UNIVERSITE HASSIBA BENBOUALI DE CHLEF
Faculté de Technologie
Département d'Electronique

MEMOIRE DE MASTER

Domaine : SCIENCES ET TECHNOLOGIES
Filière : TÉLÉCOMMUNICATION
Spécialité : SYSTÈME DE TÉLÉCOMMUNICATION

Design and Simulation of 5G Patch Printed Antenna for Mobile Phone Operating in Millimeter-wave Spectrum

Par

HAMMOUNI Amani
KHELOUF Ikram

Encadreur :

M. GUENAD Boumediene

Maître de conférences « A » à UHBC

Co-Encadrant :

M. KOURDI Zakarya Maitre de Recherche Classe A

Centre de Développement des Satellites (CDS)

Agence Spatiale Algérienne (ASAL), Oran.

Chlef, Juin 2025

DEDICATION

A. HAMMOUNI

I would like to sincerely thank my supervisor, Professor Boumediene Guenad, for his attentive guidance, constant support, wise advice, and encouragement. His vast knowledge has been a great source of inspiration.

I express my deepest gratitude to my parents, who have always believed in me and taught me perseverance. A special thought goes to my beloved mother, who brightens my life with her tenderness — she has truly been my pillar.

I also thank my sisters, Ibtissem and Malek, and my brother Younes, for their continuous love and support. My warm thanks go as well to my maternal aunt, who has always been by my side and has never hesitated to offer her help.

A heartfelt thank you to my husband, Abdelghani, for his tireless encouragement and unwavering support. I am profoundly grateful.

I. KHELOUF

May God be praised…
I dedicate this thesis:

To my grandfather, who passed away in 2017 — my first guide since birth. May God welcome him into His eternal Paradise.

To my dear parents, whose unwavering support and heartfelt prayers have always uplifted me.

To my sister Hadjer, my brothers Mohamed and Abdelnour, and my little nephew Mehdi, for their constant love and encouragement.

To my cousins Amina, Fatima Zahra, Fatima, Marwa and her beloved son Abdelkader, Mohamed, and Abdelkader, and to my entire maternal family, the Kheloufs.

To all those who supported me in my academic journey: my childhood friends and dear friends Douaa, Aya, Hind, and Nazi.

To my professors, for their guidance and dedication.

To this land, our beloved Algeria, where I was born.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank Almighty God for guiding me through this journey and granting me the strength, patience, and perseverance to complete this work.

I extend my heartfelt thanks to my supervisor, Professor Boumediene Guenad, for his constant presence, wise advice, and valuable guidance, which greatly contributed to the success of this thesis.

I also wish to thank all the professors and staff of the Faculty of Science and Technology at Hassiba Benbouali University of Chlef for their efforts and support.

I express my sincere gratitude to my family, especially my parents, for their unconditional love, moral strength, and material support throughout the years.

My sincere thanks also go to the members of the jury for the time and effort they dedicated to evaluating this work.

Finally, I would like to thank our colleagues and friends for their help, encouragement, and the moments we shared that made this academic journey memorable.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

Acronym	**Definition**
1G	First Generation (Analog Cellular)
2G	Second Generation (Digital Cellular)
3G	Third Generation (Mobile Broadband)
4G	Fourth Generation (LTE)
5G	Fifth Generation (Next-gen Mobile Network)
AF	Application Function
AMF	Access and Mobility Management Function
AR	Augmented Reality
AUSF	Authentication Server Function
CN	Core Network
CPW	Coplanar Waveguide
CST	Computer Simulation Technology
D2D	Device-to-Device
DN	Data Network
GNB	gNodeB (Next Generation Node B)
GPS	Global Positioning System
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
ITU-R	International Telecommunication Union – Radiocommunication Sector
LTE	Long Term Evolution
MIMO	Multiple Input Multiple Output
NEF	Network Exposure Function
NRF	Network Repository Function
NSSF	Network Slice Selection Function
NSSAAF	Network Slice Specific Authentication and Authorization Function
PCBs	Printed Circuit Boards
PCF	Policy Control Function
Qo	Quality of Observation
RAN	Radio Access Network
RFID	Radio Frequency Identification
SCP	Service Communication Proxy
SIM	Subscriber Identity Module
SMF	Session Management Function
UDM	Unified Data Management
UE	User Equipment
UPF	User Plane Function
VR	Virtual Reality
VSWR	Voltage Standing Wave Ratio
Wi-Fi	Wireless Fidelity

List of Acronyms

GENERAL INTRODUCTION

The advent of fifth-generation (5G) mobile systems marks a transformative jump in wireless communication, promising unprecedented information rates, ultra-low latency, and massive network for emerging applications such as autonomous vehicles, augmented reality, and the Internet of Things (IoT). At the heart of this revolution lies the require for advanced antenna systems capable of operating efficiently at millimeter-wave (mmWave) frequencies (30–300 GHz), where wider bandwidths enable higher data throughput. However, the shift to mmWave frequencies introduces significant challenges, including limited signal propagation, helplessness to blockages, and the need for dense infrastructure deployment.

Printed antennas, especially microstrip patch antennas, have emerged as a cornerstone technology for 5G due to their compact measure, low profile, ease of integration with printed circuit boards (PCBs), and compatibility with mass production. These antennas are pivotal in addressing the requests of 5G, such as beamforming, multi-band operation, and high gain, while following to the stringent size constraints of modern devices. Their design flexibility allows for customization to specific frequency bands, such as 28 GHz and 60 GHz, which are critical for 5G's improved mobile broadband (eMBB) and ultra-reliable low-latency communication (URLLC) use cases.

This professional project investigates the design, simulation, and optimization of printed antennas for 5G mmWave applications. Through a precise approach, we examine different antenna geometries rectangular, circular, and triangular analyzing their execution measurements, including reflection coefficient (S_{11}), voltage standing wave ratio (VSWR), gain, directivity, and radiation efficiency. Using CST Microwave Studio, a leading electromagnetic simulation device, we demonstrate these antennas to evaluate their suitability for 5G systems. The study also dives into parametric optimizations, substrate material choice, and feeding techniques to improve bandwidth and efficiency.

By addressing the technical challenges and leveraging the advantages of printed antennas, this project points to contribute to the development of high-performance, cost-effective solutions for 5G infrastructure and gadgets, paving the way for the next generation of wireless communication.

CHAPTER 1

INTRODUCTION TO 5G AND PRINTED ANTENNAS FOR MILLIMETER WAVES

5G technology delivers ultra-fast speeds (20 Gbps) and low latency (<1 ms), enabling IoT and advanced applications. Millimeter-wave (mmWave) bands are key to its performance, requiring efficient printed antennas. This chapter examines their design and role in modern communication systems.

1 Introduction

The fifth era of portable systems, commonly alluded to as 5G, marks a transformative step in remote communication innovations. Planned to succeed its forerunners, 5G offers essentially higher information rates—up to 20 Gbps—and ultra-low idleness, coming to underneath 1 millisecond. These capabilities clear the way for advanced applications such as autonomous vehicles, virtual and expanded reality, and telemedicine. Besides, 5G is built to back the enormous extension of the Web of Things (IoT), advertising a thick and dependable network structure. This chapter gives an diagram of 5G innovation and the part of printed recieving wires, particularly inside the millimeter-wave recurrence groups, which are basic to meet the execution requests of cutting edge communication frameworks.

2 History and Evolution of Mobile Networks From 1G to 5G

Advances in mobile communications have played a key role in the digitisation of the world over the last 30 years. Mobile technologies of all generations introduce new applications and technological advances, while simultaneously improving on the capabilities of their predecessors. The commercialisation of mobile phone networks generally follows three main stages: Definition,Standardization and implementation, Deployment and usage .

At the definition level, innovations in research institutions and industry leaders are coordinated with national regulatory bodies within the Telecommunication Union Radio Sector (ITU-R) to create framework conditions and define scenarios for the use of radio technology in mobile communications. Once the ITU-R defines the requirements for the radio interface, industry players and standardisation organisations work together to develop technical standards that guide the implementation of mobile technology. Once the required systems and solutions have been developed, create them in a variety of commercial applications to ensure compliance with strict regulatory frameworks for highly regulated types of telecoms sector. 2G introduced a digital system that included text messages. 3G brought broadband mobile data access. G expanded multimedia services in all digital industries. Today's 5G offering will dramatically increase the number of connected devices, improving functionality for consumers and businesses.[1]

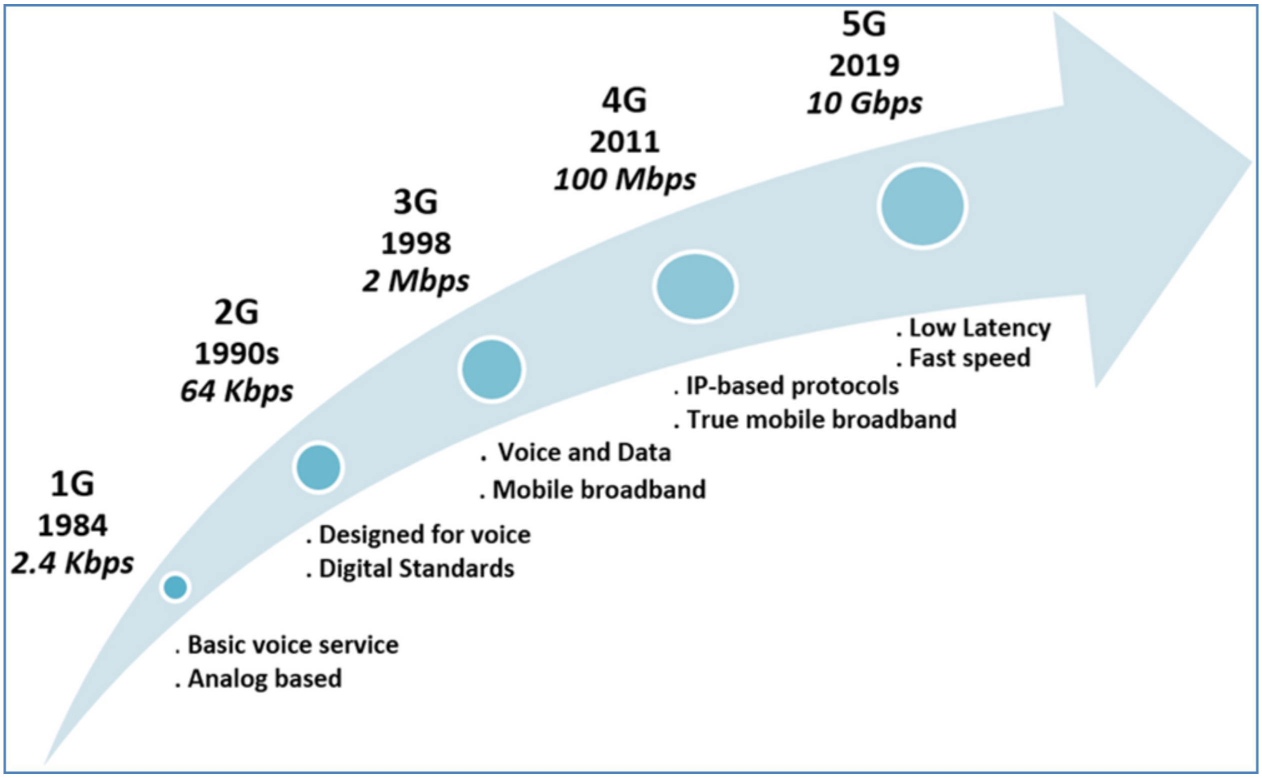


Figure 1.1: The Evolution of Mobile Communications: From 1G to 5G

3 Definition of 5G and its Requirements

What is 5G?

Fifth generation (5G) mobile communications networks must provide exceptional adaptability and exchange in a variety of applications, even in complex scenarios with diverse applications (QO). 5G supports both device-to-US and device-to-device (UE-to-nu) communication, demonstrating expansion beyond traditional wireless technology and includes federated network architectures.[2]

4 5G Mobile Network Architecture

The 5G network consists of three main layers:[3][4]

- **User Equipment (UE)**:A smartphone, or a broad range of applications for the Internet of Things (IoT), smart cities, and industrial applications.

- **Radio Access Network (RAN)**: Antennas or base stations that transmit signals from the user to the core network and vice versa.
- **Core Network (CN)**: The core network contains distributed virtual units, as follows:

  Access and Mobility Management Function (AMF): The AMF defines a unique gateway for communication with the user device. The user device determines the service functions it requires. **Session Management Function (SMF)**: Manages the various user sessions and controls the flow of data. **User Plane Function (UPF)**: Transports data from the IP address (user plane) to the user device and the external network. **Authentication Server Function (AUSF)**: Allows the authentication server to authenticate the user device.

  Unified Data Management (UDM): Stores and manages user data.

  Network Slice Selection Function (NSSF):Determines the type of slice the user will use.

  Network Discovery Function (NEF):Allows external applications to communicate with the network in a secure manner.

  Network Registry Function (NRF):Registers all units on the network and lets them find each other

  Policy Control Function (PCF): Determines what permissions a user has (in terms of speed and limitations).

  Application Function (AF): Serves specific applications that intervene in network policies.

  Network Slice-Specific Authentication and Authorization Function(NSSAAF): Verifies that the user is authorized to use the requested SIM card.

  Service Communications Agent (SCP): Regulates communication between all functions (like a distributor).

  Data Network(DN): The Internet or any other network.

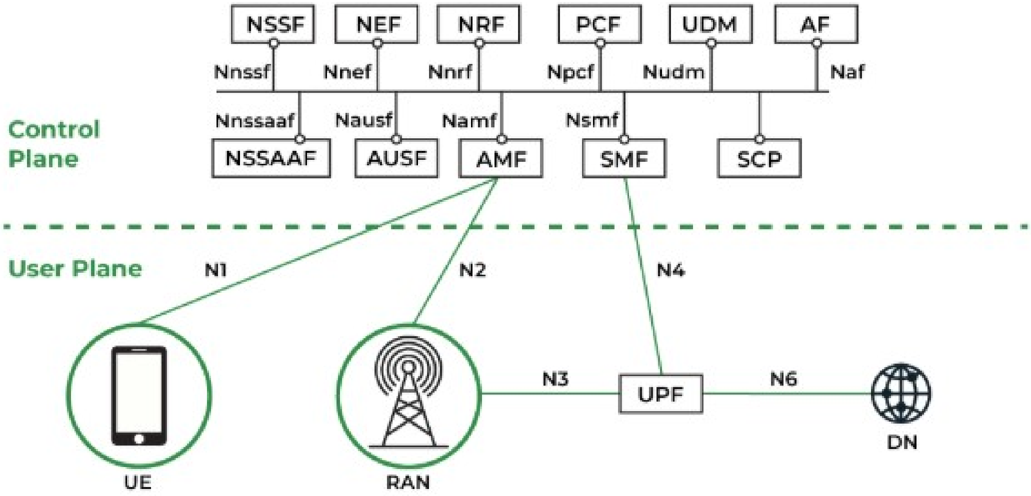


Figure 1.2: 5G Network Architecture: RAN, Core, and Internet Connectivity [5]

5 Challenges and Technical Requirements of 5G

Telecommunications companies and developers face challenges and difficulties in deploying 5G networks, in addition to their availability and operational efficiency requirements.

5.1 Challenges Associated With Deploying 5G Network

- **Coverage**: 5G systems require an awfully thick framework, with the expansion of little cells, which are especially valuable in thickly populated ranges. Due to the constrained run of millimeter wave frequencies for 5G systems, the require for little cells and boomforming innovation is expanding. Physical hindrances, such as trees and buildings, moreover posture establishment challenges that hinder flag engendering.[6]
- **Signal Delay**:5G innovation must meet desires of high-speed media clients, such as independent driving and farther surgery.[6][7]
- **Cost**:The money related costs related with building up and keeping up the establishment required for 5G utilization put critical money related weight on advantage providers.[6]

5.2 Essential Elements for a Mobile Network with Staying Power

- **Spectrum Utilization**: Spectrum must be managed efficiently. The lower the frequency band, the better the coverage (below 6 GHz). On the other hand, higher frequency bands offer faster data rates but require higher antenna density.[8][9]
- **Reliability**: Aim for service availability of 99 point 9 percent to allow the users to have almost constant access to the functions of the system.[8]
- **Low latency**:5G aims for an ideal latency of under 1 ms to accommodate for more de-manding technologies like self-driving cars.[8]
- **Support for a large number of devices in the context of the Internet of Things**

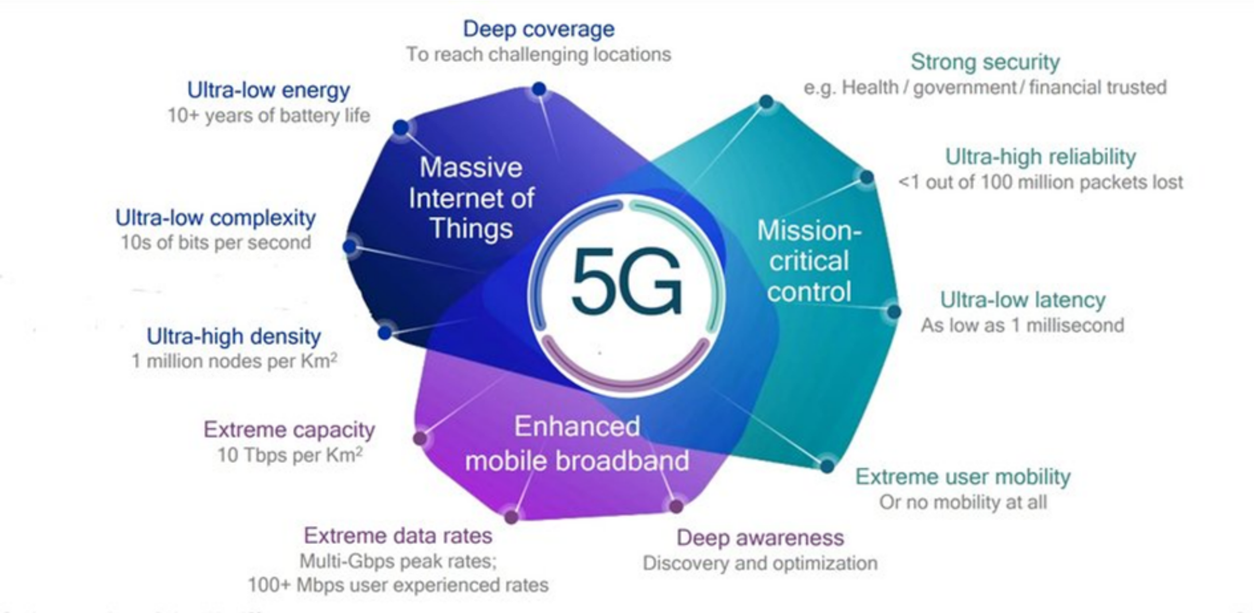


Figure 1.3: Key Challenges in 5G Deployment

6 Emerging Technologies for 5G

Adjustments like the ones mentioned above also require the addition of new technologies that focus on improving the overall performance, capacity, and even greater efficiency in the deployment of networks. Below is a summary of the primary technologies such as millimeter-waves, small cells, massive MIMO, full duplex and beamforming, which focus on enhancing the performance of 5G networks.

6.1 Key Technologies

- **Millimeter Waves (mmWave)**:A frequency range from 30 GHz to 300 GHz is referred to as millimeter waves. This range allows deep subminiature radio frequency integrated circuits to be fabricated that paves the way for high bandwidth data transfer. As a result, speeds of more than 1 Gbps and coming close to 10 Gbps can be achieved under the right conditions. The number of simultaneous connections that can be made on mmWave frequencies is substantial, making it vital for mobile broadband and IoT use cases. mmWave signals are, nevertheless, incapable of penetrating obstacles and have a shorter range, which opens the doors for creativity to use small cells as one of the innovative solutions to boost coverage and performance within the network .[7]

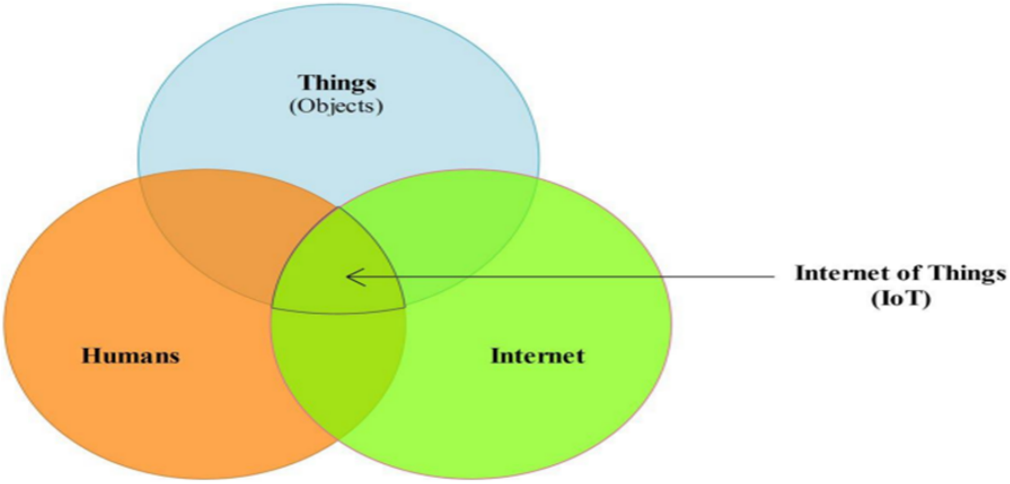


Figure 1.4: The relationship between Internet, Things and Humans.

- **Small Cells**: Soft-powered radio access nodes, also known as further nodes, are vital for increasing the density and capacity of the network. They are essential for spectral efficiency in metropolitan areas as they enable reuse of the same frequency more times than before [2] . The design of small cells is important in order to balance the data load and to provide constant coverage for a large number of users.[7]

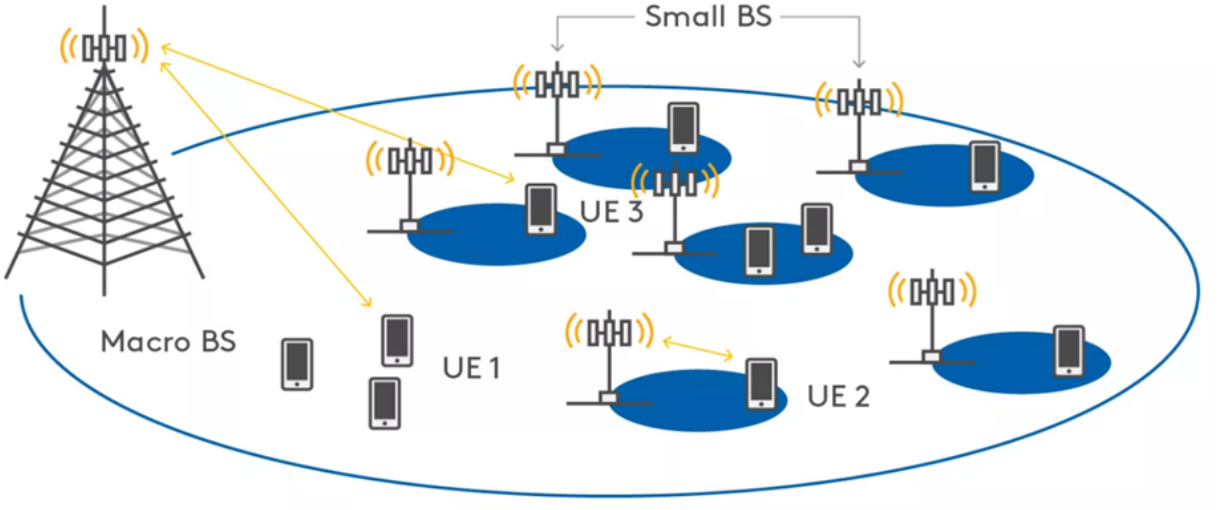


Figure 1.5: Small cells

- **Massive MIMO (Multiple Input, Multiple Output)**: Provide large scale antenna technology that handles multiple user connections from multiple base stations at the same time. their use has great potential to raise significantly the capacity and efficiency of the network thanks to spatial multiplexing, which gives the ability to transmit several data streams at once . Massive MIMO is effective at mid-band frequencies (Sub-6 GHz), which pair well with mmWave because they have good coverage and can easily be used on longer distances.[8]

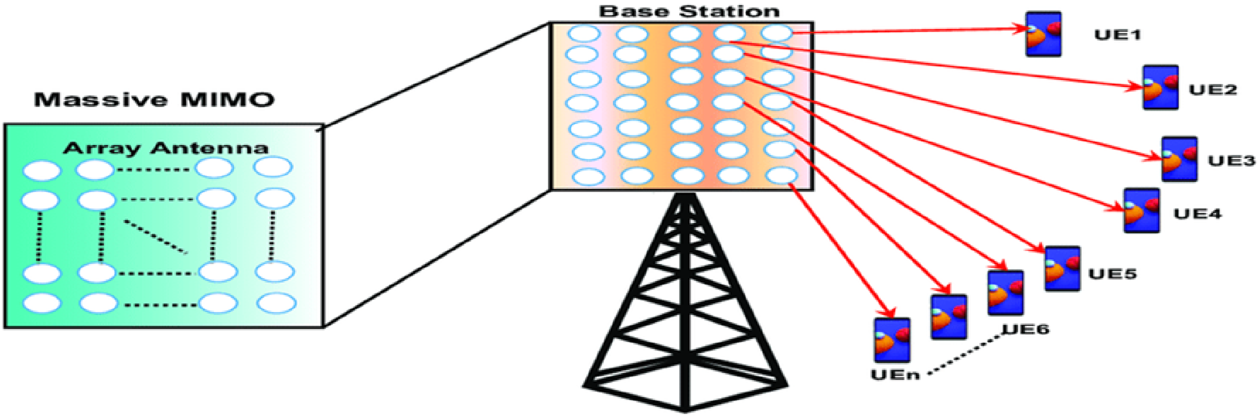


Figure 1.6: Massive MIMO.

- **Full Duplex**:With full duplex, data can be received and sent at the same frequency channel simultaneously. This increases the capacity of wireless communication systems to double in comparson to systems using half-duplex, which transmit or receive one at a time. In situations where low latency and high throughput are required, this type of duplex technology proves to be very useful.[9]

- **Beamforming**: a user specific radio signal can now be sent using beamforming, unlike before when signals were sent in all direction. With the use of this targeted method, the quality of the signal is improved and the interference is reduced, leading to an improvement in the strength of the network. More advanced techniques in the beamforming are needed to fully utilize the power of mmWave communications so as to achieve better coverage and faster data transmission.[10]

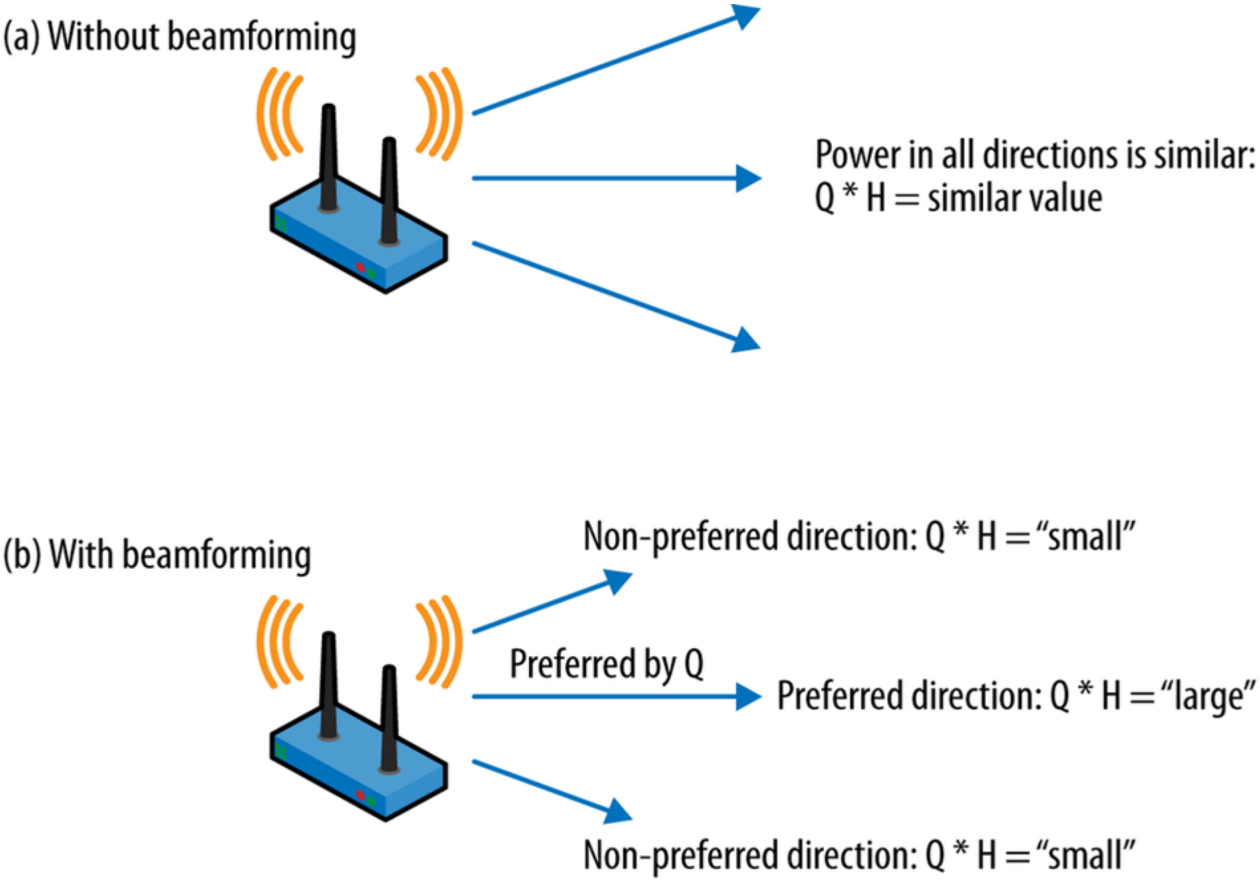


Figure 1.7: Beamforming Effect on Signal Distribution

6.2 The Significance of Millimeter Waves Within the Scope of 5G

One of the major benefits of the millimeter wave is that it broadens the available spectrum,which is vital for the growing connected devices. In addition, mmWave makes possible augmented and virtual reality (AR, VR) and ultra-high definition video streaming because of its high capacity and low latency characteristics. However, such solutions incur new challenges, such as signal loss, the requirement for line-of-sight access, and antennae arrays alongside small cells to mitigate such issues.[11]

6.3 Functions of Small Cells in Network Densification

Small cells enable high user density coverage, providing localized coverage in areas of need. The deployment of small cells increases network efficacy by exploiting the available frequencies, thus improving network performance. With continuous urban expansion, the deployment of small cells in existing networks will be required to satisfy the level of demand for mobile data services.[12]

6.4 Opportunities Presented by Extensive MIMO

Massive MIMO makes 5G networks outperform others in yielding increased benefits with respect to capacity and efficiency. With MIMO, more antennas can be deployed simultaneously at the transmitter and receiver which enhances the speed and signal strength while reducing the load on the network infrastructure, all of which contributes to higher user satisfaction and lower latency. This can be very helpful in a dense environment where users are always online and regular MIMO systems are insufficient.[13][14]

7 5G Antennas and Printed Antennas

MIMO antennas and phased array antennas are essential for efficient and efficient operations of 5G systems, thus, the progress of 5G technology is highly dependent on the advancement of those antennas and the design methodologies as well. This part of the report zeroes in on advanced designs of range of antennas: dipole antennas, loop antennas, slot antennas, parabolic reflector antennas, along with active antennas and printed antennas with comments on printed antennas for small-sized transceivers.[3]

7.1 Introduction to Antenna Realization Techniques

This section is focused on the antenna realization techniques and different methods for their design and production in regard to 5G[6]. Most important include:[15]

- **Patch Microstrip Antennas:** Due to its low profile and ease of integration with circuit boards, it is easy to see why this is so widely used. It can also be made to operate at different frequency bands which are needed for 5G.
- **Array Antennas:** With the use of many elements, directivity and gain are improved, which is really important for 5G network beamforming applications.
- **Metamaterials:** There are materials that enable special modification of electromagnetic waves for more effective antenna radiation and miniaturization of the antenna, for example, these materials need to be improved for more effective antennas.

7.2 Types of Antennas for 5G Networks

To be able to meet the necessities of higher data rate, coverage, and communication, there is a need for different types of antennas as the 5G technology evolves. Following is a comprehensive guide on the most popular types of antennas for 5G networks.[10]

Dipole Antennas

Dipole receiving wires are habitually utilized in radio communications and have a clear plan. Two conducting components orchestrated in a straight line make up a dipole receiving wire, which is as a rule made to operate at half-wavelength resonators of the desired recurrence. Typical examples are the half-wave dipoles which alternately are fed current and so efficiently radiate electromagnetic waves. Other types include full-wave dipoles, folded dipoles, inverted V-dipoles, and collinear dipole arrays. The latter four types serve different applications including broadcasting, telecommunications, radio astronomy, and short-range wireless communication. Dipole antennas are simple, efficient, multi-oriented, and sensitive which allow their widespread use. dipole antennas, however, are not without limitations pertaining to size and environmental sensitivity. Differently, dipole antennas are effective and practical for communications and due to their many advantages, they serve a fundamental role in modern communication systems.[16][17]

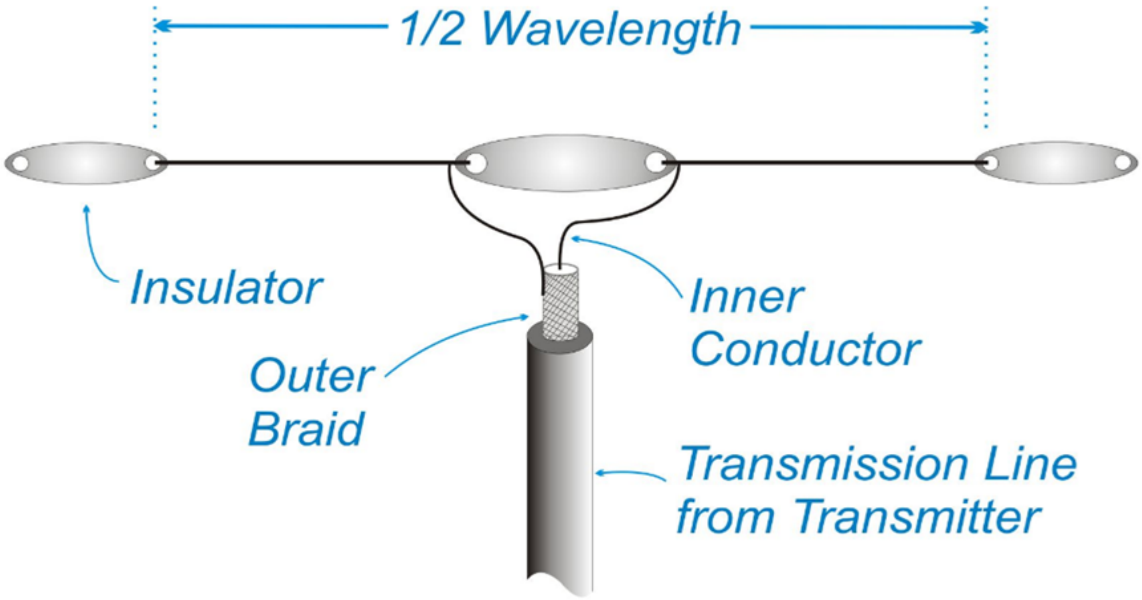


Figure 1.8: Dipole Antenna

Loop Antennas

Loop antennas are a sort of radio radio wire that comprises of a circle or coil of conductive fabric and works on the elemental guideline of electromagnetic acceptance. There are two sorts of circle radio wires. Little circle radio wires are compact and utilized basically for flag gathering since of their tall radiation resistance, in spite of the fact that their moo effectiveness rate causes them to be to a great extent wasteful. Large loop antennas have a circumference that is approximately equal to their wavelength, so they are better suited for more transmitting and receiving signals at greater distances. The operation depends on the alternating current that flow through the loop, as it produces magnetic fields which induce voltage in the antenna loop, allowing transmission of signals effectively. Due to their compact size, directional nature, and superb noise rejection features, loop antennas are used for radio communications, direction finding, field probing, and wireless sensors. Unfortunately, small loops are not very efficient for transmission, unlike larger designs. All in all, loop antennas are an important aspect of modern communication systems, providing critical size, efficiency, and versatility.[17]

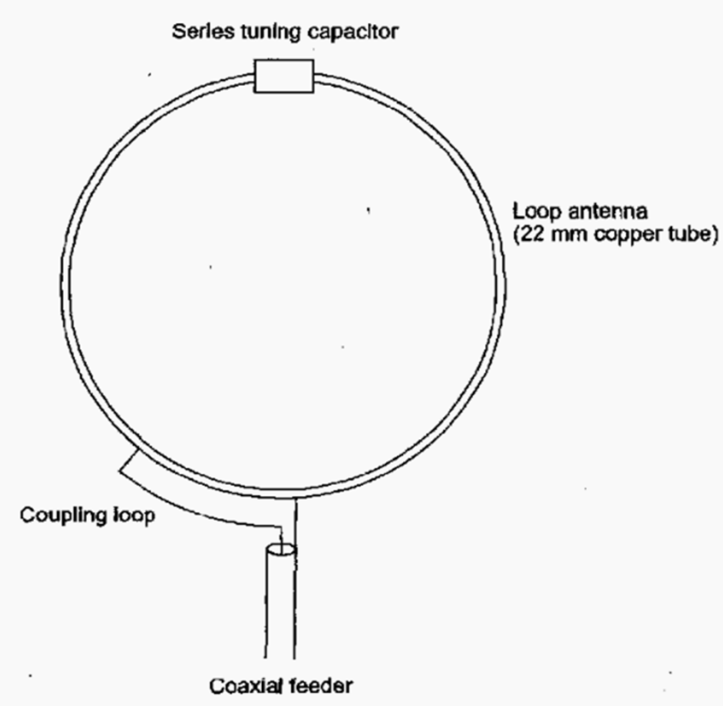


Figure 1.9: loop antenna

Slot Antennas

Slot antennas are antennas with a slot or opening cut into a conductive surface. They work because an electric field across the slot sends out electromagnetic waves. Their design is about half as long as the wavelength of the frequency they should work at, which makes sure they resonate to send signals well. People utilize opening radio wires in radar frameworks remote communication, and broadcasting since they're little, send signals in all headings, and are simple to create. These antennas have great focuses: you'll construct them into things that as of now exist, and they do not fetched much to create. But they moreover have downsides: they do not work well with as numerous frequencies, and they can send signals in one course at a time. All in all, space recieving wires are key in today's communication frameworks. They're valuable and work well in numerous diverse ways.[18]

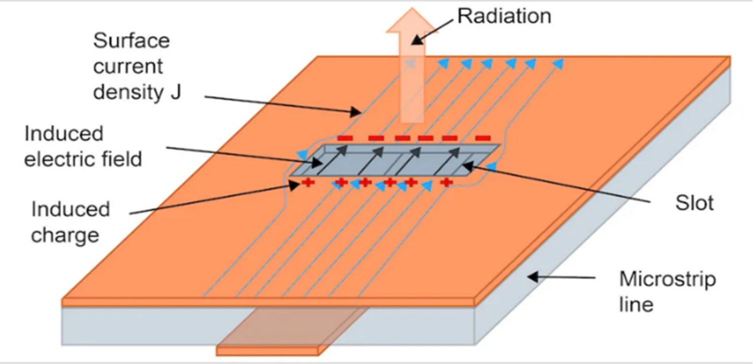


Figure 1.10: Slot Antenna.

Parabolic Reflector Antennas

Dish antennas too called parabolic radio wires, utilize a parabolic-shaped reflector to center and coordinate electromagnetic waves. This gives them tall directivity and pick up. They work by setting a nourish receiving wire at the central point, which sends out waves that bounce off the reflector into a centered pillar. People use these antennas a lot in satellite communications, microwave relay links, radar systems, and radio telescopes[22]. They have some big pluses: they offer major gain, a narrow beamwidth that boosts signal quality, and they work well across many frequencies. But they're not perfect. To get high directivity, you need a bigger antenna. And you have to build them just right to keep that parabolic shape. Even so parabolic reflector antennas play a key role in today's communication systems because they're so good at focusing signals.[13]

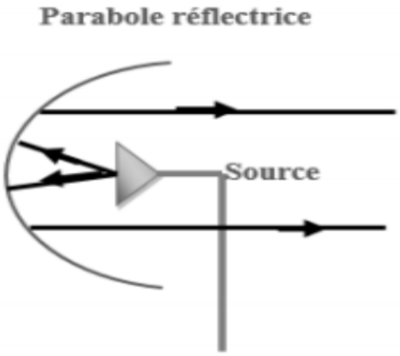


Figure 1.11: Parabolic Reflector Antennas

Printed Antennas

Printed antennas, or microstrip antennas, are level antennas made on printed circuit sheets (PCBs) utilizing photolithographic strategies. They have a metal fix on one PCB side and a ground plane on the other. These antennas send out electromagnetic waves well when rotating current goes through the fix. Individuals utilize them in customer products, cars, wellbeing gadgets, and phone frameworks. Printed receiving wires are little, cheap to form, and simple to plan in numerous ways. But they have a few downsides as well. They work in a little longer range of frequencies and do not send signals as faraway as bigger antennas. Indeed so printed antennas are key in today‘s wireless communication systems since they fit well with other parts and can do many occupations.[13][18]

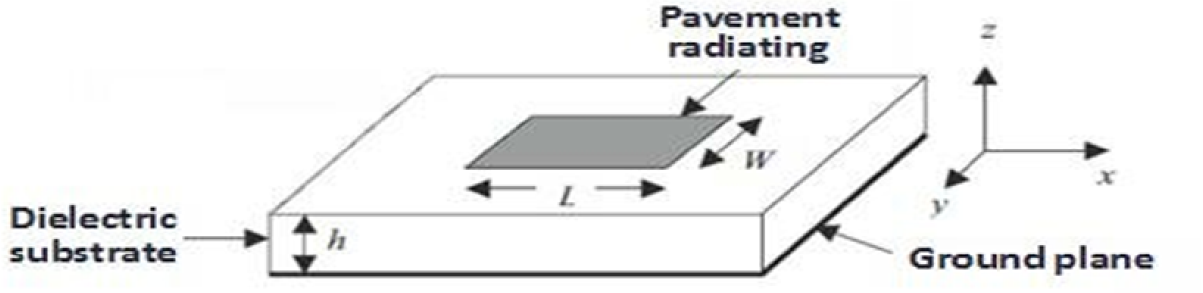


Figure 1.12: Example of a Printed Antenna

7.3 Active Antennas Matter for Spatial Scanning

Active antennas put amplifiers right into the radio wire structure. This makes a contrast in making a difference them get ready signals prevalent. This setup is required to:[12]

- **Beamforming:** Energetic antennas empower energetic pillar controlling, progressing scope and capacity by planning signals toward clients rather than broadcasting consistently.
- **Spatial Diversity:** Utilizing numerous dynamic components permits way better execution in multipath situations common in urban settings.

7.4 Advantages of Printed Antennas for Miniaturized Transceivers

The printed antennas offer some advantages that make them ideal for modern communication systems:[16]

- **Compact Size:**Low configuration of them allows integration into small devices without significant space binding.
- **Production of profit:** Production processes compatible with standard PCB production techniques, reducing production costs.
- **Design Flexibility**: Printed antennas can easily be personalized to meet frequency requirements and specific performance characteristics.

8 Proposed Frequencies for 5G

The consider of recurrence range allotment is vital for the pre -standardization of 5G innovation, because it decides the operational capabilities and productivity of the organize. This diagram talks about the significance of range thinks about, the recurrence groups underneath and over 6 GHz, and the utilize of millimeter waves in portable communication.[9]

8.1 Importance of Spectrum Study for 5G Pre-Standardization

Understanding and analyzing the recurrence range is basic for creating successful 5G measures. The allotment of recurrence groups impacts arrange execution, counting information rates, scope, and capacity. As 5G innovation advances, administrative bodies and industry partners must collaborate to distinguish reasonable recurrence ranges that can suit the expected increment in information activity and network requests. The beginning sending of 5G will basically utilize existing groups that have been utilized by past eras of portable systems, such as those underneath 1 GHz, whereas moreover investigating higher frequencies for future improvements.[8][19]

8.2 Frequency Bands Below and Above 6 GHz

- **Frequency Bands Below 6 GHz**: Frequencies underneath 6 GHz are fundamental for early courses of action of 5G frameworks. Bunches such as 700 MHz and 3.7 GHz are particularly promising for directors due to their capacity to supply wide scope and enter buildings effectively.These lower frequencies are principal for guaranteeing that country and common ranges get agreeable palatable agreeable tasteful Synonyms advantage whereas supporting a colossal number of related contraptions.[11]

- **Frequency Bands Above 6 GHz**: Frequencies over 6 GHz, especially within the millimeter-wave (mmWave) run (30-300 GHz), offer critical transfer speed focal points that empower tall information rates and moo idleness. In any case, mmWave signals have constrained run and are more helpless to constriction from deterrents like buildings and trees. As a result, conveying a thick arrange of little cells prepared with beam-forming innovation will be essential to guarantee solid network in urban situations.[11]

8.3 Use of Millimeter Waves for Mobile Communication

Millimeter waves are indispensably to accomplishing the high-speed capabilities imagined for 5G systems. These frequencies have been utilized in different applications, counting radar frameworks and point-to-point communications, illustrating their viability in transmitting huge sums of information over brief separations. The selection of mmWave innovation in portable communication will encourage progressed applications such as increased reality (AR), virtual reality (VR), and ultra-high-definition video spilling, which require significant transfer speed.[10]

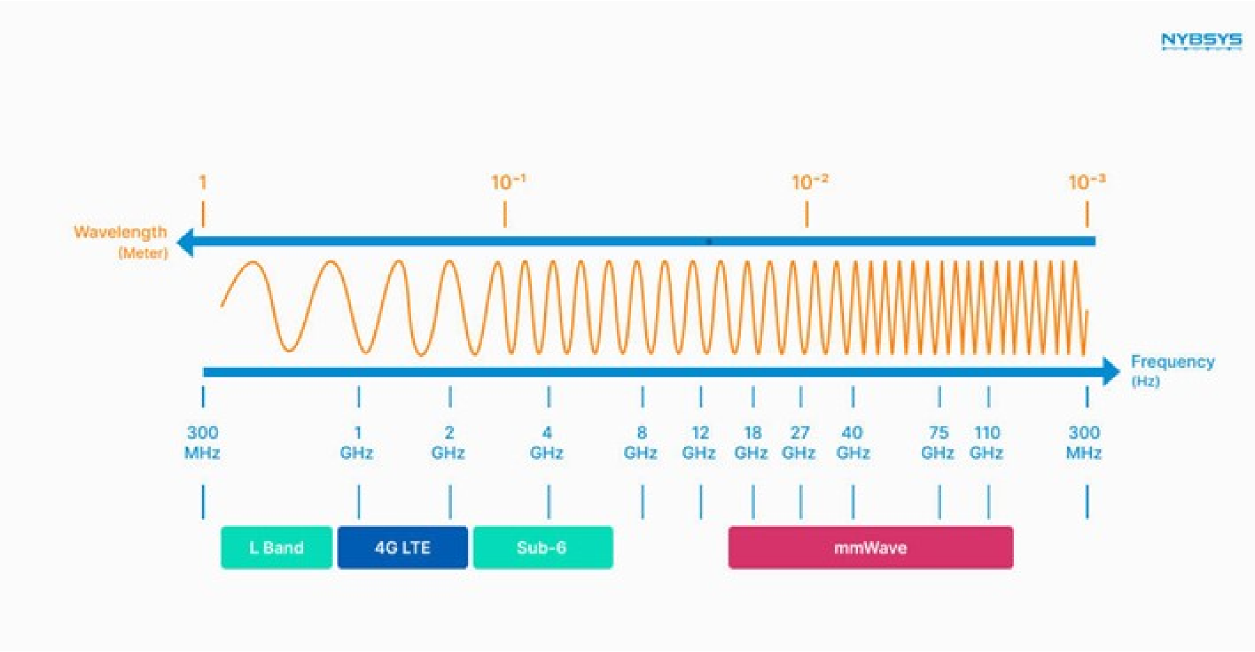


Figure 1.13: 5G Millimeter-Wave Spectrum

9 Conclusion

The evolution of mobile systems has led to the emergence of 5G, a technology designed to upgrade mobile broadband, ultra-reliable low-latency communication and massive connectivity. Its flexible design makes it appropriate for a wide range of applications, despite technical challenges such as spectrum allocation, interference management and infrastructure. Key technologies, such as millimeter wave and advanced printed antennas, are basic to its deployment. Finally, strategic frequency band planning illustrates the transformative potential of 5G on future communications.

CHAPTER 2

DESIGN PRINCIPLES AND STRUCTURE OF PRINTED PATCH ANTENNAS FOR 5G

Printed antennas are lightweight, compact, and easily integrated into devices like phones and satellites. Made from PCB materials, they support multiple polarizations but suffer from narrow bandwidth. Techniques like DGS can improve their performance. Essential for modern wireless communication, they balance versatility and functionality.

1 Introduction

Printed antennas, also known as microstrip antennas, are lightweight devices that are easy to integrate into a variety of electronic devices. They come in several shapes and can be adapted to different polarisations. Despite their reduced bandwidth and low radiation efficiency, they are still widely used in telecommunications. Advanced techniques such as DGS improve their performance. They are essential for wireless networks and satellite communications.

2 Definition of a Patch Antenna (Printed)

A fix antenna, moreover known as a printed antenna, could be a sort of radio wire with a low profile, which can be mounted on a level surface. It comprises of a level rectangular sheet or "fix" of metal, mounted over a bigger sheet of metal called a ground plane. The patch and ground plane are isolated by a dielectric substrate. Fix antennas are broadly utilized in remote communication frameworks due to their compact measure, ease of creation, and capacity to be coordinates with printed circuit sheets (PCBs). They are commonly utilized in applications such as GPS, portable phones, and lackey communication.[15][20]

3 Components of a Patch Antenna

Fix recieving wires, as well known as microstrip getting wires, are transcendent radio communication contraptions due to their fundamental orchestrate and reasonability. Here could be a format of their structure and characteristics:[21]

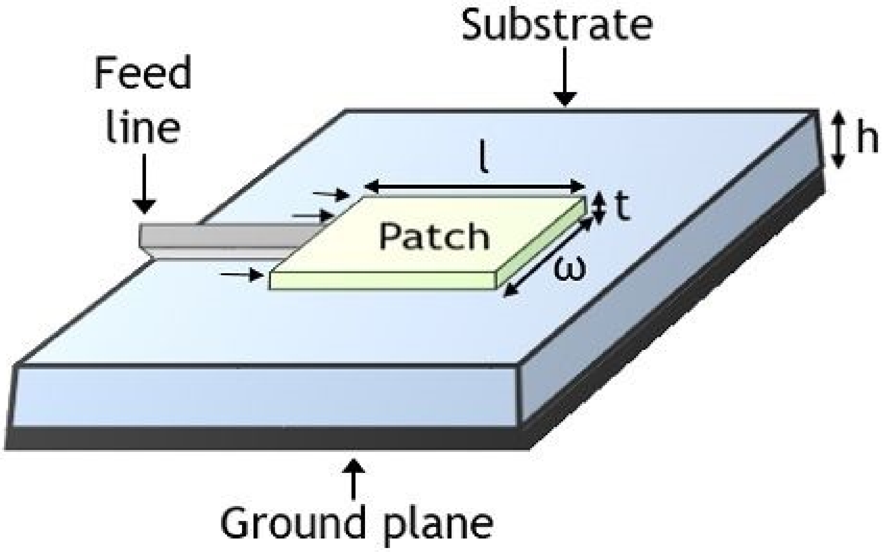


Figure 2.1: Components of a Patch Antenna

3.1 The Ground Plane

The ground plane might be a conductive surface, frequently made of copper, that covers the lower parcel of the substrate. It plays a pivotal part in empowering the upper portion of the receiving wire to emanate successfully. The measurements of the fix are for the most part on the arrange of half the wavelength, and the choice of length depends on the thunderous recurrence of the antenna. Be that as it may, the ground plane cannot be interminable in estimate. In hone, it is regularly outlined to be three or four times the wavelength, which can some of the time result in a critical physical impression. Diminishing the measure of the ground plane can lead to changes within the antenna's properties, such as its radiation design and impedance coordinating, which must be carefully considered amid the plan handle.[21]

3.2 The Dielectric Substrate

The dielectric substrate is made of a protection fabric, regularly with a thickness much littler than the wavelength and a relative permittivity extending between 2.2 and 12. The properties of the substrate straightforwardly impact the execution of the radio wire. It is utilized to upgrade the transmitted control, decrease Joule misfortunes, and progress the antenna's bandwidth. In a few cases, it is best to utilize dielectric substrates with more noteworthy thickness and lower permittivity to realize higher proficiency and a more extensive transfer speed. The choice of substrate fabric and its characteristics are basic in optimizing the antenna's in general execution.[21]

3.3 The Patch: Core Radiating Element of Patch Antennas

Center Transmitting Component of Patch Receiving wires the patch is the most transmitting component of a fix receiving wire, ordinarily made of a lean, level conductor (like copper) and put on a dielectric substrate. Its estimations, particularly the width (W) and length (L), are carefully arranged to resound at a specific repeat, guaranteeing capable radiation. The patch's shape and assess direct affect the antenna's execution, tallying its radiation plan, exchange speed, and impedance characteristics.[21]

3.4 Patch Antenna Design Algorithm

The orchestrate of a settle recieving wire takes after a useful approach to ensure idealize execution in terms of radiation capability, impedance orchestrating, and transmission capacity. The procedure begins with the calculation of the settle width (W), which is chosen by the working reiterate and the properties of the dielectric substrate.The width particularly impacts the antenna's radiation coordinate and impedance characteristics.[22]

- **Patch Width Calculation** The patch width (W) is given by [22]

$$W = \frac{c}{2f_{01}}\sqrt{\frac{2}{\varepsilon_r + 2}} \tag{2.1}$$

where:

- c is the speed of light (3×10^8 m/s),
- ε_r is the relative permittivity of the substrate,
- f_{01} is the resonant frequency.

Next, the effective relative permittivity (ε_{eff}) of the substrate is calculated. This parameter accounts for the influence of the dielectric material on the antenna's electrical length and is crucial for determining the patch's dimensions.[22]

$$\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\frac{1}{\sqrt{1 + 12h/w}} \tag{2.2}$$

The fringing fields at the edges of the patch are then considered by calculating the length extension (ΔL), which adjusts the physical length of the patch to account for these effects. The length extension (ΔL) is given by:[23]

$$\Delta L = 0.421h\frac{(\varepsilon_{\text{eff}} + 0.3)(0.264 + L/h)}{(\varepsilon_{\text{eff}} - 0.258)(0.8 + L/h)} \tag{2.3}$$

The patch length (L) is calculated next, ensuring that the antenna resonates at the desired frequency. This step is critical, as the length directly affects the resonant frequency and bandwidth of the antenna.[22]

$$L = \frac{\lambda_{g,\text{dielectric}}}{2} - 2\Delta L = \frac{c}{2f_{01}\sqrt{\varepsilon_{\text{eff}}}} - 2\Delta L \tag{2.4}$$

Following this, the input impedance (Z_A) is calculated to ensure proper matching with the feeding network. Impedance matching is essential to minimize reflections and maximize power transfer.[23][24]

$$Z_A = 90\frac{\varepsilon_r^2}{\varepsilon_r - 1}\left(\frac{L}{W}\right) \tag{2.5}$$

Finally, the feeding technique is selected based on the application requirements. Common methods include probe feeding and notch feeding.

For probe feeding, the depth of the feeding point (x_p) is calculated as:[24]

$$x_p = \frac{L}{\pi}\cos^{-1}\left(\sqrt{\frac{Z_A(x = x_p)}{Z_A(x = 0)}}\right) \tag{2.6}$$

While for notch feeding, the depth (x_i) is determined. These calculations ensure that the feeding mechanism is properly positioned to achieve impedance matching and optimal performance.[24]

$$x_i = \frac{L}{\pi}\cos^{-1}\left(\left(\frac{Z_A(x = x_i)}{Z_A(x = 0)}\right)^{\frac{1}{4}}\right) \tag{2.7}$$

With:

$$Z_A(x = x_i) = Z_A(x = x_p) = 50\Omega \tag{2.8}$$

3.5 Microstrip Antennas

Microstrip (also called printed) antennas consist of a dielectric with a metal ground plane on one side, while a metal patch on the other side carries the surface currents that create the electromagnetic radiation. The radiation mechanism of a microstrip patch antenna is due to the edge fields around the edges of the patch.[10][15]

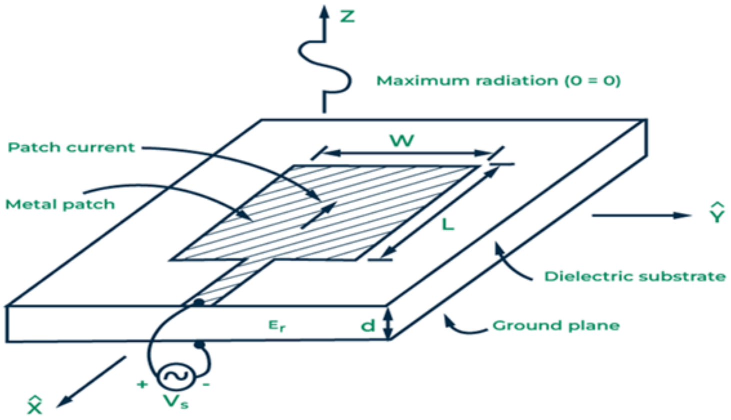


Figure 2.2: Standard Printed Antenna Structure

4 Exploring the Diversity of Patch Antenna Shapes

4.1 Rectangular Patch Antenna

The rectangular patch antenna is the first commonly utilized outline due to its effortlessness in arrange and creation. It comprises of a rectangular metallic component set on a dielectric substrate, with a ground plane underneath. This shape is culminate for applications requiring straight polarization, such as Wi-Fi or RFID systems . In any case, its transfer speed is generally limit, regularly between 1.[16]

4.2 Square Patch Antenna

The square patch antenna is comparable to the rectangular shape but with equal-length sides. This geometric symmetry makes it basic for specific courses of action, such as twofold-polarization recieving wires. It is intermittently utilized in radar systems or applications where orchestrate or circular polarization is required. In spite of the fact that its transfer speed is comparable to that of the rectangular shape, its symmetry permits for more uniform radiation within the level plane. In any case, like the rectangular shape, its transmission capacity remains constrained.[16]

4.3 Circular Patch Antenna

The circular patch antenna is recognized by its circular shape, which gives symmetrical radiation in all bearings of the level plane. This shape is especially suited for applications requiring circular polarization, such as GPS or disciple communication frameworks. The transmission capacity of this radio wire is marginally more extensive than that of rectangular or square shapes, making it an alluring choice for applications where transfer speed may be a basic figure. In any case, its plan is somewhat more complex, which can increment fabricating costs.[17]

4.4 Triangular Patch Antenna

The triangular patch antenna, as often as possible in an equilateral or isosceles shape, is less common but offers specific central focuses. Its compact shape makes it profitable for applications where space is compelled, such as in miniaturized systems . It is additionally utilized in multiband arrangements. Be that as it may, its plan is more complex than that of rectangular or square shapes, and its execution in terms of transfer speed and pick up is for the most part comparable to that of less difficult shapes.[17]

4.5 Annular (Ring-shaped) Patch Antenna

The annular patch antenna is characterized by a ring shape with a central hole. This arrangement permits for a more extensive transfer speed than rectangular or circular shapes, making it appropriate for multiband or wideband applications. It is frequently utilized in communication frameworks where wide transfer speed is required. In any case, its plan is more complex, and its measure may be somewhat bigger than that of less difficult shapes, which can constrain its utilize in profoundly compact frameworks.[17]

4.6 U-shaped or E-shaped Patch Antenna

U-shaped or E-shaped patch antennas are outlined by cutting areas of the fix to alter its radiation properties. These shapes permit for more extensive transfer speed and are regularly utilized in wideband applications, such as Wi-Fi or 5G. They moreover offer multiband execution, making them flexible. In any case, their plan is more complex, and they may be more vulnerable to obstructions due to the cuts within the fix.[17]

4.7 Slot Patch Antenna

The slot patch antenna could be a variation where spaces are cut into the fix to adjust its radiation properties. These spaces permit for more extensive transfer speed and control over polarization, making it valuable for applications such as radar frameworks or wideband communications. Be that as it may, the plan of these radio wires is complex, and they may be delicate to obstructions due to the disturbances presented by the openings.[17]

4.8 Irregular-shaped Patch Antenna

Irregular-shaped patch antennas are planned to meet particular needs, with polygonal or customized shapes. These recieving wires offer awesome adaptability in plan, but their complexity makes modeling and manufacture more challenging. They are ordinarily utilized in custom applications where standard shapes don’t meet specialized prerequisites.[17]

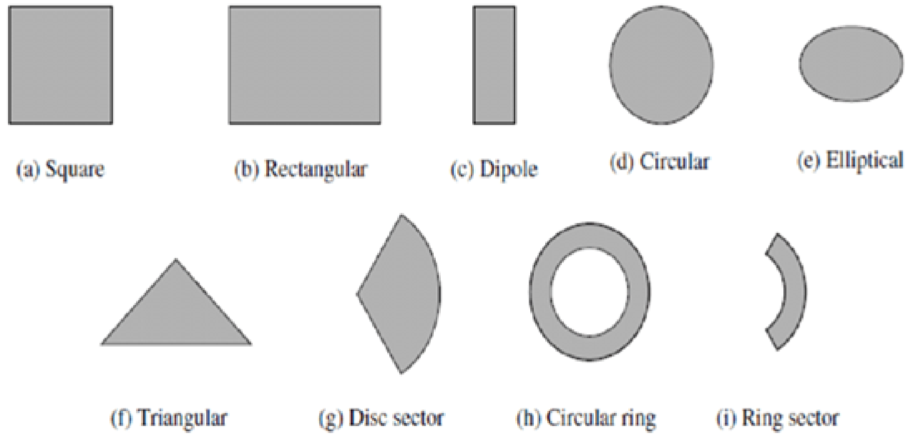


Figure 2.3: Variety of Patch Antenna Shapes

5 Feeding Techniques for Patch Antennas

5.1 Contact Feeding

RF power is directly transmitted to the radiating patch using a connecting element.

Microstrip Line: The technique involves using a microstrip transmission line to provide the feed signal to the patch. One way to accomplish the feeding is to connect directly to a microstrip line. The advantage of this approach is that it simplifies the generation prepare by permitting the nourish to be carved on the same substrate. The inward conductor of a coaxial connector is associated to the transmitting component, whereas the external conductor is associated to the ground plane. This procedure is direct to execute and gives a wide transmission capacity.[2]

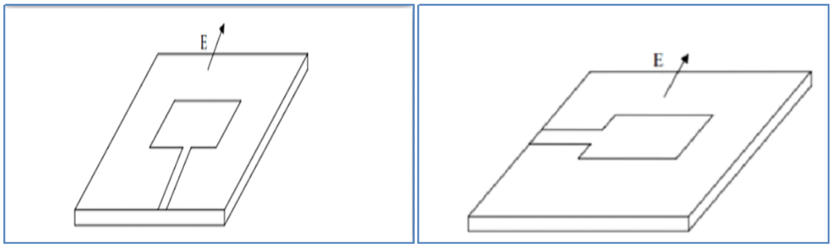


Figure 2.4: Contact Feeding Techniques (Microstrip Line and Coaxial Feeding).

The coaxial cable feed passes through the antenna substrate and the ground plane. Coaxial feeding, also known as probe feeding, is a widely used method for feeding microstrip patch antennas. One of the main advantages of using the probe feeding technique is its flexibility to insert the feed at any location inside the patch, allowing proper matching to the input impedance.[2]

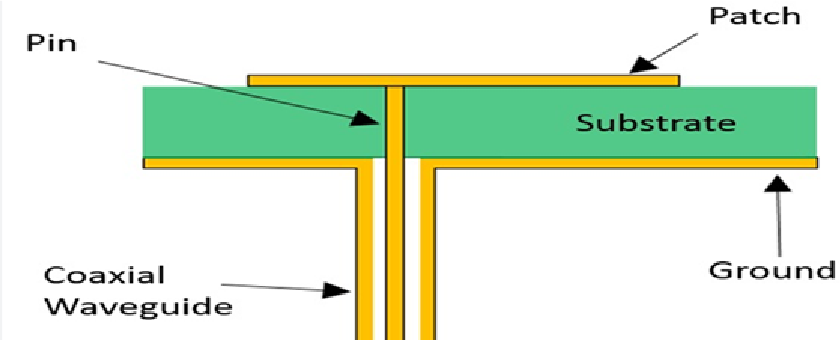


Figure 2.5: Coaxial Feeding of a Patch Antenna.

5.2 Contactless Feeding

Electromagnetic Field Coupling: An electromagnetic field coupling is performed to transfer energy between the microstrip line and the radiating patch.

Aperture Coupling: The radiating patch and the feed line are separated by the ground plane. The conjunction between the patch and the feed line is achieved by an aperture or slot in the ground plane. Energy is transmitted from the microstrip line to the radiating patch by electromagnetic coupling. To optimize the radiation emitted by the patch, a high dielectric material is often used for the lower substrate, while a thick substrate with lower dielectric constants is used for the upper substrate.[17]

Proximity Coupling: A microstrip line is positioned on the lower substrate, while the patch antenna element is placed on the upper substrate. A capacitive interaction is observed between the feedline and the antenna patch in this design arrangement. Proximity coupled feeding offers a distinct advantage as it effectively eliminates parasitic feed radiation and provides remarkably high bandwidth (up to 13%).[17]

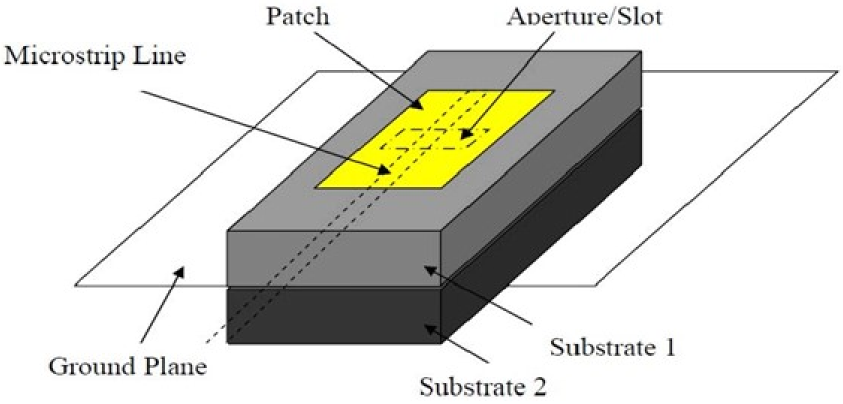


Figure 2.6: Contactless Feeding Techniques

Coplanar Waveguide (CPW): In this technique, the ground plane and the feedline are located on the same side of a dielectric substrate. The radiating element is fed by a central metal strip placed between two parallel ground planes.[2][17]

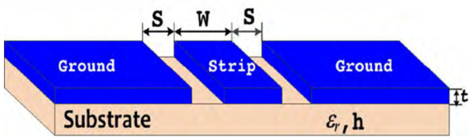


Figure 2.7: Coplanar Waveguide (CPW) Feeding.

5.3 Comparison of Feeding Techniques for Patch Antennas: Advantages and Disadvantages

Points of interest and Drawbacks: The choice of nourishing method could be a critical angle of fix antenna plan, because it specifically impacts the antenna's execution, counting impedance coordinating, transfer speed, radiation productivity, and manufacture complexity. Diverse bolstering strategies offer one of a kind advantages and trade-offs, making them reasonable for particular applications. Underneath may be a comparison of four common nourishing procedures: Nearness Coupled, Microstrip Line, Coaxial Feed, and Aperture Coupled. Each strategy is assessed based on its points of interest and impediments to assist originators select the foremost fitting approach for their prerequisites.

Feeding Technique	**Advantages**	**Disadvantages**
Proximity Coupled	• No direct contact between feed and patch • Large effective thickness possible	• Multilayer fabrication required
Microstrip Line	• Monolithic design • Easy to fabricate • Simple impedance matching	• Spurious radiation (thick substrates)
Coaxial Feed	• Easy impedance matching • Low spurious radiation	• Large inductance (thick substrates) • Requires soldering
Aperture Coupled	• Avoids substrate effects • No direct contact • No feed radiation	• Multilayer fabrication • Higher back lobe radiation

Table 2.1: Comparative Analysis of Feeding Techniques for Patch Antennas

6 Design of Patch Antennas for 5G in the Millimeter Band

Patch antennas for 5G applications in the millimeter-wave (mmWave) band must be outlined with various key contemplations, counting recurrence choice, fabric choice, transmission innovation, and execution optimization. The fundamental components are summarized as takes after:[3][25]

6.1 Frequency and Bandwidth

Operating Frequency: Many designs focus on specific frequencies in the millimeter-wave range, such as 28 GHz, 37 GHz, and 60 GHz, which are critical for 5G communication systems.

Bandwidth: Achieving wide bandwidth is critical to achieving the high data rates required for 5G. For example, one design achieved a bandwidth of 1.43 GHz at 28 GHz with a reflection coefficient of -35.91 dB.

6.2 Antenna Design

Microstrip Patch Antenna Array: A common approach is to use a microstrip patch antenna array, such as a 2x1 design, which improves performance by increasing gain and efficiency.[16]

Slot Design: Incorporating slots into the patch design helps optimize performance. For example, one design includes a rectangular patch with three embedded slots fed by a microstrip line, resulting in a reflection coefficient of -39.534 dB and a gain of 6.16 dBi.

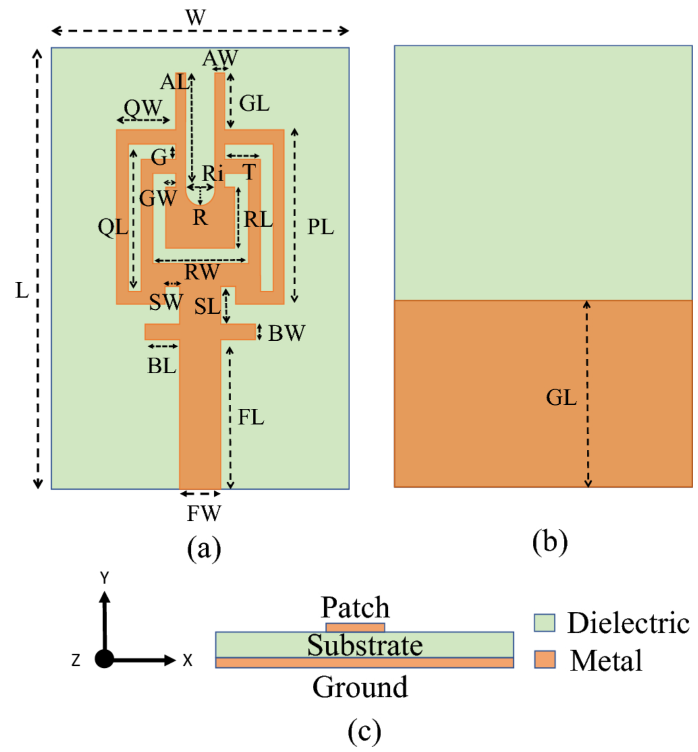


Figure 2.8: Slot-Embedded Patch Antenna Design for 5G.[26]

6.3 Section Material Selection

The choice of substrate is basic to antenna execution. Common materials incorporate Rogers RT/Duroid® 5880, which contains a relative dielectric steady of 2.2 and a moo dissemination figure for high-frequency applications. The (table II.2) speaking to the execution of fix radio wires with distinctive substrate materials.[3] Substrate thickness is chosen according to the antenna's desired performance and the material's permittivity. A common rule of thumb is:

Parameter	**FR4** ($\varepsilon_r = 4.4$)	**NELTEC** ($\varepsilon_r = 3.48$)	**DUROID** ($\varepsilon_r = 2.2$)	**FOAM** ($\varepsilon_r = 1.05$)
Resonant Frequency (GHz)	3.13	2.97	2.98	2.99
Gain (dB)	2.2	5.5	7.0	8.7
VSWR	1.6	1.8	1.5	1.2
Return Loss (dB)	-17.5	-11.0	-12.9	-19.8

Table 2.2: Performance comparison of patch antennas with different substrate materials.

$$0.003\lambda_0 \leq h \leq 0.05\lambda_0 \tag{2.9}$$

where λ_0 is the wavelength in air ($\lambda_0 = \frac{c}{f_r}$). The thickness also plays a role. For example, one design used a thickness of 0.508 mm to achieve the desired resonant characteristics.

6.4 Delivery Methods

Several delivery techniques are used to improve performance:[16][20]

- **Microstrip line feed:** This method simplifies modeling, lowers stray radiation, and enables impedance matching.
- **Electromagnetic coupling feed:** This technique can be used to boost bandwidth and reduce cross-polarization effects.

6.5 Design Parameters

Conventional patch antennas are narrowband, but significant research has been conducted to realize wideband patch antennas. One way to achieve a wide bandwidth is to use a U-slot microstrip antenna with an E-shaped stacked patch. Several parameters must be considered when designing a patch antenna:[27]

S11 Reflection Coefficient

The S11 reflection coefficient quantifies the amount of power that is reflected back to the input port when a signal is applied. It is mathematically expressed as:[21]

$$S_{11} = \frac{b_1}{a_1} \tag{2.10}$$

where b_1 is the reflected wave and a_1 is the incident wave.

Bandwidth

Bandwidth is defined as the width measurement of a frequency range, indicating the difference between the upper and lower frequencies where a signal maintains a specific level of performance, often at least 70% of full-scale power.[21]

Directivity

Directivity determines how much the radiation of an antenna is concentrated on one beam. It is defined as:[27]

$$D = \frac{U(\theta, \phi)}{P_{avg}} \tag{2.11}$$

where:

- $U(\theta, \phi)$ is the radiation intensity in a given direction.
- P_{avg} is the average radiation intensity in all directions.

For an isotropically radiating antenna, the directivity is defined as 1 (0 dBi) because it radiates in all directions with the same strength. A higher directivity means that the signal can be transmitted further, allowing for more regions to be covered with this focused beam.[27]

Gain

Gain corresponds to the developed value radiation of the antenna power in a certain direction, relative to an isotropic antenna. It is expressed as:

$$G = 10 \log_{10} \left(\frac{P_{rad}}{P_{iso}} \right) \tag{2.12}$$

where:

- P_{rad} is the power radiated by the antenna.
- P_{iso} is the power radiated by an isotropic source.

The use of more effective antennas permits signal amplification, calling for a need for increased gain patch antenna. For patch antennas, effective aperture can be approximated based on their physical dimensions and the operational frequency. The gain can also be due to other factors like type of substrate used, shape and configuration of the antenna and the feeding techniques used.[23]

Efficiency

Efficiency is defined as the ratio of the power radiated by the antenna (P_R) to the total power supplied to it (P_A):[27]

$$\eta = \frac{P_R}{P_A} \tag{2.13}$$

Radiation Pattern

A radiation pattern shows the strength of radio waves in relation to the direction and position of an antenna. The pattern is usually plotted in spherical coordinates and may be shown in either 2D or 3D. The patterns assist in the visualization of the areas where the antenna dominantly radiates power.[23]

7 Challenges and Considerations

Developing millimeter wave frequency antennas faces the following challenges:

- Maintaining compact size while achieving wide bandwidth.
- Ensuring efficient heat dissipation in high-performance applications.
- Minimizing interference with other components in devices such as smartphones.

8 Conclusion

In conclusion, planning patch antennas for 5G smartphone applications may well be a complex plan that requires cautious thought of specialized judgments, texture choice, and arrange parameters. Through optimization and execution examination, it's conceivable to form radio wires that meet the asking prerequisites of 5G communication.Joining settle recieving wires into helpful phones in expansion requires innovative organize procedures to overcome space and preventions challenges.This chapter gives a comprehensive chart of the settle radio wire organize get arranged, setting the organize for offer help examination in a brief time afterward chapters.

CHAPTER 3

FULL SIMULATION AND ANALYSIS OF PATCH ANTENNAS WITH DIFFERENT GEOMETRIES

This chapter centers on the design and simulation of circular, rectangular, and triangular patch antennas for 5G applications. Utilizing CST Microwave Studio, we analyze the execution of these antennas in terms of gain, bandwidth, and radiation patterns. The objective of the simulation is to optimize gain and bandwidth whereas keeping up a a compact size. The simulation comes about will give experiences into the effectiveness of the proposed designs.

1 Introduction

The development of fifth-generation 5G technology is creating significant challenges, particularly in the design of antennas that must meet certain requirements, including bandwidth in excess of 1 GHz and high benefits of up to 12 dB for ideal performance. The use of millimetre-wave frequencies is a practical solution to meet the demands of this next-generation technology.

In this chapter, we present the design of various printed antennas suitable for 5G communications. These antennas have been modelled and simulated to operate efficiently at millimetre frequencies, in particular around 28 GHz and 60 GHz. In this study, we explore several structures (rectangular, circular and triangular) in order to analyse their performance. The results obtained will provide a better understanding of the impact of geometric parameters on their efficiency. The aim is to optimise the design to meet the requirements of modern high-speed applications.

2 CST Microwave Studio: A Powerful Tool for Electromagnetic Design

CST Microwave Studio is three-dimensional electromagnetic simulation program particularly designed for modeling inactive structures. It utilizes the limited integration strategy to unravel Maxwell's conditions. This numerical strategy empowers spatial discretization, permitting for a coordinate three-dimensional representation of all components inside the frameworks being analyzed. As a result, CST Microwave Studio can be connected to a wide spectrum of electromagnetic problems, extending from inactive scenarios to microwave frequencies, and it bolsters both time-domain and frequency-domain investigations.

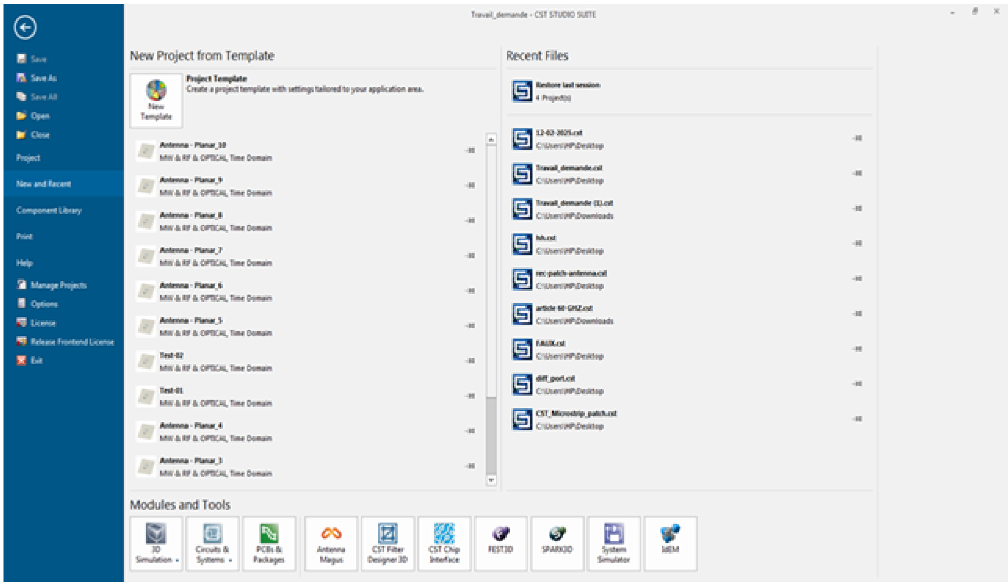


Figure 3.1: CST Microwave Studio simulation environment

3 Design of the 28GHz rectangular Patch Antenna

3.1 Structure of the Proposed Patch Antenna

The proposed antenna, as shown in Figure 3.32, consists of:[28]

- A rectangular patch made of annealed copper (radiating component).

- Dielectric substrate: Rogers RT/Duroid 5880($\varepsilon_r = 2.2$, $\tan\delta \approx 0.0009$)

- Grounding plane: Annealed copper (idealize electrical conductor).

This basic and viable structure guarantees productive radiation and performance, making it reasonable for high-frequency applications.

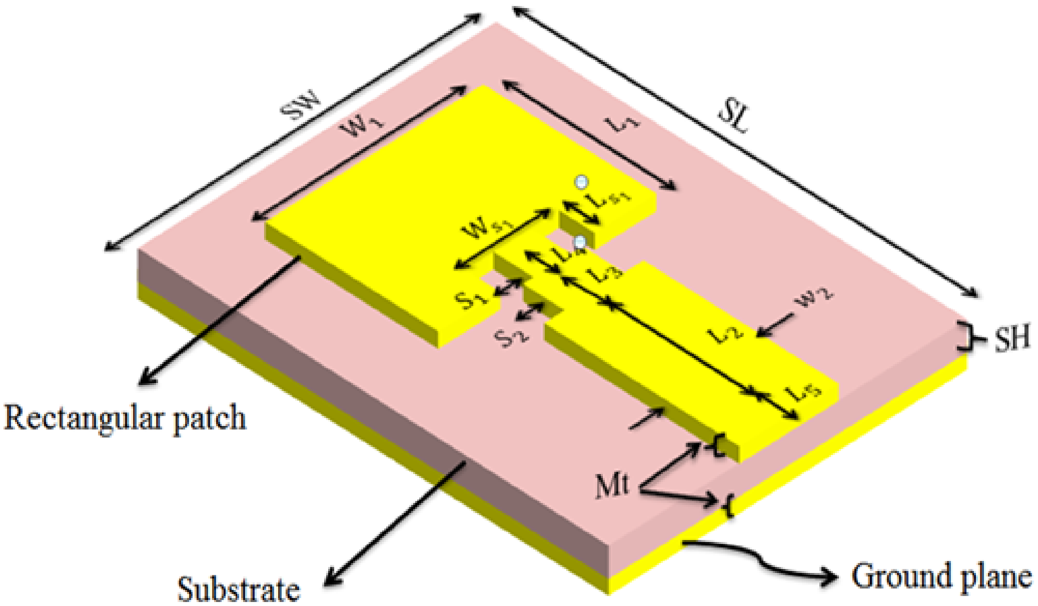


Figure 3.2: Structure of the Proposed Patch Antenna.[28]

and its dimensions are detailed in Table 1.1.

Parameter	Description	Value (mm)	Parameter	Description	Value (mm)
SL	Substrate length	20	L4	Length of middle patch section	1.00
SW	Substrate width	13	L5	Length of upper patch section	0.49
SH	Substrate height	0.508	LS1	Length of primary slot	0.65
W1	Patch width	4.22	S1	Width of primary slot	0.375
L1	Patch length	3.46	S2	Width of secondary slot	0.07
L2	Length of secondary slot	7.88	Mt	Ground/patch height	0.035
L3	Length of lower patch section	1.60	W2	Width of feed line or patch section	1.19
WS1	Width of lower patch section	1.05	–	–	–

Table 3.1: Geometrical Dimensions of the Rectangular Patch Antenna

3.2 Results and Discussion

By utilizing the aforementioned parameters, it is possible to simulate S-parameters and even the three-dimensional radiation pattern of the single-element patch using *CST MWS*. The simulation results for the S11 values, 3D radiation patterns, gain and VSWR are illustrated in Figures 3.3 through 3.5.

The S-parameter Results

The S-parameter results, specifically the S11 magnitude in dB, are presented in the graph for the frequency range of 25GHz to 30GHz. The plot indicates the reflection coefficient

(S11) of the antenna, which is a critical parameter for evaluating its impedance matching and efficiency.

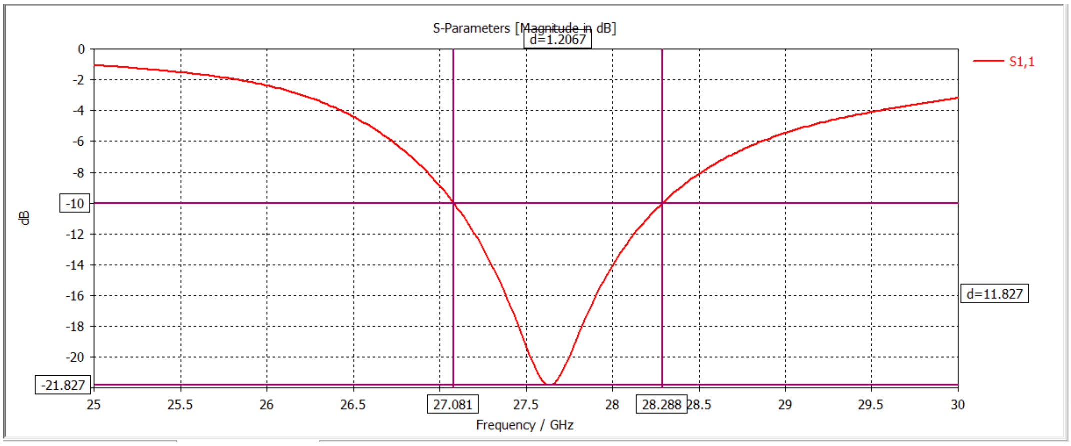


Figure 3.3: S-Parameter (S11) Curve for Rectangular Patch Antenna.

The S11 results reveal a minimum reflection coefficient of -27.941dB at 27.941GHz, which is very close to the target frequency of 28GHz. This indicates excellent impedance matching and efficient power transmission near the desired frequency. The maximum bandwidth, represented by $d = 1.4488$, spans from 26.493GHz to 29.5GHz (where S11 $< -10dB$). These results confirm that the antenna is well-suited for 28GHz applications, such as 5G, with only minor adjustments potentially needed to fine-tune the resonant frequency to exactly 28GHz.

Voltage Standing Wave Ratio (VSWR)

The results of the Voltage Standing Wave Ratio (VSWR) are presented for the frequency range of 25GHz to 30GHz. The minimum VSWR value of 1.066 occurs at 26.453GHz, indicating excellent impedance matching at this frequency. A VSWR close to 1 is ideal, as it reflects minimal energy reflection and efficient power transmission.

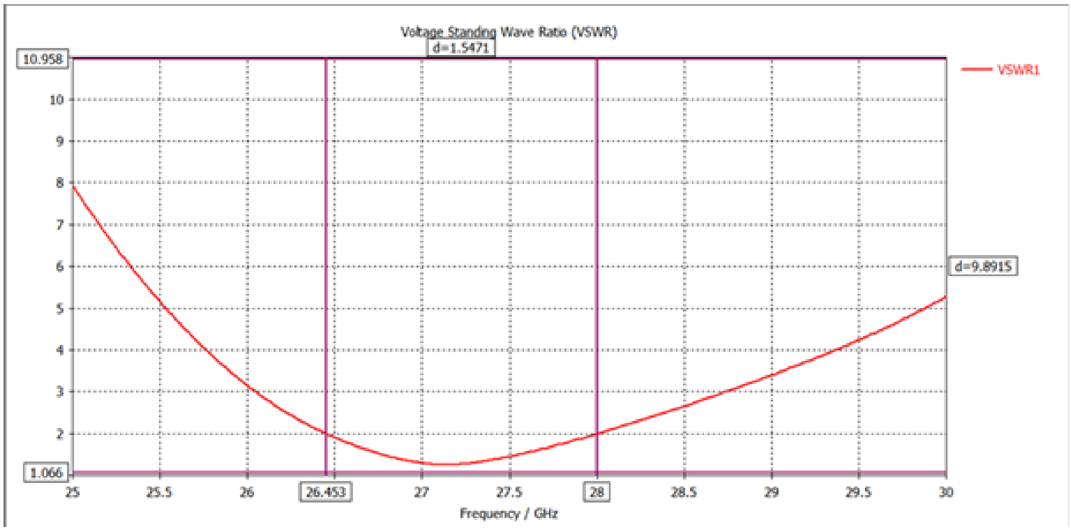


Figure 3.4: Voltage Standing Wave Ratio (VSWR) of the Rectangular Antenna).

The maximum bandwidth, represented by d=1.5471, covers a frequency range where the VSWR remains acceptable (typically below 2). In this case, the bandwidth extends from 26.453 GHz to 29.5 GHz, demonstrating that the antenna performs optimally across a wide range of frequencies around 28 GHz.

The Gain

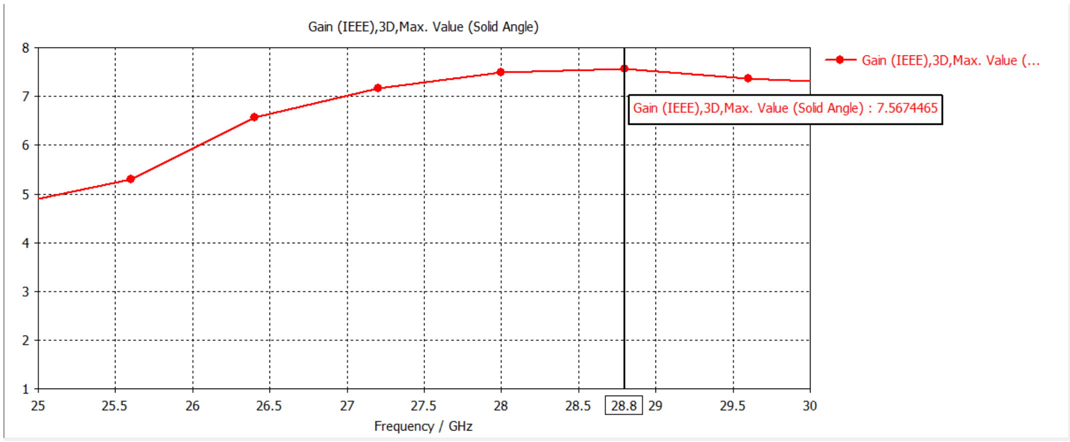
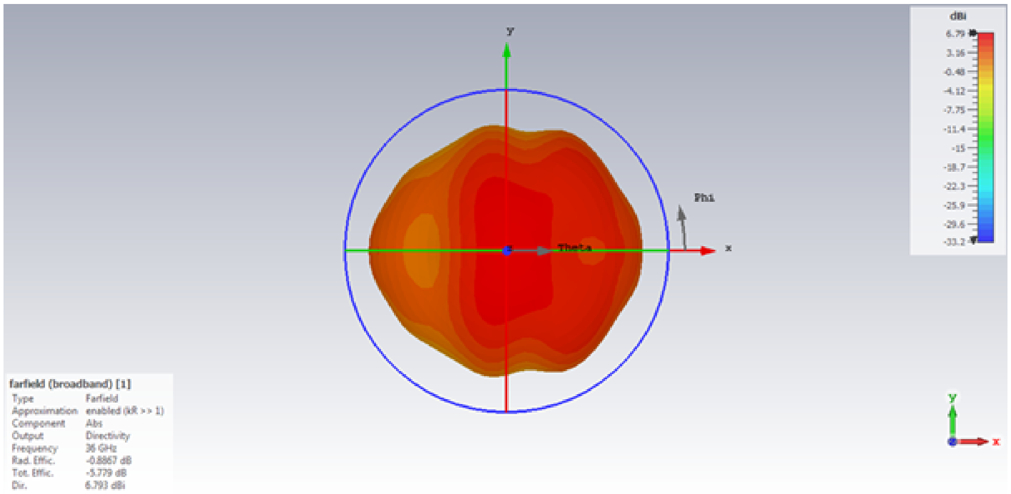


Figure 3.5: Gain variation of the Rectangular patch antenna

The figure above illustrates the simulated 3D maximum gain (IEEE standard, solid angle method) of a rectangular microstrip patch antenna working in the millimeter-wave band, specifically centered around 28 GHz. The simulation was conducted employing a full-wave electromagnetic solver, and the antenna performance was evaluated over a frequency range of 25 GHz to 30 GHz. The gain curve shows a clear increasing trend from 25 GHz to approximately 28.4 GHz, where it comes to its peak value. Beyond this point, a gradual decline is observed. The maximum gain is achieved at 28.8 GHz, where the antenna shows a gain of around 7.56 dBi. This gain is considered suitable for 5G applications, especially in urban microcell or small cell environments where beamforming and moderate directivity are required. The smooth variation in gain across the frequency band illustrates great broadband behavior and a stable radiation mechanism, which is characteristic of an optimized antenna structure and impedance matching over the operating bandwidth.

Radiation Pattern

- 3D radiation pattern of directivity



farfield (broadband) [1]
Type Farfield
Approximation enabled (kR >> 1)
Component Abs
Output Directivity
Frequency 36 GHz
Rad. Effic. -0.8867 dB
Tot. Effic. -5.779 dB
Dir. 6.793 dBi

Figure 3.6: 3D radiation pattern of directivity

3D radiation pattern of directivity The directivity peaks at 6.793 dB, confirming the antenna's ability to concentrate radiation efficiently. The radiation efficiency of -0.8867 dB and the total efficiency of -5.779 dB indicate some losses in the system, probably due to material properties or impedance mismatches, but these do not significantly compromise the overall performance of the antenna. The far-field radiation pattern, calculated using the broadband approximation (kR » 1), shows that the antenna operates efficiently in the far-field region, where the radiation characteristics are well defined. The absolute component of the radiation pattern highlights the directional behaviour of the antenna, with minimal energy lost in undesired directions.

These results collectively demonstrate that the antenna is highly directional, efficient and suitable for applications requiring precise beam shaping and minimal interference.

- 2D radiation pattern of directivity at $\phi = 0°$

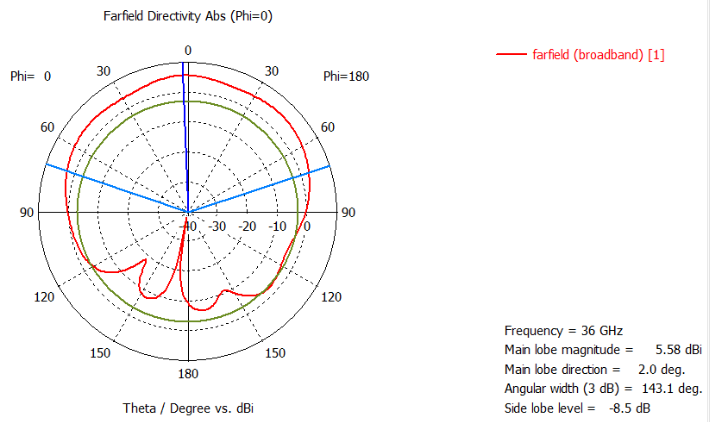


Figure 3.7: 2D radiation pattern of directivity at$\phi = 0°$

2D radiation pattern of directivity The polar diagram shows the far-field directivity of the simulated antenna in the $\Phi = 0°$ plane at a frequency of 36 GHz. The antenna exhibits a maximum directivity of 5.58 dBi, with a main lobe centered at 2°, close to the normal direction, which is typical of a well-designed planar antenna. The -3 dB beamwidth extends over 143.1°, indicating wide angular coverage—ideal for wide-field applications such as 5G access points or short-range radar. The secondary lobe level of -8.5 dB reflects effective rejection of unwanted radiation.

- 2D radiation pattern of directivity at $\phi = 90°$

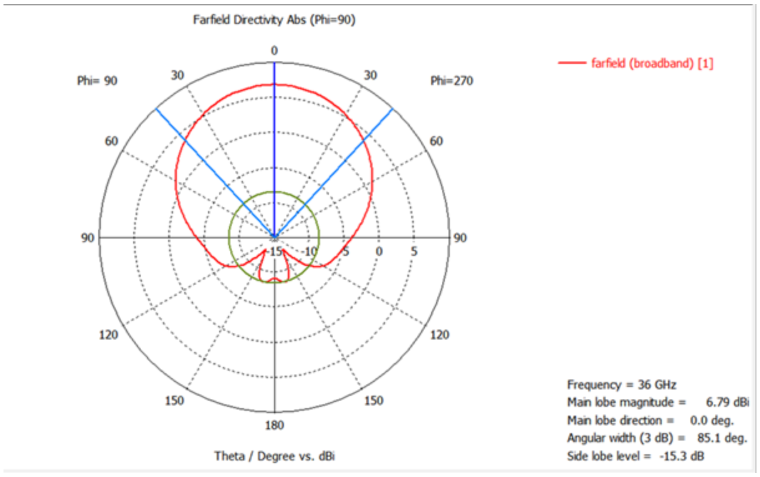


Figure 3.8: 2D radiation pattern of directivity at $\phi = 90°$

Similarly, the directivity results at 36Ghz confirm the antenna's ability to effectively focus radiation. The radiation pattern at $\Phi = 90°$ and $\Phi = 270°$ demonstrates symmetrical behavior, with the main lobe direction aligning precisely at 0°. This symmetry and directional focus make the antenna suitable for applications requiring accurate beamforming, such as 5G and satellite communications. The θ-degree versus directivity (dBi) plot further illustrates the antenna's performance, emphasizing its ability to concentrate energy in the desired direction while effectively suppressing side lobes.

3.3 Parametric Study

Ground Plane and Substrate

- Length "SL"

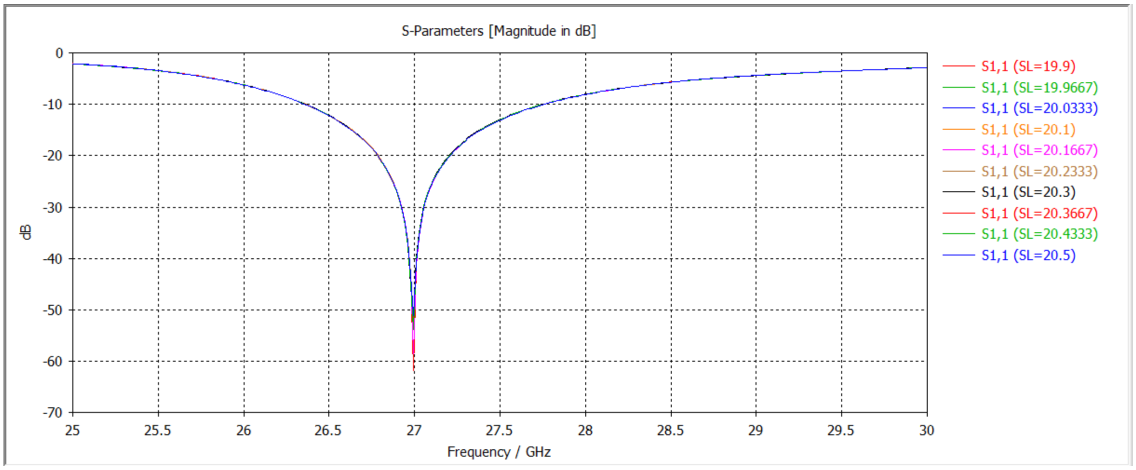


Figure 3.9: Parametric study of substrate height effect on S-parameters (magnitude in dB) for Antenna Optimization.

"SL" The parametric study investigates the impact of SL on antenna performance, particularly its effect on the reflection coefficient (S11). The analysis reveals that specific values of SL, such as 20mm, achieve optimal performance at 27GHz. At these values, the S11 is recorded below -20dB, indicating minimal reflections and highly efficient power transfer.

- Length "SH"

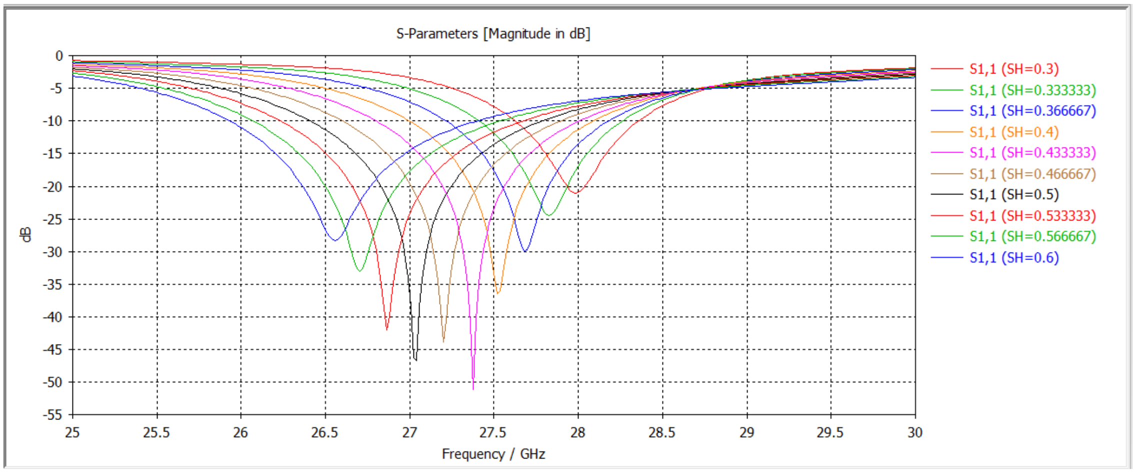


Figure 3.10: Parametric Study of Substrate Height Effect on S-Parameters (Magnitude in dB).

Height "SH" This parametric study investigates the effect of substrate height on antenna performance, focusing on the reflection coefficient (S11). The results demonstrate that substrate height significantly impacts impedance matching and reflection losses. For specific heights, as represented by the curves $S_{1,1}^{(3)}$ to $S_{1,1}^{(54)}$, notable variations in S11 magnitude are observed across the frequency range (25GHz to 30GHz). S11 values below -20dB indicate excellent impedance matching, with minimal reflections and efficient power transfer.

Patch

- Patch Length "PL"

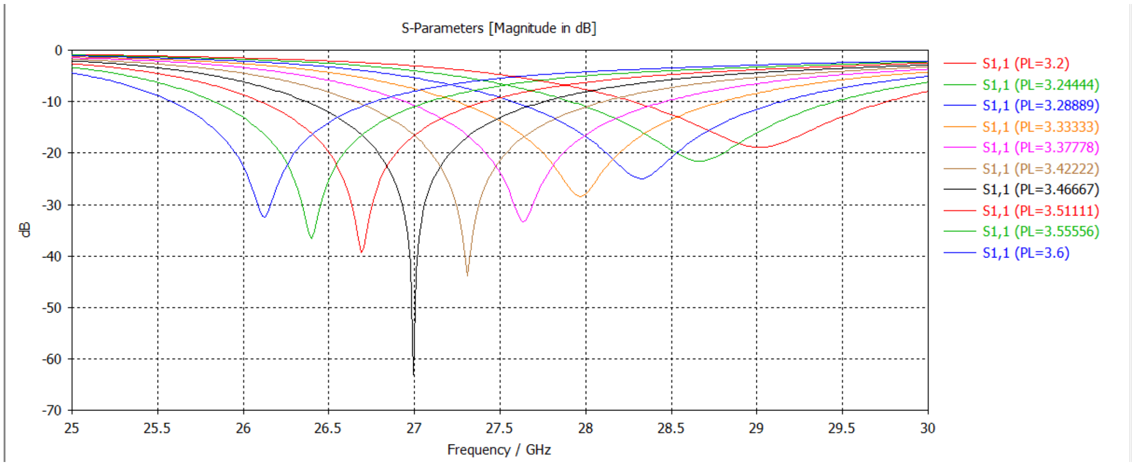


Figure 3.11: Parametric Study of Patch Length Effect on S-Parameters (Magnitude in dB)

This study looks at how the patch length (PL) impacts antenna performance, especially the reflection coefficient(S11). The results show that patch length plays a crucial role in impedance matching and bandwidth optimization. The optimal performance is achieved at PL = 3.42222mm (curve $S_{1,1(57)}$).

- Patch width "PW"

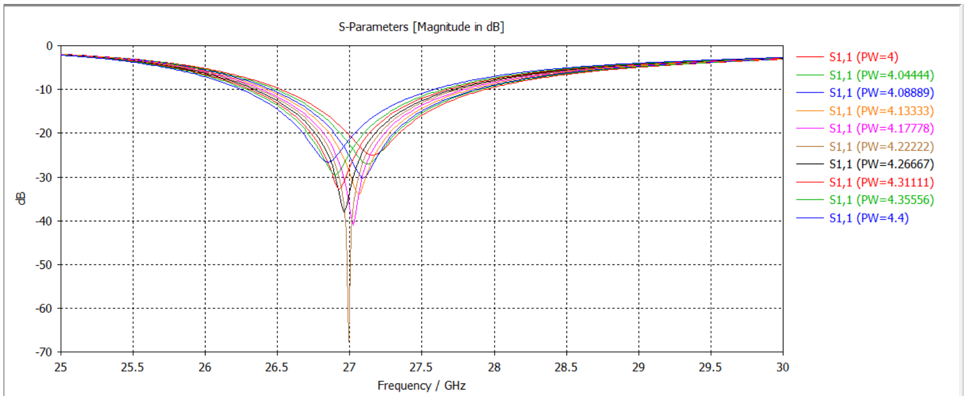


Figure 3.12: Parametric Study of Patch Width Effect on S-Parameters (Magnitude in dB)

"PW" The parametric analysis of patch width (PW) demonstrates significant effects on both impedance matching and radiation pattern characteristics. Best performance is observed at PW = 4.2222mm (curve $S_{1,1}^{(84)}$), with S11 values below -25dB across the 26GHz to 29GHz range.

- "MT"

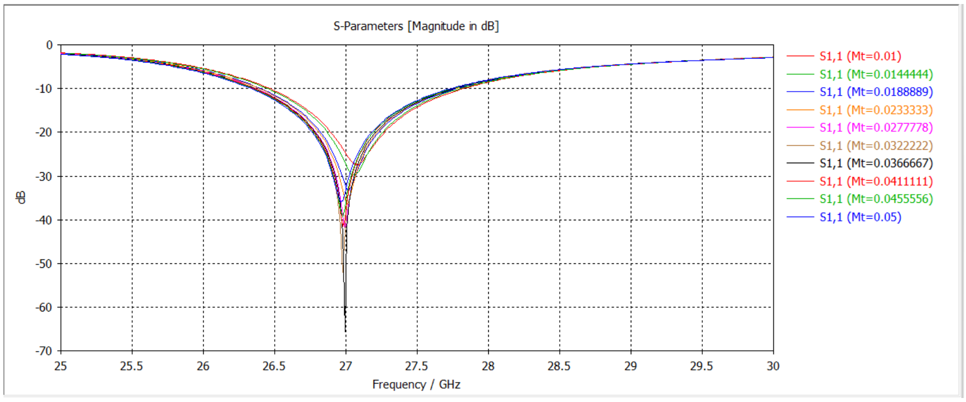


Figure 3.13: Parametric Study of Patch and Ground Plane Height Effect on S-Parameters (Magnitude in dB)

"MT" This parametric study investigates the combined effect of patch height and ground plane height (MT) on antenna performance, focusing on the reflection coefficient (S11). The results demonstrate that these heights significantly impact impedance matching and reflection losses. For specific heights, as represented by the curves S1,1 (123)to S1,1 (155), notable variations in S11 magnitude are observed across the frequency range (25 GHz to 30 GHz). The best performance is achieved for a height of MT = 0.0366667 mm, corresponding to the curveS1,1 (146).

4 Design of the circular Patch Antenna

4.1 Structure of the Proposed Patch Antenna[28]

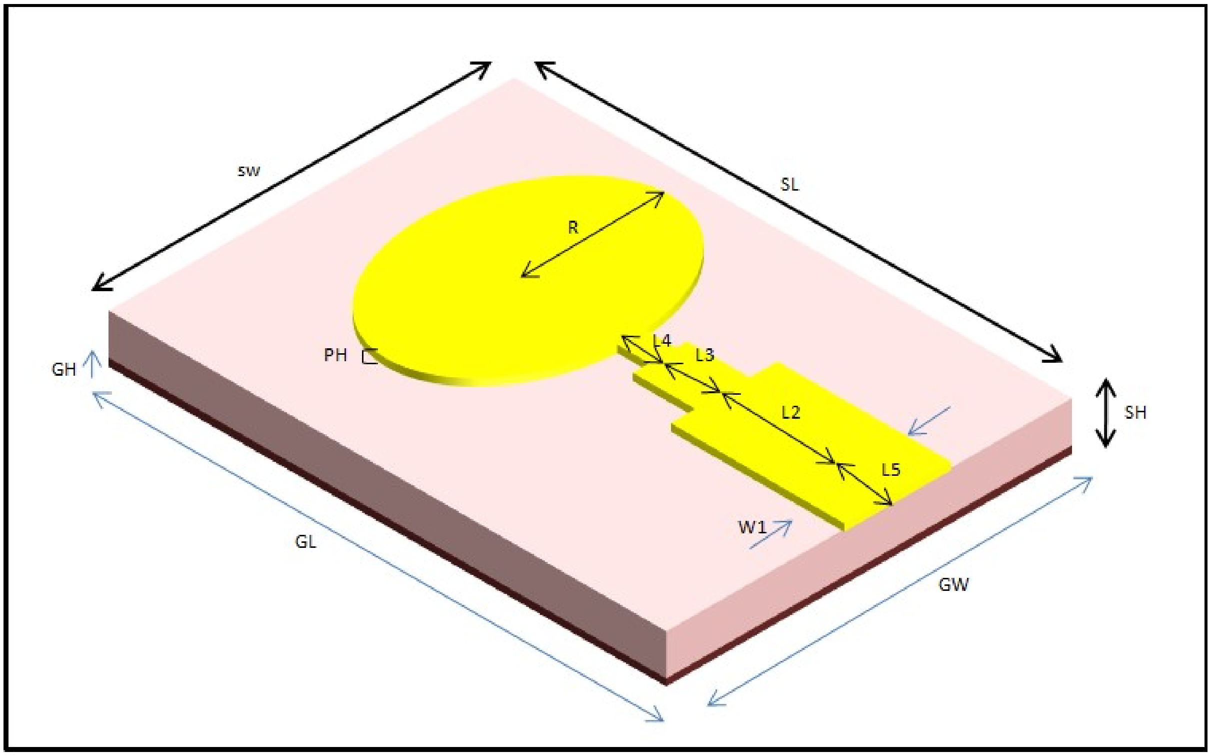


Figure 3.14: Structure of the Proposed Patch Antenna (circular)

Parameter	Symbol	Value (mm)
Radius	R	1.73
length of feed line	L4	1
length of feed line	L3	1.60
length of feed line	L5	0.49
length of feed line	L2	7.88
thickness of patch	PH	0.035
Width of feed line	WP	1.19

Table 3.2: Geometrical Dimensions of the Circular Patch Antenna

4.2 Results and Discussion

The S-parameter Results [S11]

The S-parameter results, specifically the S11 magnitude in dB, are presented in the graph for the frequency range of 45GHz to 85GHz. The plot indicates the reflection coefficient (S11) of the antenna, which is a critical parameter for evaluating its impedance matching and efficiency. The S11 results reveal a minimum reflection coefficient of -40.20dB at 72.28GHz. This indicates excellent impedance matching and efficient power transmission near the desired frequency.

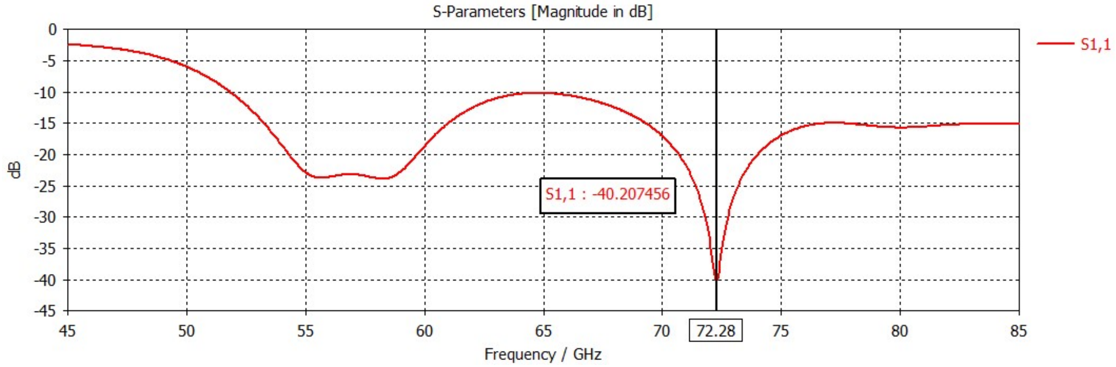


Figure 3.15: s-parameter (s11) response of the circular patch antenna

Standing wave ratio [VSWR]

The results of the Voltage Standing Wave Ratio (VSWR) are presented for the frequency range of 45GHz to 85GHz. The minimum VSWR value of 1.01 occurs at 72.28GHz, indicating excellent impedance matching at this frequency. A VSWR close to 1 is ideal, as it reflects minimal energy reflection and efficient power transmission.

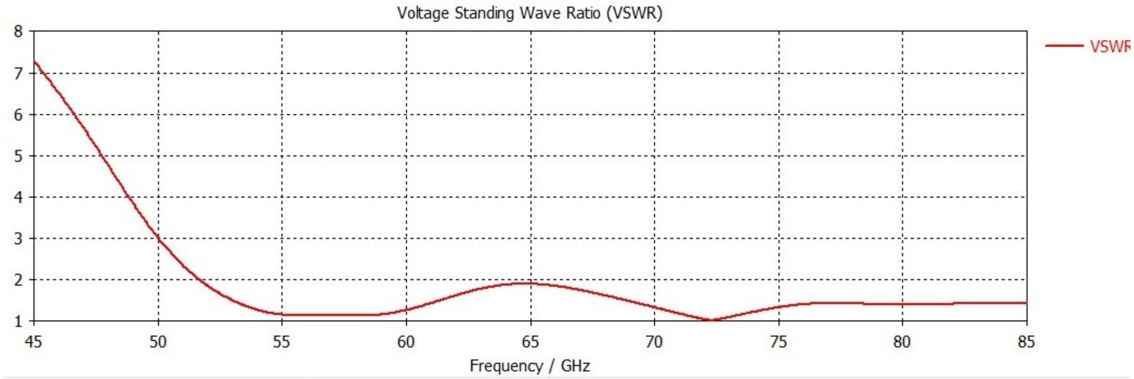


Figure 3.16: voltage standing wave ratio (vswr) of the circular patch antenna

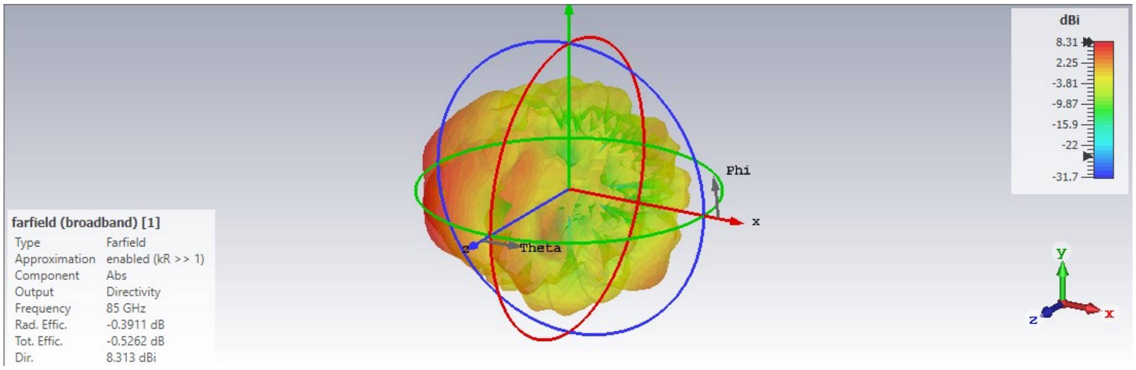
The Gain

Gain results are displayed for the frequency range from 45 GHz to 85 GHz. The value occurs at 72.28 GHz is 6.90 dB, indicating good antenna directional capability at this frequency. Gains greater than 6 dB are considered good for wireless communications, especially in 5G AND the millimeter wave band.

Figure 3.17: Gain variation of the circular patch antenna

radiation pattern

- 3D radiation pattern of directivity

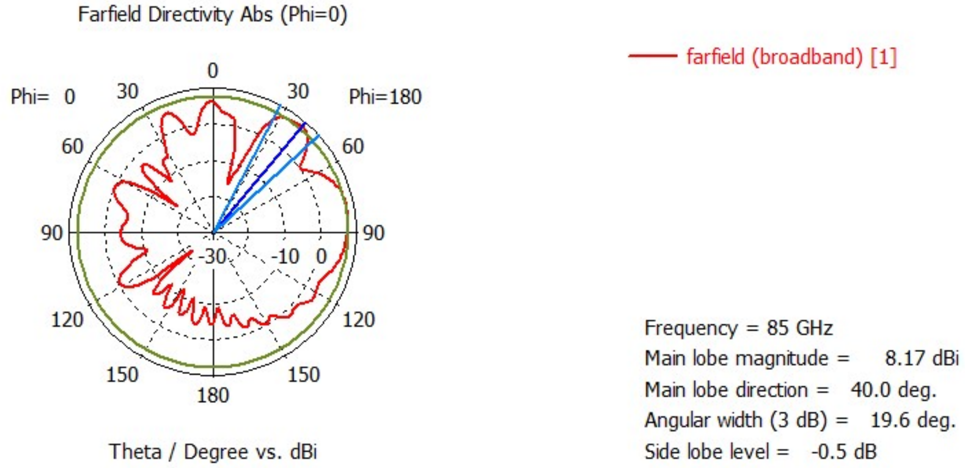


farfield (broadband) [1]
Type Farfield
Approximation enabled (kR >> 1)
Component Abs
Output Directivity
Frequency 85 GHz
Rad. Effic. -0.3911 dB
Tot. Effic. -0.5262 dB
Dir. 8.313 dBi

Figure 3.18: Three-dimensional radiation patterns

The polar radiation pattern at $\phi = 90°$ shows the directivity of the antenna in different directions. The maximum directivity is 0.219 dBi, indicating that the radiation is mainly directed in a certain direction. The main lobe direction at 0.0° means that the highest radiation level occurs at the expected angle. The beam width at -3 dB is 27.6°, reflecting the spread range of the main beam and showing that the antenna is highly directional, making it suitable for intelligent pointing and beam steering systems. The side lobe level is -1.7 dB, which means low interference and unwanted radiation, thus reducing interference with other systems. In general, this antenna is suitable for communication systems that require precise pointing and interference reduction.

- 2D radiation pattern of directivity



Frequency = 85 GHz
Main lobe magnitude = 8.17 dBi
Main lobe direction = 40.0 deg.
Angular width (3 dB) = 19.6 deg.
Side lobe level = -0.5 dB

Figure 3.19: 2D radiation pattern at $\phi = 0°$

This polar plot shows the far-field directivity of a broadband antenna at 85 GHz in the $\phi = 0°$ plane. The main lobe has a peak directivity of 8.17 dBi and is directed at

$\phi = 40°$, with a 3 dB beamwidth of $\phi = 19.6°$. The sidelobe level is relatively high at -0.5 dB, indicating notable off-axis radiation. These characteristics suggest a tilted and moderately narrow beam. Overall, the antenna shows directional behavior with a clear main beam and controlled sidelobes.

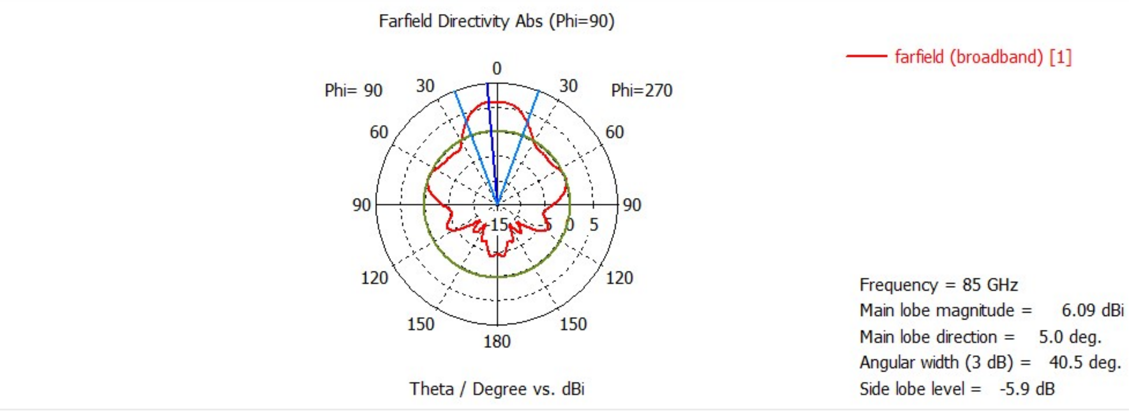


Figure 3.20: 2D radiation pattern at $\phi = 90°$

This far-field radiation pattern at 85 GHz in the $\phi = 90°$ plane demonstrates the antenna's directional capability with a main lobe peak at 5.0° and a gain of 6.09 dBi. The beam exhibits a 3 dB angular width of 40.5°, offering balanced directivity and coverage. Sidelobe suppression is excellent, with the highest sidelobe level at -5.9 dB, reducing interference and off-axis radiation. The plot shows symmetry between $\phi = 90°$ and $\phi = 270°$, indicating stable bidirectional behavior. The antenna efficiently directs energy forward with controlled side radiation.

4.3 Parametric Study

- patch length "L2"

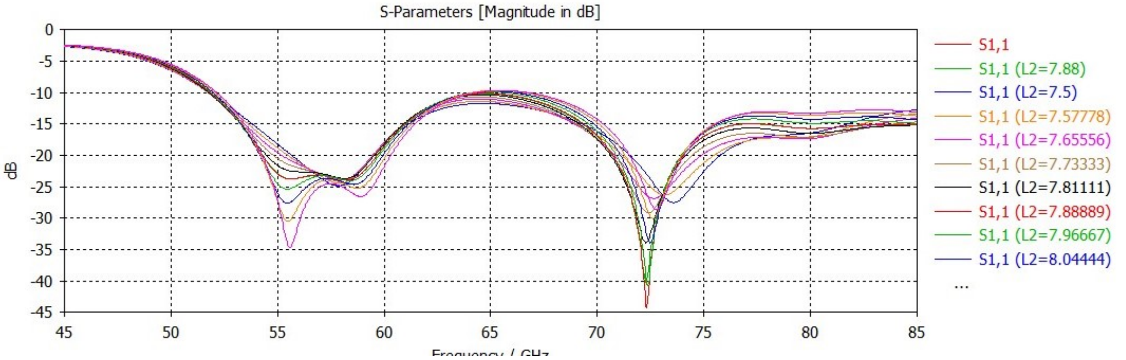


Figure 3.21: Parametric Study of length L2 Effect on S-Parameters (Magnitude in dB)

Parametric research on the effect of L2 on antenna performance shows that its value directly affects the reflection coefficient (s11) . By analyzing the results, it was found that the values of L2 = 7.88 mm and L2 = 7.96667 mm reached the best consistency at 72 GHz, which is recorded here s11 . these valuescan be adopted to improve antenna performance at this frequency and can be fine-tuned to achieve a wider operating range and improve gain and directivity

- patch length “L3”

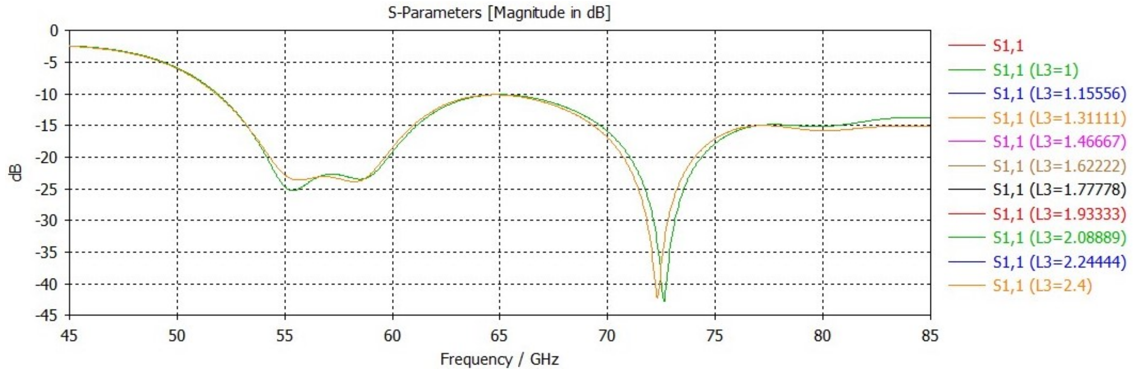


Figure 3.22: Parametric Study of length L3 Effect on S-Parameters (Magnitude in dB)

Parametric research on the effect of L3 on antenna performance shows that its value directly affects the reflection coefficient (s11) . By analyzing the results, it was found that the values of L3 = 1 mm reached the best consistency at 72 GHz, which is recorded here s11 these values can be adopted to improve antenna performance at this frequency and can be fine-tuned to achieve a wider operating range and improve gain and directivity

- patch length “L4”

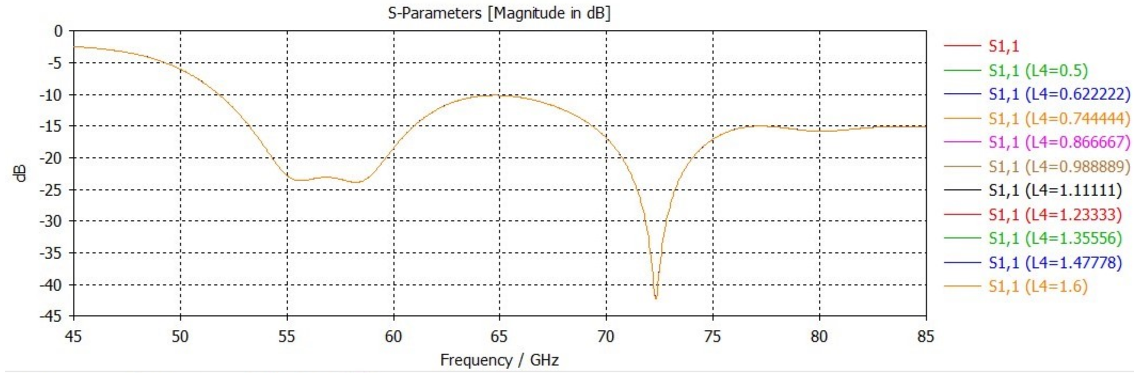


Figure 3.23: Parametric Study of length L4 Effect on S-Parameters (Magnitude in dB)

Parametric research on the effect of L4 on antenna performance shows that its value directly affects the reflection coefficient (s11) . By analyzing the results, it was found that the values of L4 = 1.6 mm reached the best consistency at 72 GHz, which is recorded here s11 these values can be adopted to improve antenna performance at this frequency and can be fine-tuned to achieve a wider operating range and improve gain and directivity

- patch length “L5”

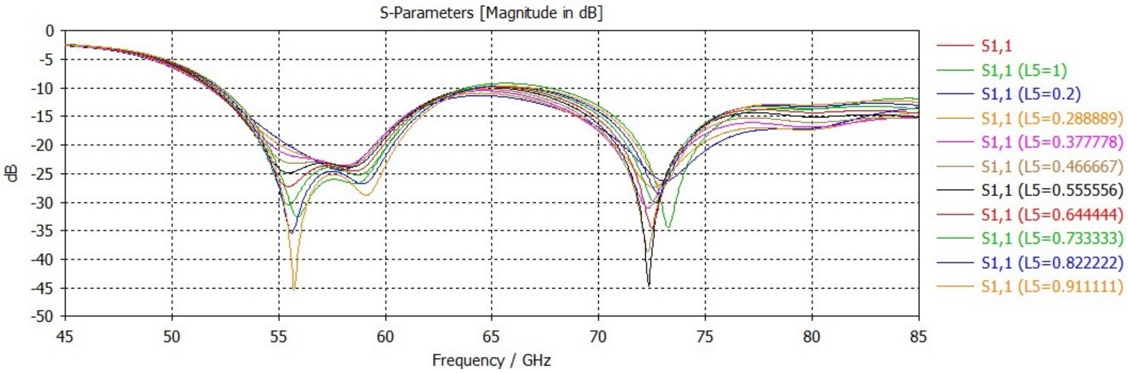


Figure 3.24: Parametric Study of length L5 Effect on S-Parameters (Magnitude in dB)

Parametric research on the effect of L5 on antenna performance shows that its value directly affects the reflection coefficient (s11) . By analyzing the results, it was found that the values of L5 = 0.5 mm reached the best consistency at 72 GHz, which is recorded here s11 these values can be adopted to improve antenna performance at this frequency and can be fine-tuned to achieve a wider operating range and improve gain and directivity

5 Design of the triangular Patch Antenna

5.1 Structure of the Proposed Patch Antenna

The configuration shown illustrates the geometric structure of a printed monopole antenna. This antenna is built on a rectangular dielectric substrate with dimensions SLSW and thickness SH. The ground plane is located on the underside of the substrate, while the radiating patch is located on the upper surface. The patch is triangular in shape and oriented upwards. It is powered by a microstrip transmission line (feedline), which is directly connected to the base of the triangle. This feedline is represented by a succession of rectangular segments noted L2, L3 ,L4, and L5, with a width of W2 , enabling energy to be transmitted efficiently from the input port to the radiating patch. There are also two rectangular slots, called insets, located on either side of the supply line. They are characterised by the dimensions LS1,WS1 and WS2. These cut-outs are generally used to optimise the antenna impedance or to introduce secondary resonance effects in order to widen the bandwidth.[29]

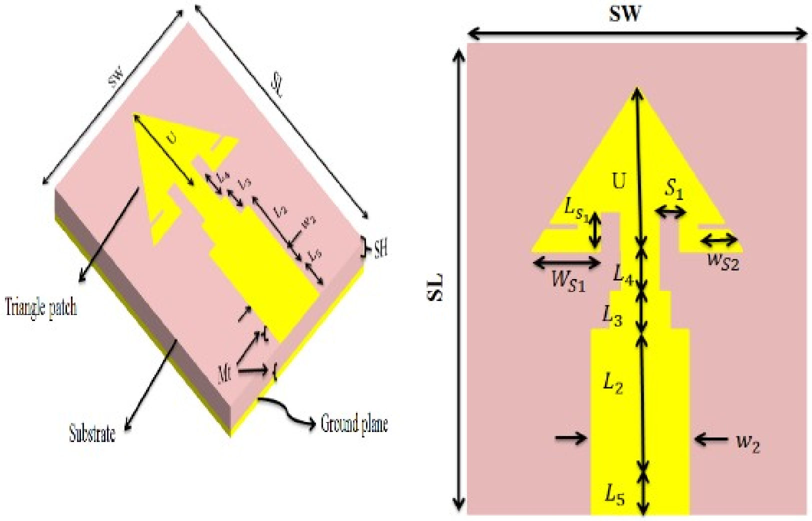


Figure 3.25: Structure of the Proposed Patch Antenna (Triangle).[29]

and its dimensions are detailed in Table 3.3.

Parameter	Description	Value (mm)
SL	The substrate length	20
SW	The substrate width	13
SH	Substrate height	0.508
U	Height of the triangular patch	4.22
WS2	Width of the secondary inset	0.64
L2	Length of the secondary slot	7.88
L3	Length of the lower patch section	1.60
L4	Length of the middle patch section	1
L5	Length of the upper patch section	0.49
LS1	Length of the primary slot	0.70
S1	Width of the primary slot	0.28
W2	Width of the feed line or patch section	1.19
Mi	Ground plane and patch height	0.035

Table 3.3: Geometrical Dimensions of the Triangular Patch Antenna.

5.2 Results and Discussion

The S-parameter Results [S11]

The S11 results indicate a minimum reflection coefficient of -22.702 dB occurring at approximately 60.0 GHz, which demonstrates very good impedance matching and effective energy transfer at this frequency. The bandwidth where S11 remains below -10 dB extends from 58.243 GHz to 61.4 GHz, resulting in a 3.157 GHz bandwidth. This relatively wide impedance bandwidth confirms that the antenna is well-suited for millimeter-wave applications in the 60 GHz band, such as short-range high-speed remote communication systems.

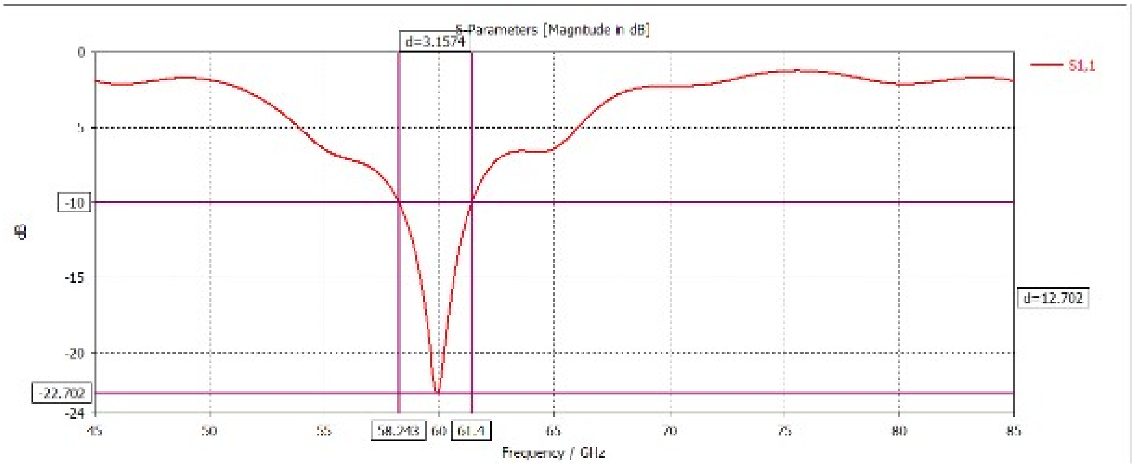


Figure 3.26: The S-parameter results (Triangle).

Voltage Standing Wave Ratio (VSWR)

The VSWR curve, plotted over the 45 GHz to 85 GHz frequency range, shows a minimum VSWR value close to 1.3 at approximately 60 GHz, which indicates good impedance matching and efficient power delivery at this frequency. Ideally, a VSWR value close to 1 implies minimal signal reflection and maximum power transfer to the antenna.

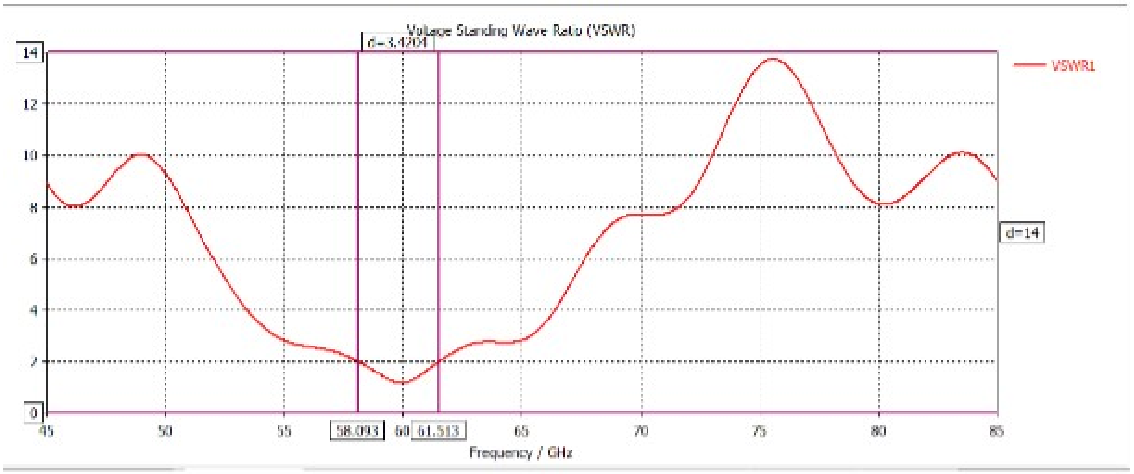


Figure 3.27: The Voltage Standing Wave Ratio (Triangle-VSWR)

The bandwidth, highlighted by d = 3.4204 GHz, spans from 58.093 GHz to 61.513 GHz, where the VSWR remains below 2 — the standard threshold for acceptable performance. These results align well with the S11 performance, reinforcing that the antenna achieves strong matching and operates efficiently across the desired frequency range.

The Gain

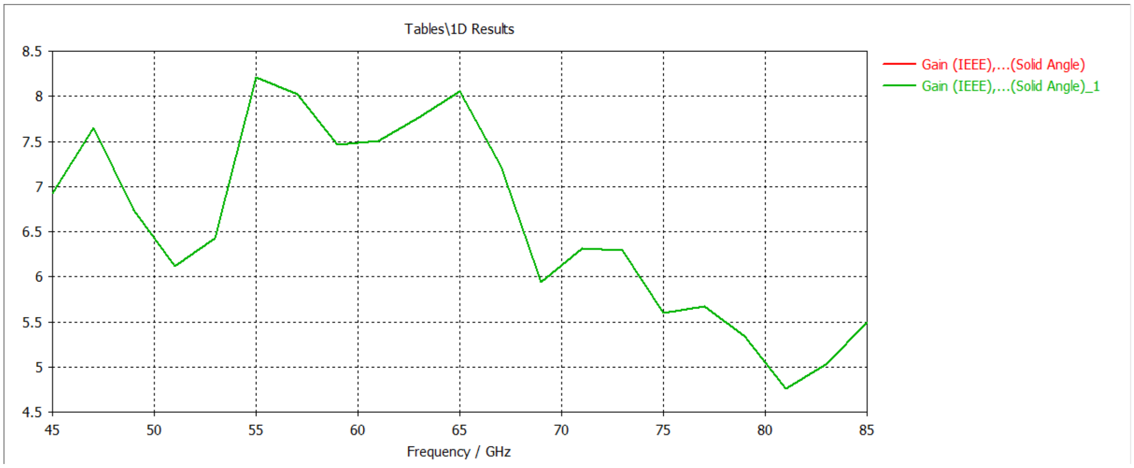


Figure 3.28: Gain variation of the triangular patch antenna

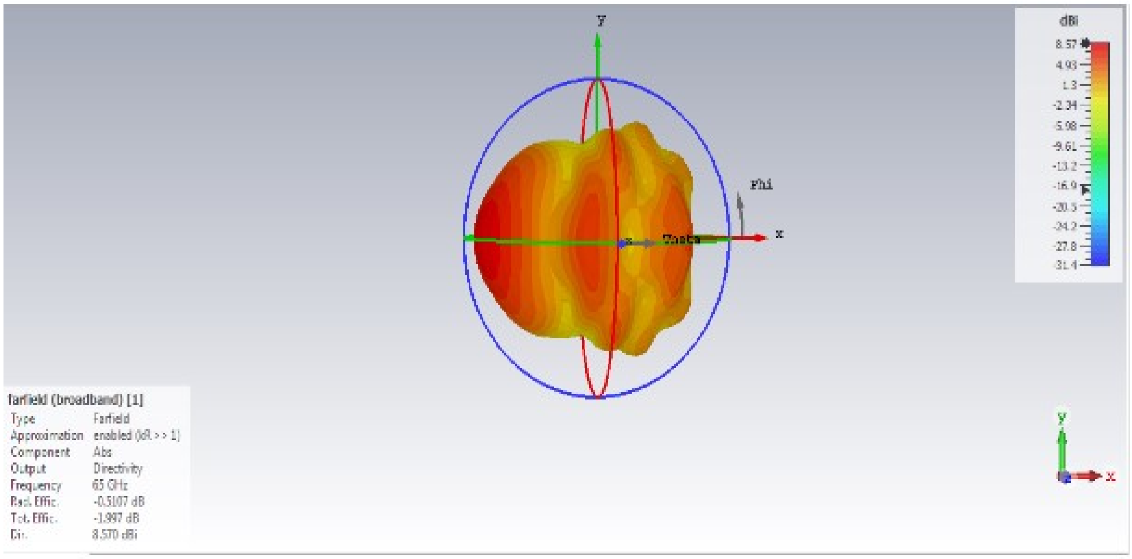
The graph above presents the simulated 3D maximum gain (IEEE standard, calculated utilizing strong point integration) for a triangular patch antenna across a broad frequency range, from 45 GHz to 85 GHz. This analysis is critical for assessing the antenna's suitability for millimeter-wave applications, especially in the 60 GHz and 77 GHz bands, which are prominent candidates in progressed 5G. The gain profile exhibits significant variation across the band, which reflects the sensitivity of triangular geometries to frequency due to the excitation of higher-order resonant modes. The following key observations can be made:

- Peak gain performance is achieved around 56 GHz and 65 GHz, with values exceeding 8 dBi, indicating highly efficient radiation at these frequencies.
- Between 60 GHz and 70 GHz, the gain remains relatively stable and above 7 dBi, which is suitable for medium-range high-data-rate wireless communication.
- A noticeable drop in gain is observed beyond 70 GHz, reaching values close to 5 dBi around 80–82 GHz, possibly due to mode distortion, impedance mismatch, or increased dielectric and conductor losses at these higher frequencies.
- The oscillatory behavior in the gain curve is a typical signature of triangular microstrip patches due to their complex current distribution and sensitivity to fabrication tolerances at small dimensions.
- The oscillatory behavior in the gain curve is a typical signature of triangular microstrip patches due to their complex current distribution and sensitivity to fabrication tolerances at small dimensions.
- Overall, this simulation confirms that the triangular patch antenna gives high-gain performance within the 50–65 GHz range, making it a promising candidate for short-range high-frequency 5G links, mmWave radar systems, and wearable or compact wireless modules.

radiation pattern

Directivity and Efficiency Metrics The second plot reveals the directivity, which reaches a peak of 8.570 dBi, indicating the theoretical capability of the antenna to concentrate energy in the desired direction in an ideal lossless scenario. This value, in close agreement with the realized gain, confirms low loss characteristics. Supporting metrics include:

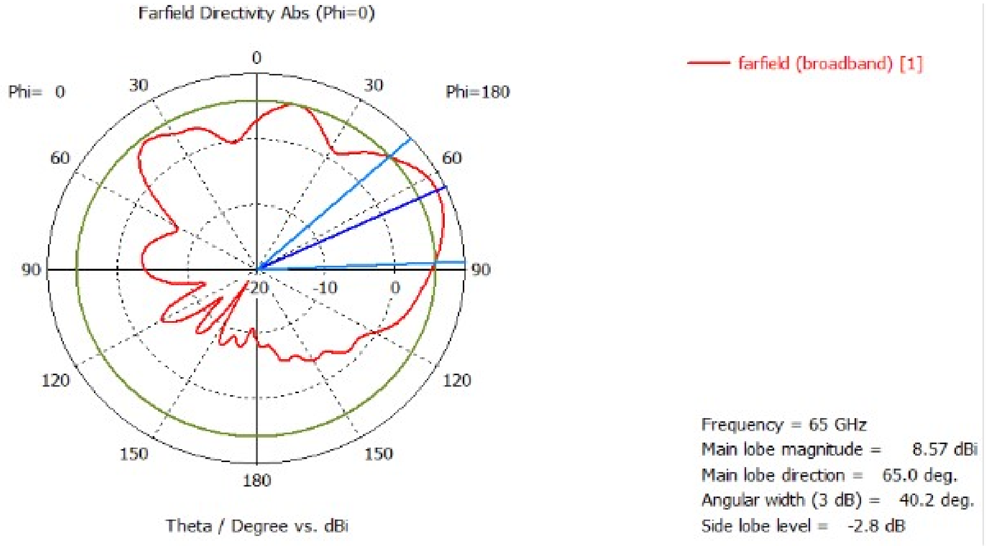
- Radiation Efficiency: $-0.5107\,\mathrm{dB}$ ($\approx 89.1\%$)
- Total Efficiency: $-1.997\,\mathrm{dB}$ ($\approx 63.4\%$)



farfield (broadband) [1]
Type Farfield
Approximation enabled (kR >> 1)
Component Abs
Output Directivity
Frequency 65 GHz
Rad. Effic. -0.5107 dB
Tot. Effic. -1.997 dB
Dir. 8.570 dBi

Figure 3.29: Three-dimensional radiation patterns

These figures suggest that the antenna maintains a high radiation efficiency, with moderate total efficiency losses likely attributed to dielectric loss in the substrate or minor impedance mismatches in the feed network. Nevertheless, the total efficiency remains within acceptable bounds for high-frequency practical applications.



Frequency = 65 GHz
Main lobe magnitude = 8.57 dBi
Main lobe direction = 65.0 deg.
Angular width (3 dB) = 40.2 deg.
Side lobe level = -2.8 dB

Figure 3.30: 2D radiation pattern at $\phi = 0°$

This configuration exhibits a strong concentration of radiated energy around 65°, along with relatively high directivity, indicating effective focusing of the main beam. The angular width of 40.2° indicates a moderately directional beam, ideal for applications where a compromise between angular coverage and signal concentration is required. The secondary lobe level at -2.8 dB shows a noticeable presence of radiation outside the main direction, which can potentially introduce interference or losses if the environment is reflective or multipath.

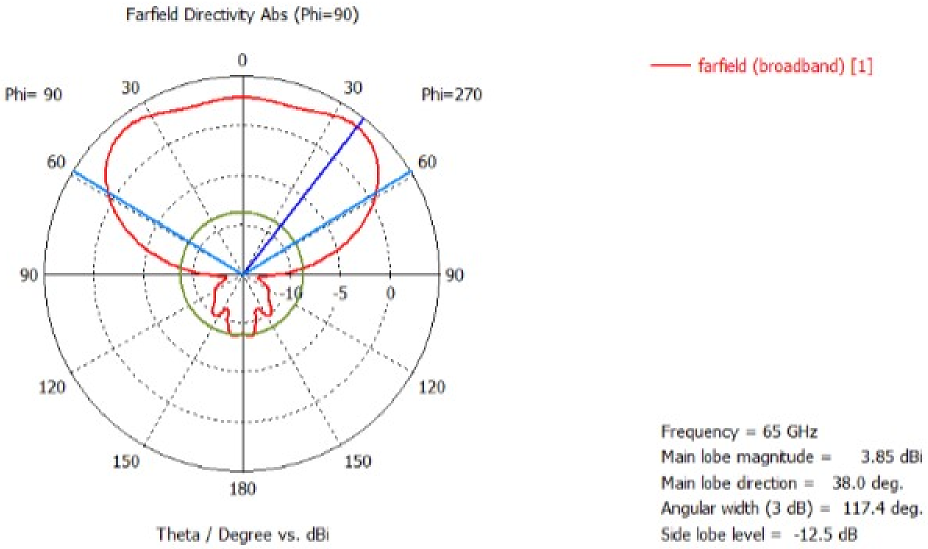


Figure 3.31: 2D radiation pattern at $\phi = 90^\circ$

In this orthogonal plane, directivity drops significantly, illustrating a more diffuse distribution of radiation. This is consistent with an antenna designed to maximise directivity in a principal plane (here $\Phi = 0^\circ$), with quasi-omnidirectional behaviour in the $\Phi = 90^\circ$ plane. The wide angular aperture of 117.4° is typical of a more dispersed behaviour, useful for covering large areas but less effective in terms of focusing the signal. The low level of the secondary lobes ($-12.5\,\mathrm{dB}$) is a positive indicator, reflecting effective reduction of stray radiation.

5.3 Parametric Study

Analysis S11 shows the reflection behaviour of the simulated antenna in the 45-85 GHz band,with particular emphasis on the 60 GHz band (V-band). It evaluates the impedance matching for different configurations or unit cells in an antenna or antenna array context.

Height of the triangular patch “U”

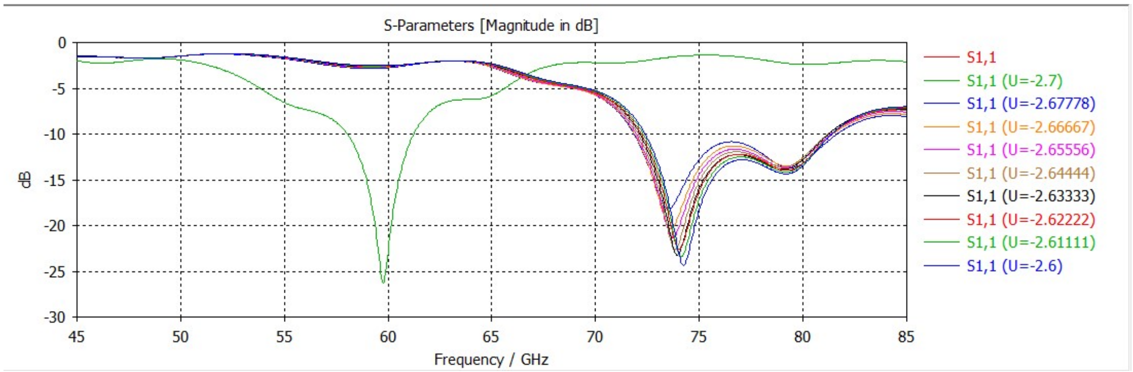


Figure 3.32: Parametric study of the height (h) of the triangular patch

- All the curves show a deep S11 minimum around 60 GHz of -25 dB, indicatingexcellent impedance matching ($>$ 99.7% of power transmitted to the antenna).
- At 60 GHz, the S11 curves of the various ports remain close and stable, demonstrating control of the coupling and response of the antenna array.
- Slight variations at 74-76 GHz between curves (S1,1(3), S1,1(5), etc.), due to differences in power supply or mutual environment in the network.

6 conclusion

This study evaluated several printed antennas reasonable for 5G. Each structure performed well in terms of gain, directivity and efficiency. Simulations affirm their capacity to operate efficiently at target frequencies. Alterations can be made to upgrade their response according to requirements. These antennas are promising solutions for next-generation wireless networks.

GENERAL CONCLUSION

The development of printed antennas for 5G networks represents a major breakthrough in wireless telecommunications. Thanks to their compactness, ease of integration and ability to operate efficiently in millimetre bands, these antennas meet the critical requirements of future 5G infrastructures, particularly in terms of high throughput, low latency and massive connectivity. In this consider, we explored different antenna arrangements (rectangular, circular and triangular) using advanced electromagnetic simulations. The comes about confirm their suitability for the target frequencies (28 GHz and 60 GHz), with remarkable execution in terms of impedance matching, gain and directivity. Parametric analyses were moreover used to optimise their dimensions and properties in order to maximise their efficiency. In conclusion, printed antennas are a promising solution for 5G applications, combining technical performance and industrial feasibility. Their advantages in terms of miniaturisation and cost make them ideal candidates for future mobile devices and access systems. Further research could further improve their performance, in particular by integrating emerging technologies such as metamaterials and reconfigurable antennas.

In this way, this study helps to strengthen the technological foundations required for the successful deployment of 5G networks, paving the way for a new era of ultra-fast, reliable connectivity.

BIBLIOGRAPHY

[1] S. Yrjölä, M. Matinmikko-Blue, and P. Ahokangas, “The Evolution of Mobile Communications,” in *The Changing World of Mobile Communications*, P. Ahokangas and A. Aagaard, Eds. Cham: Springer, 2024, pp. 13–33.

[2] M. Sabeur and C. Bouabdallah, *Conception d’une antenne microruban opérant à 28 GHz pour les réseaux mobiles 5G*, Master thesis, Université Mohamed Boudiaf - M’Sila, Faculté de Technologie, Département d’Électronique, Algérie, 2021.

[3] *Microwave and Millimeter-Wave Antenna Design for 5G Smartphone Applications*. Piscataway, NJ, USA: IEEE Press, 2021.

[4] M. Bellahsene and I. Medjadi, *Étude et Ingénierie du Déploiement du Réseau 5G NSA Dans La Bande C*, Mémoire de Master, Université Salah Boubnider – Constantine 3 (USDB), 2023.

[5] GeeksforGeeks, "5G Network Architecture", 13 novembre 2022. Disponible sur : `https://www.geeksforgeeks.org/5g-network-architecture/`.

[6] 3GPP, *Study on Scenarios and Requirements for Next Generation Access Technologies*, 3GPP TR 38.913 V14.3.0, Tech. Rep., June 2017.

[7] RF Wireless World, "5G KPIs: Key Performance Indicators Explained", `https://www.rfwireless-world.com/terminology/5g/5g-kpis`.

[8] G. Ancans et al., “Analysis of Characteristics and Requirements for 5G Mobile Communication Systems,” *Latvian Journal of Physics and Technical Sciences*, vol. 54, no. 4, pp. 3–16, 2017.

[9] A. Osseiran, J. F. Monserrat, and P. Marsch, Eds., *5G Mobile and Wireless Communications Technology*. Cambridge: Cambridge University Press, 2016.

[10] I. Minin, Ed., *Microwave and Millimeter Wave Technologies: Modern UWB Antennas and Equipment*. Vukovar, Croatie: In-Tech, 2010.

[11] H. Aliakbari, *Antenna System Design for 5G and Beyond – A Modal Approach*, Doctoral dissertation, Lund University, Sweden, 2023.

[12] Rohde & Schwarz, *Millimeter-Wave Beamforming: Antenna Array Design Choices & Characterization*, White Paper, Version 1.0, avril 2023. Disponible sur : http://www.rohde-schwarz.com/appnote/1MA276.

[13] L. Matekovits et al., Eds., *Printed Antennas for 5G Networks*, PoliTO Springer Series. Cham, Suisse: Springer.

[14] NYB Systems, "Types of 5G Antennas: A Guide to 5G Antenna Types", https://nybsys.com/types-of-5g-antennas/.

[15] R. Waterhouse, Ed., *Printed Antennas for Wireless Communications*. Maryland, USA: John Wiley & Sons Ltd, 2007.

[16] A. Pandey, *Practical Microstrip and Printed Antenna Design*. Norwood, MA, USA: Artech House, 2019.

[17] I. Lazreg and S. Maouche, *Analyse et amélioration des nouvelles formes d'une antenne imprimée pour les systèmes de communication sans fils de 5G*, Mémoire de Master, Université de Chlef, 2021.

[18] Z. M. T. Aissa, *Conception des antennes planaires directives à polarisations circulaires pour des applications spatiales*, Mémoire de Master, Université de Tlemcen, 2021.

[19] Test, Measurement, and KPIs Validation Working Group, *KPIs Measurement Tools: From KPI Definition to KPI Validation Enablement*, White Paper, Version 1.0, 5G Initiative, 5G-PPP, 2023.

[20] A. Boriskin and R. Sauleau, Eds., *Aperture Antennas for Millimeter and Sub-Millimeter Wave Applications*, Springer, 2018.

[21] H. Si Ali and I. Benamara, *Antenne Patch Pour La 5G Millimétrique*, Projet de fin d'études, Université de Ain Témouchent, 2023.

[22] K. Bangash et al., "Design of a Millimeter Wave Microstrip Patch Antenna and Its Array for 5G Applications," in *Proc. 2019 Int. Conf. on Computing, Mathematics and Engineering Technologies (iCoMET)*, Pakistan, 2019.

[23] A. Fouque, *Contribution à la Conception d'un récepteur mobile faible coût et faible consommation dans la bande Ku pour le standard DVB-S*, Thèse de doctorat, Université de Bordeaux 1, France, 2012.

[24] S. Soltane, *Étude et caractérisation d'antennes imprimées pour système ultra-large bande*, Mémoire de Magistère, Université de Biskra, 2015.

[25] V. K. Singh et al., *Design and Optimization of Sensors and Antennas for Wearable Devices*, Advances in Mechatronics and Mechanical Engineering, IGI Global.

[26] S. Gupta et al., "Design and performance analysis of a miniaturized metamaterial-inspired wideband antenna for 5G applications," *Scientific Reports*, vol. 13, p. 18050, Oct. 2023.

[27] Z. Liu et al., "Understanding Deployment Experience of 5G," in *Companion Proc. of the ACM Web Conf. 2024*, Singapore, 2024, pp. 742–745.

[28] D. A. Outerelo et al., "Microstrip Antenna for 5G Broadband Communications: Overview of Design Issues," in *IEEE AP-S Symposium*, 2015, pp. 1–4.

[29] M. A. Khan et al., "An Overview of 5G Architecture, Design, and Emerging Applications," in *Proc. of ICETE 2023*, Singapore: Springer, 2024, pp. 3–21.

Abstarct

The development of 5G technology requests advanced antenna solutions able of supporting millimeter-wave frequencies (28GHz and 60GHz) for high-speed, low-latency communication. This project investigates printed microstrip patch antennas as a compact, cost-effective solution for 5G applications. Through three comprehensive chapters, we first establish the theoretical foundations of 5G systems and antenna principles, then explore the design and simulation of rectangular, circular, and triangular patch arrangements using CST Microwave Studio. Finally, we analyze and compare their performance characteristics, giving optimized antenna plans tailored for next-generation wireless systems. The study bridges theoretical concepts with practical execution, offering valuable insights for 5G antenna development.

Keywords: fifth generation, mmWave, antenna arrays, Printed antennas, design, CST Microwave Studio.

ملخص:

يتطلب ظهور تكنولوجيا الجيل الخامس 5Gحلول هوائيات متقدمة قادرة على دعم ترددات الموجات المليمترية (28 جيجاهرتز و60 جيجاهرتز) للاتصالات عالية السرعة ومنخفضة الكمون. يبحث هذا المشروع في هوائيات الرقعة المجهرية المطبوعة كحل مدمج وفعال من حيث التكلفة لتطبيقات الجيل الخامس. من خلال ثلاثة فصول شاملة، نؤسس أولاً الأسس النظرية لأنظمة الجيل الخامس ومبادئ الهوائي، ثم نستكشف تصميم ومحاكاة تكوينات الرقعة المستطيلة والدائرية والمثلثة باستخدام استوديو الموجات الدقيقة CST. أخيرًا، نحلل ونقارن خصائص أدائها، ونقدم تصاميم هوائيات محسّنة مصممة خصيصًا لشبكات الجيل التالي اللاسلكية. تربط الدراسة بين المفاهيم النظرية والتطبيق العملي، وتقدم رؤى قيمة لتطوير هوائي الجيل الخامس.