Optimization and Efficiency Improvement of Multiband PIFA Antenna System for 5G

Tsegaab Getu Jenbere

A Thesis Submitted To

The Department of Electronics and Communication Engineering School of Electrical and Computing

Presented in Partial Fulfillment of The Requirement for the Degree of Master's in

Electronics and Communication Engineering

Office of Graduate Studies

Adama Science and Technology University

June 2023

Adama, Ethiopia

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APPROVAL OF BOARD OF EXAMINERS

We, the undersigned, members of the Board of Examiner of the thesis by Tsegaab Getu Jenbere have read and evaluated the thesis entitled *"***Optimization and Efficiency Improvement of Multiband PIFA Antenna System for 5G***"* and examined the candidate during open defense. That is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Communication Engineering.

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DECLARATION

I hereby declare that this Master Thesis entitled "Optimization and Efficiency Improvement of Multiband PIFA Antenna System for 5G" is my original work. That is, it is not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Tsegaab Getu Jenebere		
Name of Student	Signature	Date

RECOMMENDATION

We, the advisors of this, hereby certify that we have read the revised version of the thesis entitled "**Optimization and Efficiency Improvement of Multiband PIFA Antenna System for 5G**" prepared under our guidance by Tsegaab Getu Jenebere submitted in partial fulfillment of the requirement for the degree of Masters of Science in Communication Engineering. Therefore, we recommend the submission of revised version of the thesis is to the department following the applicable procedures.

Dr. Rajaveerappa Devadas ____________	____________	____________
Major Advisor	Signature	Date
Dr. Demissie Jobir ____________	____________	____________
Co-advisor	Signature	Date

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LIST OF ACRONYMS

3D	Three-Dimensional
5G	5th Generation
BW	Band Width
CST	Computer Simulation Technology
dB	Decibel
Dir.	Directivity
EM	Electromagnetic
GHz	Gigahertz
GPS	Global Positioning Systems
GSM	Global System for Mobile Communications
HF	Higher Frequency
LTE	Long Term Evolution
MHz	Megahertz
MIMO	Multiple Input Multiple Output
Mm	Millimeters
mm-Wave	Millimeter-Wave
NR	New Radio
PIFA	Planar Inverted F Antenna
Rad.effic.	Radiation Efficiency
RF	Radio Frequency
SINR	Signal To Interference And Noise Ratio
SIW	Substrate Integrated Wave Guide
Tot.effic.	Total Efficiency
VSWR	Voltage Standing Wave Ratio

List of Symbols

η	Antenna efficiency
c	Velocity of light in free space
d	Distance between the antennas
ε_r	Relative dielectric constant of substrate
ε_{reff}	Effective dielectric constant
e_0	Total efficiency
e_r	Reflection efficiency
e_d	Dielectric efficiency
f_0	Operating frequency
y_0	Feeding gap
G	Gain of the antenna
h	Height of the antenna patch
λ	Operating wavelength/Lambda
L	Length of the patch antenna
L_{eff}	Effective length of patch
p_i	Total input power
p_r	Power for receiving antenna
p_{rad}	Total power radiated
p_t	Power for transmitting antenna
R_{in}	Antenna resistance at the terminals
R_s	Source resistance
t	Patch thickness
U	Radiation intensity of the antenna
U_0	Radiation intensity of an isotropic source
Wg	Width of ground plane
Ws	Width of the shortening plate
Z_{in}	Antenna impedance at the terminals
Z_s	Source impedance
$\|\|\Gamma\|\|$	Reflection coefficient

ABSTRACT

Numerous developments have been made in recent years to address the growing demand for antennas on portable terminals, starting with the shorted-circuit quarter wave antenna, also known as the Planar Inverted-F Antenna (PIFA). Along with their remarkable performances, these antennas' primary benefits are their compactness and low manufacturing costs. In this article, we'll provide a multiband PIFA design that adds a new frequency band and optimizes this antenna's performance by adjusting the same parameters of existing methods. Multiband PIFA antenna systems are particularly attractive for 5G systems as they can operate in the frequency bands allocated for 5G communications, which are typically in the millimeter-wave range. However, the design and optimization of multiband PIFA antenna systems for 5G can be challenging due to the need for high performance over a wide frequency range. . This thesis investigates the PIFA antenna and the role of periodic structures over the antenna to fulfil the fifth-generation (5G) requirements. An efficient system will be designed by paying close attention to the isolation between the antennas and the efficiency of the antenna system during the optimization phase. All simulation of proposed antenna will be done using Computer Simulation Technology (CST) software communication tools. Based on the results obtained PIFA multiband antenna has a maximum gain of 7.4 dBi and a directivity of 7.99 dBi. The VSWR and return loss value are found to be 1.09 and -25.6 dB, respectively. According to the investigation, the PIFA antenna is a clear choice for mobile applications because it is capable of delivering the highest performance levels.

Keywords: *Optimization method, Multiband antennas, efficiency, planar inverted-F antenna (PIFA), 5G, optimization, genetic algorithm, impedance matching, gain, bandwidth, Millimeter Wave.*

CHAPTER ONE

1. INTRODUCTION

1.1 Background of the Study

Antenna-based mobile and wireless communication has advanced significantly in recent years. The scientific community should put more effort into enhancing the functionality of this apparatus (antenna) and using it significantly in both current and future applications. The production of a tiny antenna that can be integrated into the terminal architecture has become important in order to satisfy the growing demands of the recently emerging multifunction wireless devices and meet the new requirements of the future technology.(Stutzman and Thiele 2012, Balanis 2016)

High data rates, minimal latency, and large machine-type communications are promised by the fifth generation (5G) of wireless communication, which will enable new services and applications including driverless vehicles, smart cities, and virtual and augmented reality. In order to achieve the needed performance, it is essential to develop efficient and optimized antennas, which are a crucial part of 5G systems. Due to their small size profile, simplicity in manufacture and capacity to operate across various frequency bands, planar inverted-F antenna (PIFA) devices are a preferred alternative for 5G applications. Since they can operate in the frequency ranges designated for 5G communications, which are typically in the millimeter-wave range, multiband PIFA antenna systems are particularly appealing for 5G systems.

The development of 5G technology is a result of the rising demand for communication with minimal latency and high-speed data transport. In order to achieve the needed performance, it is important to develop efficient and optimized antennas, which are a crucial part of 5G systems. A common option for 5G systems is PIFA antennas because of their compact profile, simplicity in fabrication, and broad bandwidth. However, because of the complex antenna geometry and the requirement for good performance over a broad frequency range, designing and optimizing PIFA antennas for 5G can be difficult.

The way we engage with one another, our surroundings, and one other is projected to change dramatically with the introduction of 5G wireless communication.

High data rates, minimal latency, and other benefits are promised by 5G. Antennas are a critical component in 5G systems, and the design of efficient and optimized antennas is essential for achieving the desired performance.

When a cell phone is in use, the electromagnetic radiation could have major negative effects on health. In dedicated mode, the body's tissues absorb a significant amount of this energy, which is measured in terms of a Specific Absorption Rate (SAR).(Huang 2021) The phrase "exposure standards" is used to describe them in the context of public health. The antenna geometry, radiated power, exposure frequency, and distance between the antennas and the head all affect the peak values of SAR. Additionally, the performance of the antenna's communication is significantly diminished by the absorption of electromagnetic radiation in the head and hand.(Zhao, Ying et al. 2020)

The objective of this study is to design and optimize a multiband PIFA antenna system for 5G applications and to improve its efficiency. The performance of the optimized antenna system will be compared with the original design, and the effect of optimization on key performance metrics such as impedance bandwidth, gain, and radiation efficiency will be analyzed.

1.2 Types of Antennas

Radio waves can be sent or received using an antenna. Antennas come in a variety of shapes and sizes, including dipole, aperture, horn, patch, loop, reflector, Yagi-Uda, inverted-F, and many more. Many of them are utilised in mobile communication systems and some of them are quite low profile. Here, we separated such low-profile antennas into magnetic and electrical antennas.

1.2.1 Electrical Antennas

Electrical antennas are those antennas that use electric field to receive or transmit signals, such as dipole antenna, inverted-F antenna and patch antenna.

Dipole antenna

Dipole antenna is a simple wire antenna. It commonly consists of two identical conductive elements such as metal wires or rods(Zhao, Ying et al. 2020). The most commonly used antenna is the half-wavelength dipole.

The input impedance of an antenna consists of real part and imaginary part. For a half-wavelength dipole, the radiation resistance is 73ohm. The imaginary part of input resistance is j42.5. Thus, the total input impedance for $l=\lambda/2$ is equal to $Z=73+j42.5$(Balanis 2016). By matching the antenna, the imaginary part can be reduced to zero so that the reactance part can be vanished. Through the radiation resistance, the power is transferred from guided wave to free space.

Patch antenna

A patch antenna is a type of antenna that consists of a very thin metallic patch placed on dielectric material (referred to as the substrate) and supported by ground plane. They are low-profile, conformable to planar and non-planar surfaces and easy to manufacture. There are plenty of substrates that can be used for patch antennas. The dielectric constants are usually in the range of $2.2 \leq \epsilon \leq 12$. Smaller dielectric constant can provide higher efficiency, larger bandwidth for radiation into space. For patch antenna, the radiating elements and the feed lines are photo etched on the substrate. The shape of the patch can be square, rectangular and so on. By far, the rectangular patch is the most widely used.

PIFA antenna

PIFA stands for planar inverted F antenna. It is a type of patch antenna with very low profile and omnidirectional pattern so is widely used in mobile market, portable communication and short-range communication. PIFA antenna resonant at a quarter wavelength. The resonant frequency of the PIFA antenna is determined by the length of the patch L, the width of the patch W, the width of the shorting sheet ws, and the height of the substrate h, which makes PIFA antenna can easily be tuned by changing those elements (Kumari,V. R. 2011). PIFA antenna has several advantages such as light weight, easy to design, low cost and typically has good SAR (Specific Absorption Rate).

1.2.2 Magnetic Antenna

Magnetic antennas are those antennas that use magnetic field on a metal rod to receive or transmit signals, such as magnetic loop antenna, slot antenna. To generate a magnetic field, an electric current is needed.

Slot Antenna

Cutting a slit into a ground plane creates a radiating device known as a slot antenna (Zahid, Z.et al 2017). The slot antenna is omnidirectional and may be carved out to fit any shape or surface it will be put on. It could qualify as a complementary dipole. Dipole antennas have the same polarization no matter where they are located.

Loop Antenna

An antenna with a loop or coil of wire conveying radio frequency current is referred to as a loop antenna. This kind of magnetic antenna exists. The number of turns and the size of each loop affect the performance of magnetic loop antennas. The gain of a magnetic loop antenna may be increased by expanding the ground plane. Because the current on the ground plane is the principal source of radiation that defines the impedance and radiation pattern of the antennas, the ground plane has a substantial impact on impedance bandwidth and radiation pattern. (Cheng, M. 2022).

1.3 5G Technology

The next 5G is the fifth generation of wireless technology, a new international wireless standard, following 1G, 2G, 3G, and 4G. 5G is meant to provide better connectivity in contrast to older technology. Simply put, 5G is supposed to enhance cellular capabilities by boosting data rates and mobile capacity while also providing greater broadband power. 5G cellular networks are actually 10 to 50 times quicker than those of earlier generations. (Intelligence 2014, Agiwal, Roy et al. 2016).

1.3.1 5G Expected Spectrum

More spectrums need to be investigated in order to provide 5G services that stand up to future aspirations for innovative new wireless technologies. Clearing essential bands should be given priority since 5G would require an enormous amount of new harmonized spectrum to satisfy market demand. The following three bands make up the 5G spectrum

i. Low-Band
ii. Mid-band
iii. High-Band

I. *Low-Band:* This sub-1 GHz spectrum enables extensive coverage indoors and in urban, suburban, and rural areas. To reduce the digital divide and increase equity between urban and rural broadband connectivity, there must be an increase in low-band capacity.

II. *Mid-band:* It offers a favorable balance of coverage and capacity benefits. The 3.3-3.8 GHz band is where the majority of commercial 5G networks use spectrum. Additional spectrum (e.g., 3.3-4.2 GHz, 4.8 GHz, and 6 GHz) willalso be needed to maintain 5G service quality and meet rising demand.

III. *High-Band:* The GSMA advises adopting the 26 GHz, 28 GHz, 40 GHz, and 66-71 GHz bands for mobile devices. At mm-wave frequencies, there are new obstacles to overcome in order to achieve high-quality link requirements.

1.4 Contributions

Any design of an antenna device with particular needs requires for several "cut and-trial" iterations. This research seeks to reduce the number of experimental iterations by offering efficient first-cut design routes. It advances and improves the current state of the art for producing micro strip PIFA in a variety of configurations. The contributions of this study to the creation and analysis of the PIFA are further discussed in these chapters.

1.5 Statement of the Problem

The development of the fifth-generation mobile system faces new challenges in terms of enabling high-quality multimedia apps in upcoming smart phones due to the huge increase in mobile data rates. Due to the shortage of frequency spectrum below 6 GHz, bands at the millimeter Wave frequencies have repeatedly been suggested as options. The substantially larger bandwidths might be used to increase the capacity and enable users to experience several gigabits per second data rates. (Koul and Karthikeya 2020).

Given the increased need for small mobile phone devices, a single mobile phone's capacity to operate across several frequency bands is crucial. Mobile devices must roam between networks and nations, where the frequency bands used can frequently vary, necessitating the usage of multi-band antennas. Due to the increasing throughput requirements of mobile phone users, we may optimize the PIFA antenna to produce the greatest throughput and most effective network. These antennas are also resonant at a quarter-wavelength and have substantial SAR (Specific Absorption Rate) properties, which take up less space, especially on mobile phones.

However, PIFA antennas have a number of drawbacks, including poor efficiency, a limited bandwidth, and a lack of multiband flexibility. To overcome these limitations, particularly the bandwidth ones, and to satisfy the needs of mobile devices for miniaturization, we enhance the PIFA antenna. However, switching to a higher-priced cellular carrier Equation 1.1 below demonstrates how frequencies used today (700 MHz–2.6 GHz) up towards the mm wave bands cause a much higher free space path loss. In void space, the wave is neither reflected nor absorbed.(Orakwue and Ridha Al-Khafaji 2022). When there is a clear, unimpeded line of sight between the transmitter and receiver, the received signal strength is predicted using the free space path loss model. Equation 1.1's "Friis Equation" identifies the power in free space that a reception antenna will receive from a transmitting antenna with a d-length path.

$$p_r = p_t G_t G_r \tag{1.1}$$

where, p_r is the received power,p_t is the transmitted power,d is the distance between the antennas,G_t is the transmitter antenna gain,G_r is the receiver antenna gain, λ is the wavelength of the antenna and d is the distance between transmitting and receiving antennas. All terms are in linearunits, not dB.

Expressing in decibel (dB) we get,

$$p_r(dBm) = p_t(dBm) + G_t(dB) + G_r(dB) - L_p(dB) \tag{1.2}$$

where $L_p(dB) = 20\log(4\pi d/\lambda)$ (1.3)

This idea is known as "free space path loss". The free space route loss for the higher frequency band than the current mobile networks will be substantially higher because of the shorter wavelength.

In order to compensate for the increased route loss without consuming any extra power, antenna strengths should be adjusted in base stations and portable terminals.(Kirshnan, Alphones et al. 2019).

1.6 Objectives of the Study

1.6.1 General Objectives

The main objective of this thesis is to enhance the performance of mobile communication systems by Optimizing and improving the efficiency of Multiband PIFA Antenna System for 5G.

1.6.2 Specific Objectives

The specific objectives of this thesis are:

- To design, analyze and simulate Multi band PIFA antenna operating on, 3.4 GHz, 3.6GHz, 3.8GHz, 31 GHz and 33 GHz.
- To compare and contrast the performance of the Antenna at different parameters.
- To select an antenna parameter which has better radiation pattern, gain, directivity and efficiency.
- To optimize the antenna parameters for the desired frequency bands.

1.7 Significance of the Study

The design of a handset multisystem is becoming more popular as a result of the quick development of wireless communication technologies and the growing need for multisystem applications. Internal antennas are more common now because of their inherent benefits. The internal antenna that has been most commonly used in commercial wireless communication applications is the PIFA. Additionally, by maximizing the PIFA antenna's limitations, this study intends to increase the PIFA antenna's effectiveness.

1.8 Scope of the Study

This thesis focuses on improving performance of mobile communication systems. A new compact PIFA antenna design that supports multiple operating commercial mobile communication services and wireless communication services is proposed. It has been concluded that this combination in a mobile phone antenna help to achieve good matching and radiation characteristics. The main design parameters of the proposed antenna will be studied and discussed. The characteristics that will be simulated include return loss, antenna gain, radiation patterns, radiation efficiency and directivity will be provided to validate the proposed antenna. All simulation of proposed antenna will be done using computer simulation technology (CST) software communication tools.

1.9 Limitation of the Study

The potential limitation of a study on optimization and efficiency improvement of a multiband PIFA antenna system for 5G may include Simulation vs. measurement: The study may be based on simulations rather than actual measurements, which can introduce uncertainties and discrepancies between the expected and actual performance of the antenna.

1.10 Thesis Outline

This thesis organized into five Chapters. Those chapters describe briefly different topics. The first chapter introduces the research problem and objectives, Provide background information on 5G and PIFA Antenna, State the research Problem and Outline the structure of the thesis. The second chapter focuses on Literature Review it Review the relevant literature on PIFA antennas for 5G, Summarize the existing research and identify gaps and limitations, Discuss the design factors and performance metrics of PIFA antennas Analyze different optimization and efficiency improvement techniques for PIFA antennas. The third chapter describes the methodology used in the study, including the simulation and measurement techniques, Specify the parameters and variables used in the design and evaluation of the PIFA antenna system and explain the process of optimization and improvement of the antenna system. The fourth chapter presents the design considerations and optimization results for the multiband PIFA antenna system, describe the simulation setup and results for the antenna system in various operating conditions analyze the performance metrics of the antenna system, such as bandwidth, efficiency, and radiation pattern. The fifth chapter summarizes the main findings of the study, the contributions and significance of the research, Discuss the implications of the study for the development of PIFA antennas for 5G, Provide suggestions for future research directions.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Chapter Overview

This chapter mainly focuses overview of wireless technology related to 5G technology, antenna design for 5G, multiband PIFA antenna design, and related works on multiband PIFA antennasystems. The review shows that 5G technology requires high data rates, low latency, and massive machine-type communications, which can be achieved by designing efficientand optimized antennas.

2.2 Review of Evolution of Wireless Technology

Remote correspondence has improved over the years as wireless communication has improved due to the development of complex heterogeneous systems.(Su, Liu et al. 2010). Following 4G communication, the fifth generation (5G) of wireless communication has attracted interest. When compared to earlier generations of wireless technology, which were initially made commercially available in 2009, the upcoming generation will be more advanced. In comparison to 4G, which has a maximum speed of 100 Mbps, 5G might have a maximum speed of 10 gigabits per second. High-definition (HD) movies larger than 1 GB can be downloaded quickly with this fast network. The "internet of things" will place more demands on the network, thus it will be necessary to enhance both the bandwidth and transmission speed of the 5G network.(Calin 2015, Huang 2018). Many devices and services, including user experience continuity and mission-critical services, will have direct connections thanks to 5G. (Schaich, Sayrac et al. 2015). The requirement for 5G applications is the multiband smart antenna. It can be distinguished by an adjustable array that modifies the beam pattern in response to user and interference motions. Digital beam shaping is utilized for direction of arrival (DOA) estimation null enforcement. (Ohishi, Oodachi et al. 2005, Rawat, Yadav et al. 2012, Ban, Li et al. 2016). To overcome the shortcomings of earlier generations, advanced generation systems are introduced, including high speed, bandwidth, capacity, high-quality digital video conferencing, online gaming, and constant network availability wherever. Figure 1 depicts how cellular technology has advanced from earlier iterations.

The first-generation communication, sometimes referred to as AMPS (Advanced mobile phone system), was initially developed in 1980. Compared to the IMTS (Improved Mobile Telephone System), it supported 5 to 10 times more users thanks to the frequency re-use idea. First-generation systems, however, were vulnerable to issues including security risks and full-duplex analogue communication. The GSM (Global system for mobile communication) standard-based 2nd generation communication systems, which were introduced in 1990, were able to get beyond some of the restrictions of the 1st generation (See Figure 1). The 2G systems used more of the spectrum and were digitally protected. They have made text messaging services possible. It was first developed in 1995 and combined GSM and packet switch networks, with data rates of up to 160 kbps. Typically, this technology is referred to as 2.5G. The Evolution (EDGE) used 8 PSK modulations, which does indeed offer quick internet access at this time because e-services were becoming more common. (Shafi, Hashimoto et al. 1997). The cost of upgrading base stations for 3G was very high and the requirement to keep base stations adjacent to one another drove up the cost even more. The addition of the long-term evolution technology to 4G, which offers an ultra-rapid broadband wireless network(Frattasi, Fathi et al. 2006).

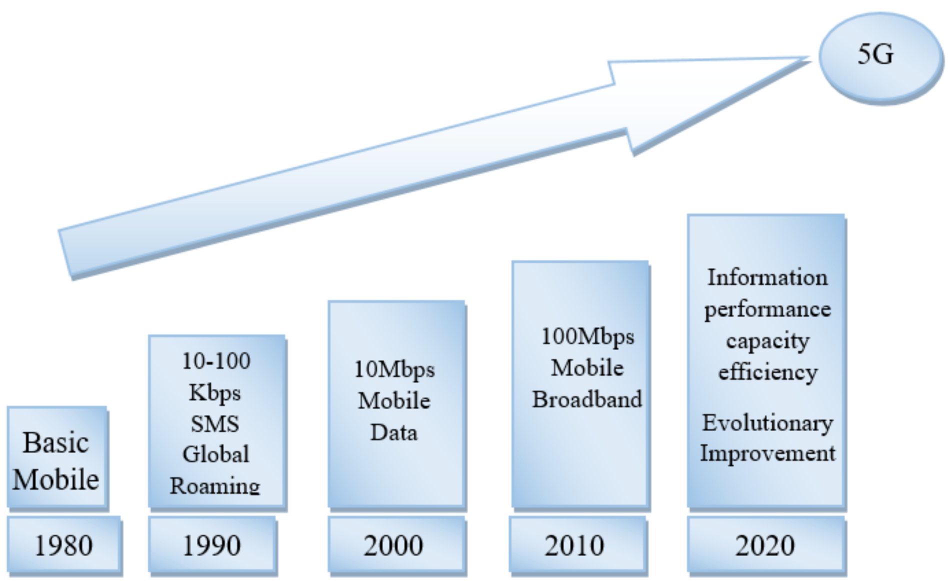


Figure 1 Wireless technology advancement

2.3 Antenna Requirements for Future Wireless Technology

The demand for effective signal transmission and reception in wireless communication technologies is rising quickly in laptops, smart phones, and satellite communication. As a result, the antenna is essential to wireless communication systems for both signal transmission and reception. An antenna's function is to transform electronic signals into electromagnetic impulses or the other way around. According to the IEEE, an antenna is a structure that serves as a bridge between free space and a guiding device and enables the transmission or reception of radio waves. (Kraus 1988). Future wireless technology would benefit greatly from the antenna's high gain, wide bandwidth, low ohmic losses, and high radiation efficiency qualities. (Balanis 2005). Antennas with high-speed transmission, high gain for extensive network coverage, and small size are needed for 5G technology. Network capacity beam forming antennas are a key component for mobile operators in 5G new radio (NR). One important method for creating high-gain antennas is beam forming technology. It is the capacity to produce extremely directional (high-gain) antenna patterns, particularly electrically steerable patterns, in a useful manner. In earlier wireless technologies, traditional antennas could only broadcast and receive on specific radiation patterns. On the other hand, beam shaping antennas dynamically shape their main and null beam directions dependent on the location of connected users. A beam-forming antenna's capacity to lessen interference, improve the signal-to-interference-and-noise ratio (SINR), and provide better-directed signals (Hamdy 2020).

2.4 Different Types of Antennas

Beam formation and beam steering can be accomplished using a variety of antenna types, including monopole, PIFA, micro strip patch, and others.

2.4.1 Monopole Antenna

The monopole antenna is a common component in wireless communication systems due to its simple layout, inexpensive price, and omnidirectional emission pattern. As shown in Figure 2, a monopole antenna is made of a straight conducting rod that is parallel to a metal ground plane. Excitation is applied with respect to a metal ground plane.(Chang 1968).

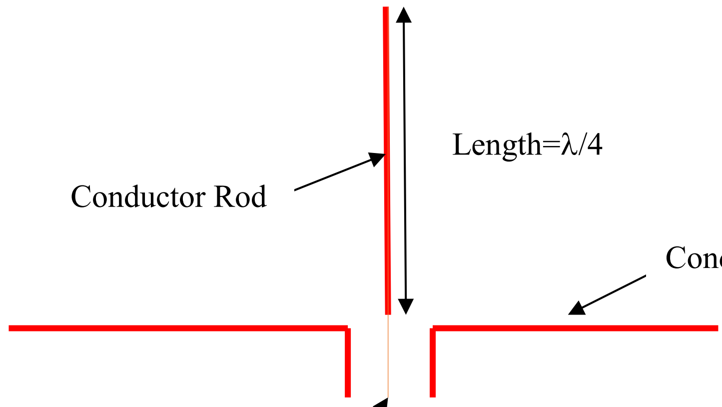


Figure 2 Monopole antenna with conductive road and ground plane

2.4.2 Inverted Planner F-Antennas

Compact antennas have been the subject of extensive research in the past 20 years due to the rapid progress of wireless communication. Due to their low description, small weight, and inexpensive production, microstrip antennas are highly desired for wireless communication..(Li, Tian et al. 2021). For wireless applications like mobile phones, the size of microstrip antennas at lower microwave frequencies is a problem. A contender to reduce the size of the microstrip antenna is the inverted-F antenna, a modified version of the microstrip antenna.

The PIFA antenna, which takes the shape of bent wire as seen in Figure 3, was first presented by Ronold W. P. King in 1958. The top of the wire is folded down parallel to the ground in a monopole antenna variation known as a PIFA antenna, which further boosts radiation resistance. (Waterhouse 2008). The antenna is low profile and compact due to its 4/λ length. Wireless devices like mobile phones, tablets, laptops, satellite applications, and missiles frequently employ the PIFA antenna. (Rowell and Murch 1997). It has a single shorting pin and is fed via a probe that is placed a fair distance from the shorting pin. While the impedance matching can be adjusted by adjusting the distance between the feed and the shorting, the impedance bandwidth is regulated by changing the air gap between the PIFA antenna's top and the ground. As the feed approaches the shorting pin, the impedance reduces; on the other hand, the impedance rises as the feed moves farther from the short edge. The PIFA's impedance can be changed using this option. W establishes the resonance frequency of the PIFA.

If so, the patch's whole length will be covered by the shorting pin.

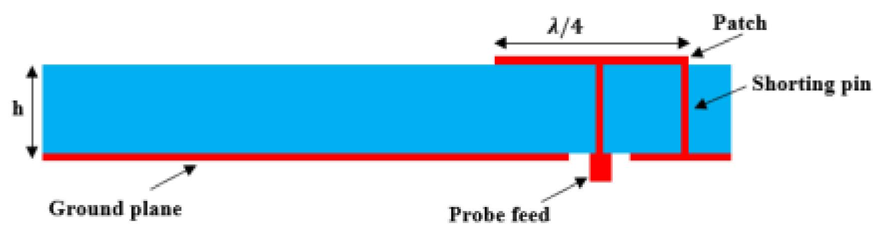


Figure 3 Inverted-F Antenna (Seyyedesfahlan, Uzun et al. 2020)

An inverted-F antenna usually consists of a grounding pin or plate, a rectangular planar element above the ground, and a feeding system for the planar radiating element. The inverted-F antenna developed from the monopole antenna, as can be seen in Figure 3, where the top component has been bent down to make it parallel to the ground plane. This lowers the height while maintaining a constant resonant trace length.The capacitance that this parallel segment imparts to the antenna's input impedance is corrected by adding a short-circuiting stub. The ground plane is connected to the terminal of this short circuit stub. The inverted F antenna is currently commonly used in mobile and portable applications because to its simple design, light weight, low cost, conformal nature, and reliable performance. (Addepalli and Anitha 2021, Wang, Chen et al. 2023). The inverted-F antenna is a development of numerous other portable antenna designs, and it is a primary component of numerous dual-band and even tri-band antennas. (Seyyedesfahlan, Uzun et al. 2020, Ahmad, Choi et al. 2022).

The planar inverted-F antenna (FIFA), which increases bandwidth by swapping out the wire for a plate, extends the wire inverted-F antenna. Here are a few advantages of the PIFA antenna.

- PIFA is able to fit in with the packaging of the mobile device, unlike the whip, rod, and helix antennas.
- Rearward radiation emitted at the individual's head has decreased thanks to PIFA, which has also reduced electromagnetic wave power absorption (SAR) and enhanced antenna performance.
- PIFA exhibits an average to significant gain in both the vertical and horizontal states of polarization.

In some wireless communications where the antenna direction is not set and there are surroundings reflections, this capacity is quite helpful. The most important variable to consider in these situations is the total field, which is the vector sum of the horizontal and vertical states of polarization.

Areas where PIFA antennas have already proven to function better or where it is projected that they will soon overtake the competition include: Satellite and ground-based communication (Abbas, Abbasi et al. 2020), For cellular communications, many base stations and handset terminals are used. (Jadhav and Deshpande 2020), GPS devices(Cao and Krzysztofik 2019), biomedical transceivers and implantable applications(Pournoori, Ma et al. 2019, Haque, Rashid et al. 2022), WLAN transceivers(Kim, Cho et al. 2019) and Bluetooth devices(Ali, Sovuthy et al. 2020, Choudhary, Malhotra et al. 2021), and MIMO systems (Rubani, Gupta et al. 2020).

2.4.3 Microstrip Patch Antenna

Decamps first presented the idea of a microstrip patch antenna in 1953. Because of the following factors, microstrip patch antenna is frequently employed as an interior antenna: i. Portability ii. Manufacturing costs are low. The capacity to design high gain arrays IV. Diversity of polarization the antenna is made with metal partially printed on the upper portion and totally covered by metal on the lower portion of the substrate. The patch may have a square, rectangle, circle, triangle, elliptical, or other shape. Figure 4 depicts a microstrip patch antenna with a rectangular shape.

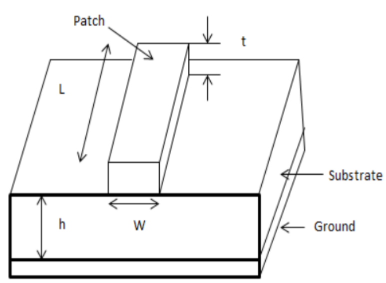


Figure 4 Microstrip patch antenna(Waterhouse 2008).

2.4.4. Substrate Integrated Waveguide (SIW)

The substrate is enclosed between two metallic layers in the substrate integrated waveguide (SIW) technology, and metallic posts are placed to connect the lower and upper metallic layers of the substrate. Because the microstrip line has significant radiation losses at high frequencies, it is typically used at millimeter wave frequencies.

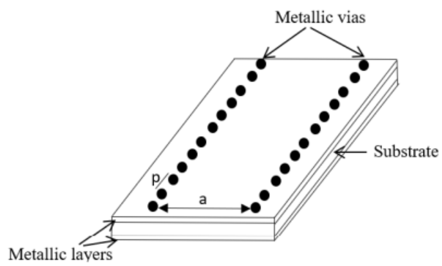


Figure 5 Substrate integrated waveguide(Waterhouse 2008).

2.5 Previous Related Works

An overview of 5G technology, antenna design for 5G, multiband PIFA antenna design, and multiband PIFA antenna system optimization methods are provided in this study of the literature. The analysis demonstrates that in order to support enormous machine-type communications, low latency, and high data rates for 5G technology, efficient and optimized antenna design is necessary. These needs must be met in part via antennas, and the development of effective and optimized antennas is crucial to the success of 5G.

The research also demonstrates that because of its low profile and versatility in frequency bands, multiband PIFA antennas are a good contender for 5G applications. Operating in several frequency bands is crucial for 5G since it enables the aggregation of various frequency bands to boost the system's capacity and data speeds. Due to the requirement for good performance over a broad frequency range, multiband PIFA antenna systems for 5G might be difficult to design and optimize.

2.5.2 High Gain Antenna

The various approaches to obtaining high gain and beamforming for 5G applications are the main focus of this section. Low-profile, small wireless devices are well suited for planar inverted-F antennas (PIFA).

The PIFA antenna's ability to be integrated with other electronic parts provides an additional advantage. For use with WLAN, various low-profile, flexible textile PIFA are available.

In (Chen et al.2000) suggested two PIFA arrays, one of which has shorting pins at the outer edges and the other of which has shorting pins at the inner edges, both of which boost the antenna's gain and widen its bandwidth. While Sievenpiper et al. demonstrate that the use of an artificial magnetic conductor (AMC) can increase the antenna's performance in terms of bandwidth, gain, and efficiency without affecting the size of the antenna (Zahid.Z.2017). The purpose of AMC is to add in phase with an antenna and reflect the wave at 0° phase, which improves the bandwidth and gain, respectively (Cheng, M.2022).

(Gao et al.2019) used a high permittivity metasurface (MS) that was put over the antenna to accomplish miniaturisation and high gain. While Yang et al. presented in (Hwang et al 2004) a thick cavity that served as an antenna's magnetic ground plane and increased peak gain by 1.73 dB. A 22 antenna array also improves the performance of the antenna.

Due to its simple construction, quarter wavelength length, inexpensive price, and omnidirectional emission pattern, monopole antennas are employed in wireless communication. A monopole antenna has a high response impedance throughout a significant section of its frequency range.

2.5.3 Multiband Antenna

In (Sabila, Prakoso et al. 2022) The assessment criteria for contrasting the simulated results of rectangular patch and PIFA antennas were return loss and VSWR using Ansoft HFSS at a 2.4 GHz operating frequency. The patch and PIFA antennas were found to have return loss values of -30.65 dB and -41.04 dB, respectively. The VSWR values for the patch and PIFA antennas were found to be 0.51 and 0.15, respectively. The resultant impedance bandwidth of these antennas supports both WCS and SDR bands. The results demonstrated that, in terms of return loss values, PIFA antenna outperforms patch antenna.

This thesis compares the performance of three antenna types at a 28 GHz operating frequency: a planar inverted-f antenna, a microstrip patch antenna, and a printed dipole antenna. The CST microwave studio electromagnetic simulator is used to simultaneously analyze gain, directivity, efficiency, return loss, and VSWR in order to compare the simulated results of various antennas.

In (Fakih, Diallo et al. 2019) The design of a dual-band antenna system for 22 HD MIMO 4G communications and FD 5G Tx/Rx is shown in this work. The system is intended for mobile terminals with a standard size of 140mm70mm, which is suitable for contemporary smart phones. The main goal was to make available the two necessary frequency bands, the 4G and 5G bands. In order to make it simpler to apply analogue and digital cancellation techniques later, while the full mobile device was being made, the next objective was to use a field cancellation technique to obtain the best isolation level for the 5G band. In addition, a high level of isolation for the 4G band is required for The HD application exclusively employs the field cancellation method; no other methods are used. The ideal scenario is to simultaneously and easily satisfy the HD MIMO 4G and FD 5G communications separation needs. To do this, a characteristic mode analysis was successfully finished. The research results presented in this paper show that our solution perfectly satisfies the requirements for HD MIMO of 4G in the low band in terms of matching and bandwidth, with a minimum isolation level of 20 dB.

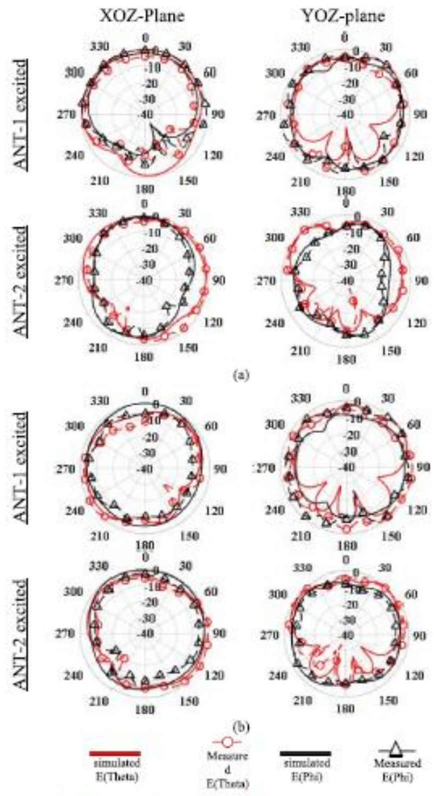


Figure 6 Simulated and measured radiation patterns of the two-PIFA (Fakih, Diallo et al. 2019)

In (Wikiman, Idowu-Bismark et al. 2019) In this paper, a single-band wearable and PIFA antenna that works at 32 GHz is described. The PIFA antenna has an incredibly high efficiency of 86% at 32 GHz. using a 2 dB power level and an essentially omnidirectional far-field pattern. This antenna can be utilized for military purposes as well as wearable technologies including medical implants, remote patient monitoring, and search and rescue operations. Before we can configure the PIFA antenna to function in dual band mode, we still need to work on it. We can also build a prototype of the suggested antenna to test the numerical findings.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Chapter overview

This chapter mainly focuses on materials and methods used to accomplish the research work, different micro strip model, and their mathematical representation and performance metrics which used to analyses the proposed antenna.

3.2 Materials

Software materials used in this thesis are CST, MATLAB R2020a, and Microsoft word. MATLAB R2020a, which is computing software that consists of Editor, used to write a code for calculating the parameters of the antenna. Microsoft Word is an integrated writing environment. It is writing tool which is user friendly to write.

3.3 Methods

First different literatures are reviewed and the research gap is identified. Figure 7 shows the methodology used in flow chart format:

- Select the material and its dielectric constant, as well as the frequency at which the antenna will operate.
- To determine the resonant frequency, use the design formula.
- To get high gain, low return loss, and low VSWR, uses the proper procedures.
- Used CST to design the suggested antenna structure.
- To determine the impact of various parameters on the performance of the antenna, do parametric analysis.

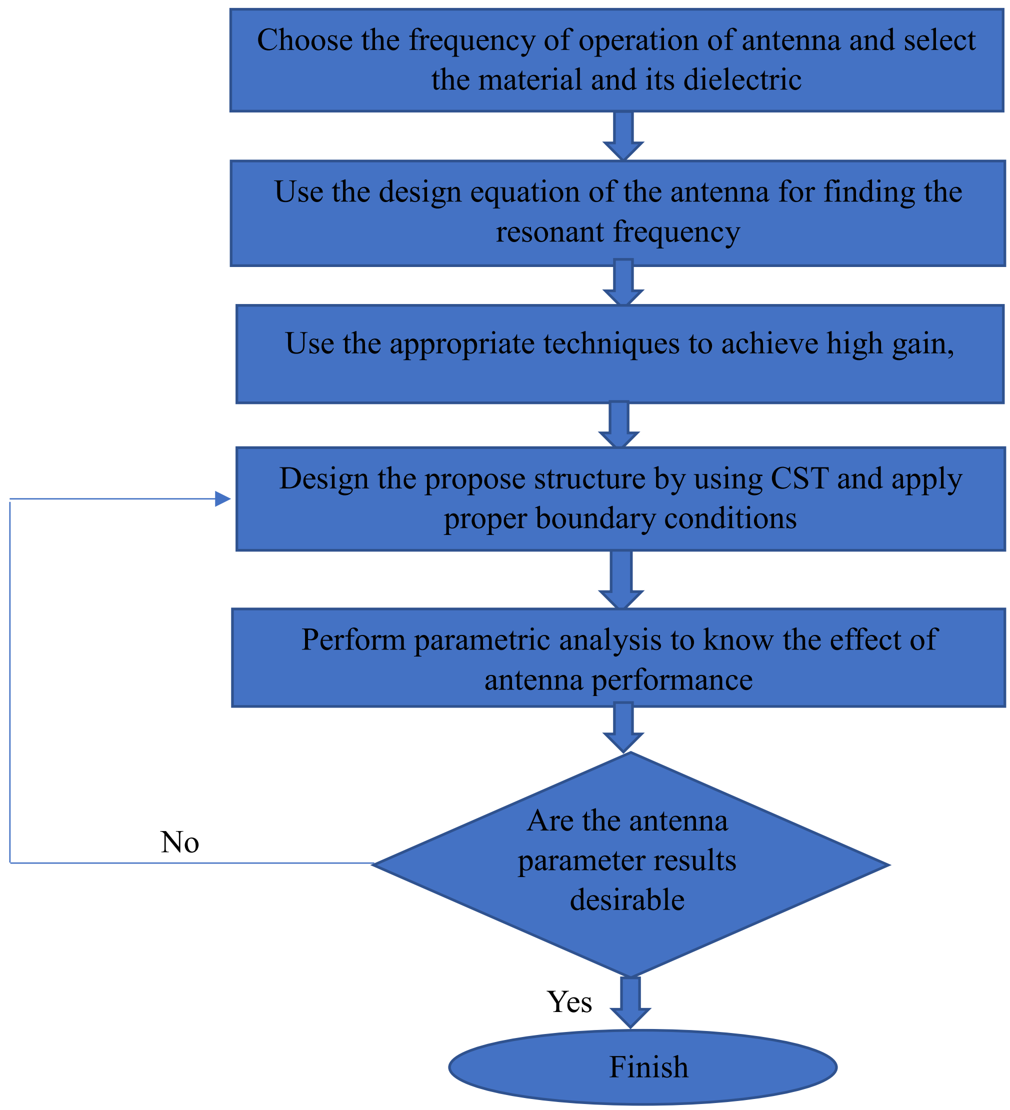


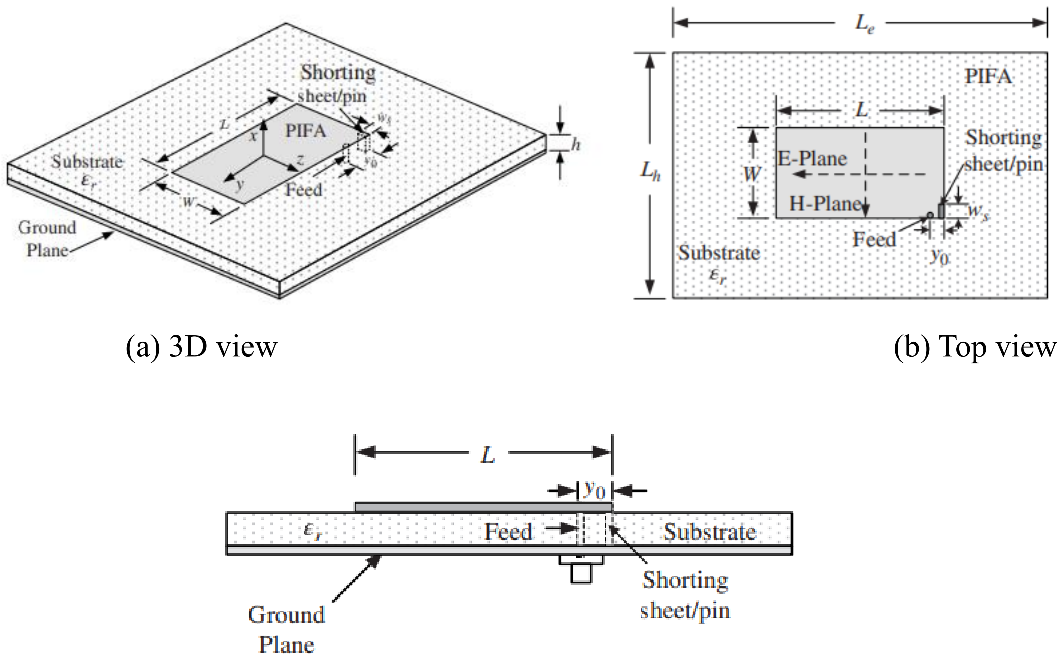
Figure 7 Design methodology of the proposed antennas

3.4 Design Procedure and Parametric Studies of PIFA Antenna

The process for designing an antenna is covered in this section, along with parametric analyses on the position of the feed and shorting pin and the impact of the air gap between the patch and the ground.

3.4.1 Effective Length, Resonant Frequency, and Effective Width

Figure 8 depicts the proposed composite antenna's geometry. The substrate's bottom meets the ground, and the PIFA antenna and its ground are printed on top of the substrate.



(a) 3D view (b) Top view

(c) Side view

Figure 8 Planar Inverted-F Antenna (PIFA) design(Balanis 2016)

The top PIFA antenna's distance from the feed to the shorting pin is indicated by the symbol "y_0" while the space between the PIFA and the ground is indicated by the letter "h." The PIFA design equation is provided as

1. A useful width for an effective radiator that results in high radiation efficiency is. (Bahl, Bhartia et al. 1982)

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (3.1)$$

2. Determine the effective dielectric constant of the micro strip antenna using (3.2).

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}} \quad (3.2)$$

3. Once W is found using (3.1), determine the extension of the length ΔL using (3.3).

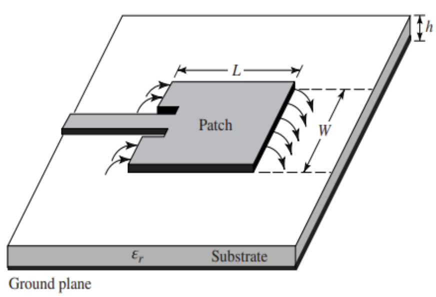
$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.2664\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \quad (3.3)$$

4. The actual length of the patch can now be determined by

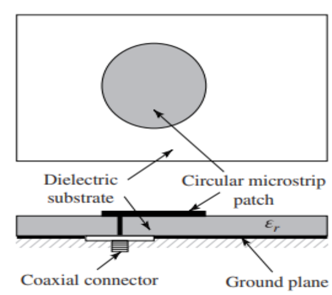
$$L \approx (0.47 - 0.49)\frac{\lambda_0}{\sqrt{\varepsilon_r}} = (0.47 - 0.49)\lambda_d \qquad (3.4)$$

3.4.2 Feeding Methods

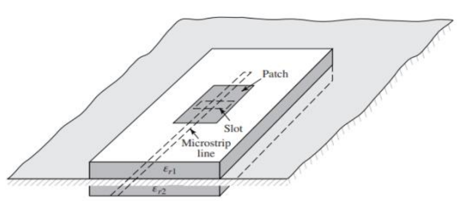
Micro strip antennas can be fed in a variety of combinations. The coaxial probe, proximity coupling, aperture coupling, and micro strip line are the four most widely used. (Carver and Mink 1981, Bahl, Bhartia et al. 1982, Katehi and Alexopoulos 1984). Figure 3.3 shows them in an illustration. Figure 9 displays one set of equivalent circuits for each of them. Another conducting strip, the microstrip feed line is typically much narrower than the patch. The microstrip-line feed is easy to model, simple to manufacture, as well as easy to match simply changing the inset location. Yet, surface waves and spurious feed radiation develop with substrate thickness, limiting the bandwidth (usually 2-5%) for practical devices. Coaxial-line feeds, which connect the coax's outer conductor to the ground plane and its inner conductor to the radiation patch, are also frequently utilized. The coaxial probe feed has low spurious radiation and is simple to manufacture and align. We are employing a coaxial feed for this thesis.



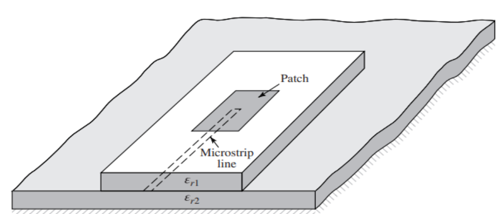
(a) Microstrip line feed



(b) Probe feed



(c) Aperture-coupled feed



(d) Proximity-coupled feed

Figure 9 Feeding mechanisms of micro strip antennas(Balanis 2016)

3.4.3 Conductance

the conductance can be expressed as

$$G_1 = \frac{I_1}{120\pi^2} \tag{3.5}$$

where

$$I_1 = \int_0^{\pi} \left[\frac{\sin(\frac{k_0 W}{2} cos\theta)}{cos\theta} \right]^2 sin^3\theta d\theta \tag{3.6}$$

3.4.4 Resonant Input Resistance

Given by (3.7), the resonant input resistance does not account for interactions between the slots. (Derneryd 1978)

$$Rin = \frac{1}{2(G_1 \pm G_{12})} \tag{3.7}$$

where the minus (-) sign is applied for modes with even (symmetric) resonant voltage distribution, whereas the plus (+) sign is applied to modes with odd (antisymmetric) resonant voltage distribution beneath the patch and between the slots. Using the far-zone fields as a reference, the mutual conductance is defined as

$$G_{12} = \frac{1}{120\pi^2} \int_0^{\pi} \left[\frac{\sin(\frac{k_0 W}{2} cos\theta)}{cos\theta} \right]^2 J_{0(k_0 Lsin\theta) sin^3\theta d\theta} \tag{3.8}$$

The input resistance for the inset feed is given approximately by(Derneryd 1978, Carver and Mink 1981)

$$Rin = \frac{1}{2(G_1 \pm G_{12})} \left[cos^2 \frac{\pi}{L} y_0 + \frac{G_1^2 + B_1^2}{Y_c^2} sin^2 \left(\frac{\pi}{L} y_0 \right) - \frac{B_1}{Y_c} \sin \left(\frac{2\pi}{L} y_0 \right) \right] \tag{3.9}$$

where Yc = 1⁄Zc. Since for most typical microstrips G_1/Yc ≪ 1 and B_1⁄Yc ≪ 1, (reduces to

$$Rin(y = y_0) = \frac{1}{2(G_1 \pm G_{12})} cos^2 \left(\frac{\pi}{L} y_0 \right) = Rin(y = 0) cos^2 \left(\frac{\pi}{L} y_0 \right) \tag{3.10}$$

3.5 Antenna Theory, Impedance Matching, Software Introduction

Antenna parameters are used to describe the performance of an antenna when designing and measuring antennas. In this section, characteristics such as the directivity, bandwidth, radiation pattern, gain, efficiency, input impedance, return loss and s-parameters are explained.

3.5.1 Antennas reciprocity

Antenna reciprocity refers to the antenna's electrical and magnetic characteristics. These characteristics include the antenna efficiency, S parameters, input impedance, radiation pattern, gain, beam width, bandwidth, and voltage standing wave ratio (VSWR).

3.5.2 Radiation Pattern

The radiation pattern is expressed in terms of the relative strength of a field radiated by an antenna in various directions. It is described using the phrase "spatial distribution of a quantity that characterizes the electromagnetic field generated by antenna". A radiation pattern is made up of spatial distributions of power flux density, radiation intensity, field strength, directivity, phase, or polarization that can be two- or three-dimensional. The direction in which the greatest radiation is produced is traversed by the radiation pattern, which follows a surface or route with a constant radius. The spherical coordinate system is often used to represent the radiation pattern. When the value is constant, a two-dimensional pattern may be affected by the elevation angle, azimuth angle, or both. (Gvozdarev 2022). In Figure 10, the spherical coordinate system is displayed. Three areas—a reactive near-field, a radiating near-field, and a far-field can be distinguished in an antenna's radiation fields. The radiation pattern close to the antenna differs from the pattern at great distances. The electric and magnetic fields are extremely unpredictable in the reactive near-field, which is a field pattern that surrounds an antenna element. A short distance from the reactive near-field, the radiating near-field takes over and is where the antenna's radiation field is developing. Far field is the phrase used to describe the field pattern at very long distances. What is typically of importance is the far field, which is the radiated power, also known as the radiation field. Since it makes computations easier, measurements and beam patterns are typically seen in the far-field region.(Balanis 2016, Jeripotula and Rajendra Naik 2022).

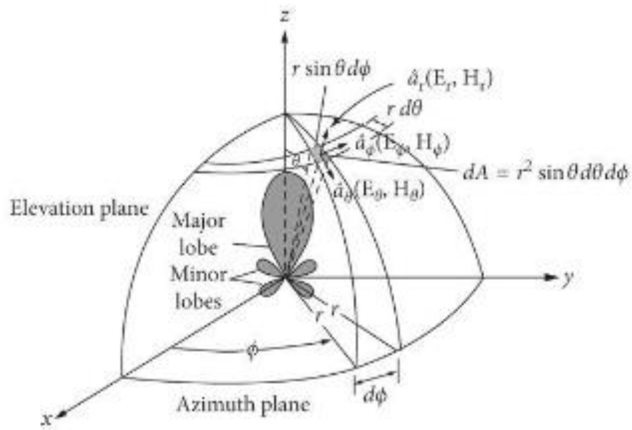


Figure 10 Spherical Coordinate Systems for Antenna Analysis(Balanis 2016)

3.5.3 Directivity

The directivity of an antenna is one of the most important variables in this work since it will be utilized to compare antennas using a figure of merit. As stated by (Balanis 2016), An antenna's directivity is determined by dividing the radiation intensity it emits in the direction it is aimed at by the radiation intensity it emits on average. Where the average radiation intensity, or radiation intensity from an isotropic source,U_0 is equal to the total power radiated by the antenna divided by four. This can be stated as follows:

$$D(\theta,\varphi) = U(\theta,\varphi)U_0 = 4\pi U(\theta,\varphi)p_{rad} \qquad (3.11)$$

where, D is the directivity of the antenna is the radiation intensity of the antenna U_0 is the radiation intensity of an isotropic source p_{rad} is the total power radiated.

Directivity is a dimensionless quantity since it is the ratio of two radiation intensities. As a result, it is frequently stated in dBi. When compared to an isotropic source, an antenna can radiate more or less intensely in certain directions depending on its directivity. The main lobe of a small antenna has stronger directivity than the main lobe of a broad antenna, making it more directional.

3.5.4 Gain

The gain is the ratio of the radiation intensity in a particular direction to the radiation intensity that would come from the antenna's power being transmitted isotopically..(Houtz, Blackwell et al. 2019). It should be noted that while the gain takes the conduction and dielectric efficiency into account, the definition and directivity are still tightly related: The relationship between antenna gain and directivity is shown by an equation (3.12)

$$G(\theta,\varphi) = 4U(\theta,\varphi)p_{in} = 4\pi\eta U(\theta,\varphi)p_{rad} = \eta D(\theta,\varphi) \quad (3.12)$$

Where, G is the gain of the antenna, D is the directivity of the antenna. p_{in} = total input power [W]

η = antenna efficiency ($0 \leq \eta \leq 1$)

3.5.5 Antenna Efficiency

The power delivered to the antenna's feed is not entirely radiated. Since some of the power will be lost or reflected, it is possible to define a number of efficiencies relating to these losses: The efficiency of reflection is affected by the mismatch between the impedances of the feeding line and the antenna. The dielectric efficiency is the same as the conduction efficiency but considers losses in the dielectric of the antenna rather than its conductors. Conduction efficiency is the ratio of input power to losses produced in the antenna's conductors. In light of this, the following definition of an antenna's overall efficiency,

$$e_0 = e_r e_c e_d \quad (3.13)$$

Where, *e0* = total efficiency e_r= reflection (mismatch) efficiency, e_c = conduction efficiency, e_d = dielectric efficiency

Conduction efficiency and dielectric efficiency are multiplied to create an antenna's radiation efficiency. Conduction and dielectric losses are what are referred to as I^2R losses.

3.5.6 Input Impedance

The input impedance of an antenna is characterized by (Balanis 2016) " the voltage to current ratio at both terminals, the impedance an antenna displays at its terminals, or the proportion of the relevant elements of the magnetic and electric fields at a specific place. Because it has a considerable impact on how well an antenna matches, it must always be considered when building an antenna. The correct impedance matching between a port and an antenna can reduce unwanted reflections. Because these two impedances view one another identically, the reflection is diminished. The total of an antenna's terminal resistances and reactance is known as input impedance in mathematics. The antenna's impedance can therefore be expressed using equation (3.14).

$$Z_{in} = R_{in} + X_{in} \tag{3.14}$$

Where, Z_{in} is the antenna impedance, R_{in} is the antenna resistance, X_{in} is the antenna reactance. The imaginary part, X_{in} of the input impedance, which represents the power kept close to the antenna.

The input impedance is influenced by the shape, conductivity, excitation method, and properties of the surrounding objects of conducting items. Some antennas don't use conducting metals as their base, and instead rely on dielectric materials or slots in a plane for their resonation. Their input impedance is influenced by additional factors including the dielectric's permittivity. (Balanis 2016).

Making the input impedance equal to the source impedance as shown in the equation results in impedance matching, this reduces reflections. (3.15)

where

$$Z_{in} = Z_S^* \tag{3.15}$$

$$Z_{in} = R_{in} + jX_{in} \tag{3.16}$$

$$Z_s = R_s + jX_s \tag{3.17}$$

Z_s is the source impedance, R_s is the source resistance, X_s is the source reactance when Z_{in} is Z_S^* complex conjugate, there is the greatest amount of power transmission. To put it another way, X_{in} = -X_s and $R_{in} = R_s$. Complex conjugate matching is another name for this.

Standing waves are caused when some of the power is reflected back, preventing all of it from reaching the target point. The Voltage Standing Wave Ratio (VSWR) is a quantity that can be used to describe standing waves when the matching condition is not met. The reflection coefficient, which measures the power reflected from the antenna, is a factor in VSWR. Equation is used to determine the value of VSWR when the reflection coefficient is given.(3.18) (Makarov, Wartman et al. 2020).

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \tag{3.18}$$

$$\Gamma = \frac{V_r}{V_i} = \frac{Z_{in}-Z_s}{Z_{in}+Z_s} \tag{3.19}$$

Where, Γ is called the reflection coefficient, V_r is the amplitude of the reflected wave V_i is the amplitude of the incident wave.

The impedance mismatch between the transmitter and the antenna is essentially measured by the VSWR. The mismatch is bigger the higher the VSWR, which shouldn't be greater than 3. The ideal match has a VSWR of unity, which is the minimal value. The power is not reflected from the antenna in that case, which is excellent. Equation 3.18 demonstrates that the antenna with lower VSWR has better return loss than the antenna with greater VSWR. The majority of radio equipment is built for an input impedance of 50 or 75; therefore, a realistic antenna design should have one of these values.

3.5.7 Return Loss

This metric measures the power reflected by the antenna due to the mismatch between the transmission line and antenna. The return loss is an indicator, like the VSWR, of how well the transmitter and receiver have been matched. The power of the incident wave to the power of the reflected wave is measured, and the ratio is given in decibels(Nazli , Balanis 2016). The Return Loss is given by:

$$Return\ Loss = -20 \log|\Gamma|\ (dB) \qquad (3.20)$$

Where |Γ| denotes the size of the reflection coefficient, and this number is never higher than 1.

Γ = 1 has an RL = 0dB, which suggests that there is nothing to radiate by the antenna because the power delivered to the antenna is totally reflected. In contrast, Γ = 0 has an RL =-∞, which indicates no power would be reflected back.

Equation 3.21 can also be used to determine the Return Loss from the VSWR. It should be noted that the return loss is presented as a ratio with decibels.

$$ReturnLoss = -20 log \frac{VSWR-1}{VSWR+1} dB \qquad (3.21)$$

A negative number is provided as the return loss. Being a loss, the returned power must be lower than the forward power, and as a result, the return loss is denoted by a minus sign or by negative decibel values.

3.5.8 S-parameters

In microwave design, the S-parameters are essential for describing the behavior of electrical devices. The majority of electrical qualities, such as VSWR, return loss, gain, and so forth, are related to the S parameters. S-parameters are used to characterize the input and output relationship between ports in an electrical system. The S-parameters S11 and

S22 stand in for input and output reflection, respectively, whereas S21 and S12, which indicate the forward transmission coefficient (gain) and the reverse transmission coefficient (isolation), which measure the power transmitted from port 1 to port 2, respectively. (Palanisamy, Thangaraju et al. 2021)

The reflection coefficient, abbreviated S11 (also known as return loss), measures how much power is reflected from the antenna. All of the power is reflected from the antenna and not radiated if S11 = 0 dB.

3.5.9 Bandwidth

The bandwidth of an antenna is the range of frequencies over which it can operate effectively in relation to specific characteristics. Typically, characteristics like gain, radiation pattern, VSWR, etc. are mentioned. The VSWR, commonly known as the impedance bandwidth, is the bandwidth metric for concerns that is most usually employed.

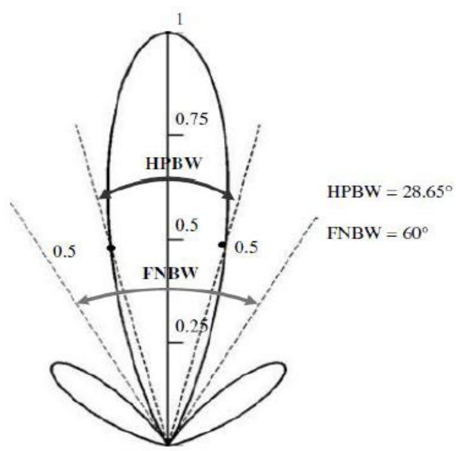


Figure 11 Two-dimensional power pattern(Balanis 2016)

According to equation (3.22), bandwidth is the difference between a band's higher frequency (FH) and lower frequency (FL).

$$BW = FH - FL \qquad (3.22)$$

The bandwidth can alternatively be expressed as a proportion of the band's center frequency as follows:

$$BW = 100 \times \frac{FH-FL}{Fc} \qquad (3.23)$$

Where, FH is the highest frequency FL is the lowest frequency, and FC is the center frequency in the band.

3.5.10 Simulation Software CST

Before designing the PIFA, we will look at the functions of the simulation software, CST. It is simulation software used for electromagnetic analysis to obtain parameters such as return losses and radiation pattern. The name CST is an abbreviation of Computer Simulation Technology.

It is commonly used by engineers and researchers in the fields of microwave engineering, antenna design, RF (Radio Frequency) and wireless communication, signal integrity, and EMC (Electromagnetic Compatibility) analysis. The CST software suite includes several modules that allow users to model and simulate electromagnetic phenomena in a variety of applications. The modules include:

CST Studio Suite: This is the main software package that includes all the necessary tools for electromagnetic simulation and analysis, including 3D electromagnetic simulation, circuit simulation, and thermal simulation.

CST Microwave Studio: This module is specifically designed for microwave and RF engineering, and includes tools for designing and simulating microwave components, such as filters, couplers, and antennas.

CST PCB Studio: This module is designed for analyzing and optimizing the electromagnetic performance of printed circuit boards (PCBs).

CST Cable Studio: This module is designed for simulating and analyzing the electromagnetic behavior of cables and cable assemblies.

CST EMCS: This module is designed for electro-magnetic compatibility (EMC) analysis and includes tools for predicting and analyzing the interaction between electromagnetic fields and electronic equipment.

The CST software suite uses numerical methods, such as the finite element method (FEM) and the method of moments (MoM), to solve complex electromagnetic problems. It also includes a powerful visualization and post-processing tool that allows users to analyze and interpret simulation results in a user-friendly way.

3.6 Selection Criteria

The goal of this thesis is to design a multi-band, effective, compact, and low profile antenna for use with handheld transceivers. The operation for use in 5G networks, specifically NR 3.4GHz, NR 3.6GHz, NR 3.8GHz, NR 31GHz, and NR 33GHz networks, must also be included in this antenna. As a result, several miniaturised multi-band handheld transceiver antennas (some of which are presented in Chapter 2) were researched to begin with. Several options, including Microstrip Antenna, Planar Inverted-F Antenna (PIFA), and other multi-band antenna designs, were discovered via the research. Due to its many benefits, some of which were stated in earlier chapters, PIFA is the most promising choice out of these antennas. In order to understand about the various designs and techniques used to construct a multi-band PIFA operated in 5G, comprehensive research on PIFA was conducted.

After learning about the properties of these multi-band PIFAs and evaluating their performance (using simulator software), it was discovered that some of the approaches employed did not yield good results .However, the search for a strategy to create a new multi-band antenna continues despite the failures.

3.7 Single Band PIFA

We will examine the designing process of a single band PIFA and the characteristics of each single band PIFA at the several proposed frequency bands before starting the construction of the multi band PIFA. Understanding the traits and many aspects that affect the PIFA's performance was made easier because to this designing. The following equation is used to derive the fundamental dimensions of the PIFA using the design parameters provided in above equations.

$$W + L \approx c/4f_r \tag{3.24}$$

where f_r is the resonant frequency.

The resulted dimensions for the pifa based on equation 3.24 are:

Once the fundamental dimensions have been determined, a process of trial and error is started to create new dimensions so that the PIFA can meet its performance requirements. And by adjusting L, W, Ws, h, the location of the feed source, and the ground plane's dimensions, multiple efforts were made to achieve the necessary resonance frequency and bandwidth using CST.

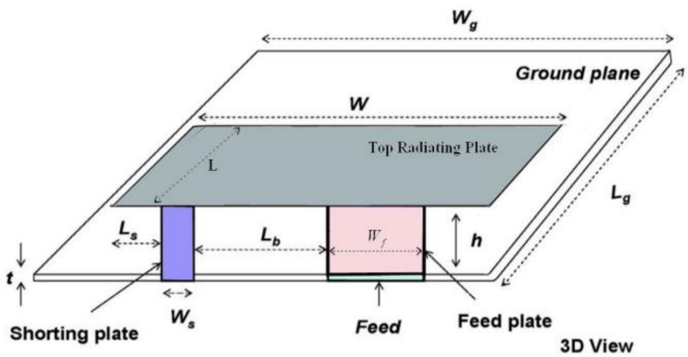


Figure 12 Typical layout of PIFA(Thangaraju et al. 2021)

First, using the fundamental dimensions for the 3.4GHz PIFA as a starting point, the equation was used to estimate additional dimensions such as the height (h), the width of the short-circuit plate (Ws), and the location of the feed source. CST was used to run the simulation using all of the required data.

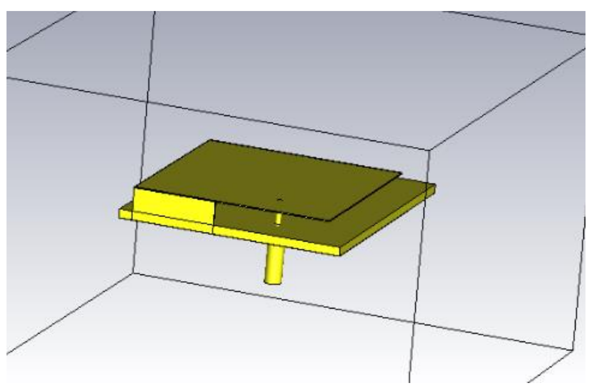
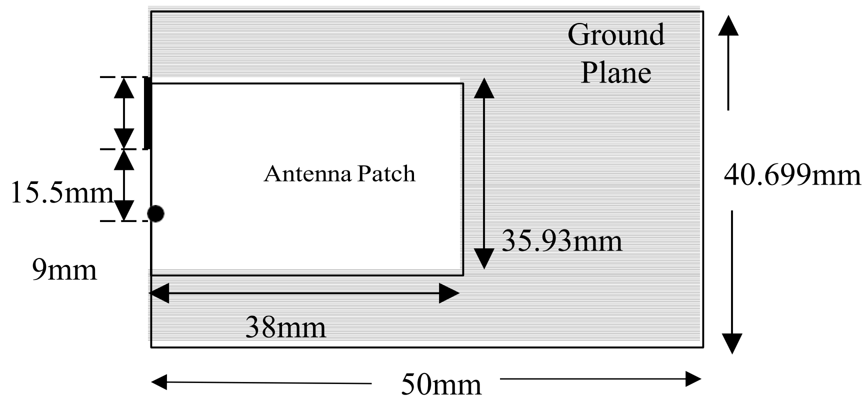


Figure 13 Single band PIFA with Ground displayed in CST

The outcomes were quite promising, with a return loss at 3.4GHz of about -47.202dB. With this result, it became necessary to move forward with the investigation of a finite ground's effects. In order to define a finite ground plane, research was conducted once more.Therefore, a comparable finite ground plane (shown in Figure 13) is being defined without altering the patch's dimension.

Hence the various dimensions of the antenna patch were varied to achieve an optimum return loss at the desired frequency. And with the knowledge gain from the researches, the resonance of the antenna depends on size of the antenna patch; patch size was changed to conform to the desired frequency.

Finally after all aspect of the 3.4 GHz PIFA were examined, the final dimensions weredetermined to be:

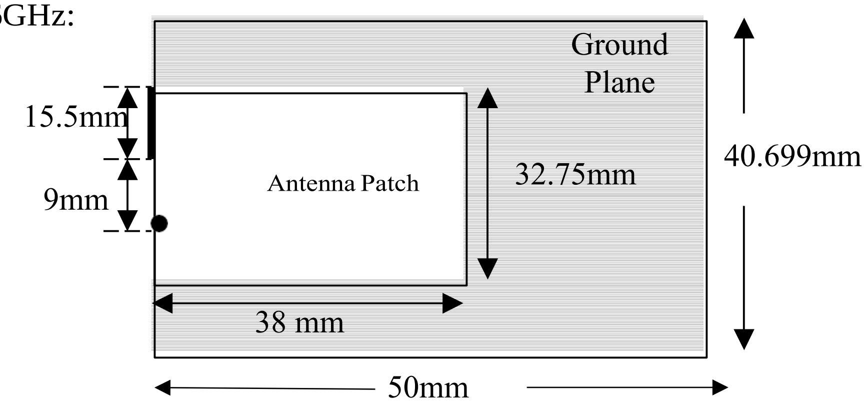


* Height of the antenna patch form the ground plane is 5.5mm

Figure 14 Antenna dimension for 3.4GHz band

The PIFA's dimensions for other resonant frequencies were then established in the same manner as they were for the 3.4GHz PIFA. These are the measurements,

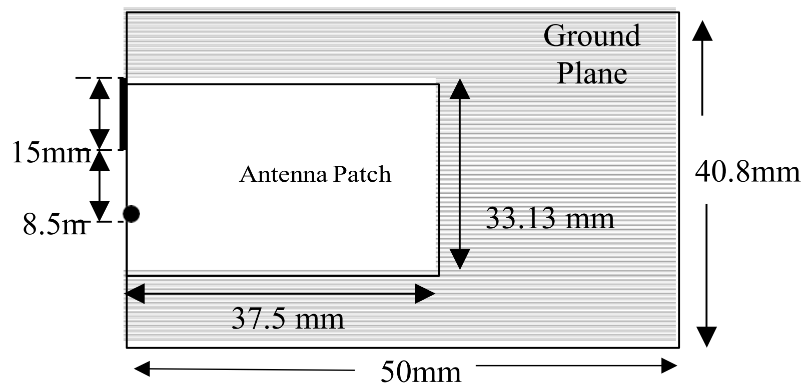
For 3.6GHz:



* Height of the antenna patch form the ground plane is 5.5mm

Figure 15 Antenna dimension for 3.6GHz band

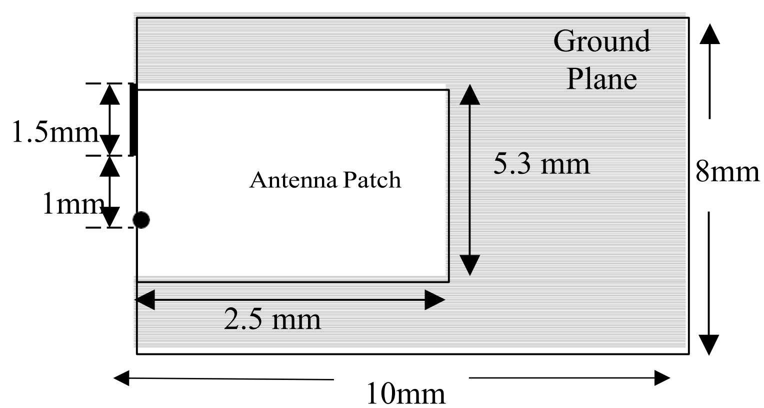
For 3.8GHz:



* Height of the antenna patch form the ground plane is 5.5mm

Figure 16 Antenna dimension for 3.6GHz band

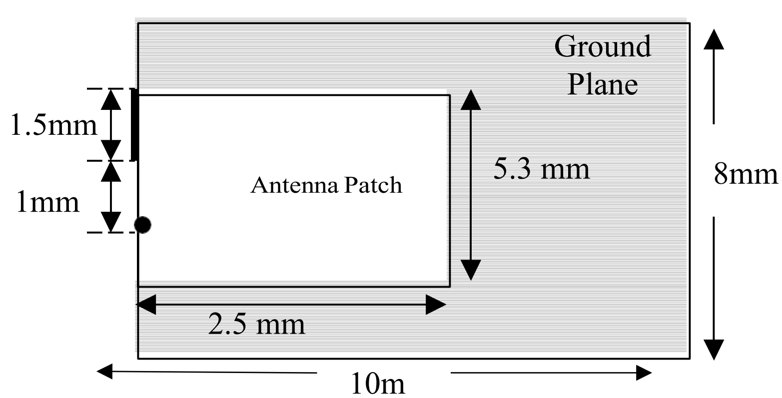
For 31GHz:



* Height of the antenna patch form the ground plane is 1mm

Figure 17 Antenna dimension for 31GHz band

For 33 GHz:



* Height of the antenna patch form the ground plane is 1mm

Figure 18 Antenna dimension for 33GHz band

After finally comprehending the PIFA's features, it is now possible to create the multi band PIFA. Even though the single band PIFA tests were all fundamental, they did prove to be highly useful in the subsequent creation of the multi band PIFA.

3.4 Multi-Band PIFA

3.4.2 Multiband PIFA

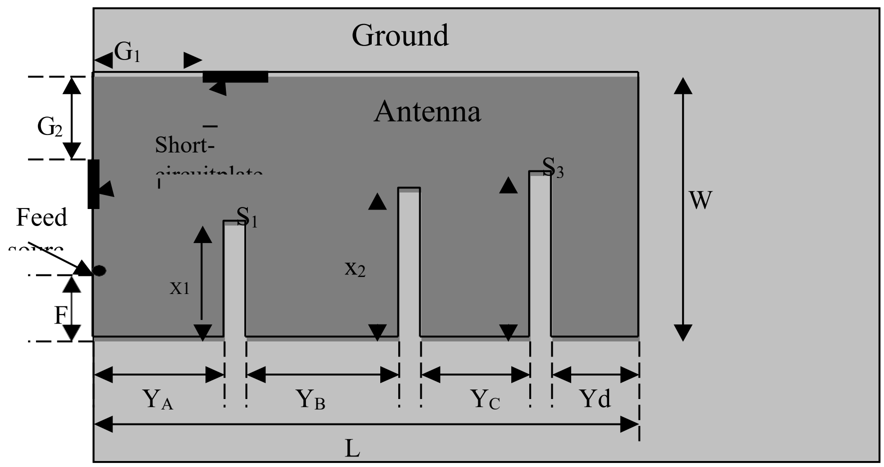


Figure 19 Design of the Multi Band PIFA

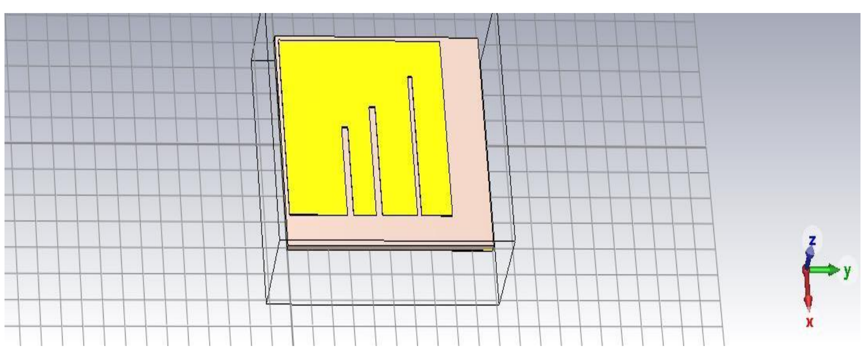


Figure 20 Muti band PIFA using CST

The effort didn't end there; rather, additional tests were run to refine the design so that it would function at the correct resonant frequencies. Then, following a number of trials, a result was obtained with resonance frequencies that were somewhat near to the intended ones.

More research was done to determine how to boost bandwidth. The results of the single band simulations did in fact, demonstrate a large rise in the bandwidths, it was then realised. The antenna was then subjected to variations in those specifications, including height, feed source position, and short-circuit plate width. Finally, a set of outcomes were obtained, and the dimensions are as follows:

Table 1 Dimension of multiband PIFA

Ly=30.25	G1=6.7	Y_C = 3.7
X1=7.34	Wx=30.5	Yb=5
X2=11.52	Y_A =12.4	G_2 =6.78

Height = Width of the short-circuit plate = 5.5mm

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1 Overview

The overall research findings are briefly discussed in this chapter. Simulated outcomes are within allowable bounds. To evaluate the effectiveness of the antenna, the return loss versus frequency, VSWR versus frequency, radiation pattern, gain, and directivity are used.

4.2 Single Band PIFA

Before starting to construct the multi band PIFA, we will first examine the design process of a single band PIFA and the features of each single band PIFA at the various proposed frequency bands.

Table 2 General Parameters for the simulation

Parameters	Frequency				
	3.4 GHz	3.6MHz	3.8GHz	31GHz	33GHz
Patch length(mm)	35.93	32.75	33.13	5.3	5.05
Patch Width(mm)	38	38	37.5	2.5	2.5
Patch Height	Vary	Vary	Vary	1	1
Ground Width	40.699	40.699	40.68	10	10
Substrate	FR-4	FR-4	FR-4	FR-4	FR-4
Ground Length	50	50	50	8	8
Shorting Pin width	Vary	Vary	Vary	Vary	Vary
Yo_coaxial_feed position	Vary	Vary	Vary	Vary	Vary

Understanding the traits and many aspects that affect the performance of the PIFA is made easier thanks to this designing. The fundamental dimension of the PIFA is determined using the above-mentioned design parameters.

4.2.1 Return loss Vs Frequency with varying Short-circuit plate width, Ws for 3.4 GHz

The antenna patch's optimal dimension was reached with a return loss of -48.09dB at 3.4GHz. Another round of trial and error was conducted on the other antenna settings because the impacts of the other antenna parameters had not yet been investigated. First, it was discovered that the short-circuit plate's width might influence resonance frequency. This finding supported the notion put forward in Chapter 3, according to which resonant frequency drops as short-circuit plate width decreases, as shown in Figure 21.

Reflection Coefficient vs. Frequency

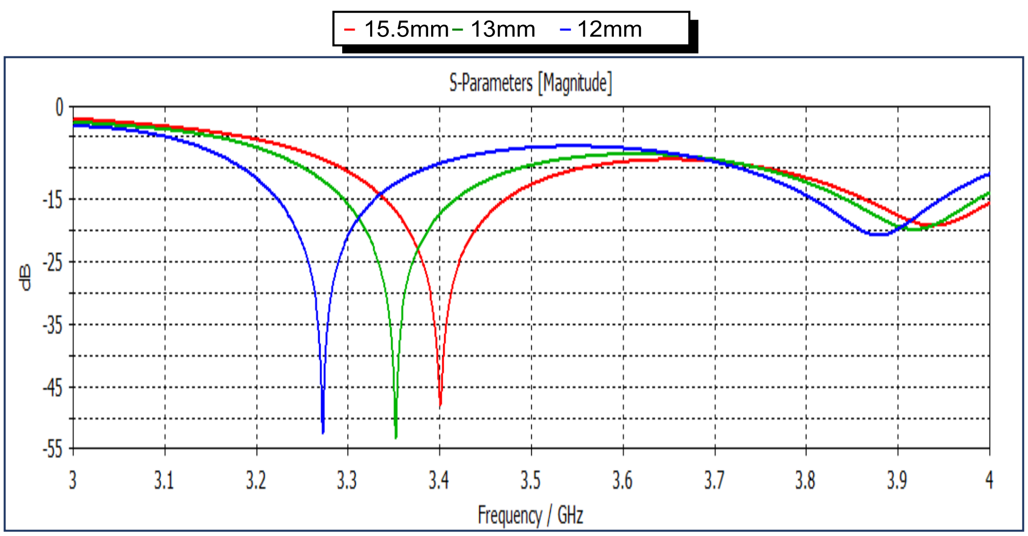


Figure 21 Simulated Return Loss for 3.4GHz PIFA with changing Short-circuit Width, Ws

Table 3 Effect of the Shorting-circuit width

Width(mm)	Ws=15.5mm	Ws=13mm	Ws=12mm
Gain(dBi)	7.677dBi	7.679dBi	7.679dBi
Directivity(dBi)	7.950dBi	7.952dBi	7.952dBi
Tot. efficiency(dB)	-0.273dB	-0.275dB	-0.275dB
Rad. efficiency(dB)	-2.676dB	-2.678	-1.678dB
Return Loss	48.09	53.43	52.74
VSWR	1.007	1.005	1.005
Bandwidth	265MHz	233MHz	233MHz

4.2.2 Return loss Vs Frequency with varying Height of antenna patch for 3.4 GHz

The results are presented in Figure 22 The effects of altering the antenna patch's height from the ground h, were then examined. The resonant frequency was observed to drop as the antenna patch's height increased.

Reflection Coefficient vs. Frequency

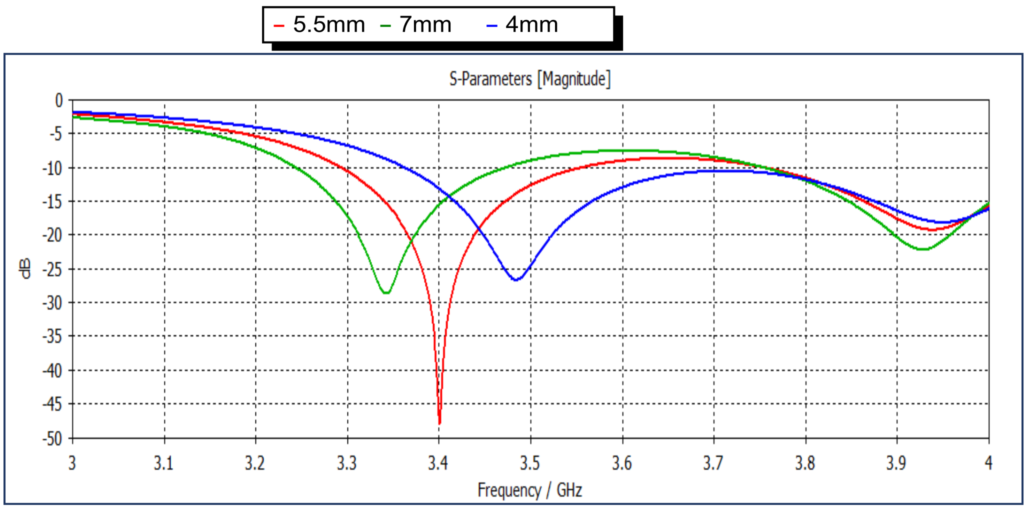


Figure 22 Simulated Return Loss for 3.4 GHz PIFA with varying Height of the Antenna Patch, h

Table 4 Effect of the Antenna patch height

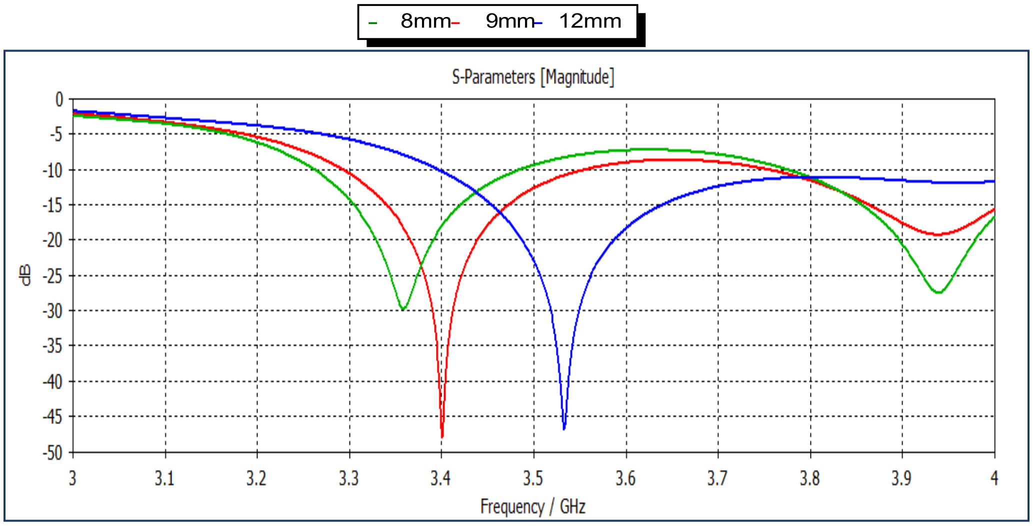
Height(mm)	Ws=4mm	Ws=5.5mm	Ws=7mm
Gain(dBi)	4.56dBi	7.677dBi	4.47dBi
Directivity(dBi)	4.84dBi	7.950dBi	4.52dBi
Tot. efficiency(dB)	-0.193dB	-0.273dB	0.1787dB
Rad. efficiency(dB)	1.282dB	-2.676dB	0.984dB
Return Loss	3.487	48.09	3.346
VSWR	1.24	1.007	1.28
Bandwidth	237MHz	265MHz	374MHz

Hence, taking a look at a chapter 3 equation, h will rise as the wavelength increases while L1 and L2 are fixed. Therefore, frequency will decrease as wavelength increases. That allowed it to be confirmed that the findings were accurate.

4.2.3 Return loss Vs Frequency with varying Position of the feed source for 3.4 GHz

The consequences of changing the feed source's position were then examined.

Reflection Coefficient vs. Frequency



*Figures display the distance in mm from the shorting plate.

Figure 23 Simulated Return Loss for 3.4 GHz PIFA with varying Position of the Feed source

Table 5 Effect of the Antenna patch height

Height(mm)	Ws=8mm	Ws=9mm	Ws=12mm
Gain(dBi)	4.55dBi	7.677dBi	7.665dBi
Directivity(dBi)	4.81dBi	7.950dBi	7.945dBi
Return Loss	-29.99	-48.09	-47.13
VSWR	-1.25	-1.007	1.008
Bandwidth	206MHz	265MHz	390MHz

The initial task in this thesis was to design and simulate the 3.4 GHz planar inverted-F antenna using CST. As can be seen above, a series of simulations resulted in the final structure and dimensions of the antenna. The final antenna design's return losses are depicted in the following graph.

Reflection Coefficient vs. Frequency

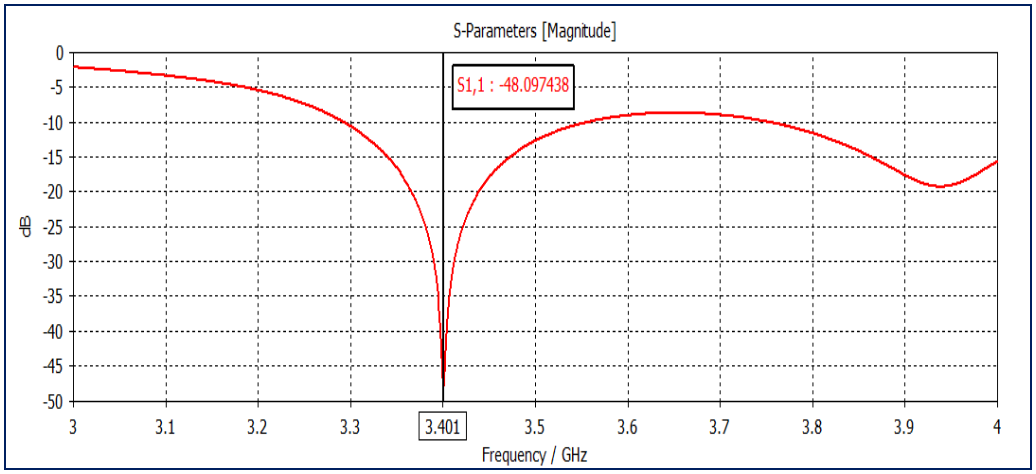


Figure 24 Simulated Return Loss for 3.4 GHz PIFA

A resonance frequency of 3.4GHz has been attained, as seen in the graph in Figure 25 The estimated return loss attainment at 3.4GHz with bandwidth for S11 - 10dB of 265MHz (7.74%) was -48.09dB. It operates between 3.29GHz to 3.55GHz in frequency. The antenna's VSWR, Directivity, and Gain have also been displayed.

VSWR

Figures 26 for the single band planer IFA show that the value of VSWR at 3.4 GHz is almost equivalent to 1.007.

VSWR vs. Frequency

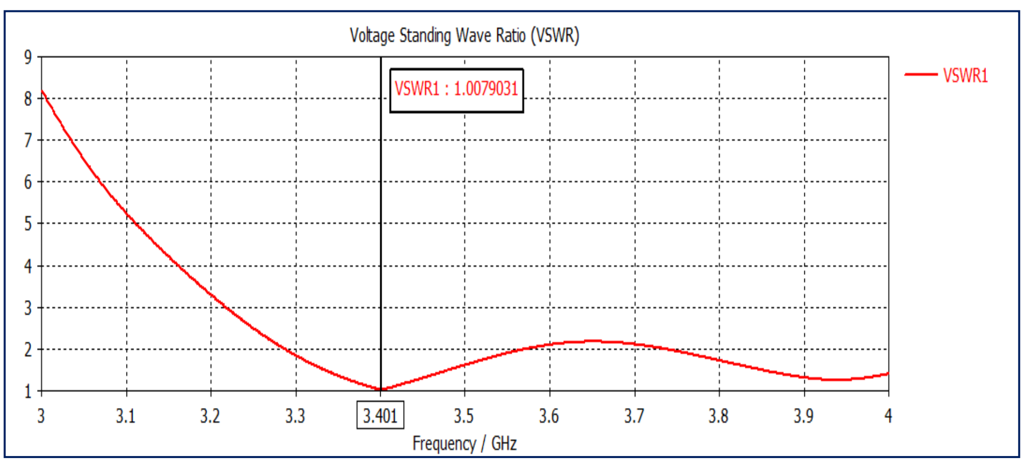


Figure 25 Simulated VSWR for 3.4 GHz PIFA

Radiation Pattern:

Figures 26 to 29 display various views of the single band PIFA antenna's three-dimensional far-field emission pattern. For the 3.4GHz single band PIFA antenna, the gain and directivity are found to be 7.677 dBi and 7.95 dBi, respectively.

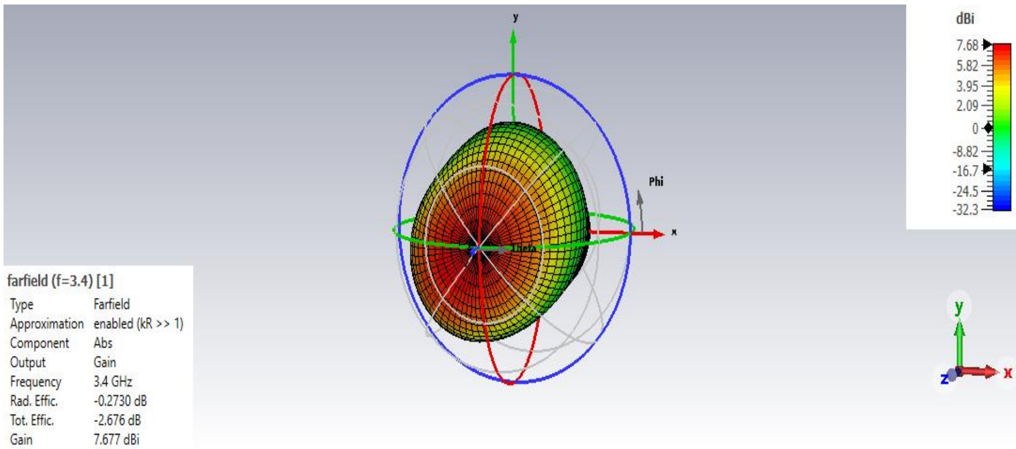


Figure 26 D far-field Gain of 3.4GHz PIFA

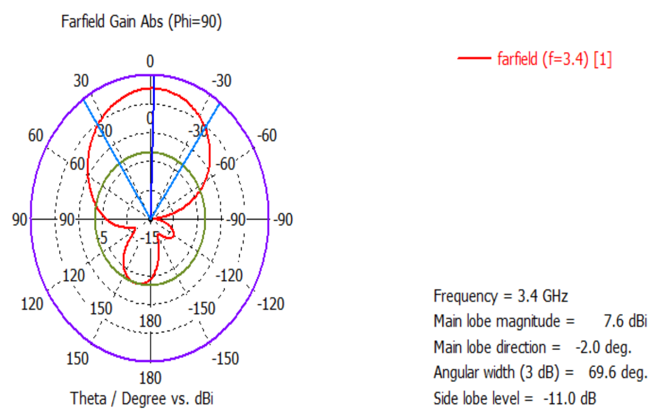


Figure 27 polar plot of 3.4GHz PIFA array antenna

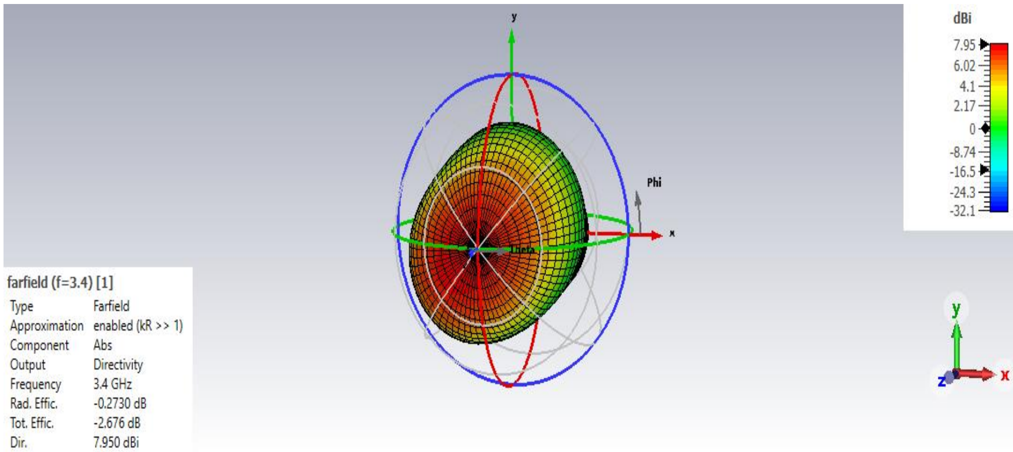


Figure 28 D far-field Directivity of 3.4GHz PIFA

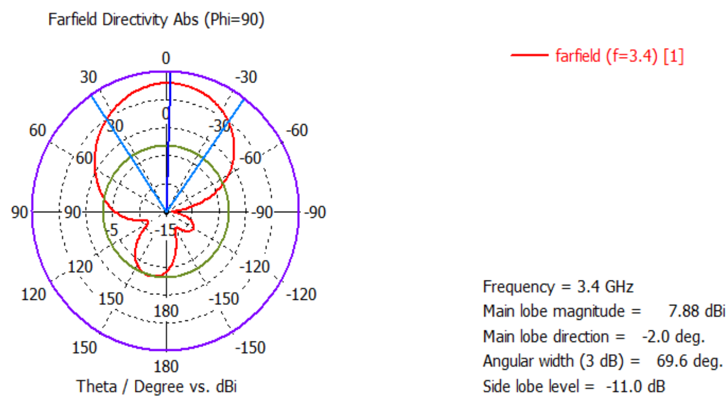


Figure 29 1D polar plot of 3.4GHz PIFA array antenna

4.2.4 Return loss Vs Frequency for 3.6 GHz

Reflection Coefficient vs. Frequency

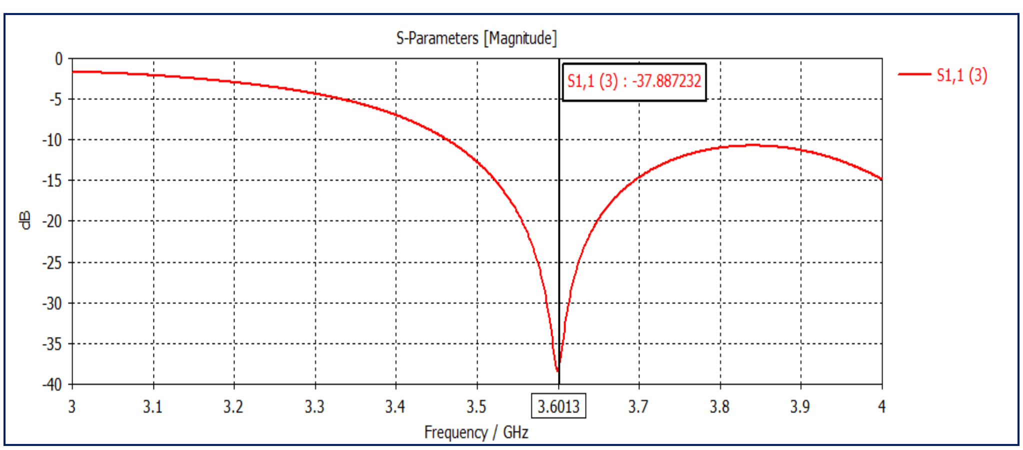


Figure 30 Simulated Return Loss for 3.6 GHz PIFA

A resonance frequency of 3.6GHz has been attained, as seen in the graph in Figure 30. At 3.6GHz, the return loss attainment was calculated to be around -37.88 dB, with a bandwidth for S11 - 10dB of 337MHz (9.82%). It operates between the frequencies of 3.46GHz and 3.79GHz. The antenna's VSWR, Directivity, and Gain have also been displayed.

VSWR

Figure 32 shows that the single band planer IFA's VSWR value at 3.6 GHz is almost similar to 1.024.

VSWR vs. Frequency

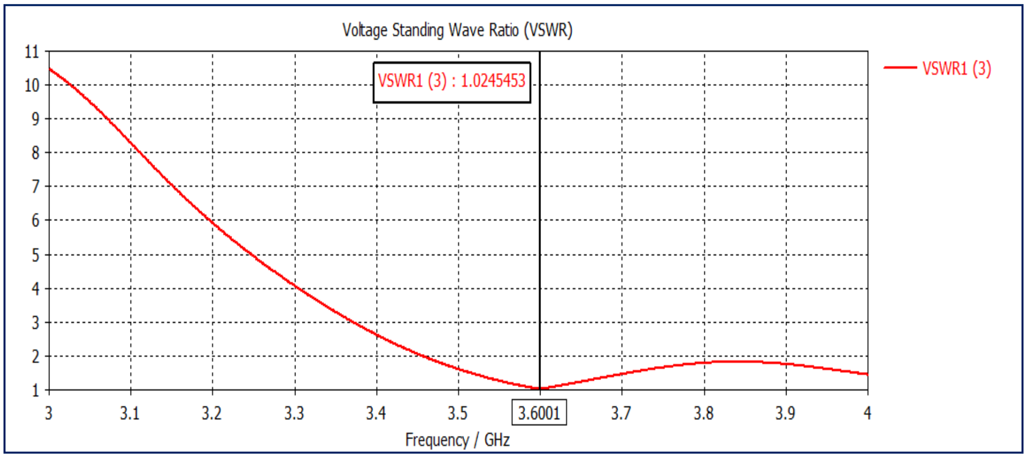


Figure 31 Simulated VSWR for 3.6 GHz PIFA

Radiation Pattern:

Figures 32 to 35 display various views of the single band PIFA antenna's three-dimensional far-field emission pattern. For the 3.6GHz band PIFA antenna, the gain and directivity are found to be 7.947 dBi and 8.125 dBi, respectively.

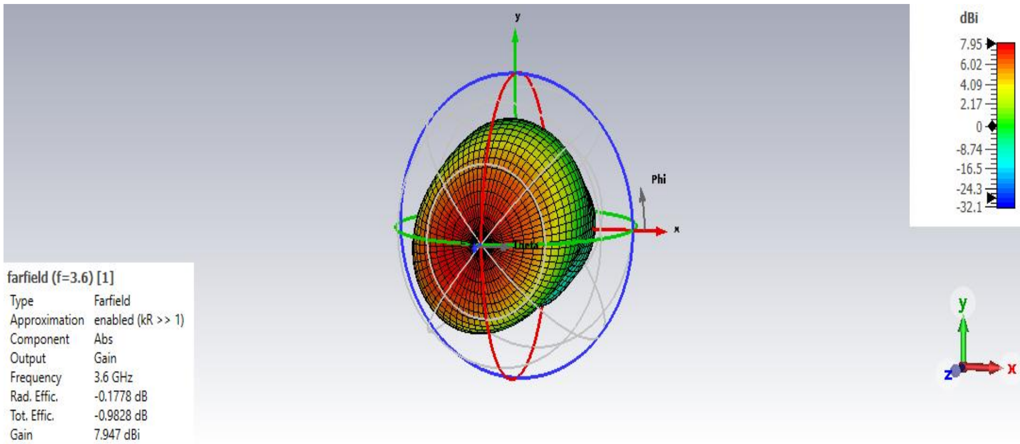


Figure 32 3D far-field Gain of 3.6GHz PIFA

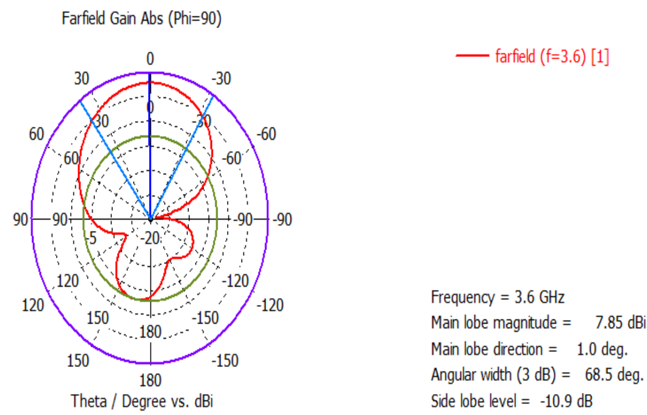


Figure 33 1D polar plot of 3.6GHz PIFA array antenna

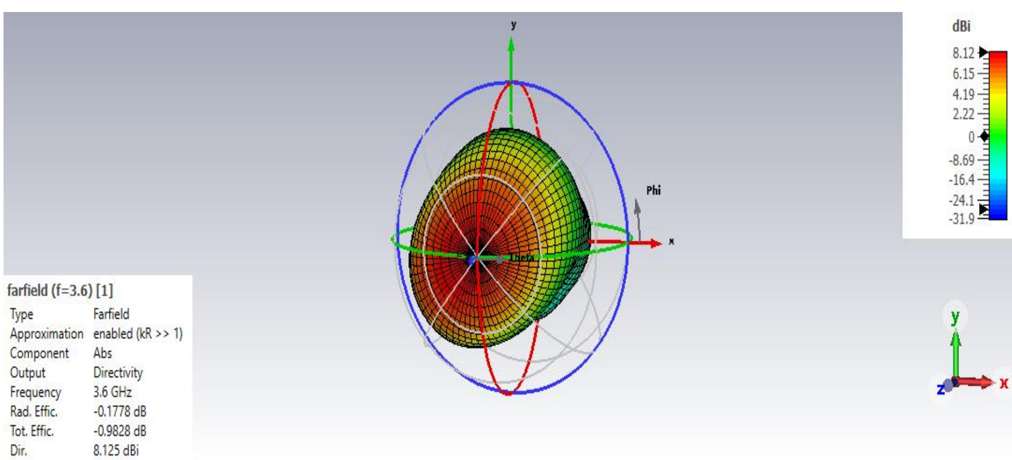


Figure 34 3D far-field Directivity of 3.6GHz PIFA

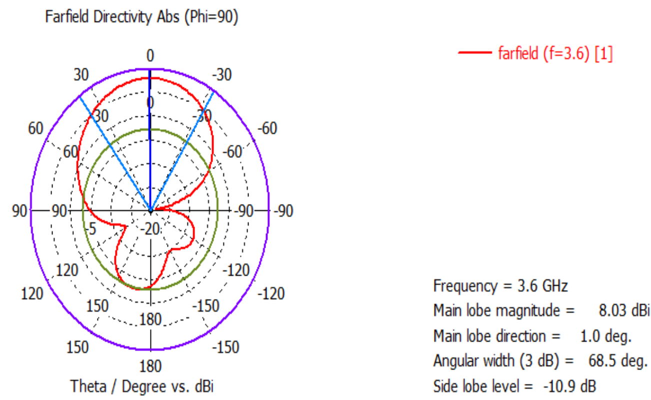


Figure 35 1D polar plot of 3.6GHz PIFA array antenna

4.2.5 Return loss Vs Frequency for 3.8 GHz

Reflection Coefficient vs. Frequency

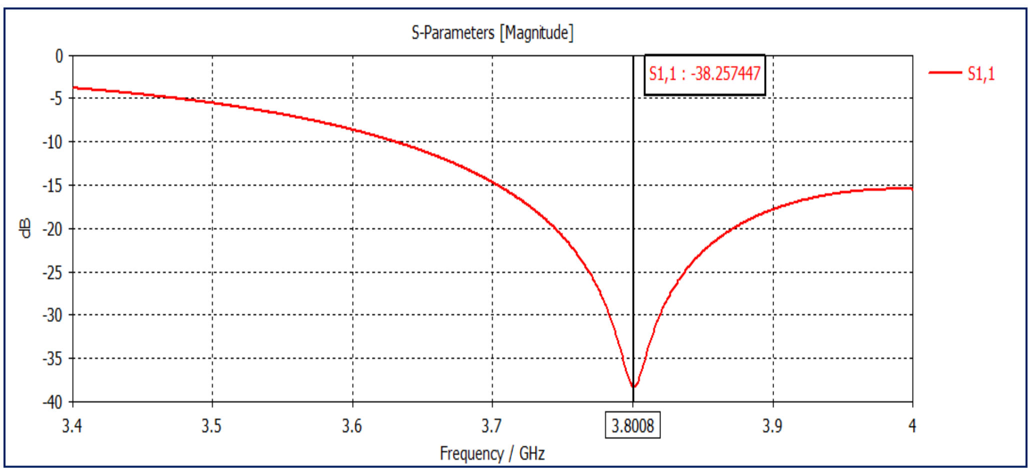


Figure 36 Simulated Return Loss for 3.6 GHz PIFA

A resonance frequency of 3.6GHz has been attained, as seen in the graph in Figure 36. With a bandwidth for S11 - 10dB of 570MHz (14.57%), the return loss attain was estimated to be -38.25 dB at 3.8GHz. It operates between 3.63GHz and 4.2GHz in frequency. The antenna's VSWR, Directivity, and Gain have also been displayed.

VSWR

Figure 37 shows that the single band planer IFA's VSWR value at 3.8 GHz is almost similar to 1.024.

VSWR vs. Frequency

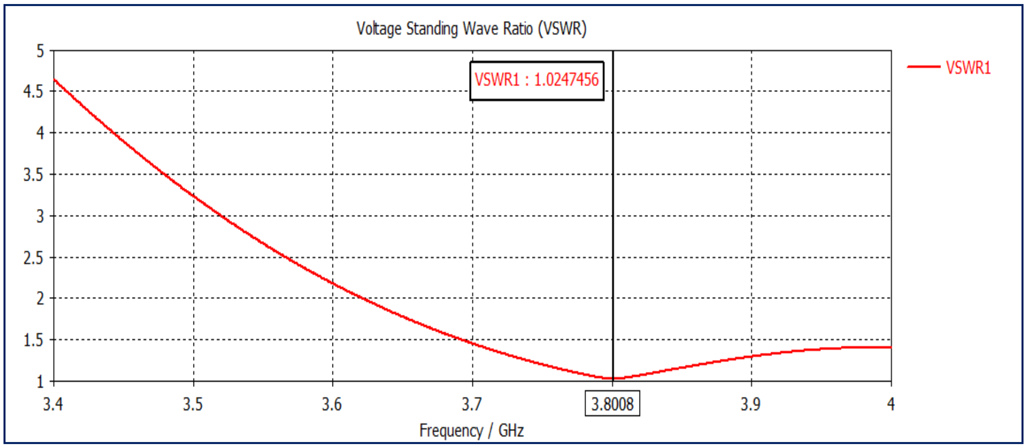


Figure 37 Simulated VSWR for 3.8 GHz PIFA

Radiation Pattern:

Figures 38 to 41 display various views of the single band PIFA antenna's three-dimensional far-field emission pattern. For the 3.6GHz band PIFA antenna, the gain and directivity are found to be 8.073 dBi and 5.28 dBi, respectively.

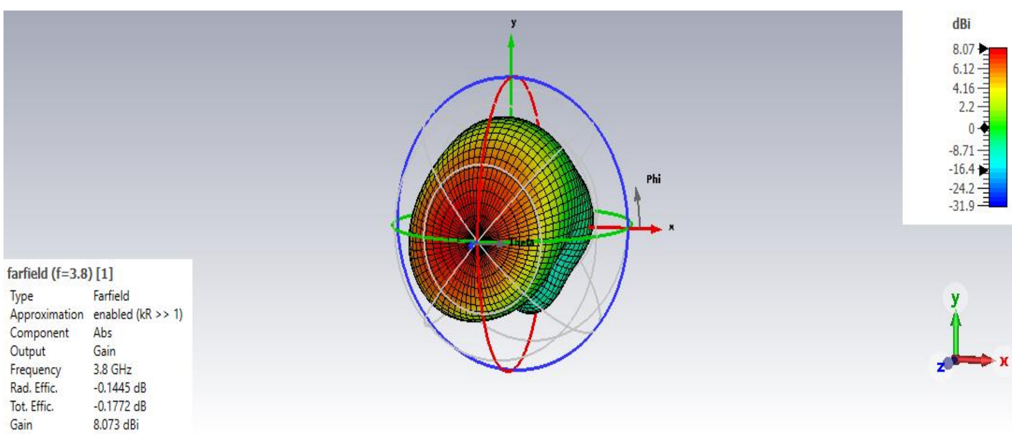


Figure 38 3D far-field Gain of 3.8GHz PIFA

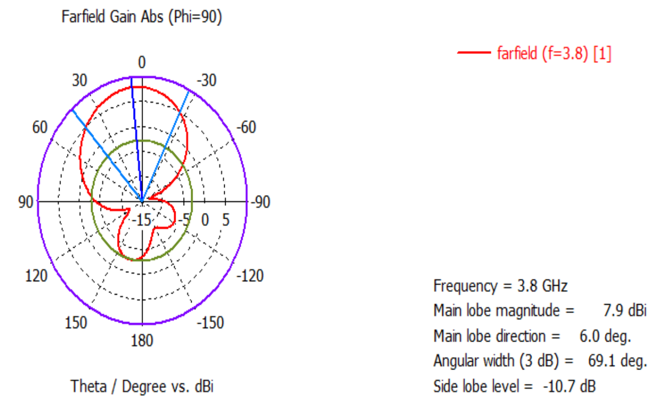


Figure 39 1D polar plot of 3.8GHz PIFA array antenna

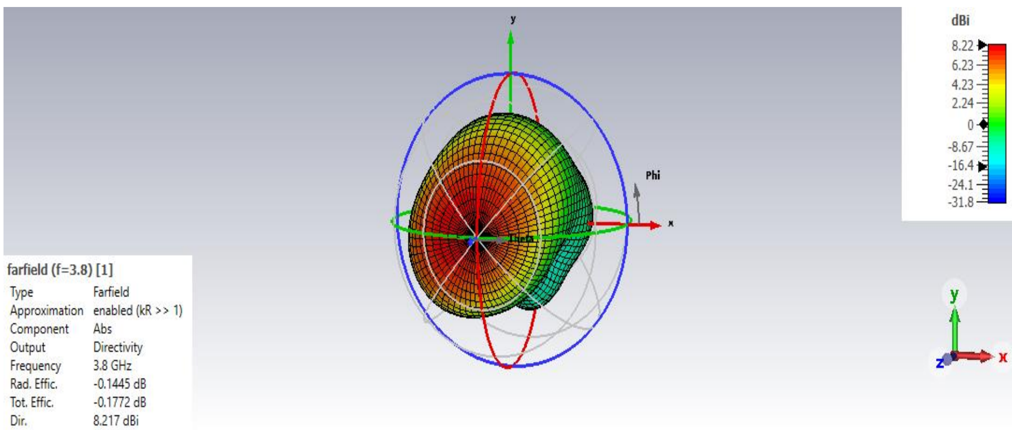


Figure 40 3-D far-field Directivity of 3.8GHz PIFA

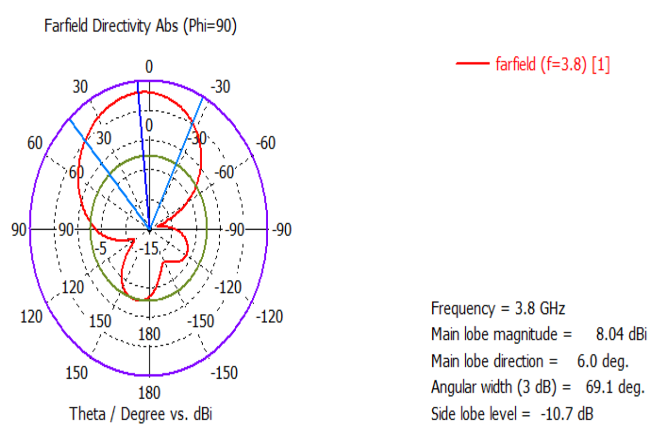


Figure 41 1D polar plot of 3.8GHz PIFA array antenna

4.3 Multiband PIFA

The addition of slots has allowed the antenna to resonate at multiple frequencies, enabling it to operate across a broader frequency range than a single-band antenna to resonate at multiple frequencies, enabling it to operate across a broader frequency range than a single-band antenna. This will be particularly useful in applications where the available frequency spectrum is limited or where the antenna needs to support multiple wireless standards. Overall, the design of the slots has proven to be an effective technique for creating a versatile and efficient multiband antenna system, the microwave multi band PIFA antenna is shown below.

Return loss Vs Frequency for micro wave multiband antenna by adding the first slot

Reflection Coefficient vs. Frequency

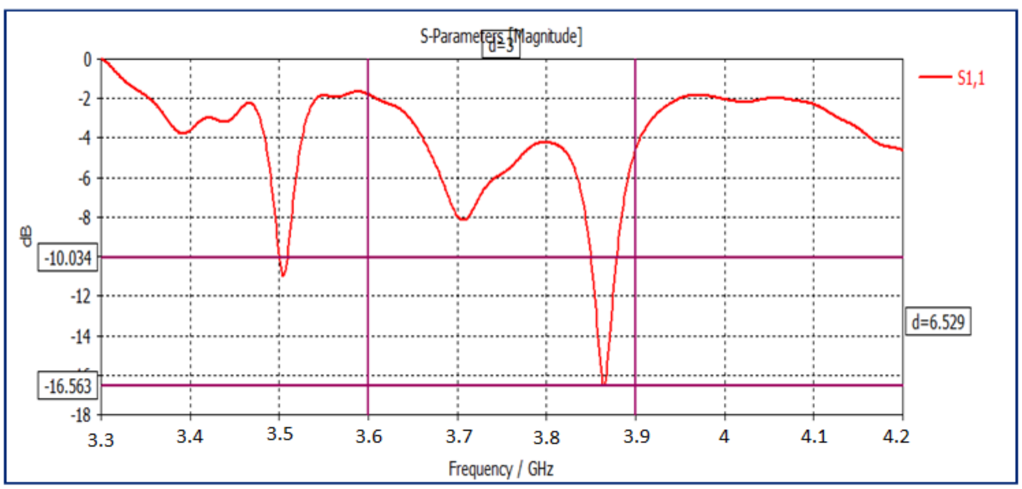


Figure 42 Simulated Return Loss one slot PIFA antenna

Return loss Vs Frequency for micro wave multiband antenna by adding three slots

Reflection Coefficient vs. Frequency

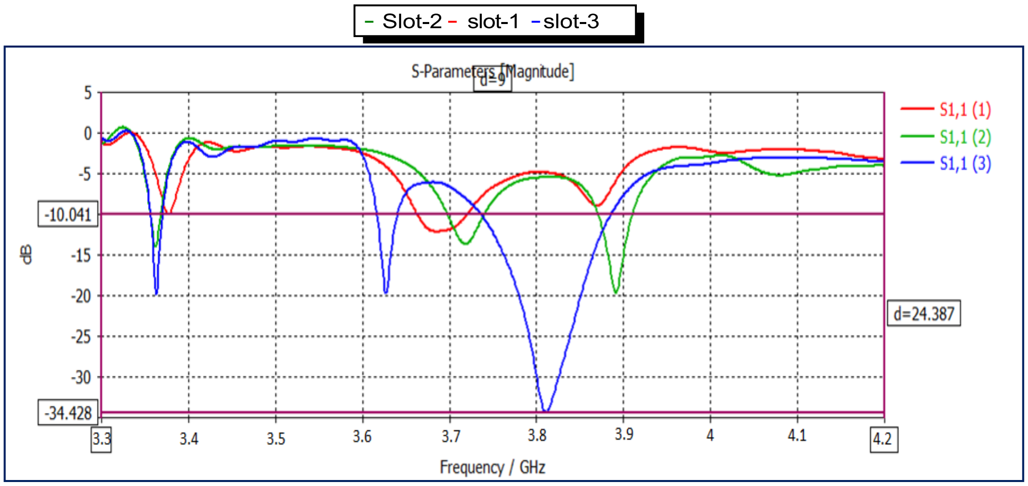


Figure 43 Simulated Return Loss microwave bands

The designed antenna resonates at three frequencies 3.365GHz, 3.63GHz and 3.81GHz. Based on our analysis the output result indicate that the antenna is capable of operating across the three microwave frequency bands.

VSWR

Figure 44 shows that the single band planer IFA's VSWR value at 3.365GHz,3.63GHz and 3.81GHz is almost similar to 1.22,1.25 and 1.102 respectively

VSWR vs. Frequency

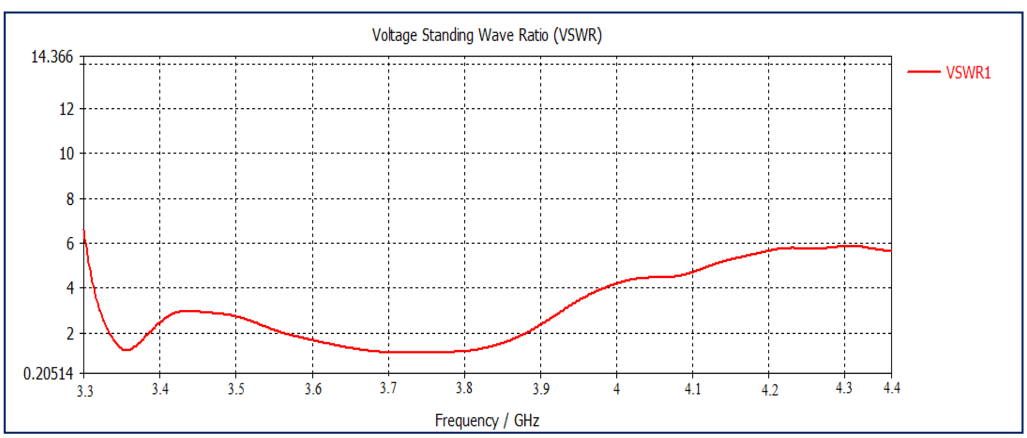


Figure 44 Simulated VSWR microwave bands

4.3.1 Millimeter wave

Return loss Vs Frequency for 31 GHz

Reflection Coefficient vs. Frequency

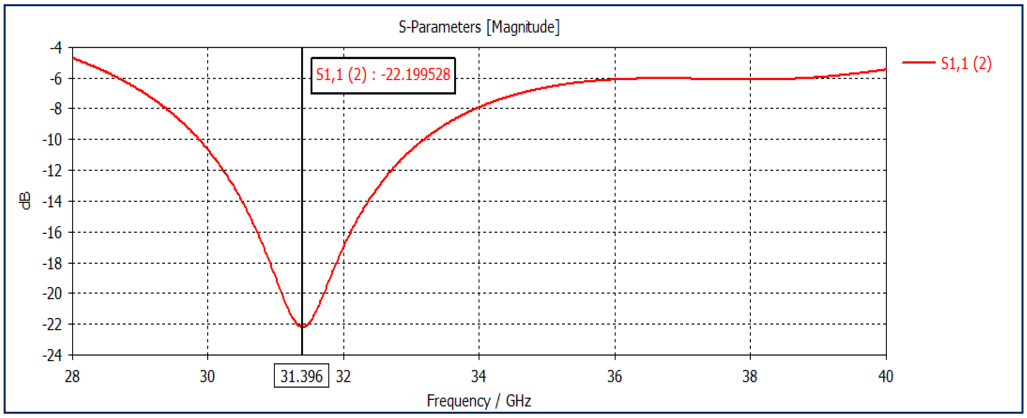


Figure 45 Simulated Return Loss for 31 GHz PIFA

A resonance frequency of 31GHz has been attained, as seen in the graph in Figure 46. With a bandwidth for S11 - 10dB of 3.32 GHz(10.49%), the return loss attain was estimated to be -22.19 dB at 31GHz. It operates between 29.872GHz and 33.19GHz in frequency. The antenna's VSWR, Directivity, and Gain have also been displayed.

VSWR

Figure 46 shows that the single band planer IFA's VSWR value at 31 GHz is almost similar to 1.16.

VSWR vs. Frequency

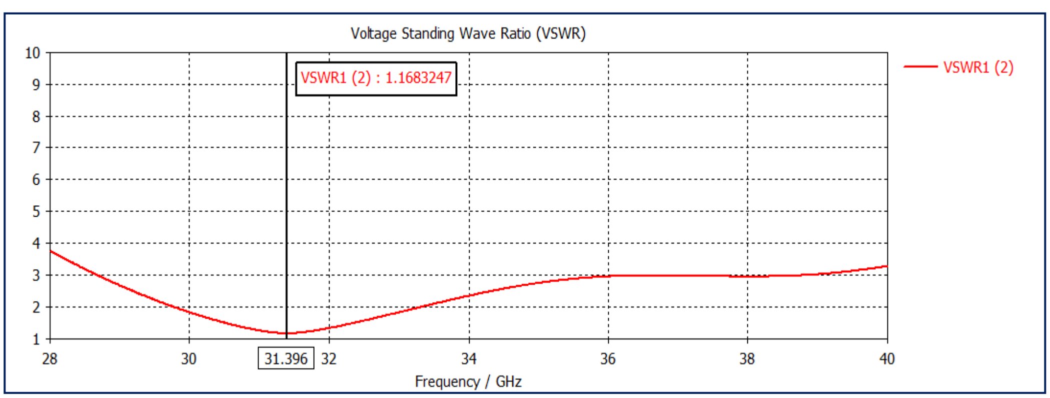


Figure 46 Simulated VSWR for 31 GHz

Return loss Vs Frequency for 33 GHz

A resonance frequency of 33GHz has been attained, as seen in the graph in Figure 47. With a bandwidth for S11 - 10dB of 3.33 GHz is 3.41GHz (10.23%), the return loss attain was estimated to be -24.23 dB at 33GHz. It operates between 31.688GHz and 35.101GHz in frequency.

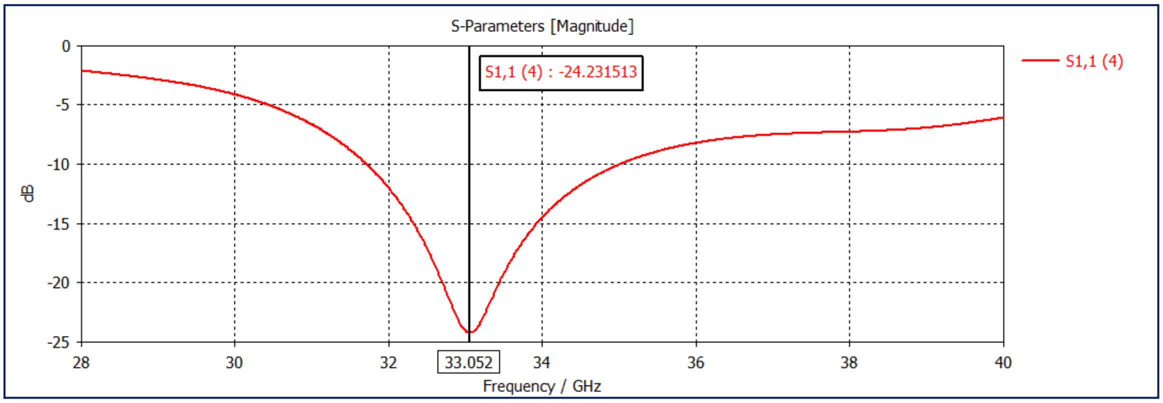


Figure 47 Simulated Return Loss for 33 GHz

A multi band PIFA antenna that supports a microwave and millimeter wave can be designed following the same procedure as the above but varying some parameters. Which can be carefully designed using equations mentioned in chapter 3.

Return loss Vs Frequency for Mid-band and high-band PIFA

A resonance frequency of mid-band and high-band PIFA has been attained, as seen in the graph in Figure 48. With a bandwidth for S11 - 10dB of mid-band is 620MHz (15.86%), the return loss attain was estimated to be -24.23 dB at 33GHz. It operates between 31.688GHz and 35.101GHz in frequency.

Reflection Coefficient vs. Frequency

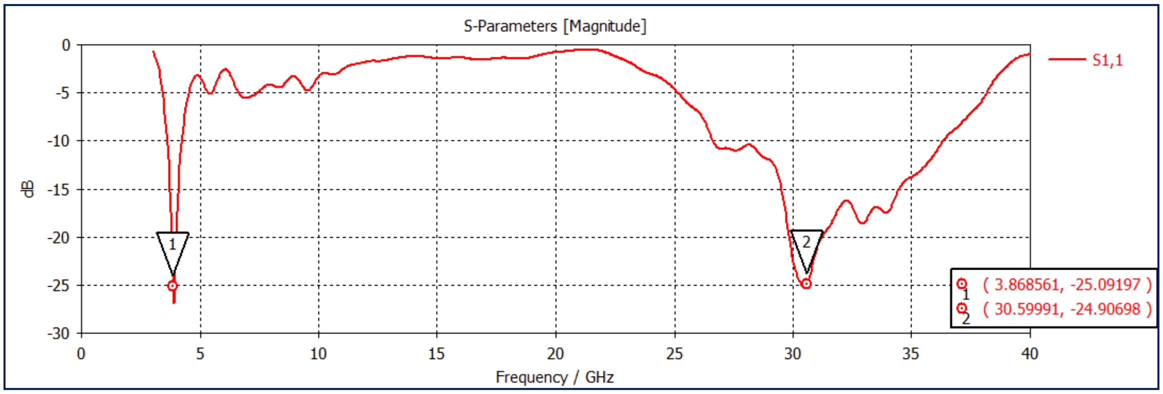


Figure 48 Simulated Return Loss for mid-band and high-band PIFA

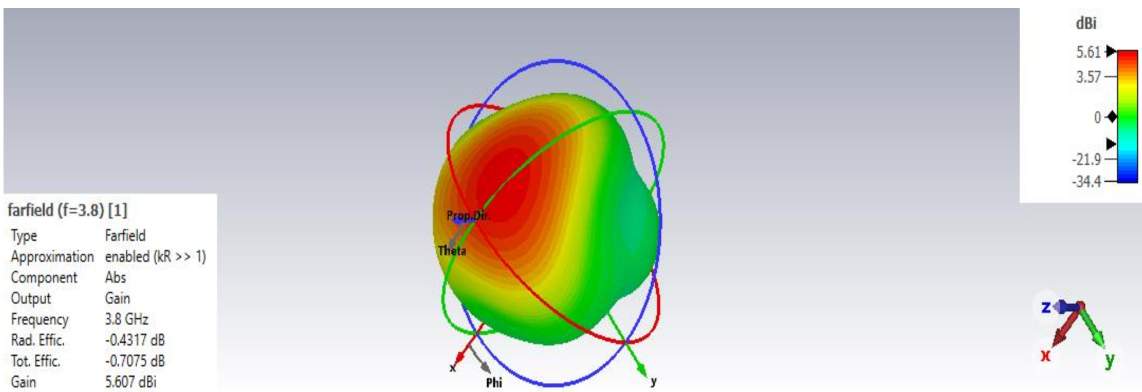


Figure 49 far field Gain for mid-band PIFA

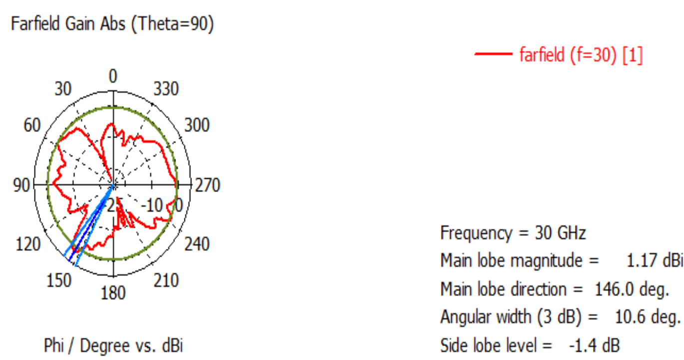


Figure 50 2D far fields Gain for high-band PIFA

Table 6 Comparison of PIFA antenna

References	Frequency (GHz)	Area(mm^2)	S11 parameter	VSWR	Gain	Directivity
(Wikiman, Idowu-Bismarket al. 2019)	27	35	NA	NA	4.6-6.7	NA
Fakih, Diallo etal. 2019)	22	9800	-35	1.23	2.3-2.8	NA
Sabila, Prakosoet al. 2022)	38	152	-30.65	0.51	2.32dBi	2.24dBi
Sabila, Prakosoet al. 2022)	2.4	2250	-41.04	0.52	2.4dBi	NA
Proposed antenna	3.4	1365.34	-53.43	1.005	7.679dBi	7.952dBi
	3.6	1244.5	-37.88	1.024	7.947dBi	7.943dBi
	3.8	1242.375	-38.25	1.024	8.073dBi	8.217dBi
	31	13.25	-22.19	1.168	3.439dBi	7.497dBi
	33	12.625	-24.23	1.21	3.667dBi	8.184dBi

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

In this thesis a planner inverted F antenna has been designed and stimulated using CST Microwave Studio software for mobile communication.

Cell phones that are in hand can have this antenna affixed to the outside. To obtain high data rates for the following generation of mobile communication networks, antennas operating at high-band 5G frequencies are necessary. To compensate for the substantial path loss at mm-wave frequencies, they should have a high gain. Wide coverage is provided for data exchange by the high gain antenna. In this thesis, a slotted antenna with multiband aimed at 5G mobile communications is adopted since the gain acquired through the slotting antenna process is significantly larger than that of single element antenna. For the purpose of analyzing their performances at suggested operating frequencies, the radiation pattern as well as other crucial metrics including gain, return loss, efficiency, directivity, and VSWR have been researched.

5.2 RECOMMENDATION

The following study areas are deserving of attention for conducting additional research. First, future study should include an experimental demonstration of the impact of a person's hands and body on the signal transmission between the transmitter and the receiver. The parameters can also be tuned by the researcher to boost antenna performance even more. Finally, it is advised to provide a workable infrastructure for the antenna systems described above.

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