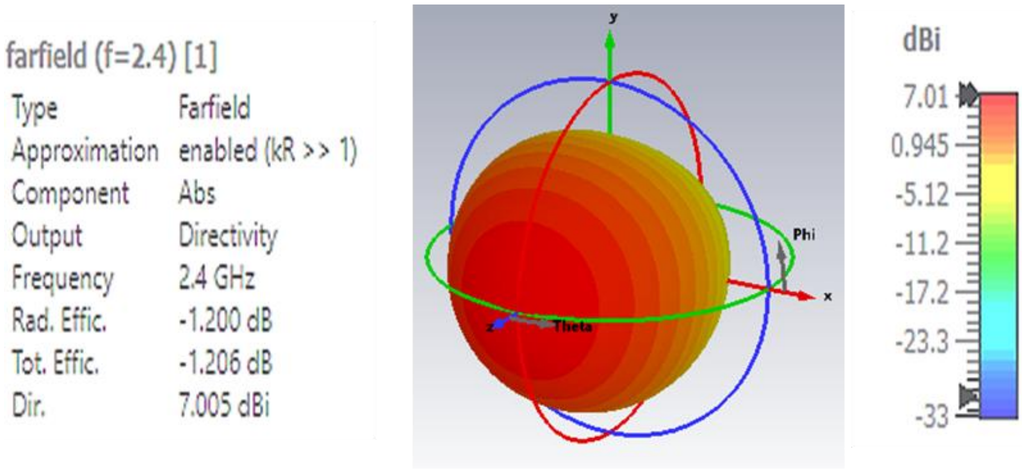
b

Figure 19. . a) Radiation efficiency of microstrip line feed and b) Coaxial probe feed of MPA

The read efficiency of the coaxial probe feed is 93.4%, which is much greater than the microstrip line's 75.9%. This indicates that the coaxial probe performs power transfer from the feed to the transmission line or antenna more successfully. While, the total efficiency of the microstrip line is 75.6% higher than that of the coaxial probe feed, which is 52.3%. This indicates that, when all system losses are taken into account, the microstrip line has a higher total power transmission efficiency.

D. Directivity

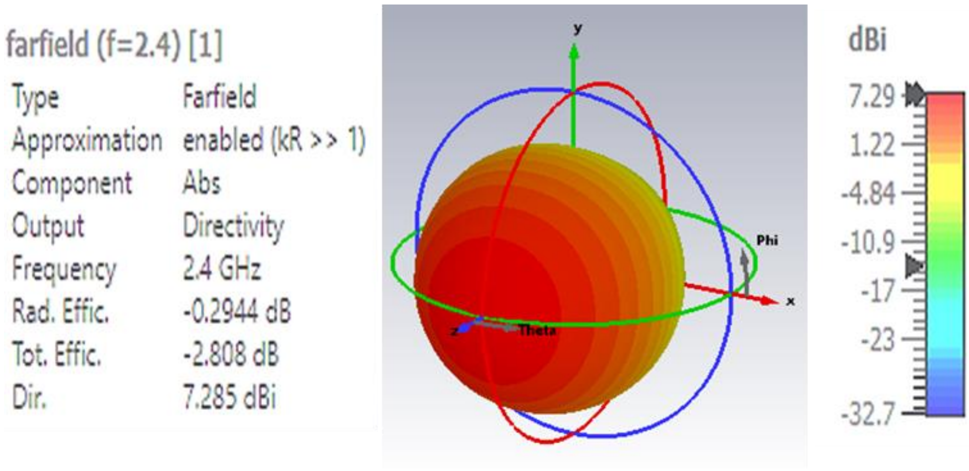
Directivity measures the intensity radiation power in a particular compared to isotropic radiator.in this case the coaxial couple outperform the microstrip line in terms of this directivity. The microstrip line feed achieved a directivity of 7.01dBi which indicates a relatively focused radiation pattern, while the coaxial couple feed method obtained a slightly higher directivity of 7.32dBi, indicating that it can more effectively concentrate the radiated energy.



farfield (f=2.4) [1]

Type Farfield
Approximation enabled (kR >> 1)
Component Abs
Output Directivity
Frequency 2.4 GHz
Rad. Effic. -1.200 dB
Tot. Effic. -1.206 dB
Dir. 7.005 dBi

Figure 20. Directivity of microstrip line feed of MPAs



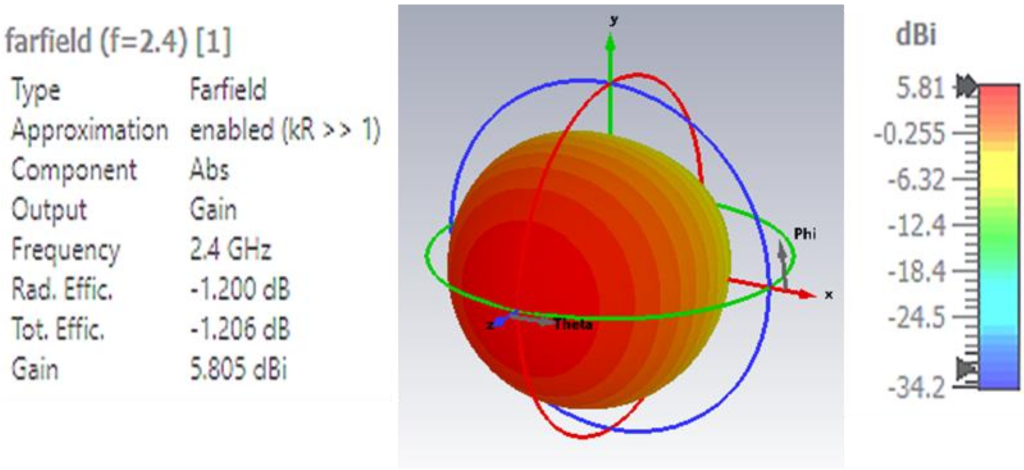
farfield (f=2.4) [1]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Directivity
Frequency	2.4 GHz
Rad. Effic.	-0.2944 dB
Tot. Effic.	-2.808 dB
Dir.	7.285 dBi

Figure 21. Directivity of coaxial probe feed of MPAs

E. Beam Gain

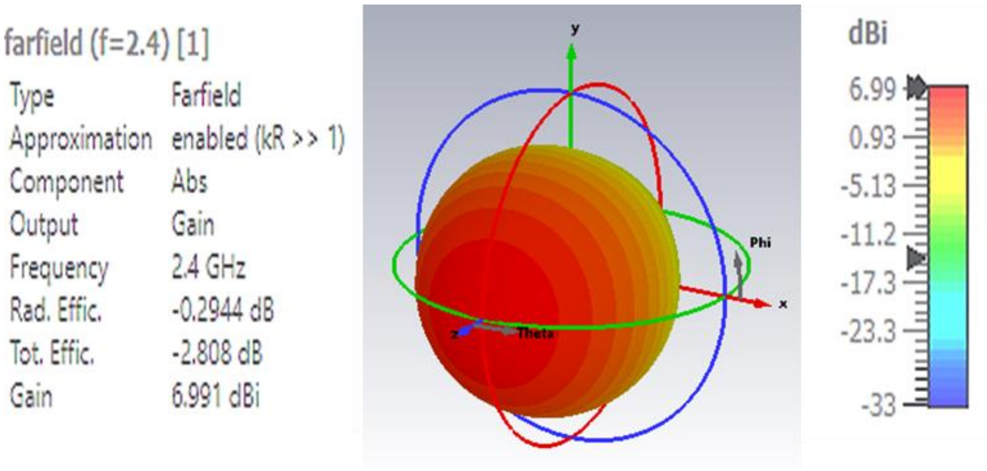
The beam gain of an antenna is the difference between the signal strength in a particular direction to the reference antenna. The beam gain of microstrip line is 5.87 dBi, while coaxial coupe feed found a higher gain of 6. 99dBi.The coaxial couple feed has a higher gain than the microstrip line feed, it is better able to send and receive signals in the desired direction.



farfield (f=2.4) [1]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	2.4 GHz
Rad. Effic.	-1.200 dB
Tot. Effic.	-1.206 dB
Gain	5.805 dBi

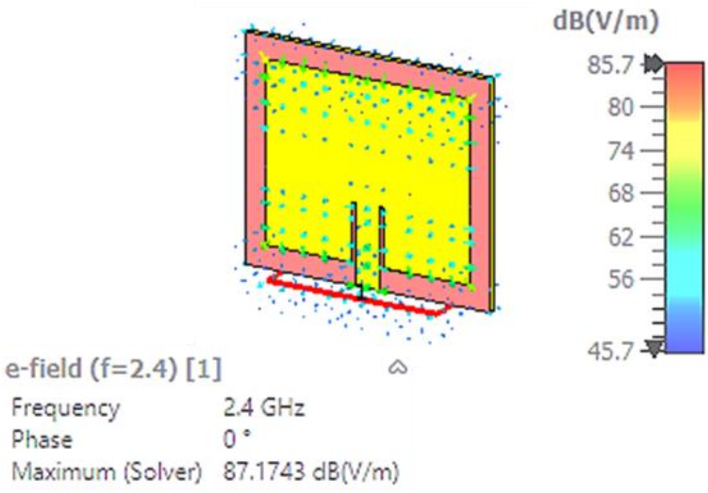
Figure 22. Beam gain of microstrip line feed of MPAs



farfield (f=2.4) [1]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	2.4 GHz
Rad. Effic.	-0.2944 dB
Tot. Effic.	-2.808 dB
Gain	6.991 dBi

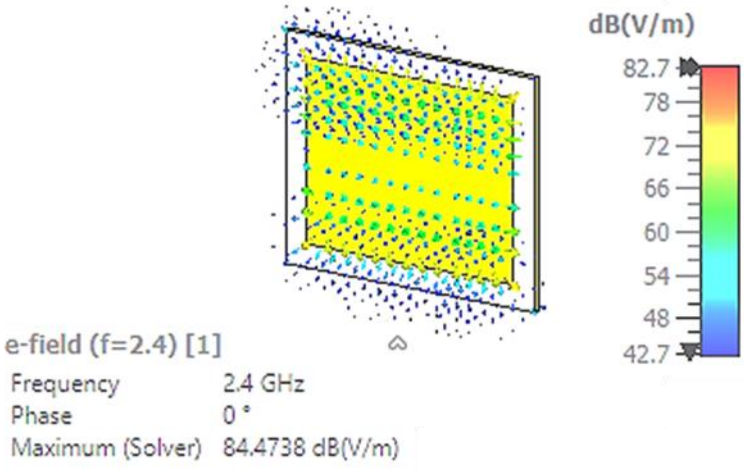
Figure 23. Beam gain of coaxial probe feed of MPAs



e-field (f=2.4) [1]

Frequency	2.4 GHz
Phase	0 °
Maximum (Solver)	87.1743 dB(V/m)

Figure 24. E-field of microstrip line feed at fr 2.4GHz

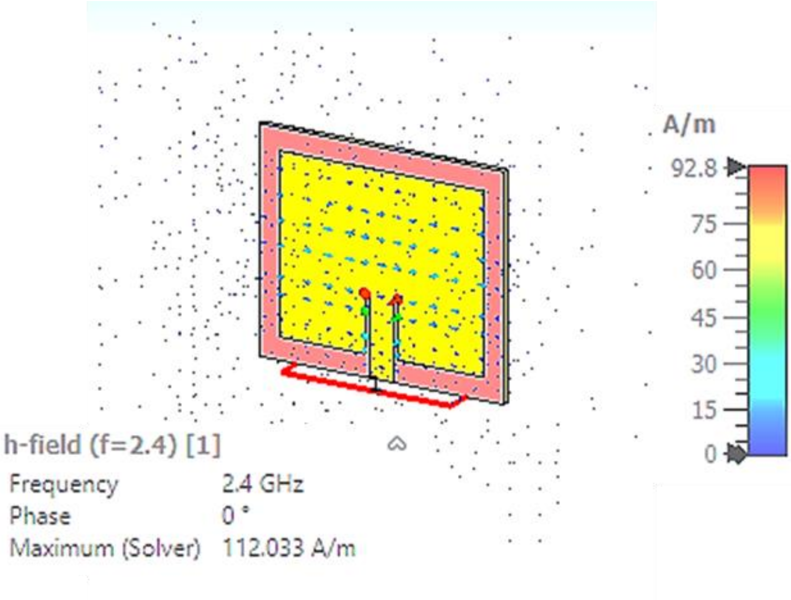


e-field (f=2.4) [1]

Frequency	2.4 GHz
Phase	0 °
Maximum (Solver)	84.4738 dB(V/m)

Figure 25. E-field of coaxial probe feed at fr 2.4GHz

The strength of the electric field surrounding the microstrip line feed of MPAs is shown by the observed E-field strength of 85.7 dB (V/m), while the coaxial probe feed is 82.7dB (V/m) as show in figure 23. Comparing those results microstrip line feed has better E-field. In general, higher E-field magnitude is preferred for effective signal propagation. The given results indicate a significant electric field strength, which is essential for the antenna to function properly at the given frequency of 2.4 GHz in terms of both transmit and receive signals. Regarding a thorough interpretation of the E-field results, elements like radiation pattern and impedance matching must be taken into consideration.



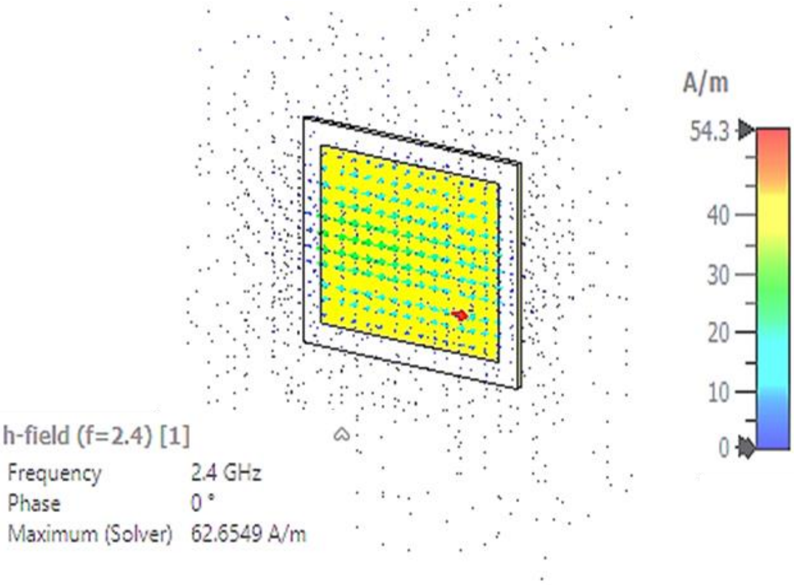
h-field (f=2.4) [1]

Frequency 2.4 GHz

Phase 0 °

Maximum (Solver) 112.033 A/m

Figure 26. H-Field of microstrip line feed at fr 2.4GHz.



h-field (f=2.4) [1]

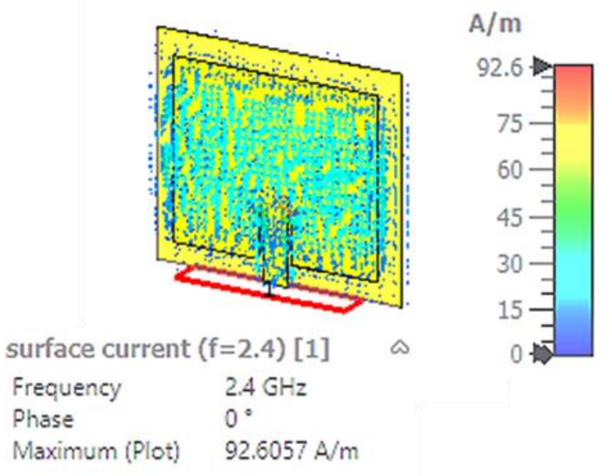
Frequency 2.4 GHz

Phase 0 °

Maximum (Solver) 62.6549 A/m

Figure 27. H-Field of coaxial probe feed at fr 2.4GHz.

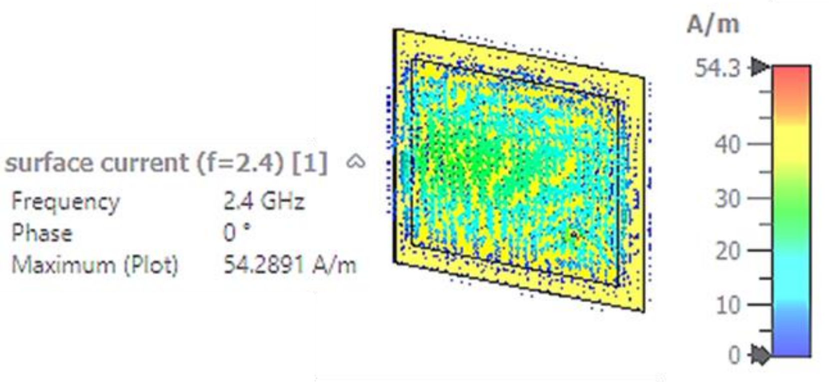
The strength of the magnetic field created by the microstrip line feed is indicated by the measured H-field strength of 92.8 A/m, while coaxial couple probe is shown 54.7A/m. To ensure that the antenna can send and receive electromagnetic waves, in particular, it must have a strong H-field. Effective energy transfer between the antenna and the surrounding space at its resonant frequency of 2.4 GHz is ensured by the recorded value, which indicates a strong magnetic field strength.



surface current (f=2.4) [1]

Frequency	2.4 GHz
Phase	0 °
Maximum (Plot)	92.6057 A/m

Figure 28. Surface-current of microstrip line feed.

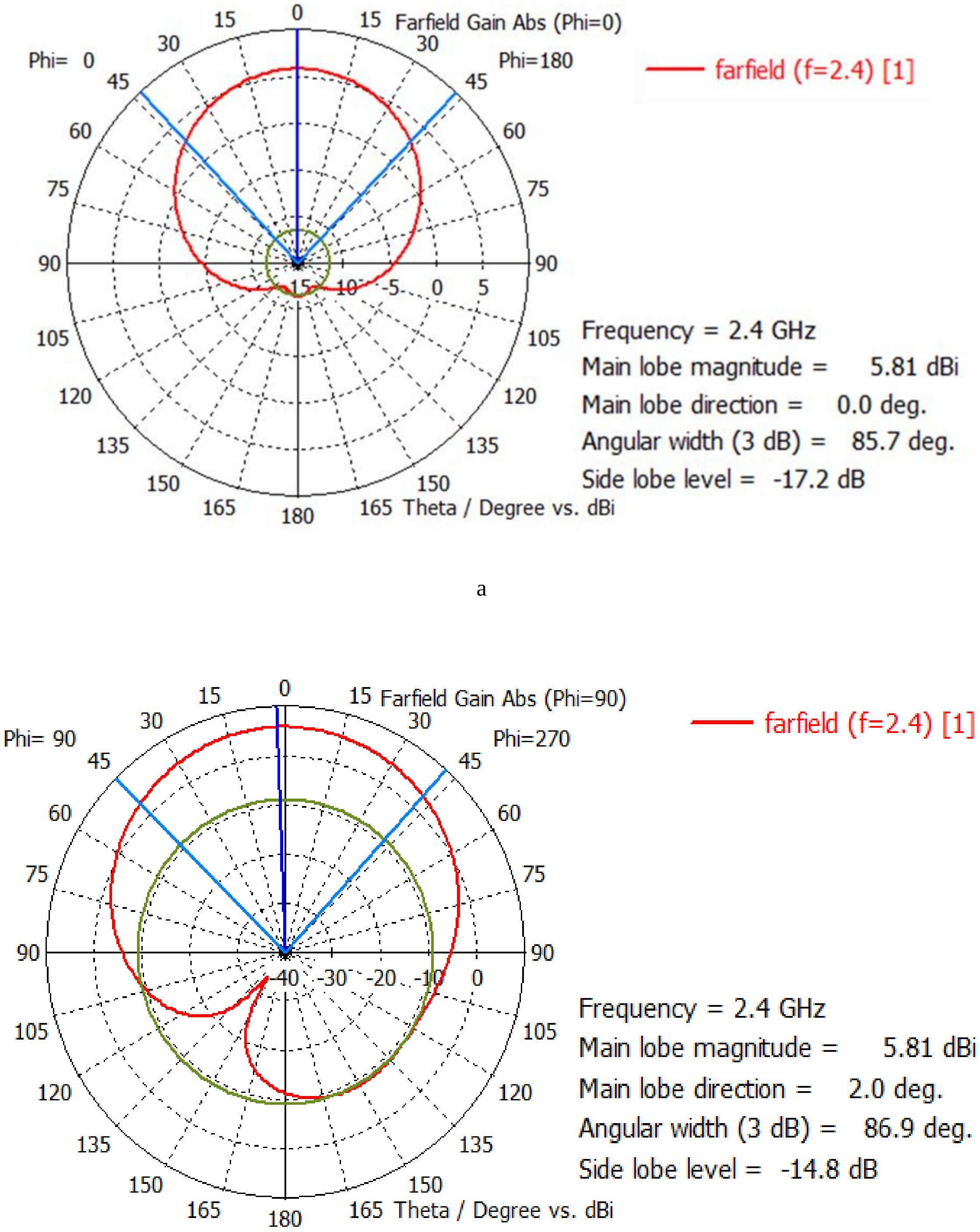


surface current (f=2.4) [1]

Frequency	2.4 GHz
Phase	0 °
Maximum (Plot)	54.2891 A/m

Figure 29. Surface-current of microstrip line feed.

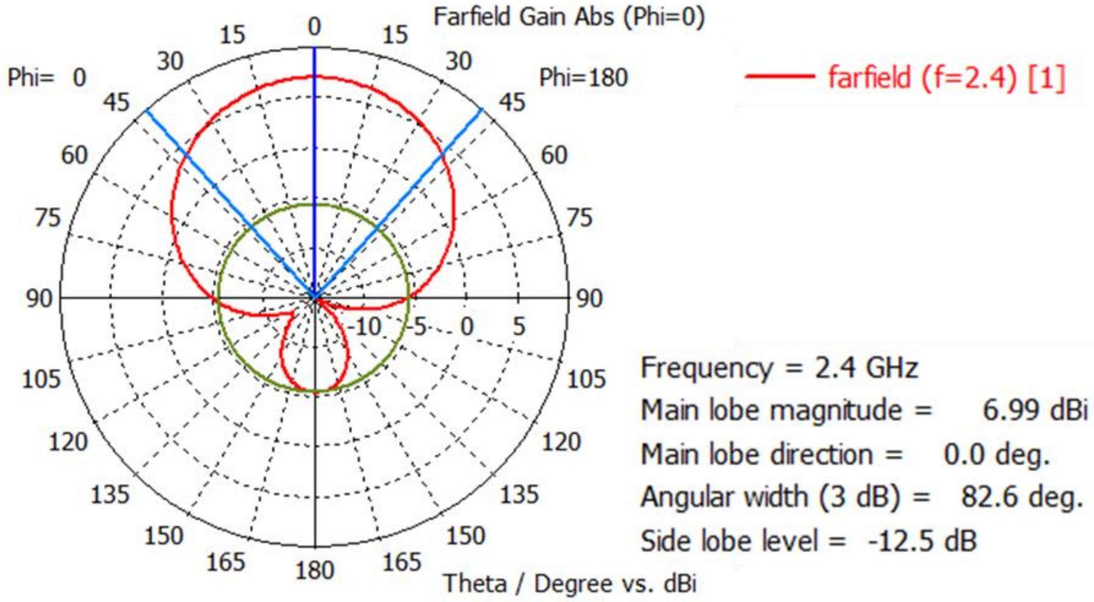
The microstrip patch antenna's surface electric charge is shown by the stated surface current, microstrip line feed has value of 92.6 A/m, while coaxial probe has 54.3A/m. One important component that affects the radiation characteristics of the antenna is this current. The observed data shows the successful distribution of electric charge throughout the antenna's structure by indicating an extensive surface current. For optimal radiation efficiency and reliable signal transmission at the designated 2.4 GHz frequency, this surface current must be distributed properly.



a

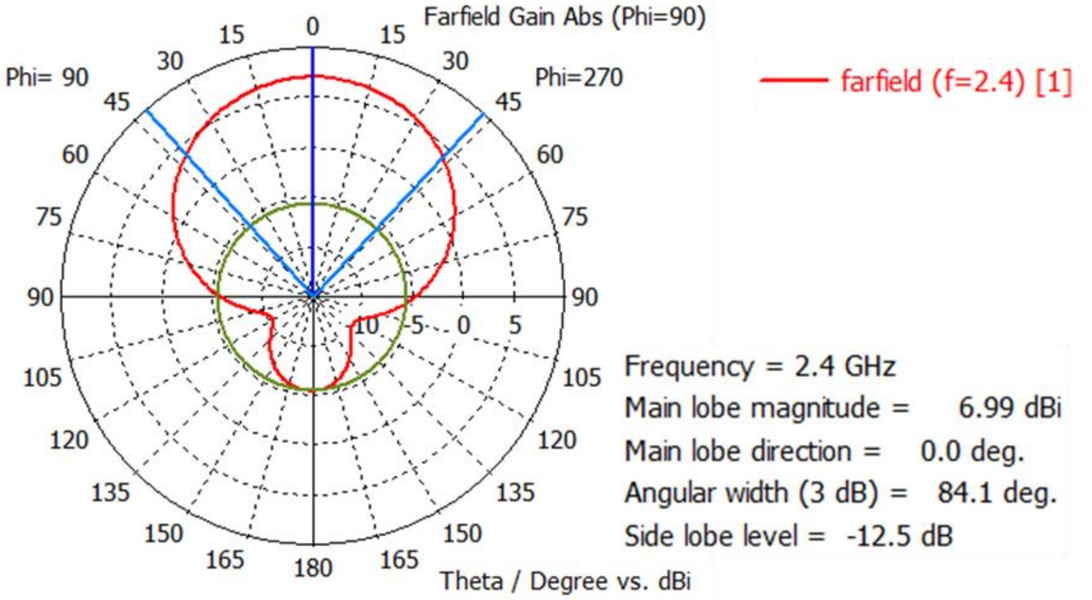
b

Figure 30. Far field radiation pattern of microstrip line feed a) phi=0 and b) phi=90 of MPAs



Frequency = 2.4 GHz
Main lobe magnitude = 6.99 dBi
Main lobe direction = 0.0 deg.
Angular width (3 dB) = 82.6 deg.
Side lobe level = -12.5 dB

c



Frequency = 2.4 GHz
Main lobe magnitude = 6.99 dBi
Main lobe direction = 0.0 deg.
Angular width (3 dB) = 84.1 deg.
Side lobe level = -12.5 dB

d

Figure 31. Far field radiation pattern of coaxial probe feed a) phi=0 and b) phi=90 of MPAs

Table 5. Comparisons of microstrip line feed and coaxial probe feed parameters of MPAs

No	F_r	Return loss	VSWR	Directivity	Gain	Bandwidth	Efficiency
Microstrip line feed of MPAs	2.4GHz	-28.5dB	1.07	7.005dBi	5.805dBi	41.48MHz	75.9%
Coaxial probe feed of MPAs	2.4GHz	-10.31dB	1.08	7.32dBi	6.99dBi	81.68MHz	93.3%

Figure 31 (a), (b) show far field radiation patterns for microstrip feed line antenna with phi = 0 and phi = 90, and Figure 32 (c), (d) show far field radiation patterns for coaxial probe feed antennas with phi = 0 and phi = 90. Table 5 compares the performance of microstrip line feed and coaxial probe feed. According to table 5, the results show that both feed methods coaxial probe and microstrip line can deliver good impedance matching and low signal refraction, as shown by their return loss and VSWR which close the values of 1. However, comparing the two feed methods, the coaxial probe feed exhibited better performance over the microstrip line feed across various parameters. It proved to be significantly more efficient, with a broader bandwidth and higher gain. The coaxial probe feed's higher effectiveness indicates it is efficient at transmitting radiation power to the antenna. But it's important to note that the microstrip line feed still performed well, especially in terms of efficiency and bandwidth

Tables 6 and 7 compare the simulated performance of the current work to other reported designs. The elevated beam gain featured in the design allows for improved signal reception and transmission over long distances.

Table 6. Comparison of microstrip line feed technique with other reported design

Ref.	Frequency[GHz]	Return loss [dB]	VSWR	Bandwidth [%]	Gain [dBi]	Efficiency[%]
[V. Mokal et al., 2017]	2.437	-16.02	1.32	1.8	6.022	40.5
[B. Patil et al., 2015]	2.4	-36.57	1.3	-	4.65	68.65
Proposed design	2.4	-28.5	1.07	1.73	5.81	75.9

Table 6 compares a microstrio line feed techniques to designs reported in the literature, including references [V. Mokal et al., 2017], [B. Patil et al., 2015], and proposed design study. In terms of performance, the proposed study outperforms with a relatively lower VSWR of 1.07 and a higher gain of 5.81 dBi. Additionally, the bandwidth of 1.73% indicates competitive frequency coverage. Based on the parameters provided, the microstrip line feed techniques reported in this work appears to exhibit improved overall performance compared to the designs referenced in [V. Mokal et al., 2017], [B. Patil et al., 2015].

Table 7. Comparison of coaxial probe feed technique with other reported design

Ref.	Frequency [GHz]	Return loss [dB]	VSWR	Bandwidth [%]	Gain [dBi]	Efficiency[%]
[V. Mokal et al., 2017]	2.44	-26.8	1.14	3.2	2.239	46.6
[J.Kaur, R.Khanna, 2013]	5.2	-23.15	1.16	-	4.72	73.9
Proposed design	**2.4**	**-10.31**	**1.08**	**3.4**	**6.99**	**93.3**

Table 7 suggest that the coaxial probe feed technique implemented in this proposed design outperforms the referenced designs in terms of return loss, VSWR, bandwidth, gain, and efficiency at the specified frequency.

V. CONCLUSION

The analysis of radiation characteristics and efficiency of microstrip patch antennas (MPAs) is essential for understanding their performance within the scope of their utilization in Internet of Things (IoT) applications. In this thesis, two different feeding methods, namely microstrip line feed and coaxial probe feed, were used to investigate their impact on antenna performance at a frequency of 2.4GHz.

The MPA microstrip line feed showed a 2.4GHz resonant frequency (Fr) and an impressive -28.5dB return loss, indicating a good impedance match with low reflected power. A low loss of both transmitting and receiving is further demonstrated through the antenna's Voltage Standing Wave Ratio (VSWR) of 1.07. The antenna's ability to concentrate radiation in particular directions is demonstrated by its 7.005dBi directivity and 5.805dBi gain, which add to its directive qualities. With a measured bandwidth of 41.48MHz and an efficiency of 75.9%, the antenna demonstrates capability to operate over a range of frequencies with a high level of power utilization

On the other hand, the coaxial probe feed of MPAs demonstrated a 2.4GHz resonance frequency and a -10.301dB return loss. The return loss indicates that there is a good impedance match even though it is not as noticeable as the microstrip line feed. The transmission line characteristics appear to be sufficient based on the VSWR of 1.08. Compared to the microstrip line feed, the coaxial probe feed exhibited a higher directivity of 7.32dBi and gain of 6.99dBi, demonstrating its ability to concentrate radiated energy. Although the measured bandwidth of 81.68MHz is higher than the microstrip line feed, could be indicative to performance compromises in certain sectors. With an efficiency of 93.3%, the coaxial probe feed outperformed the microstrip line feed in terms of efficiency, indicating its advantage in transforming input power into radiated energy.

The results of this study have important implications for Internet of Things applications. Although all feeding techniques showed possibility, the IoT device's specific requirements will determine which of them is better. Due to its higher efficiency and gain, the coaxial probe feed can be a better choice for applications that depend significantly on good signal receiving and power efficiency. On the other hand, in situations where simplicity and performance require to be balanced, the microstrip line feed, with its acceptable efficiency and bandwidth, may be taken into consideration. Overall, this research provides useful insights for engineers and designers working on Internet of Things devices and their communication system guidelines.

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- Network Protocols such as TCP/IP, IPv4, IPv6
- Network Troubleshooting

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- MATLAB
- Microsoft office
- Time Management
- Creativity
- Teamwork

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- Workshop for Implementing and managing Network infrastructure using cisco Routers &Switches Sep-2019.
- Participation of: The 3th CONFERENCE OF ENGINEERING, SCIENCE AND TECHNOLOGY CEST2019.
- **Presenter of paper**: The 4th CONFERENCE OF ENGINEERING, SCIENCE AND TECHNOLOGY CEST2020

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- Cisco Networking Academy (certificate): **IT Essentials, Introduction to IoT, Networking Essentials, introduction to Cyber security-** Sep2018-Dec2020
- Certificate of Participation **Youth Leadership Programmer's 6th Regional for UNDP-Nov-2020**

Publications:

No	Title	Journal name	Link of the article	Date of Publication
1.	Design and Performance Analysis of 2x2 and 3×3 Phased Array Patch Antennas in C Band	Journal of Aeronautics and Space Technologies (JAST)	https://jast.hho.msu.edu.tr/index.php/JAST.	July,2024
2.	Radiation Characteristics and Efficiency Analysis of Microstrip Patch Antennas for 5G Wireless Communication	INTERNATIONAL JOURNAL OF ELECTRONICS, MECHANICAL AND MECHATRONICS ENGINEERING	https://ijemme.aydin.edu.tr/tr.	January 2025